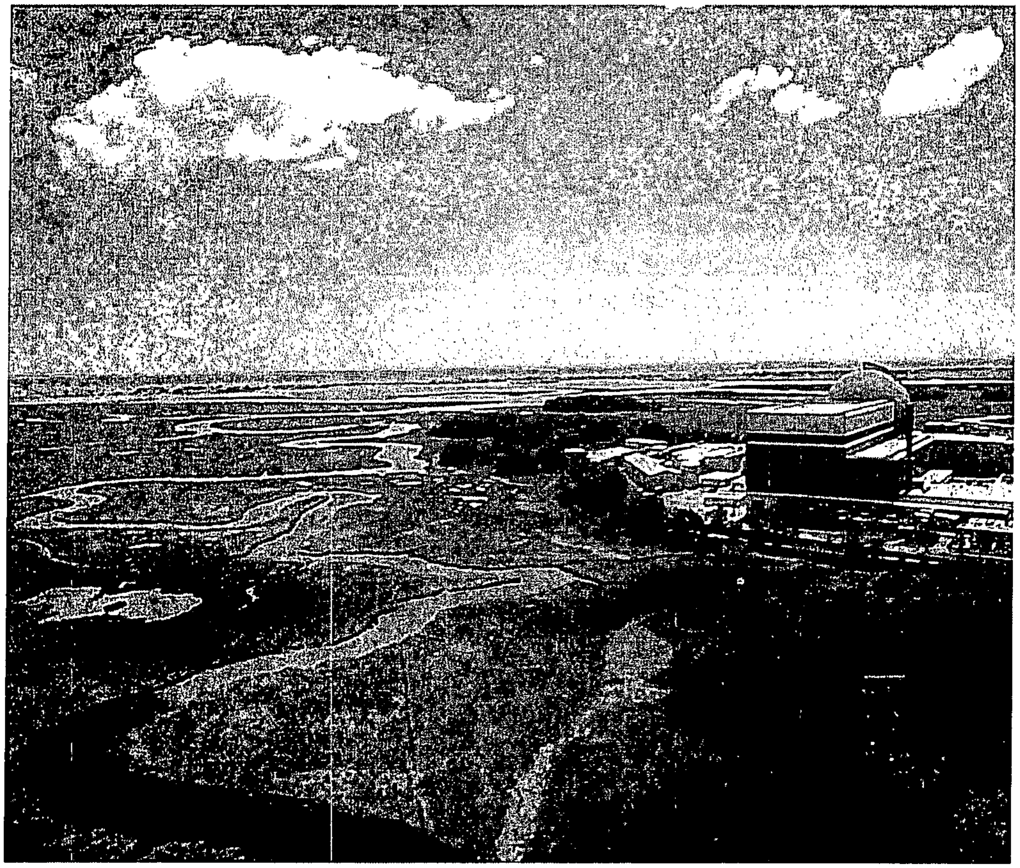
SBK-L-10185



Attachment 2

Vol. 3

SEABROOK STATION

1993 ENVIRONMENTAL STUDIES IN THE HAMPTON-SEABROOK AREA

A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS

North Atlantic

SEABROOK ENVIRONMENTAL STUDIES, 1993
A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS IN THE HAMPTON-SEABROOK AREA DURING THE OPERATION OF SEABROOK STATION

Prepared for

NORTH ATLANTIC ENERGY SERVICE CORPORATION
P.O. Box 300
Seabrook Station
Seabrook, New Hampshire 03874

Prepared by

NORMANDEAU ASSOCIATES
25 Nashua Road
Bedford, New Hampshire 03110-5500

and

NORTHEAST UTILITIES
CORPORATE AND ENVIRONMENTAL AFFAIRS
Millstone Station Environmental Laboratory
P.O. BOX 128
Waterford, Connecticut 06385

September 1994

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

1.1 APPROACH

Environmental monitoring studies were conducted to determine whether the operation of Seabrook Station had an effect on the "Balanced Indigenous Populations of Fish, Shellfish and Wildlife" in the nearfield coastal waters of New Hampshire. A biological monitoring program established under the National Pollutant Discharge Elimination System (NPDES) permit, jointly issued by the Environmental Protection Agency and the state of New Hampshire, forms the framework for study.

In order to determine whether the operation of Seabrook Station affected the aquatic biota, a systematic approach of impact assessment was utilized. This approach incorporated both temporal and spatial components for each biological community evaluated (Figure 1-1). Potential operational effects could be ruled out if: (1) results from the operational period were similar to previous (preoperational) years, given the natural variability in the system, or (2) differences within the operational period were observed in both nearfield and farfield areas. In addition, other potential sources of change have been investigated before the conclusions specified within this report were drawn. This study design was modeled after objectives discussed by Green (1979), which have been described previously in more detail (NAI 1991).

The validity of the impact assessment model is based on comparisons between nearfield stations within the influence of Seabrook Station and outside its influence at farfield stations. Modeling studies, as well as operational validation clearly indicates this to be true for thermal effects in relation to the thermal plume. The extent of a +3 °F (1.7 °C) isotherm has been shown to cover a relatively small 32-acre surface area (Padmanabhan and Hecker 1991). Due to the buoyant nature of the thermal discharge, temperature differences do not extend below the thermocline. Due to its location within the water column, the intake is also expected to have only a localized effect. This is characterized by the entrainment and impingement sampling programs.

A basic assumption in the monitoring program is that there are two major sources of naturally-occurring variability: (1) that which occurs among different areas or stations, i.e., spatial, and (2) that which varies in time, from daily to weekly, monthly or annually, i.e., temporal. In the experimental design and analysis, the Seabrook Environmental Program has focused on the major source of variability in each community type and then determined the magnitude of variability in each community. The frequency and spatial distribution of the sampling effort were determined based on the greatest sources of variability for each parameter (NAI 1991).

Biological variability was measured on two levels: species and community (Table 1-1). A species' abundance, recruitment, size and/or growth are important for understanding operational impact, if any, should changes occur in these parameters between stations or over time. These parameters were monitored for selected species from each community type. Selected species were chosen for more intensive study based on either their commercial or numerical importance, sensitivity to temperature, potential as a nuisance organism, or habitat preference. Overall community structure of the biota, e.g., the number and type of species, total abundance and/or the dominance structure, was also reviewed to determine plant impact, if any, for those not detected by monitoring individual species. Trends in these parameters were reviewed against the natural variation in community structure.

A previous Summary Report (NAI 1977) concluded that the balanced indigenous community in the Seabrook study area should not be adversely influenced by loss of individuals due to entrapment in the Circulating Water System (CWS), exposure to the thermal plume, or exposure to increased particulate material (dead

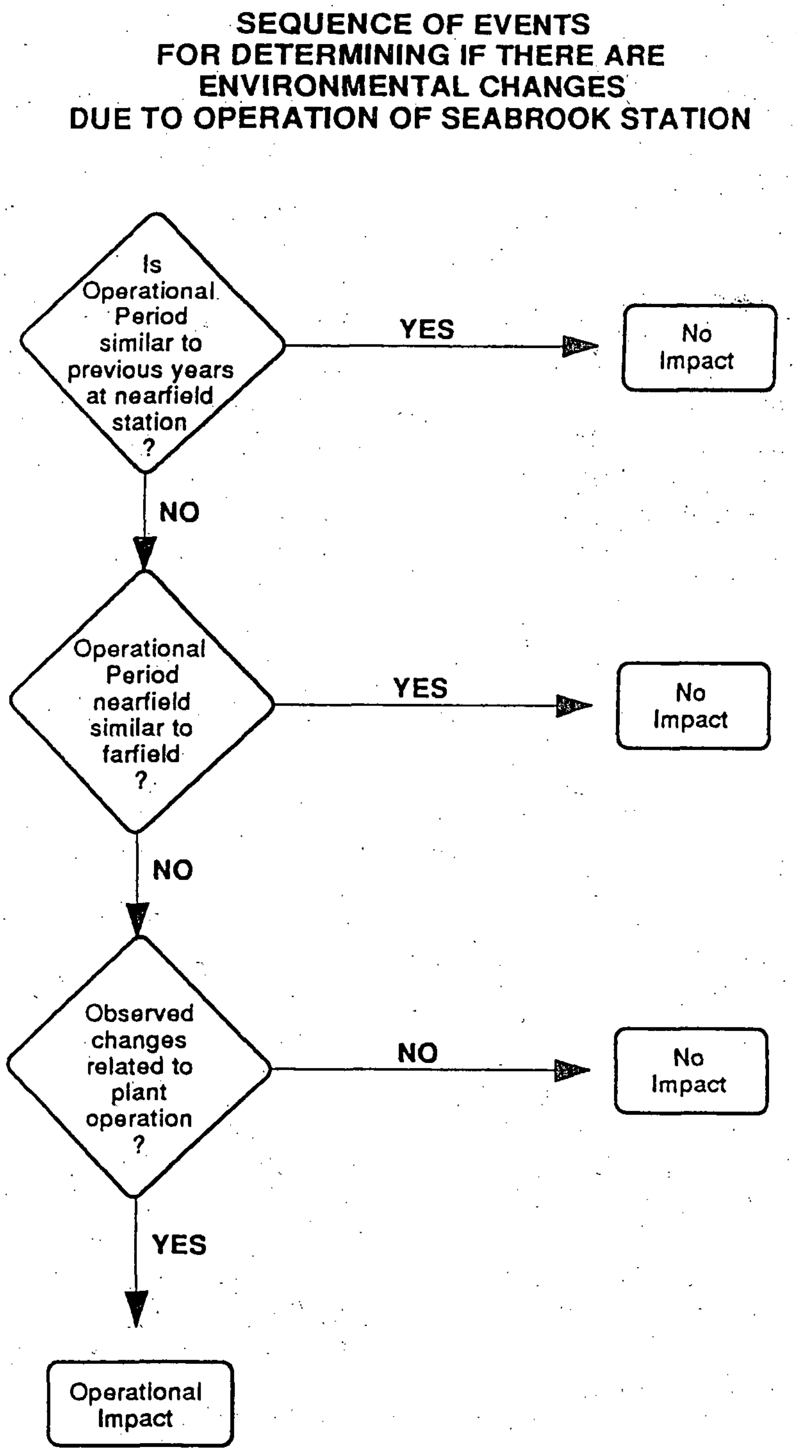


Figure 1-1 Sequence of events for determining if there are environmental changes due to the operation of Seabrook Station. Seabrook Operational Report, 1993.

TABLE 1-1. SUMMARY OF BIOLOGICAL COMMUNITIES AND TAXA MONITORED FOR EACH POTENTIAL IMPACT TYPE SEABROOK OPERATIONAL REPORT, 1993.

MONITORING AREA	IMPACT TYPE	SAMPLE TYPE	LEVEL MONITORED: COMMUNITY	LEVEL MONITORED: SELECTED SPECIES/ PARAMETERS
Intake	Entrainment	Microzooplankton	x	x
		Macrozooplankton	x	x
		Fish eggs	x	
		Fish larvae	x	x
		Soft-shell clam larvae		x
		Cancer crab larvae		x
	Impingement	Juvenile/Adult fish	x	x
		Lobster adults		x
Discharge	Thermal Plume	Nearshore water quality		x
		Phytoplankton	x	x
		Lobster larvae		x
		Intertidal/shallow subtidal macroalgae and macrofauna	x	x
		Subsurface fouling community	x	x
	Turbidity (Detrital Rain)	Mid-depth/deep macrofauna and macroalgae	x	x
		Bottom fouling community		x
		Demersal fish	x	x
		Lobster adults		x
		Cancer crab adults		x
Estuary	Cumulative Sources	Estuarine temperature		x
		Soft-shell clam spat and adults		x
		Estuarine fish	x	x

organisms) settling from the discharge. The current study continues to focus on the likely sources of potential influence from plant operation, and the sensitivity of a community or parameter to that influence within the framework of natural variability (Table 1-1). A community or species within the study area might be affected by more than one aspect of the CWS. Results from this monitoring program will be discussed in light of that aspect of the cooling water system that has the greatest potential for affecting that particular component of the biological community. Entrainment and impingement were addressed through in-plant monitoring of the organisms entrapped in the CWS.

The effects on the balanced indigenous populations of aquatic biota in the vicinity of the CWS intake and discharge structures were evaluated through continued monitoring at sampling stations established during the preoperational period, with statistical comparison of the results at both the community and the species levels. The null hypothesis in all tests is that there has been no change in community structure or selected species abundance or biomass that is restricted to the nearfield area. This in turn would indicate, based on the approach outlined in Figure 1-1, that the balanced indigenous populations have been maintained.

1.2 STUDY PERIODS

Environmental studies for Seabrook Station began in 1969 and focused on plant design and siting questions. Once these questions were resolved, a monitoring program was designed to assess the temporal (seasonal and yearly) and spatial (nearfield and farfield) variability during the preoperational period as a baseline against which conditions during station operation could be evaluated. This report focuses on the preoperational data collected from 1976 through 1989 for fisheries studies and from 1978 through 1989 for most plankton and benthic studies; during these years sampling design had consistently focused on providing the background to address the question of operational effects.

Commercial operation of Seabrook Station began intermittently in July and August 1990, and continued for periods of approximately three weeks in September and October. Therefore, August 1990 is considered the beginning of the operational period for the purposes of this environmental assessment. After operation at 100% for less than a week at the beginning and end of November, the plant operated nearly continuously from December 1990 through July 1991 when it was shut down for routine maintenance. Resumption of full power operation began again in October 1991 and continued through a second maintenance outage in late September 1992. Full power operation began again in November 1992 and has continued with only minor interruptions throughout 1993 (Figure 1-2). Monthly characteristics of the Circulating Water System operation throughout 1990, 1991, 1992 and 1993, are presented in Table 1-2.

1.3 SUMMARY OF FINDINGS

Water Quality

Water quality parameters were collected to aid in interpreting information obtained from the biological monitoring program, as well as to determine whether the operation of the Seabrook Station Circulating Water System had a measurable effect on the physical or chemical characteristics of the water column. Water quality samples were obtained within the vicinity of Seabrook's intake and discharge structures, and at farfield locations outside of the influence of operation. Measured parameters included temperature, salinity, dissolved oxygen, and nutrients (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia).

Potential impacts related to the operation of Seabrook Station include: (1) temperature changes resulting from the discharge of a heated cooling water from the Station condensers, (2) the discharge of chlorine (sodium

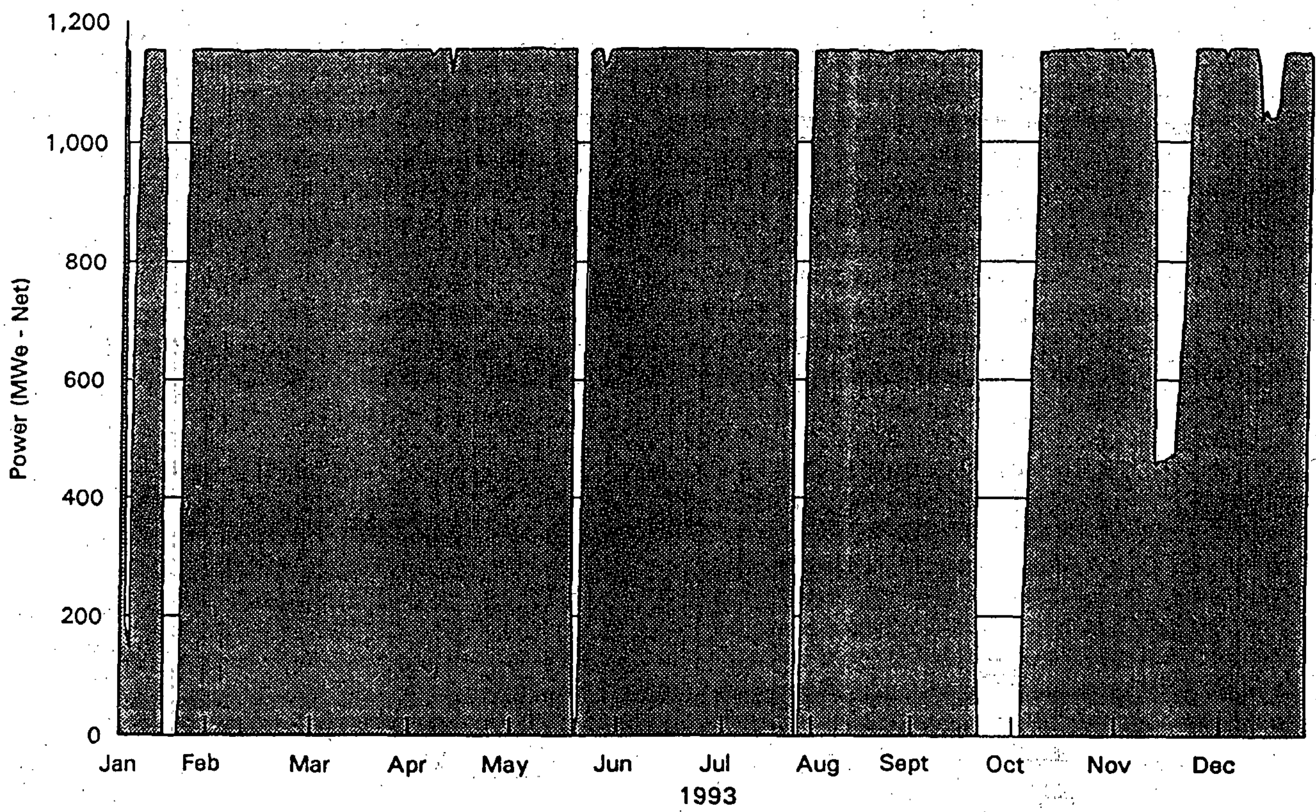


Figure 1-2 Average Daily Power Level at Seabrook Station during 1993 Seabrook Operational Report, 1993.

TABLE 1-2. MONTHLY CHARACTERISTICS OF SEABROOK STATION OPERATION FOR THE PERIOD 1990 THROUGH 1993 SEABROOK OPERATIONAL REPORT, 1993

	DAYS OF CIRCULATING WATER SYSTEM OPERATION				AVERAGE DAILY FLOW (mgd)			
MONTH	1990	1991	1992	1993	1990	1991	1992	1993
Jan	31	31	31	31	324	584	585	587
Feb	28	28	29	28	564	580	578	587
Mar	31	31	31	31	563	580	581	580
Apr	30	30	30	30	563	581	576	579
May	31	31	31	31	562	581	581	582
Jun	30	30	30	30	563	578	593	582
Jul	31	31	31	31	582	535	593	578
Aug	31	21	31	31	588	253	583	579
Sep	30	26	29	30	588	257	314	574
Oct	31	31	24	31	590	552	159	574
Nov	30	30	30	30	590	590	566	612
Dec	31	31	31	31	589	591	563	608

hypochlorite) utilized to prevent the settlement and accumulation of biological fouling organisms within the Circulating Water System, and (3) associated changes related to the addition of moribund entrained phytoplankton to the nearshore marine environment.

Annual average surface temperatures during 1993 were warmer at each station when compared to recent preoperational years (1987-1989) but were similar to the average temperatures over all preoperational years. This reflects a cooling trend observed in 1992 and 1993 compared to 1991, when the average annual surface temperature at the intake and discharge station was the highest of record during the fifteen year study period. Significant spatial differences in the annual mean surface temperature between the three monitoring locations were identified during 1993. Although between-period and among-station differences were significant for both surface and bottom temperatures, the differences in surface and bottom water temperatures between the preoperational and operational periods were consistent at all three stations.

Seasonal patterns of surface and bottom salinity were similar between preoperational and operational periods; however, 1993 annual mean salinities at each station decreased by approximately 1.5-1.6 ppt compared to the preoperational means. 1993 bottom salinities declined by 1.3-1.4 ppt. Over both the preoperational and operational periods, mean surface salinities have been similar among the three stations while mean bottom salinities have been higher at the farfield station.

Surface and bottom dissolved oxygen concentrations exhibited a seasonal pattern in 1993 similar to previous years. Differences in annual mean surface and bottom dissolved oxygen concentrations were small. Preoperational concentrations were slightly, but significantly higher, this probably corresponds to cooler preoperational temperatures.

Nutrient concentrations in 1993 showed both spatial and temporal differences for each of the five parameters analyzed. There were significant spatial and temporal differences for all nutrient parameters monitored, however, these were consistent with preoperational characteristics and not attributed to the operation of Seabrook Station. This is based on the consistency of spatial trends between the two periods, as well as the similarity of seasonal patterns across the years.

Most water quality parameters showed a distinct seasonal cycle that was consistent throughout the monitoring period. Significant differences among years were typical, reflecting high year-to-year variability. Increases or decreases in all parameters were consistent between nearfield and farfield stations, indicating that the chemical and physical environments in the study area are dominated by larger regional trends. These appear unrelated to the operation of Seabrook Station.

Phytoplankton

The phytoplankton monitoring program was initiated to identify seasonal, annual, and spatial trends in the phytoplankton community and to determine if the operation of Seabrook Station had a measurable effect on this community. The purpose of the monitoring program is to determine if the balanced indigenous phytoplankton community in the Seabrook area has been adversely influenced, within the framework of natural variability, by exposure to the thermal plume. Specific aspects of the community evaluated included phytoplankton (taxa ≥ 10 µm in size) abundance and species composition; ultraplankton (taxa < 10 µm in size) abundance and species composition; community standing crop as measured by chlorophyll *a* concentrations; abundance of selected species (*Skeletonema costatum*); and toxicity levels of paralytic shellfish poison (PSP, as measured by concentrations of *Alexandrium* spp. in the tissue of the mussel *Mytilus edulis*) in the Hampton-Seabrook area and at farfield stations.

Monthly abundances of phytoplankton during 1993 and the operational period were within the 95% confidence intervals established for the preoperational period for most months. On average, diatoms (Bacillariophyceae) dominated the phytoplankton assemblage during 10 of 12 months during the operational period, while the yellow-green alga *Phaeocystis pouchetti* dominated during the remainder of the months. This pattern of seasonal succession in phytoplankton is well documented in other northern temperate waters. Phytoplankton abundances at the intake station showed large shifts from year to year throughout the operational and preoperational periods. The geometric mean abundance in 1993 (104,400 cells/L) was the lowest of the operational period and lower than in five of the seven preoperational years. Preoperational geometric mean abundances were similar between the discharge station and intake monitoring locations; however, they were higher than those at the northern station. In general, abundances at each station were higher during the operational period, although 1993 abundances were similar to the preoperational. Overall, the abundances of the 15 numerically important taxa were not different among the stations in 1993.

Monthly Log(x+1) mean ultraplankton abundances were similar at all stations in 1993 and exhibited a weak seasonal pattern at each station. Annual mean geometric abundances were similar among the three stations throughout the operational period. Ultraplankton assemblages were also similar among the three stations in 1993. As in 1991 and 1992, Cyanophyceae were overwhelmingly dominant and followed a similar pattern of occurrence at each station.

During both the preoperational and operational periods, monthly arithmetic mean total chlorophyll *a* concentrations exhibited an early spring peak. Monthly mean operational concentrations were lower than preoperational concentrations in all months. On an annual basis, chlorophyll *a* concentrations and phytoplankton abundances appear to be inversely related. This difference is likely due to differences among taxa with respect to cell size and chlorophyll *a* content. Preoperational and operational chlorophyll *a* concentrations followed a pattern similar to that of phytoplankton abundances during the same periods.

Skeletonema costatum was chosen as a selected species because of its historic omnipresence and overwhelming dominance during much of the year. During the operational period both spring and fall peaks were larger but followed the same general pattern as the preoperational period. In 1993, *S. costatum* abundances generally followed historic patterns, except in January when mean abundances were higher than those typically observed and April mean abundances were lower.

During the preoperational period, paralytic shellfish poison (PSP) toxicity levels, commonly known as red tide, were above the detection limit in tissue of the mussel *Mytilus edulis* and above the closure limit during the late spring, early summer, and late summer. In 1991, only two occurrences of PSP above the detection limit were recorded. PSP was not detected during 1992. In 1993, PSP was detected above the closure level in May and June. Red tide events in New Hampshire coincided with those in adjacent states. There were no outbreaks of red tide that were restricted to New Hampshire.

Zooplankton

Three components of the zooplankton community, microzooplankton, bivalve larvae, and macrozooplankton, were sampled separately to identify spatial and temporal trends at both the community and species level. Initial monitoring characterized the source and magnitude of variation in the zooplankton community and provided data for comparison to that obtained during the operational period. The zooplankton community is currently evaluated to determine whether entrainment within the Circulating Water System (CWS) of Seabrook Station has had a measurable effect on the community or any species. The entrainment of bivalve larvae within the CWS has also been evaluated.

Since the operation of Seabrook Station, microzooplankton species composition continued to resemble the historical patterns. While the abundances of some taxa were different between the operational and preoperational periods, these differences were generally consistent between stations. Patterns of seasonal variation recorded during the operational years (1991-1993) for the selected microzooplankton species were generally similar to those observed during the preoperational period. Operational differences, if they occurred, were observed at both nearfield and farfield stations.

The species composition of bivalve larvae during the operational and preoperational periods was similar to previous years. Community structure was not significantly different among the nearfield and farfield stations throughout the study; however, it was significantly different at all three stations (combined) during the operational period compared to the preoperational (1988-1989). Higher abundance of almost all taxa accounted for the difference.

Entrainment collections provide a measure of the actual number of organisms directly affected by Station entrainment. Monthly entrainment of all taxa was less in 1991 and 1992 in comparison to 1990 and 1993. Reduced CWS flow during outage periods in the summer when larvae typically reach their peak abundance levels in the local coastal waters may have led to reduced entrainment in 1991 and 1992. Abundances of *Mytilus edulis* larvae in bivalve larvae collections from all stations in 1991 and 1992 were also reduced when compared to 1990 and 1993, contributing to reductions in entrainment. Entrainment within the CWS has not affected bivalve larvae abundance. The seasonal pattern of the bivalve larvae *Mytilus edulis* in the operational period was similar to recent preoperational years. *M. edulis* larvae were significantly more abundant during the operational period than the recent preoperational period at all three stations, likely the result of high abundances in 1993.

Plankton that spend all or a portion of their life in the water column (holo- and meroplankton) were found to be similar to those in other portions of the Gulf of Maine. The seasonal change in the holo- and meroplankton community composition at both nearfield and farfield stations was found to be consistent during the past six years.

Tychoplankton are those plankton that inhabit both the substrate and the water column as a result of excursions related to light, lunar cycle, storm events, reproduction or nonspecific aggregation. This community exhibited greater spatial variability than either the holo- or meroplankton community. Seasonal changes in species composition were generally similar between the operational and preoperational periods. Substrate differences between the nearfield and farfield stations account for some of the variability observed in the tychoplankton assemblages.

Differences between the spatial and temporal components of the macrozooplankton assemblages have been consistent. Abundance differences between the preoperational and operational periods have occurred at both the nearfield and farfield stations. Spatial patterns for other species (tychoplankton) have been similar both in the preoperational and operational periods.

There has essentially been no change in the abundances or seasonality in most of the macrozooplankton selected species. With the exception of *Canalus finmarchicus* copepodites, average abundances of all selected species of macrozooplankton were not significantly different from the recent preoperational period.

Fish Population

Finfish studies at Seabrook Station began in 1975 to investigate all life stages of fish, including ichthyoplankton (eggs and larvae), juveniles, and adults. Potential impacts of Seabrook Station operation on local populations include the entrainment of eggs and larvae through the Circulating Water System and the impingement of larger specimens on travelling screens within the Circulating Water pumphouse. Local distribution could also potentially be affected by the thermal plume, with some eggs and larvae being subjected to thermal shock due to plume entrainment upon discharge from the system diffusers. The main objective of the finfish studies is to assess whether the operation of Seabrook Station since 1990 has had any measurable effect on the nearshore fish population.

Ichthyoplankton analysis focused on seasonal assemblages of both eggs and larvae, as well as on the collection of selected larval species. Consistent temporal (among months and years) and spatial (among stations) egg and larval assemblages identified through the monitoring programs suggest that the operation of Seabrook Station has not altered the seasonal spawning time nor the distribution of eggs in the Hampton-Seabrook area. Although the temporal occurrence of fish larvae, both monthly and annually, was found not to be as consistent as for eggs, spatial parameters were consistent. Monthly observations at all three stations during each year were grouped together and the three stations were very similar within the same year and month. Temporal changes in assemblage abundances were consistent at all three stations.

During 1993, monitoring revealed that 13 egg and 20 larval taxa were entrained within the Circulating Water System. Total annual estimates of entrainment were 315.6 million eggs and 126.1 million larvae. The total egg entrainment in 1993 was the lowest since the Station began operation, even though the annual condenser water volume was the greatest. Taxa entrained in 1993 have dominated previous year's entrainment samples and were also dominant in offshore collections during 1993. Entrainment of larvae in 1993 was within the range of earlier years.

Adult pelagic fish were dominated by the Atlantic herring, Atlantic mackerel, alewife, rainbow smelt, and Atlantic cod. In general catch per unit effort (CPUE) followed similar trends during the 18-year sampling period. The spiny dogfish has become increasingly abundant during the operational period, increasing continuously since the 1960s. Together with skates, spiny dogfish now compose about 75% of the fish biomass of the Georges Bank.

The geometric mean CPUE of demersal fish at all stations combined in 1993 increased over 1992, but was the second lowest since sampling began in 1976. Catches of nearly all species declined from preoperational to the operational period, particularly for the yellowtail flounder. Differences in CPUE and species composition were apparent among stations. This may be due to the fact that the bottom at the discharge station is located in shallow water off the mouth of Hampton-Seabrook Harbor where the substrate has a tendency to be inundated with drift algae. The farfield stations were located in deeper water with sandier bottoms.

The geometric mean CPUE for demersal estuarine fish caught at all stations during 1993 increased from 1992 and decreased for pelagic species. Catches generally were smaller during 1987-1993 compared to 1976-1984. Average catches were less for the operational period than observed during the preoperational, however, this declining trend began in advance of Station operation. The Atlantic silverside has dominated catches in all years sampled. Winter flounder, killifishes (mummichog and striped killifish), ninespine stickleback, and rainbow smelt also contributed to the catch. Trends in the CPUE were found to be due to fluctuations in catch of the dominant species, Atlantic silverside.

During 1993 an estimated 1174 fish were impinged on the travelling screens at Seabrook Station. Since the Station began Circulating Water System operation, a total of 3,866 fish and 42 American lobsters have been reported. During the 4-year operational period, winter flounder, pollock, windowpane. lumpfish, longhorn sculpin, sea raven, and Atlantic silverside have made up 61% of the estimated impingement.

The design of the Seabrook Station offshore intake with a mid-water depth intake fitted with a velocity cap has clearly resulted in minimal numbers of fish being impinged when compared to other coastal sited power plants. Estimates of impingement indicate that the operation of the Seabrook Circulating Water System is presenting a negligible impact on local populations.

A number of differences were found between the preoperational and operational periods for fish assemblages in general, and for most selected species in particular. In nearly all cases where differences were found, abundance during the operational period was significantly lower than during the preoperational period. However, in many instances, the declines began in the early or mid-1980s. Several of the decreases reflect long-term declining trends of overexploited commercial fishes, including Atlantic cod, winter flounder, and yellowtail flounder.

Marine Macrobenthos

The predominant benthic marine habitat within the vicinity of Seabrook Station's intake and discharge is rocky substrate in the form of ledge and boulders. These rocky surfaces support rich and diverse communities of attached plants and animals (macrobenthos). Because these hard-bottom communities are ecologically important, and are potentially vulnerable to localized coastal anthropogenic impacts, studies of these communities have been an important part of the ecological monitoring program. The program has been designed to determine whether differences exist among communities at sites within the Hampton-Seabrook area that can be attributed to the operation of Seabrook Station. Potential impacts include temperature-related community alteration to areas directly exposed to the thermal discharge plume. This would occur at sites in the upper portion of the water column due to the buoyant nature of a thermal plume. Thermal impacts are unlikely in deeper areas; however, increased turbidity resulting from the transport of suspended solids and entrained organisms could increase shading and sedimentation.

Studies were implemented to identify plant and animal species occupying nearby intertidal and subtidal rock surfaces and at those at farfield control locations. The studies also describe temporal and spatial patterns of species occurrence, identify physical and biological factors that induce variability in these communities, and relate these to the operation of Seabrook Station.

Potential Thermal Plume Effects

Hydrodynamic modeling and subsequent field studies indicated that benthic locations experienced either no temperature increase at intertidal sites, or increases of <1 °F at shallow subtidal sites (Padmanabhan and Hecker 1991). Analysis of the overall intertidal benthic community structure indicated that the nearfield macroalgal and macrofaunal communities have changed little since operation of Seabrook Station began. In high, mid, and low intertidal areas, frequency of occurrence of dominant taxa, including barnacles, snails, mussels, fucoids, and *Chondrus crispus*, generally remained consistent over the preoperational and operational periods.

Abundance patterns of selected dominant intertidal taxa indicated that of the four taxa studied, only one (the amphipod *Ampithoe rubricata*) was significantly different between nearfield and farfield stations during operation. *Nucella lapillus*, and Mytilidae had significantly lower abundances while *Chondrus crispus* had higher biomass during the operational period; however, this occurred at both the nearfield and farfield stations. *Ampithoe rubricata* abundance revealed significant decreases in the nearfield and increases in the farfield; however, these shifts occurred prior to Station operation.

For the shallow subtidal benthic communities, no changes have occurred that can be related to the operation of Seabrook Station. Numerical classification of macroalgal and macrofaunal data revealed no substantive changes in species composition or overall community structure. Abundances of selected taxa were consistent between nearfield and farfield stations over both the preoperational and operational periods for *Chondrus crispus*, *Laminaria saccharina*, and *Jassa marmorata*. Two other taxa, Asteriidae and Mytilidae, exhibited preoperational to operational period shifts only at the farfield station. A significant reduction in abundance of *Laminaria digitata* was observed at the nearfield station during operation, but had begun in advance of operation. A similar, but statistically significant decline was observed at near and farfield mid-depth stations.

Potential Turbidity Effects

Assessments of community parameters and overall community structure indicate no changes in the nearfield mid-depth community during the operation of Seabrook Station. Significant decreases in both measures of community abundance (total algal biomass and total faunal density) were observed at the mid-depth intake station during the operational years, while consistent levels were observed at both the nearfield and farfield stations over the entire study period. High similarity in annual collections within depth zone were characterized for the overall faunal and algal community structure at mid-depth sites. No substantive changes in community composition have occurred in the mid-depth zone.

Two taxa, *Laminaria digitata* and *Modiolus modiolus*, exhibited area-wide decreases during the operational period. Another kelp, *Laminaria saccharina*, exhibited consistent patterns of occurrence over both periods, as did the green sea urchin *Strongylocentrotus droebachiensis*. High densities of adult green sea urchin were found in both nearfield and farfield transect areas in 1993. A significant decrease in the abundance of the amphipod, *Pontogeneia inermis*, was detected during the operational period at only the farfield station. Nearfield abundance of *P. inermis* was comparable to the preoperational period. Mytilids were significantly more abundant during the operational period at the nearfield station, no significant difference was observed at the farfield station.

Measurement of the deep water macrobenthic communities and assessment of the overall community structure revealed that nearfield and farfield communities have remained stable over the preoperational and operational periods. An increase in the total faunal density was observed at the intake station during the operational period. Overall, the macrobenthic communities appear unaffected by Station operation

Surface Panels

The surface fouling panels program was designed to study settlement patterns and community development in the discharge plume and in farfield areas. Panels provide information on the temporal sequence of settlement activity, as well as on species growth and patterns of community development.

Seasonal cycles in faunal richness, as observed on short-term (monthly) panels, were similar in 1993 and during the operational period to the operational trend. The average number of taxa was higher during the operational period than during the preoperational average at all monitoring locations. Total mean abundance at all stations in 1993 exceeded all previous operational years. However, there were no significant differences between the nearfield and farfield stations.

Historically, Mytilidae (mainly *Mytilus edulis*) was the most dominant noncolonial taxon. In 1993, the seasonal recruitment pattern for Mytilidae during 1993, closely followed the operational and preoperational trends at all monitoring stations. The amphipod *Jassa marmorata* is a common fouling organism. In 1993, *J. marmorata* abundances were low throughout the year at nearfield stations, except for a late summer increase, which closely follows the established seasonal pattern for the operational and preoperational periods. Abundances were lower during the operational period but not significantly different between the nearfield and farfield deep stations. The hydroid *Tubularia* sp. is a dense summer colonizer that can provide a substrate and food source to epifaunal taxa. The operational mean percent frequency was significantly lower than during the preoperational mean at all monitoring stations.

Seasonal patterns of abundance of the community dominants observed on monthly sequential panels in 1993 were similar to those observed during the preoperational period in most cases. The mean numbers of non-colonial taxa identified in 1993 and the operational period, were greater than the preoperational mean at all for stations.

The community settling and developing on surface panels has shown predictable seasonal patterns throughout the study, as evidenced both by measures of community structure (biomass, abundance, and number of taxa) and by abundance or percent frequency of occurrence of dominant taxa. Most measures showed significant differences between operational and preoperational periods, a reflection of year-to-year variability in recruitment. These differences were consistent among nearfield and farfield stations. One exception is the increase of Mytilidae at the nearfield mid-depth station whereas numbers decreased at its farfield counterpart. These numbers, although higher than average, indicate a nearfield-farfield difference that was similar to previous years.

Total biomass was higher at the mid-depth nearfield station during the operational period, while other stations showed no significant change.

Epibenthic Crustacea

The objective of the epibenthic crustacea monitoring program was to determine the monthly, spatial, and annual trends in larval density and catch per unit effort (CPUE) for juvenile and adult stages of American lobster (*Homarus americanus*), Jonah crab (*Cancer borealis*) and rock crab (*Cancer irroratus*). Analyses were done to determine if the discharge from Seabrook Station had any measurable effect on these species.

Annual mean densities of lobster larvae continued the trends observed in 1991 and 1992. Lobster larvae densities during 1993 were higher than during the preoperational period (1988-1989) at each station. Average larval densities during the three year operational period were significantly higher than the average densities during the preoperational period. There were no significant differences among the three stations during the 1988-1993 monitoring period. Monthly trends were found to be similar to those observed in previous years. Increases in densities during 1993 were due mainly to increases in Stage I and Stage IV larvae, historically the most numerous of the four stages. Stage IV larvae are hypothesized to originate, at least in part, offshore in the warm southwestern waters of the Gulf of Maine and Georges Bank.

The 1993 CPUE for adult lobster was lower than that during the operational period (1991-1993) at both nearfield and farfield stations. This decline, however, was greater at the farfield station. The monthly trend of CPUE in 1993 was similar to that observed during the preoperational period. Legal sized lobsters were

6% of the total catch at the nearfield station and 3% at the farfield station, slightly lower than the preoperational averages of 8% and 7% respectively.

In 1993, one lobster was impinged in the Station's Circulating Water System. Four were impinged in 1990, 29 in 1991, and 6 in 1992.

Cancer spp. larvae had slightly higher peak period abundances in 1993 than during the preoperational period at all stations. The average density during the three year operational period was significantly higher than the preoperational average for each station. The 1993 mean CPUE for Jonah crab at the nearfield station was higher than the preoperational average. In contrast, that at the farfield station declined and was lower than the preoperational average. Trends in mean CPUE during the operational period also differed between the nearfield and farfield stations. The 1993 rock crab CPUE at the nearfield and farfield stations decreased from the high catches observed in 1992, but were still above the preoperational average. Differences between stations were significant, with more crabs occurring at the nearfield station. Rock crabs have been less prevalent than their congener in the study area, probably because of their preference for sandy substrate.

Estuarine Benthos

Environmental studies conducted in Hampton Harbor since 1978 have included monitoring of the physical parameters (temperature and salinity), fish populations, benthic macrofauna, and juvenile and adult soft-shell clams (*Mya arenaria*). Current estuarine monitoring efforts are directed to identify potential effects from either the Settling Basin discharge or Seabrook Station operation. The objectives of the estuarine benthos studies are to characterize the macrofaunal communities in the Hampton estuary in terms of abundance and species composition, to identify spatial and temporal patterns in community structure and abundance, and to assess whether observed changes are related to the operation of Seabrook Station.

The mean monthly salinity at low tide in Browns River during 1993 ranged from 17.9 ppt in March to 29.5 ppt in August, a pattern similar to long-term averages. The monthly range in Hampton Harbor was somewhat smaller, 20.8 in April to 29.7 in July. Salinities at both Browns River and Hampton Harbor were consistently lower at low tide than at high tide. Seasonal patterns of salinity corresponded to variations in precipitation. Mean monthly precipitation was highest in April, similar to previous years.

Mean monthly temperatures at Browns River at low tide during 1993 ranged from a low of 0.0 °C in January to a high of 27.0 °C in July. Temperature ranges in Hampton Harbor were smaller (0.3 °C in February to 19.8 °C in August). At both sites the monthly water temperatures during 1993 were similar to the monthly values reported since 1979.

The general macrobenthic community structures at both nearfield (Browns River) and farfield (Mill Creek) stations in the vicinity of Seabrook Station were typical for East Coast estuarine areas with fine-grained sediments. Species abundances and dominance in the estuary are generally controlled by the physical environment, and the most numerous species are those that tolerate fluctuating water temperatures and salinity and a changing sedimentary environment. Total macrofaunal density averaged 4062 individuals /m^2 at all sites during 1993, and was within the range of densities reported since 1978.

Densities of the opportunistic sedentary bottom feeders *Capitella capitata* and *Hediste diversicolor* increased at all sites from 1992 to 1993, and the density of *Streblospio benedicti* at Browns River also increased in 1993. These changes were probably related to higher than average precipitation which resuspends sediment in the estuary. In the study area, although the densities of some species increased in 1993 relative to 1992, densities of the dominant species were within the density ranges that have been reported since 1978. Increases were observed at both the nearfield and farfield stations.

Soft-Shell Clam

The objectives of the soft-shell clam (*Mya arenaria*) monitoring programs are to determine the spatial and temporal pattern of abundance of various life stages of *Mya arenaria* in the vicinity of Hampton Harbor. Pelagic life stages may be subject to impacts from Seabrook Station operation due to entrainment into the Circulating Water System. Benthic stages (after settlement to the bottom) in the Hampton-Seabrook estuary may be subject to impacts from discharges from the Station Settling Basin. Nearfield / farfield comparisons of clam densities are also made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich MA.

Mya arenaria larvae occurred most weeks from May through October during the preoperational years. Peak abundances in 1993 were seen in September and October and were above the preoperational average. However, the overall operational mean larval abundance at all three stations was significantly less than the preoperational means, yet was consistent at both nearfield and farfield stations.

In 1993, average density of young-of-year (1-5 mm size class) clams was slightly higher than the preoperational averages at all three flats. Densities in 1993 were higher than for the previous two years. Trends in spat (6-25 mm size class) clams indicate the survival of young-of-year that have overwintered. During 1993, recruitment into this size class increased over the previous year at each flat, but remained below the preoperational mean at all three flats. Mean densities of juvenile (26-50 mm size class) clams in 1993 remained lower than the preoperational means and have been declining since the late 1980s. Adults (>50 mm size class) in 1993 had densities similar to the operational means at all flats. Adult clam densities increased significantly at the southern flat; however, no significant differences occurred at others.

In 1993, the density of seed clams in the nearfield area (Hampton Harbor) was the highest since the study began in 1987. In the farfield area (Plum Island Sound) in 1993, density increased only slightly over 1992 levels.

Clams in Hampton Harbor have historically been subjected to predation from green crabs (*Carcinus maenas*) and human clam digging. Mean densities of green crabs during the 1991-1993 operational period were lower than preoperational densities for most of the year. Recreational clam digging on Hampton Harbor flats has not been permitted by the New Hampshire Department of Health and Human Services since April 1989 due to coliform contamination.

1.4 LITERATURE CITED

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, N.Y. 257 pp.

Normandeau Associates Inc. (NAI) 1977. Summary document: assessment of anticipated impacts of construction and operation of Seabrook Station on the estuarine, coastal and offshore waters of Hampton-Seabrook, New Hampshire.

__________. 1991. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

Padmanabhan M. and Hecker, G.E. 1991. Comparative Evaluation of Hydraulic Model and Field Thermal Plume Data, Seabrook Nuclear Power Station. Alden Research Laboratory, Inc.

TABLE OF CONTENTS

SUMMARY

Most water quality parameters showed a distinct seasonal cycle that was consistent throughout the monitoring program. Significant differences among years were typical, reflecting high year-to-year variability. Surface and bottom temperatures showed a significant increase during the operational period at Stations P2, P5, and P7. Surface and bottom salinities showed a significant decrease at each station over the same period, along with surface dissolved oxygen concentrations. Bottom dissolved oxygen concentrations remained similar to preoperational levels. Operational surface nitrite, ammonia, and orthophosphate concentrations also remained similar to preoperational levels. Increases or decreases in all parameters were consistent between nearfield and farfield areas, indicating that the chemical and physical environments in the study area are dominated by larger regional trends. No localized effects due to the operation of Seabrook Station were observed.

LIST OF FIGURES

LIST OF TABLES

2.0 WATER QUALITY

2.1 INTRODUCTION

Water quality parameters were collected to aid in interpreting information obtained from the biological monitoring program and to determine whether the operation of the Seabrook Station Circulating Water System has had a measurable effect on the physical and chemical characteristics of the water column. To provide information on the physical environment, water quality samples were collected in the vicinity of the Seabrook Station intake and discharge, as well as at a farfield location outside of the influence of Station operation. Parameters measured included temperature, salinity, dissolved oxygen, and nutrients. Potential impacts related to the cooling water system include both that of temperature, through the discharge of a heated effluent from the condensers, and the application of sodium hypochlorite as a biofouling control measure.

Seabrook Station employs a once-through Circulating Water System. Ambient ocean water is drawn into the system from approximately 7,000 feet offshore through three intake structures and returned through a multiport diffuser system approximately 5,500 feet offshore. All discharges are controlled under the Station's National Pollutant Discharge and Elimination System (NPDES) Permit issued by the State of New Hampshire and the Environmental Protection Agency (EPA). This permit specifies that the temperature rise shall not exceed 5°F (3°C) within the nearfield jet mixing region. This applies at the surface of the receiving waters within 300 feet of the submerged diffuser in the direction of discharge.

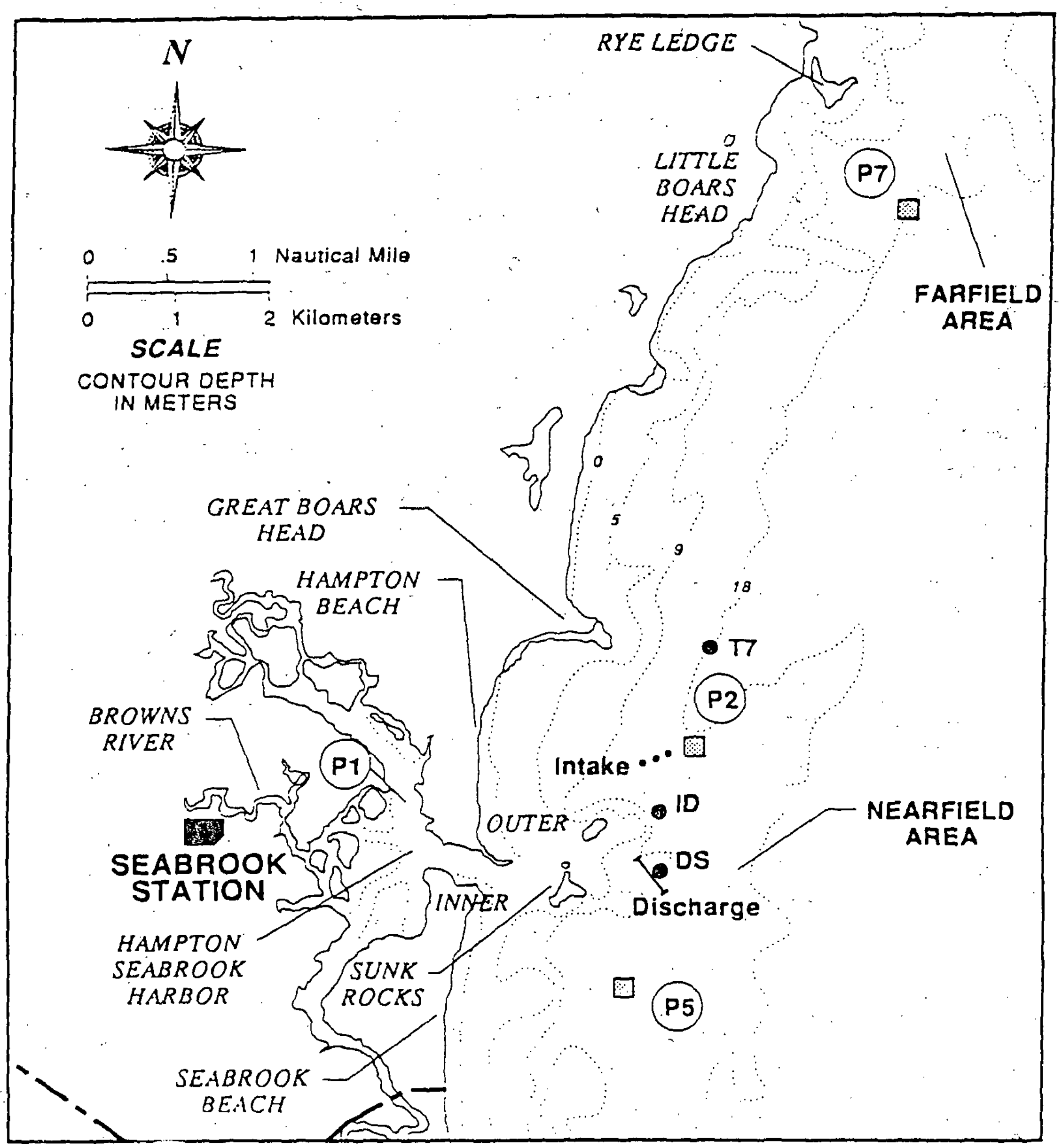
Seabrook Station utilizes continuous low level chlorination in the Circulating and Service Water Systems to control biofouling. Information is gathered through the Chlorine Minimization Program, which assesses the effectiveness of chlorine application in preventing biofouling while utilizing the least amount of chlorine. To date residual levels of chlorine at the diffusers have been below detection limits.

2.2 METHODS

2.2.1 Field Methods

Near-surface (-1 m) water samples for nutrient analysis were collected during daylight hours using a General Oceanics® 8-L water sampler from the intake (Station P2, 16.8 m depth, MLW), discharge (Station P5, 16 m depth, MLW), and farfield (P7, 18.3 m depth, MLW) sampling locations (Figure 2-1). Nutrient sampling commenced at Stations P2 and P5 in 1978 and at Station P7 in 1982. Sampling continued until 1981 at P5 and until 1984 at P2 and P7. Sampling resumed at all three stations in July 1986, and continued to the present. Water samples were taken once in January, February, and December and twice monthly from March through November, in conjunction with the phytoplankton and microzooplankton sampling, and within 24 hours of the weekly macrozooplankton and ichthyoplankton sampling.

Temperature, dissolved oxygen, and salinity measurements began in 1979 at Stations P2 and P5, and in 1982 at Station P7. Sampling at P2 and P7 continued to the present; sampling at P5 was interrupted from January 1982 until July 1986, but was sampled concurrently with P2 and P7 from July 1986 until the present. At all stations, temperature and salinity profiles were taken four times per month during January through December with a Beckman® Thermistor Salinometer (through March 1989) or a YSI® (Model 33) S-C-T Meter (1990 to 1993) within 24 hours of the weekly macrozooplankton and ichthyoplankton sampling. Full temperature, salinity, and dissolved oxygen profiles are reported in appendix tables contained in data summary reports prepared in conjunction with the baseline (preoperational) and operational reports. Only surface and bottom temperature, salinity, and dissolved oxygen values are reported here. Duplicate dissolved



LEGEND

P2 ▨ = water quality stations

T7 ● = continuous temperature recorders

Figure 2-1. Water quality sampling stations, Seabrook Operational Report, 1993.

oxygen samples were also collected at near-surface and near-bottom (2 m above bottom) depths, and were fixed in the field with manganese sulfate and alkaline iodide-azide. Additionally, operational continuous temperature data from the discharge (Station DS), nearfield (Station ID) and farfield (Station T7) areas were collected and provided by Yankee Atomic Electric Company (YAEC) as part of their NPDES permit compliance program (Figure 2-1).

2.2.2 Laboratory Methods

Water quality samples were analyzed for five nutrients (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia) using a Technicon® Autoanalyzer II system. All analyses were performed according to EPA Methods for Chemical Analyses of Water and Wastes (USEPA 1979) and Standard Methods (APHA 1989).

2.2.3 Analytical Methods

Results from these collection efforts were used to describe the seasonal, temporal, and spatial characteristics of the water column within the nearshore waters off Seabrook Station. Analyses used data from all stations, but focused on Station P2 since it was sampled for a longer period of time than Stations P5 and P7. Any values that were less than the detection limits were assigned a value equal to one-half of the detection limit for computational purposes (Gilbert 1987). Seasonal trends were analyzed using monthly arithmetic mean temperatures and dissolved oxygen, salinity, and nutrient concentrations. Monthly means for the preoperational and operational periods were calculated from the monthly arithmetic means for each year within each period, resulting in a sample size equal to the number of years in each period. Monthly means for 1993 were calculated as the arithmetic average of all samples taken within a given month.

Among-year and between-period trends were evaluated using annual or period (preoperational, operation) means. Annual means of 1993 collections were calculated as the arithmetic mean of all observations within the year. The means of preoperational and operational collections were calculated as arithmetic means of annual means over all years within each period, which varied among stations and parameters. The precision of the mean was described by its coefficient of variation. The preoperational periods for the different analyses are listed on the appropriate tables and figures; in all cases the operational period consists of collections from 1991-1993. Collections from 1990 were not included in these analyses since the year was divided between the preoperational and operational periods, and the inclusion of partial years in each period would bias the means.

Operational/preoperational and nearfield/farfield differences in monthly means were evaluated using a multi-way analysis of variance procedure (ANOVA), which was designed to specifically test for potential impacts of plant operation. Main effects included PREOP-OP (preoperational and operational periods), YEAR, MONTH, and STATION. An interaction term, PREOP-OP X STATION, was also specified in order to determine if changes in spatial relationships coincided with the start of plant operation. This ANOVA model was more conservative (more likely to detect significant differences) than alternative models that treat some sources of variation, such as YEAR, as random variables. The preoperational period for each analysis was specified as 1987-1989, which was the period during which all three stations were sampled concurrently (thus maintaining a balanced model design). These results were evaluated in conjunction with means calculated over all available preoperational years to help distinguish between recent trends and long-term trends.

2.3 RESULTS

2.3.1 Physical Environment

Temperature

Monthly mean surface water temperatures at Station P2 followed a similar seasonal pattern during both the preoperational and operational periods (Figure 2-2). In 1993 specifically, surface temperatures were coolest in February (2°C cooler than in January), then warmed by approximately 2°C by the end of April. Temperatures warmed by 7°C between April and May (the largest consecutive monthly difference observed during the year), then continued to warm steadily (1.5°C to 3.5 °C per month) through August, when the annual maximum occurred. Temperatures then cooled by 4.5°C by the end of September, and continued to cool by about 3°C per month through December.

Monthly mean surface temperatures recorded in 1993 at Station P2 were generally cooler during winter months and warmer during summer months compared to preoperational monthly means (all years; Figure 2-2). This is reflected in the range of temperatures recorded during 1993, which was wider at each station compared to the average minimum and maximum temperatures over the preoperational period (Table 2-1). Surface temperatures in 1993 at Stations P5 and P7 followed the same seasonal pattern observed at P2; temperatures were warmer at Station P5 than at P2 and P7, as in the preoperational period (Table 2-1).

Average annual surface temperatures in 1993 were warmer at each station compared to recent preoperational years (1987-1989), but were similar to average temperatures over all preoperational years (Table 2-1). This reflects a cooling trend observed in 1992 and 1993 compared to 1991, when the average annual surface temperature at P2 was the highest recorded during the fifteen year study period (Figure 2-3). There were significant differences in annual mean surface temperatures among stations (P5>P2>P7) and between the preoperational and operational periods (OP>PREOP; Table 2-2).

As noted for surface temperatures, monthly mean bottom temperatures at each station were generally cooler during the winter and warmer during the summer in 1993 compared to preoperational monthly mean temperatures (Figure 2-2). This is reflected in the wider range of temperatures observed in 1993 compared to the average range of temperatures recorded during the preoperational period (Table 2-1). Average annual bottom temperatures were warmer at Station P5 compared to P2 and P7, as in the preoperational period. Annual mean temperatures were cooler at each station in 1993 compared to preoperational mean temperatures.

Although between-period (OP>PREOP) and among-station differences were significant for both surface and bottom temperatures, the differences in surface and bottom water temperatures between the preoperational and operational periods were consistent at all three stations (i.e., no significant interaction term; Table 2-2).

Monthly mean differences between surface and bottom temperatures (surface - bottom; Figure 2-4) indicated that the water column at each station was essentially isothermal ($\Delta T = -1°C$ to $+1°C$) during seven of twelve months, during both operational and preoperational periods. A weak temperature stratification began to develop in May, with a ΔT of approximately 4°C. Maximum surface-bottom differences of 6-7°C occurred in July or August. Temperature differences then began to decline to approximately 3-4°C by September. The water column returned to isothermal conditions by late October. Throughout 1993, average surface-bottom temperature differences were generally larger than during the preoperational period, but exceeded upper 95% confidence limits of preoperational means only in March (all stations), May (P2 and P7), and in August at P7 and in September at P2.

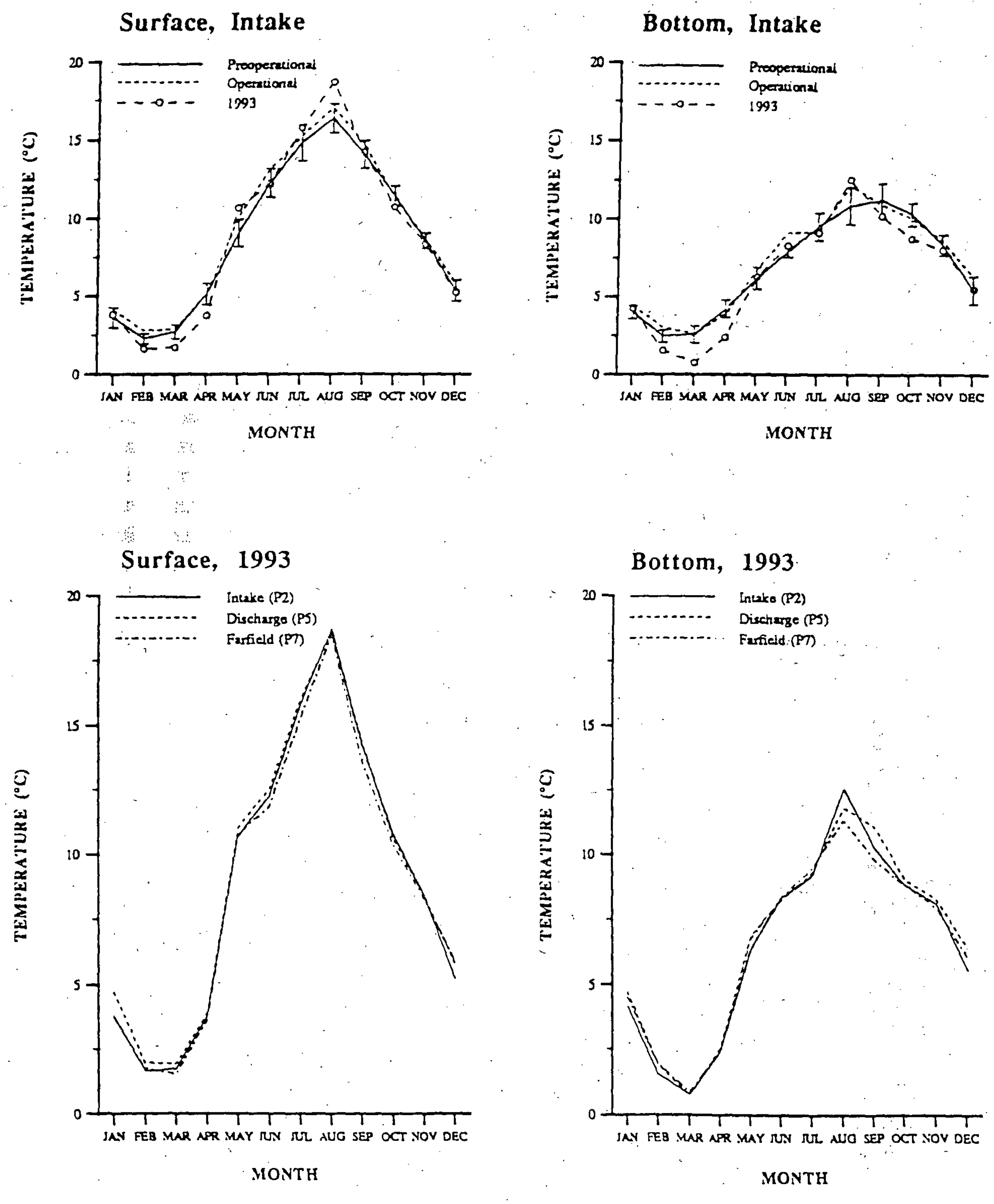


Figure 2-2. Surface and bottom temperature (°C) at nearfield Station P2, monthly means and 95% confidence intervals over the preoperational period (1979-1989) and the operational period (1991-1993), and monthly means of surface and bottom temperature at Stations P2, P5, and P7 in 1993. Seabrook Operational Report, 1993.

TABLE 2-1. ANNUAL MEANS AND COEFFICIENTS OF VARIATION (CV,%) AND AVERAGE MINIMA AND MAXIMA FOR WATER QUALITY PARAMETERS MEASURED DURING PLANKTON CRUISES AT STATIONS P2, P5, P7 OVER PREOPERATIONAL[a] AND OPERATIONAL (1991-1993) YEARS, AND THE ANNUAL MEAN, MINIMUM AND MAXIMUM IN 1993. SEABROOK OPERATIONAL REPORT, 1993.

	PREOPERATIONAL														
	ALL YEARS[a]				RECENT YEARS[b]				OPERATIONAL				1993		
PARAMETER	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	MIN	MAX
TEMPERATURE (°C)															
Surface															
P2	9.13	7.99	1.54	18.45	8.99	2.97	1.23	18.53	9.34	6.46	1.80	18.90	9.11	0.00	19.20
P5	9.53	5.59	2.01	18.53	9.15	3.73	1.13	18.13	9.61	5.29	1.90	19.23	9.33	0.10	19.70
P7	8.73	6.26	1.39	18.00	8.84	3.61	0.93	18.20	9.16	5.80	1.87	18.57	8.92	0.20	19.70
Bottom															
P2	7.13	8.84	1.72	14.35	6.57	2.70	1.13	14.00	7.30	8.85	2.03	14.80	6.61	0.10	15.50
P5	7.05	8.23	2.22	14.12	6.65	3.71	1.10	13.60	7.45	7.87	2.07	14.23	6.84	0.00	13.20
P7	6.85	9.30	1.55	13.61	6.44	3.07	1.03	13.90	7.16	8.17	1.90	13.60	6.62	0.20	13.30
SALINITY (ppt)															
Surface															
P2	31.59	1.35	28.42	33.32	31.57	1.12	26.90	33.37	30.57	2.08	27.32	32.56	29.95	25.16	32.54
P5	31.61	0.91	28.16	33.70	31.50	1.06	25.50	34.36	30.48	1.91	25.18	32.53	29.94	25.40	32.34
P7	31.53	1.36	26.69	33.58	31.39	1.04	24.97	33.54	30.51	2.04	27.01	32.64	29.86	25.20	32.75
Bottom															
P2	32.18	0.84	30.63	33.52	32.07	0.94	30.10	33.73	31.09	1.37	28.31	32.57	30.79	28.45	32.54
P5	32.24	0.71	31.00	33.47	32.13	0.71	30.50	33.57	31.09	1.67	26.52	32.56	30.72	26.88	32.44
P7	32.23	0.83	30.51	33.52	32.18	0.82	30.47	33.63	31.24	1.83	28.08	33.21	30.74	27.43	32.65
DISSOLVED OXYGEN															
(mg/L)															
Surface	9.69	3.14	7.39	12.45	9.71	0.95	7.40	12.27	9.61	1.03	7.47	11.87	9.64	7.00	11.60
P2	9.71	3.92	7.64	11.64	9.73	0.98	7.57	12.33	9.68	1.22	7.50	12.03	9.72	7.00	11.60
P5	9.66	0.95	7.28	12.65	9.70	1.26	7.43	12.23	9.57	1.08	7.53	11.73	9.60	7.30	11.50
P7															
Bottom															
P2	9.19	4.58	6.59	12.03	9.22	4.22	6.60	11.73	9.24	3.19	6.67	11.73	9.33	6.00	11.60
P5	9.21	5.20	6.73	11.19	9.20	4.45	6.77	11.87	9.29	2.44	6.70	11.73	9.33	7.10	11.50
P7	9.09	2.50	6.10	12.50	9.12	4.40	6.43	11.70	9.18	2.47	6.77	11.67	9.29	6.80	11.50

(continued)

TABLE 2-1. (Continued)

PARAMETER	PREOPERATIONAL ALL YEARS[a] $\bar{x}$	CV	MIN	MAX	PREOPERATIONAL RECENT YEARS[b] $\bar{x}$	CV	MIN	MAX	OPERATIONAL $\bar{x}$	CV	MIN	MAX	1993 $\bar{x}$	MIN	MAX
SURFACE NUTRIENTS (μg/L)															
Orthophosphate	12.95	27.38	2.40	27.10	14.91	14.67	2.83	32.00	14.46	7.92	3.83	31.17	15.75	3.50	32.00
P2	12.10	22.70	1.93	34.86	14.57	12.22	2.33	37.67	14.28	7.81	3.67	28.33	15.15	2.00	30.00
P5	15.91	10.18	2.25	32.83	15.57	11.36	2.50	33.67	14.82	5.23	5.17	31.67	15.70	5.50	29.00
P7															
Total Phosphorus															
P2	25.84	18.76	9.05	51.95	29.18	11.83	11.67	53.33	26.42	7.70	15.50	53.67	26.18	12.00	43.00
P5	27.46	22.56	10.07	56.86	29.72	5.90	16.67	56.67	26.34	13.57	15.17	47.00	26.18	9.50	44.50
P7	29.11	12.22	11.33	56.83	30.97	13.18	13.33	60.00	26.86	10.11	12.50	49.67	26.95	15.50	44.50
Nitrite															
P2	2.05	30.87	0.55	5.50	2.05	16.16	0.50	6.00	2.20	10.13	0.67	6.33	2.28	0.50	6.00
P5	2.14	25.95	0.57	6.29	1.96	13.62	0.50	6.67	1.82	8.52	0.67	5.17	1.73	0.50	6.50
P7	1.90	32.32	0.50	5.75	2.17	17.51	0.50	7.33	2.30	4.26	0.67	6.83	2.33	0.50	7.00
Nitrate															
P2	40.00	20.87	5.50	156.50	44.03	24.48	5.00	170.00	40.54	20.64	3.33	145.00	46.38	2.50	160.00
P5	39.84	19.94	5.71	150.00	42.19	26.19	5.00	163.33	37.88	31.98	3.33	140.00	44.00	2.50	160.00
P7	42.06	24.42	5.00	157.83	47.44	22.45	5.00	166.67	42.37	17.83	3.33	155.00	49.25	2.50	160.00
Ammonia[c]															
P2	6.42	10.65	5.00	20.00	--	--	--	--	6.92	58.83	3.33	20.00	11.00	2.50	30.00
P5	6.07	24.96	5.00	12.50	--	--	--	--	6.36	59.46	3.33	13.33	10.50	2.50	20.00
P7	7.57	18.77	5.00	25.00	--	--	--	--	7.40	50.36	3.33	20.00	11.25	2.50	30.00

[a]Mean of annual means, minima and maxima for preoperational years:
Water quality parameters: P2 = 1979-1989; P5 = 1979-1981, 1987-1989; P7 = 1982-1989
Nutrients: P2 = 1978-1984, 1987-1989; P5 = 1978-1981, 1987-1989; P7 = 1982-1984, 1987-1989

[b]1987-1989; preoperational period specified in ANOVA (Table 2-2), mean of annual means.

[c]Because analytical methods for ammonia changed in April 1988, preoperational period for ammonia is April 1988 - December 1989.

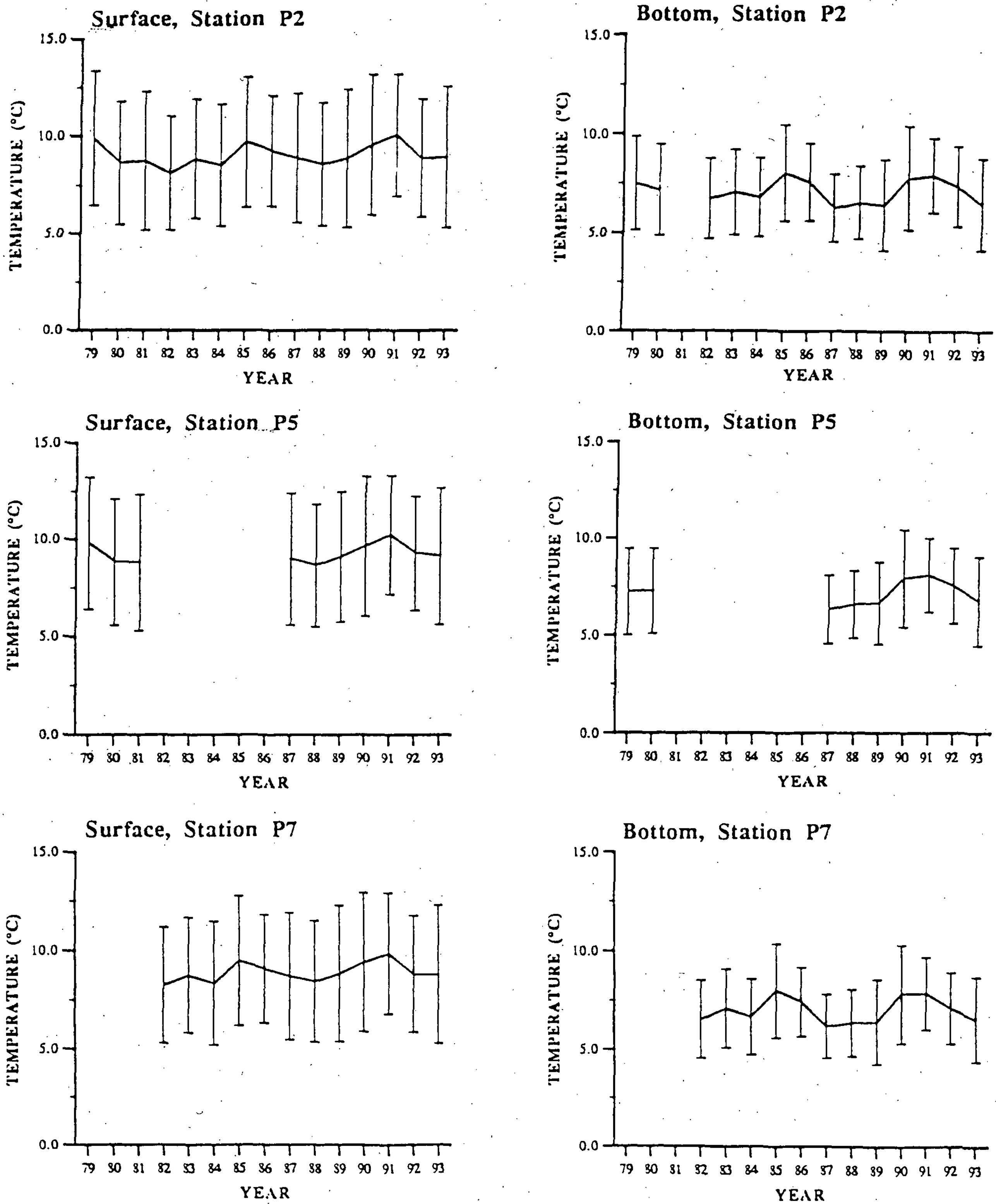


Figure 2-3. Time-series of annual means and 95% confidence intervals of **surface** and **bottom temperatures** at Stations P2, P5 and P7, 1979-1993. Seabrook Operational Report, 1993.

TABLE 2-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING WATER QUALITY CHARACTERISTICS AMONG STATIONS P2, P5, AND P7 DURING RECENT PREOPERATIONAL YEARS (1987-1989) AND OPERATIONAL (1991-1993) YEARS. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[h] (ranked in decreasing order)
Surface Temperature	PREOP-OP[b,c]	1	16.76	287.87***	OP>PREOP
	YEAR (PREOP-OP)[d]	4	7.73	132.79***	
	MONTH (YEAR)[e]	66	78.96	1355.97***	
	STATION[f]	2	2.49	42.78***	P5>P2>P7
	PREOP-OP X STATION[g]	2	0.10	1.72 NS	
	ERROR	140	0.06		
Bottom Temperature	PREOP-OP	1	42.66	486.31***	OP>PREOP
	YEAR (PREOP-OP)	4	8.76	99.91***	
	MONTH (YEAR)	66	28.47	324.57***	
	STATION	2	1.11	12.67***	P5>P2>P7
	PREOP-OP X STATION	2	0.03	0.37 NS	
	ERROR	140	0.09		
Surface Salinity	PREOP-OP	1	44.80	503.69***	PREOP>OP
	YEAR (PREOP-OP)	4	10.81	121.56***	
	MONTH (YEAR)	66	4.84	54.37***	
	STATION	2	0.34	3.87*	P2 P5 P7
	PREOP-OP X STATION	2	0.13	1.43 NS	
	ERROR	140	0.09		
Bottom Salinity	PREOP-OP	1	51.77	1022.62***	PREOP>OP
	YEAR (PREOP-OP)	4	5.75	113.49***	
	MONTH (YEAR)	66	1.42	28.04***	
	STATION	2	0.38	7.41***	P7>P5 P2
	PREOP-OP X STATION	2	0.03	0.64 NS	
	ERROR	140	0.05		

(continued)

TABLE 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[b] (ranked in decreasing order)
Surface Dissolved Oxygen	PREOP-OP	1	1.09	62.56***	PREOP>OP
	YEAR (PREOP-OP)	4	0.41	23.58***	
	MONTH (YEAR)	66	2.84	163.24***	
	STATION	2	0.09	4.92**	P5 P2 P7
	PREOP-OP X STATION	2	0.03	1.62 NS	
	ERROR	140	0.02		
Bottom Dissolved Oxygen	PREOP-OP	1	<0.01	0.21 NS	
	YEAR (PREOP-OP)	4	3.93	184.47***	
	MONTH (YEAR)	66	4.59	215.33***	
	STATION	2	0.19	8.87***	P5 P2>P7
	PREOP-OP X STATION	2	0.02	1.06 NS	
	ERROR	140	0.02		
Orthophosphate	PREOP-OP	1	10.89	3.71 NS	
	YEAR (PREOP-OP)	4	79.11	26.93***	
	MONTH (YEAR)	66	206.54	70.31***	
	STATION	2	5.89	2.01 NS	
	PREOP-OP X STATION	2	1.22	0.41 NS	
	ERROR	140	2.94		
Total Phosphorus	PREOP-OP	1	591.38	25.27***	PREOP>OP
	YEAR (PREOP-OP)	4	361.23	15.44***	
	MONTH (YEAR)	65	325.02	13.89***	
	STATION	2	28.84	1.23 NS	
	PREOP-OP X STATION	2	24.52	1.05 NS	
	ERROR	138	23.40		
Nitrate	PREOP-OP	1	1464.84	34.84***	PREOP>OP
	YEAR (PREOP-OP)	4	4030.32	95.87***	
	MONTH (YEAR)	66	9711.81	231.02***	
	STATION	2	289.52	6.89**	P7 P2 P5
	PREOP-OP X STATION	2	3.67	0.09 NS	
	ERROR	140	42.04		

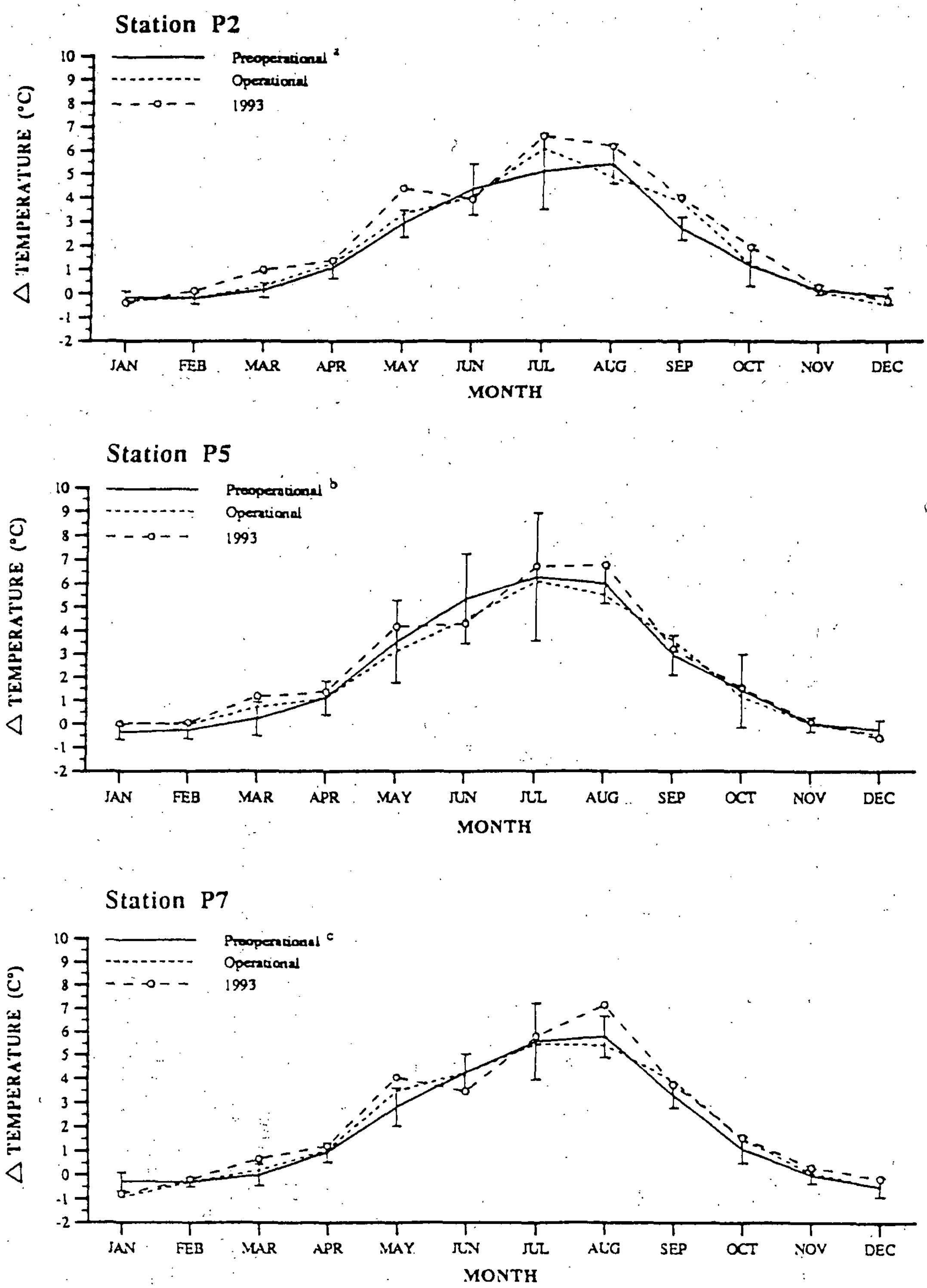
(continued)

TABLE 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[h] (ranked in decreasing order)
Nitrite	PREOP-OP	1	0.13	0.31 NS	
	YEAR (PREOP-OP)	4	2.00	4.93***	
	MONTH (YEAR)	66	7.83	19.28***	
	STATION	2	1.77	4.37*	P7 P2>P5
	PREOP-OP X STATION	2	0.51	1.26 NS	
	ERROR	140	0.41		
Ammonia	PREOP-OP	1	8.10	2.21 NS	
	YEAR (PREOP-OP)	3	412.94	112.64***	
	MONTH (YEAR)	52	32.86	8.96***	
	STATION	2	20.29	5.53**	(Non-est.)[i]
	PREOP-OP X STATION	2	1.54	0.42 NS	
	ERROR	110	3.67		

[a]Based on averaged monthly collections for all parameters
[b]Preoperational years: 1987-1989 at each station for all parameters except ammonia, which was April 1988 through December 1989
[c]Preoperational versus operational period, regardless of station
[d]Year nested within preoperational and operational periods, regardless of station
[e]Month nested within year nested within preoperational and operational periods, regardless of station
[f]Station P2 versus P5 versus P7, regardless of year
[g]Interaction between main effects
[h]Underlining indicates no significant difference based on a test of H_o: LSMEAN(i)=LSMEAN(j)
[i]Too few preoperational data available to compute the LSMEANS for STATION

NS = not significant ($p \geq 0.05$)
* = significant ($0.05 \geq p > 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)



[a] Preoperational years = 1979-1989

[b] Preoperational years = 1979-1981, 1987-1989

[c] Preoperational years = 1982-1989

Figure 2-4. Monthly mean difference and 95% confidence intervals between surface and bottom temperatures (°C) at Stations P2, P5, and P7 for the preoperational period and monthly means for the operational period (1979-1989) and 1993. Seabrook Operational Report, 1993.

Continuous surface temperatures recorded at Stations DS (discharge) and T7 (farfield) by YAEC in 1993 showed a similar seasonal pattern as temperatures recorded at the plankton stations, including a distinct August peak (Figure 2-5). The annual mean temperature at DS decreased since 1991 (Table 2-3). With the exception of May, July and August, monthly mean temperatures at DS were cooler than during previous years (Table 2-4).

At T7, temperatures during most months were cooler in 1993 than in 1991 and 1990, but were warmer during most months compared to 1992 (Table 2-4). Compared to earlier operational years, temperatures in October through December in 1993 were particularly warm, especially in comparison to coincident temperatures observed at the plankton stations in 1993 (Figure 2-2 and Table 2-4). This, combined with the relatively cool temperatures observed at DS during these months in 1993, resulted in a shift in the monthly average ΔT from typically positive values (DS > T7) to relatively large negative values (DS < T7). This shift appears unusual compared to results from 1990-1992, although the temperatures observed at T7 in 1993 were similar to average temperatures recorded during the early years of preoperational monitoring (1975-1977; NAI 1979). Average monthly ΔT values showed full compliance with the Station's NPDES permit.

Salinity

Monthly average surface salinities followed a distinct seasonal pattern (Figure 2-6) that was related to freshwater influx and precipitation, air temperatures and winds, and tides and currents. Several major freshwater sources influence salinities observed in the nearshore area off Hampton Harbor, including the Penobscot and Kennebec Rivers in Maine, the Piscataqua River in New Hampshire and the Merrimack River in Massachusetts. Salinities were typically highest during the colder months due to low temperatures and low precipitation and runoff. Salinities declined to their lowest levels of the year when freshwater influx reached its peak level in the spring, due to spring storms combined with snow melt. Bottom salinities exhibited a similar but less pronounced seasonal pattern. Waters within the study area are relatively shallow, thus storms and strong currents can, at times, affect the entire water column (NAI 1979). However, bottom waters in 1993 generally exhibited a more stable temperature and salinity structure compared to surface waters, i.e., temperature and salinity changed at a faster rate and to a larger degree over the course of the year in surface waters when compared to bottom waters.

TABLE 2-3. ANNUAL MEAN SURFACE TEMPERATURES[a] AND COEFFICIENTS OF VARIATION (CV,%) AT STATIONS DS AND T7 DURING OPERATIONAL MONITORING CONDUCTED BY YAEC. SEABROOK OPERATIONAL REPORT, 1993.

	STATION DS		STATION T7	
YEAR	MEAN	CV	MEAN	CV
1991	10.55	38.85	9.88	48.10
1992	9.44	41.92	8.32	54.57
1993	9.17	53.34	8.61	57.44

[a]mean of monthly means; n=12 in 1991 and 1993; n=11 in 1992.

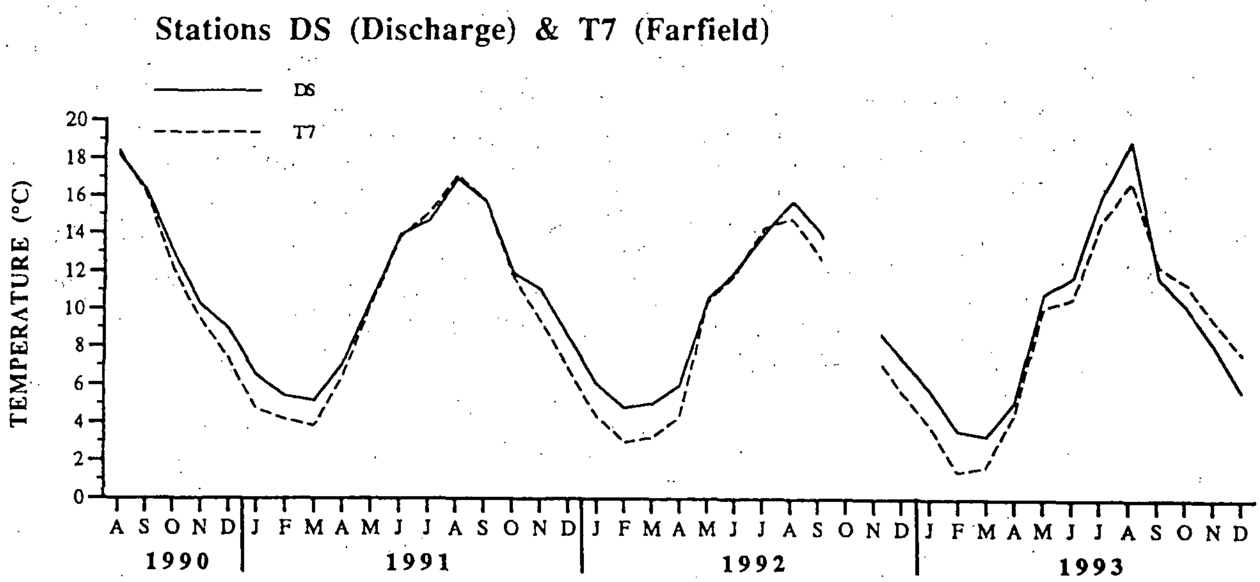


Figure 2-5. Comparison of monthly averaged continuous temperature (°C) data collected at the surface at discharge (DS) and farfield (T7) stations during commercial operation, August 1990-December 1993. Seabrook Operational Report, 1993.

TABLE 2-4. MONTHLY MEAN TEMPERATURES (°C) AND TEMPERATURE DIFFERENCES (ΔT,°C) BETWEEN DISCHARGE (DS) AND FARFIELD (T7) STATIONS AT THE SURFACE, AND NEARFIELD (ID) AND FARFIELD (T7) STATIONS AT SURFACE, MID-DEPTH (8.5 m) AND BOTTOM (16.2 m) DEPTHS COLLECTED FROM CONTINUOUSLY-MONITORED TEMPERATURE SENSORS, JULY 1990-DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

	1990			1991			1992			1993		
MONTH	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT
DISCHARGE - FARFIELD (SURFACE)												
JAN	--[b]	--	--	6.47	4.71	1.76	6.02	4.32	1.70	5.69	3.80	1.89
FEB	--	--	--	5.38	4.17	1.21	4.74	2.92	1.82	3.52	1.38	2.14
MAR	--	--	--	5.11	3.78	1.33	4.94	3.16	1.78	3.26	1.63	1.63
APR	--	--	--	6.99	6.37	0.62	5.93	4.26	1.67	5.04	4.44	0.60
MAY	--	--	--	10.43	10.21	0.22	10.52	10.32	0.20	10.74	10.02	0.72
JUN	--	--	--	13.81	13.70	0.11	11.94	11.84	0.10	11.65	10.53	1.12
JUL	14.54	14.63	-0.08	14.58	15.02	-0.44	13.81	14.16	-0.35	15.92	14.54	1.39
AUG[a]	18.16	18.36	-0.20	16.86	17.06	-0.20	15.61	14.69	0.92	18.77	16.69	2.08
SEP	16.31	16.09	0.22	15.66	15.69	-0.03	14.03	12.69	1.34	11.62	12.19	-0.57
OCT	13.04	12.11	0.93	11.87	11.68	0.19	--	--	--	10.13	11.27	-1.14
NOV	10.24	9.44	0.80	11.00	9.33	1.67	9.01	7.59	1.42	8.03	9.33	-1.30
DEC	8.91	7.32	1.59	8.45	6.81	1.64	7.32	5.61	1.71	5.64	7.55	-1.91

	1990			1991			1992			1993		
MONTH	ID	T7	ΔT	ID	T7	ΔT	ID	T7	ΔT	ID[c]	T7	ΔT
NEARFIELD - FARFIELD (SURFACE)												
JAN	--	--	--	4.63	4.72	-0.09	4.08	4.32	-0.24	3.64	3.80	-0.16
FEB	--	--	--	4.24	4.14	0.10	2.81	2.84	-0.03	1.35	1.50	-0.15
MAR	--	--	--	3.95	3.77	0.18	--	3.17	--	1.37	1.78	-0.41
APR	--	--	--	6.36	6.21	0.15	--	4.98	--	3.90	4.44	-0.54
MAY	--	--	--	10.29	10.21	0.08	9.55	10.33	-0.78	9.06	10.02	-0.96
JUN	--	--	--	13.78	13.70	0.08	11.56	11.84	-0.28	9.62	10.53	-0.91
JUL	14.69	14.63	0.07	15.12	15.02	0.10	14.24	14.21	0.03			
AUG	18.11	18.11	0.01	16.70	16.57	0.13	--	11.70	--	DECOMMISSIONED		
SEP	16.22	16.06	0.16	15.34	15.38	-0.04	12.21	12.76	-0.55			
OCT	13.17	12.98	0.19	11.58	11.68	-0.10	--	--	--			
NOV	9.38	9.39	-0.02	9.16	9.34	-0.18	7.43	7.61	-0.18			
DEC	7.37	7.34	0.03	6.59	6.81	-0.22	5.26	5.61	-0.35			

(continued)

TABLE 2-4. (Continued)

MONTH	1990 ID	1990 T7	1990 ΔT	1991 ID	1991 T7	1991 ΔT	1992 ID	1992 T7	1992 ΔT	1993 ID[c]	1993 T7[c]	1993 ΔT
NEARFIELD - FARFIELD (MID-DEPTH)												
JAN	--	--	--	4.83	5.00	-0.17	4.44	4.70	-0.26	3.86	4.03	-0.17
FEB	--	--	--	4.19	4.31	-0.12	3.00	--	--	1.31	1.58	-0.27
MAR	--	--	--	3.53	3.64	-0.11	3.01	--	--	1.14	1.40	-0.26
APR	--	--	--	5.36	5.44	-0.08	4.63	--	--	3.53	3.75	-0.22
MAY	--	--	--	8.11	8.39	-0.28	8.12	8.13	-0.01	7.31	7.42	-0.11
JUN	--	--	--	11.19	11.46	-0.27	9.63	9.79	-0.16	9.16	8.99	0.17
JUL	11.76	11.50	0.26	11.24	11.74	-0.50	10.93	11.31	-0.38			
AUG	14.81	15.42	-0.61	14.96	14.88	0.08	12.09	12.39	-0.30	DECOMMISSIONED		
SEP	14.06	13.94	0.12	13.74	13.87	-0.13	11.09	11.40	-0.31			
OCT	11.92	11.85	0.07	10.94	11.14	-0.20	--	--	--			
NOV	9.42	9.53	-0.11	9.41	9.58	-0.17	7.63	7.68	-0.05			
DEC	7.47	7.57	-0.11	6.86	7.11	-0.25	5.54	5.83	-0.29			

MONTH	1990 ID	1990 T7	1990 ΔT	1991 ID	1991 T7	1991 ΔT	1992 ID	1992 T7	1992 ΔT	1993 ID[c]	1993 T7[c]	1993 ΔT
NEARFIELD - FARFIELD (BOTTOM)												
JAN	--	--	--	5.14	5.74	-0.60	4.16	4.34	-0.18	4.15	--	
FEB	--	--	--	4.19	4.81	-0.62	2.98	3.06	-0.08	1.55	--	
MAR	--	--	--	3.39	3.87	-0.48	3.09	3.12	-0.03	0.82	0.84	-0.02
APR	--	--	--	4.83	5.13	-0.30	4.29	4.26	0.03	3.18	--	
MAY	--	--	--	6.32	6.67	-0.35	6.19	6.09	0.10	5.77	--	
JUN	--	--	--	9.15	9.46	-0.31	8.04	7.96	0.08	7.61	--	
JUL	9.08	9.62	-0.54	9.01	9.34	-0.33	8.65	8.51	0.14			
AUG	13.26	13.14	0.12	13.08	12.92	0.16	10.08	9.77	0.31	DECOMMISSIONED		
SEP	12.14	12.31	-0.17	11.89	11.99	-0.10	9.79	9.68	0.11			
OCT	11.03	11.17	-0.14	10.28	10.37	-0.09	--	--	--			
NOV	9.49	9.91	-0.42	9.40	--	--	8.62	8.83	-0.21			
DEC	7.43	7.96	-0.53	6.93	--	--	5.76	--	--			

[a]Commercial operation began in August, 1990.
[b]Data either not collected, or an equipment failure occurred.
[c]ID (surface, mid-depth, bottom) and T7 (mid-depth and bottom) sensors decommissioned July 1, 1993.

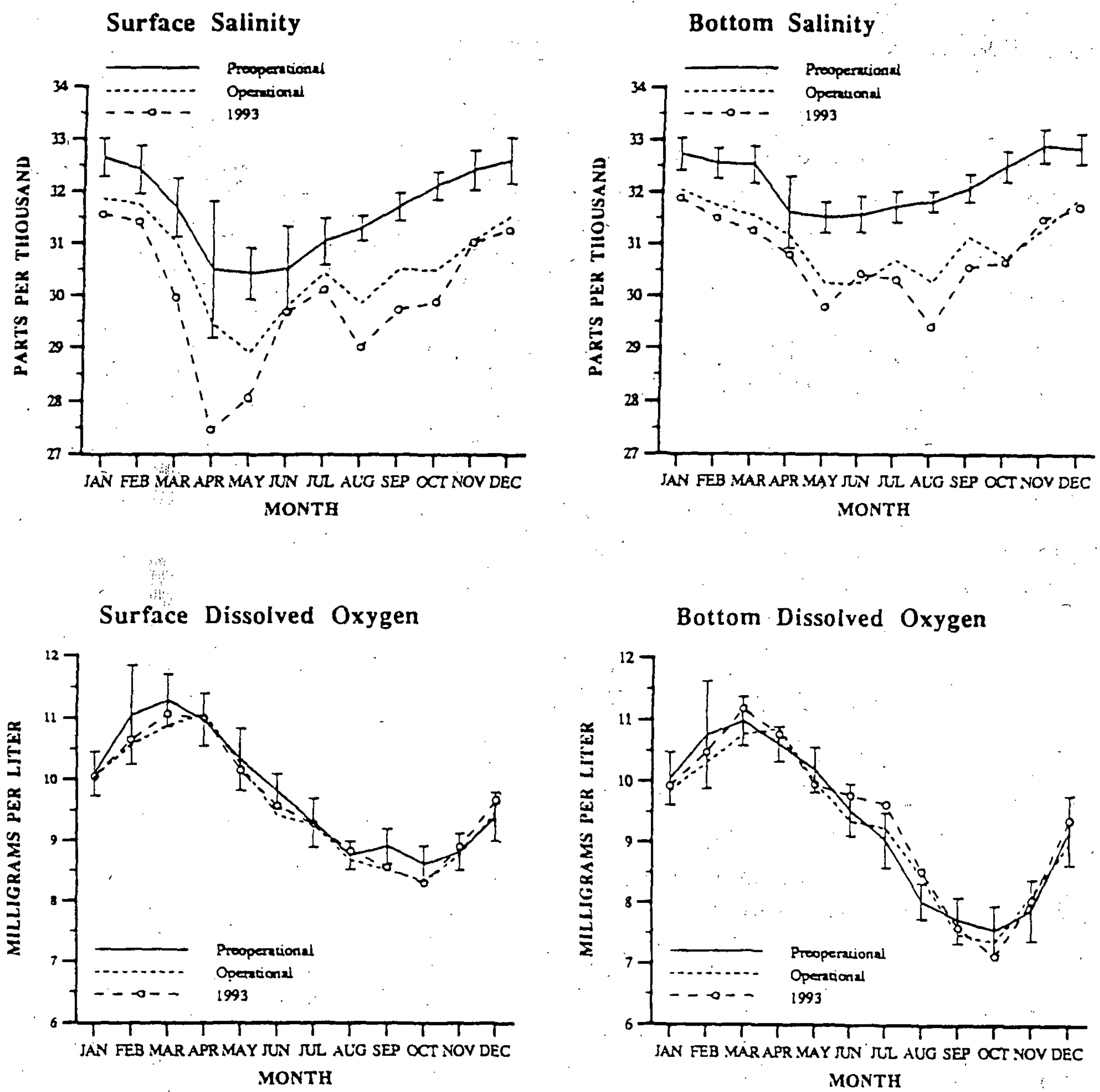


Figure 2-6. Surface and bottom **salinity** (ppt) and **dissolved oxygen** (mg/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1989) and monthly means for the operational period (1991-1993) and 1993. Seabrook Operational Report, 1993.

Although seasonal patterns of surface and bottom salinity were similar between preoperational and operational periods, 1993 annual mean surface salinities at each station decreased by approximately 1.5-1.6 ppt compared to preoperational means, and 1993 bottom salinities declined by approximately 1.3-1.4 ppt (Table 2-1). Differences between operational and preoperational salinities were significant (Table 2-2). Over both the preoperational (all years and recent years) and operational periods, mean surface salinities have been similar among the three stations while mean bottom salinities have been higher at Station P7 than at P5 and P2. These relationships have remained consistent regardless of operational status of Seabrook Station (Table 2-2).

Examination of long term trends in annual mean salinities (Figure 2-7) revealed that the decline in salinity began between 1988 and 1989 at all stations and at both depths. A similar phenomenon was observed at the Maine Department of Marine Resources West Boothbay Harbor long term environmental monitoring station. This station is fairly comparable to the Seabrook plankton stations; although in a more protected location, there is relatively little freshwater input to the harbor. Long term (1966-1985) annual mean surface salinities (taken at -5.5 feet MLW) at the West Boothbay Harbor station ranged between 30 and 32 ppt (MDMR 1987), and in recent years annual mean salinity has declined from 30.7 ppt in 1990 to 29.2 ppt in 1993 (MDMR 1991, 1992, 1993, 1994).

The reason for the decline in Seabrook salinities remains unexplained, and probably reflects a combination of several factors, including climatological conditions and general circulation patterns in the Gulf of Maine. Instrumentation error may have been a contributing factor to the observed differences. The YSI meter used through 1993 produced readings within its stated specifications (±6.5%) but were approximately 1 ppt lower than duplicate samples analyzed in the laboratory. As additional data from the Seabrook studies and other investigations in the nearshore area of the Gulf of Maine become available, this phenomenon will be examined further.

Dissolved Oxygen

Surface and bottom dissolved oxygen concentrations exhibited a seasonal pattern in 1993 similar to previous years (Figure 2-6). Dissolved oxygen concentrations were highest during the cooler winter months, and peaked in late winter (February and March); concentrations were lowest during the summer months when temperatures reached the annual maximum (Figure 2-2). Operational and 1993 mean surface concentrations were within preoperational 95% confidence limits during all months; mean bottom concentrations in 1993 were greater than preoperational confidence limits in July and August only, and were lower than preoperational confidence limits in October.

Although preoperational-operational differences in annual mean surface dissolved oxygen concentrations were small (≤0.13 mg/L, Table 2-1), preoperational concentrations were significantly greater than operational concentrations (Table 2-2), corresponding to cooler preoperational temperatures and warmer operational temperatures. Differences in annual mean bottom concentrations between preoperational and operational periods were even smaller (< 0.9 mg/L), and were not significant (Table 2-2).

Station differences in dissolved oxygen concentrations were significant across all years at both depths (Table 2-2). Concentrations were similar between Stations P2 and P5 at both depths. Concentrations were similar between P2 and P7 at the surface, but concentrations at P7 were significantly less than at P5 at the surface and less than P5 and P2 at bottom depths. The interaction term, however, was not significant at either depth (Table 2-2).

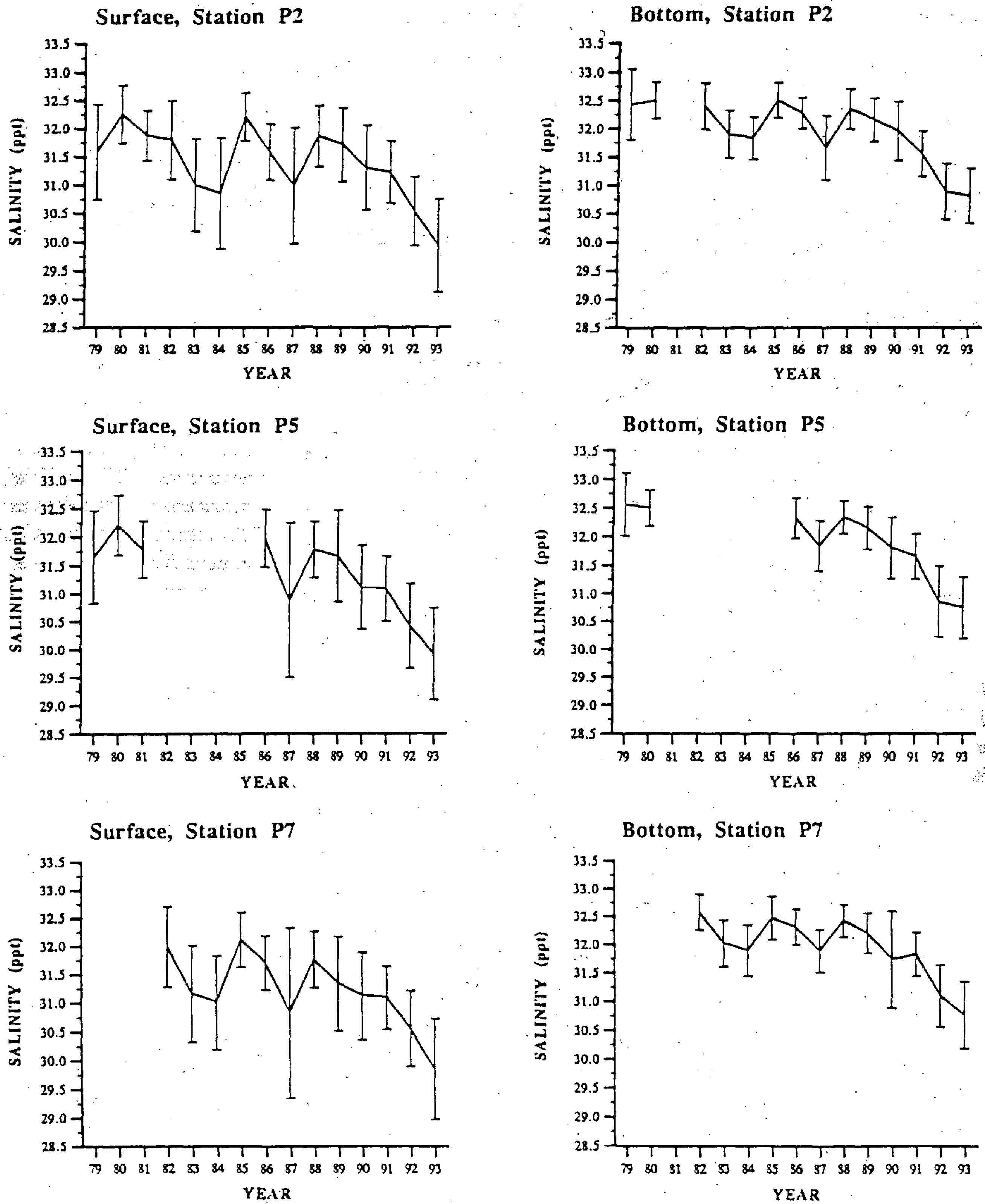


Figure 2-7. Time-series of annual means and 95% confidence intervals of surface and bottom salinity (ppt) at Stations P2, P5, and P7, 1979-1993. Seabrook Operational Report, 1993.

2.3.2 Nutrients

Phosphorus Species

Monthly mean surface orthophosphate concentrations followed a distinct seasonal pattern in 1993 that was typical of earlier years (Figure 2-8). Concentrations were highest during late-fall to late-winter, and lowest during summer months. This pattern, typical of nutrients in northern temperate waters in general, is caused largely by the uptake of phosphorus during the warmer months by primary producers (Section 3.0).

Orthophosphate concentrations during January, February, September and December in 1993 exceeded preoperational upper 95% confidence limits, but were similar to preoperational monthly means during all other months. Operational-preoperational (recent years) mean differences ranged from 0.25 to 0.75 mg/L (Table 2-1), and were not statistically significant (PREOP-OP term, Table 2-2). Differences between stations, during both periods, were also not significant, nor was the interaction of main effects (PREOP-OP X STATION, Table 2-2).

Trends in total phosphorus and orthophosphate concentrations were similar on a seasonal basis (Figure 2-8). Monthly mean total phosphorus concentrations observed in 1993 fell within the 95% confidence limits of preoperational monthly means in all months except August, when the 1993 monthly mean exceeded the preoperational August upper confidence limit. Operational mean concentrations were significantly (approximately 3 mg/L) lower than preoperational mean concentrations (Table 2-1; Table 2-2).

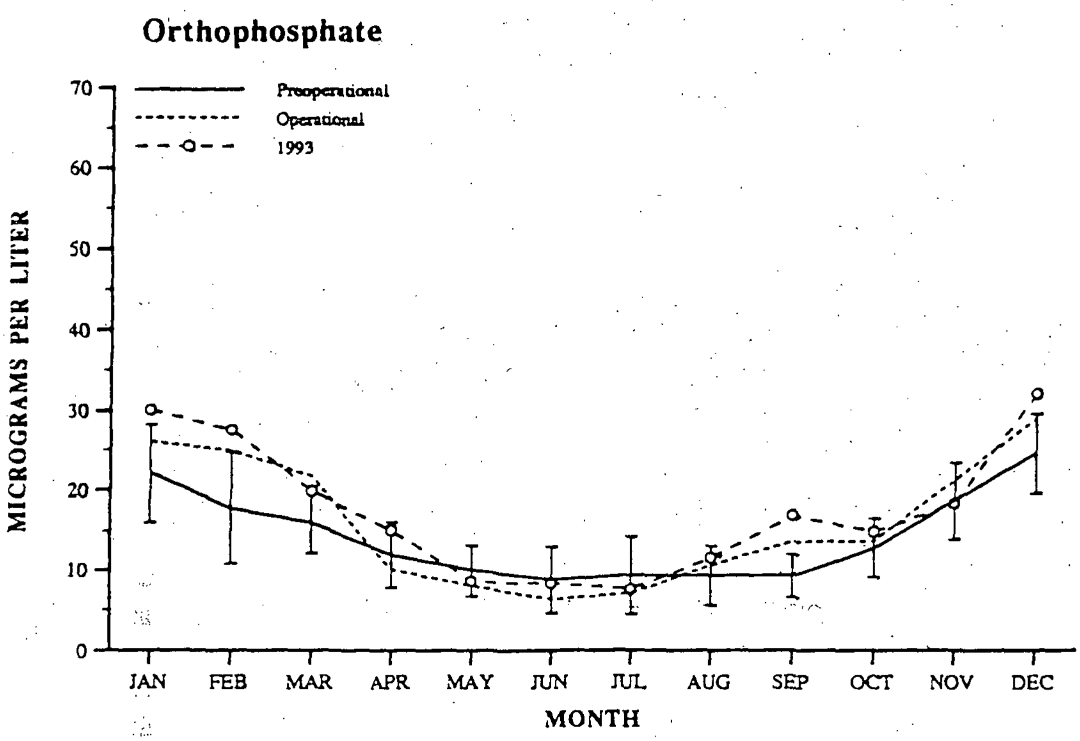
During all operational years, total phosphorus concentrations differed on an annual basis by less than 1 mg/L among the three stations (Table 2-1). Across all preoperational years, among-station differences as large as 3 mg/L were observed. Over the period of 1987-1993, however, differences among stations were not significant, nor was the interaction of the main effects (Table 2-2).

Nitrogen Species

Nitrate concentrations exhibited the same strong seasonality observed in phosphorus concentrations (Figure 2-9). Monthly mean concentrations in 1993 closely tracked preoperational means during spring through fall, but were higher in January, February and March. Only the February mean concentration exceeded the upper 95% confidence interval of the preoperational mean. Although the annual mean concentrations observed in 1993 were higher than during the period 1987-1989 (Table 2-1), the preoperational mean over all three stations was still significantly greater than the operational mean (Table 2-2). Station differences were also significant over all years (P7 > P5), but the interaction between main effects was not.

Nitrite concentrations exhibited a weaker, but still significant (Table 2-2) monthly (seasonal) pattern compared to other nutrients (Figure 2-9). Over the whole year, monthly mean concentrations in 1993 were variable, and exceeded preoperational upper 95% confidence limits in some months and were less than preoperational lower 95% confidences limits in others. Operational and preoperational annual mean concentrations were not significantly different (Tables 2-1 and 2-2). Differences between stations were significant over the period 1987-1993 (Table 2-2), with P7 and P2 > P5. As with other nutrients, the interaction term was not significant.

Although ammonia concentrations did not show the distinct seasonality observed in other nutrients, monthly differences were significant over all years from 1987-1993 (Figure 2-9 and Table 2-2). Monthly mean concentrations in 1993 were higher than preoperational monthly means in all months except July and October by as much as 25 µg/L. In spite of the large differences between 1993 and preoperational means (roughly 4



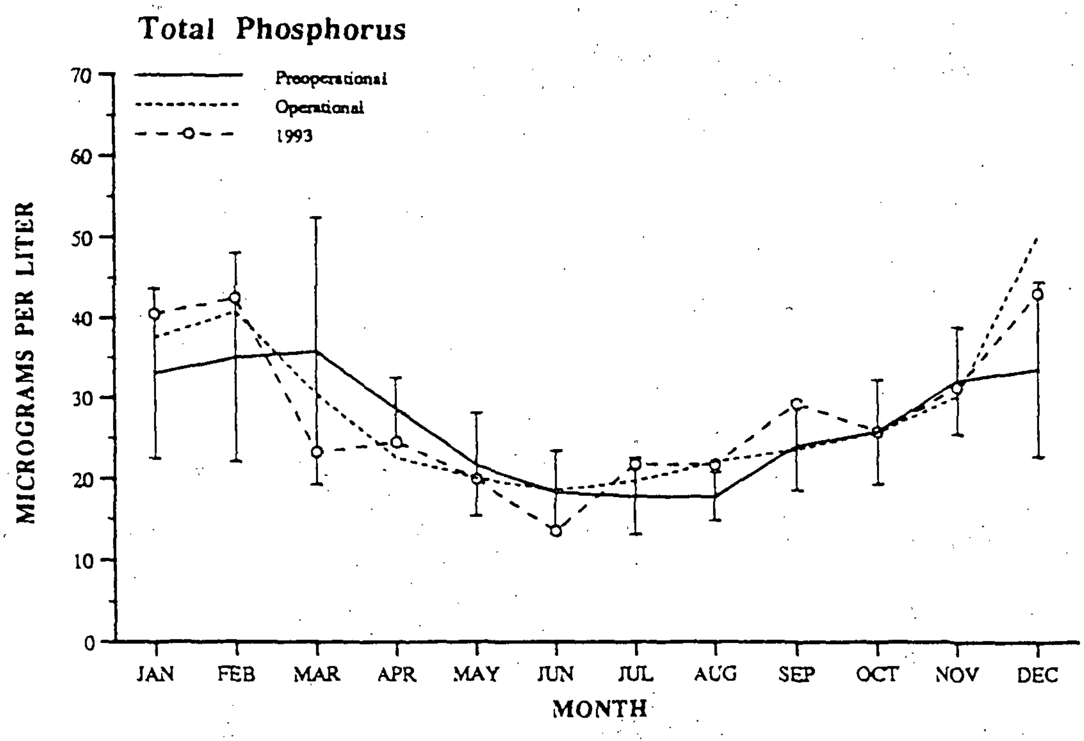
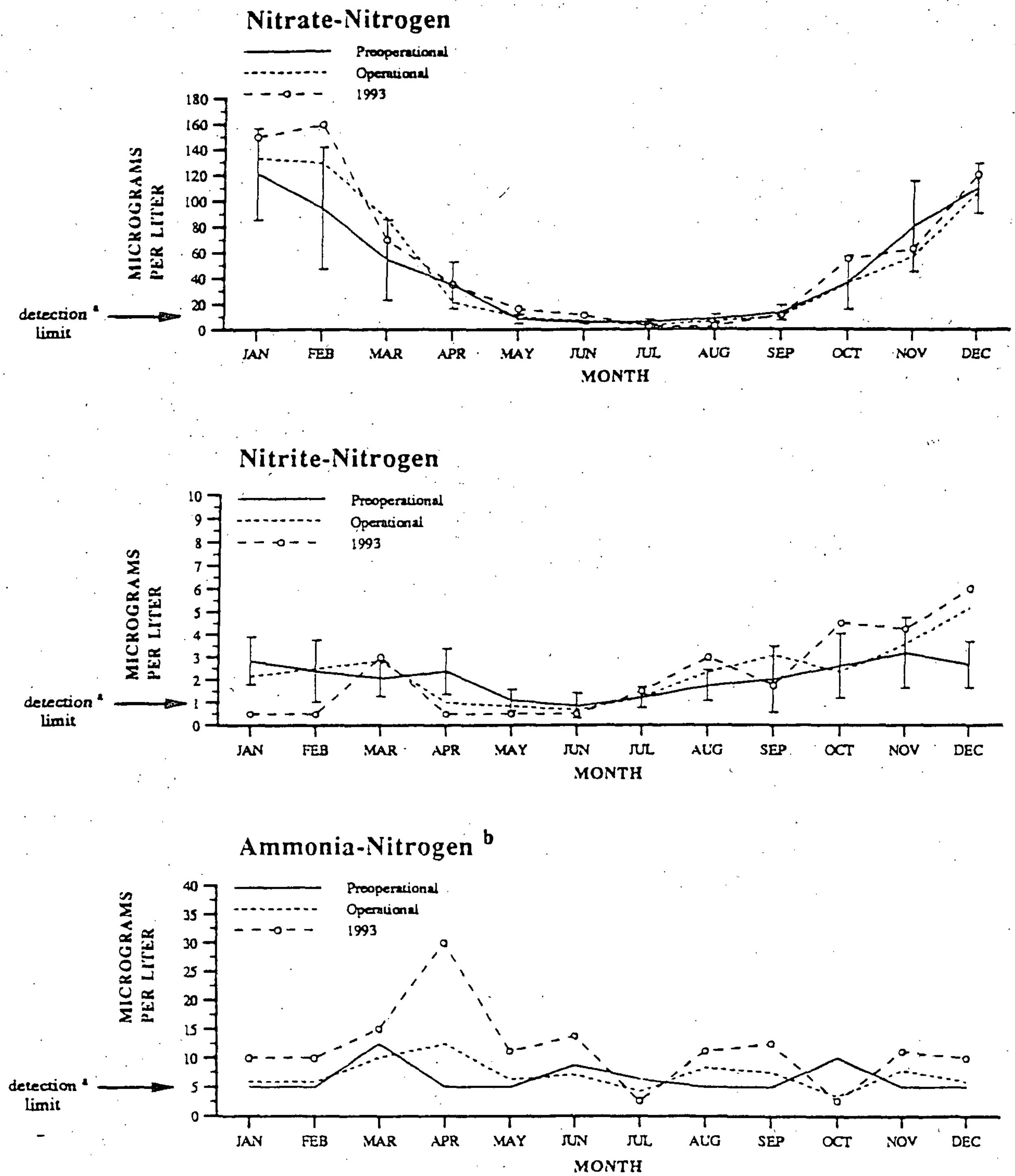


Figure 2-8. Surface orthophosphate and total phosphorus concentrations (µg P/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-1989), and monthly means for the operational period (1991-1993) and 1993. Seabrook Operational Report, 1993.



[a] For the purpose of calculating monthly means, data points reported as "below detection limit" were given a value of one-half the detection limit.

[b] Preoperational period for ammonia is April 1988-December 1989; confidence intervals not calculated for this period.

Figure 2-9. Surface nitrite-nitrogen, nitrate-nitrogen and ammonia-nitrogen concentrations (μg N/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-1989), and monthly means for the operational period (1991-1993) and 1993. Seabrook Operational Report, 1993.

μg/L at each station; Table 2-1), operational-preoperational differences over all stations were not significant (Table 2-2). This difference is due in large part to the fact that ammonia was not detected during any previous operational month except August in 1992 (NAI 1993).

2.4 DISCUSSION

Water quality information collected during 1993 showed a moderately well-mixed water column at each station through most of the year. Although surface-bottom differences were present at times during the year, a strong stratification that would block the cycling of nutrients between surface and bottom waters did not develop at any time. Temperatures were generally cooler compared to earlier operational years, although over the operational period as a whole, temperatures were still warmer compared to the preoperational surface and bottom mean temperatures. Salinities were significantly lower during the operational period compared to the preoperational period, although long term trends indicate that the decline began in the late 1980s. Monitoring data collected by the MDMR in West Boothbay Harbor, Maine suggest that these temperature and salinity trends may be typical of the nearshore Gulf of Maine region. However, the change in instrumentation in 1990 may have contributed to the observed decline in salinity. Surface dissolved oxygen concentrations decreased during the operational period in response to warmer surface temperatures, while operational bottom dissolved oxygen concentrations remained similar to preoperational concentrations. In both cases, station differences were consistent over time, indicating that there was no effect due to plant operation. Nutrient concentrations showed both temporal and spatial differences, but for each of the five analyzed, the interaction term in the ANOVA model was not significant, indicating that observed results were not influenced by the operation of Seabrook Station.

In spite of several preoperational-operational differences in the water quality parameters (Table 2-5), there is currently no evidence to indicate any significant change in water quality caused by the operation of the Seabrook Station cooling water system. This is based on the consistency of spatial trends between the two periods, as well as the similarity of seasonal patterns across the years.

2.5 REFERENCES CITED

APHA (American Public Health Association). 1989. Standard methods for the examination of water and wastewater, 17th edition.

Gilbert, Richard O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold Co. Inc., New York.

Maine Department of Marine Resources. 1991. Boothbay Harbor Environmental Data, 1990. West Boothbay Harbor, Maine.

_________. 1992. Boothbay Harbor Environmental Data, 1991. West Boothbay Harbor, Maine.

_________. 1993. Boothbay Harbor Environmental Data, 1992. West Boothbay Harbor, Maine.

_________. 1994. Boothbay Harbor Environmental Data, 1993. West Boothbay Harbor, Maine.

Normandeau Associates Inc. (NAI). 1979. Annual Summary Report for 1977 Hydrographic Studies off Hampton Beach, New Hampshire. Tech. Rep. X-I. Preoperational Ecol. Monit. Stud. for Seabrook Station.

USEPA (United States Environmental Protection Agency). 1979. Methods for chemical analyses of water and wastes. EPA-600/4-79-020. EMSL, Cincinnati, OH.

TABLE 2-5. SUMMARY OF POTENTIAL EFFECTS OF SEABROOK STATION ON AMBIENT WATER QUALITY. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER	DEPTH	OPERATIONAL PERIOD SIMILAR TO RECENT PRE-OPERATIONAL PERIOD?[a]	SPATIAL TRENDS CONSISTENT WITH PREVIOUS YEARS[b]
Temperature	surface	Op>Preop	yes
	bottom	Op>Preop	yes
Salinity	surface	Preop>Op	yes
	bottom	Preop>Op	yes
Dissolved oxygen	surface	Preop>Op	yes
	bottom	yes	yes
Nitrite	surface	yes	yes
Nitrate	surface	Preop>Op	yes
Ammonia	surface	yes	yes
Orthophosphate	surface	yes	yes
Total phosphate	surface	Preop>Op	yes

[a]based on ANOVA for 1987-1993, when all 3 stations were sampled concurrently
[b]PREOP-OP X STATION term in ANOVA model

TABLE OF CONTENTS

SUMMARY

The phytoplankton community continued to show variability in abundance and community structure during the operational period. Taxa of the class Bacillariophyceae (diatoms) generally dominated the community numerically, although in 1992 the Prymnesiophycea *Phaeocystis pouchetii* was dominant. Such shifts between diatoms and *Phaeocystis* were observed during the preoperational period. Total community abundance and abundance of the selected species (the diatom *Skeletonema costatum*) increased significantly during the operational period, although chlorophyll *a* concentrations decreased significantly over the same period. This increase in abundance without a corresponding increase in chlorophyll *a* concentrations was likely due the high numbers of *Phaeocystis pouchetii*, a small-celled form, which was present in exceptionally high numbers in 1992. The phytoplankton community historically has been highly variable in species composition and abundance. This trend has continued during the operational period.

LIST OF FIGURES

LIST OF TABLES

PAGE

LIST OF APPENDIX TABLES

3.0 PHYTOPLANKTON

3.1 INTRODUCTION

The phytoplankton monitoring program was initiated to identify seasonal, annual, and spatial trends in the phytoplankton community to determine if the operation of Seabrook Station had a measurable effect on the community. The purpose of the monitoring program is to determine if the balanced indigenous phytoplankton community in the Seabrook area has been adversely influenced, within the framework of natural variability, by exposure to the thermal plume. Specific aspects of the community evaluated included phytoplankton (taxa ≥ 10 µm in size) abundance and species composition; ultraplankton (taxa < 10 µm in size) abundance and species composition; community standing crop as measured by chlorophyll *a* concentrations; abundance of the selected species (*Skeletonema costatum*); and toxicity levels of paralytic shellfish poison (PSP, as measured by concentrations of *Alexandrium* spp. in the tissue of the mussel *Mytilus edulis*) in the Hampton-Seabrook area.

3.2 METHODS

3.2.1 Field Methods

Near-surface (-1 m) water samples for phytoplankton and chlorophyll *a* analyses were collected during daylight hours at Stations P2 (intake), P5 (discharge) and P7 (farfield) (Figure 3-1) using an 8-L Niskin bottle. Collections were taken once per month in January, February and December, and twice monthly from March through November. Sampling occurred at Station P2 from 1978-1984; from 1978-1981 at Station P5; and from 1982-1984 at Station P7. Chlorophyll *a* collections resumed at all three stations in July 1986 and phytoplankton collections resumed in April 1990. These collections continued on this schedule through December 1993. From each whole water collection, two one-quart (0.946 L) jars containing 10 mL of a modified Lugol's iodine fixative were filled for phytoplankton taxonomic analyses and one gallon (3.785 L) was reserved for chlorophyll *a* analyses. Weekly paralytic shellfish poisoning (PSP) toxicity levels from mussels collected in Hampton Harbor were provided by the State of New Hampshire.

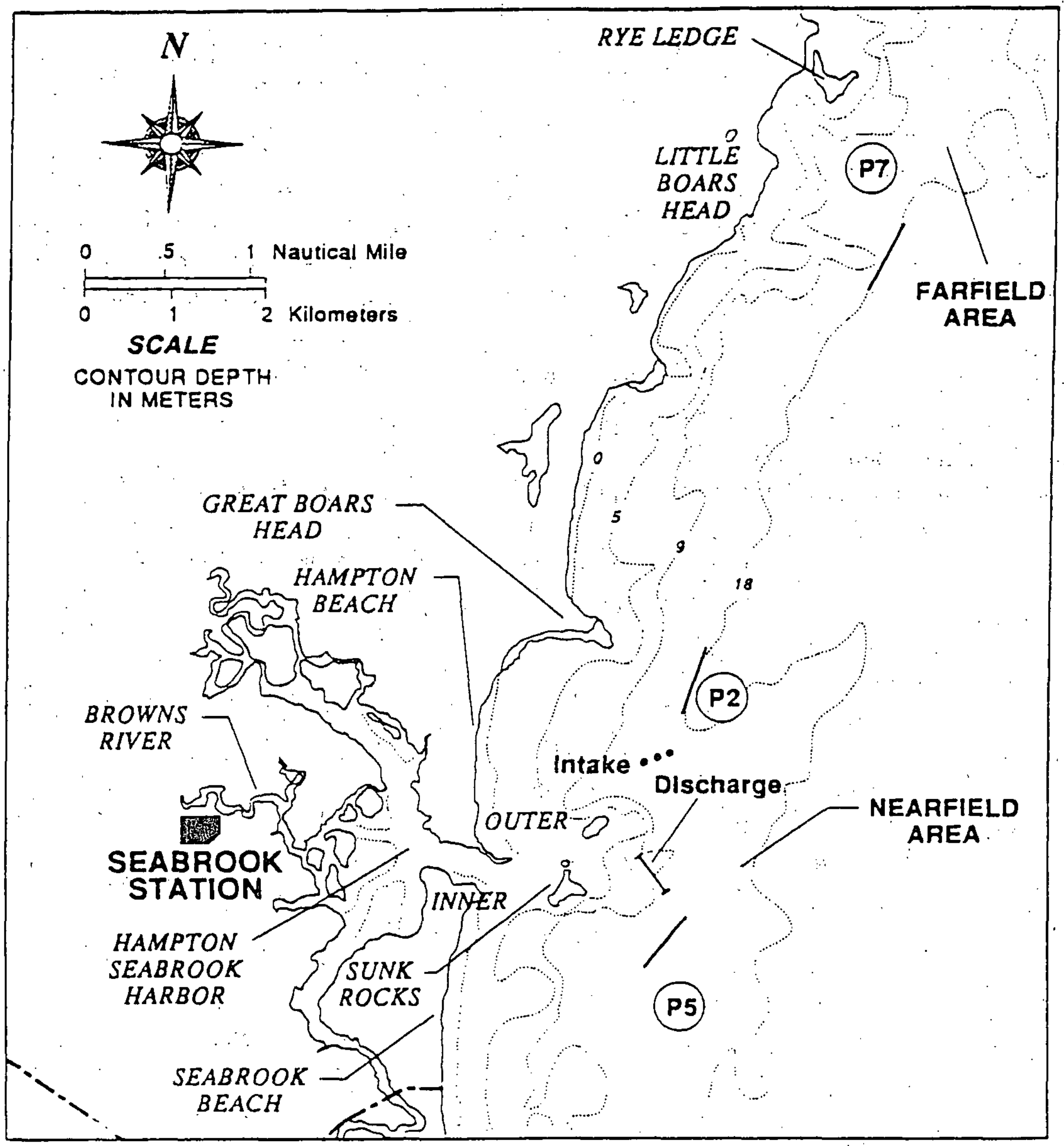
3.2.2 Laboratory Methods

Phytoplankton samples were prepared for analysis following the steps outlined in NAI (1991). One randomly-selected replicate from each station and sample period was analyzed for all taxa and a second replicate was analyzed for *Skeletonema costatum* only. Two 0.1-mL subsamples from each replicate were withdrawn and placed in Palmer-Maloney nanoplankton counting chambers. For those replicates selected for taxonomic analyses, the entire contents of the chamber were enumerated and identified to the lowest practical taxon.

Procedures for preparation of chlorophyll *a* water samples followed NAI (1991). Following the extraction of the plant pigment, fluorescence was determined and chlorophyll *a* and phaeophytin concentrations (µg/L) were computed separately.

3.2.3 Analytical Methods

Members of the phytoplankton community were classified into two size fractions as defined by Marshall and Cohen (1983): ultraplankton (<10 µm) and phytoplankton (≥10 µm). These groups were analyzed separately. During the earlier years of the Seabrook program, ultraplankton forms were only partially identified (the picoplankton size fraction, or forms <2.0 µm in size, were generally not identified). Beginning in the mid-1980s, an effort to identify these smaller forms was initiated throughout the scientific community (Stockner 1988). This effort plus use of an improved identification technique (phase contrast microscopy)



LEGEND

—— = phytoplankton stations

Figure 3-1. Phytoplankton sampling stations. Seabrook Operational Report, 1993.

was undertaken on this project when phytoplankton enumeration was re-initiated in 1990. These issues and their impacts on ultraplankton enumeration were discussed in more detail in NAI (1992b). Since the ultraplankton have been enumerated in greater detail during the operational period than during the preoperational period, an impact assessment that relies on comparisons between the two periods was not appropriate. Therefore, analyses focused only on nearfield-farfield comparisons during the operational period.

Seasonal abundance patterns of the phytoplankton assemblages during the preoperational and operational periods were compared graphically using Log (x+1)-transformed monthly mean abundances for ultraplankton, total phytoplankton and the selected species (*Skeletonema costatum*; Table 3-1). The Log (x+1) transformation was performed on the sample period mean, prior to calculating monthly means. Temporal (preoperational-operational) patterns in species abundances were evaluated using geometric means and community composition was evaluated by examining the percent composition of dominant (>1%) taxa. Chlorophyll *a* temporal and seasonal comparisons were based on untransformed monthly and yearly arithmetic mean concentrations. The similarity among the three stations with respect to species composition of the dominant phytoplankton taxa was evaluated statistically using a multivariate analysis of variance procedure (MANOVA, Harris 1985). Operational/preoperational and nearfield/farfield differences in total abundances of *S. costatum* and phytoplankton and mean chlorophyll *a* concentrations were evaluated using a multi-way analysis of variance procedure (ANOVA, SAS Institute, Inc. 1985). The ANOVA model was more conservative (more likely to detect significant differences) than alternative models that treat some sources of variation such as Year as random variables. An ANOVA model was run on ultraplankton abundances as well, but included only Year, Month and Station as sources of variation. Preoperational periods for each analysis are listed on the appropriate figures and tables. For all preoperational comparisons, the focus was on intake Station P2 due to the greater number of years of data collection. In all cases the operational period evaluated in this report includes collections from 1991-1993.

Weekly mean PSP toxicity levels were arithmetically averaged over the preoperational and operational periods and examined graphically.

3.3 RESULTS

3.3.1 Total Community

3.3.1.1 Phytoplankton

Seasonal Trends at Station P2

Monthly abundances during 1993 and the operational period were within the 95% confidence intervals established for the preoperational period with the exception of January and September (1993 only, Figure 3-2). The increased abundances in January during the operational period consist largely of high counts of chain forming centric diatoms and unicellular alga (NAI 1994). Seasonally, during both preoperational and operational periods, the most distinct period of peak abundance occurred in the fall (October) with a smaller secondary increase in early summer (May-June).

On average, diatoms (Bacillariophyceae) dominated the phytoplankton assemblage during 10 of 12 months during the preoperational period, while the Prymnesiophyceae taxon *Phaeocystis pouchetii* dominated during April and May and composed a minor portion of the assemblage in August (Figure 3-2). This pattern of seasonal succession in phytoplankton is well documented in other northern temperate coastal waters (Cadée and Hegeman 1986; Peperzak 1993). Other groups, primarily the dinoflagellates (Dinophyceae), were present in low numbers throughout the summer during the preoperational period. Seasonal succession during the operational period showed a similar pattern, with

TABLE 3-1. SUMMARY OF METHODS USED IN EVALUATION OF THE PHYTOPLANKTON COMMUNITY. SEABROOK OPERATIONAL REPORT, 1993.

ANALYSIS	TAXA	STATIONS	DATES USED IN ANALYSIS[a]	DATA CHARACTERISTICS	SOURCE OF VARIATION
PHYTOPLANKTON					
Percent Composition	All	P2	1978-1984; 1991-1993	Monthly and annual arithmetic mean abundances	--
		P2,P5,P7	1993	Monthly arithmetic mean abundances	--
Abundance	All	P2,P5,P7	1978-1984; 1991-1993	Monthly log (x+1) and annual geometric mean abundances	--
	Skeletonema costatum	P2	1978-1984; 1991-1993	Monthly log (x+1) and annual geometric mean abundances	--
MANOVA	15 dominants	P2,P5,P7	1993	Monthly log (x+1) mean abundances; species <1% of total abundance not included	Station
ANOVA	All	P2,P7	1982-1984; 1991-1993	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
	Skeletonema costatum	P2,P7	1982-1984; 1991-1993	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
		P2,P5	1979-1981; 1991-1993	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station

(continued)

TABLE 3-1. (Continued)

ANALYSIS	TAXA	STATIONS	DATES USED IN ANALYSIS[a]	DATA CHARACTERISTICS	SOURCE OF VARIATION
ULTRAPLANKTON Percent Composition	All	P2,P5,P7	1993	Monthly arithmetic mean abundances	--
Abundance	All	P2,P5,P7	1991-1993	Monthly log (x+1) and annual geometric mean abundances	--
ANOVA	All	P2,P5,P7	1991-1993	Monthly log (x+1) mean abundances	Year, Month, Station
CHLOROPHYLL *a* Concentration	--	P2	1979-1989; 1991-1993	Monthly arithmetic mean concentrations	--
		P2,P5,P7	1978-1984; 1987-1989; 1991-1993	Annual arithmetic mean concentrations	--
ANOVA	--	P2,P5,P7	1987-1989; 1991-1993	Monthly arithmetic mean concentrations	Preop-Op, Year, Month, Station
PSP TOXICITY	--	--	1983-1989; 1991-1993	Weekly arithmetic mean concentrations	--

[a]PREOPERATIONAL PERIOD:
A. PHYTOPLANKTON
P2 = 1978-1984
P5 = 1978-1981
P7 = 1982-1984

B. CHLOROPHYLL [a]
P2 = 1978-1984, 1987-1989
P5 = 1978-1981, 1987-1989
P7 = 1982-1984, 1987-1989

OPERATIONAL PERIOD: 1991-1993, all stations and parameters

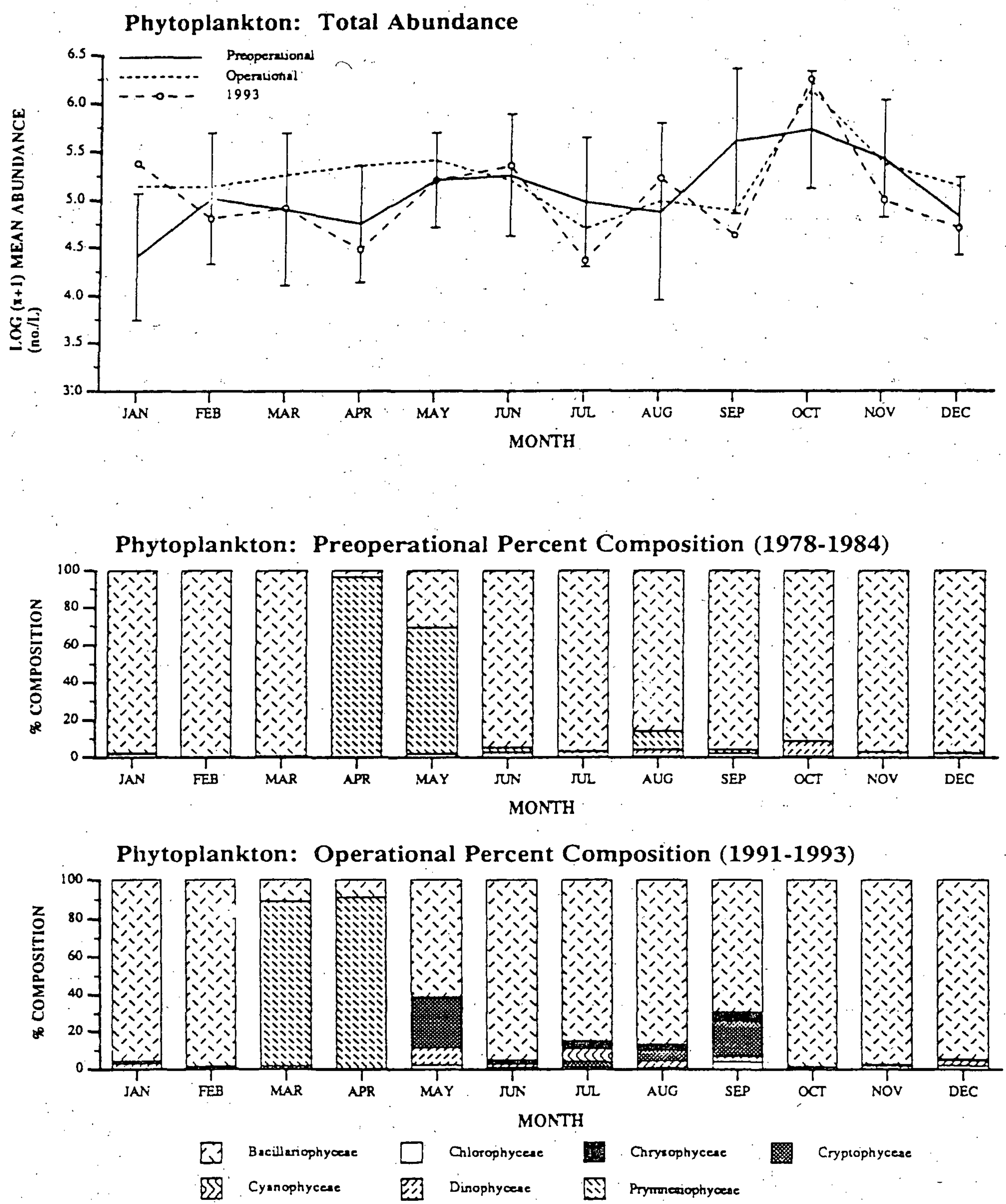


Figure 3-2. Monthly mean log (x+1) total abundance (no./L) of **phytoplankton** (**≥10** µm) at nearfield Station P2, monthly means and 95% confidence intervals over all preoperational years (1978-1984), and monthly means over operational years (1991-1993); and percent composition by major division for preoperational and operational periods. Seabrook Operational Report, 1993.

diatoms dominant in all months except March and April, when *P. pouchetii* was dominant. The dominance of *P. pouchetii* in operational averages was due to the extremely high numbers encountered in 1992 (an average of over 3 million cells/L over the four sample dates on which it was present; NAI 1993a). This is in contrast to a nearly complete absence of *P. pouchetii* in 1991 (NAI 1992b) and 1993 (NAI 1994).

Among-Year Trends at Station P2

Phytoplankton abundances at Station P2 showed large shifts from year-to-year throughout both the preoperational and operational periods (Figure 3-3). Although some preoperational years had higher annual geometric mean abundances than some operational years, on average the operational geometric mean abundance (166,400 cells/L) was higher than the preoperational mean abundance (119,000 cells/L; Table 3-2). This was due in large part to the high annual mean abundance during 1992 (334,800 cells/L), which was higher than in any individual preoperational year (Figure 3-3). The geometric mean abundance in 1993 (104,400 cells/L) was the lowest of the operational period (Table 3-2), and lower than in five of the seven preoperational years (Figure 3-3).

Based on historical data, the annual phytoplankton community at Station P2 can be divided into four major components: *Skeletonema costatum* (Bacillariophyceae), all other diatom taxa, *Phaeocystis pouchetii*, and all remaining taxa. Although these groupings are descriptive of both the preoperational and operational periods,

TABLE 3-2. GEOMETRIC MEAN ABUNDANCE (x 10^4 cells/L) OF PHYTOPLANKTON ($\geq 10\mu m$) AND *SKELETONEMA COSTATUM*, AND CHLOROPHYLL *a* CONCENTRATIONS (mg/m^3) AND COEFFICIENT OF VARIATION (CV,%) FOR THE PREOPERATIONAL AND OPERATIONAL (1991-1993) PERIODS, AND 1993 GEOMETRIC MEANS. SEABROOK OPERATIONAL REPORT, 1993.

	PREOPERATIONAL			OPERATIONAL		1993
STATION	$\bar{x}$[a]	CV	(YEARS)[b]	$\bar{x}$[a]	CV	$\bar{x}$
PHYTOPLANKTON						
P2	11.86	4.79	(78-84)	16.64	5.13	10.44
P5	12.60	3.97	(78-81)	22.36	5.54	13.13
P7	9.94	4.32	(82-84)	13.72	3.99	8.31
SKELETONEMA COSTATUM						
P2	0.23	44.23	(78-84)	0.77	33.56	0.43
P5	0.11	68.95	(78-81)	0.53	41.21	0.21
P7	0.24	36.95	(82-84)	0.46	41.07	0.18
CHLOROPHYLL *a*						
P2	0.78	68.13	(87-89)	0.72	57.62	0.52
P5	0.88	70.81	(87-89)	0.78	62.67	0.55
P7	0.75	63.38	(87-89)	0.72	58.58	0.48

[a]Mean of annual means.
[b]( ) = preoperational years.

the relative importance of each group or species, as well as individual abundances, varied considerably on a year-to-year basis (Figure 3-3).

Diatoms (including *Skeletonema costatum*) as a group composed approximately 77% of the preoperational assemblage (532,000 cells/L), 60% of the operational assemblage (329,400 cells/L), and 93% of the 1993 assemblage (273,500 cells/L; Table 3-3). *Skeletonema costatum* alone accounted for 35% of the preoperational assemblage, 22% of the operational assemblage, and 23% of the 1993 assemblage. Within the preoperational period, the relative abundance of *Skeletonema costatum* varied from 5% in 1983 to 80% of total abundance in 1980 (Figure 3-3). Within the operational period, the relative abundance of *Skeletonema costatum* varied from 17% in 1991 (NAI 1992b) to 26% in 1993. The remaining diatom taxa accounted for 42% (288,400 cells/L) of the preoperational assemblage (Table 3-3), ranging from 16-17% in 1980 and 1983 to 70% in 1979 (Figure 3-3).

Diatom taxa other than *Skeletonema costatum* that were important during the preoperational period were *Chaetoceros* spp. and *Rhizosolenia delicatula/ fragilissima* (each at 14% over the period; Table 3-3). These taxa were less important during the operational period and in 1993 (approximately 7% during both periods). The two *Leptocylindrus* taxa combined were more abundant in the operational period and in 1993 (13-15%) compared to the preoperational period (1.5%). *Asterionella glacialis* was present in 1993 and composed 21% of the assemblage. This species, however, did not occur above 1% of total abundance during any other year.

Phaeocystis pouchetii abundances varied over a wide range during the preoperational period, ranging from less than 1% in 1982 and 1984 to 76% in 1983 (Figure 3-3). Although this species accounted for 33% (181,300 cells/L) of the operational assemblage, it accounted for less than 1% of the 1991 and 1993 assemblages (Figure 3-3).

All remaining species accounted for 5-6% of both the preoperational and operational assemblages and 3% of the 1993 assemblage (Table 3-3). *Prorocentrum micans* (Dinophycea) accounted for slightly more than 1% of the preoperational assemblage, and *Cryptomonas* sp. (Cryptophyceae) accounted for about 2% of the operational and 1993 assemblages. All other taxa composed less than 1% of total abundance over both periods and in 1993 (Table 3-3).

Spatial Trends

Phytoplankton abundance and community composition were evaluated in the nearfield (Stations P2 and P5) and farfield (Station P7) areas to determine whether historical spatial relationships were maintained during the operational period. Preoperational geometric mean abundances were similar between Stations P2 (1978-1984) and P5 (1978-1981; Table 3-2), while abundances at Station P2 were higher than abundances at P7 (1978-1982). Abundances at each station were higher during the operational period compared to the preoperational period, although 1993 abundances were similar to preoperational abundances. Spatial differences during the operational period paralleled those that existed during the preoperational period (Table 3-2).

Operational abundances were significantly greater than preoperational (1982-1984) abundances over Stations P2 and P7 combined (Table 3-4). In addition, abundances among individual years, months, and between the two stations (P2 > P7) were significantly different (Table 3-4). However, these differences were consistent regardless of operational status, as indicated by the non-significant interaction term, indicating no apparent effect on abundances due to the operation of Seabrook Station.

Groups of taxa or individual taxa composed similar proportions of the total assemblage among the three stations in 1993 (Table 3-5). Diatoms as a group com-

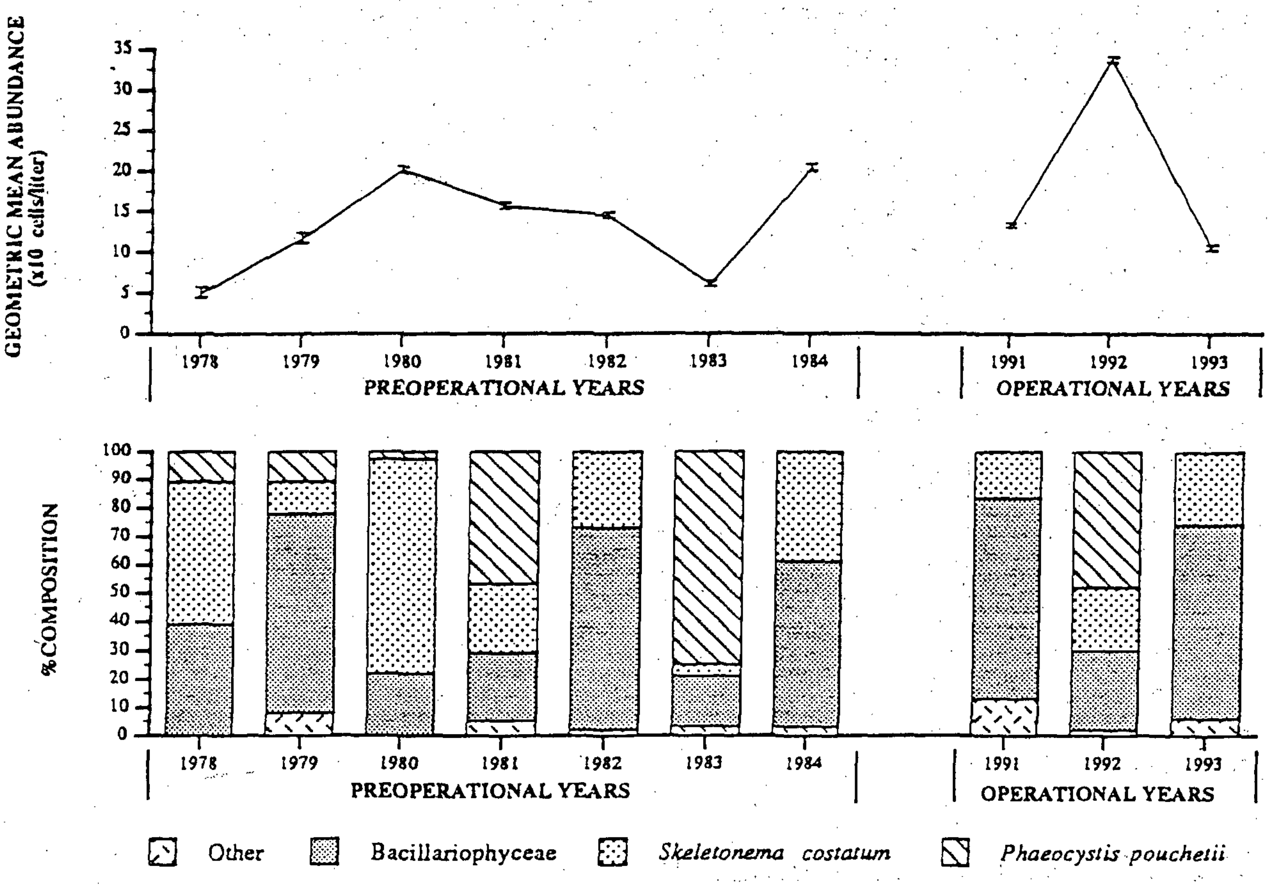


Figure 3-3. Geometric mean abundances (x 10^4 cells/L) and 95% confidence intervals of annual assemblages, and percent composition of four selected phytoplankton groupings at Station P2 during each year of the preoperational and operational periods. Seabrook Operational Report, 1993.

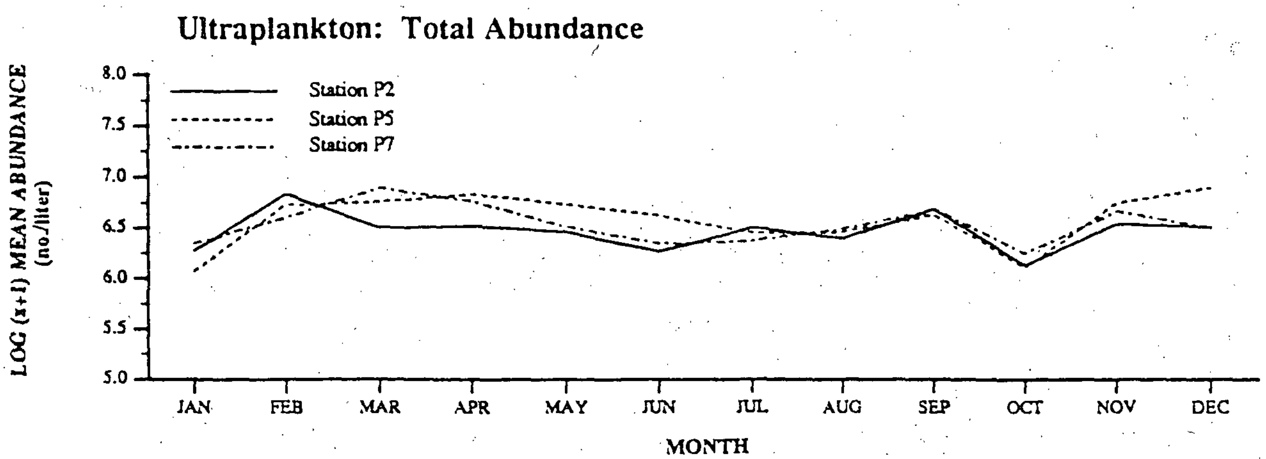


Figure 3-4. Monthly mean log (x+1) total abundance of ultraplankton (<10μm) at Stations P2, P5 and P7 during 1993. Seabrook Operational Report, 1993.

TABLE 3-3. ARITHMETIC MEAN ABUNDANCE (x 10^4 cells/L) AND PERCENT COMPOSITION OF DOMINANT PHYTOPLANKTON TAXA DURING THE PREOPERATIONAL PERIOD (1978-1984), OPERATIONAL PERIOD (1991-1993), AND 1993 AT NEARFIELD STATION P2. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL		OPERATIONAL		1993	
CLASS	TAXON	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION
Dinophyceae	*Prorocentrum micans*	0.79	1.15	0.18	<1.00	<0.01	<1.00
Cryptophyceae	*Cryptomonas* spp.	<0.01	<1.00	1.10	2.02	0.69	2.35
Prymnesiophyceae	*Phaeocystis pouchetii*	11.80	17.09	18.13	33.34	0.03	<1.00
Bacillariophyceae	Bacillariophyceae	0.77	1.11	0.92	1.69	0.57	1.94
	Asterionella glacialis	0.05	<1.00	2.07	3.80	6.20	21.01
	Cerataulina bergonii	0.95	1.39	0.00	<1.00	0.00	0.00
	Chaetoceros debilis	2.12	3.08	0.33	<1.00	0.05	<1.00
	Chaetoceros decipiens	0.02	<1.00	0.60	1.10	0.36	1.22
	Chaetoceros socialis	6.50	9.45	1.28	2.35	0.34	1.16
	Chaetoceros spp.	1.19	1.74	1.87	3.45	1.23	4.19
	Cylindrotheca closterium	0.07	<1.00	0.82	1.51	0.85	2.88
	Leptocylindrus danicus	0.40	<1.00	3.70	6.80	3.37	11.44
	Leptocylindrus minimus	1.00	1.46	3.54	6.51	1.22	4.15
	Nitzschia spp.	3.20	4.65	2.41	4.43	2.56	8.69
	Rhizosolenia delicatula/fragilissima	9.89	14.38	1.72	3.17	1.55	5.25
	Skeletonema costatum	24.35	35.41	11.96	21.99	7.62	25.82
	Thalassionema nitzschioides	1.33	1.94	0.94	1.73	0.64	2.17
	Thalassiosira spp.	1.89	2.74	1.11	2.04	0.84	2.85

[a]Mean abundance over all year(s) in each period; species accounting for <1% of total abundance not presented, therefore percent composition as shown does not sum to 100.

TABLE 3-4. RESULTS OF ANALYSIS OF VARIANCE COMPARING ABUNDANCES OF TOTAL PHYTOPLANKTON, ULTRAPLANKTON AND *SKELETONEMA COSTATUM*, AND CHLOROPHYLL *a* CONCENTRATIONS AMONG STATIONS P2, P5 AND P7 DURING PREOPERATIONAL AND OPERATIONAL (1991-1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS
PHYTOPLANKTON: P2 VS P7 (PREOP = 1982-1984; OP = 1991-1993)[a]				
Preop-Op[b]	1	0.69	27.96 ***	Op>Preop
Year (Preop-Op)[c]	4	1.36	54.71 ***	
Month (Year)[d]	66	0.59	24.04 ***	
Station	1	0.26	10.57 **	P2>P7
Preop-Op X Station[e]	1	<0.01	0.00 NS	
Error	70	0.02		
CHLOROPHYLL *a*: P2, P5, P7 (PREOP = 1987-1989; OP = 1991-1993)[a]				
Preop-Op[b]	1	0.23	4.53 *	Preop>Op
Year (Preop-Op)[c]	4	1.13	22.39 ***	
Month (Year)[d]	66	0.61	11.97 ***	
Station	2	0.19	3.74 *	P5>P2 P7
Preop-Op X Station[e]	2	0.02	0.46 NS	
Error	140	0.05		
***SKELETONEMA COSTATUM*: P2 VS. P7 (PREOP = 1982-1984; OP = 1991-1993)[a]**				
Preop-Op[b]	1	4.96	11.10 **	Op>Preop
Year (Preop-Op)[c]	4	3.31	7.42 ***	
Month (Year)[d]	66	2.89	6.48 ***	
Station	1	0.71	1.60 NS	
Preop-Op X Station[e]	1	0.23	0.52 NS	
Error	70	0.45		
***SKELETONEMA COSTATUM*: P2 VS. P5 (PREOP = 1979-1981; OP = 1991-1993)[a]**				
Preop-Op[b]	1	9.26	19.54 ***	Op>Preop
Year (Preop-Op)[c]	4	2.76	5.82 ***	
Month (Year)[d]	65	5.05	10.65 ***	
Station	1	1.07	2.25 NS	
Preop-Op X Station[e]	1	<0.01	0.02 NS	
Error	69	0.47		
ULTRAPLANKTON: P2, P5, P7 (Operational period only, 1991-1993)				
Year	2	0.37	9.52 ***	93 91>92
Month (Year)[d]	33	0.43	11.10 ***	
Station	2	0.03	0.79 NS	
Year X Station[e]	4	0.08	2.14 NS	
Error	66	0.04		

[a]ANOVA based on mean of twice-monthly collections Mar-Nov and monthly collections Dec-Feb; only years when collections at these stations were concurrent are included; analyses include ~~only~~ only years when all 12 months were sampled.
[b]Preoperational versus operational period regardless of station.
[c]Year, regardless of preop-op.
[d]Month nested within year regardless of station or year.
[e]Interaction between main effects.
NS = not significant ($p \geq 0.05$)
* = significant ($0.05 > p \geq 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)

TABLE 3-5. 1993 PHYTOPLANKTON ($\geq 10\mu m$) AND ULTRAPLANKTON ($<10\mu m$) SPECIES COMPOSITION BY STATION. SEABROOK OPERATIONAL REPORT, 1993.

CLASS	TAXA	P2	P5	P7
PHYTOPLANKTON[a]				
Cryptophyceae	*Cryptomonas* sp.	2.35	1.88	2.56
	Chroomonas sp.	3.73	2.59	2.62
Bacillariophyce	*Asterionella glacialis*	21.01	23.89	25.85
	Bacillariophyceae	1.94	2.75	2.51
	Chaetoceros debilis	<1.00	1.04	<1.00
	Chaetoceros decipiens	1.22	<1.00	2.99
	Chaetoceros socialis	1.16	2.25	1.46
	Chaetoceros sp.	4.19	3.40	3.38
	Cylindrotheca closterium	2.88	2.95	2.75
	Leptocylindrus danicus	11.44	10.27	8.85
	Leptocylindrus minimus	4.15	7.98	6.55
	Nitzschia sp.	8.69	8.19	6.93
	Rhizosolenia delicatula/fragilissima	5.25	4.62	6.70
	Skeletonema costatum	25.82	21.01	21.29
	Thalassionema nitzschioides	2.17	2.39	1.93
	Thalassiosira spp.	2.85	3.44	2.24
ULTRAPLANKTON[b]				
Chlorophyceae	Alga; Flagellate	2.97	2.18	2.22
	Alga; Unicellular	18.96	20.19	20.02
Dinophyceae	*Oxytoxum* sp.	0.63	0.50	0.45
Cyanophyceae	Cyanophyceae; Total[c]	73.71	74.54	74.69

[a]Presents only taxa accounting for ≥1% of total abundance
[b]All ultraplankton taxa presented
[c]Includes colonials and filamentous forms

posed 93-94% of total abundance at each station. *Cryptomonas* sp. was the only other taxon present at any station in amounts greater than 1% of the total, composing approximately 2 to 2.5% of total abundance. A similar assemblage was present at each station in 1993. The only differences were that *Chaetoceros debilis* occurred only at Station P5, while *Chaetoceros decipiens* occurred at P2 and P7 but not at P5 (Table 3-5). Overall, the abundances of the 15 numerically important taxa (Table 3-3) were not significantly different among the three stations in 1993 ($p = 0.35$, Wilkes' Lambda as computed by the MANOVA).

3.3.1.2 Ultraplankton

Monthly Log (x+1) mean ultraplankton abundances at Stations P2, P5, and P7 were similar in 1993, and exhibited a weak seasonal pattern at each station (Figure 3-4). Annual geometric mean abundances were similar among the three stations throughout the operational period (Table 3-6). Abundances were lowest in 1992 at each station, a trend that was opposite that in phytoplankton abundances (Table 3-2). A one-way analysis of variance (ANOVA) confirmed that ultraplankton abundances were not significantly different among the three stations during the operational period (Table 3-4), and that abundances in 1991 and 1993 were significantly greater than abundances in 1992.

The ultraplankton assemblage was similar among the three stations in 1993 (Table 3-5). As in 1991 and 1992, Cyanophyceae were overwhelmingly dominant at each station (approximately 75% of the assemblage), and followed a similar seasonal pattern of occurrence at each station (NAI 1992a, 1993a, 1994).

For reasons discussed in Section 3.2.3, it was not possible to test preoperational-operational differences in the ultraplankton community. However, the lack of nearfield-farfield differences in the ultraplankton assemblage indicates that there was no effect caused by Seabrook Station.

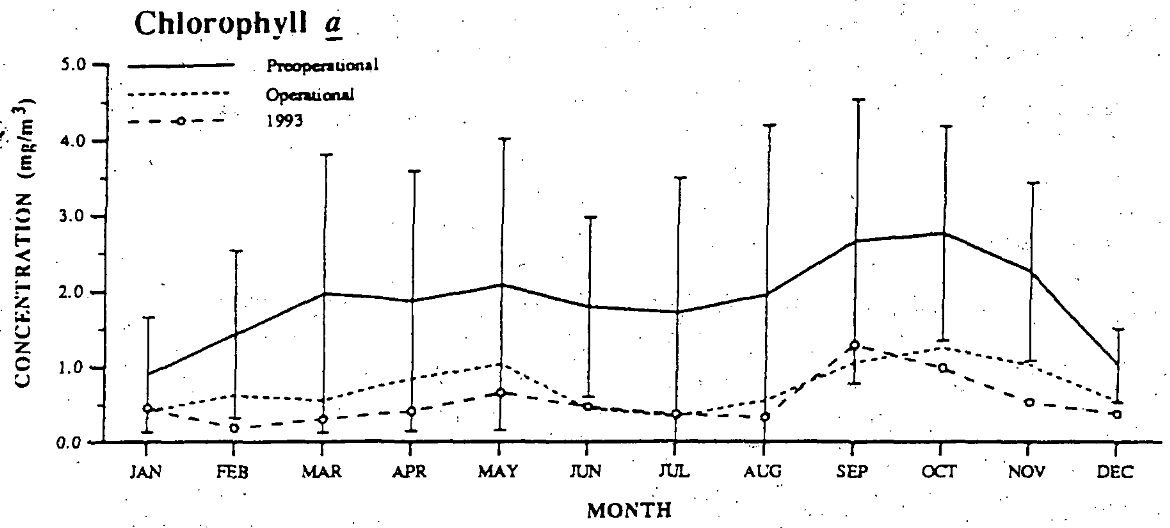
3.3.1.3 Chlorophyll *a* Concentrations

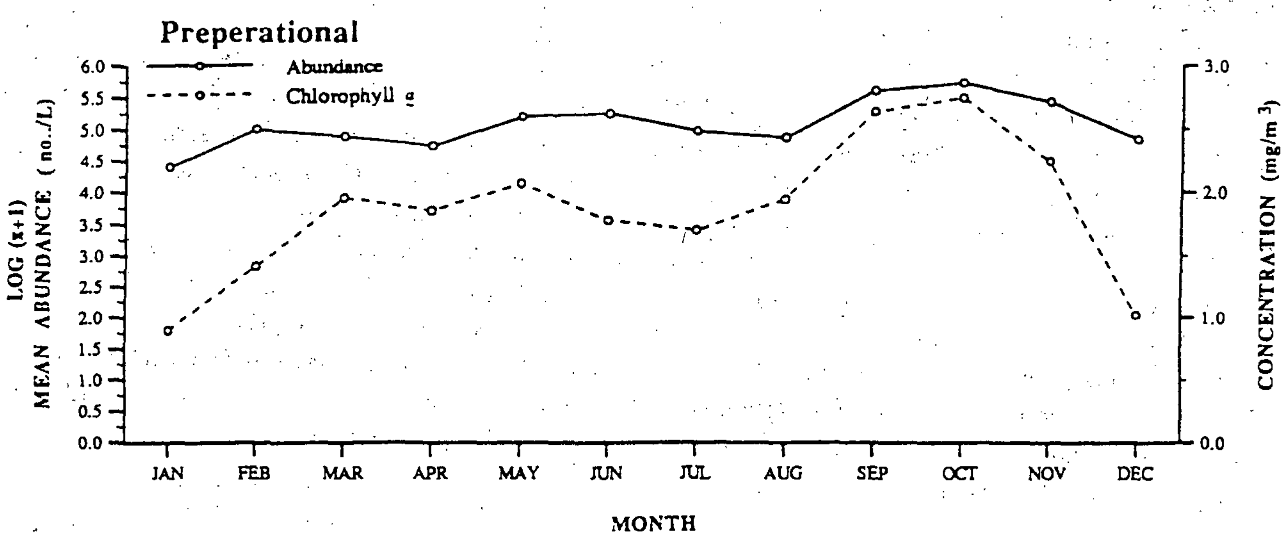
During both the preoperational and operational periods, monthly arithmetic mean total chlorophyll *a* concentrations exhibited an early spring peak, mid-summer decline, and late fall peak. Monthly mean operational concentrations were lower than preoperational concentrations in all months, and below the lower 95% confidence limits of the preoperational means in June, October and November (Figure 3-5). The 1993 monthly mean concentrations were less than preoperational lower 95% confidence limits in February, June, October, November and December.

TABLE 3-6. GEOMETRIC MEAN ABUNDANCE (10^4 CELLS/L) AND COEFFICIENT OF VARIATION (CV, %) OF ULTRAPLANKTON AT STATIONS P2, P5 AND P7 DURING THE OPERATIONAL PERIOD. SEABROOK OPERATIONAL REPORT, 1993.

	STATION					
	P2		P5		P7	
YEAR	MEAN	CV	MEAN	CV	MEAN	CV
1991[a]	355.93	6.04	293.91	7.15	294.88	5.59
1992[a]	188.42	8.90	190.37	8.45	284.92	8.21
1993[a]	288.88	2.91	380.22	4.06	339.11	2.94
OP MEAN[b]	268.58	2.19	277.09	2.36	305.42	0.62

[a]Annual means are means of monthly means, n = 12.
[b]Operational means are means of annual means, n = 3.





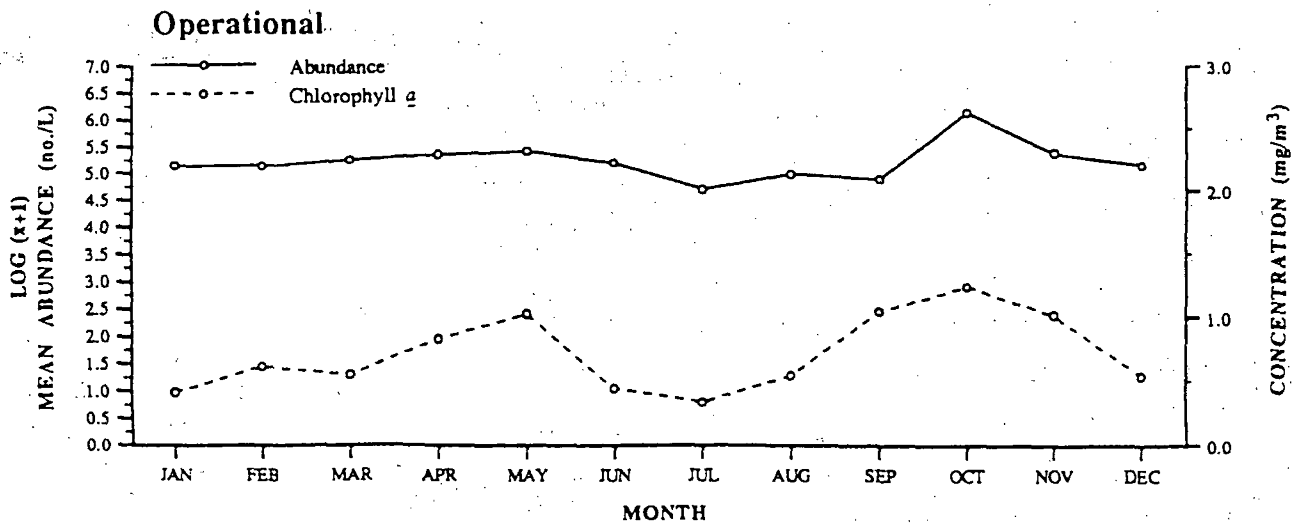


Figure 3-5. Mean monthly chlorophyll *a* concentrations and 95% confidence intervals at Station P2 over preoperational years (1979-1989) and monthly means over operational years (1991-1993); and mean monthly chlorophyll a concentrations and phytoplankton log (x+1) abundances during the preoperational and operational periods. Seabrook Operational Report, 1993.

Chlorophyll *a* concentrations at each station declined slightly (by 0.03 to 0.1 mg/m^3) during the operational period (Table 3-2). Over the three stations combined, operational mean concentrations were significantly lower than preoperational means (Table 3-4). Throughout the entire study, chlorophyll *a* concentrations were higher at Station P5 than at Stations P2 and P7, and differences between P2 and P7 were not significant (Tables 3-2 and 3-4). Since the relationship of chlorophyll *a* concentrations among the stations remained the same during both the preoperational and operational periods, the interaction between the main effects of operational status and station was not significant (Table 3-4).

On an annual basis, chlorophyll *a* concentrations and phytoplankton abundances appear to be inversely related, rather than directly related as expected. Chlorophyll *a* concentrations declined between the preoperational and operational periods at each station, while phytoplankton abundances increased (Table 3-2). The decline in chlorophyll *a* concentrations was statistically significant. The differences observed in trends between phytoplankton abundances and chlorophyll *a* concentrations were likely due to differences among taxa with respect to cell size and chlorophyll *a* content. For example, during 1992 phytoplankton abundances were higher than during any other year of the study, primarily due to the presence of *Phaeocystis pouchetii* on only a few dates (Figure 3-3). While *P. pouchetii* had a large effect on phytoplankton abundances, it had only a minor effect on chlorophyll *a* concentrations (NAI 1992b) since it is a small-celled taxon (Lee 1980). Evidence for the relationship between chlorophyll *a* concentrations and phytoplankton abundances exists in the comparison of seasonal patterns. Preoperational and operational chlorophyll *a* concentrations followed a pattern similar to that of phytoplankton abundances during the same periods (Figure 3-5).

3.3.2 Selected Species

Skeletonema costatum was chosen as a selected species because of its historic omnipresence and overwhelming dominance during much of the year. At Station P2, peak abundances generally occurred in the spring and fall during the preoperational period (Figure 3-6). During the operational period both the spring and fall peaks were larger but followed the same general seasonal pattern of the preoperational period. Operational mean abundances were higher than preoperational means in all months except September, and exceeded preoperational upper 95% confidence limits during January and April. In 1993, *S. costatum* abundances generally followed historical patterns, except that the January mean abundance was higher than typically observed, and the April mean abundance was much lower than typically observed. A small August peak was also present in 1993 (Figure 3-6).

Like phytoplankton abundances, abundances of *Skeletonema costatum* increased during the operational period at each station (Table 3-2). *S. costatum* abundances were evaluated in two separate ANOVA tests since all three stations were not sampled concurrently during the preoperational period (particularly Stations P5 and P7; Table 3-2). For both tests (P2 versus P7 and P2 versus P5), operational abundances were significantly greater than preoperational abundances, and there were significant differences among individual years and among months (Table 3-4). No differences in abundances were detected between the nearfield (Station P2) and the farfield (Station P7) areas or between Stations P2 and P5 in the nearfield area. The interaction of main effects was not significant for either pairing, thus preoperational-operational differences were unrelated to the operation of Seabrook Station (Table 3-4).

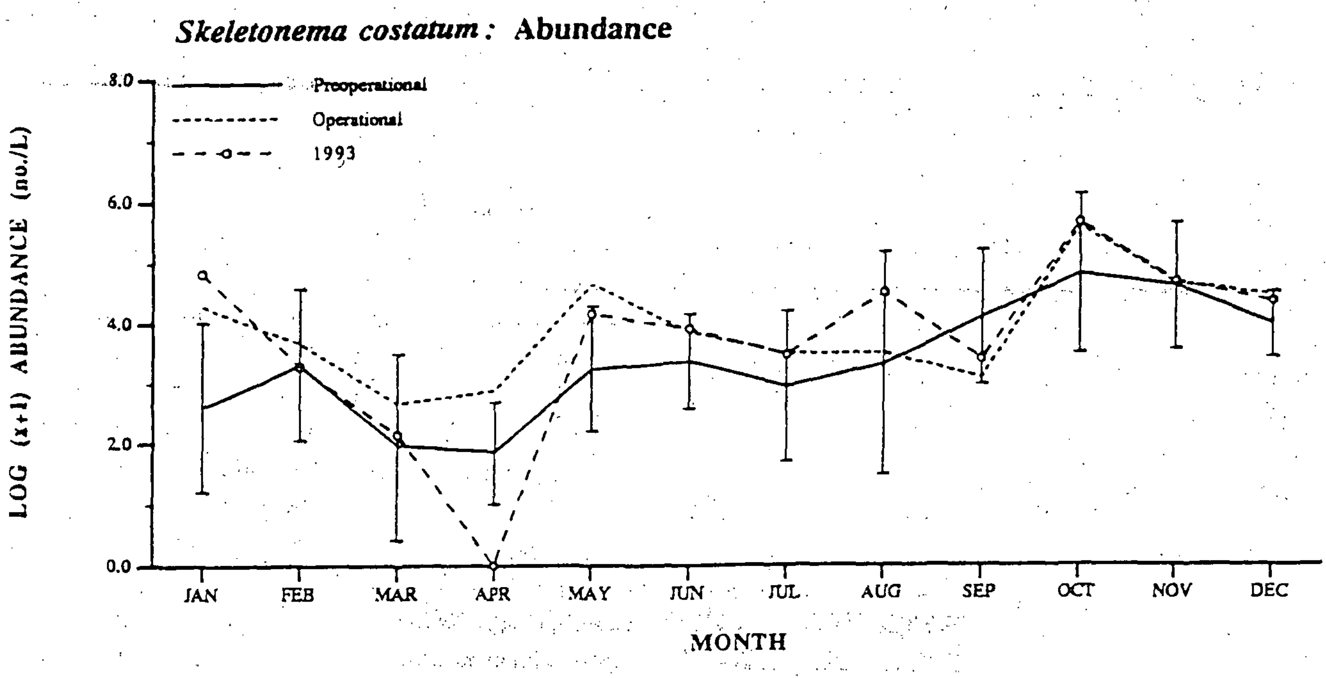


Figure 3-6. Log (x+1) abundance (no./L) of *Skeletonema costatum* at nearfield Station P2; monthly means and 95% confidence intervals over all preoperational years (1978-1984) and monthly means for the operational period (1991-1993) and 1993. Seabrook Operational Report, 1993.

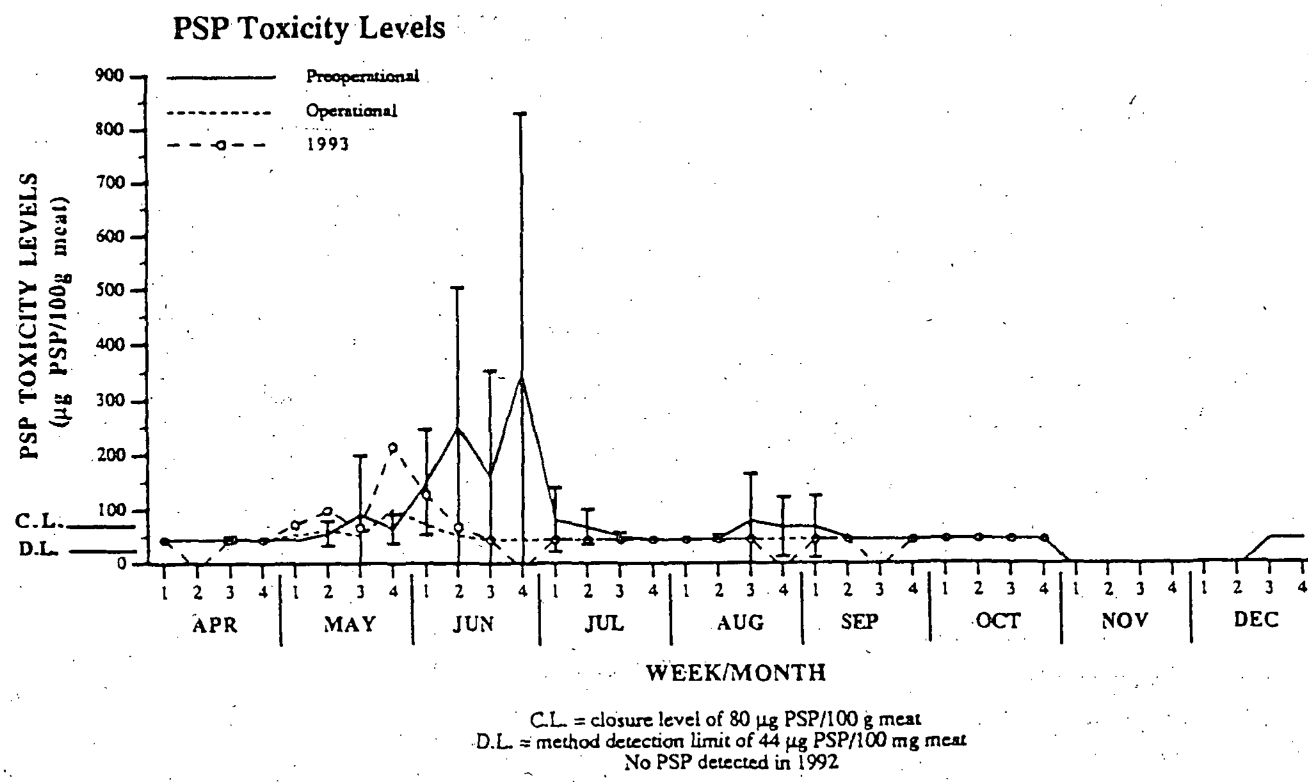


Figure 3-7. Weekly paralytic shellfish poisoning (PSP) toxicity levels in *Mytilus edulis* in Hampton Harbor, mean and 95% confidence intervals over preoperational years (1983-1989) and operational years (1991-1993). Data provided by the State of New Hampshire. Seabrook Operational Report, 1993.

3.3.3 PSP Levels

PSP toxicity levels were above the detection limit of 44 μg PSP/100 g tissue of the mussel *Mytilus edulis* and above the closure limit of 80 μg PSP/100 g tissue during the late spring, early summer and late summer during the preoperational period (Figure 3-7). PSP toxicity was rarely detected during the operational period, however. In 1991, the State of New Hampshire recorded only two occurrences of PSP levels above the detection limit, and these measured only 45 μg/100 g (NAI 1992b). No PSP toxicity was detected in 1992 (NAI 1993b). In 1993, PSP levels registered above the 80 μg/100 g tissue closure level in May and June. The widespread occurrence of PSP toxicity in the coastal areas of northern New England (NAI 1993b) indicates that the occurrence of PSP toxicity in the project area was unrelated to the operation of Seabrook Station.

3.4 DISCUSSION

3.4.1 Community Interactions

The seasonal patterns of total abundance and the occurrence of domir~~nt taxa in the phytoplankton assemblage were similar between the preoperational and operational periods, although phytoplankton abundances increased significantly during the operational period (Table 3-7). The phytoplankton assemblage was dominated by diatoms (Bacillariophyceae) both annually and seasonally during both periods. In some years, however, the Prymnesiophyceae species *Phaeocystis pouchetii* accounted for as high a proportion of the community at each station as did total diatoms (Figure 3-3). On average, *P. pouchetii* composed a greater proportion of the operational assemblage (33%) than the preoperational assemblage (17%; Table 3-3), due solely to its presence during the spring of 1992. With the exception of *P. pouchetii*, the group of taxa that accounted for the majority of the community changed little between the preoperational and operational periods (Figure 3-3). On a year-to-year basis, however, assemblages differed considerably. For this reason, the phytoplankton study included an analysis of parameters that were expected to be more predictable indicators of community status than species composition, such as the abundance of the selected species (*Skeletonema costatum*), or total biomass as estimated by chlorophyll *a* concentrations. Like total phytoplankton abundance, the annual mean abundance of *S. costatum* increased during the operational period. Seasonal patterns between the two periods remained

TABLE 3-7. SUMMARY OF POTENTIAL EFFECTS (BASED ON ANOVA) OF OPERATION OF SEABROOK STATION ON THE PHYTOPLANKTON COMMUNITY. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PRE-OPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
Phytoplankton	Op>Preop	yes
Skeletonema costatum	Op>Preop	yes
Chlorophyll *a*	Preop>Op	yes

similar, and no nearfield/farfield differences in abundance were detected (Table 3-4). Although annual mean chlorophyll *a* concentrations declined significantly during the operational period, on a monthly basis chorophyll *a* concentrations did closely track phytoplankton abundance. The overall increase in phytoplankton abundance without a corresponding increase in chlorophyll *a* concentrations may be due to the large number of small *P. pouchetii* cells in 1992 collections.

There were no significant interactions between operational status and station for total phytoplankton abundance, *Skeletonema costatum* abundance, or chlorophyll *a* concentrations (Table 3-4). This indicates that the operation of Seabrook Station has had no measurable effect on these aspects of the phytoplankton community.

The focus of the investigation of the ultraplankton assemblage was an examination of nearfield-farfield differences during the operational period, as identification techniques and information availability substantially improved after preoperational collections ended in 1984. During 1993, the ultraplankton assemblage was dominated by Cyanophyceae, particularly colonials (Table 3-5). Percent composition of each of the ultraplankton taxa, and the seasonal occurrences of total abundances, were similar among the three stations. Other studies conducted in the Gulf of Maine indicated that these forms were prominent throughout the region during both the preoperational and operational periods (Shapiro and Haugen 1988; Haugen 1991).

Only minor occurrences of PSP toxicity have been documented in the study area during the operational period. The occurrence of PSP toxicity in this portion of the Gulf of Maine was first documented in 1972 (NAI 1985), possibly as the result of the transport of the PSP-producing dinoflagellate *Alexandrium* spp. (formerly called *Gonyaulax* sp.) from the Bay of Fundy following Hurricane Carrie (Franks and Anderson 1992a). With few exceptions, PSP has been recorded seasonally in this region of the western Gulf of Maine ever since, although not always at toxic levels. It is currently thought that *Alexandrium* spp. blooms are transported to this region on coastally-trapped buoyant plumes derived from the Androscoggin and/or Kennebec Rivers (Maine)(Franks and Anderson 1992a). This theory is consistent with the generally observed north-to-south seasonal progression of occurrence of this dinoflagellate and the PSP levels (Franks and Anderson 1992b). Local sources of dinoflagellates may also contribute to the blooms as well. Thus, occurrences of PSP toxicity in New Hampshire have been associated with larger regional occurrences in southern Maine and northern Massachusetts, and are not a localized occurrence.

3.4.2 Effects of Plant Operation

The phytoplankton community varied both temporally and spatially during the whole of the study period. The high variability in density levels and community structure from year-to-year was due to the influence of both physical and chemical factors, some cyclical and some transitory, and to the rapid turnover rate of phytoplankton populations. Thus, it has been difficult to succinctly describe the long-term temporal community structure (NAI 1985). However, all documented characteristics of the phytoplankton community in the vicinity of Seabrook Station indicate that, although some community changes occurred over time, these changes occurred at all three stations. In some cases (i.e. the apparent increase of certain Cyanophyceae forms), these changes were widely documented in the Gulf of Maine. Therefore there is no evidence indicating that the operation of Seabrook Station had a measurable or detrimental effect on any aspect of the local phytoplankton community.

3.5 REFERENCES CITED

Cadée, G.C. and J. Hegeman. 1986. Seasonal and annual variation in *Phaeocystis pouchetii* (Haptophyceae) in the westernmost inlet of the Wadden Sea during the 1973 to 1985 period. Neth. J. Sea Res. 20(1):29-36.

Franks, P.J.S. and D.M. Anderson. 1992a. Alongshore transport of a toxic phytoplankton bloom in a buoyant current: *Alexandrium tamarense* in the Gulf of Maine. Mar. Biol. 112:153-164.

Franks, P.J.S. and D.M. Anderson. 1992b. Toxic phytoplankton blooms in the southwestern Gulf of Maine: testing hypotheses of physical control using historical data. Mar. Biol. 112:165-174.

Harris, R.J. 1985. A primer of multivariate statistics. Acad. Press, Orlando. 575 pp.

Haugen, E. 1991. Unpublished phytoplankton data filed with MWRA, Deer Island offshore outfall monitoring studies, 1990.

Lee, R.E. 1980. Phycology. Cambridge University Press, New York. 478 pp.

Marshall, H.G. and M.S. Cohen. 1983. Distribution and composition of phytoplankton in northeastern coastal waters of the United States. Estuar. Coast. and Shelf Sci. 17:119-131.

Normandeau Associates Inc. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rep. XVI-II.

_________. 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Report XXII-I.

_________. 1992a Seabrook Environmental Studies. Unpubl. 1991 Data.

_________. 1992b Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

_________. 1993a. Seabrook Environmental Studies. Unpubl. 1992 Data.

_________. 1993b. Seabrook Environmental Studies, 1992. A characterization environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XIV-I.

_________. 1994. Seabrook Environmental Studies. Unpub. 1993 Data.

Peperzak, Louis. 1993. Daily irradiance governs growth rate and colony formation of *Phaeocystis* (Prymnesiophyceae). J. Plank. Res. 15(7):809-821.

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 edition. SAS Inst., Inc. Cary, N.C. 956 pp.

Shapiro, L.P. and E. M. Haugen. 1988. Seasonal distribution and temperature tolerance of *Synechococcus* in Boothbay Harbor, Maine. Estuar. Coast. Shelf Sci. 26:517:525.

Stockner, J.G. 1988. Phototrophic picoplankton: an overview from marine and freshwater ecosystems. Limnol. Oceanogr. 33:765-775.

APPENDIX TABLE 3-1. CHECKLIST OF PHYTOPLANKTON TAXA CITED IN THIS REPORT. SEABROOK OPERATIONAL REPORT, 1993.

BACILLARIOPHYCEAE	*Asterionella glacialis* Castracane (syn. *A. japonica* Cleve)
	Cerataulina bergonii H. Péragallo
	Chaetoceros debilis Cleve
	Chaetoceros decepiens Cleve
	Chaetoceros socialis Lauder
	Cylindrotheca closterium (Ehrenberg) Reimann. and Lewin
	Leptocylindrus danicus Cleve
	Leptocylindrus minimus Gran
	Nitzschia sp.
	Rhizosolenia delicatula Cleve
	Rhizosolenia fragilissima Bergon
	Skeletonema costatum (Greville) Cleve
	Thalassionema nitzschioides Hustedt
	Thalassiosira sp.
CRYPTOPHYCEAE	*Cryptomonas* sp.
	Chroomonas sp.
DINOPHYCEAE	*Oxytoxum* sp.
	Prorocentrum micans Ehrenberg
PRYMNESIOPHYCEAE	*Phaeocystis pouchettii* (Hariot) Lagerheim

TABLE OF CONTENTS

PAGE

SUMMARY

Microzooplankton have historically shown distinct seasonal changes that relate to changing abundances of dominant taxa, including copepods *Pseudocalanus* sp. and *Oithona* sp., bivalve larvae, and copepod nauplii. Seasonal patterns during the operational period were similar to those observed during the preoperational period, although abundances of some key species showed significant differences. These include *Eurytemora* sp., *Pseudocalanus/Calanus* nauplii, and *Oithona* copepodites and adults. No differences in abundance were observed between nearfield and farfield areas, indicating that there is no evidence of an effect related to Seabrook Station.

The umboned bivalve larval assemblage is defined by varying abundances of dominants such as *Hiatella* sp., *Mytilus edulis*, and *Anomia squamula*. Seasonal appearances of dominant species were similar to previous years. However, average abundances for many of the species during the operational period were elevated in comparison to the preoperational average. Since increased abundances occurred at both nearfield and farfield stations, they suggest an areawide trend unrelated to the operation of Seabrook Station. The level of entrainment of bivalve larvae changes with the abundance of larvae in the surrounding waters. Entrainment in 1993 was higher than the previous two years because of increased numbers of larvae in the study area and continuous plant operation (and thus larval entrainment) during peak periods (July through September). There is no evidence that larval entrainment has resulted in decreased numbers of bivalve larvae in coastal waters.

The macrozooplantkon community is composed of a true planktonic component (defined as holo/meroplankton) including copepods *Calanus finmarchicus*, *Centropages typicus*, *Pseudocalanus* sp., and *Temora longicornis*, along with larval stages of decapods and barnacles. Amphipods, cumaceans, and mysids occasionally venture into the water column, forming what is defined as the tychoplanktonic component. The assemblage of species changes seasonally, and, for the most part, has been consistent throughout the study period. However, abundances of many of the dominants were elevated during the operational period when compared to the preoperational period. For the holo/meroplankton, increased abundances occurred at all three stations, suggesting an areawide change. Tychoplankton have historically shown nearfield-farfield differences that are related to variations in substrate. These spatial differences have been consistent during both preoperational and operational periods. No changes in the macrozooplankton community have been observed that could be related to the operation of Seabrook Station.

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

4.0 ZOOPLANKTON

4.1 INTRODUCTION

Three components of the zooplankton community, microzooplankton, bivalve larvae and macrozooplankton, were sampled separately to identify spatial and temporal trends at both the community and species level. One station outside the area most likely to be affected by plant operation was selected as a farfield site. Initial monitoring characterized the source and magnitude of variation in each zooplankton community and provided a base of data for comparing operational monitoring. Current trends in zooplankton population dynamics were evaluated to determine whether entrainment in Seabrook Station's cooling system intake has had a measurable effect on the community or any individual species. In addition, entrainment of bivalve larvae in the plant's cooling water system was estimated.

4.2 METHODS

4.2.1 Field Methods

4.2.1.1 Microzooplankton

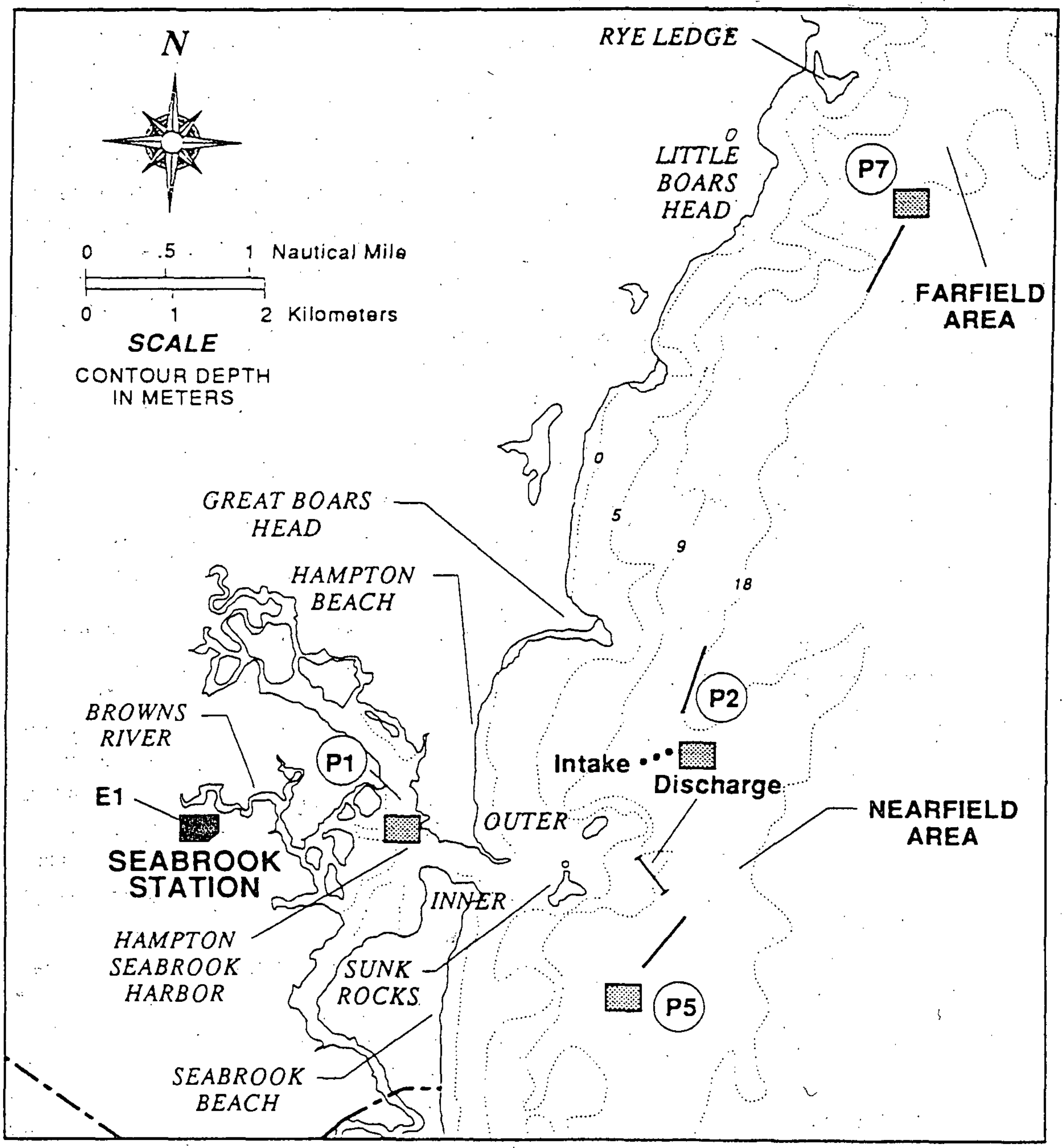
Microzooplankton were sampled twice a month from March-November and monthly in December-February at intake (Station P2), discharge (Station P5) and farfield (Station P7) areas (Figure 4-1). Sampling at all three stations occurred from July through December 1986 and from April 1990 through December 1993. In addition, Station P2 was sampled from January 1978 through December 1984 and Station P7 from January 1982 through December 1984. Four replicate samples were collected by pump at both 1 m below the surface and 2 m above the bottom at each station on each sampling date. Discharge from the pumps was directed into a 0.076-mm mesh plankton net (12 cm diameter) set into a specially-designed stand filled with seawater to within 15 cm of the top of the net. Pumping time was recorded to calculate volume filtered based on predetermined pumping rates. Volume filtered averaged 125 liters and ranged from 105-235 liters (NAI 1991a). Microzooplankton were rinsed from the nets into sample containers after pumping and were preserved in borax-buffered 3% formalin.

4.2.1.2 Bivalve Larvae

The spatial and temporal distributions of 12 taxa of umboned bivalve larvae were monitored using a 0.5-m diameter, 0.076-mm mesh net. Samples were collected weekly from mid-April through October at Hampton Harbor (P1), and at Stations P2, P5 and P7 (Figure 4-1). Sampling began at Station P2 in July 1976. Farfield Station P7 was added to the program in 1982, and Station P1 was added in July 1986. Samples were collected at Station P5 from July-December 1986 and April 1988 through October 1993. Two simultaneous two-minute oblique tows were usually taken at each station. In cases when nets were clogged, vertical tows were taken. Volume filtered ranged from 6-13 m^3 and averaged 9 m^3 for oblique tows, and ranged from 2-5 m^3 and averaged 3 m^3 for vertical tows (NAI 1991a). The volume of water filtered was recorded with a General Oceanics® flowmeter. Upon recovery, net contents were preserved with 1-2% borax-buffered formalin (with sugar added to enhance color preservation) and refrigerated.

4.2.1.3 Entrainment

Bivalve larvae entrainment sampling was conducted up to four times a month by NAESCO personnel within the circulating water pumphouse on-site at Seabrook Station from July 1986-June 1987 and June 1990-October 1993. Three replicates were collected during each sampling date. Sampling dates coincided with offshore bivalve larvae sampling whenever possible. Entrainment sampling was not conducted on several scheduled sampling dates, however, due to either station



LEGEND

——— = zooplankton stations

▒ = bivalve larvae stations

E1 = Seabrook Entrainment Station

Figure 4-1. Plankton and entrainment sampling stations. Seabrook Operational Report, 1993.

outages or sampling equipment problems. Scheduled station outages occurred from August-November 1991 and September-October 1992.

Samples were taken using a double barrel collection system. A 0.076-mm mesh plankton net was suspended in a 30-gallon drum which, in turn, was suspended in a 55-gallon drum. Water diverted from the cooling water system entered the 55-gallon drum from the bottom and overflowed the 30-gallon drum into the plankton net. After passing through the net, the water discharged through the bottom of both drums. The water supply was adjusted to maintain three to six inches of water above the plankton net at all times. One double drum collector was operated at a time. After the water was drained from the system, the contents of the four nets were consolidated and placed in one sample jar with 1% buffered formalin. The volume filtered was measured with an in-line flowmeter and averaged approximately 7 m^3 per replicate.

4.2.1.4 Macrozooplankton

Macrozooplankton were collected from July 1986 through December 1993 at Stations P2, P5, and P7 (Figure 4-1). Station P2 was also sampled from January 1978 through December 1984. Station P7 was also sampled from January 1982 through December 1984.

Macrozooplankton collections were made at night four times per month, concurrent with ichthyoplankton sampling. On each date, four replicate oblique tows were made with 1-m diameter 0.505-mm mesh nets at each station. The nets were set off the stern and towed for 10 minutes while varying the boat speed, causing the net to sink to approximately 2 m off the bottom and to rise to the surface at least twice during the tow. When nets became clogged due to plankton blooms, tows were shortened to 5 minutes. The volume filtered, determined with a General Oceanics® digital flowmeter, ranged from 408-567 m^3 (averaged 494 m^3) for 10-minute tows, and ranged from 109-280 m^3 (averaged 166 m^3) for 5-minute tows (NAI 1991a). Upon retrieval, each net was rinsed and the contents preserved in 6% buffered formalin.

4.2.2 Laboratory Methods

4.2.2.1 Microzooplankton

Two replicates from each depth and station on all sample dates were analyzed for microzooplankton; the remaining two replicates were archived and stored as "contingency" samples. The sample was concentrated or diluted to a known volume that provided an optimal working number of organisms (ca. 200 per 1-ml subsample). Each sample was agitated with a calibrated bulb pipette to distribute the contents homogeneously. A 1-ml subsample was removed, placed in a Sedgewick-Rafter cell and examined under a compound microscope using magnifications of 40X to 200X. All microzooplankton taxa present in the subsample (generally, all taxa smaller than adult *Calanus finmarchicus*: <4.0 mm) were counted and identified. Most copepods were identified to developmental stages, e.g., nauplii, copepodites or adults (copepodite 6). Two subsamples were analyzed for each replicate. Individual abundances for all taxa (no./m^3) were computed for each subsample and then averaged to provide mean abundances per taxon for each replicate.

4.2.2.2 Bivalve Larvae

Each bivalve larvae sample collected at each station was analyzed. When the total umboned larvae collected ranged from 1-300, the entire sample was processed. Samples were split when the total umboned bivalve larvae count exceeded 300 specimens and two subsample fractions were examined with a dissecting scope. Umboned larvae were identified from an established species list and enumerated. Specimens of other species were enumerated as Bivalvia. Subsamples (when present) were averaged for each tow. Samples collected in 1985 were analyzed for *Mytilus edulis* and *Mya arenaria* only.

4.2.2.3 Macrozooplankton

Macrozooplankton were analyzed from three of the four tows (randomly selected) at each station for two of the four sampling periods each month (usually alternating weeks). Copepods were analyzed by concentrating or diluting the sample to a known volume from which a subsample of approximately 150 copepods per 1 ml could be attained. The sample was agitated with a Stempel pipette to homogeneously distribute the contents and 1 ml was removed and examined under a dissecting microscope. Subsampling continued until at least 30 of the dominant copepod taxon and 150 total copepods were counted. If an even distribution of copepods could not be attained, the sample was serially split using a Folsom plankton splitter. Cyclopoids and copepodites of smaller calanoid species (which were not efficiently collected in the macrozooplankton samples) were not included in the copepod counts. For the selected species *Calanus finmarchicus*, both lifestage and sex were identified. After enumeration, subsamples were recombined with the sample.

To enumerate rarer copepods (*Anomalocera opalus*, *Caligus* sp., *Candacia armata*, *Euchaeta* sp., Harpacticoida, Monstrillidae and *Rhincalanus nasutus*) and the remaining macrozooplankton, the sample was placed in a Folsom plankton splitter and serially split into fractions that provided counts of at least 30 individuals of each dominant macrozooplankton taxon (as defined in NAI 1984). A maximum of 100 ml of settled plankton was analyzed. Macrozooplankton taxa were enumerated by species using a dissecting microscope at magnifications between 6x and 150x. Selected species (*Cancer* sp., *Carcinus maenas*, *Crangon septemspinosa*, and *Neomysis americana*) were identified to detailed developmental stage (lifestage and/or sex). Splits were recombined upon completion.

For each sample type, species counts were converted to density by multiplying each species' count by the appropriate scaling ratio (the proportion of the sample analyzed for each particular organism) and dividing by the volume of water filtered during field collection. Microzooplankton and bivalve larvae abundances were reported as no./m^3; macrozooplankton abundances were reported as no./1000 m^3.

4.2.3 Analytical Methods

4.2.3.1 Communities

Community structure of the microzooplankton, bivalve larvae, and macrozooplankton components of the zooplankton community was evaluated by numerical classification, multivariate analysis of variance (MANOVA), and qualitative comparison of log abundances or geometric means for periods (operational, preoperational and 1993)(Table 4-1). The macrozooplankton community includes numerous species that exhibit one of three basic life history strategies. The holoplankton species, e.g. copepods, are planktonic essentially throughout their entire life cycle. Meroplankton includes species that spend a distinct portion of their life cycle in the plankton, e.g. larvae of benthic invertebrates. Species that alternate between association with the substrate and rising into the water column on a regular basis are called tychoplankton, e.g. mysids. Because of these behavioral differences, as well as large differences in abundances, macrozooplankton species were categorized into holo/meroplanktonic species or tychoplanktonic species prior to statistical analysis. The same types of analyses were performed on each group of species.

Temporal and spatial changes in the community structure of microzooplankton, bivalve larvae, and the two components of macrozooplankton were evaluated using numerical classification techniques (Boesch 1977). This technique forms groups of stations and/or sampling periods based on similarity levels calculated for all

TABLE 4-1. SUMMARY OF METHODS USED IN NUMERICAL CLASSIFICATION AND MULTIVARIATE ANALYSIS OF VARIANCE OF ZOOPLANKTON COMMUNITIES, AND ANALYSIS OF VARIANCE OF ZOOPLANKTON SELECTED SPECIES. SEABROOK OPERATIONAL REPORT, 1993.

ANALYSIS	TAXON	LIFESTAGE	STATIONS	DATES USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN (M)ANOVA
MICROZOOPLANKTON MANOVA	29 dominants	--	P2 P5 P7	1993	Log (x+1) transformation of each "replicate" sample, $\bar{x}$ of surface and bottom; species excluded with frequency of occurrence <20%	Station
ANOVA	Selected species: *Eurytemora* sp. *Eurytemora herdmani* *Pseudocalanus/Calanus* *Pseudocalanus* sp. *Oithona* sp.	 C[b] A N C,A N,C,A	P2 P7	1982-1984; 1991-1993	Monthly mean, surface, and bottom	Preop-Op, Year, Month, Station
Numerial classification	35 dominants	--	P2	1978-1984, 7/86-12/86 4/90-12/93	Log (x+1) transformation of each individual (replicate) sample, $\bar{x}$ of surface and bottom; species excluded with frequency of occurrence <7%	--
BIVALVE LARVAE MANOVA	All taxa except Bivalvia	--	P2 P5 P7	1988-1993[c]	Log (x+1) transformation of individual (replicate) sample, then weekly means computed	Preop-Op, Station, Year, Week
ANOVA	Selected species: *Mytilus edulis*	--	P2 P5 P7	1988-1993[c]	Same as above	Preop-Op, Station, Year Week
Numerical classification	All taxa except Bivalvia	--	P2 P5 P7	1988-1993[c]	Log (x+1) transforamtion of each individual (replicate) sample, half-monthly means calculated from weekly $\bar{x}$	--

(continued)

TABLE 4-1. (Continued)

ANALYSIS	TAXON	LIFESTAGE	STATIONS	DATES USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN (M)ANOVA
MACROZOOPLANKTON Numerical classification	Tycho: 22 dominants Holo/mero: 50 dominants	--	P2 P5 P7	1988-1993	Monthly $\bar{x}$. Tychoplankton: used all taxa except Mysidacea and Amphipoda. Holo/mero: deleted taxa occurring in ≤5% of samples and general taxa.	--
MANOVA	Tycho: 22 dominants Holo/mero: 50 dominants	--	P2 P5 P7	1988-1993c	Sample period $\bar{x}$ sampled twice per month. Tychoplankton: used all taxa except Mysidacea and Amphipoda. Holo/mero: deleted taxa occurring in ≤5% of samples and general taxa.	Preop-Op, Station, Year, Month
ANOVA	Selected species: *Calanus finmarchicus* *Cancer* sp.[d] *Carcinus meanas*[e] *Crangon septemspinosa* *Neomysis americana*	 C,A[b] L L L All	P2 P5 P7	1988-1993[c]	Sample period $\bar{x}$, sampled twice per month	Preop-Op, Station, Year, Month

[a]All data log (x+1) transformed unless otherwise noted
[b]C = copepodite; A = adult; N = nauplii; L = larvae
[c]1990 excluded
[d]*Cancer* spp. discussed in Section 8.0
[e]*Carcinus maenas* larvae are essentially absent for 7 of 12 months, therefore a peak period of June-October only was analyzed.

possible combinations of stations/sampling periods and the species that occur there. The Bray-Curtis similarity index (Clifford and Stephenson 1975, Boesch 1977) was used. Values of the indices ranged from 0 for absolute dissimilarity to 1 for absolute similarity. The classification groups were formed from arithmetic averages by the unweighted pair-group method (UPGMA: Sneath and Sokal 1973). Results were simplified by combining the entities based on their similarity levels, determined by both the within-group and between-group similarity values. Results were presented graphically by dendrograms, which show the within-group similarity value and the between-group similarity (value at which a group links to another group). The groups were characterized by the mean abundance of the dominant taxa. Communities during the operational period (August 1990-December 1993) were judged to be similar to previous years if collections were placed in the same group as the majority of collections taken at the same time during previous years. A potential impact was suggested if community differences occurred solely during the operational period and were restricted to either the near-field or the farfield area. This situation would initiate additional investigations. If community differences occurred at both nearfield and farfield stations, they were assumed to be part of an area-wide trend, and unrelated to plant operation.

Multivariate analysis of variance (MANOVA, Harris 1985) was the statistical test used to assess simultaneously the differences in abundance between periods (preoperational and operational), stations (nearfield and farfield), years and weeks (Table 4-1). The interaction term (Station X Period) was used to determine if there was an impact from plant operation for bivalve larvae and macrozooplankton. Microzooplankton data from 1993 were tested only to determine station differences. Historically, there have been few differences in planktonic species assemblages among nearfield intake and discharge and farfield stations. Continuation of the trend during plant operation would suggest that there were no effects of plant operation on these communities. Probabilities associated with the Wilks' Lambda test statistic (SAS 1985) were reported. Abundance data from each individual (replicate) sample was log (x+1) transformed prior to use in the MANOVA model in order to more closely approximate the normal distribution.

Untransformed densities of bivalve larvae in entrainment samples were multiplied by the month's average daily volume pumped through the circulating water system, and by the number of days represented by each sampling date, and then summed within month to estimate the number of bivalve larvae entrained by Seabrook Station on a monthly basis.

4.2.3.2 Selected Species

Biologically important or numerically dominant taxa were selected for further investigation (Table 4-1). The operational, preoperational, and 1993 geometric means and coefficients of variation were tabulated. Monthly log (x+1) means and 95% confidence limits for the preoperational and operational periods, and 1993 were compared graphically to provide a visual estimate of their magnitude and seasonality. Finally, an analysis of variance (ANOVA) was used on log (x+1) transformed data to evaluate the plant impact by comparison of preoperational and operational means among nearfield and farfield stations. All sources of variation in the analysis of variance model were assumed to be fixed. This was a conservative model, more likely to detect significant differences than alternate models that assume some of the sources of variation were random. When the F value was significant ($P \leq 0.05$) for the interaction term or class variable (Station or Preop-Op), the least squares means procedure (SAS 1985) was used to evaluate differences among means. Collections from all three stations intake (P2), discharge (P5) and farfield (P7) were used in the analysis where the preoperational database was sufficient. Some species (e.g. all bivalve larvae, *Carcinus maenas*) were common only during part of the year (peak periods). Data from the peak periods were used in analysis of variance and to compute operational, preoperational, and 1993 geometric means.

4.3 RESULTS

4.3.1 Microzooplankton

4.3.1.1 Community Structure

Temporal Characteristics

Temporal variability in species abundances and taxonomic composition of the nearshore microzooplankton community (surface and bottom samples averaged) at Station P2 for all preoperational and operational collections was examined using numerical classification. Collections were grouped into five major groups that corresponded with the annual seasonal progression of dominant species and two smaller groups (one collection date was ungrouped; Figure 4-2). The major seasonal patterns in the microzooplankton community structure were largely delineated by changes in both total abundance and the dominance structure of numerically important taxa. The copepods *Oithona* sp. and *Pseudocalanus* sp., and *Pseudocalanus/Calanus* nauplii were the most abundant organisms in virtually every seasonal group during both preoperational and operational periods (Table 4-2). Early winter samples (Group 1) were characterized by low abundances of all taxa including *Oithona* sp. and Copepoda nauplii during both periods (preoperational and operational). Increased numbers of these taxa and the appearance of Cirripedia larvae marked the appearance of the winter/spring assemblage (Group 2). The spring assemblage (Group 3) was characterized by increased abundance of Copepoda nauplii and the presence of low densities of *Acartia* sp. and bivalve veliger larvae. The late spring/summer assemblage (Group 4) had peak abundances of *Oithona* sp., Copepoda nauplii, *Pseudocalanus/Calanus* nauplii, *Pseudocalanus* sp., and bivalve veliger larvae. In the fall assemblage (Group 5), numbers of bivalve veligers diminished (<5% of total group abundance) and numbers of *Oithona* sp., *Pseudocalanus* sp. lifestages, and copepod nauplii decreased. The summer/fall and miscellaneous groups (Groups 6 and 7) did not differ appreciably from the other collection dates with respect to those taxa that were numerically important. The ungrouped sample mean was taken in late May 1982 and had very high abundances of *Oithona* sp. and *Acartia* sp., and Polychaeta larvae and Rotifera were common.

Comparison of the specific sampling periods included within the major cluster groups indicated that differences among years were generally moderate. Collections from the operational period were generally placed into groups containing corresponding dates from the preoperational period, although some collections from summer/fall 1990 and 1991 with lower-than-typical abundances were identified as a separate group (Group 6) (Figure 4-2). Preoperational and operational periods were similar in the rank order of numerically dominant taxa identified from each cluster group (Table 4-2). Differences among groups, in large measure, were attributed to seasonal variability in the abundances of these dominant taxa. For example, the fall assemblage (Group 5) in 1993 persisted into January, which also occurred in 1978 and 1981. Seasonal groups identified by numerical classification generally encompassed collection periods with similar temperature regimes, particularly with respect to the depth and intensity of the thermocline (NAI 1985, NAI 1991b).

Spatial Patterns

Spatial variation in the microzooplankton community structure was examined separately for both the preoperational and operational periods. Historical comparisons of total microzooplankton densities revealed no significant differences between Stations P2 and P7; although some numerically important taxa exhibited large differences in rank order or percent composition between stations, their individual abundances were not

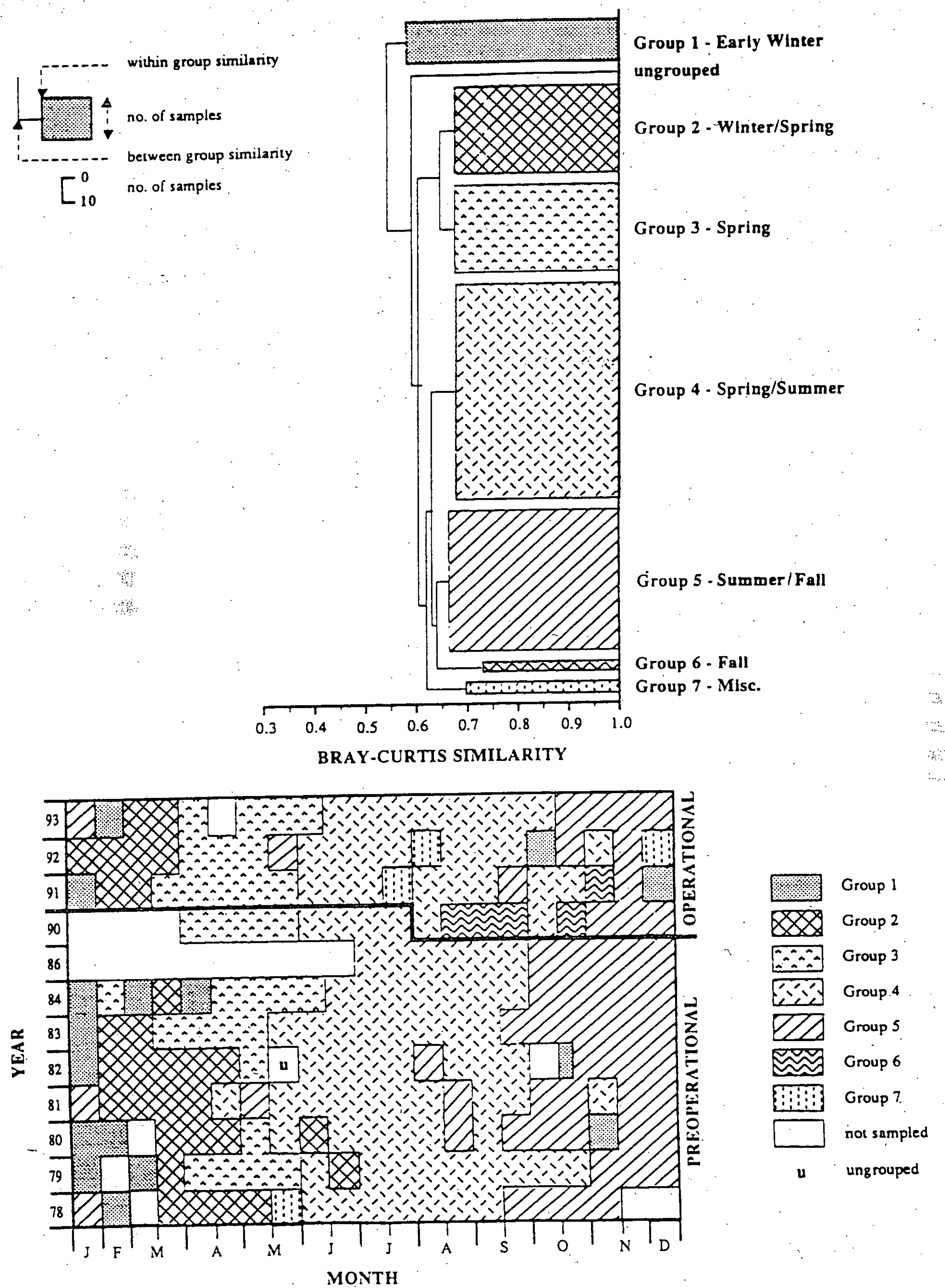


Figure 4-2. Dendrogram and seasonal groups formed by numerical classification of log (x+1) transformed **microzooplankton** abundances (no./m^3) at nearfield Station P2, 1978-1984, July-December 1986, April 1990-December 1993. Seabrook Operational Report, 1993.

TABLE 4-2. GEOMETRIC MEANS OF MICROZOOPLANKTON ABUNDANCE (No./m^3), 95% CONFIDENCE LIMITS, AND NUMBER OF SAMPLES FOR DOMINANT TAXA OCCURRING IN SEASONAL CLUSTER GROUPS IDENTIFIED BY NUMERICAL CLASSIFICATION OF COLLECTIONS AT NEARFIELD STATION P2, 1978-84, JULY-DECEMBER 1986, APRIL-DECEMBER 1990, 1991-93. SEABROOK OPERATIONAL REPORT, 1993.

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL PERIOD				OPERATIONAL PERIOD			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1 Early Winter (0.58/0.55)	Copepoda nauplii	12	66.2	126	240.1	4	4.3	65	813.0
	Oithona sp.		99.4	218	477.1		21.8	292	3755.3
	Pseudocalanus sp.		28.3	64	143.3		28.8	95	309.4
	Pseudocalanus/Calanus nauplii		32.8	72	158.3		0.3	16	235.7
	Tintinnidae		10.0	83	643.1		3.9	21	100.9
	Foraminiferida		5.7	14	33.5		7.5	40	204.1
2 Winter/Spring (0.67/0.65)	Cirripedia larvae	24	48.7	105	223.6	8	48.5	231	1084.2
	Copepoda nauplii		323.0	506	793.8		334.4	567	959.2
	Oithona sp.		539.0	923	1581.4		340.3	1025	3081.8
	Pseudocalanus sp.		108.4	197	357.9		35.9	77	163.8
	Pseudocalanus/Calanus nauplii		423.6	654	1008.5		46.6	114	278.9
3 Spring (0.68/0.65)	Copepoda nauplii	20	612.1	1089	1936.0	12	1363.9	1901	2650.6
	Oithona sp.		565.9	1075	2042.0		1381.4	2167	3400.2
	Pseudocalanus sp.		87.0	180	370.2		165.8	357	768.6
	Pseudocalanus/Calanus nauplii		230.1	451	883.7		165.6	508	1551.9
4 Spring/Summer (0.66/0.64)	Bivalvia veliger larvae	64	479.6	736	1128.7	26	204.5	422	870.3
	Copepoda nauplii		2313.0	3098	4149.1		2872.3	3953	5440.3
	Oithona sp.		3447.2	4194	5102.8		5356.1	6960	9043.5
	Pseudocalanus sp.		561.0	769	1054.5		293.7	557	1055.2
	Pseudocalanus/Calanus nauplii		1264.9	1654	2162.4		350.4	612	1069.9

ontin

TABLE 4-2. (Continued)

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL PERIOD				OPERATIONAL PERIOD			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
5 Fall (0.66/0.65)	Copepoda nauplii	44	437.5	614	860.4	13	417.5	612	897.2
	Oithona sp.		1001.6	1323	1748.6		1019.6	1515	2249.8
	Pseudocalanus sp.		146.9	221	332.3		145.4	220	334.0
	Pseudocalanus/Calanus nauplii		345.2	482	673.2		47.3	117	289.4
	Tintinnidae		30.1	71	165.7		47.4	287	1710.9
6 Summer/Fall (0.74/0.65)	Bivalvia veliger larvae	not represented				5	31.8	142	625.7
	Copepoda nauplii						263.1	508	980.2
	Oithona sp.						506.7	1092	2353.9
	Pseudocalanus sp.						36.4	114	352.4
7 Misc. (0.69/0.63)	Bivalvia veliger larvae	1	--	1180	--	3	17.4	405	8954.9
	Copepoda nauplii		--	2344	--		300.6	1834	11158.8
	Oithona sp.		--	670	--		48.1	2383	115710.4
	Pseudocalanus sp.		--	1124	--		0.0	69	25648.9
	Pseudocalanus/Calanus sp.		--	1079	--		0.0	60	114672.6

[a]within group similarity/between group similarity
[b]taxa comprising ≥ 5% of total group abundance in either preoperational or operational period

significantly different, and confidence intervals of the preoperational and operational abundances generally overlapped (NAI 1985). Similarly, 1993 abundances of the 29 dominant taxa were not significantly different among the three stations when tested with MANOVA (Wilks' Lambda=0.33, F=0.74, p>F=0.87), as was found in previous years (NAI 1991b, 1992, 1993b).

4.3.1.2 Selected Species

The copepods *Pseudocalanus* sp. and *Oithona* sp. were selected for further analysis in the microzooplankton program because of their numerical dominance. Their abundance and trophic level make them important members of the marine food web throughout the Gulf of Maine and nearby Atlantic Shelf waters (Sherman 1966, Tremblay and Roff 1983, Davis 1984, Anderson 1990). The third selected species, *Eurytemora herdmani*, although not dominant, has been reported to be an abundant coastal copepod in the northern region of the western Atlantic (Katona 1971). Lifestages of these taxa were identified whenever possible to develop an understanding of the dynamics of population recruitment cycles. In some cases, however, the possible presence of congeneric species made it impossible to routinely identify all lifestages to species level.

Eurytemora sp.

Earlier studies indicated that *Eurytemora* sp. copepodite and *E. herdmani* adult populations in Hampton Harbor and the nearfield Station P2 underwent similar seasonal cycles, but during the spring the population density in the estuary was much higher than the nearfield population density (NAI 1978, 1979). These observations suggest that recruitment to the coastal population may be supplemented by the estuarine population. Other sources of recruitment in the spring might be maturation of, and subsequent reproduction of, overwintering copepodites or hatching of diapause (overwintering) eggs (Grice and Marcus 1981, Marcus 1984).

Eurytemora sp. copepodite monthly mean densities for the operational period and 1993 failed to exhibit the mid-summer density peak that has been observed in the preoperational years (1982-1984) and were well below the preoperational average density from June through October (Figure 4-3). However, mean operational densities displayed (1) a late-spring peak that was comparable in magnitude to the preoperational mid-summer peak, and (2) a fall peak that was comparable to the fall peak in preoperational years. Abundance peaked only in the fall during 1993. The operational and 1993 annual geometric means for *Eurytemora* sp. copepodites at Station P2 were below the overall mean for the preoperational years (Table 4-3), but were within the range of mean values for individual years (NAI 1991b). ANOVA results indicated that *Eurytemora* sp. copepodite abundances during the operational period were significantly lower than densities from recent preoperational years (Table 4-4). The differences were consistent between stations, indicating they occurred areawide, and were not a localized effect of plant operation. Significant differences were also noted among years and months. Average densities at Station P2 were not significantly different from those at Station P7.

Temporal changes in the abundance of *Eurytemora herdmani* adults during the operational period followed the same general seasonal pattern as described for *Eurytemora* sp. copepodites with the exception that a fall peak was not detected in *E. herdmani* adult abundances in either the preoperational or operational years (Figure 4-3). The mean abundances of *E. herdmani* adults during the operational period and 1993 were below the mean densities for the preoperational years (Table 4-3), and the mean operational density of *E. herdmani* adults was found to be significantly lower than the preoperational mean (Table 4-4). However, the differences were consistent between the nearfield and farfield areas, indicating an areawide decrease, not a

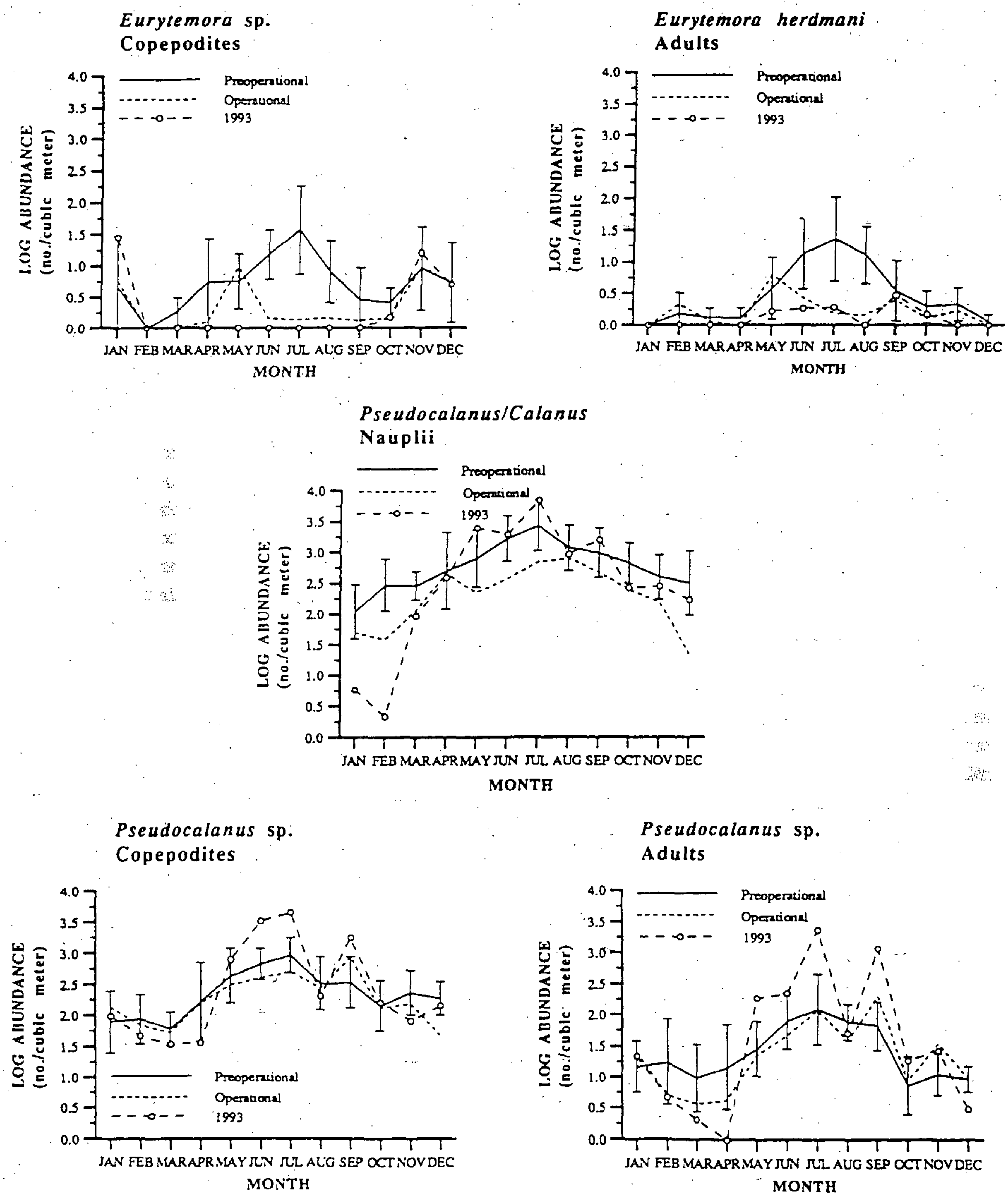


Figure 4-3. Log (x+1) abundance (no./m^3) of ***Eurytemora* sp. copepodites** and ***Eurytemora herdmani*** **adults**, ***Pseudocalanus/Calanus*** **sp. nauplii**, and ***Pseudocalanus*** **sp.** copepodites and adults; monthly means and 95% confidence intervals over all preoperational years (1978-1984 and 1986) and monthly means for 1993 and operational period at nearfield Station P2. Seabrook Operational Report, 1993.

TABLE 4-3. GEOMETRIC MEAN DENSITY (No/m³) AND THE COEFFICIENT OF VARIATION (CV,%) OF SELECTED MICROZOOPLANKTON SPECIES AT STATIONS P2, P5, AND P7 FOR PREOPERATIONAL AND OPERATIONAL PERIODS AND 1993. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL		OPERATIONAL		1993
SPECIES/LIFESTAGE	STATION	MEAN	CV	MEAN[b]	CV	MEAN
Eurytemora sp. copepodites	P2	4	35.1	1	16.6	1
	P5	--	--	1	29.4	1
	P7	4	56.4	1	52.4	<1
Eurytemora herdmani adults	P2	2	50.2	1	44.4	<1
	P5	--	--	1	35.5	<1
	P7	3	51.2	1	53.0	<1
Pseudocalanus/Calanus sp. nauplii	P2	593	7.5	187	9.1	284
	P5	--	--	133	3.2	136
	P7	499	11.2	144	6.2	186
Pseudocalanus sp. copepodites	P2	223	8.6	179	5.1	243
	P5	--	--	152	8.2	103
	P7	193	14.0	156	5.2	118
Pseudocalanus sp. adults	P2	23	17.4	19	14.4	32
	P5	--	--	18	9.8	21
	P7	25	16.4	19	7.1	16
Oithona sp. nauplii	P2	465	11.7	539	7.1	531
	P5	--	--	558	2.9	505
	P7	403	15.1	465	8.0	384
Oithona sp. copepodites	P2	490	10.1	779	3.6	641
	P5	--	--	746	6.0	480
	P7	299	20.1	643	3.8	533
Oithona sp. adults	P2	107	13.5	188	7.4	188
	P5	--	--	178	10.5	132
	P7	98	23.9	158	7.9	164

[a]Preoperational years: P2 = 1978-84, P5 = not sampled, P7 = 1982-84. Mean of annual means.
[b]Operational years = 1991-93; 1990 not sampled during January through March, data not included. Mean of annual means.

TABLE 4-4. RESULTS OF THE ANALYSIS OF VARIANCE OF LOG (X+1) TRANSFORMED DENSITY (No./m³) OF SELECTED MICROZOOPLANKTON SPECIES AMONG PREOPERATIONAL YEARS (1982-84) AND OPERATIONAL YEARS (1991-93) AND NEARFIELD (STATION P2) VS. FARFIELD (STATION P7) AREAS. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[a]	df	MS	F	MULTIPLE COMPARISONS[b]
Eurytemora sp. copepodite	Preop-Op	1	5.81	22.52***	Op<Preop
	Year (Preop-Op)	4	2.76	10.69***	
	Month (Year X Preop-Op)	66	0.82	3.17***	
	Area	1	0.04	0.16 NS	
	Preop-Op X Area	1	0.35	1.35 NS	
	Error	176	0.26		
Eurytemora herdmani adult	Preop-Op	1	7.14	38.77***	Op<Preop
	Year (Preop-Op)	4	2.17	11.81***	
	Month (Year X Preop-Op)	66	0.84	4.58***	
	Area	1	0.31	1.70 NS	
	Preop-Op X Area	1	0.12	0.68 NS	
	Error	176	0.18		
Pseudocalanus/Calanus sp. nauplii	Preop-Op	1	13.75	55.32***	Op<Preop
	Year (Preop-Op)	4	2.17	8.74***	
	Month (Year X Preop-Op)	66	1.33	5.35***	
	Area	1	0.36	1.44 NS	
	Preop-Op X Area	1	0.15	0.62 NS	
	Error	176	0.25		
Pseudocalanus sp. copepodite	Preop-Op	1	0.42	1.59 NS	
	Year (Preop-Op)	4	1.52	5.81***	
	Month (Year X Preop-Op)	66	1.07	4.08***	
	Area	1	0.12	0.45 NS	
	Preop-Op X Area	1	0.02	0.08 NS	
	Error	176	0.26		
Pseudocalanus sp. adult	Preop-Op	1	0.58	2.14 NS	
	Year (Preop-Op)	4	1.95	7.15***	
	Month (Year X Preop-Op)	66	1.33	4.86***	
	Area	1	0.00	0.00 NS	
	Preop-Op X Area	1	0.00	0.00 NS	
	Error	176	0.27		

(continued)

TABLE 4-4. (Continued)

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[a]	df	MS	F	MULTIPLE COMPARISONS[b]
Oithona sp. nauplii	Preop-Op	1	0.14	0.74 NS	
	Year (Preop-Op)	4	3.76	19.44***	
	Month (Year X Preop-Op)	66	0.91	4.69***	
	Area	1	0.60	3.10 NS	
	Preop-Op X Area	1	0.00	0.00 NS	
	Error	176	0.19		
Oithona sp. copepodite	Preop-Op	1	5.33	33.71***	Op>Preop
	Year (Preop-Op)	4	3.60	22.75***	
	Month (Year X Preop-Op)	66	1.20	7.58***	
	Area	1	0.88	5.59*	P2>P7
	Preop-Op X Area	1	0.01	0.05 NS	
	Error	176	0.16		
Oithona sp. adult	Preop-Op	1	2.29	12.14***	Op>Preop
	Year (Preop-Op)	4	4.42	23.47***	
	Month (Year X Preop-Op)	66	1.19	6.34***	
	Area	1	0.53	2.81 NS	
	Preop-Op X Area	1	<0.00	0.01 NS	
	Error	176	0.19		

NS = Not Significant (P> 0.05)
* = Significant (0.05 ≥ P >0.01)
** = Highly Significant (0.01 ≥ P > 0.001)
*** = Very Highly Significant (P ≤ 0.001)

[a]Preop-Op = preoperational period vs. operational period, regardless of area
Year (Preop-Op) = year nested within preoperational and operational periods, regardless of area
Month (Year X Preop-Op) = month nested within year
Area = nearfield vs. farfield stations
Preop-Op X Area = interaction of main effects

[b]Least squares means compared with a paired *t*-test

localized plant effect. Significant differences were noted among years and months.

Pseudocalanus sp.

Historically, *Pseudocalanus/Calanus* sp. nauplii were present year-round at Station P2 in large numbers (Figure 4-3), and were among the numerically dominant taxa composing the microzooplankton community in most seasons (Table 4-2). Seasonal peak abundance occurred during mid-summer during preoperational years and in 1993, and slightly later during the operational period (Figure 4-3). The 1993 abundances were much lower than the preoperational averages from January - March. Mean densities for the operational period were significantly lower than the preoperational mean at both stations (Tables 4-3, 4-4). However, the differences between periods were consistent between the nearfield and farfield areas, indicating an areawide decrease rather than a localized plant effect. Differences among months and years were significant, while spatial differences were not significant.

Pseudocalanus sp. copepodites and adults were also present throughout the year, with peak abundances occurring from mid-summer through fall (Figure 4-3). Monthly mean abundances in 1993 were lower than the preoperational average in spring and higher than average from May - July and in September. The mean densities of both copepodites and adults during the operational period were not significantly different from the preoperational (1982-1984) means (Tables 4-3, 4-4). Differences between periods at the nearfield and farfield stations were consistent, indicating no effect due to plant operation occurred. Significant differences were noted among years and months, but not between stations.

Oithona sp.

All *Oithona* sp. (mostly *Oithona similis*) lifestages were present year-round and together constituted one of the most abundant microzooplankton taxa throughout the preoperational and operational periods (Tables 4-2 and 4-3). *Oithona* sp. nauplii densities at Station P2 during the operational period and 1993 generally exhibited the same seasonal pattern of abundance as during the preoperational period (Figure 4-4). The 1993 monthly geometric means for P2 were about equal to or higher than the overall (1978-1984) preoperational mean, except in February and April. Average operational densities were slightly higher when compared to the preoperational (1982-1984) mean (Table 4-3), but the difference was not significant (Table 4-4). Mean densities at the nearfield and farfield stations showed similar trends between the preoperational (1982-1984) and operational periods, indicating the slight increase was areawide, not localized in the vicinity of the plant (Table 4-4). Significant differences were noted among years and months, but not between stations.

Oithona sp. copepodites also followed the same general pattern of seasonal abundances during the operational period and 1993 that was evident during the preoperational period (Figure 4-4). The operational and 1993 geometric means for copepodites at Stations P2 and P7 were considerably larger than the means for the preoperational period (Table 4-3). Operational densities were significantly larger than those during the preoperational (1982-1984) period when stations were averaged (Table 4-4). Differences among years and months were also significant. The density of copepodites at Station P2 over all sampling dates was significantly greater than at Station P7 (Table 4-4). Mean densities at the nearfield and farfield stations showed similar increases between the preoperational (1982-1984) and operational periods, indicating the increase was areawide, not localized in the vicinity of the plant (Table 4-4).

Seasonal fluctuations in abundance of *Oithona* sp. adults during the operational period and 1993 were similar to those observed during the preoperational

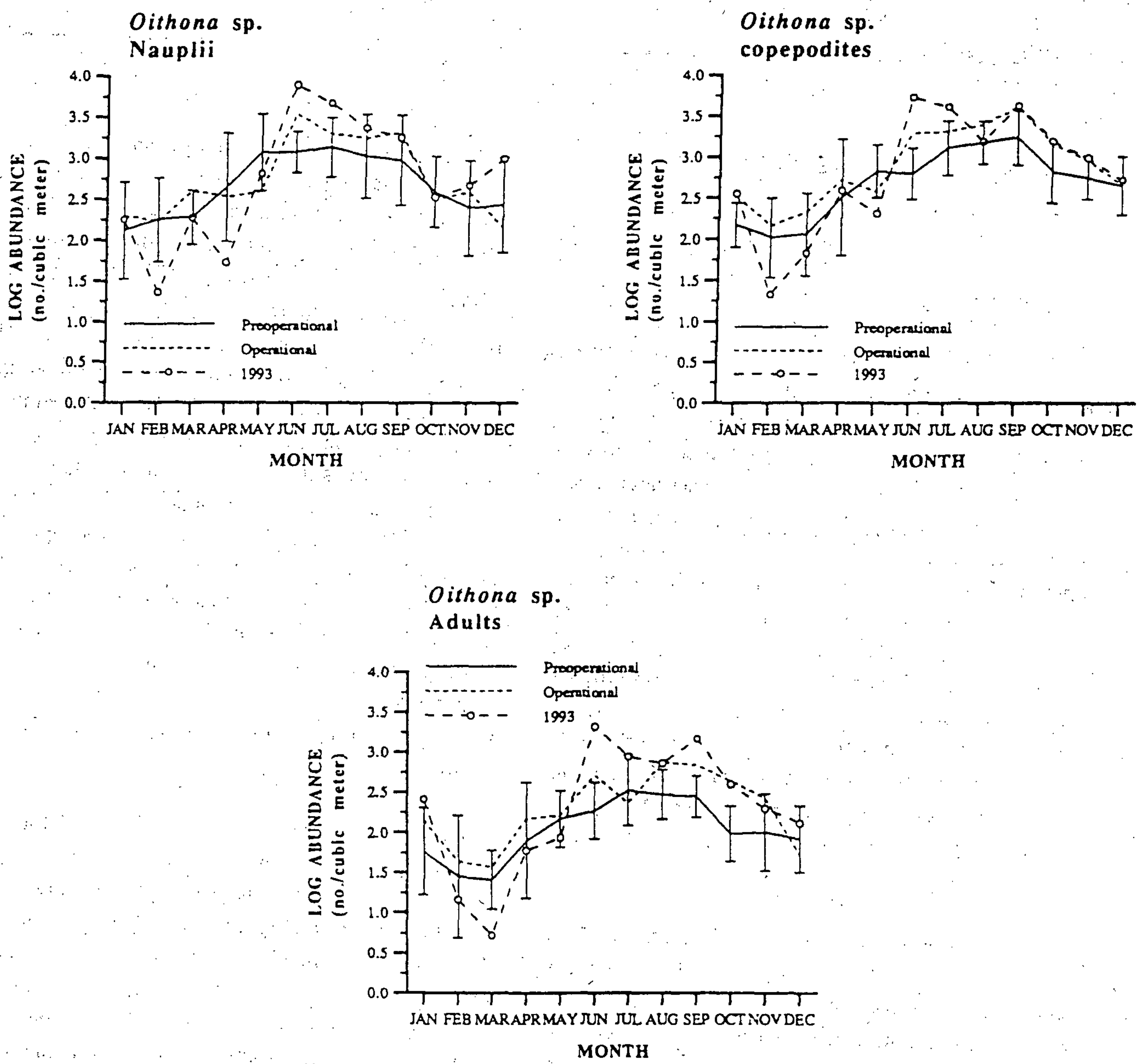


Figure 4-4. Log (x+1) abundance (no./m³) of *Oithona* sp. nauplii, copepodites and adults; monthly means and 95% confidence intervals over all preoperational years (1978-1984 and 1986) and monthly means for 1993 and operational period at nearfield Station P2. Seabrook Operational Report, 1993.

period (Figure 4-4). Geometric mean abundance for adults at Station P2 for the operational years and 1993 were slightly higher than the mean for all preoperational years (Table 4-3). Mean operational densities of *Oithona* sp. adults were significantly greater than the recent preoperational (1982-1984) means at both nearfield and farfield stations. Mean densities at the nearfield and farfield stations showed similar increases between the preoperational (1982-1984) and operational periods, indicating the increase was areawide, not localized in the vicinity of the plant (Table 4-4). Differences among years and months were also significant. No significant differences were detected between stations.

4.3.2 Bivalve Larvae

4.3.2.1 Community Structure

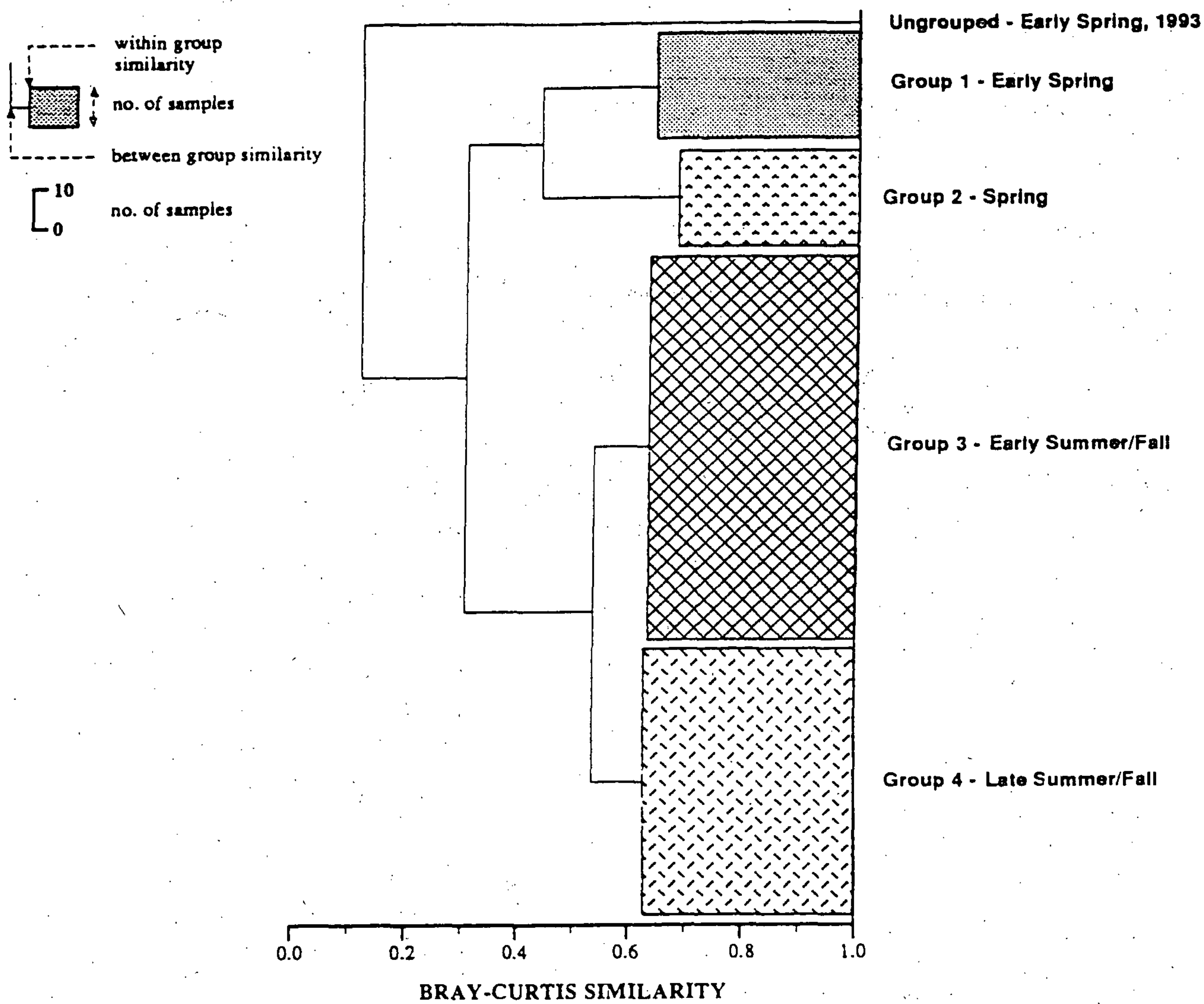
Patterns of abundance of the umboned bivalve larvae assemblage were examined using numerical classification to address whether there were differences among stations (spatial patterns) or between the preoperational and operational periods (temporal patterns). This aggregation of meroplanktonic species exhibited strong seasonal patterns that were generally consistent among years and stations, especially for the early spring and spring groups (Figure 4-5). Mean abundances were grouped seasonally, falling into one of four distinct groups. The seasonal structure of the community reflected recruitment of different taxa and their abundance (Table 4-5).

Temporal Patterns

The bivalve larvae assemblage showed predictable seasonal changes that were generally consistent among years. No unusual assemblages (groups) of bivalve larvae have occurred during the operation of Seabrook Station, as evidenced by the classification of all the operational period collections into groups that occurred preoperationally (Figure 4-5 and Table 4-5). Early spring collections (Group 1) were characterized by low densities of only a single species, *Hiatella* sp. The transition to the late spring assemblage (Group 2) was marked by peak densities of *Hiatella* sp., the earliest spawner, along with moderate densities of *Mytilus edulis*, *Mya truncata* and Solenidae. Peak mean densities of *M. edulis*, *Anomia squamula*, and *Modiolus modiolus* typified one of the two summer/fall assemblages, Group 3. This assemblage was followed by a period of low-to-moderate densities of bivalve larvae (Group 4) that occurred in July or August. In most years, including 1993, a second peak of *M. edulis*, *A. squamula* and *M. modiolus* led to the recurrence of the summer/fall assemblage (Group 3) in late summer or fall, which was often again followed by low to moderate densities of larvae, primarily *A. squamula*, *M. edulis* and *M. modiolus* (Group 4). No single group characterized the bivalve larvae assemblage from August-October every year. The bivalve larvae assemblage during the operational period (beginning in August 1990) was similar to previous years.

In 1993 the early spring assemblage (Group 1) characterized most stations in late April and early May (Figure 4-5). During late May, as the spawning season progressed, the late spring community (Group 2) characterized all stations. During June and early July, the high density summer/fall assemblage (Group 3) characterized all stations. From late July through August, most stations were characterized by low density summer/fall assemblage (Group 4). During September, the high density assemblage (Group 3) recurred, and during October densities declined and Group 4 again characterized all stations.

During the operational period (1990-93) geometric mean densities in the two summer/fall assemblages (Groups 3 and 4) were somewhat higher than preoperational densities (Table 4-5). Operational densities in the late spring assemblage (Group 2) were lower than preoperational densities for all dominant taxa. Multivariate analysis indicated that operational



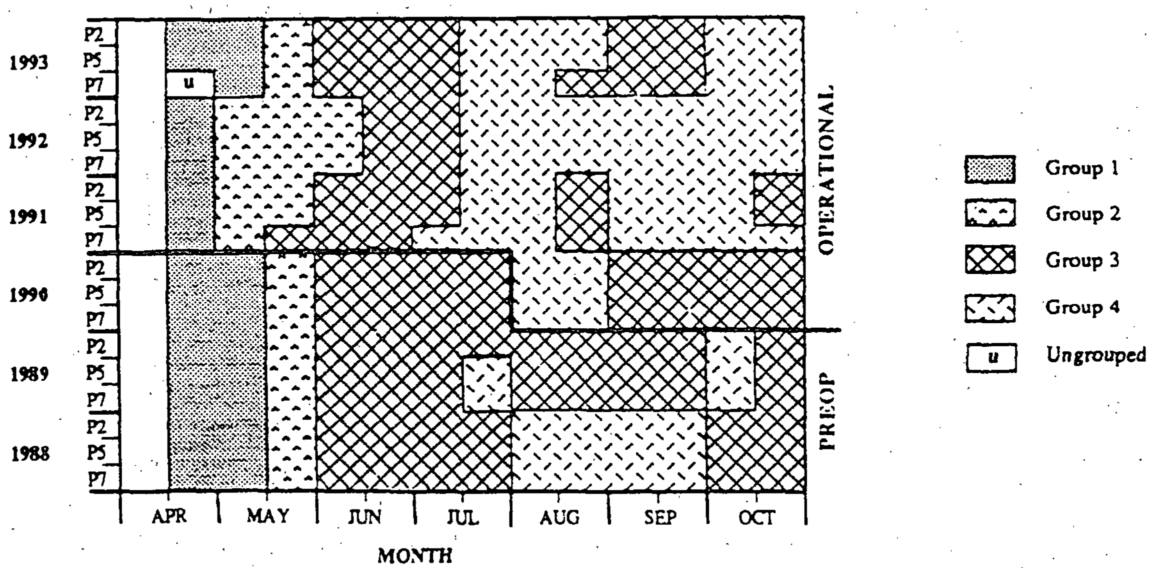


Figure 4-5. Dendrogram and seasonal groups formed by numerical classification of **bivalve larvae** log (x+1) transformed abundances (half monthly means; no./m³) at Seabrook intake (P2), discharge (P5) and farfield (P7) stations, April-October, 1988-1993. Seabrook Operational Report, 1993.

TABLE 4-5. GEOMETRIC MEAN ABUNDANCE (No./m^3), AND THE 95% CONFIDENCE LIMITS OF DOMINANT TAXA AND NUMBER OF COLLECTIONS OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF BIVALVE LARVAE COLLECTIONS AT INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) STATIONS, 1988-1993. SEABROOK OPERATIONAL REPORT, 1993.

GROUP NO./ NAME SIMILARITY[c]	DOMINANT TAXA[a]	PREOPERATIONAL YEARS[b]				OPERATIONAL YEARS[b]			
		N[d]	LCL	$\overline{X}$	UCL	N	LCL	$\overline{X}$	UCL
1 Early spring (0.64/0.44)	*Hiatella* sp.	18	28	39	55	11	20	44	92
2 Late spring (0.68/0.44)	*Hiatella* sp.	9	632	1316	2741	17	434	650	974
	Mya truncata		56	112	223		5	10	19
	Solenidae		38	51	69		8	13	23
	Mytilus edulis		11	28	70		2	5	14
3 Summer/Fall (0.64/0.54)	*Mytilus edulis*	55	1103	1912	3315	48	1553	2455	3879
	Anomia squamula		364	621	1061		579	972	1630
	Modiolus modiolus		200	309	477		102	186	339
	Hiatella sp.		95	185	360		164	293	522
	Mya arenaria		8	12	19		2	4	7
4 Summer/Fall (0.63/0.54	*Anomia squamula*	17	50	96	181	58	184	240	312
	Modiolus modiolus		15	29	56		5	7	10
	Mytilus edulis		23	39	65		97	153	242
	Mya arenaria		5	10	19		6	9	13
	Spisula solidissima		5	8	13		10	14	20
Ungrouped (--/.13)	*Hiatella* sp.	--	--	--	--	1	--	2	--

[a]those taxa contributing ≥5% of total group abundance in either preoperational or operational period collections
[b]preoperational = April 1988-October 1989; operational = August 1990-October 1993
[c](within-group similarity/between-group similarity)
[d]N = number of half-monthly means calculated from weekly means (first half-month includes weeks beginning with days 1-15; second half with days 16-31)

densities were significantly different than densities in 1988 and 1989 (Wilks' Lambda=0.30, F=50.6, p=0.0001): these differences were consistent among stations (Preop-Op X Station: Wilks' Lambda=0.88, F=1.47, p=0.08).

Spatial Patterns

Distribution of bivalve larvae in marine waters was related to several factors: distribution of spawning adults, length of larval existence and local hydrographic conditions. The dominant bivalve larvae collected in coastal waters of New Hampshire were species whose adults were widely distributed along the New England coastline. Duration of larval stage is dependent on temperature, but may be as long as six weeks (Bayne 1965, 1976; Jury et al. 1994). The local hydrography is dominated by tidal and longshore currents (NAI 1980). Stations P2, P5 and P7 are located in waters of similar depth (Figure 4-1) with no physical barriers between them. These conditions tended to create a spatially homogenous bivalve larvae community. It was not unexpected, then, that the species composition was usually similar at each of the three stations (Figure 4-5). During 90% of the sampling periods, assemblages at all three stations were similar, and were grouped together; assemblages at nearfield Stations P2 and P5 were grouped together 100% of the time. In 1993, the assemblage from the earliest samples taken (late April 1993) at Station P7 (farfield) was not similar to any other group because only extremely low numbers of *Hiatella* sp. were present. By early May 1993, the P7 assemblage was similar to that at P2 and P5 and placed in the early spring assemblage (Group 1).

The only other sampling period in 1993 where all three stations were not placed in the same faunal group occurred in late August. Collections from Station P7 (farfield) were placed in Group 3, the high density summer/fall assemblage, while collections at Stations P2 and P5 (nearfield) were placed in Group 4. By early September, the assemblage at all three stations was similar (Group 4). Multivariate analysis of variance indicated there were no significant differences among the three stations during the preoperational (1988, 1989) and operational (1991, 1992, and 1993) years (Wilkes' Lambda=0.91, F=0.99, p=0.48).

4.3.2.2 Selected Species

Mya arenaria was identified as a selected species because of the interest in recreational (locally) and commercial (regionally) harvesting of adults and the concern that impacts to the larval population could decrease the standing stock of harvestable clams (Section 10.0). *Mytilus edulis* has been the most abundant species encountered in bivalve larvae investigations. Temporal and spatial patterns of both species were examined to evaluate whether there was evidence of impacts induced by operation of Seabrook Station.

Mya arenaria

This species is discussed in detail in Section 10.0.

Mytilus edulis

Abundances of *Mytilus edulis* peaked in mid-June at Station P2 during the preoperational and operational periods and during 1993, and remained relatively abundant through the end of sampling in October (Figure 4-6). Monthly abundances in 1993 were usually higher than the average operational and preoperational abundances, and were generally above the upper 95% confidence limit of preoperational means after the third week of June. The 1993 peak abundance (in late June) was greater than the preoperational peak by more than an order of magnitude.

The annual abundances at both nearfield and farfield stations during 1993 were more than double the operational and preoperational abundances (Table

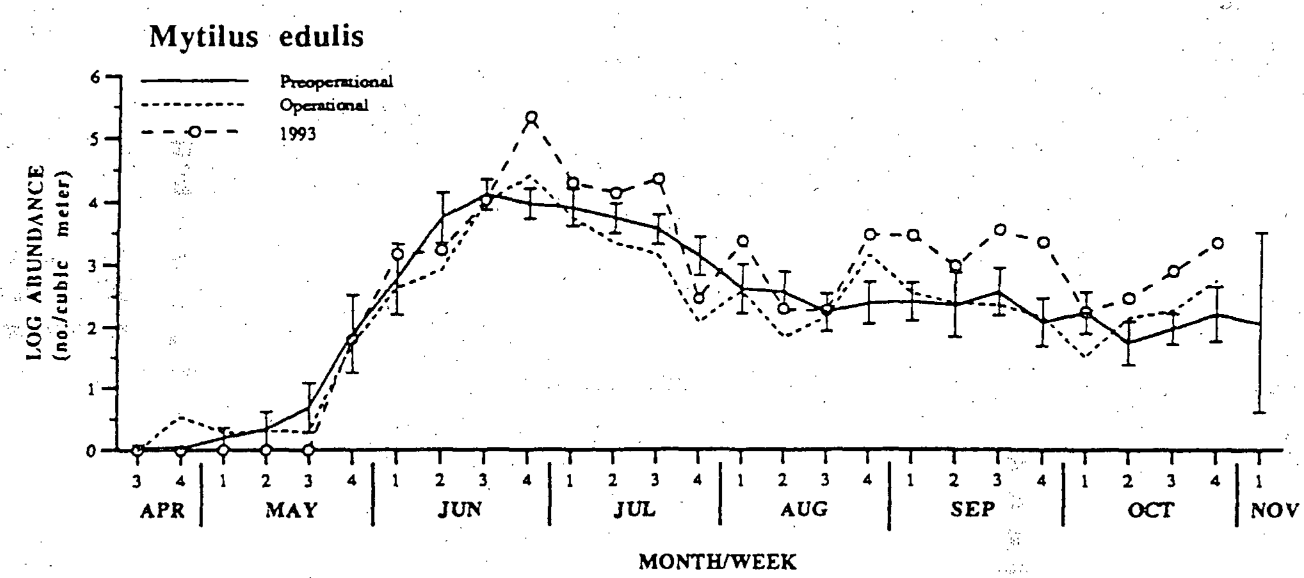


Figure 4-6. Weekly mean log (x+1) abundance (no./m³) of ***Mytilus edulis*** larvae at Station P2 during preoperational years (1978-1989, including 95% confidence intervals), and weekly means in the operational period (1991-1993) and in 1993. Seabrook Operational Report, 1993.

4-6). Mytilid abundances had been low at all stations in 1992 (NAI 1993b), but the average operational abundances at all three stations were not significantly different than recent preoperational (1988-1989) abundances (Table 4-7). Station differences were not significant during the period when collections were made at all three stations, although differences among years and months were significant. The interaction term (Preop-Op X Station) was not significant, suggesting that the plant had no effect on the abundance of *Mytilus edulis* larvae.

TABLE 4-6. GEOMETRIC MEAN ABUNDANCE (No./m^3) AND UPPER AND LOWER 95% CONFIDENCE LIMITS OF *MYTILUS EDULIS* LARVAE AT STATIONS P2, P5 AND P7 DURING PREOPERATIONAL YEARS AND GEOMETRIC MEAN ABUNDANCE DURING THE OPERATIONAL PERIOD (1991-1993) AND 1993. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL		OPERATIONAL		1993
STATION	YEAR	MEAN[a]	CV	MEAN[a]	CV	MEAN
P2	1982-1989	232.4	18.52	149.0	28.50	417.7
P5	1988-1989	184.2	18.00	146.1	24.89	305.4
P7	1982-1984, 1986-1989	250.1	13.22	162.4	27.27	487.6

[a]mean of annual means

TABLE 4-7. RESULTS OF ANALYSIS OF VARIANCE COMPARING INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) WEEKLY ABUNDANCES OF *MYTILUS EDULIS* DURING PREOPERATIONAL (1988-1989) AND OPERATIONAL (1991-1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS
Preop-Op	1	0.02	0.12 NS	
Station	2	0.20	1.49 NS	
Year (Preop-Op)	3	23.73	181.14***	
Week (Preop X Year)	122	5.31	40.57***	
Preop-Op X Station	2	0.08	0.60 NS	
Error	249	0.13		

4.3.2.3 Entrainment

The effects of operation of Seabrook Station on bivalve larvae were monitored primarily through entrainment sampling and secondarily through comparisons of both community and species abundance characteristics between the preoperational and operational periods. The estimated total number of larvae entrained in the cooling water system in 1993 is presented in Table 4-8. In 1993, entrainment samples were collected from the third week in April through October. No samples were taken during scheduled or unscheduled plant shutdowns. Scheduled plant shutdowns occurred from early August through November 1991 and in September and October 1992. The total number of bivalve larvae entrained in 1993 was greater than in 1991 and 1992 (Figure 4-7) due to the above average abundance of some species such as *Mytilus edulis* and *Anomia squamula* in the natural environment. Also, in 1993 samples were collected throughout the period when bivalve larvae were typically abundant (July - September), since there were no plant shutdowns. In 1993 *Mytilus edulis* accounted for 55% of the total bivalve larvae entrained, while *Anomia squamula* accounted for 22%, *Hiatella* sp. for 13% and *Modiolus modiolus* for 7% (Table 4-8). Most larvae were entrained during June (22%), July (39%), August (17%) and September (18%), and less than 5 % of the total was collected in late April, May and October.

Numbers of larvae entrained reflect the numbers present in the natural environment. For example, *Mytilus edulis* larvae were very abundant in 1993 from late June through the third week of July (Figure 4-6). That period of peak abundance is reflected in the high numbers entrained in July (Figure 4-7, Table 4-8). An early fall (September) peak in bivalve larvae entrainment in 1993 was due to high numbers of *Anomia squamula* and other bivalves, primarily *Modiolus modiolus* (Table 4-8). *Hiatella* sp., an early spawner, was most abundant in entrainment samples in June and July.

In all years, entrainment was highest in June or July, reflecting the natural peak in bivalve larval abundance observed nearshore. Entrainment appeared to be substantially lower in 1991 than during 1990 and 1993 (NAI 1991b), largely as a result of a four-month plant shutdown, which resulted in reduced entrainment of dominants *Mytilus edulis, Hiatella* sp. and *Anomia squamula* (Figure 4-7).

4.3.3 Macrozooplankton

4.3.3.1 Community Structure

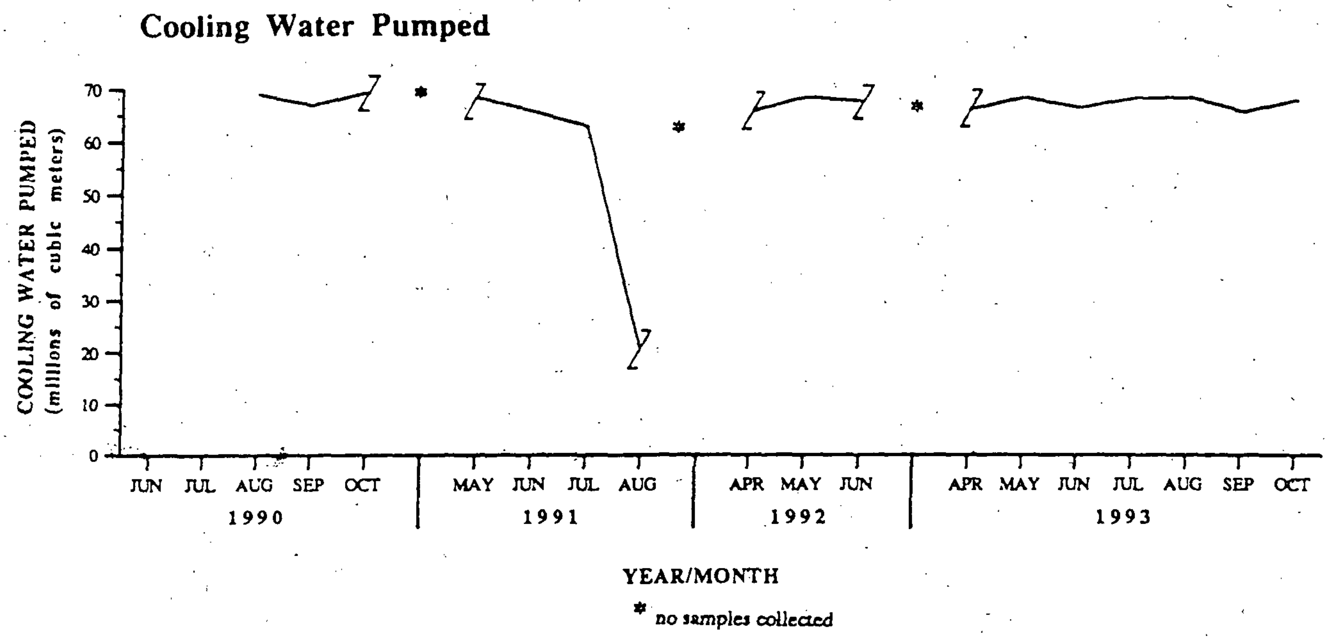
Historical analysis (1978-1984 and 1986-1989) of the macrozooplankton assemblage at the nearfield Station P2 showed seasonal changes that were greatly influenced by the population dynamics of the dominant copepods *Centropages typicus* and *Calanus finmarchicus* (NAI 1990). Other taxa, particularly meroplanktonic species, exerted short-term influences, especially during the spring and summer (NAI 1985). Because of their lower abundances, seasonal patterns of tychoplanktonic species, e.g., mysids, amphipods and cumaceans, were not well documented by numerical classification of the entire macrozooplankton assemblage. To identify seasonal patterns more clearly, the tychoplankton assemblage was analyzed separately from the mero- and holoplankton.

The Holo- and Meroplankton Assemblage

The distinct seasonal patterns of the holo- and meroplankton previously observed were again evident when 1993 collections were included in the numerical classification (Figure 4-8, Table 4-9). Groups 2, 4, 5, 6 and 7 were represented by at least one month in every year and, together included 92% of the collections. *Temora longicornis* and *Sagitta elegans* dominated some winter collections in 1990 and 1993 (Group 1). Winter and early spring (Group 2) collections were dominated by Cirripedia. Copepods

TABLE 4-8. ESTIMATED NUMBER OF BIVALVE LARVAE (X10⁹) ENTRAINED BY THE COOLING WATER SYSTEM AT SEABROOK STATION FROM THIRD WEEK IN APRIL THROUGH FOURTH WEEK OF OCTOBER 1993. SEABROOK OPERATIONAL REPORT 1993.

SPECIES	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL	%
Mytilus edulis	<0.1	0.1	2254.0	5387.5	1497.3	661.9	249.9	10050.7	55.2
Modiolus modiolus	0.0	<0.1	0.5	7.5	452.0	752.6	71.3	1283.9	7.1
Placopecten magellanicus	0.0	<0.1	8.5	7.9	0.2	0.2	<0.1	16.9	0.1
Anomia squamula	0.0	0.1	378.3	707.0	767.1	1717.4	353.0	3922.7	21.6
Spisula solidissima	0.0	0.0	0.0	11.0	6.4	13.4	17.7	48.5	0.3
Mya arenaria	0.0	0.0	0.6	1.8	2.2	0.7	17.2	22.5	0.1
Mya truncata	0.0	<0.1	1.5	0.0	0.2	0.0	0.4	2.1	<0.1
Hiatella sp.	<0.1	6.7	1126.3	917.2	271.0	79.8	4.5	2405.5	13.2
Macoma balthica	0.0	<0.1	0.1	0.0	0.0	0.0	0.1	0.2	<0.1
Bivalvia	<0.1	<0.1	82.9	109.1	57.3	57.5	27.4	334.3	1.8
Solenidae	0.0	0.1	54.5	23.7	2.4	3.4	18.4	102.5	0.6
TOTAL	<0.1	6.9	3907.1	7172.8	3056.1	3286.9	760.0	18189.8	
% OF TOTAL	<0.1	<0.1	21.5	39.4	16.8	18.1	4.0		



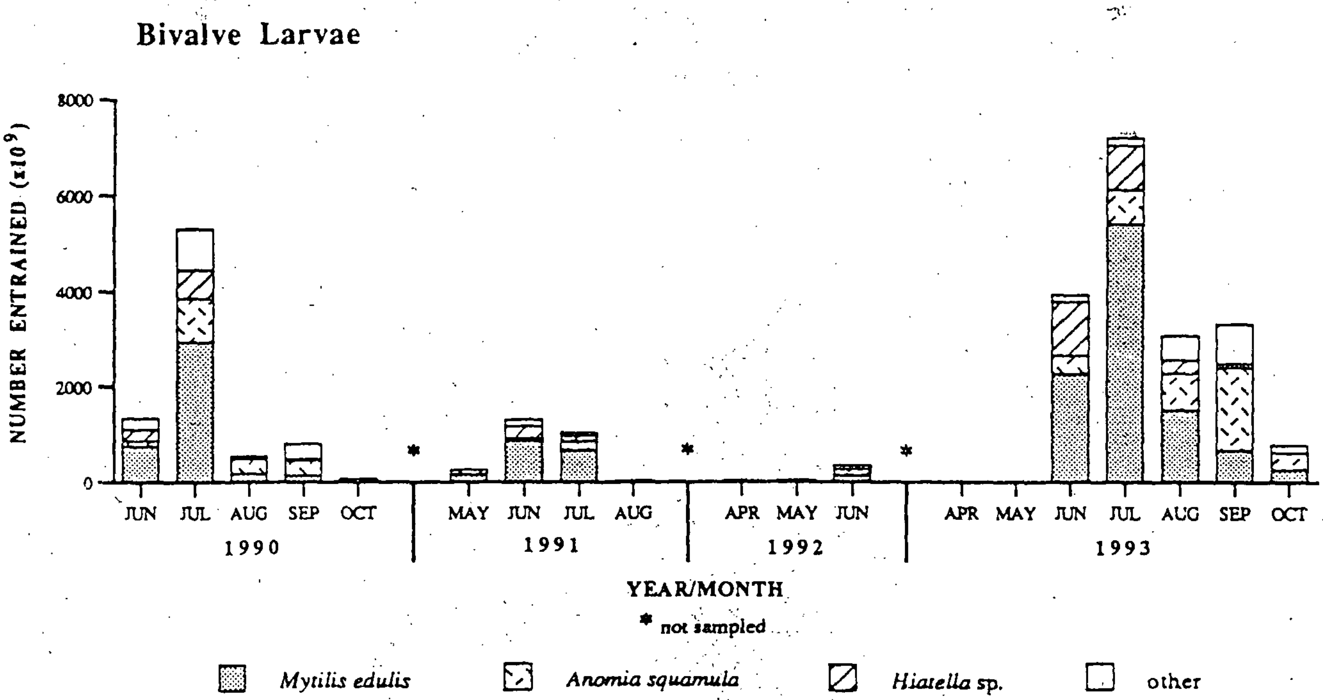


Figure 4-7. Volume of cooling water pumped during the months sampled for **bivalve larvae** and total number of **bivalve larvae** ($x10^9$) entrained by Seabrook Station, 1990-1993. Seabrook Operational Report, 1993.

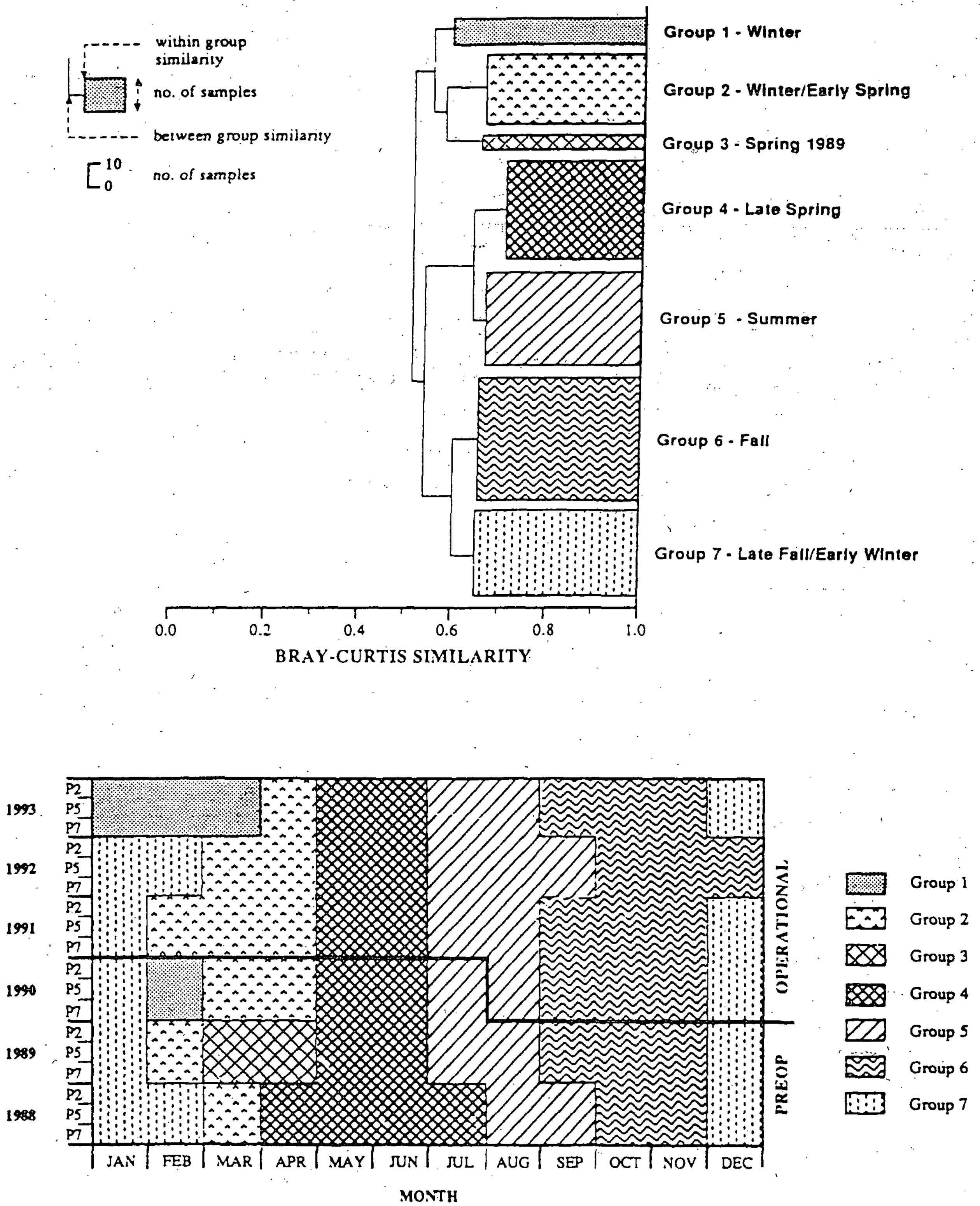


Figure 4-8. Dendrogram and seasonal groups formed by numerical classification of mean monthly log (x+1) transformed abundances (no./1000 m^3) of holo- and meroplanktonic species of macrozooplankton at intake Station P2, discharge Station P5 and farfield Station P7, 1988-1993. Seabrook Operational Report, 1993.

TABLE 4-9. GEOMETRIC MEAN ABUNDANCE (No./1000m³) AND 95% CONFIDENCE LIMITS OF DOMINANT HOLO- AND MEROPLANKTONIC TAXA OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF MACROZOOPLANKTON COLLECTIONS (MONTHLY MEANS) AT INTAKE STATION P2, DISCHARGE STATION P5 AND FARFIELD STATION P7, 1988-1993. SEABROOK OPERATIONAL REPORT, 1993.

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		n	LCL	$\bar{x}$	UCL	n	LCL	$\bar{x}$	UCL
1	*Temora longicornis*	3	3225.6	28662	254623.8	9	211.0	996	4694.6
Winter	*Sagitta elegans*		6896.1	20601	61540.4		1249.4	2148	3691.0
(0.60/0.55)	*Tortanus discaudatus*		0.9	32	575.3		141.1	653	3007.3
	Calanus finmarchicus		6.7	32	142.3		205.1	412	826.5
2	Cirripedia	12	3692.4	8431	19250.6	18	28329.0	66603	156587.8
Winter-Early Spring	*Temora longicornis*		2086.9	4065	7918.8		152.2	664	2882.9
(0.67/0.57)	*Calanus finmarchicus*		1242.9	2711	5911.7		694.0	3540	18044.1
	Pseudocalanus sp.		964.9	1867	3610.3		872.8	1867	3992.1
	Sagitta elegans		405.6	1336	4394.3		204.9	417	848.1
	Oikopleura sp.		78.8	501	3157.0		10933.7	19232	33826.6
3	*Calanus finmarchicus*	6	4389.6	7900	14217.1		not represented		
Spring 1989	Cirripedia		893.3	3550	14099.8				
(0.66/0.57)									
4	*Calanus finmarchicus*	24	38253.0	56059	82153.1	18	81399.9	144009	254774.3
Late Spring	*Eualus pusiolus*		3658.0	5598	8565.7		1301.0	1973	2992.9
(0.71/0.64)	*Temora longicornis*		2484.6	4636	8650.6		1495.5	3141	6596.5
	Evadne sp.		2065.7	4599	10235.6		7818.8	13368	22853.8
5	*Calanus finmarchicus*	15	17993.5	45735	116242.9	24	31328.7	46367	68623.1
Summer	*Cancer* sp.		15783.8	37088	87146.1		50310.2	67553	90706.6
(0.67/0.64)	*Centropages typicus*		2302.6	12059	63134.9		12601.4	24904	49214.9
	Eualus pusiolus		4806.1	11499	27509.2		6008.2	10977	20054.3
	Temora longicornis		853.0	2781	9062.3		6424.4	11752	21495.7

(continued)

TABLE 4-9. (Continued)

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		n	LCL	$\bar{x}$	UCL	n	LCL	$\bar{x}$	UCL
6	*Centropages typicus*	15	26201.3	54321	112620.3	36	29091.7	52548	94917.6
Fall	*Centropages* sp.		2563.3	5334	11099.1		546.8	1170	2501.4
(0.66/0.61)									
7	*Centropages typicus*	18	1423.4	2802	5514.9	18	2204.3	3545	5700.5
Late Fall-	*Temora longicornis*		1468.7	2446	4073.3		397.6	770	1490.5
Early Winter	*Centropages hamatus*		611.4	1102	1985.7		2.7	14	56.9
(0.66/0.61)	*Sagitta elegans*		521.5	876	1472.7		517.5	882	1503.8
	Pseudocalanus sp.		398.8	791	1568.0		69.4	171	421.5
	Tortanus discaudatus		87.5	324	1191.7		201.7	525	1363.8
	Oikopleura sp.		183.9	463	1163.7		186.3	425	967.6

[a](within-group similarity/between group similarity)
[b]those taxa contributing $\geq$5% of total group abundance in either preoperational or operational periods
[c]preoperational period = January 1988-July 1990; operational period = August 1990-December 1993

(*T. longicornis*, *Calanus finmarchicus*, *Pseudocalanus* sp.). *S. elegans* and *Oikopleura* sp. were also abundant in winter and early spring. *C. finmarchicus* with Cirripedia dominated March and April samples in 1989 (Group 3). Late spring (Group 4) collections were dominated by *C. finmarchicus*, whose abundance was an order of magnitude greater than the co-dominants *T. longicornis*, *Evadne* sp. and *Eualus pusiolus*. Summer (Group 5) collections were dominated by *Cancer* sp. and *C. finmarchicus*. *Centropages typicus*, *E. pusiolus* and *T. longicornis* were also abundant in summer. Most meroplanktonic species (e.g., *Carcinus maenas*, Sec. 4.3.3.2), though not dominant, reached their peak abundances during summer months. *C. typicus* and *Centropages* sp. copepodites were dominant in fall (Group 6). *C. typicus* also dominated late fall and early winter (Group 7) periods when other copepods, *S. elegans* and *Oikopleura* sp. were relatively abundant.

The seasonal shift in dominance among Cirripedia, *Calanus finmarchicus* and *Centropages typicus* observed in 1988 through 1993 was consistent with patterns observed historically (NAI 1990). The seasonal shifts in dominance observed among the copepods *C. finmarchicus*, *C. typicus* and to a lesser extent, *Pseudocalanus* sp. were consistent with other observations for the Gulf of Maine (Sherman et al. 1988).

Species composition of holo- and meroplankton during the operation of Seabrook Station was generally similar to the preoperational period examined. However, the period from December 1992 through March 1993 was atypical of previous years (Figure 4-8). The fall dominant *Centropages typicus* typically declined in abundance each December, but remained a dominant in the low abundance winter assemblage. However, in December 1992, *C. typicus* continued to occur in high abundance, then virtually disappeared in January 1993 (NAI 1994). Winter 1993 was dominated by species *Sagitta elegans*, *Oikopleura* sp. and *Tortanus discaudatus*, which normally were co-dominant during this time. This pattern, although abbreviated, was also observed in February 1990. A slightly delayed Cirripedia peak combined with low copepod abundances and sustained high abundance of *S. elegans* extended the winter community (Group 1) into March 1993 (NAI 1994). The delay of the spring Cirripedia and *Calanus finmarchicus* peaks, the low abundance of *C. typicus*, and the longevity of the winter group may have been the result of the lower than normal water temperatures during the winter of 1993 (Section 2.3.1).

Group abundances were generally similar between operational and preoperational periods with three exceptions. Winter (Group 1) abundance was lower in the operational period due primarily to low abundances of *Temora longicornis* and *Sagitta elegans*. Abundances of Cirripedia and *Oikopleura* sp. in winter and early spring (Group 2) were substantially higher during the operational period than the preoperational period. Late spring (Group 4) abundance was higher in the operational period due mostly to higher abundance of *Calanus finmarchicus*. Geometric mean abundances were generally higher in the operational years of 1991-1993 than in the preoperational period of 1988-1989 and the operational status was significantly different (p=0.0001) in the MANOVA. Of the the 50 taxa included in the MANOVA, 26 exhibited significantly higher abundance in the operational period while only 6 taxa were lower in abundance (individual species differences determined by ANOVA). Of the 13 taxa that dominated the holo- and meroplankton during various parts of the annual cycle, seven (*T. longicornis*, *Centropages typicus*, *Oikopleura* sp., Cirripedia, *C. finmarchicus*, *Cancer* sp. and *Tortanus discaudatus*) reached higher abundances in the operational period than in the recent preoperational period (1988-1989). Only *Centropages hamatus* declined in abundance. *S. elegans*, *Pseudocalanus* sp., *Evadne* sp., *Centropages* sp. copepodites and *Eualus pusiolus* were similar in abundance between the two time periods. Although differences in the operational and preoperational periods were detected, a similar shift was detected at all stations

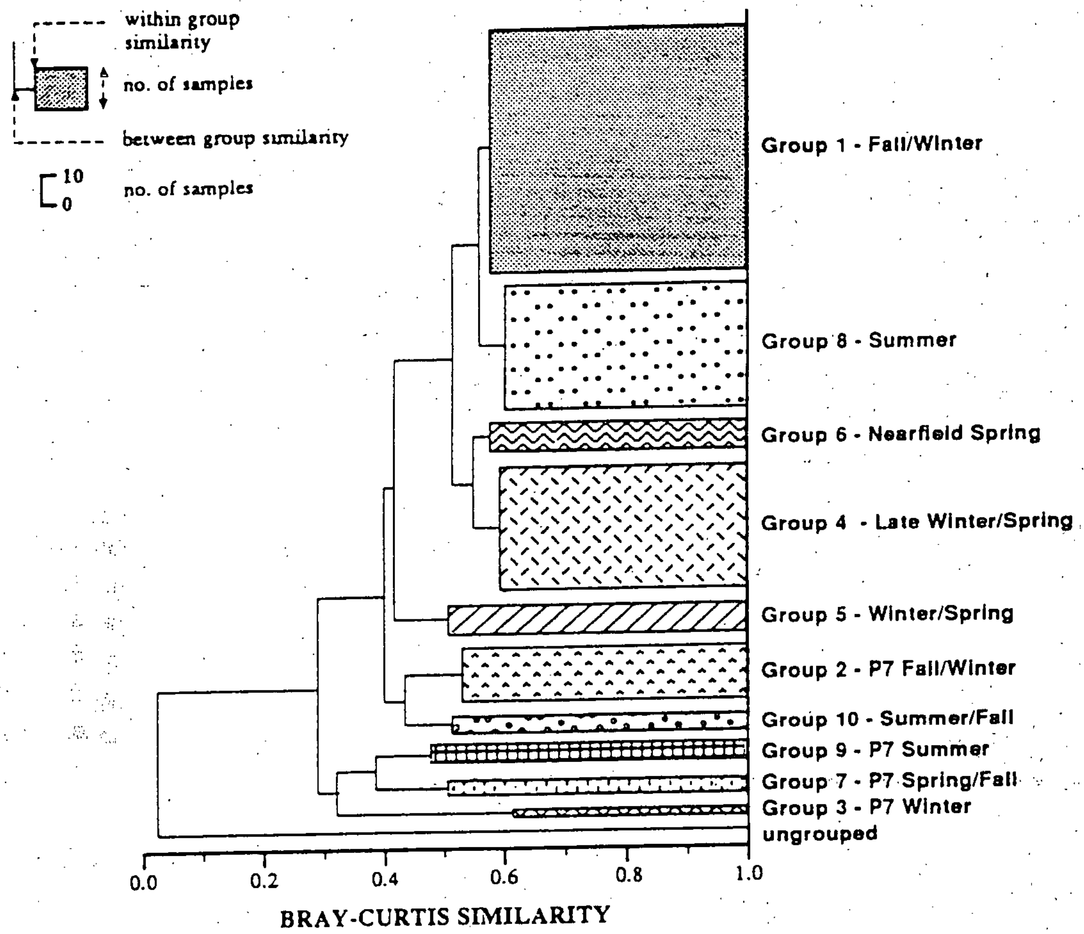
(MANOVA testing Preop-Op X Station, p=0.97) indicating a broad scale trend. Increases of holo- and meroplankton in the operational period could be attributed to a number of environmental factors such as changes in temperature, reduced abundances of ichthyoplankton predators and recruitment of macrozooplankton from other areas (Meise-Munns et al 1990; Kane 1993). Small but significant broadscale increases in temperature have been detected in the operational period, primarily 1991 and 1992 (Section 2.3.1). The abundance of ichthyoplankton, which feed on macrozooplankton, has declined in the operational period (Section 5.3.1). Copepod abundance in the Gulf of Maine has been increasing (Jossi and Goulet 1993) and New Hampshire coastal waters may be experiencing some of this increase. *Calanus finmarchicus* was reported to have exhibited an increasing trend in the Northwest Atlantic over the past 30 years (Sherman 1991). Jossi (1991) reported that total copepod abundances in the Gulf of Maine were higher in 1990 than in the previous decade.

Previous analyses have suggested that there are no spatial differences in holo- and meroplanktonic assemblages in the study area (NAI 1991b). The geography of coastal New England helps to create the hydrographic conditions of the Gulf of Maine. There are no major land barriers between the Bay of Fundy and Cape Cod that would divert coastal currents offshore, although several embayments can affect local conditions. This condition promotes a circulation pattern that allows widespread dispersal of planktonic organisms, particularly holoplankton and those meroplanktonic species with extended larval existence. The distances among Stations P2, P5 and P7 are small relative to the area from which holo- and meroplanktonic organisms could be recruited (via current transport) to coastal New Hampshire.

Numerical classification of holo- and meroplanktonic abundances in 1988-1993 revealed no spatial differences in community composition among Stations P2, P5 and P7 (Figure 4-8). Collections from all stations were grouped together within each month. Although species composition was similar among stations, differences in individual species abundances were detected by MANOVA (p=0.0001). For those species, abundances were generally higher at nearfield stations. This was the case for *Calanus finmarchicus* (see also Sec. 4.3.3.2) and *Temora longicornis*, the two numerically dominant taxa from 1988-1993. Differences could be related to spatial differences in water quality parameters or phytoplankton abundance. Temperature, for example, was higher in the nearfield area than farfield in both near-surface and near-bottom waters and dissolved oxygen was higher in near-bottom waters, while bottom salinity was higher in the farfield waters (Section 2.3.1). The larger sized phytoplankton (>10 μm), the major food source for many zooplankton, have been more abundant in the nearfield area (Section 3.3.1.1).

The Tychoplankton Assemblage

Seasonal variation in the tychoplankton species composition was influenced mostly by the nearly omnipresent dominant taxa *Neomysis americana*, Oedicerotidae and *Pontogeneia inermis* and by the seasonally dominant *Mysis mixta* (Figure 4-9; Table 4-10). Three seasonal groups encompassed 76% of the collections of the tychoplankton (93% of P2 and P5 collections). High abundances of *N. americana* dominated fall and winter collections (Group 1). *M. mixta* replaced *N. americana* as the overwhelming dominant in late winter and early spring (Group 4). A transition period between spring and summer assemblages typically occurred in May and June. This period coincides with the offshore migration of *M. mixta* juveniles, which has been linked to surface water temperatures approaching 12°C and the onset of thermal stratification (Grabe and Hatch 1982). This period was characterized by two communities; one dominated by low abundances of *M. mixta* (Group 5), the other by moderate numbers of *P. inermis*, *Ischyrocerus anguipes* and *N. americana* (Group 6) at the nearfield Stations P2 and P5. Community composition at P7



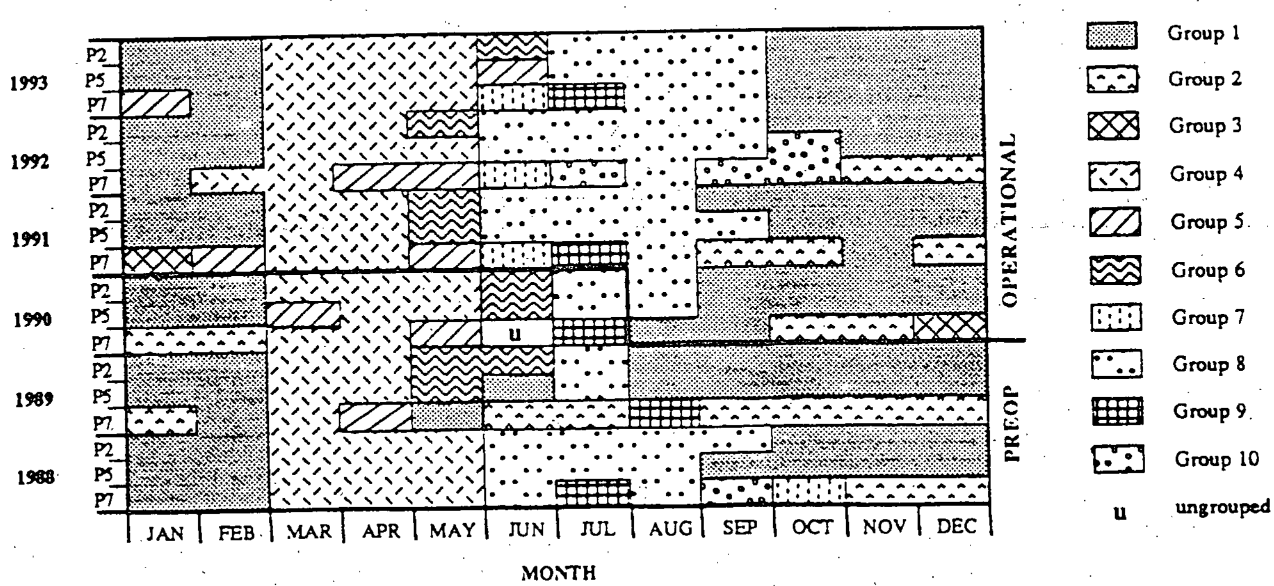


Figure 4-9. Dendrogram and seasonal groups formed by numerical classification of mean monthly log (x+1) transformed abundances (no./1000 m^3) of **tychoplanktonic species** of macrozooplankton at intake Station P2, discharge Station P5 and farield Station P7, 1988-1993. Seabrook Operational Report, 1993.

TABLE 4-10. GEOMETRIC MEAN ABUNDANCE (No./1000m^3) AND 95% CONFIDENCE LIMITS OF DOMINANT TYCHOPLANKTONIC TAXA OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF MACROZOOPLANKTON COLLECTIONS (MONTHLY MEANS) AT INTAKE STATION P2, DISCHARGE STATION P5 AND FARFIELD STATION P7, 1988-1993. SEABROOK OPERATIONAL REPORT, 1993.

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		n	LCL	$\bar{x}$	UCL	n	LCL	$\bar{x}$	UCL
1 Fall/Winter (0.59/0.58)	*Neomysis americana*	34	107.6	230	491.1	46	146.4	219	326.6
	Pontogeneia inermis		17.9	28	42.9		23.4	37	59.3
	Diastylis sp.		14.0	25	42.9		21.3	31	43.6
	Oedicerotidae		9.7	16	25.4		13.4	19	26.8
2 P7 Fall/Winter (0.53/0.44)	*Neomysis americana*	11	55.9	145	375.9	7	19.8	64	203.8
	Oedicerotidae		1.4	6	18.8		1.1	4	11.2
3 P7 Winter (0.62/0.33)	*Diastylis* sp			not represented		2	0.0	2	109.6
	Erythrops erythrophthalma						0.6	2	3.5
	Oedicerotidae						0.9	1	1.3
	Neomysis americana						0.0	1	14.4
	Hyperiidae						0.0	1	12.3
4 Late Winter/Spring (0.59/0.57)	*Mysis mixta*	21	282.7	989	3451.8	22	354.3	863	2101.7
5 Winter/Spring (0.51/0.42)	*Mysis mixta*	3	0.0	8	241.9	6	2.5	12	50.1
	Pontogeneia inermis		1.1	4	11.7		1.9	5	10.0
	Harpacticoida		0.0	2	20.5		0.2	3	10.0
	Diastylis sp.		0.6	2	4.8		0.6	3	8.5
	Ischyrocerus anguipes		0.5	2	3.9		0.1	2	6.9
	Oedicerotidae		0.0	2	165.2		0.0	1	6.3
	Neomysis americana		0.0	1	12.0		1.6	5	12.1

(continued)

TABLE 4-10. (Continued)

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		n	LCL	$\bar{x}$	UCL	n	LCL	$\bar{x}$	UCL
6 Nearfield Spring (0.59/0.57)	*Neomysis americana*	5	21.4	153	1060.8	4	0.1	15	219.8
	Pontogeneia inermis		6.5	116	1834.1		5.0	120	2420.5
	Ischyrocerus anguipes		3.8	16	61.7		62.7	132	276.1
	Mysis mixta		0.9	7	57.9		0.3	63	3197.2
	Diastylis sp.		2.2	12	54.7		5.3	22	84.2
7 P7 Spring/Fall (0.51/0.39)	*Neomysis americana*	1	--	4	--	3	1.6	3	5.4
	Gammarus lawrencianus		--	1	--		0.0	<1	1.2
	Oedicerotidae		--	1	--		0.4	1	3.2
	Harpacticoida		--	<1	--		0.0	2	17.5
	Pontogeneia inermis		--	0	--		0.0	2	12.6
	Ischyrocerus anguipes		--	0	--		0.3	1	3.5
	Corophium sp.		--	0	--		0.0	1	29.5
8 Summer (0.61/0.58)	Oedicerotidae	13	111.8	324	934.1	27	80.6	200	494.0
	Pontogeneia inermis		76.5	140	257.3		34.5	67	127.4
	Harpacticoida		18.2	44	105.0		72.6	123	208.5
	Neomysis americana		10.5	41	153.3		27.0	55	112.7
9 P7 Summer (0.48/0.39)	Harpacticoida	3	1.2	5	17.9	2	0.0	6	1961.5
	Oedicerotidae		0.0	4	53.4		0.0	23	$1.0x10^9$
	Calliopius laeviusculus		0.0	1	16.8		0.0	<1	78.7
	Pontogeneia inermis		0.0	1	8.3		0.0	1	620.1
10 Summer/Fall (0.52/0.44)	*Pontogeneia inermis*	1	--	6	--	4	0.0	4	34.9
	Hyperiidae		--	6	--		16.9	121	827.0
	Harpacticoida		--	3	--		0.8	10	70.3
	Neomysis americana		--	3	--		0.8	20	236.1
	Calliopius laeviusculus		--	1	--		0.2	2	5.6
	Oedicerotidae		--	0	--		0.0	9	526.7

[a](within-group similarity/between group similarity)
[b]those taxa contributing ≥5% of total group abundance in either preoperational or operational periods
[c]preoperational period = January 1988-July 1990; operational period = August 1990-December 1993

was highly variable during this period. Oedicerotidae became the dominant taxon in summer collections. Harpacticoida, *P. inermis* and *N. americana* were also abundant in summer (Group 8). Episodes of low tychoplankton abundance, particularly at Station P7 from June to October resulted in the formation of several small groups (Groups 7, 9 and 10) represented by diverse amphipod assemblages. Tychoplankton were also present in very low numbers in December 1990 and January 1991 (Group 3). Moderate abundances of *N. americana* and reduced abundances of amphipods and the cumacean *Diastylis* sp. formed a fall and early winter group unique to Station P7 (Group 2) which was concurrent with the dominance by *N. americana* at the nearfield stations.

Nearfield collections in 1993 followed the same pattern as observed in the recent preoperational years (Figure 4-9; Table 4-10). At Station P7, 1993 seasonal assemblages were generally typical of those observed during the preoperational period except during the fall, when higher than average abundances of *Diastylis* sp. and *Pontogeneia inermis* (NAI 1994) caused the Station P7 collections to be grouped with nearfield collections.

Seasonal patterns of the tychoplankton assemblage were similar between Stations P2 and P5 during preoperational and operational periods throughout most of the year (Figure 4-9). There was little consistency among years at Station P7, partially an artifact of the relatively low abundances at this station. MANOVA results indicated that differences in abundance between preoperational (1988-1989) and operational (1991-1993) periods existed (p=0.0001), with abundances higher during operational years than in recent preoperational years. This shift occurred in both nearfield and farfield stations (Figure 4-9; Preop-Op X Station, p=0.78), indicating a broadscale trend.

Differences between the nearfield and farfield areas in tychoplankton assemblages from 1988 through 1993 were apparent from numerical classification. Collections from Stations P2 and P5 were usually grouped together (92% of collections, Figure 4-9). The assemblage at Station P7 was distinct from that at the nearfield stations in 60% of the collections. Despite the differences at Station P7, farfield communities parallelled the nearfield progression of dominant taxa from *Neomysis americana* in the fall and winter (Groups 1,2) to *Mysis mixta* in the spring (Groups 4,5) to the amphipods in summer (Groups 8,9,10). The greatest similarity between nearfield and farfield stations occurred during the *Mysis mixta* peak in March and April and again in August when amphipods dominated. Although Station P7 generally exhibited similar seasonal patterns to Stations P2 and P5, abundances of dominant taxa, particularly *Pontogeneia inermis* and Oedicerotidae, were lower, resulting in the formation of four groups (2,3,7, and 9) composed solely of farfield collections. Results of numerical classification were substantiated by MANOVA, which indicated that there were significant differences among stations in species composition (p=0.0001). Tychoplanktonic species are often strongly associated with particular substrate types. Substrate type and complexity, along with proximity to Hampton-Seabrook estuary, may account for some of the differences observed among tychoplankters. *Neomysis americana, Pontogeneia inermis*, and Oedicerotidae have higher abundances in the heterogeneous sand and rock ledge substrate in the nearfield area than at Station P7, where the substrate is mainly sand.

4.3.3.2 Selected Species

Calanus finmarchicus

As in previous years, *Calanus finmarchicus*, particularly the copepodite lifestage, was a dominant macrozooplankton species, as observed in the community assessment (Table 4-9). Both copepodites and adults are usually present throughout the year. Average monthly copepodite abundances at Station P2 have historically exhibited a broad spring-to-fall peak (Figure 4-10). Operational and 1993 abundances followed a similar pattern, with slightly more exag-

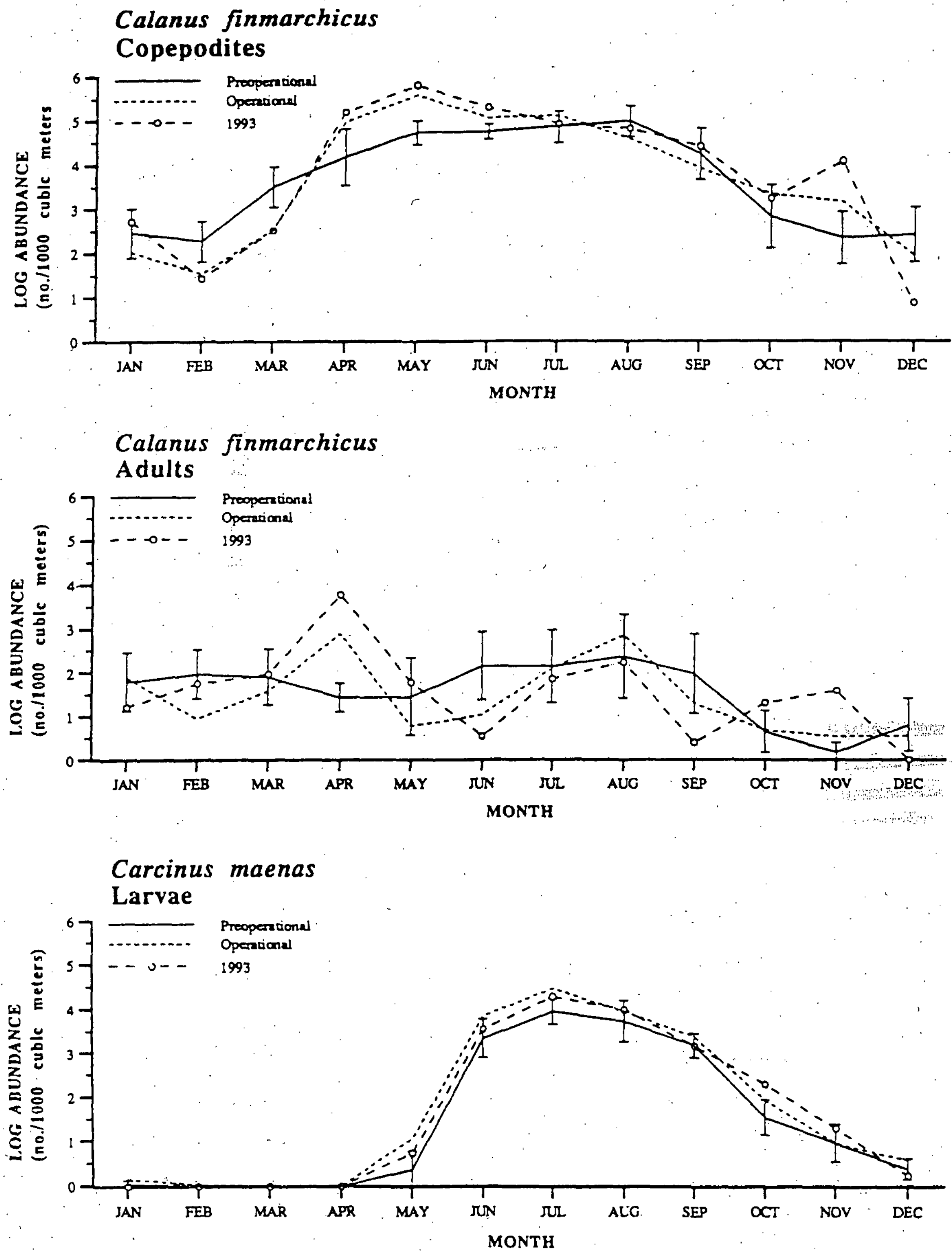


Figure 4-10. Log (x+1) abundance (no./1000 m^3) of *Calanus finmarchicus* copepodites and adults and *Carcinus maenas* larvae; monthly means and 95% confidence intervals over all preoperational years (1978-1984, 1986-1989) and monthly means for the operational period (1991-1993) and 1993 at intake Station P2. Seabrook Operational Report, 1993.

gerated seasonal extremes. Operational or 1993 monthly mean copepodite abundances exceeded the upper 95% confidence limit of preoperational means in April, May, June, and November, and were less than the lower 95% confidence limit of preoperational means during February, March and December (Figure 4-10).

Copepodite mean abundance was significantly higher during the operational period than the preoperational period (Tables 4-11, 4-12). In recent years (1987-1989 and 1991-1993), average abundances at Stations P2 and P5 have been similar (Table 4-12). Average abundances at Station P5 were significantly greater than at Station P7. Average abundances at Station P2 were not significantly different from Station P7. These differences have been consistent regardless of operational status, as indicated by the nonsignificant interaction term (Table 4-12), and do not indicate any effect due to plant operation. Significant differences were also noted among years and months.

Adult copepod abundance does not show as clear a seasonal pattern as the copepodites (Figure 4-10). Monthly mean adult abundances in 1993 were highest in April and lowest in June. Monthly mean adult abundances during the operational period exceeded the upper 95% confidence interval of preoperational monthly means in April and November, and were less than the lower 95% confidence interval of preoperational monthly means in February and June.

Mean adult abundances at Stations P2 and P7 declined slightly between the preoperational period (all years) and the operational period, while abundances at Station P5 increased slightly (Table 4-11). Average adult abundance at Station P5 and Station P2 were not significantly different. Average abundances at Station P5 were significantly different from Station P7. Abundances at Station P2 and P7 were not significantly different from each other (Table 4-12). Average adult abundances have not changed significantly between the recent (1987-1989) preoperational period and the operational period (Table 4-12). Abundances differed significantly among years, months and stations, but this was not related to the operation of Seabrook Station, as indicated by the nonsignificant interaction term (Table 4-12).

Carcinus maenas

As in previous years, monthly mean abundances of larvae of the green crab *Carcinus maenas* in 1993 show a strong seasonal pattern at Station P2, with peak abundances occurring during the late spring through early fall (Figure 4-10). The timing and abundance of green crab larvae were very similar during both the preoperational and operational periods, although operational monthly mean abundances exceeded the upper 95% confidence limit of preoperational means in May, June, and July.

Over all preoperational years and operational years, average peak period abundances have been similar at both nearfield and farfield stations (Table 4-12), and have increased between preoperational and operational periods (Table 4-11). This increase, however, was not significant, and there is no indication of any effect due to plant operation based on the nonsignificant interaction term (Table 4-12). Significant differences were noted among months.

Crangon septemspinosa

As in previous years, monthly mean abundances of the zoeae and post-larvae of sand shrimp, *Crangon septemspinosa*, in 1993 showed a peak over a broad period between late spring and early fall (Figure 4-11). Operational monthly means were higher than the upper 95% confidence limit of preoperational means in March, April and May. In September, however, the operational mean abundance was lower than the 95% confidence limit of the preoperational mean (Figure 4-11).

TABLE 4-11. GEOMETRIC MEAN ABUNDANCE (No./1000 m^3) AND COEFFICIENT OF VARIATION OF SELECTED MACROZOOPLANKTON SPECIES AT STATIONS P2, P5, AND P7 DURING PREOPERATIONAL AND OPERATIONAL YEARS (1991-1993), AND 1993. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES/LIFESTAGE (peak period)	STATION	PREOPERATIONAL $\bar{x}$[a]	PREOPERATIONAL CV	OPERATIONAL $\bar{x}$[b]	OPERATIONAL CV	1993 $\bar{x}$
Calanus finmarchicus	P2	4,153	6.39	4,324	3.54	5,747
copepodites	P5	5,713	6.99	5,605	2.93	5,887
(January-December)	P7	2,594	7.19	2,810	3.70	3,591
Calanus finmarchicus	P2	36	26.52	26	7.61	33
adults	P5	26	28.88	35	10.25	53
(January-December)	P7	29	28.96	15	6.90	17
Carcinus maenas	P2	3,506	6.72	8,030	3.59	5,548
larvae	P5	3,613	12.91	8,552	4.64	5,279
(June-September)	P7	4,245	6.24	4,593	8.19	2,617
Crangon septemspinosa	P2	212	7.95	269	5.66	200
zoeae and postlarvae	P5	170	7.24	264	3.29	295
(January-December)	P7	159	10.25	110	5.27	110
Neomysis americana	P2	151	18.94	153	7.76	114
all lifestages	P5	45	30.73	44	11.37	48
(January-December)	P7	43	22.03	17	11.94	15

[a]Years sampled:
Preoperational: P2 = 1978-1984, 1987-1989
P5 = 1987-1989
P7 = 1982-1984, 1987-1989
Mean of annual means
[b]Mean of annual means, 1991, 1992 and 1993

TABLE 4-12. RESULTS OF ANALYSIS OF VARIANCE COMPARING ABUNDANCES OF SELECTED MACROZOOPLANKTON SPECIES FROM STATIONS P2, P5, AND P7 DURING PREOPERATIONAL (1987-1989) AND OPERATIONAL (1991-1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES[a]	SOURCE[b]	d.f.	MS	F	MULTIPLE COMPARISONS[h]
Calanus finmarchicus copepodites (January-December)	Preop-Op[c]	1	3.67	7.76**	Op>Preop
	Year (Preop-Op)[d]	4	1.43	3.03*	
	Month (Year)[e]	66	11.39	24.11***	
	Station[f]	2	2.28	4.82**	P5 P2 P7
	Preop-Op X Station[g]	2	0.10	0.20 NS	
	Error	356	0.47		
Calanus finmarchicus adults (January-December)	Preop-Op	1	2.14	2.36 NS	
	Year (Preop-Op)	4	4.17	4.60**	
	Month (Year)	66	6.97	7.70***	
	Station	2	2.87	3.17*	P5 P2 P7
	Preop X Station	2	0.25	0.28 NS	
	Error	356	0.91		
Carcinus maenas larvae (June-September)	Preop-Op	1	1.38	2.08 NS	
	Year (Preop-Op)	4	0.61	0.92 NS	
	Month (Year)	18	1.92	2.89***	
	Station	2	0.54	0.81 NS	
	Preop X Station	2	0.14	0.21 NS	
	Error	116	0.66		
Crangon septemspinosa zoeae and post larvae (January-December)	Preop-Op	1	0.08	0.25 NS	
	Year (Preop-Op)	4	0.71	2.28 NS	
	Month (Year)	66	8.66	27.78***	
	Station	2	5.08	16.30***	P2 P5>P7
	Preop X Station	2	0.34	1.08 NS	
	Error	356	0.31		
Neomysis americana all lifestages (January-December)	Preop-Op	1	2.21	3.81 NS	
	Year (Preop-Op)	4	8.11	13.97***	
	Month (Year)	66	2.69	4.64***	
	Station	2	31.28	53.91***	P2> P5>P7
	Preop X Station	2	0.01	0.01 NS	
	Error	356	0.58		

[a]Based on twice monthly sampling periods. [b]Commercial operation began in August 1990; 1990 data left out of analysis to keep a balanced design in the ANOVA procedure. [c]Preoperational (1987-1989) versus operational (1991-1993) periods, regardless of station; 1987-1989 reflects the period of time that all three stations were sampled coincidentally. [d]Year nested within preoperational and operational periods, regardless of station. [e]Month nested within year, regardless of station. [f]Station P2 vs. station P5 vs. station P7, regardless of year. [g]Interaction between main effects.

NS = Not significant ($p > 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

[h]Ranked in decreasing order. Underlines indicate no significant difference in least-squares means ($\alpha \leq .05$).

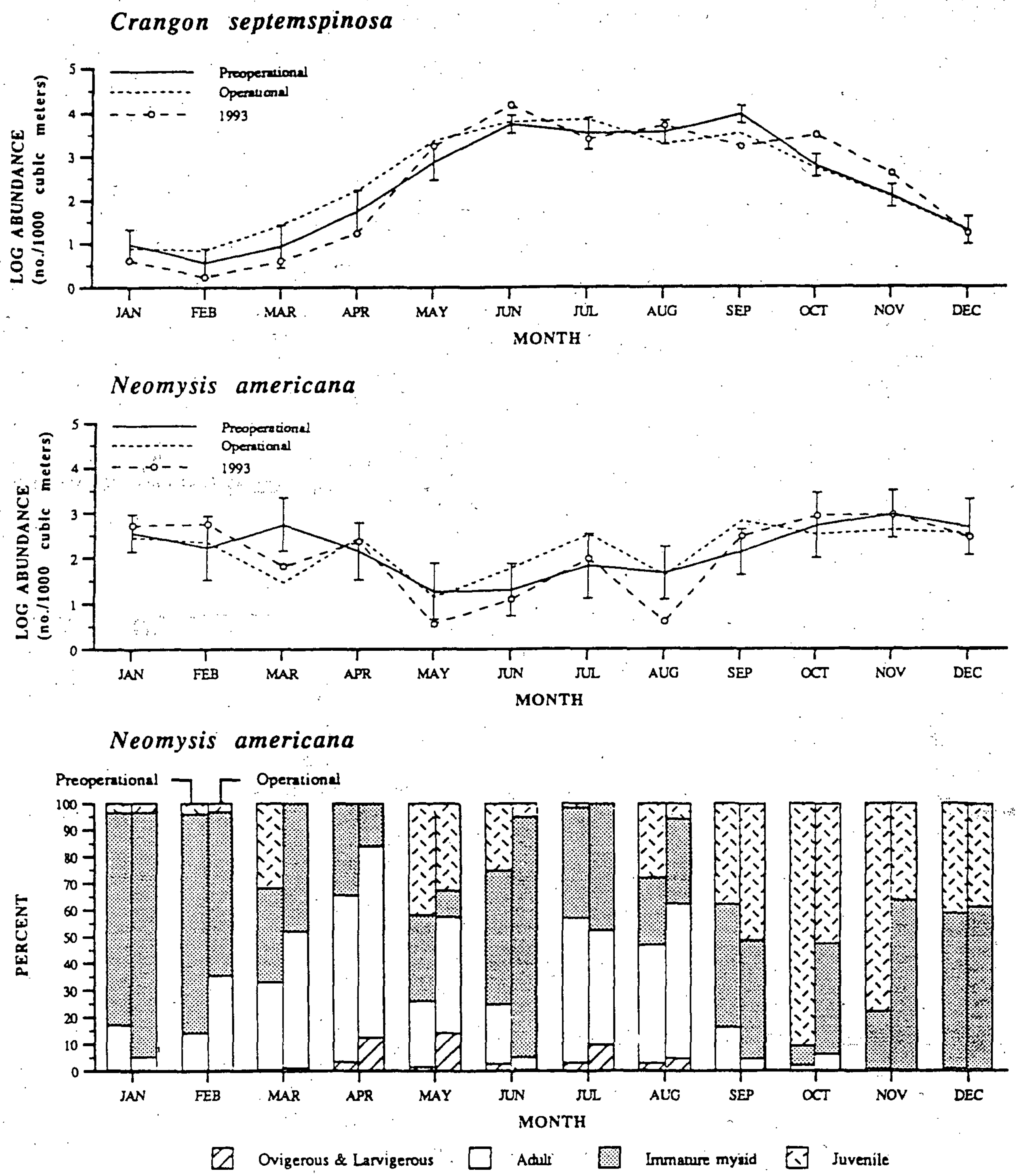


Figure 4-11. Log (x+1) abundance (no./1000 m³) of *Crangon septemspinosa* (zoea and post larvae) and *Neomysis americana* (all lifestages); monthly means and 95% confidence intervals over all preoperational years (1978-1984, 1986-1989) and monthly means for the operational period (1991-1993) and 1993; and mean percent composition of *Neomysis americana* lifestages over all preoperational years (1978-1984, 1986-1989) and for the operational period (1991-1993) at intake Station P2. Seabrook Operational Report, 1993.

Abundances have increased slightly between the preoperational (all years) and operational periods at Stations P2 and P5, and have decreased slightly at Station P7 (Table 4-11). At all three stations, however, abundances have shown no significant difference over the recent preoperational period (1987-1993)(Table 4-12). Regardless of operational status, abundances have been similar between Stations P2 and P5, yet significantly greater than abundances at Station P7 (Table 4-12). The absence of a significant interaction term indicates that there was no effect due to plant operation. Abundances showed significant differences among months.

Neomysis americana

For the combined lifestages of *Neomysis americana* (ovigerous and larvigerous females, adults, immature mysids, and juveniles), monthly mean abundances at Station P2 during both the preoperational and operational periods showed no consistent seasonal pattern, although there is a tendency towards lower abundances in the summer (Figure 4-11). Abundances averaged over all months at Stations P2, P5 and P7 have also remained stable between the preoperational and operational periods, and there have been no significant preoperational-operational differences observed at all three stations combined (Table 4-12). During both the recent preoperational period and the operational period, abundances of all life stages combined have been significantly higher at Station P2 than at either Station P5 or P7. Abundances of all life stages combined were also significantly higher at Station P5 than at Station P7 (Table 4-12).

Although the abundance of the combined lifestages changed relatively little throughout the year, the individual lifestages showed strong seasonal patterns of occurrence (Figure 4-11). During both the preoperational and operational periods, immature mysids (sexual organs differentiated but not fully developed) were the most common lifestage during January and February. The decline in the relative abundance of immature mysids during the early spring was paralleled by an increase in the relative abundance of adults. By May, juveniles (sexual organs absent or not differentiated) were also abundant. During May, there was a higher percentage of adults, ovigerous and larvigerous *Neomysis* during the operational period than during the preoperational period. The opposite was true for juveniles and immature mysids. Differences between the two periods were also seen in other months, particularly in June, October, and November, but this was not related to the operation of Seabrook Station, as shown by the nonsignificant interaction term (Table 4-12).

During the remainder of the year, percent composition of the lifestages was similar between the two periods. Adults and immatures were the most common lifestages during July and August. Juveniles increased between September and October, when they were the dominant lifestage. Juveniles began to decline during November and December, at which time immature mysids accounted for an increasing proportion of the total.

4.4 DISCUSSION

4.4.1 Community

Microzooplankton

Seasonal patterns of the natural assemblage of microzooplankton have historically been dominated by the population dynamics of the copepods *Oithona* sp. and *Pseudocalanus* sp. and the production of early lifestages (nauplius larvae) of other copepods that were present year-round. Seasonally, other taxa such as polychaete larvae, bivalve larvae and tintinnids influenced community structure. Since Seabrook Station began commercial operation, species composition continued to resemble the historical patterns (Table 4-13). Although abundances of some taxa were dif-

TABLE 4-13. SUMMARY OF POTENTIAL EFFECTS (BASED ON NUMERICAL CLASSIFICATION AND MANOVA RESULTS) OF OPERATION OF SEABROOK STATION INTAKE ON THE INDIGENOUS ZOOPLANKTON COMMUNITIES. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
MICROZOOPLANKTON		
Community Structure	yes[a]	yes
Abundances	no, variable among taxa[b]	yes
BIVALVE LARVAE		
Community structure	yes[a]	yes
Abundances	Op>Preop[b,c]	yes
MACROZOOPLANKTON		
Holo/meroplankton		
Seasonal occurrence	yes, except for winter 1993[a]	yes
Abundances	Op>Preop (most dominant taxa)[c]	yes
Tychoplankton		
Seasonal occurrence	yes	yes
Abundances	Op>Preop[c]	yes

[a]Based on results of numerical classification
[b]Based on comparisons of group mean abundances
[c]Based on MANOVA results

ferent between the preoperational and operational periods, the differences were usually consistent among the nearfield and farfield stations. Since the differences occurred areawide, they were not due to the operation of Seabrook Station.

Bivalve Larvae

Varying abundances of *Hiatella* sp., *Mytilus edulis* and *Anomia squamula* defined most seasonal groups identified by the community analysis. The species composition during the operational period was similar to previous years according to numerical classification techniques (Table 4-13). Community structure, according to MANOVA results, was not significantly different among nearfield and farfield stations throughout the study period. However, community structure during the operational period at all three stations (combined) was significantly different than the recent preoperational period (1988-89), due to higher abundances of almost all taxa during the operational period (Table 4-5). Entrainment into the circulating water system of Seabrook Station is not suspected to have affected bivalve larvae abundance.

Entrainment

The focus of monitoring plankton in the intake area was to evaluate the effect of entrainment of organisms by the circulating water system (CWS) on community structure and population levels in the nearfield area. Due to the limited control of their horizontal movements and often broad vertical distribution in the water column, most types of planktonic organisms could be exposed to entrainment. Estimates of total monthly levels of entrainment were computed (Table 4-8) to quantify losses of bivalve larvae. Community structure and abundances of selected species in the nearfield area during commercial operation were compared to historical conditions and to farfield conditions. These comparisons addressed the question of whether the balanced, indigenous planktonic populations within the study area have been affected by the plant intake during the commercial operation to date.

Although Seabrook Station operated its circulating water system at varying levels since 1985, no power or heated discharge were produced until August of 1990. Entrainment collections provide a measure of the actual number of organisms directly affected by plant entrainment. Three taxa, *Mytilus edulis* (blue mussel), *Anomia squamula* and *Hiatella* sp., accounted for more than 85% of the bivalve larvae entrained each year (Figure 4-7). *Modiolus modiolus* was intermittently entrained during 1990 and 1991 (NAI 1991b, NAI 1992) and was common in August and September 1993 (Table 4-8). Monthly entrainment of all taxa was less in 1991 and 1992 in comparison to 1990 and 1993 (Figure 4-7). Reduced CWS flows during outage periods in summer when larvae typically reach their peak abundance levels in local coastal waters led to reduced entrainment in 1991 and 1992. Furthermore, abundances of *M. edulis* larvae observed in local coastal waters (P2, P5, P7) in 1991 and 1992 were reduced when compared to 1990 and 1993 abundances, which contributed to lower entrainment levels.

Holo- and Meroplanktonic Macrozooplankton

The holo- and meroplanktonic component of the macroplankton community in the study area was similar to the other portions of the Gulf of Maine (Sherman 1966). In the study area, copepods predominate. The dominant species in the study area, *Calanus finmarchicus*, *Centropages typicus*, *Pseudocalanus* sp. and *Temora longicornis* were the dominant copepods in the Gulf of Maine and nearby Scotian Shelf and Georges Bank, occurring in a seasonal pattern similar to the study area (Anderson 1990, Kane 1993, Sameoto and Herman 1992, Tremblay and Roff 1983). The seasonal occurrence of the other groups was also similar to other observations in the Gulf of Maine (Sherman 1966).

The seasonal change in the holo- and meroplankton community composition at both nearfield and farfield stations was consistent during the past six years. Consistent seasonal changes were observed at Station P2 (nearfield) from 1978 through 1984 and from 1986 through 1990. In the recent preoperational and operational periods, community composition exhibited the greatest variation between years during the period February through April. This period corresponds to the lowest annual temperatures and the period of greatest variability in salinity in the study area (Section 2.3.1).

The community variation in February through April is probably due to combined regional water temperature and salinity effects. Winter water temperatures may be a controlling variable in the composition of the holo- and meroplankton communities. Winter water temperatures approach threshold limits for some species and small differences from year to year may have significant effects on community composition during this period. The occurrence of *Centropages typicus* has been associated with surface water temperatures of 2.2 to 26.6 °C (Grant 1988). Water temperatures in 1993 fell below 2.2 °C for an extended period (Section 2.3.1). These lower than normal water temperatures in 1993 may have reduced the population of *C. typicus* resulting in the occurrence of an anomalous group that was characterized by its usual co-dominants. Studies have shown both the timing and the magnitude of the spring copepod bloom may be related to water temperature. In the presence of high phytoplankton abundance, cold water temperatures can delay the initiation of egg production and reduce the quantity of eggs produced by *Calanus finmarchicus* (Plourde and Runge 1988). Low temperatures can also reduce growth rates and delay the development of larger copepodites (Anderson 1990). Salinity during the spring bloom may also have accounted for some of the variability in community composition. High variability in salinity among years can be caused by meteorological events. Storms can increase run-off and reduce salinity and can also cause mixing between lower salinity coastal water masses and shelf water masses.

Abundance of many holo- and meroplankton species was higher during the operational period than the recent (1988-1989) preoperational years (Table 4-13). Thirteen of the 50 macrozooplankton taxa, including two seasonal dominants, experienced order of magnitude changes from the preoperational to the operational periods. An additional three taxa, including two seasonal dominants had large increases in abundance. Interannual variations of orders of magnitude are common among copepods on Georges Bank (Kane 1993). Jossi and Goulet (1993) suggested that there has been a possible general increase in copepod abundance from 1961 through 1989 for the entire Gulf of Maine. *Calanus finmarchicus* increased in abundance in all regions except the extreme western portion of the Gulf of Maine, which includes coastal New Hampshire.

Although holo- and meroplanktonic community structure was qualitatively similar among Stations P2, P5, and P7, quantitative examination of abundances indicated that spatial differences occurred, and in fact, persisted from preoperational through operational periods (as evidenced by the MANOVA's significant station term and insignificant interaction term). Specific differences were not clearcut. Fewer than 20% of the 50 taxa examined exhibited significant station differences. Differences may be related to water quality characteristics (Section 2.0). Temperature and bottom dissolved oxygen have been higher in the nearfield (P2 and P5) while bottom salinity has been higher in the farfield (P7) (Section 2.0). The proximity of Stations P2 and P5 to Hampton Harbor may partially account for water quality patterns.

Tychoplanktonic Macrozooplankton

The tychoplantonic community, composed of species that inhabit both the substrate and the water column, exhibited greater spatial variability than the holo- and meroplanktonic community. Excursions into the plankton can be related to such factors as light, lunar cycle, storm events, reproduction and nonspecific aggregation (Mauchline 1980). These factors can influence apparent abundance dramatically.

Seasonal changes in species composition were similar between preoperational and operational years, except during the fall at Station P7 in 1993. Fall community composition at Station P7 has generally varied considerably from year to year, generally due to low abundances found there. Increased abundance of *Pontogeneia inermis* and *Diastylis* sp. (NAI 1994) account for the differences in 1993.

Substrate differences between nearfield and farfield sites may be responsible for differences in tychoplankton abundance between the sites. Tychoplankton species such as mysids (Wigley and Burns 1971; Pezzak and Cory 1979; Mauer and Wigley 1982), amphipods (Bousfield 1973) and cumaceans (Watling 1979) have substrate preferences. A relatively homogeneous substrate of sand exists at the farfield area. Rock ledges are few and generally not near the farfield station. In contrast, the nearfield substrate is heterogeneous. Station P2 is sand and hard sand with numerous nearby rock ledges. Station P5 is sand and rock ledge with considerable amounts of algae. The heterogeneous nature of the nearfield station may have increased the abundance of various tychoplankton by supplying more diverse habitat. Many amphipods such as *Pontogeneia inermis* are associated with submerged plants and algae. Higher concentrations of macroalgae in the nearfield area may provide additional habitat for some amphipods and increase their abundance. Differences in tychoplankton abundance between the nearfield and farfield areas may be due to differences in habitat and not to the operation of Seabrook Station.

While both temporal and spatial differences have been observed in various components of the macrozooplankton community, these differences have been consistent. Although abundances of a number of species have differed between the preoperational and operational periods, similar changes have occurred at nearfield and farfield locations. Other species, particularly tychoplankton, have exhibited spatial patterns that have been consistent from preoperational to operational periods. The long-term consistency in distribution indicates that operation of Seabrook Station's cooling water system has not affected the macrozooplankton community.

4.4.2 Selected Species

Microzooplankton

Patterns of seasonal variation recorded during operational years (1991-1993) for the selected microzooplankton species were generally similar to patterns observed during the preoperational period at nearfield Station P2 (Figures 4-3, 4-4). ANOVAs detected significantly lower operational mean densities for *Eurytemora* sp. copepodites, *Eurytemora* sp. adults and *Pseudocalanus/Calanus* sp. nauplii, and significantly higher abundances of *Oithona* sp. copepodites and adults during station operation. In no case, however was the interaction (Preop-Op X Area) term significant, indicating that the operational differences were observed at both nearfield and farfield stations and therefore could not be attributed to a plant effect (Table 4-14).

Bivalve Larvae

Umboned larvae of *Mytilus edulis*, have been generally present in the water column during all months sampled, but were most abundant from June through August. Their protracted presence was probably due to spawning patterns and the duration of larvae life. In Long Island Sound, spawning occurred over a two-to-three month period and was asynchronous among local populations (Fell and Balsamo 1985). Larval development requires three to five weeks (Bayne 1976), and metamorphosis can be delayed up to 40 days until

TABLE 4-14. SUMMARY OF POTENTIAL EFFECTS (BASED ON ANOVA RESULTS) OF OPERATION OF SEABROOK STATION INTAKE ON ABUNDANCES OF SELECTED INDIGENOUS ZOOPLANKTON SPECIES. SEABROOK OPERATIONAL REPORT, 1993.

PLANKTON SELECTED SPECIES AND LIFESTAGES	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL[a] PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
MICROZOOPLANKTON		
Eurytemora sp. copepodites	Op<Preop	yes
E. herdmani adults	Op<Preop	yes
Pseudocalanus/Calanus nauplii	Op<Preop	yes
Pseudocalanus sp. copepodites	yes	yes
adults	yes	yes
Oithona sp. nauplii	yes	yes
copepodites	Op>Preop	yes
adults	Op>Preop	yes
BIVALVE LARVAE		
Mytilus edulis larvae	Op>Preop	yes
MACROZOOPLANKTON		
Calanus finmarchicus		
copepodites	no	yes
adults	yes	yes
Crangon septemspinosa larvae	yes	yes
Carcinus maenas larvae	yes	yes
Neomysis americana	yes	yes

[a]recent preoperational years: 1982-1984 for microzooplankton, 1988-1989 for bivalve larvae and macrozooplankton

suitable settling conditions are encountered (Bayne 1965). The seasonal pattern of *M. edulis* larvae in the operational period was similar to recent preoperational years. *M. edulis* larvae were significantly more abundant during the operational period than the recent preoperational period, at all three stations (combined), primarily due to increased abundances in most sampling periods from late June through October in 1993 (Figure 4-6). These differences occurred at both the farfield and nearfield stations and it is unlikely that the operation of Seabrook Station was a factor (Table 4-14).

Macrozooplankton

There has essentially been no change in the abundances or seasonality in most of the macrozooplankton selected species. With the exception of *Calanus finmarchicus* copepodites, average abundances of all selected species during the operational period were not significantly different from the recent preoperational period (Table 4-14). One species, *Neomysis americana*, showed significant nearfield-farfield differences during both the preoperational and operational periods. Abundances have remained stable over time, and the relationship of abundances between the three stations has also remained unchanged.

4.5 REFERENCES CITED

Anderson, J.T. 1990. Seasonal development of invertebrate zooplankton on Flemish Cap. Mar. Ecol. Progr. Ser. 67:127-1409.

Bayne, B.L. 1965. Growth and the delay of metamorphosis of the larvae of *Mytilus edulis* (L.) Ophelia 2:1-47.

__________. 1976. The biology of mussel larvae. Chap. 4 in Bayne, B.L., ed. Marine Mussels: Their Ecology and Physiology. IBP 10. Cambridge Univ. Press. pp. 81-120.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Environmental Protection Agency, Ecological Research Report Agency, Ecol. Res. Rep., 114 pp.

Bousfield, E.L. 1973. Shallow-water Gammaridean Amphipoda of New England. Comstock Pub. Assoc. (Cornell University Press; Ithaca, NY and London. 312 pp.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

Davis, C.S. 1984. Interaction of a copepod population with the mean circulation of Georges Bank. J. Mar. Res. 42:573-590.

Fell, P.E. and A.M. Balsamo. 1985. Recruitment of *Mytilus edulis* L. in the Thames Estuary, with evidence for differences in the time of maximal settling along the Connecticut shore. Estuaries 8:68-75.

Grabe, S.A. and E.R. Hatch. 1982. Aspects of the biology of *Mysis mixta* (Lilljeborg 1852)(Crustacea, Mysidacea) in New Hampshire coastal waters. Can. J. Zool. 60(6):1275-1281.

Grant, G.C. 1988. Seasonal occurrence and dominance of *Centropages* congeners in the Middle Atlantic Bight, USA. Hydrobiol. 167/168:227-237.

Grice, G.D. and N.H. Marcus. 1981. Dormant eggs of marine copepods. Oceanogr. Mar. Biol. Ann. Rev. 19:125-140.

Harris, R.J. 1985. A primer of multivariate statistics. Orlando: Acad. Press. 575 p.

Jossi, J.W. 1991. Gulf-of-Maine copepods hit 11-year high. In Northeast Fish. Ctr. End-of-Year Rep. for 1990. NOAA-NMFS.

Jossi, J.W. and J.R. Goulet, Jr. 1993. Zooplankton Trends: U.S. Northeast Shelf Ecosystem and Adjacent Regions Differ from Northeast Atlantic and North Sea. ICES J. Mar. Sci. 50:303-313.

Jury, S.H., J.D. Field, S.L. Stone, D.M. Nelson, and M.E. Monaco. 1994. Distribution and abundance of fishes and invertebrates in North Atlantic estuaries. ELMR Rep. No. 13. NOAA/NOS Strategic Env. Asessments Div., Silver Spring, MD. 221 p.

Kane, J. 1993. Variability of Zooplankton Biomass and Dominant Species Abundance on Georges Bank, 1977-1986. Fishery Bull. 91:464-474.

Katona, S.K. 1971. The developmental stages of *Eurytemora affinis* Poppe, 1880 (Copepoda, Calanoida) raised in laboratory cultures, including a comparison with the larvae of *Eurytemora americana* Williams, 1906, and *Eurytemora herdmani* Thompson and Scott, 1897. Crustaceana 21:5-20.

Marcus, N.H. 1984. Recruitment of copepod nauplii into the plankton: importance of diapause eggs and benthic processes. Mar. Ecol. Prog. Ser. 15:47-54.

Mauchline, J. 1980. The Biology of Mysids: Part I, in The Biology of Mysids and Euphausiids. Adv. Mar. Biol. 18:3-372.

Maurer, D. and R.L. Wigley. 1982. Distribution and ecology of mysids in Cape Cod Bay, MA. Biol. Bull. 163:477-491.

Meise-Munns, C., J. Green, M. Ingham and D. Mountain. 1990. Interannual variability in the copepod populations of Georges Bank and the Western Gulf of Maine. Mar. Ecol. Progr. Ser. 65:225-232.

Normandeau Associates Inc. 1978. Seabrook Environmental Studies, 1976-1977. Monitoring of plankton and related physical-chemical factors. Tech. Rep. VIII-3.

_________. 1979. Seabrook Environmental Studies, July through December 1977. Plankton. Tech. Rep. IX-1.

_________. 1980. Annual summary report for 1978 hydrographic studies off Hampton Beach, New Hampshire. Preoperational ecological monitoring studies for Seabrook Station. Tech. Rep. X-2.

_________. 1984. Seabrook Environmental Studies. 1983 data report. Tech. Rep. XV-1.

_________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rep. XVI-II.

_________. 1988. Seabrook Environmental Studies. 1987. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1987. A preoperational study for Seabrook Station. Tech. Rep. XIX-II.

_________. 1989. Seabrook Environmental Studies. 1988. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1988. A preoperational study for Seabrook Station. Tech. Rep. XX-II.

_________. 1990. Seabrook Environmental Studies. 1989. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1989. A preoperational study for Seabrook Station. Tech. Rep. XXI-II.

_________. 1991a. Seabrook Environmental Studies, 1990 data report. Tech. Rep. XXII-1.

_________. 1991b. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

_________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

_________. 1993a. Seabrook Environmental Studies. 1992 Data. Unpub. Data Tab.

_________. 1993b. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-I.

_________. 1994. Seabrook Environmental Studies. 1993 Data. Unpub. Data Tab.

Peterson, W.T. 1985. Abundance, age structure and in situ egg production rates of the copepod *Temora longicornis* in Long Island Sound, New York. Bull. Mar. Sci. 37(2):726-738.

Pezzack, D.S. and S. Corey. 1979. The life history and distribution of *Neomysis americana* (Smith) (Crustacea, Mysidacea) in Passamaquoddy Bay. Can. J. Zool. 57:785-793.

Plourde, S. and J.A. Runge. 1993. Reproduction of the Planktonic Copepod *Calanus finmarchicus* in the Lower St. Lawrence Estuary: Relation to the Cycle of Phytoplankton Production and Evidence for a *Calanus* pump. Mar. Ecol. Progr. Ser. 102:217-227.

Sameoto, D.D. and A.W. Herman. 1992. Effect of the outflow from the Gulf of St. Lawrence on Nova Scotia shelf zooplankton. Can. J. Fish. Aquat. Sci. 49:857-869.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics, version 5 edition. SAS Ins., Inc., Cary, N.C. 956 pp.

Sherman, K. 1966. Seasonal and areal distribution of Gulf of Maine coastal zooplankton, 1963. ICNAF Special Publ. No. 6. pp. 611-623.

__________. 1991. Northwest/northeast Atlantic zooplankton show different trends. in Northeast Fish. Center End-of-Year Rep. 1990. NOAA-NMFS.

Sherman, K., M. Grosslein, D. Mountain, D. Busch, J. O'Reilly and R. Theroux. 1988. The continental shelf ecosystem off the northeast coast of the United States. Chapter 9, pp. 279-337. *In* H. Postma and J.J. Zijlstra, Ecosystems of the World 27. Continental Shelves. Elsevier, Amsterdam.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. W.H. Freeman Co., San Francisco. 573 pp.

Tremblay, M.J. and J.C. Roff. 1983. Community gradients in the Scotian shelf zooplankton. Can. J. Fish. Aquatic. Sci. 40:598-611.36

Watling, L. 1979. Marine flora and fauna of the Northeastern United States. Crustacea: Cumacea. NOAA Tech. Rep. NMFS Circular 423. 23 p.

Wigley, R.L. and B.R. Burns. 1971. Distribution and biology of mysids (Crustacea, Mysidacea) from the Atlantic Coast of the United States in the NMFS Woods Hole collection. Fish. Bull. 69(4):717-746

APPENDIX TABLE 4-1. LIST OF ZOOPLANKTON TAXA CITED IN THIS REPORT. SEABROOK OPERATIONAL REPORT, 1993.

Protozoa
- Foraminiferida
- Tintinnidae

Rotifera

Mollusca
- Bivalvia
  - *Anomia squamula* Linnaeus
  - *Hiatella* Bosc 1801
  - *Macoma balthica* Linnaeus 1758
  - *Modiolus modiolus* Linnaeus 1758
  - *Mya arenaria* Linnaeus 1758
  - *Mya truncata* Linnaeus 1758
  - *Mytilus edulis* Linnaeus 1758
  - *Placopecten magellanicus* (Gmelin 1791)
  - Solenidae
  - *Spisula solidissima* (Dillwyn 1817)

Polychaeta

Arthropoda
- Branchiopoda
  - *Evadne* Lovén
- Copepoda
  - *Acartia* Dana 1846
  - *Anomalocera opalus* Penell 1976
  - *Calanus finmarchicus* (Gunnerus 1765)
  - *Caligus* Müller 1785
  - *Candacia armata* (Boeck 1872)
  - *Centropages hamatus* (Lilljeborg 1853)
  - *Centropages* Krøyer 1849
  - *Centropages typicus* Krøyer 1849
  - *Euchaeta* Philippi 1843
  - *Eurytemora herdmani* Thompson and Scott 1897
  - *Eurytemora* Giesbrecht 1881
  - Harpacticoida
  - Monstrillidae
  - *Oithona* Baird 1843
  - *Pseudocalanus* Boeck 1872
  - *Rhincalanus nasutus* Giesbrecht 1892
  - *Temora longicornis* (Müller 1785)
  - *Tortanus discaudatus* (Thompson and Scott 1897)

(continued)

APPENDIX TABLE 4-1. (Continued)

Cirripedia

Malacostraca
- Mysidacea
  - *Erythrops erythrophthalma* (Göes 1864)
  - *Mysis mixta* (Lilljeborg 1852)
  - *Neomysis americana* (S.I. Smith 1873)
- Cumacea
  - *Diastylis* Say
- Amphipoda
  - *Calliopius laeviusculus* Krøyer 1838
  - *Corophium* Milne-Edwards 1830
  - *Gammarus lawrencianus* Bousfield 1956
  - Hyperiidae
  - *Ischyrocerus anguipes* Krøyer 1838
  - Oedicerotidae
  - *Pontogeneia inermis* (Krøyer 1842)
- Decapoda
  - *Cancer* Linnaeus
  - *Carcinus maenas* (Linnaeus 1758)
  - *Crangon septemspinosa* Say 1818
  - *Eualus pusiolus* (Krøyer 1841)

Chaetognatha
- *Sagitta elegans* Verrill 1873

Chordata
- *Oikopleura* Mertens

TABLE OF CONTENTS

PAGE

5.0 FISH

PAGE

SUMMARY

Fish of the Hampton-Seabrook area have been sampled since 1976 to assess potential impacts associated with the construction and operation of Seabrook Station on local fish assemblages. Effects include the entrainment of fish eggs and larvae and the impingement of juvenile and adult fish at the station intake; entrainment of fish eggs and larvae into and the avoidance by larger fish of the offshore discharge thermal plume; and effects related to the discharge of the plant settling basin into the Browns River within the Hampton-Seabrook estuary. The spatial and temporal abundance of specific fish assemblages were examined along with various life stages of eleven selected fish taxa. Preoperational and operational abundances were compared using multivariate analysis methods for ichthyoplankton assemblages and analysis of variance (ANOVA) for larval, juvenile, and adult stages of the selected taxa. The sampling scheme used to collect data for the ANOVA was designed to meet the Before-After/Control-Impact analysis criteria. Although a number of significant differences were found in the abundance of several species between the preoperational and operational periods, nearly all of these differences can be attributed to large-scale, regional decreases in abundance, particularly for commercially important fishes. One potential effect was found at a station that could possibly be related to plant operation: a decrease in the abundance of winter flounder at the nearfield trawl station. However, this change could be related to naturally occurring environmental factors and not necessarily to plant operation and may bear further scrutiny during the next few years. In comparison to other large New England power plants with marine intakes, Seabrook Station entrains relatively few fish eggs and larvae and impinges very few juvenile and adult fish. Because the settling basin no longer is discharged into the Browns River, this effluent has been eliminated as a potential source of impact. Based on the small numbers of individuals directly removed by station operation, the general lack of significant differences found between the nearfield and farfield stations, and the large source populations of potentially affected fishes in the Gulf of Maine, the operation of Seabrook Station does not appear to have affected the balanced indigenous populations of fish in the Hampton-Seabrook area.

LIST OF FIGURES

LIST OF TABLES

PAGE

LIST OF APPENDIX TABLES

5.0 FISH

5.1 INTRODUCTION

Finfish studies at Seabrook Station began in July 1975 and have included investigations of all life stages of fish, including ichthyoplankton (eggs and larvae), juveniles, and adults. The initial objectives of these studies were to determine the seasonal, annual, and spatial trends in abundance and distribution of fish in the nearshore waters off Hampton and Seabrook, NH to establish baseline data suitable for assessing the effects of future plant operation. In addition, the nearshore fish populations in the Hampton-Seabrook estuary were examined to determine if there was any measurable effect due to the construction of Seabrook Station and the discharge from the onsite settling basin into the Browns River. The station began commercial operation in August 1990. Potential impacts of plant operation on local fishes include entrainment of eggs and larvae through the condenser cooling water system and impingement of larger specimens on traveling screens within the circulating water pumphouse. Also, local distribution of fishes could be affected by the thermal plume, and some eggs and larvae could be subjected to thermal shock due to plume entrainment following the discharge of condenser cooling water from the diffuser system.

At present, the main objective of the finfish studies at Seabrook Station is to assess whether station operation since 1990 has had any measurable effect on the nearshore fish populations. The following report first presents general information on each finfish collection program and then provides more detailed analyses for those fish species selected because of their dominance in the Hampton and Seabrook area or their commercial or recreational importance. A list of all taxa and their relative abundance collected from July 1975 through December 1993 by various ichthyoplankton and adult finfish sampling programs are given in Appendix Table 5-1. Both the common and scientific names of fishes found in that table follow Robins et al. (1991) and they are used throughout this report.

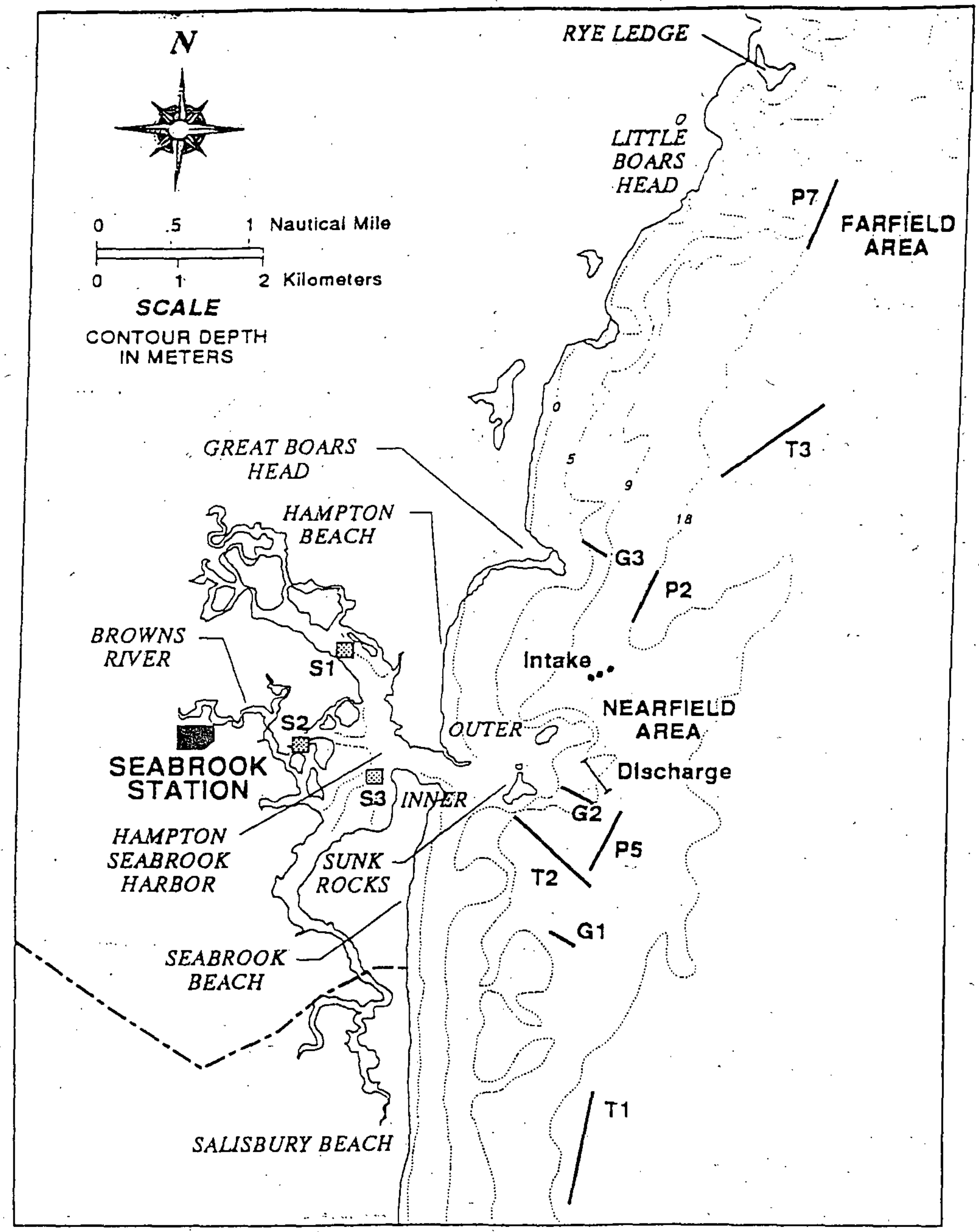
5.2 METHODS

5.2.1 Ichthyoplankton

5.2.1.1 Offshore Sampling

Ichthyoplankton sampling for Seabrook Station has been conducted since July 1975. Several modifications to the sampling methodology and collection frequencies were made as the nature of the ichthyoplankton community and its natural variability became better understood (NAI 1993). Station P2 (nearfield site for the Seabrook intakes) has been sampled consistently since the start of the program (Figure 5-1). Station P5 (nearfield site for the Seabrook discharge) was sampled from July 1975 through December 1981 and from July 1986 through December 1993. Station P7 (farfield station located about 7 km north of the nearfield stations), representing a non-impacted or control site, was sampled from January 1982 through December 1984 and from January 1986 through December 1993. Through June 1976, collections were taken monthly at each station sampled. Subsequently, a second monthly sampling period was added to February through August and to December. Beginning in January 1979, all months were sampled twice. Starting in March 1983, sample collection was increased to the current frequency of four times per month at each station.

On each sampling date and at each station, four samples were collected at night. Oblique tows were made using paired 1-m diameter, 0.505-mm mesh nets. Each net, weighted with an 8-kg



LEGEND

—— P = Ichthyoplankton Tows

—— T = Otter Trawls

—— G = Gill Nets

▩ S = Seine Hauls

Figure 5-1. Ichthyoplankton and adult fish sampling stations. Seabrook Operational Report, 1993.

depressor, was set off the stern and towed for 10 min while varying the boat speed, with the nets sinking to approximately 2 m off the bottom and rising obliquely to the surface at least twice during the tow. A standard 10-min tow was occasionally reduced to a 5-min tow to minimize net clogging due to high plankton density. The volume filtered, calculated using data from a calibrated General Oceanics® flowmeter mounted in each net mouth, averaged approximately 500 m^3 for 10-min tows and approximately 250 m^3 for 5-min tows during 1993. Upon retrieval, each net was washed down from mouth to codend and the contents preserved in 5% formalin buffered with borax.

5.2.1.2 Entrainment

Ichthyoplankton entrainment sampling was conducted up to four times a month by NAESCO personnel within the circulating water pumphouse on-site at Seabrook Station from July 1986 through June 1987 and June 1990 through December 1993. Sampling dates coincided with offshore ichthyoplankton sampling whenever possible. Three replicate samples were collected on each sampling date. Entrainment sampling was not conducted on several scheduled dates, either because of plant outages when sampling could not be conducted, or because of sampling equipment problems. The entrainment data discussed in this report are only those for the operational period of 1990-93.

Samples were taken using a double-barrel collection system. A 0.505-mm mesh plankton net was suspended in a 30-gal drum which, in turn, was suspended within a 55-gal drum. Water diverted from the cooling-water system entered the 55-gal drum from the bottom, overflowed into the 30-gal drum, passed through the plankton net, and was discharged through the bottom of both drums. The water supply was adjusted to maintain approximately 8 to 15 cm of water above the plankton net at all times. Following sampling, water was drained from the system and the contents of the nets were consolidated, placed in one sample jar, and preserved with 5% buffered formalin. The volume filtered was measured with an in-line flowmeter and averaged approximately 100 m^3 per replicate. Monthly entrainment estimates were determined by calculating the arithmetic mean density for each sampling week, multiplying the mean density by the number days in the sampling week, and by the average daily condenser cooling water volume for the month. These weekly estimates were summed for a monthly estimate. No entrainment estimates were made for the periods of August through November 1991 or September through November 1992, when sampling was suspended due to extended plant outages.

5.2.1.3 Laboratory Methods

Prior to March 1983, all four offshore ichthyoplankton samples per date and station were analyzed, except from January through December 1982, when only one sample per date and station was completely analyzed; only selected taxa were counted from the remaining three samples. Beginning in March 1983, only two of the four offshore samples (one from each pair; Section 5.2.1.1) were analyzed from each station for each sampling date; the remaining two were held as contingency samples.

Samples were subsampled with a Folsom plankton splitter and sorted for fish eggs and larvae using a dissecting microscope. Successive aliquots were analyzed until a minimum of 200 eggs and 100 larvae were sorted or until 200-400 mL settled plankton volume was sorted. All eggs and larvae were identified to the lowest practical taxon (usually species) and counted. In some instances when eggs were difficult to identify to species due to their stage of development, they were grouped with eggs of similar appearance (e.g., cunner, tautog, and yellowtail flounder were grouped as cunner/yellowtail flounder eggs; Atlantic cod, haddock, and witch flounder as Atlantic cod/haddock; and hake species and fourbeard rockling as hake/fourbeard rockling). The notochord lengths of at least 20 larvae per sample (if present) were measured to the nearest 0.5 mm for selected taxa, which included Atlantic herring, Atlantic cod, pollock, hakes, cunner, Atlantic mackerel, American sand lance, winter flounder, and yellowtail flounder. Entrainment samples were processed in a similar manner.

5.2.2 Adult Fish

5.2.2.1 Pelagic Fishes

Beginning in July 1975, gill net arrays were set for two consecutive 24-h periods twice each month at stations G1 (farfield), G2 (nearfield), and G3 (farfield) to sample the pelagic fish assemblage (Figure 5-1; Table 5-1). Starting in July 1986, sampling was reduced to once per month. Nets were 30.5 m x 3.7 m and were comprised of four panels having stretch mesh dimensions of 2.5 cm, 5.1 cm, 10.2 cm, and 15.2 cm. One net array consisting of surface and near-bottom nets was set at each station. All nets were set perpendicular to the isobath (Figure 5-1). All nets were attached between permanent moorings and tended daily by SCUBA divers. Fish collected were identified to their lowest practical taxon (usually species), measured, and length data were grouped into 2-cm size-classes.

5.2.2.2 Demersal Fishes

The inshore demersal fish assemblage was sampled monthly beginning in July 1975 by otter trawl at night at one nearfield station, T2, and two farfield stations, T1 and T3 (Figure 5-1; Table 5-1). Four replicate tows were made at each station once per month. Beginning in January 1985, sampling frequency was increased to twice per month and the number of replicate tows was reduced to two. Sampling was conducted with a 9.8-m shrimp otter trawl (3.8-cm nylon stretch mesh body; 3.2-cm stretch mesh trawl bag; 1.3-cm stretch mesh codend liner). The net was towed at approximately 1 $m \cdot sec^{-1}$ for 10 min, with successive tows taken in opposite directions. The volume of drift algae caught in the trawl was also recorded. It was not always possible to collect samples at station T2, particularly from August through October, due to the presence of commercial lobster gear; the frequency of missed samples has increased since 1983. Fish collected were identified to their lowest practical taxon (usually species), measured, and length data were grouped into 2-cm size-classes.

5.2.2.3 Estuarine Fishes

Seine samples were taken monthly from April to November at stations S1, S2, and S3, beginning in July 1975 (Figure 5-1; Table 5-1). No samples were collected in 1985 and from April through June of 1986. Duplicate daytime hauls were taken into the tidal current at each station with a 30.5 m x 2.4 m bag seine. The nylon bag was 4.3 m x 2.4 m with 1.4-cm stretch mesh, and each wing was 13.1 m x 2.4 m with 2.5-cm stretch mesh. Fish collected were identified to their lowest practical taxon (usually species), measured, and length data were grouped into 2-cm size-classes.

TABLE 5-1. DESCRIPTION OF FINFISH SAMPLING STATIONS. SEABROOK OPERATIONAL REPORT, 1993.

STATION	DEPTH	BOTTOM TYPE	REMARKS
BEACH SEINE			
S1	0-2 m	sand	Affected by tidal currents; approximately 300 m upriver from Hampton Beach Marina
S2	0-1 m	sand	Affected by tidal currents; approximately 200 m upstream from the mouth of the Browns River
S3	0-3 m	sand	Affected by tidal currents; located in Seabrook Harbor, approximately 300 m from Hampton Harbor Bridge
GILL NET			
G1	20 m	sand	Seaward of rocky outcropping off Seabrook, approximately 2 km south of the discharge
G2	17 m	sand	Seaward of Inner Sunk Rocks, approximately 250 m southwest of the discharge
G3	17 m	rock, cobble	Offshore from Great Boars Head, approximately 2.5 km north of the discharge
OTTER TRAWL			
T1	20-28 m	sand	Transect begins 0.5 miles southeast of Breaking Rocks Nun, 150-200 m from submerged rock outcroppings, approximately 4 km south of the discharge
T2	15-17 m	sand; drift algae with shell debris	100 m from Inner Sunk Rocks, approximately 1 km south of the discharge; scoured by tidal currents with large quantities of drift algae
T3	22-30 m	sand; littered with shell debris	Located off Great Boars Head, approximately 4 km north of the discharge; just seaward of a cobble area (rocks 15-50 cm in diameter)

5.2.2.4 Impingement

Fish impinged at Seabrook Station were collected after being washed from the 0.125-in mesh traveling screens within the circulating water pumphouse. Traveling screens were washed weekly (K. Dow, YAEC, pers. comm.) and impinged fish were sluiced into a collection basket. Fish from weekly collections were separated from debris, placed in dated plastic bags, and frozen. On a periodic basis, samples were thawed, identified to species, and counted by YAEC personnel. Impingement collections were noted as total counts per species by month. In addition, the number of fish impinged per billion gallons of cooling water was calculated.

5.2.3 Analytical Methods

Ichthyoplankton assemblages were investigated using multivariate numerical classification methods to determine whether species composition changed between the preoperational period (July 1990 and earlier) and the operational period (August 1990 and later). The Bray-Curtis similarity index (Clifford and Stephenson 1975) was used with the unweighted pair-group clustering method (Sneath and Sokal 1973). $Log_{10}(x+1)$ transformed sample densities (number per 1000 m^3) of eggs and larvae were analyzed separately. The data sets were reduced by averaging dates within month (transformed data); including only the more abundant taxa; and limiting the analysis to data collected since July 1986, when all three stations of concern (P2, P5, and P7) were sampled. Rare taxa were excluded on the basis of percent-composition (less than 0.1% of the untransformed data) or frequency of occurrence in samples (less than 5%). The resulting dendrograms were evaluated on the basis of whether samples from the operational period were grouped differently by the analysis than were the preoperational samples. In addition, monthly preoperational and operational means (from transformed data) were compared with *t*-tests (Sokal and Rohlf 1969) for individual taxa within each cluster group, under the assumption of unequal variances.

Multivariate analysis of variance (MANOVA; Harris 1985) was used to indicate whether fish egg and larval assemblages had differed significantly ($p \leq 0.05$) between preoperational and operational periods. $Log_{10}(x+1)$ transformed sample densities (number per 1000 m^3) were used. The analysis was restricted to collections from July 1986 through December 1993, the common period of sampling at stations P2, P5, and P7, and the taxa included were the same as those analyzed by numerical classification. The data used were the mean of $log_{10}(x+1)$ sample densities for individual sampling dates and stations. The model design was a three-way factorial with nested effects. The main effects were period (preoperational and operational), station, and month; interactions among these main effects were included in the model. The nested effect was years within period. Type III sums of squares and tests of hypothesis were used for the analyses and the rationale for their use was the same as that used for analysis of variance, discussed below. The Wilks' lambda statistic (Wilks 1932; Morrison 1976) was used to determine if the taxa assemblages in the preoperational and operational periods were significantly different. For the purpose of power-plant impact assessment, sources of variation of primary concern were the period and the period (preoperational or operational) by station interaction.

Of the 76 taxa recorded over the years, 11 were selected for detailed analyses of abundance and distribution and for an assessment of impact by Seabrook Station (Table 5-2). These species were numerically dominant in one or more sampling

TABLE 5-2. SELECTED FINFISHES AND SAMPLING PROGRAMS THAT CONTRIBUTED ABUNDANCE DATA FOR SPECIES-SPECIFIC ANALYSES. SEABROOK OPERATIONAL REPORT, 1993.

SELECTED SPECIES	PREDOMINANT SAMPLING PROGRAMS
Atlantic herring	ichthyoplankton, gill net
Rainbow smelt	otter trawl, beach seine
Atlantic cod	ichthyoplankton, otter trawl
Pollock	ichthyoplankton, gill net
Hakes	ichthyoplankton, otter trawl
Atlantic silverside	beach seine
Cunner	ichthyoplankton
American sand lance	ichthyoplankton
Atlantic mackerel	ichthyoplankton, gill net
Winter flounder	ichthyoplankton, otter trawl, beach seine
Yellowtail flounder	ichthyoplankton, otter trawl

programs, are important members of the finfish fauna of the Gulf of Maine, and most have recreational or commercial importance. Other species predominant in various sampling programs were noted when they occurred. The selected taxa, listed in Table 5-2 by sampling program, were individually evaluated for temporal and spatial changes in abundance between the preoperational and operational periods. Geometric means were compared among the preoperational, operational, and 1993 periods for each station and all stations combined to examine for trends in annual abundance. Geometric means were computed by $\log_{10}(x+1)$ transformation of individual sample abundance indices, which were number per 1000 m^3 for ichthyoplankton, and catch-per-unit-effort (CPUE) for juvenile and adult fish. CPUE was defined as the number per 24-h set for the gill net, number per 10-min tow for the trawl, and number per standard haul for the seine. A transformed mean was calculated for each year and for combined years (e.g., preoperational and operational periods). The coefficients of variability (CV) of the mean of annual means (CV = standard error of the mean divided by the mean and multiplied by 100) in the logarithmic scale were also computed. The annual and combined geometric means are presented as back-transformed values. Some life stages are seasonal, so the data used to compute the geometric means for some species were restricted to periods of primary occurrence; when trimmed data were used, it is noted in the text, figure, or table.

Analysis of variance (ANOVA) was used to test the null hypothesis that spatial and temporal abundances during the preoperational and operational periods were not significantly ($p \geq 0.05$) different. The data collected for the ANOVAs met the criteria of a Before-After / Control-Impact (BACI) sampling design discussed by Stewart-Oaten et. al. (1986), where sampling was conducted prior to and during plant operation and sampling station locations included both potentially impacted and non-impacted sites. The ANOVA was a two-way factorial with nested effects that provided a direct test for the temporal-by-spatial interaction. The main effects were period (Preop-Op) and station (Station); the interaction term (Preop-Op X Station) was also included in the model. Nested temporal effects were years within operational period (Year (Preop-Op)) and months within year (Month(Year)), which were added to reduce the unexplained variance, and thus, increased the sensitivity of the F-test. For both nested terms, variation was partitioned without regard to station (stations combined). The final variance not accounted for by the above explicit sources of variation constituted the Error term. A fixed-effects model was assumed with all sources of variation tested against the mean square error (MSE); therefore, the MSE was the common denominator in the ratios which determined the F-values. Type III sums of squares and tests of hypotheses were used for the analyses because cells in the factorial design contained unequal observations (unbalanced data). In reviews of ANOVA designs, Freund et al. (1986) and Shaw and Mitchell-Olds (1993) concluded that Type III was the most powerful (i.e., most likely to find a significant difference) test for factorial designs with interactions and unbalanced data.

For assessing Seabrook Station effects using the above ANOVA model, the sources of variation of primary concern were the Preop-Op main effect and the Preop-Op X Station interaction. However, a significant Preop-Op term would not imply power plant effect unless the Preop-Op X Station interaction was also significant (Thomas 1977; Green 1979; Stewart-Oaten et al. 1986). Even in the latter case, the interaction would have to be further examined to determine if the significance was the result of differences between potentially impacted and non-impacted stations.

The 1990 sampling year was classified as either preoperational, operational, or was excluded from the analysis for a species, depending on seasonal pattern of occurrence of each species or times of sample collection, and is noted as such on the ANOVA tables. For larvae, the data were restricted to the period July 1986 through December 1993, and for selected taxa collected by gill net, trawl, and seine, the data used were from July 1975 through December 1993. For trawl data, the months of August through October were excluded from the ANOVA because of reduced sampling effort at station T2. The data used in the analyses of gill net, trawl, and seine samples were $\log_{10}(CPUE + 1)$ transformed for each individual collection, but for larvae the mean transformed density of replicate samples was used.

5.3 RESULTS AND DISCUSSION

5.3.1 Ichthyoplankton

The analyses for the ichthyoplankton program focused on seasonal assemblages of both eggs and larvae, as well as on collections of selected larval taxa (Table 5-3) discussed in Section 5.3.2. The results for each of the selected taxa are discussed in relation to juvenile and adult stages collected in other sampling programs. In the assemblage analyses, additional taxa were included to better represent the ichthyoplankton community in the Hampton-Seabrook area.

5.3.1.1 Seasonal Assemblages

The seasonal assemblages of ichthyoplankton were examined using multivariate numerical classification (cluster analysis). These analyses were conducted to determine if the operation of Seabrook Station had altered either the seasonal occurrence or the spatial distribution of fish eggs and larvae in the Hampton-Seabrook area. More specifically, the focus of these analyses was to examine the distribution of ichthyoplankton among intake (P2), discharge (P5), and farfield (P7) stations before and after Seabrook Station operation. Typically, ichthyoplankton taxa occur

TABLE 5-3. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 1000 m^3) WITH COEFFICIENT OF VARIABILITY (CV) BY STATION (P2, P5, AND P7) AND ALL STATIONS COMBINED FOR SELECTED LARVAL SPECIES COLLECTED IN ICHTHYOPLANKTON SAMPLES DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND IN 1993. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL PERIOD[a]		1993[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
American sand lance (Jan-Apr)	P2	148.4	4	191.1	104.8	7
	P5	207.4	5	153.4	141.7	2
	P7	98.4	6	109.1	90.9	3
	All stations	151.4	4	147.3	110.5	4
Winter flounder (Apr-Jul)	P2	9.0	9	8.7	7.3	6
	P5	7.9	9	6.4	6.8	8
	P7	7.3	10	1.7	2.1	13
	All stations	8.4	8	4.6	4.7	5
Atlantic cod (Apr-Jul)	P2	3.1	19	1.2	1.7	36
	P5	3.0	22	1.0	1.8	47
	P7	1.8	28	1.2	1.5	25
	All stations	3.0	17	1.1	1.7	37
Yellowtail flounder (May-Aug)	P2	3.4	15	4.2	2.5	28
	P5	3.8	16	5.3	2.8	31
	P7	3.2	19	2.6	2.2	18
	All stations	3.6	12	3.9	2.5	25
Atlantic mackerel (May-Aug)	P2	5.6	12	5.9	7.9	33
	P5	6.1	18	5.0	5.6	33
	P7	5.9	10	4.6	7.7	32
	All stations	5.8	12	5.2	7.0	32
Cunner (Jun-Sept)	P2	42.5	6	87.7	34.6	28
	P5	43.9	9	79.8	31.0	26
	P7	50.0	9	95.9	41.7	27
	All stations	42.8	6	87.6	35.5	27
Hakes[d] (Jul-Sept)	P2	3.9	12	1.6	1.7	45
	P5	3.2	18	1.5	2.1	64
	P7	4.3	19	1.3	2.3	81
	All stations	4.0	12	1.5	2.0	66
Atlantic herring (Oct-Dec)	P2	27.4	9	5.3	6.4	21
	P5	27.5	13	7.7	8.2	14
	P7	30.3	9	8.9	9.7	16
	All stations	27.4	9	7.2	8.0	16
Pollock (Nov-Feb)	P2	6.4	14	-[e]	1.8	4
	P5	7.4	16	-	2.2	17
	P7	5.4	23	-	1.6	24
	All stations	7.0	14	-	1.8	12

[a] Preoperational: July 1975-July 1990; geometric mean of annual geometric means.
[b] Geometric mean of the 1993 data.
[c] Operational: August 1990-December 1993; geometric mean of annual geometric means.
[d] Includes red, white, and spotted hakes.
[e] Annual geometric mean not computed for pollock in 1993 because January and February 1994 data were not yet available.

during distinct seasons and periods of frequent occurrence, which are relatively consistent from year to year. The data examined were collected from July 1986 through December 1993, when all three stations (P2, P5, and P7) were sampled. The preoperational period extended through July 1990 and the operational period began in August 1990. Several of the egg taxa were grouped, because during early developmental stages it was difficult to distinguish among some species (e.g. Atlantic cod, haddock, and witch flounder; cunner, yellowtail flounder, and tautog; fourbeard rockling and hakes). Larvae were generally identified to species, except that red, white, and spotted hakes were grouped together.

Nine egg taxa met the criteria as dominant taxa and the subsequent numerical classification analysis resulted in eight groups (Figure 5-2). A total of 270 monthly observations were used for the cluster analysis and only two monthly observations (station P7, February 1990 and station P7, February 1992) did not fall within any of the eight groups. The eight groups formed two major categories, which corresponded to annual periods of cold and warm water temperatures. Groups 1-3 were found during periods of cooler water temperatures (November through April) and Groups 4-8 were taken during the warmer period (May through October). There was no difference in these two categories between preoperational and operational periods. Group 1, termed late fall, represented the beginning of the cooler water period and consisted primarily of November and December collections. Atlantic cod/pollock was the only dominant taxon in this group (Table 5-4). The operational geometric mean for cod/pollock was lower than the preoperational mean and the difference was significant ($p < 0.05$) based on results of a *t*-test on monthly means from transformed data. Atlantic cod, haddock, and witch flounder eggs can be identified to species during their late embryonic stage (Brander and Hurley 1992), and based on the frequency of occurrence in samples, Atlantic cod were probably dominant during this period, in addition to some pollock eggs. Egg abundances in Group 2, termed the winter group, were relatively low for the two dominant taxa, Atlantic cod/haddock and American plaice, during both preoperational and operational periods and no significant ($p > 0.05$) differences were detected. This winter group consisted primarily of monthly collections from January through March; from the frequency of occurrence in samples where eggs were identified to species, Atlantic cod was dominant. Group 3, termed early spring, primarily included April collections, having the same dominant taxa of the previous group with the addition of fourbeard rockling eggs. There appeared to be a decline in fourbeard rockling and an increase in American plaice abundances between preoperational and operational periods and these differences were significant ($p < 0.02$; Table 5-4).

Group 4, termed the mid spring group, was found during the beginning of the warmer water season and consisted of May collections exclusively for all years. The dominant taxa were more diverse than for the three previous groups and included eggs of cunner/yellowtail flounder, fourbeard rockling (most abundant during the preoperational period), American plaice, Atlantic mackerel (most abundant during the operational period), and Atlantic cod/haddock. For fourbeard rockling, Atlantic mackerel, and Atlantic cod/haddock the changes were significant ($p < 0.05$). Group 5 consisted of June collections exclusively and was termed the early summer grouping. This group appeared much less diverse, with only cunner/yellowtail flounder and Atlantic mackerel as dominant. These two taxa showed an approximate two-fold increase in abundance from the preoperational to the operational period, but only the cunner/yellowtail flounder difference was significant ($p < 0.05$). Group 6 was again

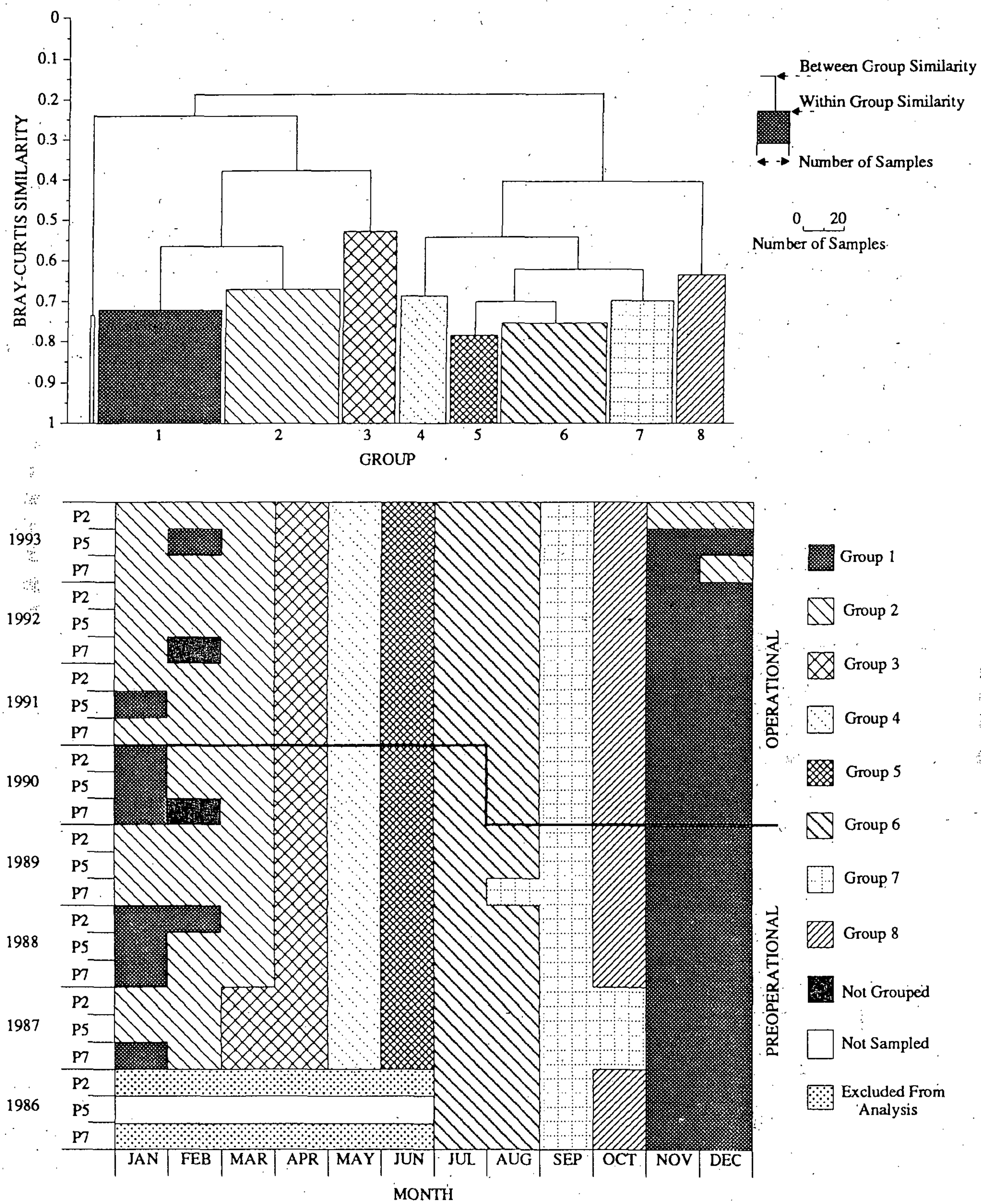


Figure 5-2. Dendrogram and temporal/spatial occurrence pattern of fish egg assemblages formed by numerical classification of ichthyoplankton samples (monthly means of $\log_{10}(x+1)$ transformed number per 1000 m^3) at Seabrook intake (P2), discharge (P5), and farfield (P7) stations, July 1986-December 1993. Seabrook Operational Report, 1993.

TABLE 5-4. GEOMETRIC MEAN DENSITY (NUMBER PER 1000 m^3) OF FISH EGGS COLLECTED AT SEABROOK INTAKE (P2), DISCHARGE (P5), AND FARFIELD (P7) STATIONS FROM JULY 1986 THROUGH DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

CLUSTER ANALYSIS GROUPS	DOMINANT TAXA[c]	PREOPERATIONAL PERIOD[a] N[d]	LCL[e]	MEAN	UCL	OPERATIONAL PERIOD[b] N	LCL	MEAN	UCL
1 - Late Fall (0.72/0.57)[f]	Atlantic cod/pollock	32	43	62	90	23	22	34	52
2 - Winter (0.67/0.57)	Atlantic cod/haddock	24	3	5	6	27	3	4	5
	American plaice		<1	1	1		<1	1	2
3 - Early Spring (0.53/0.38)	American plaice	15	21	36	62	9	52	120	274
	Atlantic cod/haddock		6	14	28		14	25	43
	Fourbeard rockling		3	8	16		<1	<1	1
4 - Mid Spring (0.69/0.55)	Cunner/yellowtail flounder	12	156	275	487	9	114	285	711
	Fourbeard rockling		67	220	713		2	11	43
	American plaice		45	63	87		17	33	65
	Atlantic mackerel		16	33	69		293	477	775
	Atlantic cod/haddock		19	28	41		3	8	23
5 - Early Summer (0.79/0.71)	Cunner/yellowtail flounder	12	5847	9891	16731	9	13124	19654	29431
	Atlantic mackerel		1283	2335	4249		2193	3393	5250
6 - Mid Summer (0.76/0.71)	Cunner/yellowtail flounder	26	1654	3636	7994	21	1974	3727	7035
	Fourbeard rockling/hake		242	433	774		260	399	612
7 - Late Summer (0.70/0.63)	Fourbeard rockling/hake	16	69	124	221	12	84	164	323
	Hakes		78	119	182		36	69	132
	Windowpane		12	26	54		52	90	156
	Fourbeard rockling		5	13	33		2	4	6
	Silver hake		4	13	36		91	144	228
8 - Early Fall (0.64/0.41)	Hakes	9	5	9	15	12	2	3	5
	Silver hake		5	7	11		4	9	19
	Fourbeard rockling		1	4	8		<1	1	1

[a] Preoperational = July 1986-July 1990.
[b] Operational = August 1990-December 1993.
[c] Those whose combined preoperational geometric mean densities accounted for ≥90% of the sum of the preoperational geometric mean densities of all taxa within the group.
[d] N represents the number of monthly means.
[e] Geometric mean and lower (LCL) and upper (UCL) 95% confidence limits.
[f] (Within group/between group similarity).

dominated by cunner/yellowtail flounder, with the addition of fourbeard rockling/hake eggs. The season for this group was termed mid summer and occurred exclusively in July and August for all years. All the dominant taxa had similar densities during the preoperational and operational periods and no significant ($p > 0.05$) differences were detected. Group 7 consisted of late summer collections, primarily those during September. The taxa comprising this group were fairly diverse, probably due to a general decline in egg abundance during this period. Differences between preoperational and operational periods were significant ($p < 0.05$) for windowpane, fourbeard rockling, and silver hake eggs. The season represented by Group 8 was early fall and collections occurred primarily in October. There was a significant ($p < 0.05$) decrease between preoperational and operational periods for hakes and fourbeard rockling eggs.

The consistent temporal (among both months and years) and spatial (among stations) assemblages suggested that operation of Seabrook Station has not altered the seasonal spawning time nor the distribution of eggs in the Hampton-Seabrook area. The spatial stability was demonstrated by the fact that about 97% of the monthly observations at all three stations during each year were found in the same groups. Furthermore, about 37% of the monthly observations at the three stations exhibited a high degree of similarity for each year and month combination. This spatial similarity was further supported by the results of MANOVA, for which a significant difference was found between the preoperational and operational periods ($p < 0.01$), but the interaction was clearly not significant ($p > 0.99$). This indicated that the temporal changes in assemblage abundance occurred concurrently at all three stations, including the farfield station (P7), the control area.

Twenty-three larval taxa were selected for numerical classification analysis, which resulted in seven cluster groups (Figure 5-3). Only one monthly observation (station P2, October 1992) did not cluster within any of the seven groups. Similar to the egg collection data, two major categories were evident, with collections in Groups 1-4 occurring primarily during the cooler water temperature period (generally November through May) and collections in Groups 5-7 during the warmer period (generally June through October). Group 1, termed late fall, included November and December collections (Table 5-5). Larval Atlantic herring was the only dominant species during this period and there was a significant ($p < 0.01$) decrease in its abundance from the preoperational to the operational period. Group 2, termed early winter, was more diverse and was generally comprised of January collections. American sand lance was most dominant, with the remaining predominant taxa found at lower abundances. There were no apparent differences between preoperational and operational geometric means for any of these taxa and this was substantiated by result of the *t*-tests. American sand lance larvae again dominated in Group 3, termed late winter/early spring. The period of occurrence for collections of this group was relatively long, generally from February through April. The geometric means were similar between preoperational and operational periods for all taxa, except the slight decline of gulf snailfish eggs in the operational period was marginally significant ($p = 0.047$). Group 4 occurred during late spring and was consistently comprised of May collections for all years, except for 1993, when this group was not present. The Atlantic seasnail was the most dominant fish in this group and its geometric mean, along with that of winter flounder larvae, decreased from the preoperational to the operational period, although these declines were not significant ($p > 0.05$).

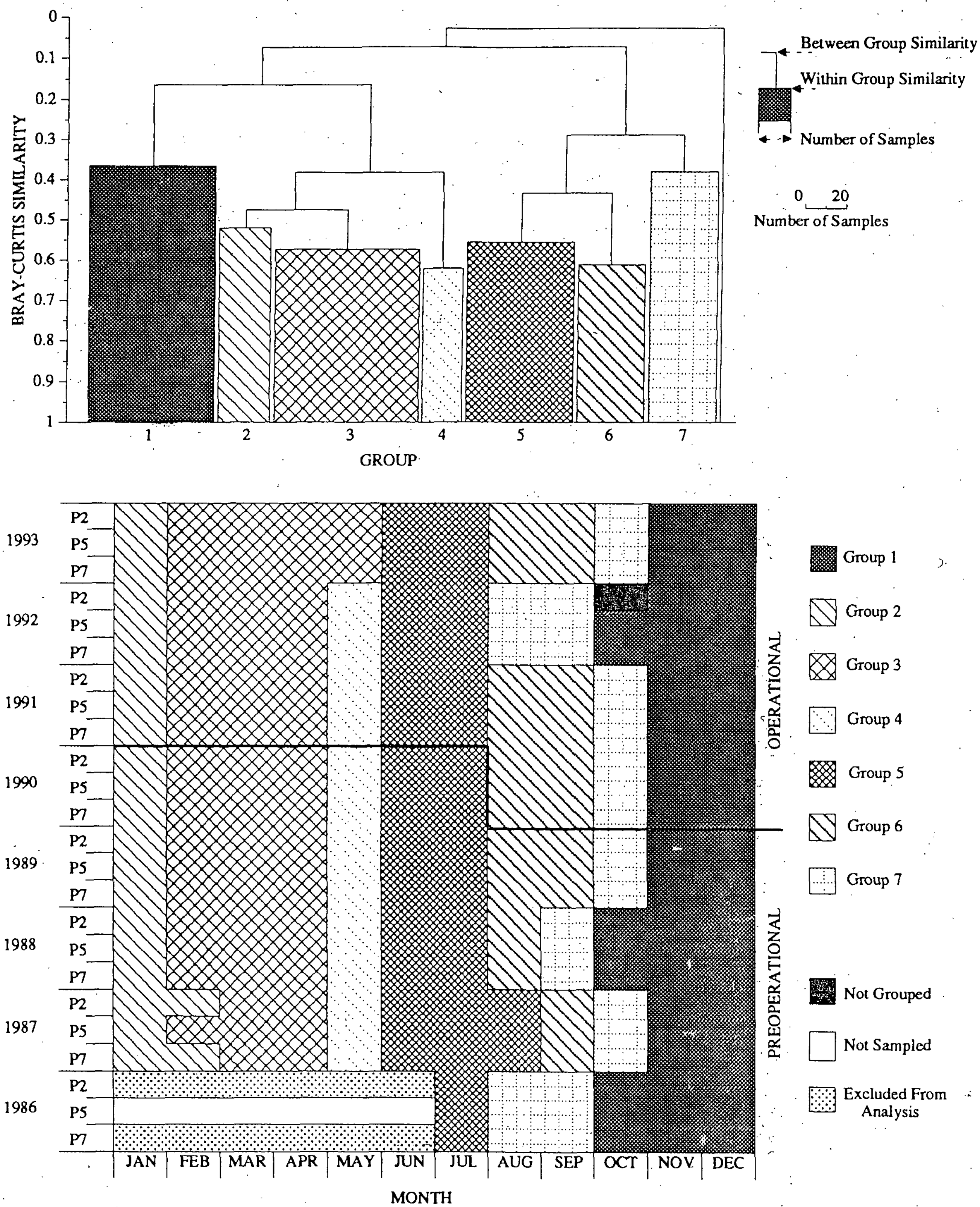


Figure 5-3. Dendrogram and temporal/spatial occurrence pattern of fish larval assemblages formed by numerical classification of ichthyoplankton samples (monthly means of $\log_{10}(x+1)$ transformed number per 1000 m^3) at Seabrook intake (P2), discharge (P5), and farfield (P7) stations, July 1986-December 1993. Seabrook Operational Report, 1993.

TABLE 5-5. GEOMETRIC MEAN DENSITY (NUMBER PER 1000 m^3) OF FISH LARVAE COLLECTED AT SEABROOK INTAKE (P2), DISCHARGE (P5), AND FARFIELD (P7) STATIONS FROM JULY 1986 THROUGH DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

CLUSTER ANALYSIS GROUPS	DOMINANT TAXA[c]	PREOPERATIONAL PERIOD[a] N[d]	LCL[e]	MEAN	UCL	OPERATIONAL PERIOD[b] N	LCL	MEAN	UCL
1 - Late Fall (0.37/0.17)[f]	Atlantic herring	30	27	46	79	26	8	12	19
2 - Early Winter (0.53/0.48)	American sand lance	14	11	22	44	9	12	23	41
	Atlantic herring		2	4	7		<1	2	4
	Gulf snailfish		2	3	5		2	4	6
	Pollock		1	3	8		1	2	3
3 - Late Winter/ Early Spring (0.58/0.48)	American sand lance	34	136	197	283	30	98	149	224
	Rock gunnel		13	21	32		8	14	23
	Gulf snailfish		8	10	14		4	6	9
	Grubby		4	6	10		3	5	8
4 - Late Spring (0.63/0.39)	Atlantic snailfish	12	32	68	143	6	11	34	105
	American sand lance		9	18	35		4	17	66
	Radiated shanny		10	14	19		7	17	39
	Winter flounder		5	10	20		1	5	13
5 - Early Summer (0.56/0.44)	Cunner	30	45	101	226	18	5	18	61
	Fourbeard rockling		26	45	78		14	23	40
	Radiated shanny		15	22	32		21	33	52
	Atlantic mackerel		8	16	31		13	36	94
	Winter flounder		4	8	15		5	9	17
6 - Late Summer (0.62/0.44)	Cunner	12	64	137	292	18	157	401	1021
	Fourbeard rockling		18	48	124		19	30	46
	Hakes		4	7	12		3	12	35
	Silver hake		2	6	14		4	13	34
	Witch flounder		2	5	10		1	1	2
	Windowpane		2	5	9		2	4	9

(continued)

TABLE 5-5. (CONTINUED)

GROUP	DOMINANT TAXA[c]	N[d]	PREOPERATIONAL PERIOD[a] LCL[e]	MEAN	UCL	N	OPERATIONAL PERIOD[b] LCL	MEAN	UCL
7 - Late Summer/ Early Fall (0.38/0.30)[f]	Cunner	15	1	3	5	15	<1	1	2
	Fourbeard rockling		1	2	5		2	4	6
	Windowpane		1	1	2		<1	1	1
	Atlantic herring		<1	1	2		<1	1	1
	Silver hake		<1	1	2		<1	1	2
	Hakes		<1	1	1		<1	1	1
	Witch flounder		<1	1	1		<1	1	2

[a] Preoperational = July 1986-July 1990.
[b] Operational = August 1990-December 1993.
[c] Those whose combined preoperational geometric mean densities accounted for ≥90% of the sum of the preoperational geometric mean densities of all taxa within the group.
[d] N represents the number of monthly means.
[e] Geometric mean and lower (LCL) and upper (UCL) 95% confidence limits.
[f] (Within group/between group similarity).

Group 5 collections occurred primarily during early summer (June and July), the beginning of the warm water groups. The geometric mean for cunner, the most dominant species in this group, declined from the preoperational to the operational period and this was significant ($p < 0.05$). The annual seasonal patterns of occurrence for Groups 6 and 7 were less consistent than for the other groups. Although Group 6 was not present every year, cunner and fourbeard rockling larvae dominated this group during late summer (August and September). When present, this group annually occurred together at all three stations. In contrast to Group 5, cunner larvae were more abundant during the operational period than the preoperational period and this increase was significant ($p = 0.01$). Finally, Group 7 was termed late summer/early fall, with most collections from August through October. All but one (Atlantic herring) of the seven dominant taxa were also present in the previous group, but at much lower densities, particularly for cunner and fourbeard rockling larvae. In general, for the months of August and September, Groups 6 and 7 were mutually exclusive, but there was no apparent pattern that could be related to plant operation.

Although the temporal occurrence of larval groups, both monthly and annually, was not as consistent as for fish eggs, spatial clustering was consistent. About 99% of the monthly observations at all three stations during each year were grouped in the same clusters, and in about 44% of the monthly observations the three stations were very similar within the same year and month. Similarity among stations was also supported by the results of MANOVA, where the preoperational-operational term was significant ($p < 0.01$), but the interaction was clearly not significant ($p > 0.99$). These results indicated that the temporal changes in assemblage abundance were consistent at all three stations, including the non-impacted farfield station (P7).

5.3.1.2 Entrainment

One of the most direct measures of potential impact of Seabrook Station on the local fish assemblages is the number of eggs and larvae entrained through the condenser cooling water system. During 1993, 13 egg and 20 larval taxa were collected in entrainment samples (Table 5-6). Total annual estimates of entrainment were 315.6 million eggs and 126.1 million larvae. The total egg entrainment in 1993 was the lowest since plant operation began, even though the annual condenser water volume was the greatest (Figure 5-4). About 90% of the eggs entrained were from six taxa: Atlantic mackerel, cunner/yellowtail flounder, Atlantic cod/haddock, hake/fourbeard rockling, windowpane, and American plaice, with over 50% attributed to Atlantic mackerel and cunner/yellowtail flounder. Eggs from these taxa have also previously dominated entrainment samples (Table 5-7) and were also dominant in offshore collections during 1993 (Table 5-4).

Total larval entrainment in 1993 was within the range of previous years, even though the 1990 estimate included only the months of June through December, and in 1991 and 1992, no entrainment sampling was conducted during a 3- to 4-mo period (August or September through November) due to plant outages. The Atlantic seasnail accounted for over 50% of the 1993 larval entrainment estimate. The dominant larval taxon entrained was not consistent from year to year, with fourbeard rockling predominating in 1990 and rock gunnel in 1991 and 1992. There was no consistent relationship between larval and egg taxa entrained in the same year. This inconsistency was probably due to varying susceptibility of the two developmental stages to entrainment. Among the species entrained that have demersal or adhesive eggs, which are not susceptible to entrainment, include the Atlantic seasnail, grubby, American sand lance, Atlantic herring, rock gunnel, winter

TABLE 5-6. MONTHLY ESTIMATED NUMBERS OF FISH EGGS AND LARVAE ENTRAINED (x 10^6) BY THE COOLING WATER SYSTEM AT SEABROOK STATION FROM JANUARY THROUGH DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

TAXON	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
EGGS														
Atlantic mackerel	0.0	0.0	0.0	0.0	18.4	94.0	0.4	0.1	0.0	0.0	0.0	0.0	112.9	35.8
Cunner/yellowtail flounder	0.0	0.0	0.0	0.1	1.6	24.8	5.9	25.9	0.0	0.1	0.0	0.0	58.4	18.5
Atlantic cod/haddock	0.0	0.0	17.9	0.4	3.0	18.4	7.1	2.3	0.3	0.1	0.1	0.7	50.3	15.9
Hakes/fourbeard rockling	0.0	0.0	0.0	0.0	0.8	10.2	3.4	10.8	7.5	0.0	0.0	0.0	32.7	10.4
Windowpane	0.0	0.0	0.0	0.0	3.5	9.6	3.2	10.9	1.9	0.0	0.0	0.0	29.1	9.2
American plaice	0.0	0.0	0.0	7.3	6.4	5.7	0.1	0.0	0.0	0.0	0.0	0.0	19.5	6.2
Lumpfish	0.0	0.0	0.0	0.1	7.3	2.0	0.1	0.0	0.0	0.0	0.0	0.0	9.5	3.0
Unidentified	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.3	0.0	0.0	0.0	0.8	0.3
Fourbeard rockling	0.0	0.0	0.0	0.0	0.0	0.7	0.2	0.4	0.1	0.0	0.0	0.0	1.4	0.4
Silver hake	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.4	0.1
Pollock	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1
Hakes	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.2	0.1
Atlantic menhaden	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Cusk	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Total	0.0	0.1	17.9	7.9	41.2	165.8	20.7	50.7	10.1	0.3	0.1	0.8	315.6	100.0
LARVAE														
Atlantic seasnail	0.0	0.3	0.0	2.3	18.6	38.1	4.6	0.5	0.0	0.0	0.0	0.0	64.4	51.1
Grubby	0.1	0.2	0.6	9.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8	10.9
American sand lance	2.8	1.4	0.1	2.9	4.6	0.1	0.0	0.0	0.0	0.0	0.0	0.1	12.0	9.5
Atlantic herring	0.1	0.2	0.0	8.7	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	9.6	7.6
Rock gunnel	0.1	0.7	1.7	1.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	4.5
Unidentified	0.1	0.0	0.5	1.5	1.7	1.3	0.1	0.2	0.0	0.0	0.1	0.0	5.5	4.4
Cunner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.2	0.0	0.0	0.0	4.7	3.7
Winter flounder	0.0	0.0	0.0	0.0	0.1	2.5	0.2	0.1	0.0	0.0	0.0	0.0	2.9	2.3
Gulf snailfish	0.6	0.7	0.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.1
Fourbeard rockling	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	0.1	0.0	0.0	0.1	2.2	1.7
American plaice	0.0	0.0	0.0	0.0	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.7	0.6
Longhorn sculpin	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3
Moustache sculpin	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.3
Lumpfish	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Snailfishes	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Shorthorn sculpin	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Radiated shanny	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.2
Atlantic cod	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Silver hake	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Windowpane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Hakes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Total	3.8	4.0	3.2	27.6	31.0	42.7	5.3	7.6	0.3	0.0	0.2	0.4	126.1	100.0

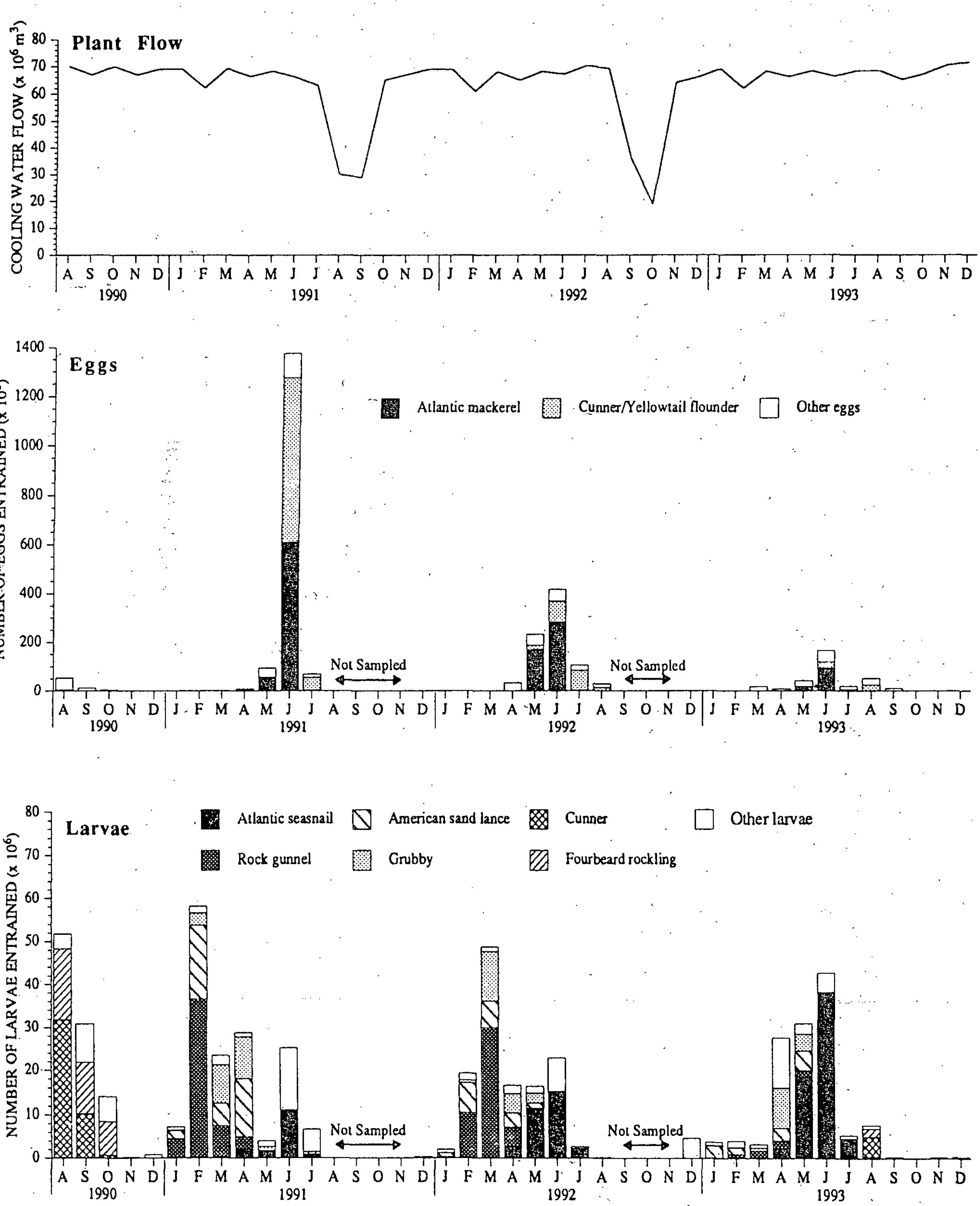


Figure 5-4. Total monthly cooling water system flow and estimated numbers of fish eggs and larvae entrained at Seabrook Station during the operational period. Seabrook Operational Report, 1993.

TABLE 5-7. ANNUAL ESTIMATED NUMBERS OF FISH EGGS AND LARVAE ENTRAINED (x 10^6) BY THE COOLING WATER SYSTEM AT SEABROOK STATION FROM JUNE 1990 THROUGH DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

TAXON	1990[a]	1991[b]	1992[c]	1993
EGGS				
Atlantic mackerel	518.8	673.1	456.3	112.9
Cunner/yellowtail flounder	490.4	716.3	198.6	58.4
Atlantic cod/haddock	29.1	74.5	39.5	50.3
Hakes/fourbeard rockling	113.6	35.1	50.6	32.7
Windowpane	36.4	19.9	22.5	29.1
American plaice	2.6	21.0	52.3	19.5
Lumpfish	0.0	0.0	0.0	9.5
Fourbeard rockling	7.4	4.3	0.8	1.4
Unidentified	0.0	2.0	0.0	0.8
Silver hake	11.4	0.0	0.1	0.4
Pollock	0.0	1.0	0.4	0.2
Hakes	37.3	2.6	0.0	0.2
Atlantic menhaden	0.0	0.5	1.4	0.1
Cusk	0.1	0.5	0.0	0.1
Total	1247.1	1550.8	822.5	315.6
LARVAE				
Atlantic seasnail	11.6	16.0	3.5	64.4
Grubby	0.0	22.4	1.9	13.8
American sand lance	0.0	37.3	18.1	12.0
Atlantic herring	0.7	0.5	4.9	9.6
Rock gunnel	0.0	51.1	45.3	5.7
Unidentified	0.7	2.1	1.4	5.6
Cunner	14.7	<0.1	0.0	4.7
Winter flounder	3.2	9.0	6.2	2.9
Gulf snailfish	0.1	2.8	1.9	2.6
Fourbeard rockling	37.9	0.5	0.1	2.2
American plaice	0.4	1.0	0.8	0.7
Longhorn sculpin	0.0	0.6	0.6	0.4
Moustache sculpin	0.0	0.1	0.3	0.4
Lumpfish	0.6	0.1	0.1	0.2
Snailfishes	0.1	0.3	0.0	0.2
Shorthorn sculpin	0.0	0.2	0.6	0.2
Radiated shanny	4.8	3.1	1.1	0.2
Atlantic cod	0.7	1.5	0.4	0.1
Silver hake	7.7	0.0	0.0	0.1
Windowpane	3.8	<0.1	0.1	0.1
Hakes	4.8	0.0	0.0	0.1
Atlantic mackerel	0.2	4.7	0.0	0.0
Yellowtail flounder	0.1	0.3	0.1	0.0
Alligatorfish	0.0	0.1	0.2	0.0
Wrymouth	0.0	0.1	0.0	0.0
Witch flounder	0.3	0.0	0.0	0.0
Tautog	0.3	0.0	0.0	0.0
Pollock	0.2	0.0	0.1	0.0
Fourspot flounder	0.2	0.0	0.0	0.0
Rainbow smelt	0.2	0.0	0.1	0.0
Goosefish	0.1	0.0	0.0	0.0
Atlantic menhaden	0.1	0.0	0.0	0.0
Redfish	0.0	0.0	0.4	0.0
Haddock	0.0	0.0	0.1	0.0
Unidentified sculpin	0.0	0.0	0.1	0.0
Total	93.5	153.8	87.8	126.2

[a] From NAI (1991). [b] From NAI (1992). [c] From NAI (1993).

flounder, and gulf snailfish. Behavioral characteristics of larvae may also reduce their susceptibility to entrainment. For instance, hake and fourbeard rockling larvae are surface oriented (Hermes 1985) and may not be susceptible to the mid-water intakes. The rapid larval development of Atlantic mackerel may enable them to develop a relatively high swimming speed (Ware and Lambert 1985) and, thus, may be able to avoid entrainment.

Annual Seabrook Station entrainment estimates for the selected taxa were compared to estimates from two other New England power plants, Pilgrim and Millstone Stations, for 1990 through 1993 (Table 5-8). Except for Atlantic seasnail larvae, annual entrainment estimates for Seabrook Station had similar annual estimates or were considerably less than at the other two power plants.

5.3.2 Adult Fish

5.3.2.1 Assemblages

5.3.2.1.1 Pelagic Fishes

The pelagic fish assemblage was sampled using a gill net array at three stations (Figure 5-1). Geometric mean CPUE of all fish caught at all three stations combined for 1993 was 1.8, a decrease from a mean of 2.7 in 1992, but generally similar to annual means found throughout the 1980s (Figure 5-5). Largest catches were made during the first 5 yr of sampling (i.e., 1976-80). Catch in 1993 was dominated by the Atlantic herring, Atlantic mackerel, alewife, rainbow smelt, and Atlantic cod (Table 5-9).

In general CPUE at the three gill net stations followed similar trends during the 18-yr period of sampling (Figure 5-5), as did the catch of the most numerous species (Table 5-9). Slightly higher catches were made at G3, the northernmost station, particularly during the first few and the most recent years of sampling. Catch during the preoperational period (1976-89) was dominated by Atlantic herring, blueback herring, silver hake, pollock, and Atlantic mackerel. For the operational period (1991-93), most of the catch was made up of Atlantic herring, pollock, Atlantic mackerel, and spiny dogfish.

The spiny dogfish has become increasingly abundant during the operational period, with a geometric mean CPUE of 0.2, which is approximately seven times the CPUE determined for the preoperational period. However, catch in 1993 (< 0.1) decreased substantially from the CPUE of 0.4 determined for 1992 (NAI 1993). Spiny dogfish have increased continuously since the 1960s, and, together with skates, now comprise about 75% of the fish biomass on Georges Bank (NFSC 1993). In the Gulf of Maine, the spiny dogfish is primarily found inshore during summer. It is known to prey upon Atlantic herring, Atlantic cod, Atlantic mackerel, and American sand lance, among other species (NFSC 1993). Because female spiny dogfish bear live young that are relatively large and well-developed, no specimens have been entrained at Seabrook Station and only 4 have been impinged on the traveling screens since 1990. The recent increase in spiny dogfish biomass has taken place concurrently with decreases in groundfish stocks in a large region of the Northwest Atlantic Ocean (NFSC 1993) and, thus, is not related to Seabrook Station operation.

5.3.2.1.2 Demersal Fishes

A 9.8-m otter trawl was used at three stations (Figure 5-1) to determine the abundance and distribution of demersal fishes. Geometric mean CPUE of all fish caught at all stations combined in 1993 was 21.9, an increase over the CPUE of 11.6

TABLE 5-8. COMPARISON OF ENTRAINMENT ESTIMATES (x 10^6) AT SELECTED NEW ENGLAND POWER PLANTS WITH MARINE INTAKES FROM 1990 THROUGH 1993. SEABROOK OPERATIONAL REPORT, 1993.

TAXON	SEABROOK	PILGRIM[a]	MILLSTONE[b]
Cunner/yellowtail flounder/tautog eggs[c]	58-716	629-2,609	2,736-4,758
Atlantic mackerel eggs	113-673	337-1,892	-
Atlantic herring larvae	1-10	1-6	-
Cunner larvae	0-15	3-134	-
Grubby larvae[d]	2-22	7-44	34-76
Atlantic seasnail larvae	4-64	2-9	-
Rock gunnel larvae	6-51	7-38	-
American sand lance larvae	12-37	23-108	7-61
Atlantic mackerel larvae	0-5	4-108	-
Winter flounder larvae	3-9	7-11	45-514

[a] MRI (1991, 1992, 1993b, and 1994); Cape Cod Bay.
[b] NUSCO (1994a, b); eggs-1990-1992, larvae-1990-1993; Long Island Sound.
[c] Seabrook: cunner/yellowtail; Pilgrim: cunner/tautog/yellowtail flounder; Millstone: cunner.
[d] Seabrook and Millstone: grubby; Pilgrim: grubby and other sculpins.

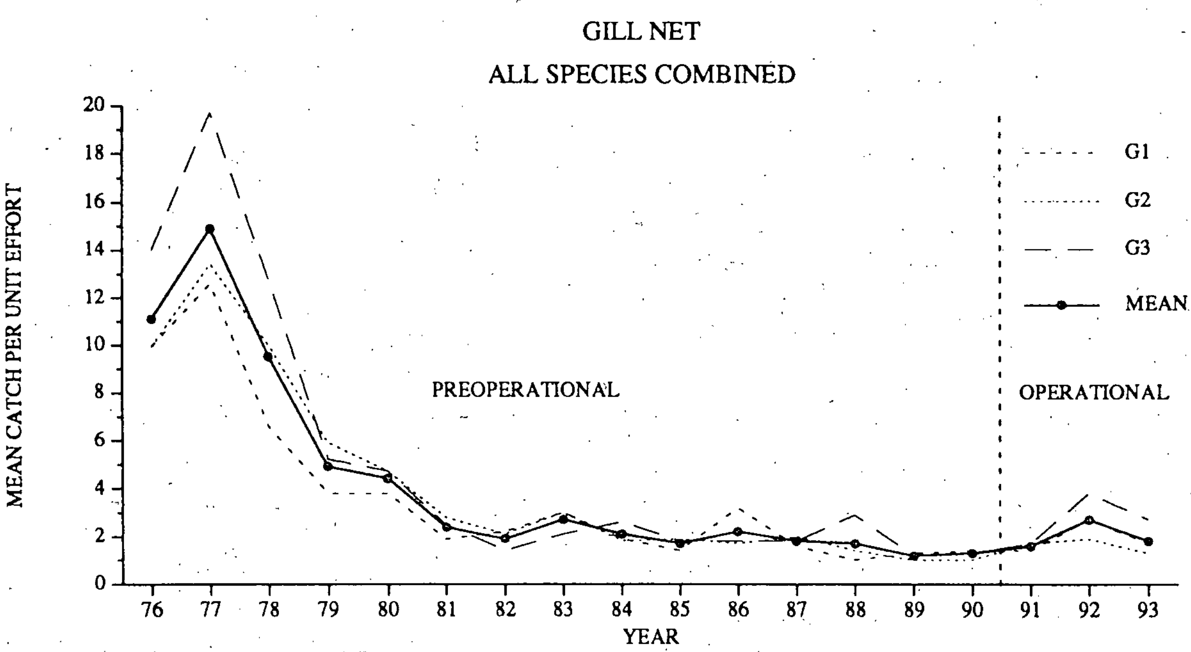


Figure 5-5. Annual geometric mean catch of **all species** combined per unit effort (number per 24-h set) in gill net samples by station and the mean of all stations, 1976-1993. Seabrook Operational Report, 1993.

TABLE 5-9. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 24-h SET, SURFACE AND BOTTOM) WITH COEFFICIENT OF VARIABILITY (CV) BY STATION (G1, G2, AND G3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED BY GILL NET DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1993 MEAN. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL PERIOD[a]		1993[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Atlantic herring	G1	1.0	18	0.4	0.4	13
	G2	1.1	20	0.1	0.3	32
	G3	1.2	20	0.4	0.5	5
	All Stations	1.1	19	0.3	0.4	13
Atlantic mackerel	G1	0.2	17	0.3	0.2	23
	G2	0.2	16	0.5	0.2	47
	G3	0.3	16	0.5	0.4	20
	All Stations	0.3	15	0.4	0.3	28
Pollock	G1	0.2	17	0.3	0.2	25
	G2	0.3	10	0.3	0.3	11
	G3	0.3	13	0.4	0.3	27
	All Stations	0.3	9	0.4	0.3	18
Spiny dogfish	G1	<0.1	45	<0.1	0.1	79
	G2	<0.1	35	<0.1	0.1	38
	G3	<0.1	27	0.1	0.3	54
	All Stations	<0.1	30	<0.1	0.2	50
Silver hake	G1	0.2	34	<0.1	0.1	69
	G2	0.3	36	<0.1	0.1	76
	G3	0.3	32	<0.1	0.1	40
	All Stations	0.3	34	<0.1	0.1	59
Blueback herring	G1	0.2	17	0.1	0.1	36
	G2	0.3	18	0.1	0.1	36
	G3	0.3	23	0.1	0.1	37
	All Stations	0.3	18	<0.1	0.1	15
Alewife	G1	0.1	17	<0.1	0.1	38
	G2	0.1	14	<0.1	0.1	45
	G3	0.1	22	0.1	0.1	41
	All Stations	0.1	15	<0.1	0.1	41
Rainbow smelt	G1	<0.1	26	0.2	0.1	68
	G2	0.1	21	0.1	<0.1	51
	G3	0.1	21	0.2	0.1	50
	All Stations	0.1	18	0.2	0.1	52
Atlantic cod	G1	0.1	17	0.0	<0.1	100
	G2	0.1	22	0.0	<0.1	100
	G3	0.1	13	0.0	0.0	-
	All Stations	0.1	13	0.2	<0.1	100
Other species	G1	0.4	9	0.2	0.3	21
	G2	0.4	10	0.2	0.3	25
	G3	0.4	11	0.1	0.3	32
	All Stations	0.14	9	0.2	0.3	22

[a] Preoperational: 1976-1989; geometric mean of annual geometric means.
[b] Geometric mean of the 1993 data.
[c] Operational: 1991-1993; geometric mean of annual geometric means.

determined for 1992, but remaining the second-lowest CPUE since sampling began in 1976 (Figure 5-6). The trawl CPUE peaked in 1980 (78.9) and 1981 (78.2), primarily due to large catches of yellowtail flounder. In 1993, catch was dominated by winter flounder, longhorn sculpin, Atlantic cod, yellowtail flounder, skates, hakes, and windowpane (Table 5-10).

Catch of nearly all species declined from the preoperational to the operational period, particularly for the yellowtail flounder (CPUE of 9.2 and 1.9, respectively). Other species showing decreases included the longhorn sculpin (4.1, 2.7), winter flounder (3.4, 3.1), hakes (3.1, 1.3), and Atlantic cod (1.9, 0.8). The catch of skates was similar (1.8, 1.7) in both periods. As noted previously, groundfish stocks have all decreased in the Northwest Atlantic and skate biomass is currently high in this area (NFSC 1993).

Differences in CPUE and species composition were apparent among the stations. The bottom at nearfield station T2, located in shallow (15-17 m) water off the mouth of Hampton-Seabrook Harbor, was occasionally inundated with drift algae. Stations T1 and T3 are in deeper (20-28 and 22-30 m, respectively) water and have sandy bottoms. CPUE of all species combined was consistently lower at T2 than at T1 and T3, which tended to have similar catches (Figure 5-6). Catch at T2 was dominated by winter flounder, whereas yellowtail flounder (preoperational period) and longhorn sculpin (operational period) were most common at T1 and T3. However, station to station comparisons are limited by the inability to sample by trawl at T2 during many sampling trips, particularly from August through October, when catches tend to be largest. Because largest catches were often made during late summer and early fall, this may have biased interstation comparisons, which used the entire database. Because of this potential bias, data from the August-October period were not used in the ANOVAs for selected species collected by trawl sampling, which is discussed below. For other months during the past 18 yr, a few collections were missed at T2, but overall trawl sampling effort at T2 was 92% of that at T1 or T3.

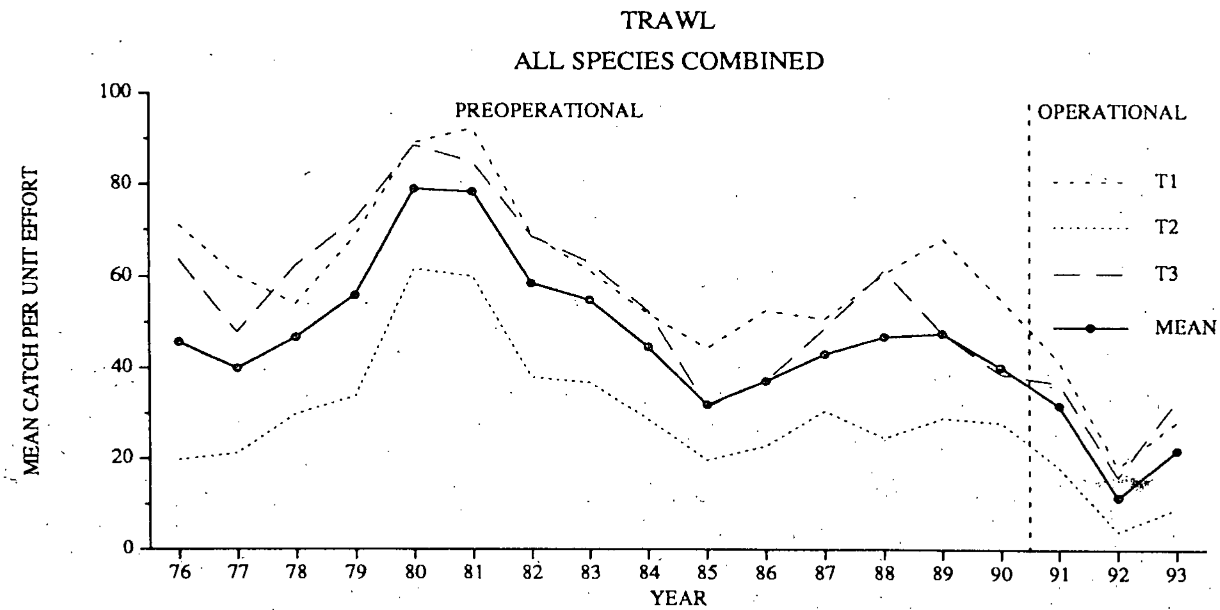


Figure 5-6. Annual geometric mean catch of **all species** combined per unit effort (number per 10-min tow) in trawl samples by station and the mean of all stations, 1976-1993. Seabrook Operational Report, 1993.

TABLE 5-10. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 10-min TOW) WITH COEFFICIENT OF VARIABILITY (CV) BY STATION (T1, T2, AND T3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED BY OTTER TRAWL DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1993 MEAN. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL PERIOD[a]		1993[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Yellowtail flounder	T1	19.9	3	5.3	4.4	19
	T2	2.9	8	0.4	0.4	34
	T3	10.2	5	2.0	1.8	28
	All Stations	9.2	4	2.2	1.9	23
Longhorn sculpin	T1	4.6	7	5.3	3.4	12
	T2	1.1	12	0.5	0.4	19
	T3	8.4	6	6.1	5.7	3
	All Stations	4.1	7	3.4	2.7	8
Winter flounder	T1	3.1	6	3.8	3.5	11
	T2	6.1	6	3.1	2.4	19
	T3	2.2	7	3.9	3.3	6
	All Stations	3.4	5	3.6	3.1	10
Hakes[d]	T1	4.2	5	1.5	1.9	14
	T2	1.6	9	0.9	0.7	24
	T3	3.6	5	0.8	1.3	23
	All Stations	3.1	5	1.0	1.3	18
Atlantic cod	T1	2.0	10	2.8	0.8	64
	T2	0.7	16	0.3	0.2	47
	T3	3.2	11	5.9	1.4	60
	All Stations	1.9	11	2.5	0.8	60
Skates	T1	1.7	16	2.0	2.7	17
	T2	0.5	10	0.4	0.2	21
	T3	3.8	5	3.5	2.8	18
	All Stations	1.8	9	1.8	1.7	15
Windowpane	T1	1.9	11	1.8	2.0	11
	T2	1.0	10	0.3	0.5	24
	T3	1.1	13	0.4	0.6	31
	All Stations	1.3	10	0.8	1.0	18
Rainbow smelt	T1	1.0	10	0.4	0.4	11
	T2	2.0	8	0.6	0.8	31
	T3	0.8	14	0.3	0.5	30
	All Stations	1.2	9	0.4	0.5	24
Ocean pout	T1	0.7	6	0.2	0.2	17
	T2	0.6	9	0.3	0.3	17
	T3	1.3	7	0.2	0.3	17
	All Stations	0.9	6	0.2	0.3	12
Silver hake	T1	0.9	16	0.3	0.4	18
	T2	0.2	21	0.1	0.1	53
	T3	0.9	14	0.4	0.7	16
	All Stations	0.6	15	0.2	0.4	17
Pollock	T1	0.3	17	0.4	0.7	33
	T2	0.7	20	0.3	0.5	25
	T3	0.2	20	0.2	0.2	28
	All Stations	0.4	17	0.3	0.5	28
Haddock	T1	0.2	34	0.0	<0.1	100
	T2	<0.1	62	0.0	0.0	-
	T3	0.5	27	0.2	0.1	58
	All Stations	0.2	28	0.1	<0.1	55
Other species	T1	5.9	2	4.6	4.2	7
	T2	3.5	2	2.0	2.1	10
	T3	6.1	2	4.5	4.2	4
	All Stations	5.3	2	4.0	3.7	6

[a] Preoperational: 1976-1989; geometric mean of annual geometric means.
[b] Geometric mean of the 1993 data.
[c] Operational: 1991-1993; geometric mean of annual geometric means.
[d] Includes red, white and spotted hakes.

5.3.2.1.3 Estuarine Fishes

Sampling for estuarine fishes was conducted at three stations within the estuary of Hampton-Seabrook Harbor (Figure 5-1) using a 30.5-m seine. Geometric mean CPUE for all fish caught at all stations during 1993 was 10.2 and, similar to CPUE for the gill net and otter trawl, represented an increase in catch from 1992 (CPUE of 5.6; Figure 5-7). Overall, seine catches generally were smaller (5.6-24.1) during 1987-93 than they were during 1976-84, when annual CPUE ranged from 22.7 to 59.1; no seine sampling took place in 1985 or April through June of 1986. The catch of most fishes by seine decreased from the preoperational to the operational period (Table 5-11). The Atlantic silverside has dominated the seine catch in all years sampled. Winter flounder, killifishes (mummichog and striped killifish), ninespine stickleback, and rainbow smelt also contributed to the catch.

Catch by station showed considerable variation over the years. Station S3, located near the mouth of the estuary, had peak catches in 1976, 1979, and 1990, but its CPUE has been generally close to the three-station mean since 1991. Station S1, located farthest from the mouth, had relatively low CPUE during the earliest years of sampling, but tended to approximate the overall mean in more recent years. CPUE at S2, located closest to Seabrook Station, had the largest CPUE value in 1993. Trends in CPUE were mostly due to the fluctuations in catch of the dominant species, the Atlantic silverside. Winter flounder and rainbow smelt were most common at S3, whereas killifish were most abundant at S1, with few taken at S3, likely due to salinity and temperature preferences.

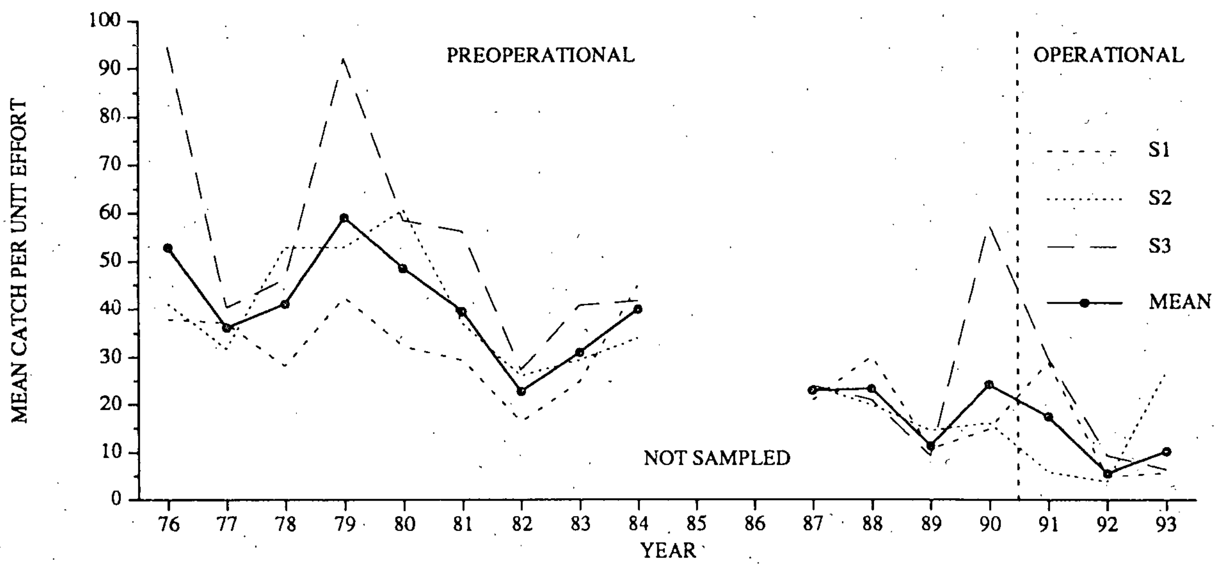


Figure 5-7. Annual geometric mean catch of **all species** combined per unit effort (number per haul) in seine samples by station and the mean of all stations, 1976-1993. Seabrook Operational Report, 1993.

TABLE 5-11. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER STANDARD HAUL) WITH COEFFICIENT OF VARIABILITY BY STATION (S1, S2, AND S3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED (CV) BY SEINE DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1993 MEAN. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL PERIOD[a]		1993[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Atlantic silverside	S1	7.7	7	2.2	3.6	19
	S2	7.3	5	7.3	3.9	18
	S3	7.5	8	2.6	4.1	15
	All Stations	7.5	6	3.6	3.8	10
Winter flounder	S1	0.9	11	0.3	0.3	63
	S2	1.1	13	1.2	0.4	62
	S3	2.9	8	0.9	1.1	9
	All Stations	1.5	9	0.7	0.6	16
Killifishes	S1	1.2	9	0.6	0.9	56
	S2	1.3	18	0.2	0.1	100
	S3	<0.1	30	0.0	0.0	-
	All Stations	0.7	12	0.3	0.3	50
Ninespine stickleback	S1	0.8	21	<0.1	0.3	50
	S2	0.6	24	0.1	0.1	25
	S3	0.6	24	0.0	0.2	77
	All Stations	0.7	20	<0.1	0.2	39
Rainbow smelt	S1	0.1	48	0.0	0.1	50
	S2	0.1	35	0.7	0.3	50
	S3	0.7	23	0.8	0.4	53
	All Stations	0.3	18	0.5	0.2	40
American sand lance	S1	0.1	44	0.3	0.3	3
	S2	0.2	47	0.8	0.2	100
	S3	0.1	27	0.1	<0.1	61
	All Stations	0.2	26	0.4	0.2	40
Pollock	S1	0.1	39	0.1	0.1	50
	S2	0.2	39	0.0	<0.1	100
	S3	0.4	35	0.0	0.2	51
	All Stations	0.2	34	<0.1	0.1	35
Blueback herring	S1	0.2	28	0.2	0.2	58
	S2	0.1	35	0.4	0.1	100
	S3	0.2	37	0.0	<0.1	100
	All Stations	0.1	28	0.2	0.1	50
Atlantic herring	S1	0.1	58	0.1	0.1	62
	S2	0.3	27	0.0	0.1	60
	S3	0.1	27	0.0	0.1	100
	All Stations	0.2	19	<0.1	0.1	52
Alewife	S1	0.1	41	0.0	<0.1	54
	S2	0.1	49	0.0	0.0	-
	S3	0.1	33	0.1	<0.1	100
	All Stations	0.1	35	<0.1	<0.1	14
Other species	S1	0.8	15	0.2	0.2	30
	S2	1.1	7	0.5	0.4	29
	S3	1.3	10	0.8	0.9	24
	All Stations	1.1	8	0.5	0.5	27

[a] Preoperational: 1976-1989; geometric mean of annual geometric means.
[b] Geometric mean of the 1993 data.
[c] Operational: 1991-1993; geometric mean of annual geometric means.

5.3.2.2 Impingement

Seabrook Station operated throughout 1993, with average circulating water flow ranging from 571 to 611.8 million gal·d^{-1} (Table 5-12). During 1993, an estimated 1,174 fish and American lobster were impinged, the same number as in 1992 (Appendix Table 5-2). Most (43%) fish were collected in December, followed by March (14%) and April (12%). Most of the impingement in December was associated with an intense coastal northeastern storm in that month (K. Dow, YAEC, pers. comm.). Only 151 specimens were impinged from June through November, with about 25% of the total comprised by Atlantic silverside and winter flounder. The lumpfish, windowpane, sea raven, northern pipefish, rainbow smelt, and grubby made up an additional 47% of the total catch.

Since 1990, when the station began more or less continuous pumping of seawater, the cumulative impingement totaled 3,866 fish and 42 American lobster (Appendix Table 5-2). More than one-third of all fish impinged since 1990 were collected in December (Appendix Table 5-3). Very few (6%) fish were impinged in summer (June-August). During the 4-yr operational period, winter flounder, pollock, windowpane, lumpfish, longhorn sculpin, sea raven, and Atlantic silverside made up 61% of the total estimated impingement. Except for pollock and Atlantic silverside, all of these fishes are primarily demersal. In fact, few pelagic fishes, such as herrings, Atlantic mackerel, and butterfish, have been impinged at Seabrook Station, even though the plant draws water from mid-depths.

The number of fish impinged annually at Seabrook Station may be compared to collections or annual estimates made at other large power plants in New England with marine intakes (Table 5-13). From November 1972 through October 1977, nearly 300,000 fish weighing 3,040 kg were collected in 215 24-h samples of impingement at the Maine Yankee Nuclear Generating Station (Evans 1978). The mean number of fish collected each year was approximately 50,000 fish during this period, with an average of 1,395 fish impinged per sampling day. Most fish were collected from November through April, when water temperatures were less than 10°C. Sticklebacks (four species), smooth flounder, alewife, rainbow smelt, Atlantic menhaden, winter flounder, and white perch dominated impingement samples, indicative of this power plant's location within the Sheepscot River estuary. No lobster were impinged at Maine Yankee.

At Pilgrim Nuclear Power Station, sited on Massachusetts Bay, an estimated annual average of 18,996 fish (adjusted for 100% plant operation) was calculated for a 20-yr period (Anderson 1994; Table 5-13). The mean impingement rate was 52 fish per day. During this period, catch was dominated mostly by Atlantic silverside, with rainbow smelt, herrings, and cunner occasionally abundant in samples. In 1993, 91 American lobster were collected, giving an estimated total impingement of 1,184 lobster for 100% station operation, which was a higher estimate than for most other years of Pilgrim Station operation (Anderson 1994).

In 21 yr of study, an average of 54,433 fish was impinged annually at the Brayton Point Station (Units 1-3), located on Mount Hope Bay in Massachusetts (MRI 1993a; Table 5-13). Atlantic menhaden, winter flounder, Atlantic silverside, hogchoker, alewife, silver hake, and threespine stickleback were most often impinged. Fish were impinged at an average rate of 118 per day. In a study to determine the effectiveness of angled screens at Brayton Point Unit 4 (LMS 1987), total numbers of fish collected on the screens were

TABLE 5-12. SPECIES COMPOSITION AND TOTAL NUMBER OF FINFISH AND AMERICAN LOBSTER IMPINGED AT SEABROOK STATION BY MONTH DURING 1993. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	PERCENT
Atlantic silverside	1	2	2	4								147	156	13.3
Winter flounder	35	12	44	20	1						1	28	141	12.0
Lumpfish	8	14	22	17	6	21	23	3				4	118	10.1
Windowpane	10	8	10	9	5					10	2	48	102	8.7
Sea raven	1	1	1	15	34	7		5	1	14	7	12	98	8.3
Northern pipefish			1	2								80	83	7.1
Rainbow smelt	6	5	2									67	80	6.8
Grubby	2		22	3	2							38	67	5.7
Atlantic cod			5	7	8		1			2	3	11	37	3.2
Longhorn sculpin	7		5	7	3	1	1	1		2	4	6	37	3.2
Skates	2	1	4								2	26	35	3.0
Righteye flounders			13	19									32	2.7
Pollock	3		3	1	1	2	1			6	13	2	32	2.7
Shorthorn sculpin	1	2	4	8	4	1	1				2	5	28	2.4
Rock gunnel	1		4	9	8	1					1	1	25	2.1
Herrings				1	1	1				2		14	19	1.6
Threespine stickleback		2	7	5								3	17	1.4
Cunner		1			8	3					1		13	1.1
Snailfishes		1	9	3									13	1.1
Wrymouth	6		1									5	12	1.0
Sculpins				5	2								7	0.6
Sea lamprey			3	3									6	0.5
Tautog					1				1	1			3	0.3
Hakes												3	3	0.3
American sand lance	1	1	1										3	0.3
Red hake						1				1			2	0.2
Alewife	1												1	0.1
Searobin	1												1	0.1
American plaice			1										1	0.1
Fourspot flounder		1											1	0.1
American lobster											1		1	0.1
TOTAL	86	51	164	138	84	38	27	9	2	38	37	500	1174	100.0
CIRCULATING WATER														
AVERAGE FLOW (MGD)	587	587	580	579	582	582	578	579	574	571	612	608		
RATE (no./10^9 gal)	4.73	3.10	9.12	4.84	2.11	1.56	1.51	0.50	0.12	2.15	2.02	26.53		

TABLE 5-13. COMPARISON OF FISH IMPINGEMENT ESTIMATES AT SELECTED NEW ENGLAND POWER PLANTS WITH MARINE INTAKES. SEABROOK OPERATIONAL REPORT, 1993.

STATION	SOURCE WATER BODY	RATED CAPACITY (MWe)	NOMINAL COOLING WATER FLOW ($m^3 \cdot sec^{-1}$)	YEARS OF STUDY	MEAN ANNUAL IMPINGEMENT	CV (%)	RANGE FOR ANNUAL ESTIMATES	MEAN NUMBER PER DAY	REFERENCE
Seabrook	Gulf of Maine	1,150	31.5	1990-93	957	33	499-1,173	2.6	------
Maine Yankee	Montsweag Bay	855	26.6	1972-77	49,999[a]	34	31,246-73,420[a]	1,395[a]	Evans (1978)
Pilgrim	Massachusetts Bay	670	20.3	1974-93	18,996[b]	81	1,143-87,752[b]	52[b]	Anderson (1994)
Brayton Point 1-3	Mount Hope Bay	1,150	39.0	1972-92	54,433	136	15,957-359,394	118	MRI (1993a)
Brayton Point 4	Mount Hope Bay	460	16.4	1984-85	-	-	1,479-18,095[a]	-	LMS (1987)
Millstone 2	Long Island Sound	870	34.6	1976-87	25,927[c] 65,927[d]	59 214	8,560-60,410[c] 8,560-511,387[d]	71[c] 181[d]	NUSCO (1988)

[a] Collected in sampling only, not a calculated annual estimate.
[b] Estimates adjusted assuming 100% station operation.
[c] Excluding an estimated 480,000 American sand lance taken on July 18, 1984.
[d] Including the sand lance mass impingement episode.

18,095 in 1985 and 1,449 in 1986. These numbers represented fish actually collected and no annual estimates were determined in this study. Bay anchovy comprised most (77%) of the catch in 1985; Atlantic silverside, northern pipefish, winter flounder, butterfish, and tautog were also relatively common.

Impingement sampling was conducted at Millstone Nuclear Power Station Unit 2, located on Long Island Sound, from 1976 through 1987 (NUSCO 1988). Annual impingement estimates for fish ranged from 8,560 to 511,387 (Table 5-13). The highest estimate, however, was skewed by a single-day catch of approximately 480,000 American sand lance. Excluding this catch, the largest annual total was 60,410 and the annual mean impingement was 25,927 (71 fish per day). Impingement samples at Millstone Unit 2 were dominated by winter flounder, anchovies, grubby, silversides, and Atlantic tomcod. Annual impingement estimates for American lobster ranged from 261 to 1,167, with an annual mean of 634 (CV = 14%).

Impingement estimates at Seabrook Station were much less (≤ 5%) than those at comparable electrical generating stations in New England. Impingement at a power plant does not reflect absolute fish abundance near the station, but is related to the susceptibility of a species to entrapment, intake design and location, plant operating characteristics, environmental variables (e.g., water temperature, wave height, wind direction and velocity), and time of day (Landry and Strawn 1974; Grimes 1975; Lifton and Storr 1978). The design of Seabrook Station offshore intake with a mid-water entrance and a velocity cap located in a relatively open water body has been successful at reducing the impingement of fish and lobster. Except for pollock and Atlantic silverside, demersal fish are most often impinged. This indicates that some features of the intake, as well as fish behavior and distribution, allow for the entrapment of bottom-dwelling species under certain conditions. The magnitude of impingement at Seabrook Station appears to be affected primarily by storms, particularly northeasters (NAI 1993). A similar phenomenon was noted at Millstone Nuclear Power Station, where large winter flounder impingement episodes were found to be related to a combination of high sustained wind and low water temperatures (NUSCO 1987). Storm events have also increased impingement at other estuarine (Thomas and Miller 1976) and freshwater (Lifton and Storr 1978) power plants.

5.3.3 Selected Species

5.3.3.1 Atlantic Herring

The Atlantic herring ranges in the Northwest Atlantic Ocean from western Greenland to Cape Hatteras (Scott and Scott 1988). Separate spawning aggregations associated with particular geographic areas in the Gulf of Maine have been recognized (Anthony and Boyar 1968; Iles and Sinclair 1982; Sinclair and Iles 1985) and tagging studies have shown high (> 90%) homing fidelity of spawning herring (Wheeler and Winters 1984). However, a lack of evidence exists for biochemical, genetic, and morphometric differentiation among these spawning groups (Kornfield and Bogdanowicz 1987; Safford and Booke 1992), indicating that there is enough gene flow to prevent the evolution of genetically distinct stocks. Atlantic herring spawning grounds are typically located in high energy environments (i.e., tidal or current), with demersal adhesive eggs deposited on marine vegetation or substrata free from silting (Haegele and Schweigert 1985). A major spawning area and source of larvae in the western Gulf of Maine is Jeffreys Ledge (Townsend 1992), although other banks and ledges in this area are also used (Boyar et al. 1971). Other major spawning grounds include Georges Bank and coastal areas of central and eastern Maine and Nova Scotia (Sinclair and Iles 1985).

Currently, the median age and size of maturity for U.S. coastal Atlantic herring is about 3 yr and 25 cm (O'Brien et al. 1993); all fish become mature by age-5 (NFSC 1993). Maximum size is about 430 mm and 0.68 kg (Bigelow and Schroeder 1953). Most spawning in the western Gulf of Maine occurs during September and October (Lazzari and Stevenson 1993). Fecundity of fall-spawning Atlantic herring from southwest Nova Scotia ranged from about 50 to 222 thousand eggs (Messieh 1976). The early life history of Atlantic herring is somewhat unique among other northern temperate fishes in that the larval stage is up to 8 mo long before metamorphosis to a juvenile phase (Sinclair and Tremblay 1984). Instead of spawning in spring to coincide with increasing water temperature and plankton food resources, fall-spawning herring must deal with extremely low winter temperatures and minimum plankton abundances (Townsend 1992). The 1.0-1.4-mm eggs hatch in about 10-15 d, when larvae are 4-10 mm (Fahay 1983). Hatching and larval growth are highly variable and depend mostly upon prevailing water temperatures. Lough et al. (1982) noted that larvae hatching at 5.7 mm grew to 30.9 mm over a 175-d period. Graham and Townsend (1985) reported mean growth of 0.199 $mm \cdot d^{-1}$ (range of 0.123-0.270) and a mortality rate of $2\% \cdot d^{-1}$ (0.7-3.1%) for Gulf of Maine larval Atlantic herring. Larvae hatched early in the season grow faster than those hatched late (Jones 1985). Larval mortality is generally highest in fall, low in winter, and increases again in spring (Graham et al. 1972). Larvae tend to drift or disperse from offshore spawning grounds into coastal bays and estuaries for further development and transformation to the juvenile phase of life. After metamorphosis, juveniles remain in coastal waters during summer. Adults tend to be found in specific summer feeding areas that are located near tidally-induced temperature fronts, where plankton productivity is high, and they overwinter after spawning in areas with slower currents than found elsewhere in the Gulf of Maine (Sinclair and Iles 1985).

Graham (1982) hypothesized that year-class strength was determined by a density-dependent mortality phase in fall and a density-independent phase in winter, both of which may be affected by the time of spawning and larval distribution following hatching and dispersion. Campbell and Graham (1991), however, noted that herring recruitment is a complex interaction among many critical factors, which may differ from year to year. A series of successive cohorts in space and time may help to limit intraspecific competition and mortality (Lambert 1984; Lambert and Ware 1984; Rosenberg and Doyle 1986). An inverse relationship was found between year-class strength and temperature during the late larval and early juvenile phases (Anthony and Fogarty 1985). Survival may be related to the rate at which temperature decreases in winter as well as to the absolute minimum temperatures (Graham et al. 1990). Low temperatures may also indirectly increase starvation and vulnerability to predation.

Abundance and landings of Atlantic herring have fluctuated considerably over the past 35 yr (NFSC 1993). During this period, the fishery in Maine has also changed from predominantly fixed gear to almost all mobile gear in recent years, due to the decreased availability of fish in nearshore areas. The Atlantic herring fishery on Georges Bank peaked at 373,600 mt in 1960, but collapsed to 43,500 mt in 1976. Recent indications are that the population on Georges Bank is recovering (Stephenson and Kornfield 1990; Smith and Morse 1993). Present biomass may even exceed pre-collapse levels, but without an offshore fishery to provide long-term catch data, present estimates of stock levels, although large, are imprecise (NFSC 1993).

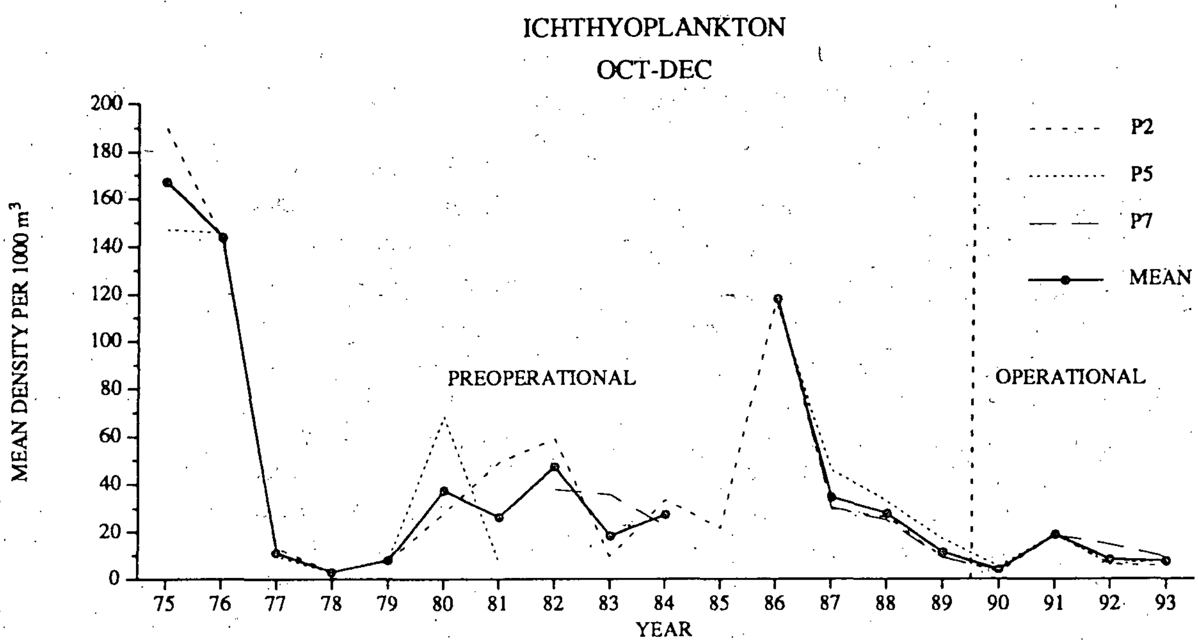
Atlantic herring eggs have not been identified in any ichthyoplankton collections for Seabrook Station studies, probably because they are demersal and adhesive. The larval stage was prevalent and typically occurred during an extended period from October through May. Peak abundance was found during the fall spawning season, from October through December (NAI 1993). Larval densities in 1993 were similar to those found during the operational period (Table 5-3) and in 1992 (NAI 1993). A large decline occurred during the preoperational period at all three ichthyoplankton stations (Figure 5-8). There was a noticeable decline in annual abundance during the late 1970s and again during a similar period in the 1980s, prior to the operation of Seabrook Station. Since 1989, annual abundance has remained relatively stable. During the period when all three stations were sampled (1986-93), similar densities were collected at each station and this was substantiated with the ANOVA results which showed no significant differences detected among stations (Table 5-14).

As pelagic fish, large juvenile and adult Atlantic herring were collected during Seabrook Station studies primarily by gill net. Catches were highest in spring and fall, with few taken during July and August (NAI 1993). Annual abundance was highest in 1976-78, began to decline in 1979-80, and has remained at a relatively low level from 1981 through the present (Figure 5-8). This was reflected by the ANOVA results, showing that the mean catch during the preoperational period was significantly greater than the operational period (Table 5-14). No significant differences were found among stations, indicating relatively uniform distribution of Atlantic herring in the area. However, as expected, catches among years and months were significantly different.

Despite their occurrence in the area of the Seabrook Station intake throughout much of the year, no Atlantic herring have been impinged on the traveling screens to date (Appendix Table 5-2). Thus, no direct plant impact to juvenile or adult fish has occurred. The Atlantic herring was the fourth-ranked species of entrained larvae in 1993, with an estimated total of 9.6 million (Table 5-6); this was the largest number entrained since the beginning of commercial operation (Table 5-7). However, this number is relatively small given that these larvae are likely drawn from the progeny of large spawning groups in the Gulf of Maine that disperse widely throughout the area over the course of a lengthy larval developmental period. The ANOVA interaction terms for both the ichthyoplankton and gill net programs were not significant, which indicated that the operation of Seabrook Station has not affected the local abundance or distribution of Atlantic herring. Even though the Georges Bank-Gulf of Maine herring biomass has increased in recent years to relatively high levels (NFSC 1993), recovery has not yet occurred in the Hampton-Seabrook area to former levels of abundance. The recovery on Georges Bank appears to be related to Atlantic herring biology and the lack of commercial fishing pressure in recent years (NFSC 1993). The stock may have re-established itself from a remnant population of fish that remained on the bank (Stephenson and Kornfield 1990) or by recolonization from other spawning grounds off Southern New England (Smith and Morse 1993).

5.3.3.2 Rainbow smelt

The anadromous rainbow smelt occurs from Labrador to New Jersey (Scott and Crossman 1973). It serves as forage for fish, birds, and seals



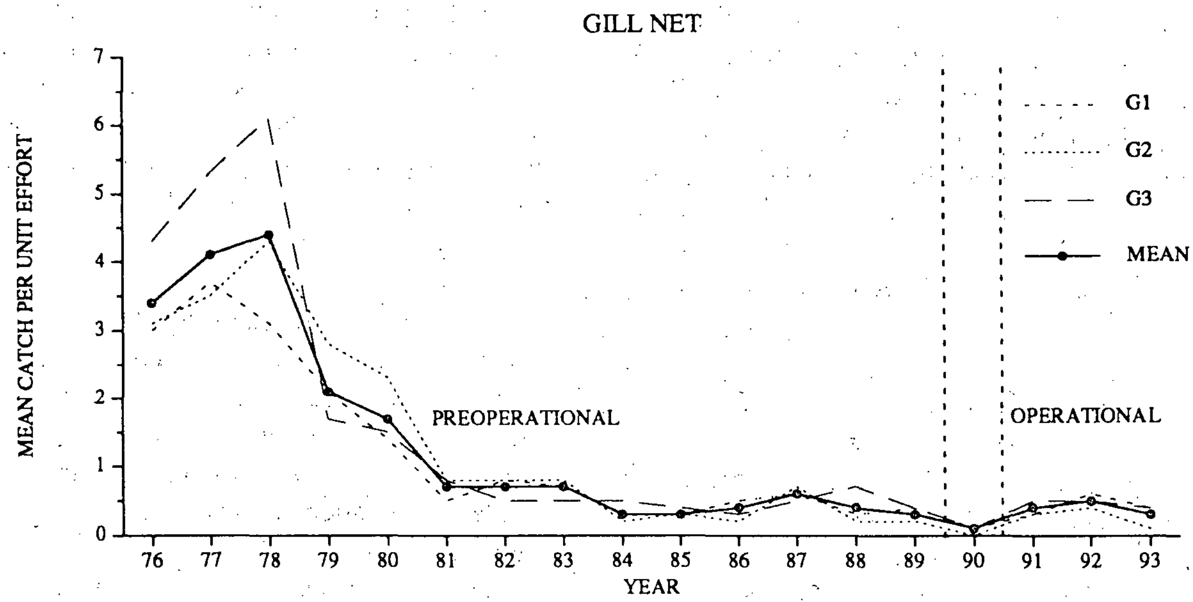


Figure 5-8. Annual geometric mean catch of **Atlantic herring** per unit effort in ichthyoplankton (number per 1000 m^3) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-14. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC HERRING DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	27.15	68.13 **	Op<Preop
(Oct.-Dec.)	Year (Preop-Op)[b]	6	4.29	10.77 **	
(1986-1993)	Month (Year)[c]	16	4.07	10.22 **	
	Station[d]	2	0.38	0.95 NS	
	Preop-Op X Station[e]	2	0.31	0.78 NS	
	Error	248	0.40		
Gill Net	Preop-Op[f]	1	3.33	84.44 **	Op<Preop
(Sep.-May)	Year (Preop-Op)	16	1.38	34.89 **	
(1975-1993)	Month (Year)	139	0.27	6.96 **	
	Station	2	0.10	2.60 NS	
	Preop-Op X Station	2	0.05	1.28 NS	
	Error	310	0.04		

[a] Preop-Op compares 1990-1993 to 1986-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares 1991-1993 to all previous years regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($p\leq 0.01$)

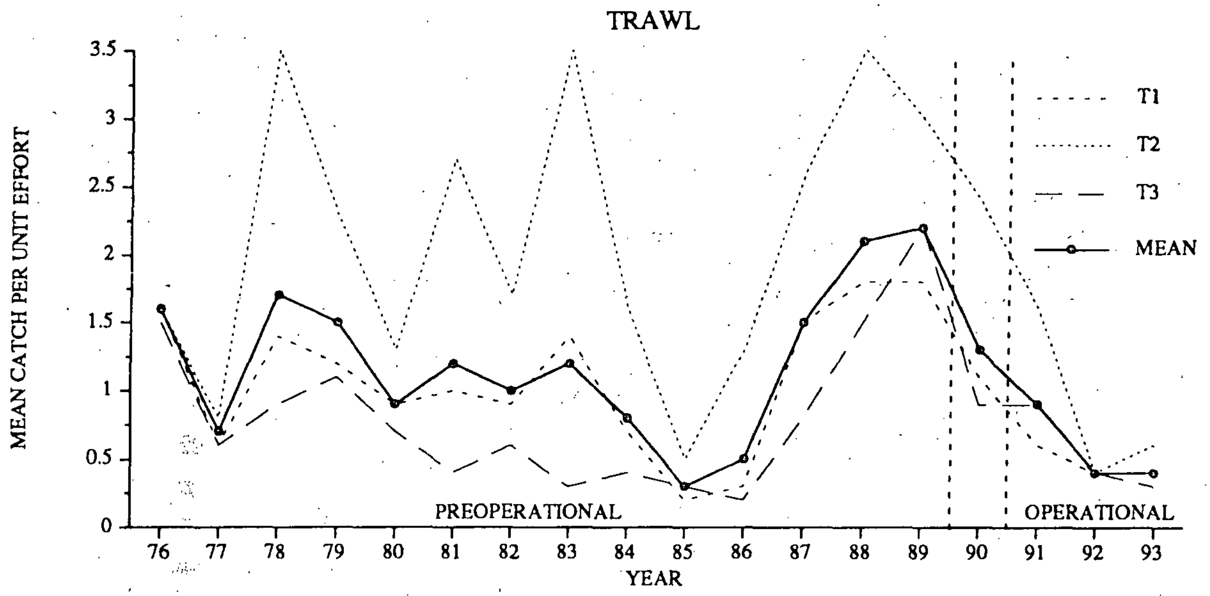
and supports minor sport and commercial fisheries in New England and Canada. A small (maximum size of about 35 cm) pelagic schooling species, it is readily available for sampling because it is mostly found in shallow, coastal waters. Adults begin to mature at ages-1 and 2 and live above 5 yr (Murawski and Cole 1978; Lawton et al. 1990). Adults enter estuaries in fall and winter and spawn in spring after ascending brooks or streams to the head of tide. Fecundity ranges from approximately 1 to 73 thousand eggs per female (Clayton 1976; Lawton et al. 1990). Spawning in the Jones River, MA commenced when water temperature was about 4°C (Lawton et al. 1990). Most of the spawners in this river were age-2 and the abundance of this age-class considerably affected spawning stock size. Based on larval production estimates, minimum egg survivorship in the Jones River was 0.06% in 1980. Eggs range in size from 0.9-1.2 mm, and attach to rocks, gravel, vegetation, or each other (Bigelow and Schroeder 1953). Larvae hatch at about 5 mm in length and grow to about 63 mm by November (Scott and Scott 1988). Larvae hatch at night (24-h periodicity) independent of water temperature or stream hydrodynamics and are carried down to estuaries, as no larvae are retained on the spawning grounds (Ouellet and Dodson 1985a, b). In the St. Lawrence River, smelt larvae are mostly found in the maximum turbidity zone of that estuary (Laprise and Dodson 1989; Dodson et al. 1989).

Stocks of rainbow smelt are localized to some extent, which would be important for impact assessment. Although adults of three geographical groups of rainbow smelt in estuarine waters of Quebec did not home to specific spawning rivers (Frechet et al. 1983), nor did fish among three different streams of the Parker River, MA estuary (Murawski et al. 1980), other isolating mechanisms apparently limit gene flow. A probable means is the ability of larvae to retain themselves in estuarine areas by using active vertical migration in relation to tides (Ouellet and Dodson 1985a; Laprise and Dodson 1989).

Near Seabrook Station, rainbow smelt were collected by otter trawl mostly from December through April (NAI 1993), which corresponds to the winter-spring spawning run. The annual geometric mean CPUE showed some evidence of cyclical variation, with the operational period beginning during a decreasing trend and CPUE in both 1992 and 1993 apparently corresponded to a period of low abundance (Figure 5-9). Catches were greatest at station T2, off the mouth of Hampton-Seabrook Harbor, and were smaller, but relatively similar at T1 and T3.

The annual geometric mean CPUE for seine sampling also showed some cyclical variation in abundance (Figure 5-9). The largest annual seine CPUE values occurred in 1979 and 1990, 1 yr after cyclical peaks were observed in trawl catches. As seine sampling occurs from April through November, these catches may have corresponded to increased numbers of age-1 fish resulting from larger-than-average adult spawning stocks of the previous year. Most rainbow smelt were taken at S3, although catches at all three stations in 1993 showed increases relative to 1991 and 1992.

The results from the ANOVA indicated that abundances were significantly greater during the operational period in comparison to the preoperational period for both the trawl and seine data (Table 5-15). Given the longer time span of preoperational sampling and the several peaks of abundance that occurred during this period, this was not unexpected. The ANOVA interaction terms for both trawl and seine catches were not significant, indicating that no power plant impact has occurred. Because of the behavior and specific life history of the rainbow smelt, no eggs and few larvae (about 3% frequency of occurrence



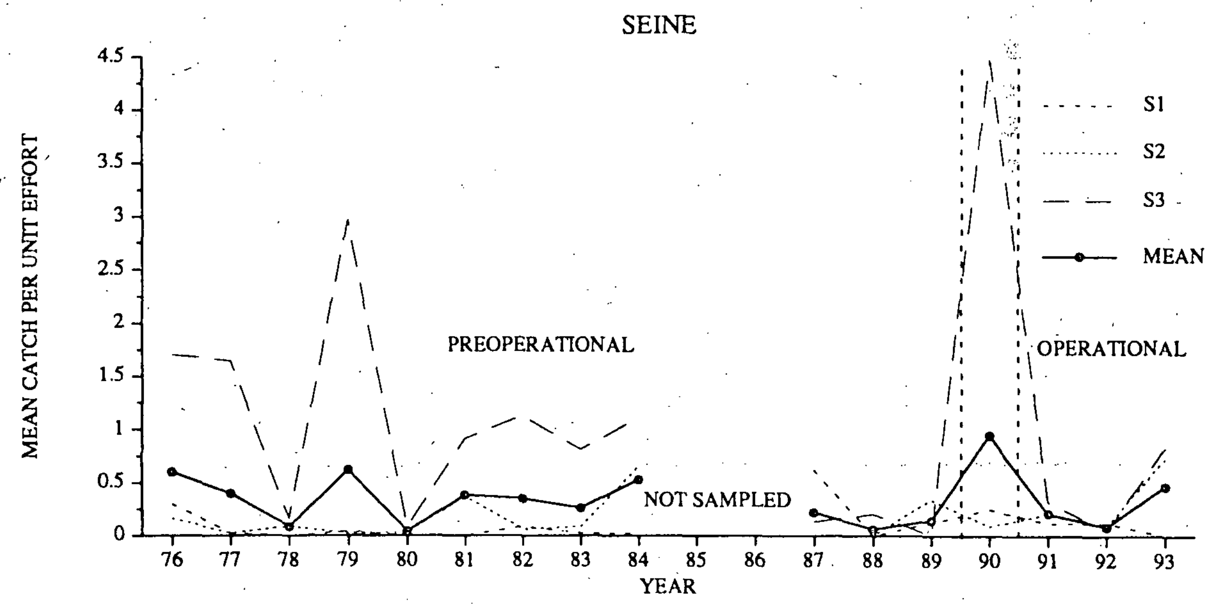


Figure 5-9. Annual geometric mean catch of **rainbow smelt** per unit effort in trawl (number per 10-min tow) and seine (number per haul) samples by station and the mean of all stations, 1976-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-15. RESULTS OF ANALYSIS OF VARIANCE FOR RAINBOW SMELT DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Trawl	Preop-Op[a]	1	3.38	53.98 **	Op<Preop
(Nov.-May)	Year (Preop-Op)[b]	16	0.50	7.92 **	
(1975-1993)	Month (Year)[c]	104	0.18	2.88 **	
	Station[d]	2	0.02	0.35 NS	
	Preop-Op X Station[e]	2	0.11	1.83 NS	
	Error	238	0.06		
Seine	Preop-Op[f]	1	4.54	29.70 **	Op<Preop
(Apr.-Nov.)	Year (Preop-Op)	13	0.63	4.14 **	
(1976-1993)	Month (Year)	105	0.92	6.05 **	
	Station	2	0.04	0.26 NS	
	Preop-Op X Station	2	0.17	1.08 NS	
	Error	236	0.15		

[a] Preop-Op compares Nov. 1990-May 1993 to all previous months/years regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares 1991-1993 to 1976-1989 regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

in all offshore samples) have been collected in the ichthyoplankton sampling program. Annual entrainment estimates have been very low, with larvae collected only in 1990 and 1992, accounting for a total entrainment estimate of about 3,000 larvae since the beginning of plant operation in 1990 (Table 5-7). A total of 159 rainbow smelt was impinged during the last 4 yr (Appendix Table 5-2). Given that so few rainbow smelt have been taken at Seabrook Station and that the abundance in trawl sampling showed similar patterns in annual CPUE at all stations, it is very unlikely that this species is affected by Seabrook Station operation.

5.3.3.3 Atlantic cod

The Atlantic cod is found in the Northwest Atlantic Ocean from Greenland to Cape Hatteras and is one of the most important commercial and recreational fishes of the United States. The highly predatory, omnivorous cod can commonly achieve a length of 130 cm, a weight of up to 25-35 kg, and can live 20 yr or more. However, smaller (50-60 cm, 1.1-2.3 kg, age-2-6) are more typically caught by the fisheries (Bigelow and Schroeder 1953; Scott and Scott 1988; NFSC 1993). The Atlantic cod is a cool-water fish, and is found and spawns at temperatures from about-1 to 10°C; distribution is also influenced by time of year, geographical location, and fish size (Jean 1964; Scott and Scott 1988; Branden and Hurley 1992). Many separate groups spawning at different locations have been noted in the Northwest Atlantic, but for management purposes two stocks (Gulf of Maine, and Georges Bank and South) are recognized in U.S. waters (NFSC 1993).

Atlantic cod mature between ages 2 and 4, with age and size of 50% maturity of 2.1-2.3 yr and 32-36 cm for Gulf of Maine fish (O'Brien et al. 1993). Fecundity can be quite high, from 0.2 to 12 million eggs spawned per female (Powles 1958). Spawning can take place from late fall through spring, but typically peaks in late winter and early spring (O'Brien et al. 1993). The 1.2-1.6-mm diameter egg is pelagic. Newly-hatched larvae are about 4-5 mm in length and growth over the first 9 mo averages about 0.21 $mm \cdot d^{-1}$ (Bolz and Lough 1988). In well-mixed waters the eggs and larvae are distributed throughout the water column (Lough and Potter 1993). However, when lengths reach 6 to 8 mm, larvae develop a diel behavior. During the day, larvae are found predominantly near the bottom and at night from mid-depths to the surface in unstratified waters and at the thermocline in stratified waters (Perry and Nielsen 1988; Lough and Potter 1993). Vertical (Lough and Potter 1993) and horizontal (Suthers and Frank 1989) movements become less extensive with age and larger (> 20 mm) pelagic juveniles occur at greater depths than larvae. By summer, juveniles 40 mm or larger make the transition from a pelagic to a demersal habitat. This transition can occur over a relatively large size range (40-100 mm) over a 1-2 mo period and even demersal juveniles may move 3-5 m off the bottom at night (Lough and Potter 1993).

Spatial distribution also changes with age and cod of ages 1-2, 3, and 4+ in Southern New England and on Georges Bank were reported by Wigley and Serchuk (1992) to be distributed at different depths during spring. Seasonal distribution shifts are likely associated with water temperature. Suthers and Frank (1989) noted that nearshore waters of Nova Scotia contained high densities of young cod and may serve as an important nursery area for fish originating from offshore spawning sites.

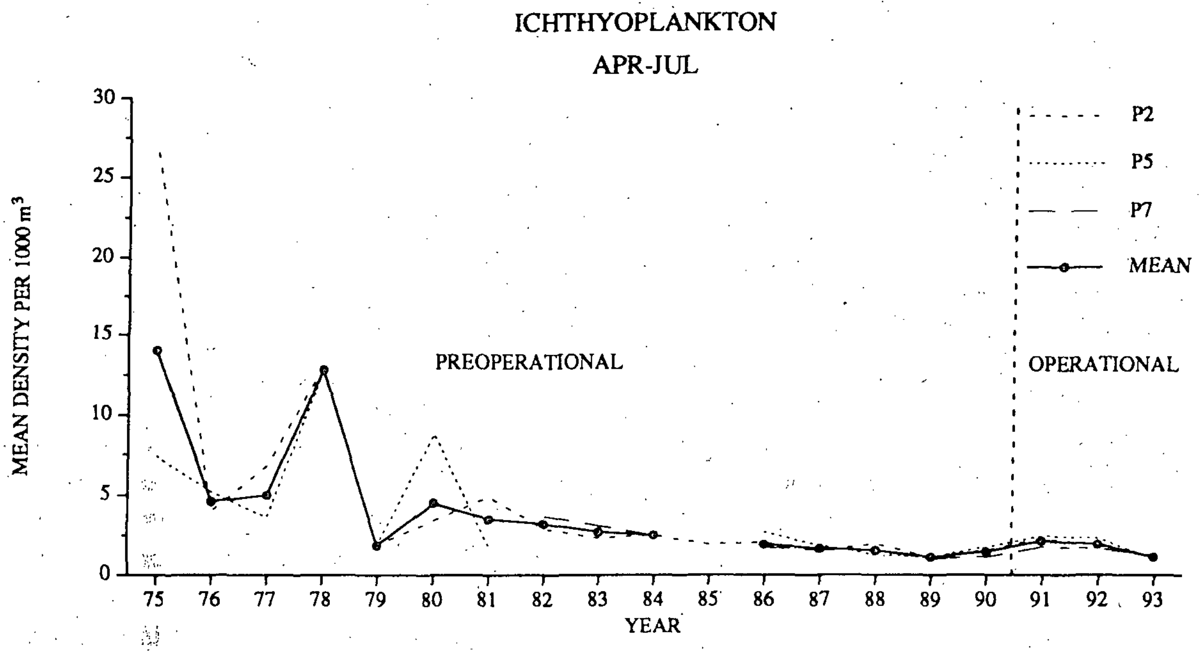
The success of cod year-classes in the Northwest Atlantic Ocean exhibit periodicities of 10 to 20 yr and there was little evidence that the annual reproductive output of adult spawners was significantly related to year-class success (Koslow et al. 1987). The periodicities observed may correspond to regional physical and biological processes (Koslow 1984). Year-class success tended to be statistically associated with large-scale meteorological patterns. Campana et al. (1989) also did not find evidence that cod year-class strength was related to egg or larval abundance. However, abundance of both pelagic and demersal juveniles did appear to reflect year-class strength. Sources of mortality were not identified, but the mortality between the larval and juvenile stages was inversely correlated to year-class strength. Timing of local physical and biological events were thought to be important for recruitment success. Brander and Hurley (1992) found that cod spawning during spring moved progressively later from southwest to northeast in Nova Scotia waters and matched peak abundance of the copepod *Calanus finmarchicus*. This may be consistent with a "match-mismatch" hypothesis (Cushing 1984) for successful reproduction in that cod spawning is coupled with copepod production, but definitive relationships remain to be demonstrated (Brander and Hurley 1992).

Because of its long history of exploitation, fishing mortality has also played a key role in determining Atlantic cod abundance. Annual sport and commercial landings for the Gulf of Maine averaged about 15,100 mt during 1972-82 and 13,100 mt for 1983-89, but rose to 18,700 mt in 1990 and to a record 20,300 mt in 1991 (NFSC 1993). Landings decreased 43% to 11,600 mt in 1992, but commercial otter trawl effort remained at near-record high levels. The catch has been dominated by the strong 1987 year-class, which accounted for about 55% of the 1992 landings. Recruitment since 1988 has been average or below average and spawning stock biomass is expected to remain at record low levels. Because of declining stock biomass and continued high rates of fishing, the Gulf of Maine Atlantic cod stock is considered overexploited (NFSC 1993).

Atlantic cod eggs in ichthyoplankton collections were grouped as Atlantic cod/haddock because it was difficult to distinguish between these two species; this aggregation also included witch flounder eggs. These taxa have been dominant during late fall (Table 5-4; Figure 5-2). Examination of larval data since July 1975 indicated that the frequency of occurrence in samples (total of 3,681) of Atlantic cod was 858, haddock was 56, and witch flounder was 668. Assuming a relatively similar hatching rate, it would appear that Atlantic cod and witch flounder eggs predominated in this egg group.

Atlantic cod larvae typically exhibited a bimodal annual occurrence, with one peak from November through February and a second, larger peak from April through July (NAI 1993). To compare abundances among years and stations, only data from April through July were used. There was a decrease in larval densities during the 1970s, but annual abundances have remained relatively stable and very similar at all stations from 1980 to the present (Figure 5-10). This decrease in abundance was evident in the comparison of preoperational and operational geometric means (Table 5-3), but the decline occurred about 10 yr before plant operation.

At Seabrook Station, larger Atlantic cod were taken year-round by the trawl sampling program, but consistent with their annual movements, catches were highest in spring and fall and lowest in summer (NAI 1993). Annual geometric mean CPUE was nearly always greater at the two farfield stations (particularly T3) than at the nearfield station T2 (Figure 5-10). This was attributed to differences in habitat between T2 and the other stations (NAI 1993). Overall, cod abundance was relatively stable from 1977-83 and then decreased. An increase in numbers followed until a peak was



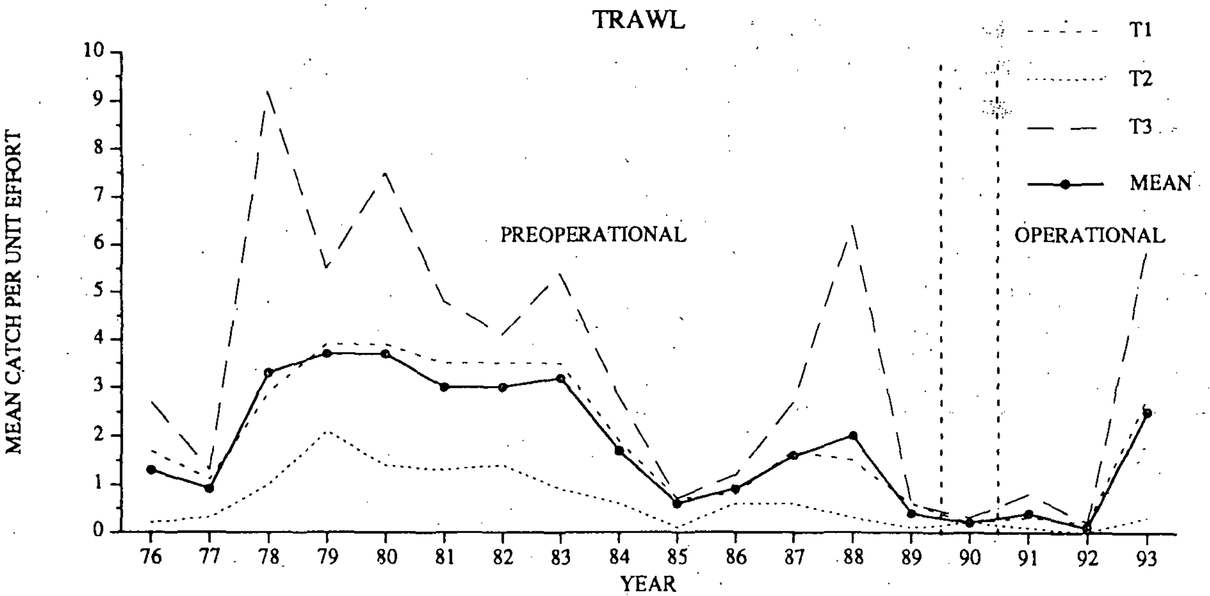


Figure 5-10. Annual geometric mean catch of **Atlantic cod** per unit effort in ichthyoplankton (number per 1000 m^3) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

reached in 1988, perhaps due to the contribution of the strong 1987 year-class. Abundance then declined abruptly to very low levels, particularly in 1992. However, a large increase in abundance occurred in 1993, especially at T3, but abundance at T2 remained depressed. Bottom water temperatures during the operational period were significantly higher than during the recent preoperational period at all stations, although 1993 was generally cooler than 1992 or 1991 (see Section 2.0 - Water Quality). Water temperature may have affected inshore abundances, especially if the temperature at the nearfield station, even if not raised by station operation, was above the preferred range for Atlantic cod.

An ANOVA applied to Atlantic cod trawl data indicated that catch during the operational period was significantly less than during the preoperational period, but for larvae the opposite was true (Table 5-16). Given the reported decreases in the Gulf of Maine stock and continued low recruitment reported by NFSC (1993), this was not unexpected for the trawl data. The significantly greater operational abundance of larval cod was due to the restriction of data from July 1986 through 1993 for the ANOVA, when all three stations were sampled; this short series showed a slight increase in abundance only during the operational period (Figure 5-10). The ANOVA interaction terms for both trawl and ichthyoplankton data were not significant, indicating a similar pattern in annual abundance at all stations during both the preoperational and operational periods. Only 109 Atlantic cod have been impinged at Seabrook Station since 1990 (Appendix Table 5-2). Egg and, in particular, larval entrainment was relatively low (Tables 5-6 and 5-7), given the high fecundity and source population size of Atlantic cod in the Gulf of Maine. Furthermore, year-class success was apparently related to large region-wide events affecting survival of pelagic and demersal juveniles. Thus, it is very likely that decreases in abundance and a possible change in local distribution are due to regional declines in Atlantic cod abundance and to a naturally-occurring increase in temperature. These changes have no relation to the operation of Seabrook Station.

5.3.3.4 Pollock

The pollock is one of the most pelagic of all the codfishes and is often found in large schools. It is a cool-water species, preferring water temperatures of 7.2-8.6°C and is not found in waters exceeding 18.3°C (Scott and Scott 1988). Pollock may reach a length of 107 cm and a weight of 32 kg. Found from southwest Greenland to Cape Lookout, NC (Bigelow and Schroeder 1953), it is most abundant on the Scotian Shelf and in the Gulf of Maine (NFSC 1993). Adults move into the southwestern Gulf of Maine in fall or early winter to spawn, which mostly occurs from November through February (Colton et al. 1979). The median age and size of maturity for female pollock is 2 yr and 39.1 cm (O'Brien et al. 1993). Typical of codfishes, the pollock is highly fecund with an average production of 225 thousand eggs and with a 10.7-kg female capable of spawning over 4 million eggs (Bigelow and Schroeder 1953). The pelagic egg is 1.04-1.20 mm in diameter (Markle and Frost 1985) and newly-hatched larvae are 3-4 mm in length (Fahay 1983). First-year growth is rapid and young can often be very abundant along Gulf of Maine coastal beaches (MacDonald et al. 1984), rocky subtidal areas (Ojeda and Dearborn 1990), and apparently even use tide pools as a nursery (Moring 1990). Young grow rapidly and by fall can achieve lengths of 215 mm (Ojeda and Dearborn 1990) before they move offshore for the winter.

TABLE 5-16. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC COD DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	0.52	5.58 *	Op>Preop
(Apr.-Jul.)	Year (Preop-Op)[b]	5	0.53	5.72 **	
(1987-1993)	Month (Year)[c]	21	0.42	4.52 **	
	Station[d]	2	0.15	1.67 NS	
	Preop-Op X Station[e]	2	0.01	0.10 NS	
	Error	289	0.09		
Trawl	Preop-Op[f]	1	1.05	24.76 **	Op<Preop
(Nov.-Jul.)	Year (Preop-Op)	16	0.52	12.34 **	
(1975-1993)	Month (Year)	140	0.08	1.95 **	
	Station	2	1.32	31.07 **	
	Preop-Op X Station	2	<0.01	0.07 NS	
	Error	308	0.04		

[a] Preop-Op compares 1991-1993 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares Nov. 1990-May 1993 to all previous months/years regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

Combined U.S. and Canadian landings for the Scotian Shelf, Gulf of Maine, and Georges Bank regions increased from a yearly average of about 38,200 mt in 1972-76 to 68,500 mt by 1986, with U.S. landings alone in 1986 of 24,500 mt (NFSC 1993). Recreational landings fluctuated between 100 and 1,300 mt. Based on NMFS trawl surveys, biomass of pollock in the Gulf of Maine and on Georges Bank has decreased sharply during the 1980s from a peak in the late 1970s and has remained relatively low in recent years. During this period, the catch of pollock was dominated by several moderately strong year-classes that occurred every 3 to 4 yr, including those from 1975, 1979, and 1982. More recently, the 1987 and 1988 year-classes appeared to be above the long-term mean and accounted for about half the landings in 1992. The 1989-91 year-classes, however, are below average in abundance. The pollock stock is considered by NFSC (1993) to be fully exploited.

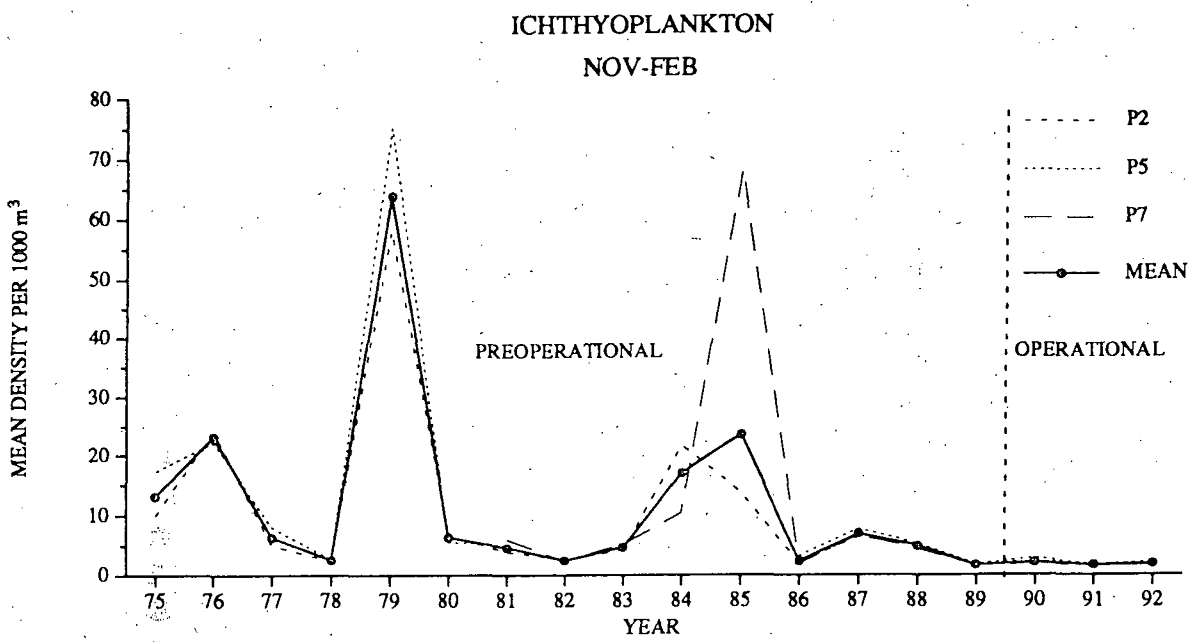
Pollock eggs and larvae were collected in relatively low densities (Tables 5-4 and 5-5). Larval pollock abundance generally peaked during November through February (NAI 1993). There was a decline in the geometric mean density between the preoperational and operational periods, with large annual fluctuations occurring during the preoperational period (Table 5-3; Figure 5-11). Except for 1985, annual abundances have been similar at all stations.

Pollock have been collected by gill net near Seabrook Station from spring through fall and were generally absent in winter (NAI 1993). Annual geometric mean CPUE varied considerably from year to year, with no single station producing consistently high or low catches (Figure 5-11). Fluctuations observed may have corresponded to the successive presence of fish from dominant and weak year-classes reported by NFSC (1993). However, an increase in catch occurred in 1993 relative to 1992 and 1991, despite estimates of below-average year-classes produced in recent years.

The ANOVA for gill net catch data showed no significant differences between preoperational and operational periods (Table 5-17). However, larval abundance was significantly greater during the preoperational period. The interaction terms for both gill net and ichthyoplankton sampling were not significant, suggesting that plant operation has not affected abundance. Relatively few eggs and larvae were entrained (Table 5-7), but the pollock ranked second among fishes impinged at Seabrook Station from 1990-93, with a total of 456 fish (Appendix Table 5-2). Nevertheless, this is a relatively small number for such a widespread and abundant species. It is likely that the catch of juvenile and adult pollock near Seabrook Station reflects natural variability in annual abundance patterns of the Gulf of Maine stock. No changes in abundance or distribution can be attributed to station operation.

5.3.3.5 Hakes

Three species of hake (genus *Urophycis*) are found in the Gulf of Maine: the red hake, white hake, and spotted hake. The spotted hake, however, is apparently quite rare in this area (Bigelow and Schroeder 1953; Scott and Scott 1988) and is not important to the fisheries. For these reasons, it will not be discussed below. Both the red and white hakes are common in the Northwestern Atlantic Ocean, particularly on sandy or muddy grounds off Northern New England. They most commonly co-occur in the Gulf of Maine (Musick 1974). Similar in appearance and in many aspects of their biology, other features differ considerably. Some of the most distinguishing characteristics between these two species are in specific geographical



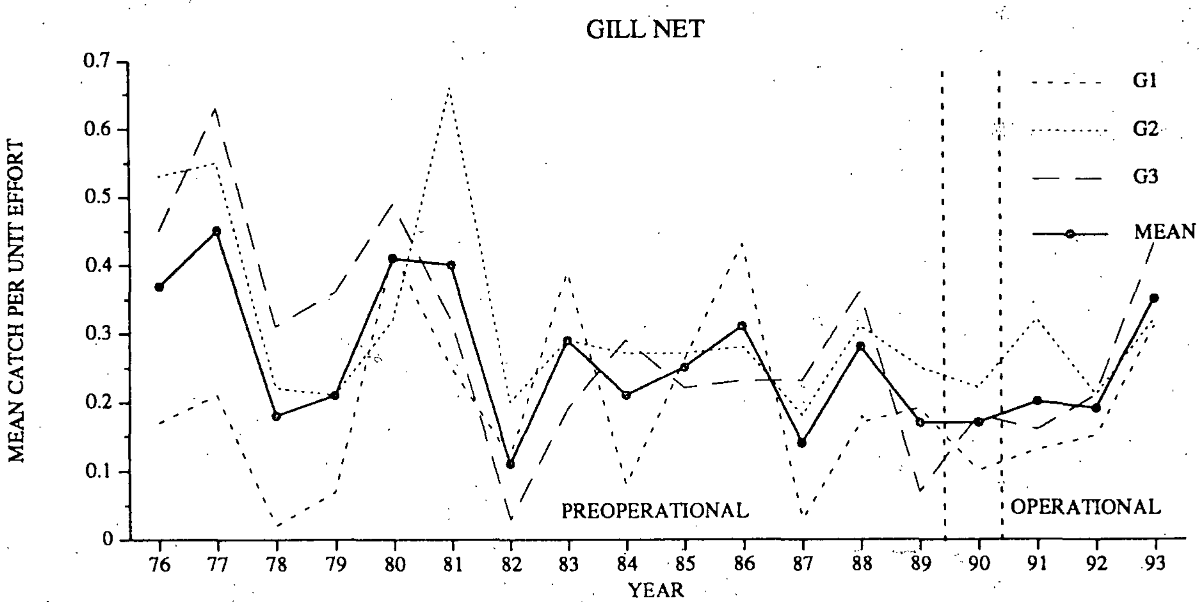


Figure 5-11. Annual geometric mean catch of **pollock** per unit effort in ichthyoplankton (number per 1000 m^3) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-17. RESULTS OF ANALYSIS OF VARIANCE FOR POLLOCK DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Nov.-Feb.) (1986-1993)	Preop-Op[a]	1	5.61	38.55 **	Op<Preop
	Year (Preop-Op)[b]	6	2.09	14.35 **	
	Month (Year)[c]	20	0.91	6.27 **	
	Station[d]	2	0.40	2.76 NS	
	Preop-Op X Station[e]	2	<0.01	<0.01 NS	
	Error	295	0.15		
Gill Net (Apr.-Dec.) (1976-1993)	Preop-Op[f]	1	0.03	0.96 NS	
	Year (Preop-Op)	15	0.28	8.99 **	
	Month (Year)	136	0.11	3.71 **	
	Station	2	0.12	3.98 *	
	Preop-Op X Station	2	0.08	2.74 NS	
	Error	302	0.03		

[a] Preop-Op compares 1990-1993 to 1986-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares 1991-1993 to 1976-1989 regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

distribution and in size attained. The red hake is found in more shallow waters of the inner continental shelf, predominantly in depths of 73 to 126 m (Musick 1974). It occurs in water temperatures of 5 to 12°C, but apparently prefers a range of 8-10°C and avoids waters colder than 4°C. In the Gulf of Maine, red hake are found inshore for spawning, but disperse offshore following spawning. Except for young, most white hake are typically found in deeper (200-1,000 m) water than red hake and are considered to be inhabitants of the outer shelf and continental slope. Temperature preferences (5-11°C), however, are similar to that of the red hake. Current estimates of median size and age of maturity for females are 26.9 cm (1.8 yr) for red hake and 35.1 cm (1.4 yr) for white hake (O'Brien et al. 1993). Maximum size of the white hake is 135 cm, much larger than the maximum of 50 cm for the red hake (NFSC 1993).

The white hake is highly fecund with a 70-cm female producing 4 million eggs and a 90-cm fish about 15 million (Scott and Scott 1988). Most white hake spawning occurs in spring on the continental slope south of the Scotian Shelf and Georges Bank, and off Southern New England (Fahay and Able 1989; Comyns and Grant 1993). Red hake spawn mostly during summer and fall in mid-shelf areas. Eggs of both species are pelagic and are similar in size (range of 0.63-0.97 mm; Fahay 1983; Markle and Frost 1985). Newly-hatched larvae of both hakes are neustonic (Hermes 1985) and even juveniles remain pelagic for a considerable time, until 25-30 mm for the red hake (Steiner and Olla 1985) and 50-80 mm for the white hake (Markle et al. 1982). Growth of young is rapid and can average about 1 $mm \cdot d^{-1}$ (Fahay and Able 1989). Larger juveniles of both species tend to be found closer to shore. White hake juveniles recruit inshore in June and July (Fahay and Able 1989) and red hake from September to December (Steiner et al. 1982). Many young red hake are inquiline and live within the mantle cavity of the sea scallop (*Placopectin magellanicus*) until they outgrow this commensal host (Steiner et al. 1982; Garman 1983; Luczkovitch 1991). Other red hake, however, find shelter under shell or other bottom structures (Steiner et al. 1982).

Commercial fishing landings of red hake in the Gulf of Maine and from the northern Georges Bank are currently very low (< 1,000 mt), with an average of only 1,100 mt landed over the period of 1977-92 (NFSC 1993). The NMFS trawl survey index showed an increasing trend in abundance from the mid-1970s to a peak in 1990; indices decreased in 1991 and 1992, but remained near the long-term average. Although year-classes produced since 1985 were termed moderate in strength, NFSC (1993) concluded that the red hake is underexploited and could sustain much higher catches. In contrast, although taken primarily in non-directed fisheries, white hake landings in the Gulf of Maine (primarily from the western portion) are currently high, being exceeded only by those for the Atlantic cod (NFSC 1993). Previous landings peaked at 7,500 mt in 1984, declined to 5,500 mt in 1990, but recently increased to an historic high of 9,600 mt in 1992. NMFS trawl survey indices have fluctuated considerably, but indications are that abundance increased in 1991 and 1992. NFSC (1993) concluded that, on the basis of the stability of stock biomass since 1981, the white hake is fully exploited and can sustain annual commercial landings of about 6,500 mt. This species may be overharvested if landings (such as those in 1992) begin to continually exceed this level. The recreational landings of both hakes in the Gulf of Maine are insignificant.

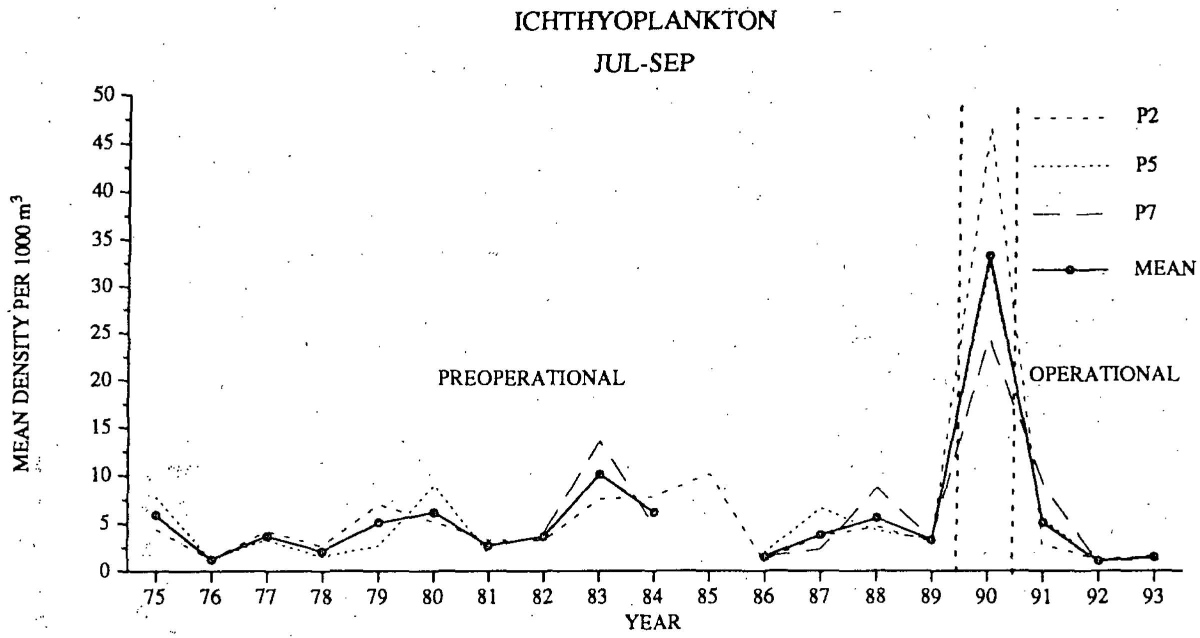
Hake eggs collected in ichthyoplankton samples are difficult to distinguish from fourbeard rockling eggs during early development and, therefore, at times were grouped as hake/fourbeard rockling. Hake and hake/fourbeard rockling eggs were the predominant eggs collected during the summer and early fall (Table 5-4). Hake larvae generally peaked during July through September (NAI 1993). During the preoperational period, catch remained relatively stable; catch was more variable during station operation, with the largest annual mean in 1990 and 1992 and 1993 among the years of lowest abundance (Figure 5-12). These low abundances in 1991-93 were apparent in the comparison of preoperational and operational geometric means (Table 5-3).

Hake have been taken year-round in trawl sampling, but peak catches were made from June through October, with a sharp decrease occurring in November (NAI 1993). Generally, catches at the nearfield station T2 were smaller than at T1 or T3 (Figure 5-12). As for the Atlantic cod, the area near T2 may not be a preferred habitat for hake. Geometric mean CPUEs were highest in 1977, 1978, and 1981. Since then, a general decreasing trend has been observed with smaller peaks seen every 3 to 4 yr. CPUE for both 1992 and 1993 were the two lowest of the time-series.

The ANOVA detected significantly larger preoperational abundances than operational abundances for both trawl and ichthyoplankton collections (Table 5-18). However, the interaction term was not significant, suggesting there were no plant operational effects. Entrainment estimates for hake eggs and larvae during 1993 were among the lowest since Seabrook Station began operation, with the highest values occurring in 1990, the year when larvae were most abundant (Table 5-7; Figure 5-12). Only 67 hake have been impinged at Seabrook Station since 1990 (Appendix Table 5-2). Trends in abundance as measured by trawl CPUE at Seabrook Station apparently differ from indices reported by NFSC (1993) for these species. Since 1976, the NFSC research trawl index for red hake has fluctuated considerably, but with an increasing trend (NFSC 1993). Commercial landings have remained uniformly low throughout this period. White hake have fluctuated without a long-term trend, but recent increases have occurred in both the trawl survey index and in landings. Some unknown factors may be reducing hake abundance in the Hampton-Seabrook area, but it is very unlikely that the operation of Seabrook Station has affected the hakes as the local decline began in the early 1980s and occurred consistently at all stations. In addition, combining the catch of all hake species may have confounded these analyses.

5.3.3.6 Atlantic silverside

The Atlantic silverside is a small, short-lived schooling fish that is ecologically important as a consumer of zooplankton and as prey for many larger fishes and birds (Bengston et al. 1987). Found in bays, salt marshes, and estuaries from the Gulf of St. Lawrence to northern Florida, the Gulf of Maine is near the northern end of its range (Conover 1992). Most Atlantic silverside complete their life cycle within 1 yr and, typically, few older fish are found in the population. Spawning begins at about 9-12°C, which restricts it to spawning in May through July in northern areas (Conover and Ross 1982; Jessop 1983; Conover and Kynard 1984). Fecundity for a Massachusetts population ranged from 4,725 to 13,525 eggs per female (Conover 1979). These eggs may be released during at least four separate periods of ripening and spawning. Spawning occurs during daylight, coincides with dates of full and new moons and is apparently synchronized with tides (Conover and Kynard 1984). The adhesive eggs are laid in shallow water on vegetation. Gender of Atlantic silverside is determined largely by water temperature during larval development (Conover and Kynard 1981; Conover and Fleisher 1986).



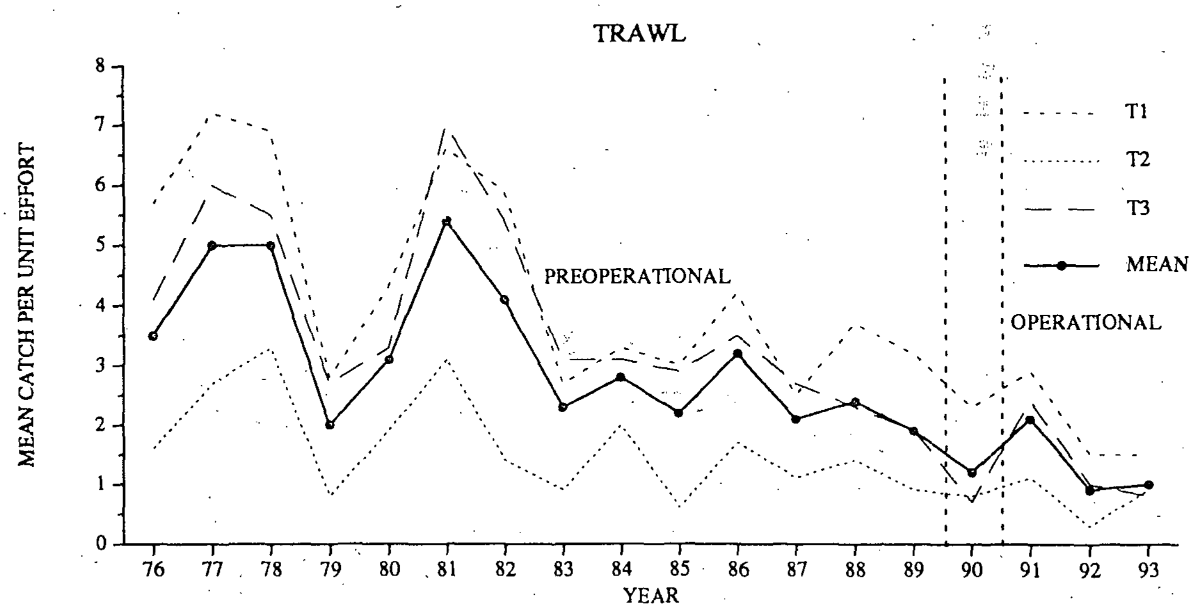


Figure 5-12. Annual geometric mean catch of **hakes** per unit effort in ichthyoplankton (number per 1000 m^3) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-18. RESULTS OF ANALYSIS OF VARIANCE FOR HAKE[a] DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jul.-Sep.) (1986-1993)	Preop-Op[b]	1	2.29	6.83 **	Op<Preop
	Year (Preop-Op)bc	5	3.08	9.17 **	
	Month (Year)[d]	14	1.85	5.51 **	
	Station[e]	2	0.27	0.81 NS	
	Preop-Op X Station[f]	2	0.05	0.14 NS	
	Error	227	0.34		
Trawl (Nov.-Jul.) (1975-1993)	Preop-Op[g]	1	1.82	47.80 **	Op<Preop
	Year (Preop-Op)	16	0.13	3.36 **	
	Month (Year)	140	0.20	5.13 **	
	Station	2	0.44	11.46 **	
	Preop-Op X Station	2	0.07	1.74 NS	
	Error	308	0.04		

[a] Hake = red, white, and spotted hakes.
[b] Preop-Op compares 1991-1993 to 1986-1989 regardless of station.
[c] Year nested within preoperational and operational periods regardless of station.
[d] Month within year regardless of year, station or period.
[e] Stations regardless of year or period.
[f] Interaction of the two main effects, Preop-Op and Station.
[g] Preop-Op compares Nov. 1990-Jul. 1993 to all previous months/years regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($p\leq 0.01$)

However, this mechanism may not be as important for northern populations because of the temporally reduced spawning season in more northern waters (Conover 1992). Larvae are planktonic, but remain near the spawning areas. Growth of young is fast and mean lengths can exceed 90 mm by November (Conover 1979). As the lower lethal temperature for Atlantic silverside is about 1-2°C (Hoff and Westman 1966; Conover and Murawski 1982), inshore distribution in northern areas is limited in winter. Atlantic silverside undertake an offshore migration in winter to inner continental shelf waters, with most fish caught within 40 km of the shore and at depths less than 50 m (Conover and Murawski 1982). It is during this period that high (up to 99%) overwintering mortality typically occurs, with apparently mostly fish larger than 80 mm able to survive the winter (Conover and Ross 1982; Conover 1992).

Atlantic silverside have been only numerous in the seine sampling program and were taken from August through November (NAI 1993). Most of these fish were likely young-of-the-year. Geometric mean CPUE were highest from 1976 through 1981, whereupon catch decreased. Since then, CPUE has fluctuated around a lower and more consistent average level to the present (Figure 5-13). Catch at each station tended to follow similar patterns, although it varied somewhat more at S2 than at S1 or S3. No significant differences were found among stations or for the interaction term (Table 5-19). The operational period mean was significantly smaller than the preoperational mean, likely because of the relatively high catches made in 1976-81. Only 231 Atlantic silverside have been impinged since Seabrook Station began operation (about two-thirds of the total in December 1993; Appendix Table 5-2) and no eggs or larvae were entrained

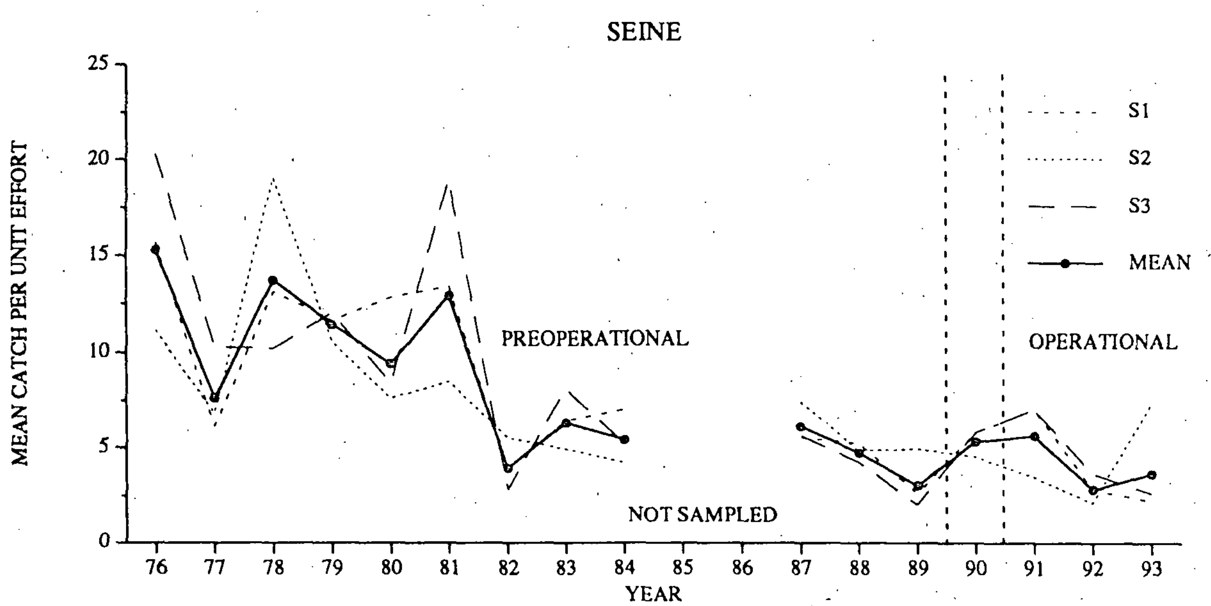


Figure 5-13. Annual geometric mean catch of **Atlantic silverside** per unit effort in seine (number per haul) samples by station and the mean of all stations, 1976-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-19. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC SILVERSIDE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Seine	Preop-Op[a]	1	6.12	45.66 **	Op<Preop
(Apr.-Nov.)	Year (Preop-Op)[b]	13	0.90	6.71 **	
(1976-1993)	Month (Year)[c]	105	1.40	10.45 **	
	Station[d]	2	0.10	0.75 NS	
	Preop-Op X Station[e]	2	0.02	0.17 NS	
	Error	236	0.13		

[a] Preop-Op compares 1991-1993 to 1976-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

(Table 5-7). The discharge from the Seabrook Station settling basin no longer enters Hampton-Seabrook Harbor and, therefore, marine biota there should no longer be potentially affected by it. As few Atlantic silverside have been harmed by station operation to date and because the decline in seine CPUE occurred before plant start-up, it is reasonable to assume that the continued operation of Seabrook Station will not have any deleterious effect on this species.

5.3.3.7 Cunner

The cunner, found from Newfoundland to Chesapeake Bay (Scott and Scott 1988), is one of the most common fishes in the Gulf of Maine (Bigelow and Schroeder 1953). A small fish residing in inshore waters, few cunner measure over 31 cm, although fish as large as 38 cm are occasionally taken in deeper waters (Johansen 1925; Bigelow and Schroeder 1953). Most cunner are closely associated with structural habitats, such as rocks, tidepools, shellfish beds, pilings, eelgrass, and macroalgae. Fish exhibit both diel and seasonal behavior in that they remain under cover and become quiescent at night and torpid in winter (Olla et al. 1975, 1979). In fall, when water temperatures fall below about 8°C, cunner move into cover to overwinter (Green and Farwell 1971; Green 1975; Dew 1976; Olla et al. 1979). Although generally remaining within 2 m of territorial shelters, some cunner will move to seasonally transitory habitats (e.g., mussel beds, macroalgae) after emerging from winter shelter when spring water temperatures reach 5 or 6°C (Olla et al. 1975, 1979).

Cunner reach maturity at small (70-90 mm) sizes and at age-1 or 2, depending upon latitude and corresponding length of the growing season (Johansen 1925; Dew 1976; Pottle and Green 1979). Cunner are serial spawners; pairs spawn within male territories, or aggregations of fish spawn together during late afternoon or early evening (Pottle and Green 1979). The reproductive season lasts from May through September, with peak spawning observed by Dew (1976) during June in Fishers Island Sound. Eggs are pelagic and range from 0.75 to 1.03 mm in diameter (Wheatland 1956); average size of eggs decreases over the season with increasing water temperature (Richards 1959; Williams 1967). Williams et al. (1973) reported that only about 5% of cunner eggs survived to hatching and speculated that predation, particularly by ctenophores, was responsible for the losses. Eggs hatch in 3 d at water temperatures of 12.8-18.3°C (Bigelow and Schroeder 1953). Newly-hatched larvae are 2 to 3 mm in length and settle into preferred habitats when 8 to 9 mm long.

Presently, cunner have no commercial value, although large quantities were apparently landed during the late 1800s and early 1900s (Bigelow and Schroeder 1953). Although the cunner is not primarily sought after, numerous fish are caught by recreational fishermen throughout New England. Because of its restricted inshore habitats and the lack of landings data, no large-area, long-term abundance indices are available for the cunner.

Cunner eggs and larvae were dominant in the ichthyoplankton program (Tables 5-4 and 5-5). Cunner eggs were grouped with yellowtail flounder (cunner/yellowtail flounder). This group also included tautog eggs, although tautog adults were probably not abundant in the Hampton-Seabrook area, which is located near the northern end of their distributional range (Bigelow and Schroeder 1953). Tautog larvae have only been present in about 3% of the ichthyoplankton samples collected since July 1975. A comparison of cunner and yellowtail flounder larval abundance indicated that most of the eggs in the cunner/yellowtail flounder group were cunner, assuming a relatively similar hatching rate between the two species (Table 5-3). The annual abundance of cunner larvae has greatly fluctuated from year to year, but similar annual densities occurred at all stations since sampling at all three stations began in July 1986 (Figure 5-14). This was substantiated by results from ANOVA, where the nested year term was highly significant and the station main effect was not significant (Table 5-20). In 1993, larval abundance increased greatly relative to 1992, when abundance was at an all-time low (Figure 5-14). The 1993 geometric mean at all stations was larger than both the preoperational and operational means (Table 5-3). The results of the ANOVA indicated that during the period when all three stations were sampled and cunner larvae were present, the operational abundance was significantly lower than abundance during the preoperational period (Table 5-20). The 1993 entrainment estimate of the cunner/yellowtail flounder egg group was 58.4 million. Annually, this group has ranked first or second since entrainment sampling was started in June 1990 (Table 5-7). Larval entrainment since 1990 has ranged from 0 to 14.7 million and the large difference between egg and larval entrainment estimates can be attributed to the high mortality during the egg stage (Williams et al. 1973). Also, recent 24-h diel studies have indicated that most of the egg mortality occurs shortly after spawning (NUSCO 1994a).

Relatively few cunner have been taken by otter trawl, gill net, or seine. Most occurrences were recorded from April through November, which likely corresponds to the period of greatest cunner activity in New Hampshire waters. Only 49 cunner were impinged at Seabrook Station during 1990-93, despite the potential of the offshore intake structure to attract cunner (Appendix Table 5-2).

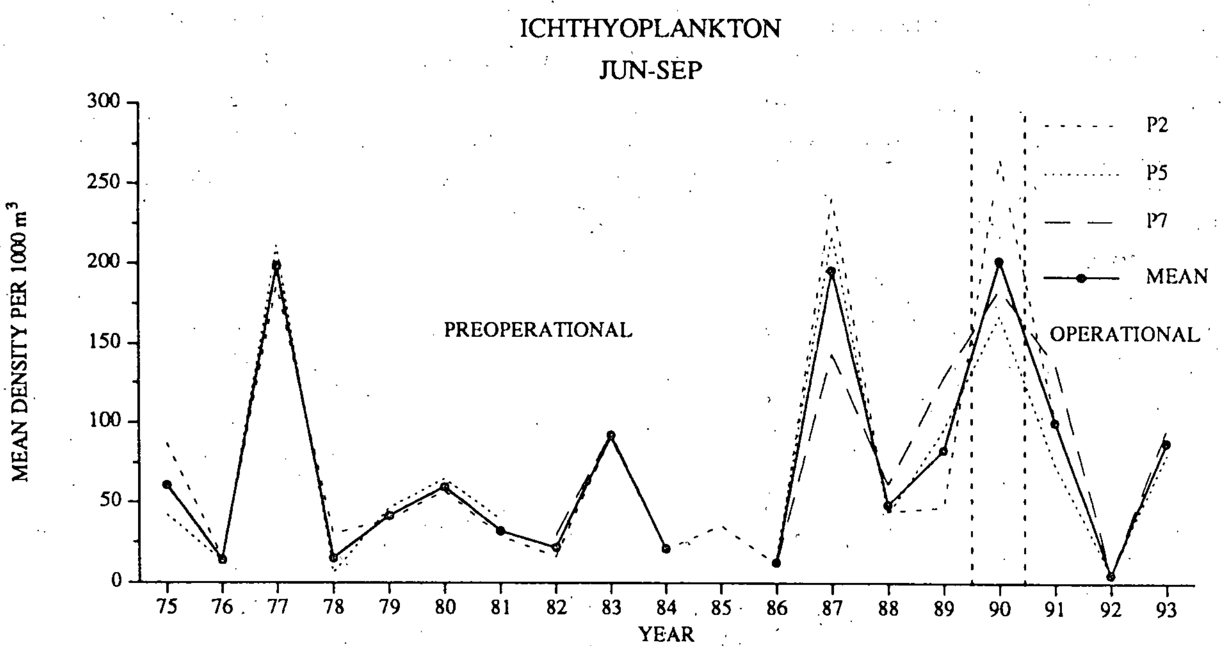


Figure 5-14. Annual geometric mean catch of **cunner** per unit effort in ichthyoplankton (number per 1000 m^3) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

TABLE 5-20. RESULTS OF ANALYSIS OF VARIANCE FOR CUNNER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jun.-Sep.) (1987-1993)	Preop-Op[a]	1	12.36	19.85 **	Op<Preop
	Year (Preop-Op)[b]	4	15.03	24.14 **	
	Month (Year)[c]	18	11.36	18.24 **	
	Station[d]	2	0.27	0.44 NS	
	Preop-Op X Station[e]	2	0.11	0.17 NS	
	Error	260	0.62		

[a] Preop-Op compares 1991-1993 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

5.3.3.8 American sand lance

Both the American sand lance (*Ammodytes americanus*) and the northern sand lance (*A. dubius*) may be taken inshore in the Gulf of Maine (Winters and Dalley 1988; Nizinski et al. 1990). However, the latter species is more common in deeper, offshore waters and all sand lance collected in Seabrook Station studies are referred to as the American sand lance. This species is found from Labrador to Chesapeake Bay (Richards 1982; Nizinski et al. 1990) and in the Gulf of Maine is usually found in depths of 6 to 20 m (Meyer et al. 1979). Found in schools ranging from hundreds to tens of thousands, sand lances are an important trophic link between zooplankton and larger fishes, birds, and marine mammals (Reay 1970; Meyer et al. 1979; Overholtz and Nicolas 1979; Payne et al. 1986; Gilman 1994).

Sand lance can live up to 9 yr, but populations are dominated by the first three age groups (Reay 1970). American sand lance can mature at age-1 at sizes of 90 to 115 mm (Richards 1982). Maximum size commonly observed is about 23-24 cm (Meyer et al. 1979; Richards 1982). An 18-cm female American sand lance is capable of producing 23 thousand eggs (Westin et al. 1979). Spawning occurs in inshore waters from November through March with a peak in December and January. Sand lance are well-adapted for winter spawning and embryonic development can occur in temperatures as low as 2°C (Buckley et al. 1984). Eggs are demersal and adhesive, forming clumps, with sizes ranging from 0.67 to 1.03 mm (Williams et al. 1964; Smigielski et al. 1984). Embryonic development is lengthy, resulting in a well-developed larva of about 6 mm in length at hatching. Larvae have ample endogenous energy reserves and can survive long periods without food (Buckley et al. 1984; Monteleone et al. 1986). Larval development is also lengthy, with metamorphosis occurring at sizes of 29-35 mm in 131 d at 4°C and 102 d at 7°C (Smigielski et al. 1984). This long period of development results in larvae being dispersed widely over continental shelf areas (Richards and Kendall 1973), even though most spawning occurs inshore.

American sand lance larvae was the dominant larval taxon collected in the ichthyoplankton program (Tables 5-3 and 5-5). Their eggs have not been collected in ichthyoplankton samples because they are demersal and adhesive. Larvae generally occurred from December through June or July, with peak abundances present during January through April (NAI 1993). Larval abundances in the Hampton-Seabrook area have declined since the early 1980s (Figure 5-15). These declines were also apparent in other areas of the Northwest Atlantic Ocean. Larval densities in Long Island Sound over a 32-yr period (1951-83) were highest in 1965-66 and 1978-79, with the latter years corresponding with a peak observed throughout the entire range of American sand lance (Monteleone et al. 1987). Similarly, larval sand lance densities were very high in Niantic Bay, CT from 1977 through 1981, with present densities an order of magnitude lower (NUSCO 1994a). Nizinski et al. (1990) also reported a peak in sand lance abundance throughout the Northwest Atlantic in 1981, with numbers declining since then. Sand lance abundance was noted to be inversely correlated with that of Atlantic herring and Atlantic mackerel (Sherman et al. 1981; Nizinski et al. 1990). Sand lance likely increased in abundance, replacing their herring and mackerel competitors, which had been reduced by overfishing in the 1970s (Sherman et al. 1981). In more recent years, Atlantic mackerel, which can prey heavily upon sand lance (Monteleone et al. 1987), have become very abundant as sand lance abundance decreased. Another factor noted to affect sand

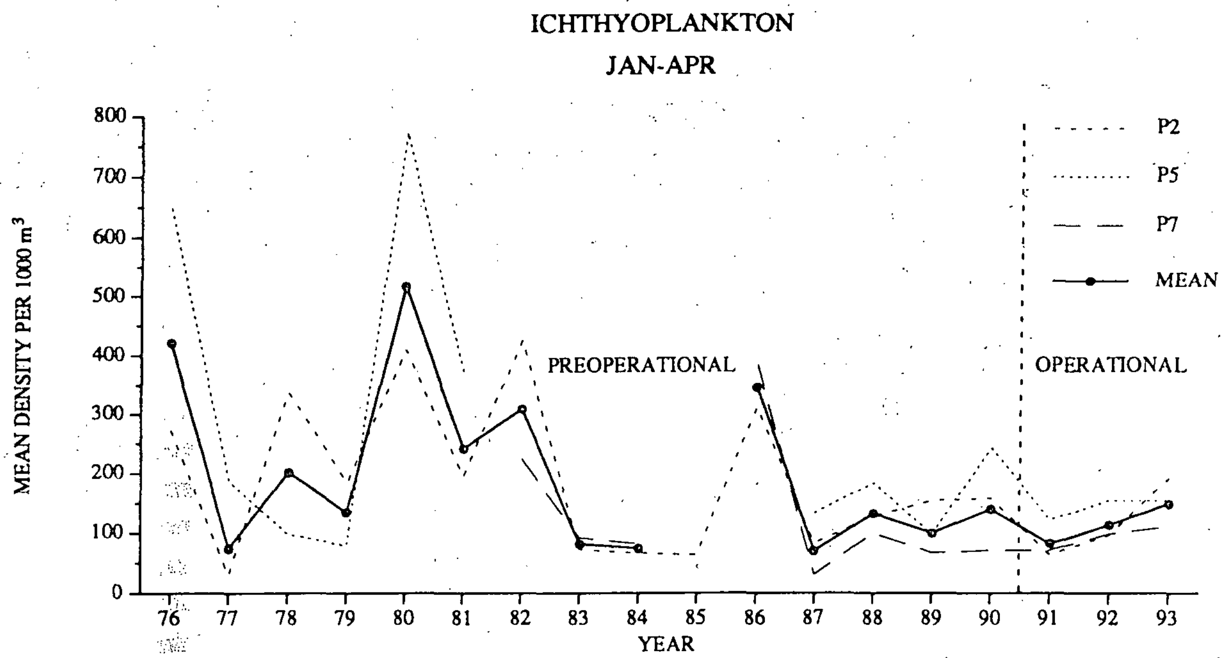


Figure 5-15. Annual geometric mean catch of **American sand lance** per unit effort in ichthyoplankton (number per 1000 m^3) samples by station and the mean of all stations, 1976-1993. Seabrook Operational Report, 1993.

lance reproduction and recruitment is water temperature, as Monteleone et al. (1987) suggested that warm December temperatures were associated with low larval densities.

Larval sand lance abundance in 1993 was similar to the average preoperational period, but was much lower than during the 1970s and early 1980s (Table 5-3; Figure 5-15). Annual geometric means have remained relatively stable since 1987. The results of the ANOVA indicated no significant difference between the preoperational and operational periods, but a significant difference was found among stations (Table 5-21). The differences detected among stations can be attributed to a consistently lower annual abundance at the control station P7 during 1987-93. American sand lance larvae dominated entrainment collections during 1991-93 (Table 5-7); their absence in entrainment samples during 1990 can be attributed to the start of sampling in June, which was after their season of occurrence. However, the ANOVA interaction term was not significant, indicating that operation of Seabrook Station did not affect the abundance of larval American sand lance in the Hampton-Seabrook area.

Very few American sand lance have been taken by Seabrook Station adult fish sampling programs. A few fish were taken sporadically by otter trawl, mostly during January through March in 1978, 1979, and 1981. Several hundred or more sand lance were occasionally taken by seine, but most catches were small and occurred infrequently. Again, abundance was highest during the late 1970s. Only 34 fish have been impinged at Seabrook Station since 1990 (Appendix Table 5-2).

TABLE 5-21. RESULTS OF ANALYSIS OF VARIANCE FOR AMERICAN SAND LANCE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jan.-Apr.) (1987-1993)	Preop-Op[a]	1	0.04	0.08 NS	
	Year (Preop-Op)[b]	5	0.91	1.67 NS	
	Month (Year)[c]	21	4.11	7.58 **	
	Station[d]	2	2.40	4.43 *	
	Preop-Op X Station[e]	2	0.48	0.89 NS	
	Error	283	0.54		

[a] Preop-Op compares 1991-1993 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

5.3.3.9 Atlantic mackerel

The Atlantic mackerel is a strongly schooling fish found from Labrador to Cape Lookout, NC that prefers a temperature range of 9 to 12°C (Scott and Scott 1988). Maximum size recorded in recent years has been 47 cm and 1.3 kg (NFSC 1993), but most fish average 32-36 cm (Scott and Scott 1988). The median size of maturity for mackerel is about 26 cm, at approximately age-2 (O'Brien et al. 1993). Atlantic mackerel exhibit a distinct pattern of extensive annual movements; fish can migrate in excess of 2,200 km (Parsons and Moores 1974). Atlantic mackerel overwinter offshore along the edge of the continental shelf (Ware and Lambert 1985) and, in spring, move inshore with two separate spawning components recognized (Sette 1950; Berrien 1978; Morse 1980). One group spawns progressively northward from mid-April through June in the Mid-Atlantic Bight and the other spawns in the Gulf of St. Lawrence from late May to mid-August; peak spawning occurs at about 13°C (Ware and Lambert 1985). Ware (1977) and Lambert and Ware (1984) suggested that the Atlantic mackerel spawning season is relatively short and coincides with peak copepod biomass. Spawning stock size appears to exert little influence on recruitment, except at very low levels, and environmental factors likely have a major effect on successful reproduction (Anderson 1979). After spawning, the southern contingent moves into coastal areas of the Gulf of Maine and the northern group remains in Canadian waters during summer and fall.

Female Atlantic mackerel are serial spawners and release five to seven successive batches of eggs; fecundity ranges from 285 thousand to almost 2 million eggs per female (Morse 1980). The 1.1 to 1.3-mm eggs hatch in 5 to 7 d. Eggs are distributed near the surface, with 85% or more concentrated within the uppermost 15 m (Ware and Lambert 1985; deLafontaine and Gascon 1989; D'Amours and Gregoire 1991). The hatched larvae are 3 mm in length, grow rapidly, and develop a streamlined form early in life that enables relatively high swimming speeds (Ware and Lambert 1985). Larvae are often cannibalistic, preying on smaller individuals from younger cohorts (Peterson and Ausubel 1984; Ware and Lambert 1985). Young from both spawning contingents reach an average size of about 200 mm in late fall, even though their growing seasons differ in length (Sette 1950; Ware and Lambert 1985; D'Amours et al. 1990).

Presently, biomass of the Atlantic mackerel stock is very high (NFSC 1993). Although two spawning contingents exist, the species is managed as a single stock. Mackerel in the Gulf of Maine are primarily landed from May through November by both sport and commercial fisheries. Landings from the U.S. (about one-third of the total) and Canada peaked at 400,000 mt in 1973 and decreased to about 30,000 mt during the late 1970s, as apparently weak year-classes were found from 1975 through 1980. Catches then increased steadily to 82,700 mt in 1988, but declined again to 38,300 mt in 1992; a very strong year-class was produced in 1982 and relatively good ones in 1984-88. With current spawning stock biomass estimated to exceed 2 million mt, catches can be increased substantially without affecting the spawning stock (NFSC 1993).

Atlantic mackerel eggs were the second-most abundant egg taxon collected in the ichthyoplankton program (Table 5-4). The larvae were very abundant in ichthyoplankton collections, but were not dominant in entrainment samples (Tables 5-6 and 5-7). Larvae typically occurred from May through August (NAI 1993) and larval abundance in 1993 was similar to the average preoperational period (Table 5-3). Annual larval abundances fluctuated, with a peak at station P5 in 1981 (Figure 5-16). Since all three stations were

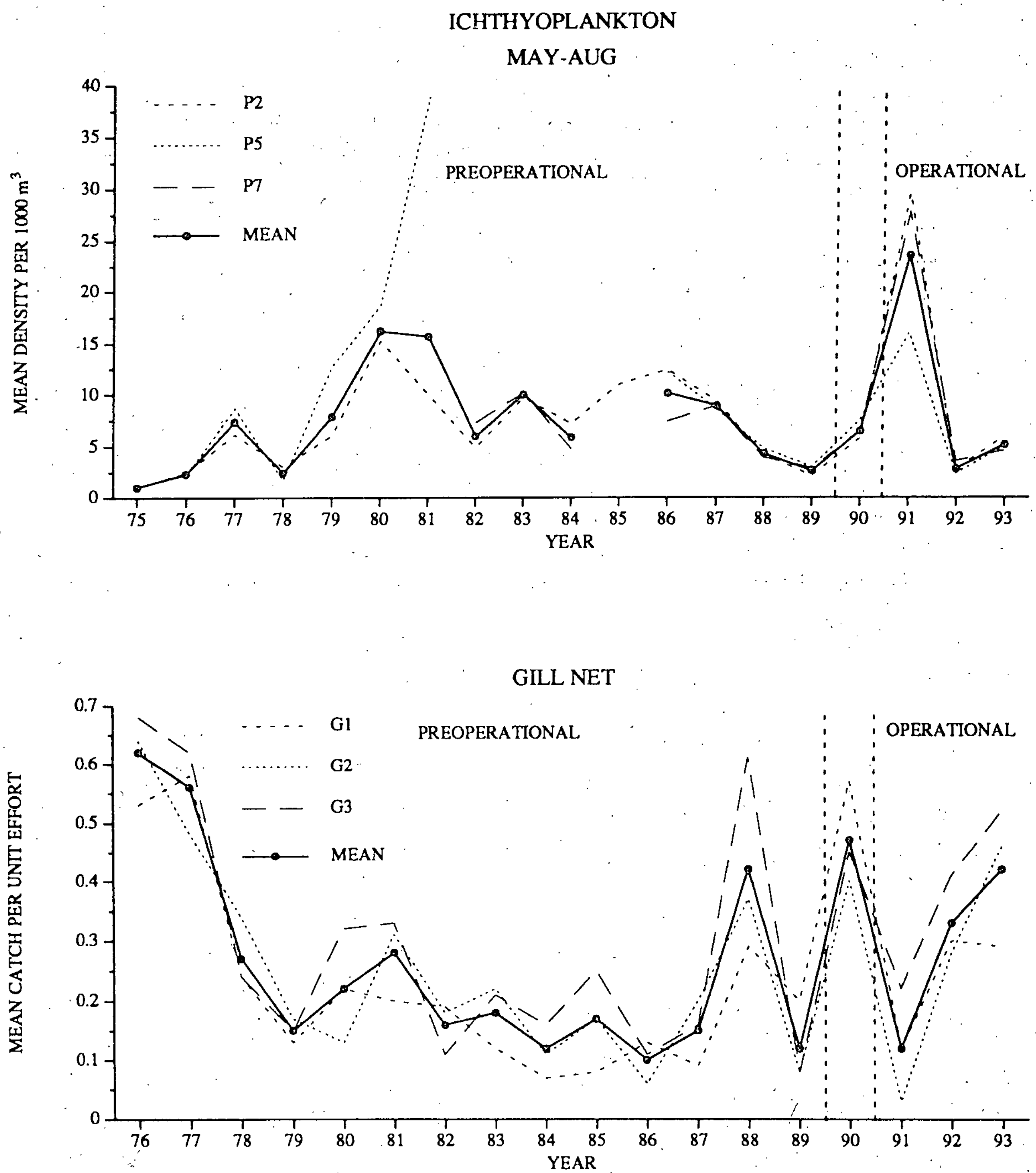


Figure 5-16. Annual geometric mean catch of **Atlantic mackerel** per unit effort in ichthyoplankton (number per 1000 m^3) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

sampled (1986-93), similar densities were found at all stations, except for 1991. The results from the ANOVA indicated no significant difference among stations or between preoperational and operational periods; the interaction term was not significant (Table 5-22).

Atlantic mackerel juveniles and adults were collected by gill net in the Seabrook station area from June through November (NAI 1993). Annual geometric mean CPUE reflected trends noted by NFSC (1993), with peak abundance observed in the mid-1970s that decreased by about two-thirds during the early 1980s (Figure 5-16). Beginning in 1988, an overall increasing trend was found, but geometric means have fluctuated sharply from year to year. Results of the ANOVA showed no difference in catch between the preoperational and operational periods, as mackerel are as abundant now as they were in the 1970s (Table 5-22). The interaction term was significant, however, and a plot of the interaction term illustrated the differences in abundance trends between G3 and that for stations G1 and G2 (Figure 5-17). A multiple comparison test indicated that catch at the farfield station G3 during the operational period was significantly greater than that of the other station-period combinations. Two relatively large catches of Atlantic mackerel were made at G3 in October 1991 and September 1992, which, in part, could have accounted for the significant differences found. Despite the significant difference in the interaction term, it is highly unlikely that the operation of Seabrook Station affected the abundance or distribution of the Atlantic mackerel. Only 20 larger fish were impinged at Seabrook Station since 1990 (Appendix Table 5-2). Large numbers of eggs were entrained and mackerel eggs ranked first or second in annual entrainment estimates since 1990 (Table 5-7). However, relatively few (0-4.7 million) larvae were entrained each year. As previously discussed in the entrainment section, this may have been related to the rapid developmental rate of Atlantic mackerel, which results in larger larvae that can avoid the intake. Atlantic mackerel biomass is currently very high and only an insignificant fraction of the egg production of this highly fecund fish is entrained at the plant, making an impact highly improbable.

5.3.3.10 Winter flounder

The winter flounder ranges from Labrador to Georgia (Scott and Scott 1988), but is most common from Nova Scotia to New Jersey (Perlmutter 1947). Maximum size of coastal fish is about 45 cm and 1.4 kg (Bigelow and Schroeder 1953). Populations of winter flounder are composed of reproductively isolated fish that spawn in specific estuaries or coastal embayments (Lobell 1939; Perlmutter 1947; Saila 1961; NUSCO 1994). North of Cape Cod, movements of winter flounder are generally localized and confined to inshore waters (Howe and Coates 1975). McCracken (1963) reported that winter flounder prefer temperatures of 12-15°C and, except for spawning, will move to remain within that range. However, others (Kennedy and Steele 1971; Van Guelpen and Davis 1979) noted that movements for feeding and to avoid turbulence and ice also affect distribution of northerly populations and Olla et al. (1969) reported observing adult fish in waters as warm as 22.5°C. Young-of-the-year are typically found in shallow estuarine waters and can withstand temperatures of 30 to 32.4°C (Pearcy 1962; Everich and Gonzalez 1977).

Adults enter inshore spawning areas in fall or early winter and spawn in late winter or early spring. Winter flounder in the Gulf of Maine mature at an average age of 3.4 yr and at a length of 27.6 cm for males and 29.7 cm for females

TABLE 5-22. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC MACKEREL DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS (Ranked in decreasing order)
Ichthyoplankton (May-Aug.) (1987-1993)	Preop-Op[a]	1	2.30	3.43 NS	
	Year (Preop-Op)[b]	4	7.10	10.60 **	
	Month (Year)[c]	18	9.16	13.67 **	
	Station[d]	2	0.08	0.12 NS	
	Preop-Op X Station[e]	2	0.28	0.42 NS	
	Error	260	0.67		
Gill Net (Jun.-Nov.) (1976-1993)	Preop-Op[a]	1	<0.01	0.02 NS	
	Year (Preop-Op)	15	0.24	10.15 **	
	Month (Year)	85	0.10	4.27 **	
	Station	2	0.15	6.35 **	
	Preop-Op X Station	2	0.10	4.12 *	3 Op 3 Pre 2 Pre 1 Pre 1 Op 2 Op[f]
	Error	200	0.02		

[a] Preop-Op compares 1991-1993 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Underlining signifies no significant differences among least square means at p ≤ 0.05.

NS = Not significant (p>0.05)
* = Significant (0.05≥p>0.01)
** = Highly significant (p≤0.01)

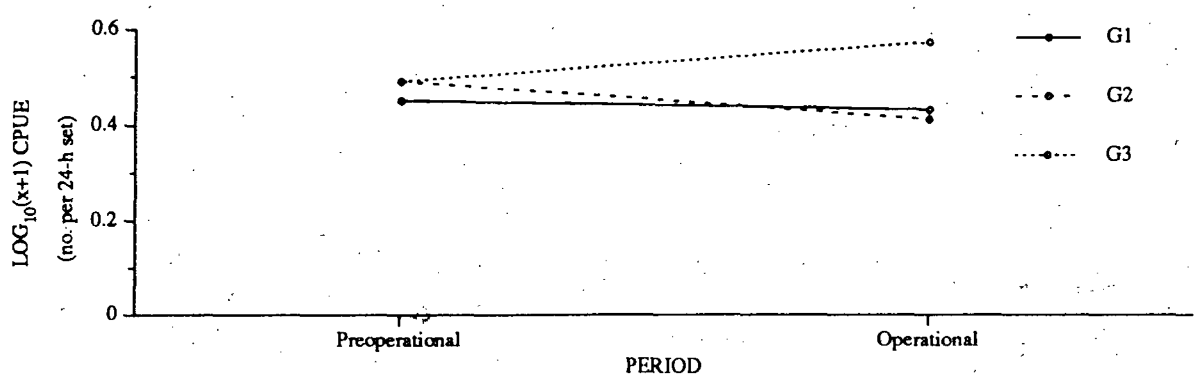


Figure 5-17. A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 24-h set) of **Atlantic mackerel** caught by gill net during the preoperational (June 1976-November 1989) and operational (June 1991-November 1993) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-22). Seabrook Operational Report, 1993.

(O'Brien et al. 1993). Average fecundity is about 500 thousand eggs per female (Bigelow and Schroeder 1953), with a maximum as much as 3.3 million for a large fish (Topp 1968). Eggs (0.71-0.96 mm) are adhesive and demersal (Fahay 1983). Winter flounder embryos develop under a relatively wide range of temperature and salinity conditions, with highest viable hatch reported at 3°C over a salinity range of 15 to 35‰ (Rogers 1976). Because winter flounder spawn during periods of low water temperature, larval development is relatively slow and can take up to 2 mo to complete. Larvae flushed out of estuarine nursery areas are believed to have lowered potential for survival and eventual recruitment to adult stocks (Pearcy 1962; Smith et al. 1975; Crawford 1990). Overall mortality of larvae can exceed 99% (Pearcy 1962). Young are common in inshore shallows, where they remain until fall, undertaking little movement away from where they settled (Saucerman and Deegan 1991).

Based on numerous meristic and tagging studies conducted for assessment and management purposes, winter flounder have been divided into three groups: Gulf of Maine, Southern New England and Middle-Atlantic, and Georges Bank (NFSC 1993). Commercial landings of winter flounder from the Gulf of Maine were relatively stable at around 1,000 mt per year from 1961 through 1977, but tripled to about 3,000 mt in 1982. Recreational landings in some years exceeded those of the commercial fishery (NFSC 1993). Since 1983, a downward trend was observed in landings with a record low of only 900 mt taken in 1992. Bottom trawl survey data from the Massachusetts Division of Marine Fisheries spring survey also showed a declining trend since 1983 (NFSC 1993). Lowest values were observed during 1988-92. Continued low landings and trawl catch indices were indications that winter flounder in the Gulf of Maine have been overexploited (NFSC 1993) and the stock likely needs rebuilding before yields can be sustained or increased.

Larval winter flounder were collected in the ichthyoplankton program, but eggs were absent because they are demersal and adhesive (Table 5-4). Larvae typically occurred in the Hampton-Seabrook area during April through July (NAI 1993). Larval winter flounder abundance has declined since the mid-1980s and this was apparent at all three stations; larger annual geometric means were usually found at P2 than at P5 or P7 (Figure 5-18). This decline was

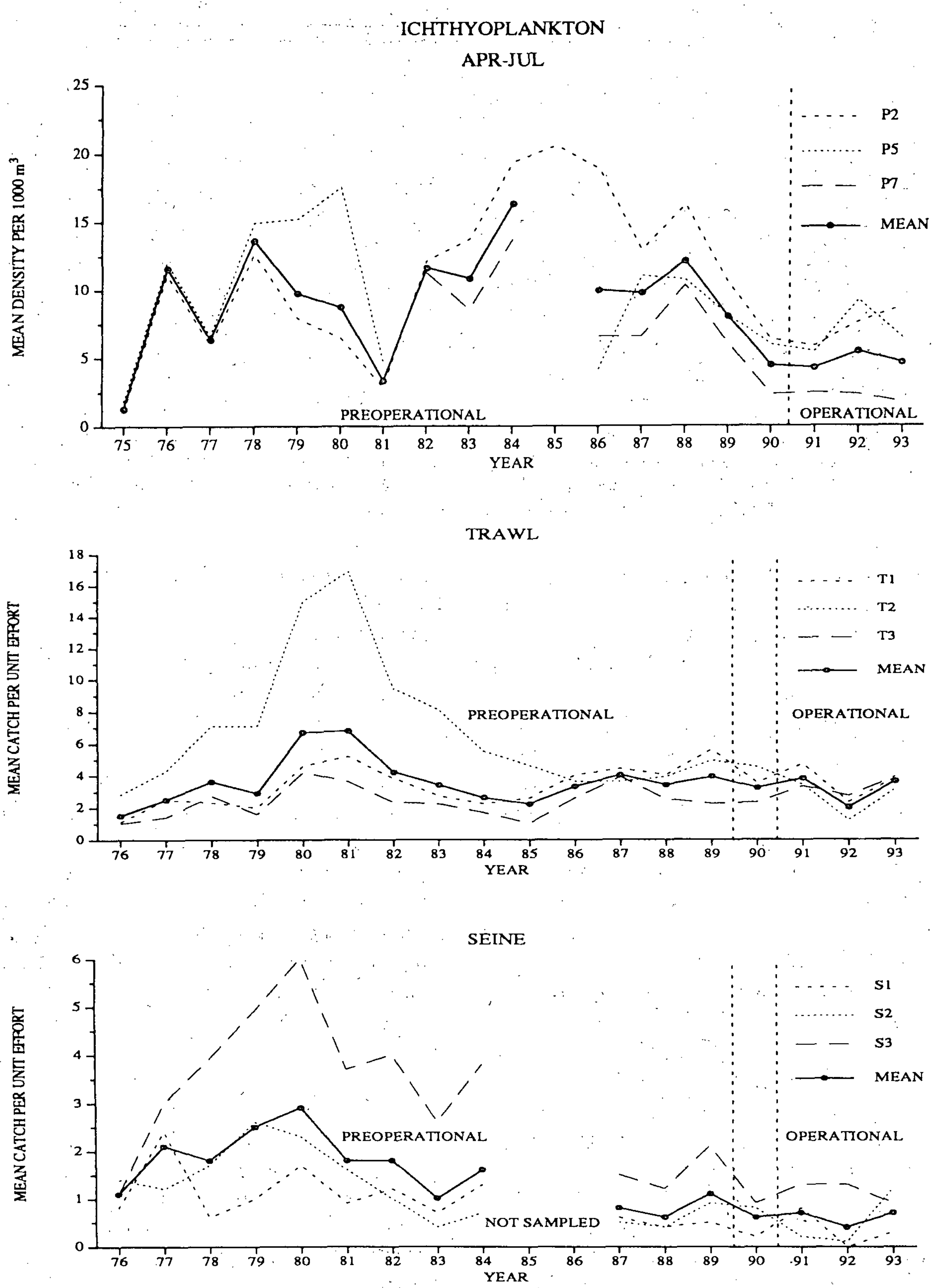


Figure 5-18. Annual geometric mean catch of **winter flounder** per unit effort in ichthyoplankton (number per 1000 m^3), trawl (number per 10-min tow), and seine (number per haul) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1993.

substantiated by the results of the ANOVA, which showed significant differences between the preoperational and operational periods, in the nested year term, and among stations (Table 5-23). Although there has been a decline in larval abundance, this was not related to plant operation because it occurred at all three stations and the interaction term in the ANOVA model was not significant. The lower abundance of larvae at station P7 may be related to its location, which is not near the Hampton-Seabrook estuary, the likely spawning area for local winter flounder.

The winter flounder was taken year-round by otter trawl at all stations, but occurred most commonly from May through October (NAI 1993). Geometric mean CPUE peaked in 1980 and 1981, primarily because of high catches made at the nearfield station T2 (Figure 5-18). Winter flounder were considerably more abundant at T2 than at T1 or T3 until 1986, when annual mean CPUE became more similar. CPUE at T3 was generally lowest of all these three stations during the 1970s and 1980s, but catches have become more similar to those at T1 and T2 since 1990. CPUE at T2 was the lowest of the three stations in 1992 and 1993. This decrease may be related, in part, to the inability since 1986 to sample at T2 on many scheduled dates during August through October, months in which winter flounder are most abundant. However, this does not account for decreased abundance observed in other months, the data for which are used with the ANOVA model.

Overall, geometric mean CPUE increased slightly from a low in 1985 and remained generally stable from 1986 through 1991 (Figure 5-18). A decrease occurred in 1992, but catch in 1993 was very similar to that in 1991. Data used for the ANOVA were from November of one year through July of the next. Trawl catch of winter flounder during the operational period was significantly less than that of the preoperational period (Table 5-23). The interaction term was also significant and the multiple comparisons test and a plot of abundance by period (Figure 5-19) indicated that there was a significant decline of winter flounder catch at station T2 between the preoperational and operational periods.

Smaller winter flounder (juveniles through age-2; NAI 1993) were collected in the Hampton-Seabrook Harbor by seine throughout the April-November sampling period. Annual geometric mean CPUE was consistently higher at station S3, located nearest to the mouth of the estuary, and generally lowest at S1, farthest inland (Figure 5-18). The annual pattern of abundance was somewhat similar to that of the trawl samples in that CPUE peaked in 1980 (1 yr earlier than for the catch by trawl) and thereafter decreased. Abundance has remained at relatively consistent levels since seine sampling resumed in July 1986. Results of the ANOVA for seine data indicated that, similar to trawl data, abundance during the preoperational period was significantly higher than during the operational period (Table 5-23). This was not surprising, given the relatively high catches made during the 1970s and early 1980s and the current depressed state of winter flounder stocks. The interaction term, however, was not significant suggesting that Seabrook Station has not affected the abundance or distribution of juvenile winter flounder in the Hampton-Seabrook estuary.

Annual entrainment estimates for 1990-93 ranged from 2.9 to 9.0 million (Table 5-7). These totals, however, are much less than those of other large New England power plants. Annual larval winter flounder entrainment at Pilgrim Nuclear Power Station in Massachusetts ranged from almost 5 to 17.8 million during 1988-93 (MRI 1994). Similarly, entrainment was much higher at the three-unit Millstone Nuclear Power Station,

TABLE 5-23. RESULTS OF ANALYSIS OF VARIANCE FOR WINTER FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS (Ranked in decreasing order)
Ichthyoplankton	Preop-Op[a]	1	2.93	8.61 **	Op<Preop
(Apr.-Jul.)	Year (Preop-Op)[b]	5	0.84	2.47 *	
(1987-1993)	Month (Year)[c]	21	4.16	12.25 **	
	Station[d]	2	5.31	15.63 **	
	Preop-Op X Station[e]	2	0.69	2.02 NS	
	Error	289	0.34		
Trawl	Preop-Op[f]	1	0.39	9.95 **	Op<Preop
(Nov.-Jul.)	Year (Preop-Op)	16	0.24	6.01 **	
(1975-1993)	Month (Year)	140	0.09	2.35 **	
	Station	2	0.40	10.28 **	
	Preop-Op X Station	2	0.57	14.52 **	2 Pre 1 Pre 1Op 3 Op 2 Op 3 Pre[g]
	Error	308	0.04		
Seine	Preop-Op[h]	1	1.28	9.54 **	Op<Preop
(Apr.-Nov.)	Year (Preop-Op)	13	0.25	1.85 *	
(1976-1993)	Month (Year)	105	0.32	2.39 **	
	Station	2	0.14	1.03 NS	
	Preop-Op X Station	2	0.11	0.84 NS	
	Error	236	0.13		

[a] Preop-Op compares 1991-1993 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares Nov. 1990-Jul. 1993 to all previous months/years regardless of station.
[g] Underlining signifies no significant differences among least square means at $p \leq 0.05$.
[h] Preop-Op compares 1991-1993 to 1976-1989 regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

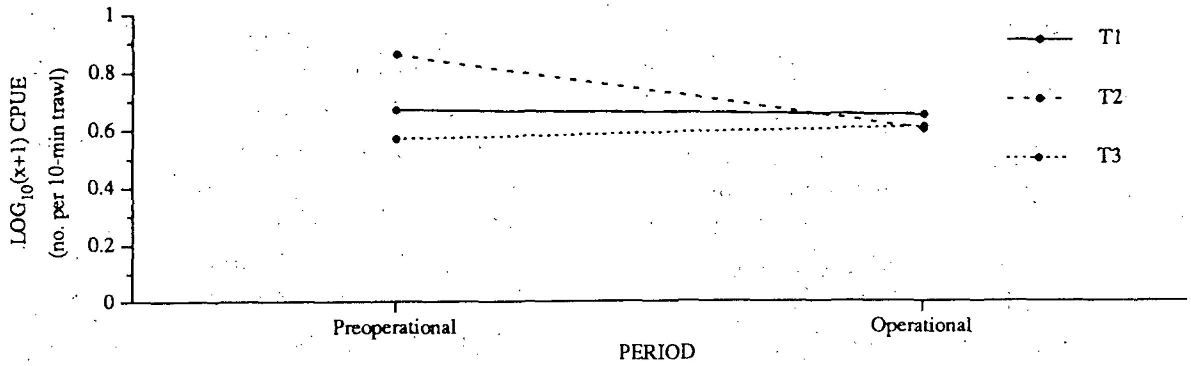


Figure 5-19. A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 10-min tow) of **winter flounder** caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 1993) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-23). Seabrook Operational Report, 1993.

annual totals for 1976-93 were from 31.2 to 513.9 million larvae (NUSCO 1994b). However, larvae entrained at the offshore intake of Seabrook Station were probably flushed from estuarine spawning areas. According to Pearcy (1962), Smith et al. (1975), and Crawford (1990), larvae not retained within estuaries have a lower probability of survival.

Since 1990, more winter flounder (484) have been impinged at Seabrook Station than of any other species (Appendix Table 5-2). However, this 4-yr total is considerable less than the number of winter flounder taken each year at several other New England power plants. During 1972-92, annual impingement of winter flounder at Brayton Point Station in Massachusetts ranged from 859 to 23,452 individuals (mean of 7,925; MRI 1993a). Annual impingement totals from 1976 through 1987 at Millstone Nuclear Power Station Unit 2 in Connecticut were from 624 to 10,077 (annual mean of 3,484; NUSCO 1988).

Abundance of winter flounder throughout the Gulf of Maine has decreased in recent years to historic lows (NFSC 1993), likely due to overfishing. This has been reflected by the reductions in catch of winter flounder in Seabrook Station monitoring studies. The persistently lower abundance at nearfield station T2 since 1991, however, is unexplained. Although perhaps beginning before plant operation, this change bears further study to determine if Seabrook Station has contributed to a distributional change following the 1990 start-up.

5.3.3.11 Yellowtail flounder

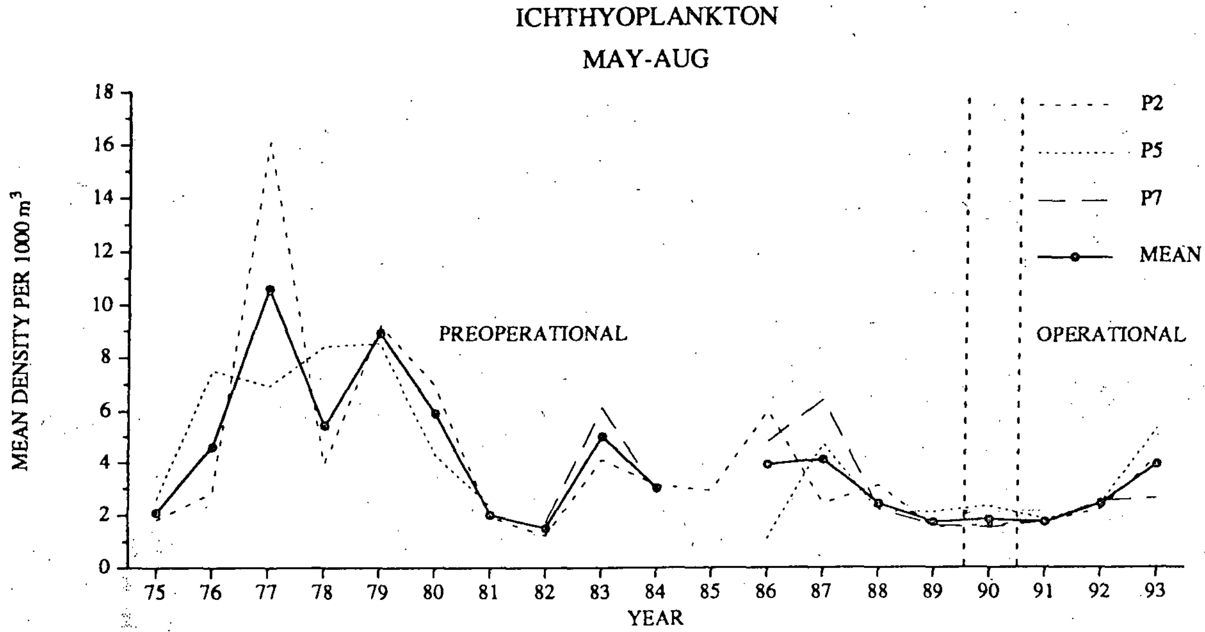
The yellowtail flounder is found from southern Labrador to Chesapeake Bay (Scott and Scott 1988), but its center of abundance is the western Gulf of Maine and Southern New England (Bigelow and Schroeder 1953). It commonly reaches a length of 47 cm and a weight of 1 kg (NFSC 1993). Yellowtail flounder prefer coarser sand and gravel bottom sediments than those preferred by other flounders of the Northwestern Atlantic Ocean (Scott 1982b) and are found mostly in depths of 37 to 91 m (Scott and Scott 1988). Individuals apparently maintain generally similar depths between seasons while tolerating a wide range of temperatures and salinities (Scott 1982a; Murawski and Finn 1988; Perry and Smith 1994). Some limited seasonal movements, however, do occur, with fish moving to shallower waters in spring and into deeper waters during fall and early winter.

Median age of maturity for female yellowtail flounder is age-2, at a size of approximately 26 cm (O'Brien et al. 1993). Fecundity can range from 350 thousand to 4.57 million eggs per female (Pitt 1971). Adults spawn in the western Gulf of Maine from March through September (Fahay 1983). Most spawning was observed by Smith et al. (1975) to occur at 4 to 9°C. Eggs (0.8-0.9 mm in diameter) are deposited at or near the bottom, but are pelagic and hatch in 5 d at temperatures of 10-11.1°C. Larvae are 2 to 3.5 mm in length at hatching (Fahay 1983). Greatest concentrations of pelagic larvae are found in water temperatures of 4.1-9.9°C (Smith et al. 1975). Larvae exhibit pronounced diel vertical movements and are found near the surface at night and at depths of 20 m or so during the day, regardless of thermal gradients (Smith et al. 1978). Ascent and descent occur at sunset and sunrise, respectively, with amplitude of movement increasing with larval size. Larvae metamorphose and become demersal at about 11 to 16 mm in length (Fahay 1983), although fish as large as 20 mm may still ascend to the surface (Smith et al. 1978).

Three discrete groups of yellowtail flounder are managed in U.S. waters, including Southern New England, Georges Bank, and Cape Cod (NFSC 1993). All of these stocks are considered to be overexploited. Abundance was relatively high in the early 1980s, but subsequently declined due to overfishing. After several years of low abundance, a relatively strong 1987 year-class produced within all three stock areas resulted in an increase in commercial landings in 1990. However, the increase was short-lived as the stocks were rapidly fished down again and current abundance is at very low levels.

Yellowtail flounder eggs were grouped as cunner/yellowtail flounder because it was difficult to distinguish between these two species; this group would also include tautog eggs, if present. The cunner/yellowtail flounder taxon was the dominant egg collected during both the preoperational and operational periods (Table 5-4). Larvae were less abundant, probably because the egg group consisted primarily of cunner, as previously mentioned (Section 5.3.3.7). Yellowtail flounder were not among the predominant larval taxa selected for numerical classification analysis (Table 5-5). The annual geometric mean of yellowtail flounder larvae during 1986-93, when all three stations were sampled, has remained relatively constant and the annual densities were similar at all stations (Figure 5-20). In addition, the 1993 geometric mean was similar to those for both preoperational and operational periods (Table 5-3). This was substantiated by the results from the ANOVA, where there was no significant difference detected between the preoperational and operational periods or among stations (Table 5-24). In addition, the interaction term was also not significant, suggesting that the operation of Seabrook Station has not altered the abundance of yellowtail flounder larvae in the Hampton-Seabrook area.

The yellowtail flounder is taken year-round in the Seabrook Station study area and in former years was one of the most abundant fishes taken by otter trawl sampling (Table 5-10). Recently, however, it was most common only from May through October (NAI 1993). To a large degree, annual mean CPUE by otter trawl (Figure 5-20) mirrored that of commercial landings reported by NFSC (1993). Trawl CPUE peaked in the early 1980s and subsequently decreased to a lower, but relatively stable level, until a slight increase was seen in 1989, perhaps due to the relatively strong 1987 year-class. CPUE then steadily decreased to near zero in 1992, before rebounding slightly in 1993.



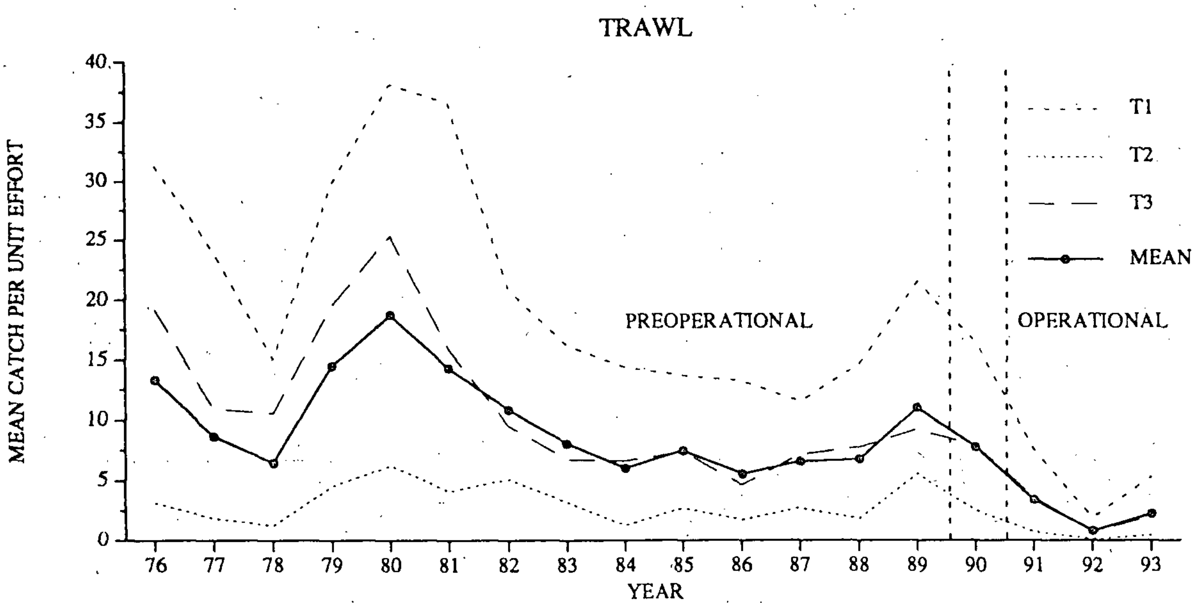


Figure 5-20. Annual geometric mean catch of **yellowtail flounder** per unit effort in ichthyoplankton (number per 1000 m^3) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1975-1993 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report 1993.

TABLE 5-24. RESULTS OF ANALYSIS OF VARIANCE FOR YELLOWTAIL FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1993.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS (Ranked in decreasing order)
Ichthyoplankton (May-Aug.) (1987-1993)	Preop-Op[a]	1	0.01	0.06 NS	
	Year (Preop-Op)[b]	4	1.61	6.43 **	
	Month (Year)[c]	18	2.11	8.46 **	
	Station[d]	2	0.12	0.50 NS	
	Preop-Op X Station[e]	2	0.16	0.65 NS	
	Error	260	0.25		
Trawl (Nov.-Jul.) (1975-1993)	Preop-Op[f]	1	13.66	227.91 **	Op<Preop
	Year (Preop-Op)	16	0.63	10.43 **	
	Month (Year)	140	0.06	1.01 NS	
	Station	2	5.45	90.98 **	
	Preop-Op X Station	2	0.29	4.83 **	1 Pre 3 Pre 1 Op 2 Pre 3 Op 2 Op[g]
	Error	308	0.06		

[a] Preop-Op compares 1991-1993 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month within year regardless of year, station or period.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Preop-Op compares Nov. 1990-Jul. 1993 to all previous months/years regardless of station.
[g] Underlining signifies no significant differences among least square means at $p \leq 0.05$.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($p \leq 0.01$)

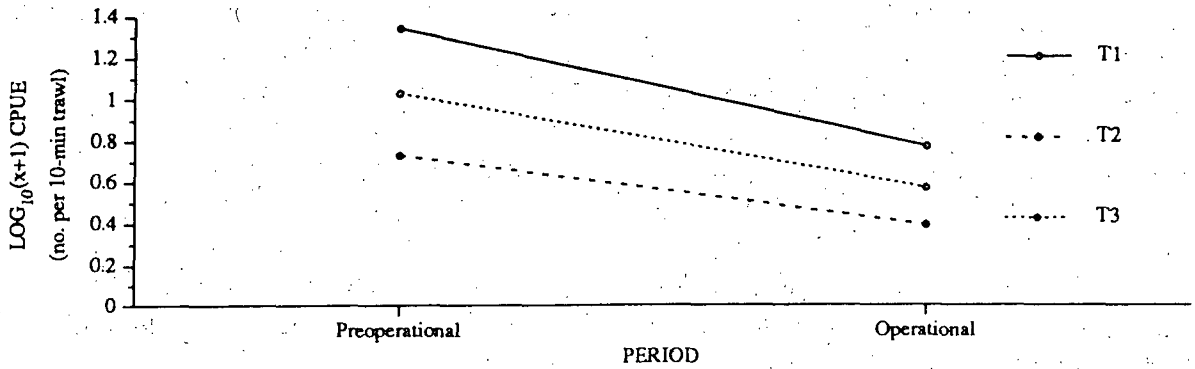


Figure 5-21. A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 10-min tow) of **yellowtail flounder** caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 1993) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-24). *Seabrook Operational Report, 1993.*

Catches have been consistently highest at farfield station T1 and lowest at nearfield station T2 throughout the 18-yr period; CPUE at T3 tended to approximate the overall mean. This pattern of abundance may reflect habitat preferences of the yellowtail flounder in the Hampton-Seabrook study area. The CPUE during the operational period was significantly smaller than during the preoperational period (Table 5-24). However, this was likely due to the overall decrease in abundance for this species since the early 1980s that resulted from overfishing. The interaction term was also significant, but a plot of the data showed that means for each station by period were essentially parallel (Figure 5-21). This indicated that the significant difference may have been due to large sample size and the sensitivity of the ANOVA model, as no plant effect was evident. Only 11 yellowtail flounder have been impinged at Seabrook Station since 1990 (Appendix Table 5-2). The cunner/yellowtail flounder group has been consistently ranked first or second among egg taxa entrained at Seabrook Station, with annual totals ranging from 58.4 to 716.3 million (Table 5-7). However, it is likely that this group is comprised mostly of cunner, as relatively few yellowtail flounder larvae (overall and relative to cunner) have been identified in entrainment samples. The yellowtail flounder has been severely reduced in abundance by overfishing throughout its range, and catch near Seabrook Station has simply reflected this decline. Increased abundance and stock rebuilding will require a substantial reduction in fishing and several years of improved recruitment (NFSC 1993).

5.4 EFFECTS OF SEABROOK STATION OPERATION

The fish community in the Hampton-Seabrook area was sampled to determine if the operation of Seabrook Station has had any discernible effects on fish abundance or distribution. Potential impacts of station operation included the entrainment of fish eggs and larvae and impingement of juvenile and adult fish at the plant intake; entrainment of fish eggs and larvae into and avoidance by larger fish of the offshore discharge thermal plume; and effects of the discharge of the plant settling basin into the Browns River within the Hampton-Seabrook estuary. Monitoring programs were established that used sampling gear appropriate for several specific fish assemblages. Samples were periodically taken at fixed stations in nearfield and farfield areas relative to the station intake and discharge for various periods prior to commencement of Seabrook Station commercial operation in August 1990 and continuously since then. The impacts of impingement and entrainment were directly estimated from samples taken at the station when it operated.

Assessment of impact was based on an ANOVA model, primarily used to examine for differences in abundance of selected fishes between the preoperational and operational periods and for the consistency of any observed differences between these periods among the fixed stations (i.e., the Preop-Op X Station interaction). Data were selected for the ANOVA taking into account the temporal distribution of a species, its occurrence relative to the August 1990 startup, and samples missing as a result of temporary cessation of monitoring or the inability to sample a station at certain times of the year. Possible changes in seasonal ichthyoplankton assemblages were also examined using multivariate analyses. In general, the species selected for analyses are abundant in the Gulf of Maine and are important to the trophic dynamics of this marine ecosystem. Most of these fishes also have commercial and recreational importance for the region. Because fishing can significantly alter the abundance, distribution, and population dynamics of heavily exploited fishes, trends in landings and present status of fishing stocks of these species were also examined to put into perspective any changes seen in the Seabrook area. Finally, comparisons of entrainment and impingement were made between Seabrook Station and those at other large marine power plants in New England to illustrate the relatively benign impact of Seabrook Station as a result of its intake design and placement.

As summarized in Table 5-25, a number of differences were found between the preoperational and operational periods for fish assemblages in general, and for most of the selected species in particular. In nearly all cases where differences were found, the abundance during the operational period was significantly lower than during the preoperational period. However, in many instances, the declines began in the early to mid-1980s, well before Seabrook Station began operation. Several of the decreases seen in the Hampton-Seabrook area simply reflect long-term declining trends of overexploited commercial fishes, including the Atlantic cod, winter flounder, and yellowtail flounder. Decreases in these and other important New England groundfishes, such as haddock, have resulted in large increases in biomass of skates and spiny dogfish. Increase of the latter was also reflected by increased catches by gill net near Seabrook Station in recent years. Larger CPUE of both Atlantic cod and pollock were noted in 1993, which perhaps is a positive sign for future increases in the area. Regional abundance of both red and white hakes is now increasing, but trawl survey indices reported by NFSC (1993) show erratic changes, likely due to varying year-class strength from year to year. A longer time-series of operational data at Seabrook Station may be needed in some cases to discern current abundance trends in the study area.

For pelagic fishes, even though abundance of Atlantic herring is presently increasing in the Northwest Atlantic Ocean, particularly on Georges Bank, CPUE in the Hampton-Seabrook area has remained essentially stable since the early 1980s, after decreasing from a relatively high peak in the late 1970s. It is unknown why abundance has not increased further in the study area, although it may be related to aspects of Atlantic herring stock structure and recruitment in the Gulf of Maine. For the past 2 yr, abundance of the Atlantic mackerel has increased near Seabrook Station, as it has throughout the Northwest Atlantic, but additional years of operational data may be needed to demonstrate a significant change in abundance.

TABLE 5-25. SUMMARY OF POTENTIAL EFFECTS OF THE OPERATION OF SEABROOK STATION ON THE ICHTHYOPLANKTON ASSEMBLAGES AND SELECTED FISH TAXA. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	SAMPLING PROGRAM	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?[a]	PREOPERATIONAL/ OPERATIONAL DIFFERENCES CONSISTENT AMONG STATIONS?[b]	RECENT ABUNDANCE TREND IN THE GULF OF MAINE[c]	STATUS OF FISHERY[c]
Fish egg assemblages	ichthyoplankton				
seasonal occurrence		Op=Preop	yes		
abundance		variable among taxa	yes		
Fish larvae assemblages	ichthyoplankton				
seasonal occurrence		Op=Preop	yes		
abundance		variable among taxa	yes		
Atlantic herring	ichthyoplankton	Op<Preop	yes	increasing	underexploited
	gill net	Op<Preop	yes		
Rainbow smelt	trawl	Op<Preop	yes	unknown	lightly to unexploited
	seine	Op<Preop	yes		
Atlantic cod	ichthyoplankton	Op>Preop	yes	decreasing	overexploited
	trawl	Op<Preop	yes		
Pollock	ichthyoplankton	Op<Preop	yes	stable	fully exploited
	gill net	Op=Preop	yes		
Hakes	ichthyoplankton	Op<Preop	yes	red hake: increasing	underexploited
	trawl	Op<Preop	yes	white hake: increasing	fully exploited
Atlantic silverside	seine	Op<Preop	yes	unknown	unexploited
Cunner	ichthyoplankton	Op<Preop	yes	unknown	unexploited
American sand lance	ichthyoplankton	Op=Preop	yes	decreasing in 1980s now stable (?)	unexploited
Atlantic mackerel	ichthyoplankton	Op=Preop	yes	increasing	underexploited
	gill net	Op=Preop	no		
Winter flounder	ichthyoplankton	Op<Preop	yes	decreasing	overexploited
	trawl	Op<Preop	no		
	seine	Op<Preop	yes		
Yellowtail flounder	ichthyoplankton	Op=Preop	yes	decreasing	overexploited
	trawl	Op<Preop	no		

[a] Based on results of numerical classification for assemblages and ANOVA for selected taxa.
[b] Based on Preop-Op X Station interaction term from the MANOVA for assemblages and ANOVA for selected taxa.
[c] For commercial species, from NFSC (1993).

Two estuarine-dependent fishes, the rainbow smelt and the Atlantic silverside, also had significant differences in CPUE, with preoperational geometric means exceeding those for the operational period. These small, short-lived species appear to exhibit variable and, perhaps, periodic patterns of annual abundance. It is unlikely that Seabrook Station would have significantly affected these species, given their mode of reproduction and concentration in estuaries distant from the plant intake and cooling-water discharge. Relatively few specimens have been entrained or impinged. Any hypothesized effects due to the settling basin discharge into the Browns River will no longer be applicable, as this discharge has been re-routed through the circulating water system in April 1994.

For three species (Atlantic mackerel, gill net; winter flounder, trawl; yellowtail flounder, trawl), the ANOVA interaction term was significant, which suggested a potential effect of Seabrook Station operation. For Atlantic mackerel, the greatest difference was an increase in catch at the farfield station G3 during the operational period, which was unlikely a result of plant operation. Yellowtail flounder, once much more common in trawl catches and with abundance now depressed by overfishing, appears to have decreased similarly at all stations. Winter flounder showed a lower abundance at the nearfield station T2 than at the two farfield stations. The reasons for this are unknown, but could be related to natural changes in the local environmental or physical conditions, which might not persist very long. However, it is also possible that this distributional change may be related, in part, to station operation and this may bear further scrutiny over the next few years.

Compared to other New England marine power plants, Seabrook Station entrains relatively few fish eggs or larvae and impinges very few juvenile and adult fish. The location and design of the offshore intakes has worked as expected in reducing these impacts. In fact, most of the impingement that does occur is not of pelagic fish, but demersal fish that predominantly encounter the intake during storm events. Numbers impinged were not only low relative to other regional power plants, but also insignificant when compared to commercial and recreational landings, or even to losses from sampling gear in the study area (NAI 1993). Impingement totals for each affected species are so low that they would not be expected to measurably reduce population size or affect reproductive capacity of local fishes and the American lobster.

In conclusion, other than a possible distributional change for winter flounder, little impact to fishes can be attributed to Seabrook Station operation. Most of the selected species are from very large and highly fecund stocks spawning throughout the Gulf of Maine. Others, such as the rainbow smelt, Atlantic silverside, and winter flounder, spawn in estuaries away from the plant intake and have egg or larval life stages that are largely maintained in inshore areas. The Atlantic cod, winter flounder, and yellowtail flounder continue to be overexploited by commercial fisheries and their stocks are presently declining. Other fishes, such as Atlantic mackerel, were overfished and now have recovered. Catch of all the selected species in the Hampton-Seabrook area simply reflect long-term, regional trends. Furthermore, the influence of regional environmental factors and interspecific interactions (e.g., American sand lance-Atlantic mackerel) introduces complexities in any evaluation. Because of the relatively small numbers of fish of all life stages directly removed by the plant and the concurrent changes in abundance at both near- and farfield stations in nearly every instance, the operation of Seabrook Station does not appear to have affected the balanced indigenous populations of fish in the Hampton-Seabrook area.

5.5 REFERENCES CITED

Anderson, E.M. 1979. Assessment of the Northwest Atlantic mackerel, *Scomber scombrus*, stock. NOAA Tech. Rep. NMFS SSRF-732. 13 pp.

Anderson, R.D. 1994. Impingement of organisms at Pilgrim Nuclear Power Station (January-December 1993). *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 43. Boston Edison Co., Boston, MA.

Anthony, V.C., and H.C. Boyar. 1968. Comparison of meristic characters of adult Atlantic herring from the Gulf of Maine and adjacent waters. Res. Bull. Int. Comm. Northw. Atl. Fish 5: 91-98.

_________, and M. J. Fogarty. 1985. Environmental effects on recruitment, growth, and vulnerability of Atlantic herring (*Clupea harengus harengus*) in the Gulf of Maine region. Can. J. Fish. Aquat. Sci. 42(Suppl. 1): 158-173.

Bengston, D.A., R.C. Barkman, and W.J. Berry. 1987. Relationships between maternal size, egg diameter, time of spawning season, temperature, and length at hatch of Atlantic silverside, *Menidia menidia*. J. Fish. Biol. 31: 697-704.

Berrien, P.L. 1978. Eggs and larvae of *Scomber scombrus* and *Scomber japonicus* in continental shelf waters between Massachusetts and Florida. Fish. Bull., U.S. 76: 95-114.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish. Wildl. Serv. Fish. Bull. 53:1-577.

Bolz, G.R., and R.G. Lough. 1988. Growth through the first six months of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, based on daily otolith increments. Fish. Bull., U.S. 86: 223-235.

Boyar, H.C., R.R. Marak, F.E. Perkins, and R.A. Clifford. 1971. Seasonal distribution of larval herring, *Clupea harengus harengus* Linnaeus, in Georges Bank-Gulf of Maine area, 1962-70. Int. Comm. Northw. Atl. Fish., Res. Doc. 71/100. 11 pp.

Brander, K., and P.C. Hurley. 1992. Distribution of early-stage Atlantic cod (*Gadus morhua*), haddock (*Melangrammus aeglefinus*), and witch flounder (*Glyptocephalus cynoglossus*) eggs on the Scotian Shelf: a reappraisal of evidence on the coupling of cod spawning and plankton production. Can. J. Fish. Aquat. Sci. 49: 238-251.

Buckley, L.J., S I. Turner, T.A. Halavik, A.S. Smigielski, S.M. Drew, and G.C. Laurence. 1984. Effects of temperature and food availability on growth, survival, and RNA-DNA ratio of larval sand lance (*Ammodytes americanus*). Mar. Ecol. Prog. Ser. 15: 91-97.

Campana, S.E., K.T. Frank, P.C.F. Hurley, P.A. Koeller, F.H. Page, and P.C. Smith. 1989. Survival and abundance of young Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as indicators of year-class strength. Can. J. Fish. Aquat. Sci. 46(Suppl.1): 171-182.

Campbell, D.E., and J.J. Graham. 1991. Herring recruitment in Maine coastal waters: an ecological model. Can. J. Fish. Aquat. Sci. 48: 448-471.

Clayton, G.R. 1976. Reproduction, first year growth, and distribution of anadromous rainbow smelt, *Osmerus mordax*, in the Parker River-Plum Island Sound estuary, Massachusetts. M.S. Thesis. University of Massachusetts, Amherst, MA. 105 pp.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

Colton, J.B., Jr., W.G. Smith, A.W. Kendall, Jr., P.L. Berrien, and M.P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76: 911-915.

Comyns, B.H., and G.C. Grant. 1993. Identification and distribution of *Urophycis* and *Phycis* (Pisces, Gadidae) larvae and pelagic juveniles in the U.S. Middle Atlantic Bight. Fish. Bull., U.S. 91: 210-223.

Conover, D.O. 1979. Density, growth, production and fecundity of the Atlantic silverside, *Menidia menidia* (Linnaeus), in a central New England estuary. M.S. Thesis. University of Massachusetts, Amherst, MA. 59 pp.

_________. 1992. Seasonality and the scheduling of life history at different latitudes. J. Fish Biol. 41: 161-178.

_________, and M.H. Fleisher. 1986. Temperature-sensitive period of sex determination in the Atlantic silverside, *Menidia menidia*. Can. J. Fish. Aquat. Sci. 43: 514-520.

_________, and B.E. Kynard. 1981. Environmental sex determination: interaction of temperature and genotype in a fish. Science 213: 577-579.

_________, and B.E. Kynard. 1984. Field and laboratory observations of spawning periodicity and behavior of a northern population of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). Envir. Biol. Fish. 11: 161-171.

_________, and S.A. Murawski. 1982. Offshore winter migration of the Atlantic silverside, *Menidia menidia*. Fish. Bull., U.S. 80: 145-150.

_________, and M. R. Ross. 1982. Patterns in seasonal abundance, growth and biomass of the Atlantic silverside, *Menidia menidia*, in a New England estuary. Estuaries 5: 275-286.

Crawford, R.E. 1990. Winter flounder in Rhode Island coastal ponds. Rhode Island Sea Grant, Univ. of Rhode Island, Narragansett, RI. RIU-G-90-001. 24 pp.

Cushing, D.H. 1984. The gadoid outburst in the North Sea. J. Cons. int. Explor. Mer 41: 159-166.

D'Amours, D., and F. Gregoire. 1991. Analytical correction for oversampled Atlantic mackerel *Scomber scombrus* eggs collected with oblique plankton tows. Fish. Bull., U.S. 90: 190-196.

_________, J.G. Landry, and T.C. Lambert. 1990. Growth of juvenile (0-group) Atlantic mackerel (*Scomber scombrus*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 47: 2212-2218.

deLafontaine, Y., and D. Gascon. 1989. Ontogenetic variation in the vertical distribution of eggs and larvae of Atlantic mackerel (*Scomber scombrus*). Rapp. P.-v. Reun. int. Explor. Mer 191: 137-145.

Dew, C.B. 1976. A contribution to the life history of the cunner, *Tautogolabrus adsperus*, in Fishers Island Sound, Connecticut. Chesapeake Sci. 17: 101-113.

Dodson, J.J., J.-C. Dauvin, R.G. Ingram, and B. D'Anglejan. 1989. Abundance of larval rainbow smelt (*Osmerus mordax*) in relation to the maximum turbidity zone and associated macroplanktonic fauna of the middle St. Lawrence estuary. Estuaries 12: 66-81.

Evans, S.D. 1978. Impingement studies. Pages 3.1-3.40 *in* Maine Yankee Atomic Power Company. Final report environmental surveillance and studies at the Maine Yankee Nuclear Generating Station 1969-1977.

Everich, D., and J.G. Gonzalez. 1977. Critical thermal maxima of two species of estuarine fish. Mar. Biol. 41: 141-146.

Fahay, M.P. 1983. Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. J. Northw. Atl. Fish. Sci. 4: 1-423.

__________, and K.W. Able. 1989. White hake, *Urophycis tenuis*, in the Gulf of Maine: spawning seasonality, habitat use, and growth in young of the year and relationships to the Scotian Shelf population. Can. J. Zool. 67: 1715-1724.

Frechet, A., and J.J. Dodson. 1983. Use of variation in biological characters for the classification of anadromous rainbow smelt (*Osmerus mordax*) groups. Can. J. Fish. Aquat. Sci. 40: 718-727.

Freund, P.J., R.C. Littell, and P.C. Spector. 1986. SAS for linear models: a guide to the ANOVA and GLM procedures. SAS Institute Inc., Cary, NC.

Garman, G.C. 1983. Observations on juvenile red hake associated with sea scallops in Frenchman Bay, Maine. Trans. Am. Fish. Soc. 112: 212-215.

Gilman, S.L. 1994. An energy budget for northern sand lance, *Ammodytes dubius*, on Georges Bank. Fish. Bull., U.S. 92: 647-654.

Graham, J.J. 1982. Production of larval herring, *Clupea harengus*, along the Maine coast, 1964-78. J. Northw. Atl. Fish. Sci. 3: 63-85.

__________, S. B. Chenoweth, and C.W. Davis. 1972. Abundance, distribution, movements, and lengths of larval herring along the western coast of the Gulf of Maine. Fish. Bull., U.S. 70: 307-321.

__________, D.K. Stevenson, and K.M. Sherman. 1990. Relation between winter temperature and survival of larval Atlantic herring along the Maine coast. Trans. Am. Fish. Soc. 119: 730-740.

__________, and D.W. Townsend. 1985. Mortality, growth, and transport of larval Atlantic herring *Clupea harengus* in Maine coastal waters. Trans. Am. Fish. Soc. 114: 490-498.

Green, J.M. 1975. Restricted movements and homing of the cunner, *Tautogolabrus adspersus* (Walbaum) (Pisces: Labridae). Can. J. Zool. 53: 1427-1431.

__________, and M. Farwell. 1971. Winter habits of the cunner, *Tautogolabrus adspersus* (Walbaum) in Newfoundland. Can. J. Zool. 49: 1497-1499.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons, New York. 257 pp.

Grimes, C.B. 1975. Entrapment of fishes on intake water screens at a steam electric generating station. Chesapeake Sci. 16: 172-177.

Haegele, C.W., and J.F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42: 39-55.

Harris, R.J. 1985. A primer of multivariate statistics. Academic Press, Orlando. 575 pp.

Hermes, R. 1985. Distribution of neustonic larvae of hakes *Urophycis* spp. and fourbeard rockling *Enchelyopus cimbrius* in the Georges Bank area. Trans. Am. Fish. Soc. 114: 604-608.

Hoff, J.G., and J.R. Westman. 1966. The temperature tolerance of three species of marine fishes. J. Mar. Res. 24: 131-140.

Howe, A.B., and P.G. Coates. 1975. Winter flounder movements, growth and mortality off Massachusetts. Trans. Am. Fish. Soc. 104:13-29.

Iles, T.D., and M. Sinclair. 1982. Atlantic herring: stock discreteness and abundance. Science 215: 627-633.

Jean, Y. 1964. Seasonal distribution of cod (*Gadus morhua* L.) along the Canadian Atlantic coast in relation to water temperature. J. Fish. Res. Board Can. 21: 429-460.

Jessop, B.M. 1983. Aspects of the life history of the Atlantic silverside (*Menidia menidia*) of the Annapolis River, Nova Scotia. Can. Ms. Rep. Fish. Aquat. Sci. 1694. 41 pp.

Johansen, F. 1925. Natural history of the cunner (*Tautogolabrus adsperus* Walbaum). Contrib. Can. Biol. 2: 423-468.

Jones, C. 1985. Within-season differences in growth of larval Atlantic herring, *Clupea harengus harengus*. Fish. Bull., U.S. 83: 289-298.

Kennedy, J.S., and D.H. Steele. 1971. The winter flounder (*Pseudopleuronectes americanus*) in Long Pond, Conception Bay, Newfoundland. J. Fish. Res. Board Can. 28: 1153-1165.

Kornfield, I., and S.M. Bogdanowicz. 1987. Differentiation of mitochondrial DNA in Atlantic herring, *Clupea harengus*. Fish. Bull., U.S. 85: 561-568.

Koslow, J.A. 1984. Recruitment patterns in Northwest Atlantic fish stocks. Can. J. Fish. Aquat. Sci. 41: 1722-1729.

__________, and W. Silvert. 1987. Recruitment to northwest Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) stocks: influence of stock size and climate. Can. J. Fish. Aquat. Sci. 44: 26-39.

Lambert, T.C. 1984. Larval cohort succession in herring (*Clupea harengus*) and capelin (*Mallotus villosus*). Can. J. Fish. Aquat. Sci. 41: 1552-1564.

__________, and D.M. Ware. 1984. Reproductive strategies of demersal and pelagic spawning fish. Can. J. Fish. Aquat. Sci. 41: 1565-1569.

Landry, A.M., Jr., and K. Strawn. 1974. Number of individuals and injury rates of fishes caught on revolving screens at the P.H. Robinson Generating Station. Pages 263-271 *in* L.D. Jensen, ed. Entrainment and intake screening. Proceedings of the second entrainment and impingement workshop. Rep. No. 15, Edison Electric Institute.

Laprise, R., and J.J. Dodson. 1989. Ontogeny and importance of tidal vertical migrations in the retention of larval smelt *Osmerus mordax* in a well-mixed estuary. Mar. Ecol. Prog. Ser. 55: 101-111.

Lawton, R., P. Brady, C. Sheehan, S. Correia, and M. Borgatti. 1990. Final report on spawning sea-run rainbow smelt (*Osmerus mordax*) in the Jones River and impact assessment of Pilgrim Station on the population, 1979 -1981. Pilgrim Nuclear Power Station Mar. Envir. Monitoring Prog. Rep. Ser. No. 4. 72 pp.

Lazzari, M.A., and D.K. Stevenson. 1993. Influence of residual circulation and vertical distribution on the abundance and horizontal transport of larval Atlantic herring (*Clupea harengus*) in a Maine estuary. Can. J. Fish. Aquat. Sci. 50: 1879-1889.

Lifton, W.S., and J.F. Storr. 1978. The effect of environmental variables on fish impingement. Pages 299-314 *in* L.D. Jensen, ed. Fourth national workshop on entrainment and impingement. EA Communications, Melville, NY.

LMS (Lawler, Matusky & Skelly Engineers). 1987. Brayton Point Station Unit No. 4 angled screen intake biological evaluation program. Vol I. Program summary report 1984-1986. Submitted to New England Power Company, Westborough, MA.

Lobell, M.J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes. Winter flounder (*Pseudopleuronectes americanus*). Suppl. 28th Ann. Rep., N.Y. Cons. Dep., Pt. I:63-96.

Lough, R.G., M. Pennington, G.R. Bolz, and A.A. Rosenberg. 1982. Age and growth of larval Atlantic herring *Clupea harengus* L., in the Gulf of Maine-Georges Bank region based on otolith growth increments. Fish. Bull., U.S. 80: 187-199.

__________, and D.C. Potter. 1993. Vertical distribution patterns and diel migrations of larval and juvenile haddock *Melanogrammus aeglefinus* and Atlantic cod *Gadus morhua* on Georges Bank. Fish. Bull. U.S. 91: 281-303.

Luczkovich, J.J. 1991. Seasonal variation in usage of a common shelter resource by juvenile inquiline snailfish (*Liparis inquilinus*) and red hake (*Urophycis chuss*). Copeia 1991: 1104-1109.

MacDonald, J.S., M.J. Dadswell, R.G. Appy, G.D. Melvin, and D.A. Methven. 1984. Fishes, fish assemblages, and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fish. Bull., U.S. 82: 121-139.

Markle, D.F., and L.-A. Frost. 1985. Comparative morphology, seasonality, and a key to planktonic fish eggs from the Nova Scotian shelf. Can. J. Zool. 63: 246-257.

__________, D.A. Methven, and L.J. Coates-Markle. 1982. Aspects of spatial and temporal cooccurrence in the life history stages of the sibling hakes, *Urophycis chuss* (Walbaum 1792) and *Urophycis tenuis* (Mitchill 1815) (Pisces: Gadidae). Can. J. Zool. 60: 2057-2078.

McCracken, F.D. 1963. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus* (Walbaum), on the Atlantic coast. J. Fish. Res. Board Can. 20:551-586.

Messieh, S.N. 1976. Fecundity studies on Atlantic herring from the southern Gulf of St. Lawrence and along the Nova Scotia coast. Trans. Am. Fish. Soc. 105: 384-394.

Meyer, T.L., R.A. Cooper, and R.W. Langton. 1979. Relative abundance, behavior, and food habits of the American sand lance, *Ammodytes americanus*, from the Gulf of Maine. Fish. Bull., U.S. 77: 243-253.

Monteleone, D.M., and W.T. Peterson. 1986. Feeding ecology of American sand lance *Ammodytes americanus* larvae from Long Island Sound. Mar. Ecol. Prog. Ser. 30: 133-143.

_________. 1987. Interannual fluctuations in the density of sand lance, *Ammodytes americanus*, larvae in Long Island Sound, 1951-1983. Estuaries 10: 246-254.

Moring, J.R. 1990. Seasonal absence of fishes in tidepools of a boreal environment (Maine, USA). Hydrobiologia 194: 163-168.

Morrison, D.F. 1976. Multivariate statistical methods. Second ed. McGraw-Hill Book Co., New York. 415 pp.

Morse, W.W. 1980. Spawning and fecundity of Atlantic mackerel, *Scomber scombrus*, in the Middle Atlantic Bight. Fish. Bull., U.S. 78: 103-107.

MRI (Marine Research, Inc.). 1991. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1990. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 37. Boston Edison Co., Boston, MA.

_________. 1992. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1991. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 39. Boston Edison Co., Boston, MA.

_________. 1993a. Brayton Point investigations annual report January-December 1992. *In* New England Power Company and Marine Research, Inc. Brayton Point Station annual biological and hydrological report January-December 1992. January 1994.

_________. 1993b. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1992. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 41. Boston Edison Co., Boston, MA.

_________. 1994. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1993. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 43. Boston Edison Co., Boston, MA.

Murawski, S.A., and C.F. Cole. 1978. Population dynamics of anadromous rainbow smelt *Osmerus mordax*, in a Massachusetts river system. Trans. Am. Fish. Soc. 107: 535-542.

_________, and C.F. Cole. 1980. Movements of spawning rainbow smelt, *Osmerus mordax*, in a Massachusetts estuary. Estuaries 3: 308-314.

_________, and J.T. Finn. 1988. Biological bases for mixed-species fisheries: species co-distribution in relation to environmental and biotic variables. Can. J. Fish. Aquat. Sci. 45: 1720-1735.

Musick, J.A. 1974. Seasonal distribution of sibling hakes, *Urophycis chuss* and *U. tenuis* (Pisces, Gadidae) in New England. Fish Bull., U.S. 72: 481-495.

NAI (Normandeau Associates Inc.). 1991. Finfish. Pages 191-277 *in* Seabrook environmental studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

_________. 1992. Finfish. Pages 3-66 - 3-123 *in* Seabrook environmental studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-1.

_________. 1993. Fish. Pages 5-1 - 5-72 *in* Seabrook environmental studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

NFSC (Northeast Fisheries Science Center). 1993. Status of fishery resources off the northeastern United States for 1993. NOAA Tech. Mem. NMFS-F/NEC-101. 140 pp.

Nizinski, M.S., B.B. Collette, and B.B. Washington. 1990. Separation of two species of sand lances, *Ammodytes americanus* and *A. dubius*, in the Western North Atlantic. Fish. Bull., U.S. 88: 241-255.

NUSCO (Northeast Utilities Service Company). 1987. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Summary of studies prior to Unit 3 operation. 151 pp.

_________. 1988. Fish ecology studies. Pages 255-307 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Three-unit operational studies 1986-1987.

_________. 1994a. Fish ecology studies. Pages 111-139 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report 1993.

_________. 1994b. Winter flounder studies. Pages 141-228 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report 1993.

Ojeda, F.P., and J.H. Dearborn. 1990. Diversity, abundance, and spatial distribution of fishes and crustaceans in the rocky subtidal zone of the Gulf of Maine. Fish. Bull., U.S. 88: 403-410.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1975. Activity, movements, and feeding behavior of the cunner, *Tautogolabrus adspersus*, and comparison of food habits with young tautog, *Tautoga onitis*, off Long Island, New York. Fish. Bull., U.S. 73: 895-900.

_________, A J. Bejda, and A.D. Martin. 1979. Seasonal dispersal and habitat selection of cunner, *Tautogolabrus adspersus*, and young tautog, *Tautoga onitis*, in Fire Island Inlet, Long Island, New York. Fish. Bull., U.S. 77: 255-262.

_________, R. Wicklund, and S. Wilk. 1969. Behavior of winter flounder in a natural habitat. Trans. Am. Fish. Soc. 98:717-720.

Ouellet, P., and J.J. Dodson. 1985a. Dispersion and retention of anadromous rainbow smelt *(Osmerus mordax)* larvae in the middle estuary of the St. Lawrence River. Can. J. Fish. Aquat. Sci. 42: 332-341.

_________, and J.J. Dodson. 1985b. Tidal exchange of anadromous rainbow smelt (*Osmerus mordax*) larvae between a shallow tributary and the St. Lawrence estuary. Can. J. Fish. Aquat. Sci. 42: 1352-1358.

Overholtz, W.J., and J.R. Nicholas. 1979. Apparent feeding by the fin whale, *Balaenopter physalus* and humpback whale, *Megaptera novaengliae*, on the American sand lance, *Ammodytes americanus*, in the Northwest Atlantic. Fish. Bull., U.S. 77: 285-287.

Parsons, L.S., and J.A. Moores. 1974. Long-distance migration of an Atlantic mackerel. J. Fish. Res. Board Can. 31: 1521-1522.

Payne, P.M., J.R. Nicholas, L. O'Brien, and K.D. Powers. 1986. The distribution of the humpback whale *Megaptera novaeangliae* on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel *Ammodytes americanus*. Fish. Bull., U.S. 84: 271-277.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18:1-78.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Coll. 11:1-92.

Perry, I. R., and J. D. Neilson. 1988. Vertical distributions and trophic interactions of age-0 Atlantic cod and haddock in mixed and stratified waters of Georges Bank. Mar. Ecol. Prog. Ser. 49: 199-214.

_________, and S.J. Smith. 1994. Identifying habit associations of marine fishes using survey data: an application to the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 51: 589-601.

Peterson, W.T., and S.J. Ausubel. 1984. Diets and selective feeding by larvae of Atlantic mackerel *Scomber scombrus* on zooplankton. Mar. Ecol. Prog. Ser. 17: 65-75.

Pitt, T.K. 1971. Fecundity of the yellowtail flounder (*Limanda ferruginea*) from the Grand Bank, Newfoundland. J. Fish. Res. Board Can. 28: 456-457.

Pottle, R.A., and J.M. Green. 1979. Field observations on the reproductive behaviour of the cunner, *Tautogolabrus adsperus* (Walbaum), in Newfoundland. Can. J. Zool. 57: 247-256.

Powles, P.M. 1958. Studies of reproduction and feeding of Atlantic cod (*Gadus callarias* L.) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Board Can. 15: 1383-1402.

Reay, P.J. 1970. Synopsis of biological data on North Atlantic sand eels of the genus *Ammodytes*. (*A. tobianus*, *A. dubius*, *A. americanus* and *A. marinus*). FAO Fish. Synop. No. 82. 28 pp.

Richards, S.W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17: 95-124.

_________. 1982. Aspects of the biology of *Ammodytes americanus* from the St. Lawrence River to Chesapeake Bay, 1972-75, including a comparison of the Long Island Sound postlarvae with *Ammodytes dubius*. J. Northw. Atl. Fish. Sci. 3: 93-104.

_________, and A. W. Kendall. 1973. Distribution of sand lance, *Ammodytes* sp., larvae on the continental shelf from Cape Cod to Cape Hatteras from *RV Dolphin* surveys in 1966. Fish. Bull., U.S. 71: 371-386.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. A list of common and scientific names of fishes from the United States and Canada. 5th ed. Am. Fish. Soc. Spec. Pub. No. 20. 183 pp.

Rogers, C.A. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fish. Bull., U.S. 74: 52-58.

Rosenberg, A.A., and R.W. Doyle. 1986. Analysing the effect of age structure on stock-recruitment relationships in herring (*Clupea harengus*). Can. J. Fish. Aquat. Sci. 43: 674-679.

Safford, S.E., and H. Booke. 1992. Lack of biochemical genetic and morphometric evidence for discrete stocks of northwest Atlantic herring *Clupea harengus harengus*. Fish. Bull., U.S. 90: 203-210.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

Sauceman, S.E., and L.A. Deegan. 1991. Lateral and cross-channel movement of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) in Waquoit Bay, Massachusetts. Estuaries 14:440-446.

Scott, J.S. 1982a. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northw. Atl. Fish. Sci. 3: 29-40.

_________. 1982b. Selection of bottom type by groundfishes of the Scotian Shelf. Can. J. Fish. Aquat. Sci. 39: 943-947.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board. Can. 184. 966 pp.

_________, and M.G. Scott. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Sette, O.E. 1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America: Part II - migrations and habits. U.S. Fish. Wildl. Serv. Fish. Bull. 51: 251-358.

Shaw, R.G., and T. Mitchell-Olds. 1993. ANOVA for unbalanced data: an overview. Ecology 74: 1638-1645.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature (London) 291: 486-489.

Sinclair, M., and T.D. Iles. 1985. Atlantic herring (*Clupea harengus*) distributions in the Gulf of Maine-Scotian Shelf area in relation to oceanographic features. Can. J. Fish. Aquat. Sci. 42:880-887.

_________, and M.J. Tremblay. 1984. Timing of spawning of Atlantic herring (*Clupea harengus harengus*) populations and match-mismatch theory. Can. J. Fish. Aquat. Sci. 41: 1055-1065.

Smigielski, A.S., T.A. Halavik, L.J. Buckley, S.M. Drew, and G.C. Laurence. 1984. Spawning, embryo development and growth of the American sand lance *Ammodytes americanus* in the laboratory. Mar. Ecol. Prog. Ser. 14: 287-292.

Smith, W. G., and W. W. Morse. 1993. Larval distribution patterns: early signals for the collapse/recovery of Atlantic herring *Clupea harengus* in the Georges Bank area. Fish. Bull., U.S 91: 338-347.

Smith, W.G., J.D. Sibunka, and A. Wells. 1975. Seasonal distributions of larval flatfishes (Pleuronectiformes) on the continental shelf between Cape Cod, Massachusetts and Cape Lookout, North Carolina, 1965-1966. NOAA Tech. Rep. NMFS SSRF-691. 68 pp.

_________. 1978. Diel movements of larval yellowtail flounder, *Limanda ferruginea*, determined from discrete depth sampling. Fish. Bull., U.S. 76: 167-177.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. W.H. Freeman Co., San Francisco. 573 pp.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 775 pp.

Steiner, W.W., J.J. Luczkovich, and B.L. Olla. 1982. Activity, shelter usage, growth and recruitment of juvenile red hake *Urophycis chuss*. Mar. Ecol. Prog. Ser. 7: 125-135.

_________, and B. Olla. 1985. Behavorial responses of prejuvenile red hake, *Urophycis chuss*, to experimental thermoclines. Envir. Biol. Fish. 14: 167-173.

Stephenson, R.L., and I. Kornfield. 1990. Reappearance of spawning Atlantic herring (*Clupea harengus harengus*) on Georges Bank: population resurgence not recolonization. Can. J. Fish. Aquat. Sci. 47: 1060-1064.

Stewart-Oaten, A., W.W. Murdoch, and K.E. Parker. 1986. Environmental impact assessment: "psuedoreplication" in time? Ecology 67: 929-940.

Suthers, I.M., and K.T. Frank. 1989. Inter-annual distributions of larval and pelagic juvenile cod (*Gadus morhua*) in southwestern Nova Scotia determined with two different gear types. Can. J. Fish. Aquat. Sci. 46: 591-602.

Thomas, D.L., and G.J. Miller. 1976. Impingement at Oyster Creek Generating Station, Forked River, New Jersey, from September to December 1975. Pages 317-341 *in* L.D. Jensen, ed. Third national workshop on entrainment and impingement. Ecological Analysts, Melville, NY.

Thomas, J.M. 1977. Factors to consider in monitoring programs suggested by statistical analysis of available data. Pages 243-255 *in* W. Van Winkle, ed. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, TN, May 3-6, 1977. Pergamon Press, New York.

Topp, R.W. 1968. An estimate of fecundity of the winter flounder, *Pseudopleuronectes americanus*. J. Fish. Res. Board Can. 25: 1299-1302.

Townsend, D.W. 1992. Ecology of larval herring in relation to the oceanography of the Gulf of Maine. J. Plankton Res. 14: 467-493.

Van Guelpen, L., and C.C. Davis. 1979. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus*, in two contrasting inshore locations in Newfoundland. Trans. Am. Fish. Soc. 108: 26-37.

Ware, D.M. 1977. Spawning time and egg size of Atlantic mackerel, *Scomber scombrus*, in relation to the plankton. J. Fish. Res. Board Can. 34: 2308-2315.

__________, and T. C. Lambert. 1985. Early life history of Atlantic mackerel (*Scomber scombrus*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 42: 577-592.

Westin, D.T., K.J. Abernethy, I.E. Meller, and B.A. Rogers. 1979. Some aspects of biology of the American sand lance *Ammodytes americanus*. Trans. Am. Fish. Soc. 108: 328-331.

Wheatland, S.B. 1956. Oceanography of Long Island Sound. 1952-1954. II. Pelagic fish eggs and larvae. Bull. Bingham Oceanogr. Coll. 15: 234-314.

Wheeler, J.P., and G.H. Winters. 1984. Homing of Atlantic herring in Newfoundland waters as indicated by tagging data. Can. J. Fish. Aquat. Sci. 41: 108-117.

Wigley, S.E., and F.M. Serchuk. 1992. Spatial and temporal distribution of juvenile Atlantic cod *Gadus morhua* in the Georges Bank-Southern New England region. Fish. Bull., U.S. 90: 599-606.

Wilks, S.S. 1932. Certain generalizations in the analysis of variance. Biometrika 24: 471-494.

Williams, G.C. 1967. Identification and seasonal size changes of eggs of the labrid fishes, *Tautogolabrus adspersus* and *Tautoga onitis*, of Long Island Sound. Copeia 1967: 452-453.

__________, S.W. Richards, and E.G. Farnworth. 1964. Eggs of *Ammodytes hexapterus* from Long Island, New York. Copeia 1964: 242-243.

__________, D.C. Williams, and R.J. Miller. 1973. Mortality rates of planktonic eggs of the cunner, *Tautogolabrus adspersus* (Walbaum), in Long Island Sound. Pages 181-195 *in* A. Pacheco, ed. Proceedings of a workshop on egg, larval and juvenile stages of fish in Atlantic coast estuaries. Nat. Mar. Fish. Serv., Mid. Atl. Coast. Fish. Ctr. Tech. Pub. No. 1.

Winters, G.H., and E.L. Dalley. 1988. Meristic composition of sand lance (*Ammodytes* spp.) in Newfoundland waters with a review of species designations in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 45: 515-529.

APPENDIX TABLE 5-1. FINFISH SPECIES COMPOSITION BY LIFE STAGE AND GEAR, JULY 1975 - DECEMBER 1993. SEABROOK OPERATIONAL REPORT, 1993.

SCIENTIFIC NAME[a]	COMMON NAME[a]	ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
		EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Acipenser oxyrhynchus	Atlantic sturgeon			R[b]		
Alosa aestivalis	blueback herring		--	R	C	C
Alosa mediocris	hickory shad		--		R	
Alosa pseudoharengus	alewife		--	O	O	O
Alosa sapidissima	American shad		--	R	O	O
Alosa spp.	river herring		R	--	--	--
Ammodytes americanus	American sand lance		A	O	R	O
Anarhichas lupus	Atlantic wolffish			R		
Anchoa hepsetus	striped anchovy				R	
Anguilla rostrata	American eel		C	R		
Apeltes quadracus	fourspine stickleback				R	
Archosargus probatocephalus	sheepshead			R		
Aspidophoroides monopterygius	alligatorfish		C	O		
Brevoortia tyrannus	Atlantic menhaden	O	O	R	O	R
Brosme brosme	cusk	O	O			
Caranx hippos	crevalle jack				R	
Centropristis striata	black sea bass			R	R	
Conger oceanicus	conger eel		R			
Clupea harengus	Atlantic herring		C	O	A	O
Cryptacanthodes maculatus	wrymouth		O	R		
Cyclopterus lumpus	lumpfish		C	R	R	R
Enchelyopus cimbrius	fourbeard rockling	C	C	O		
Fundulus spp.[c]	killifish					C
Gadus morhua	Atlantic cod	--	C	C	O	R
Gadus/Melanogrammus	Atlantic cod/haddock	C	--	--	--	--
Gasterosteus spp.[d]	stickleback		R	R		C
Glyptocephalus cynoglossus	witch flounder	C	C	O		
Hemitripterus americanus	sea raven		O	C	O	R
Hippoglossoides platessoides	American plaice	C	C	O		
Hippoglossus hippoglossus	Atlantic halibut			R		
Labridae/*Pleuronectes*	cunner/yellowtail flounder[e]	A	--	--	--	--
Liparis atlanticus	Atlantic seasnail	R	C		--	--
Liparis coheni	gulf snailfish		C	--	--	--
Liparis spp.[f]	snailfish	R	--	O		
Lophius americanus	goosefish	R	O	O	R	
Lumpenus lumpretaeformis	snakeblenny		O	R		
Lumpenus maculatus	daubed shanny		R	R		
Macrozoarces americanus	ocean pout		O	C	R	
Melanogrammus aeglefinus	haddock	--	O	C	R	
Menidia menidia	Atlantic silverside		R	O	R	A
Menticirrhus saxatilis	northern kingfish				R	
Merluccius bilinearis	silver hake	C	C	C	C	R

(continued)

APPENDIX TABLE 5-1. (Continued)

SCIENTIFIC NAME[a]	COMMON NAME[a]	ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
		EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Microgadus tomcod	Atlantic tomcod		R	R		O
Morone americana	white perch					R
Morone saxatilis	striped bass			R		R
Mugil cephalus	striped millet					R
Mustelus canis	smooth dogfish			R		
Myoxocephalus aenaeus	grubby		C	O	R	O
Myoxocephalus octodecemspinosus	longhorn sculpin		C	A	O	R
Myoxocephalus scorpius	shorthorn sculpin		C	O	R	R
Odontaspis taurus	sand tiger				R	
Oncorhynchus kisutch	coho salmon				R	R
Oncorhynchus mykiss	rainbow trout					R
Osmerus mordax	rainbow smelt		O	C	O	C
Paralichthys dentatus	summer flounder		R	R		
Paralichthys oblongus	fourspot flounder	R	O	C	R	
Peprilus triacanthus	butterfish	O	O	R	O	R
Petromyzon marinus	sea lamprey				R	
Pholis gunnellus	rock gunnel		C	O	R	R
Pleuronectes americanus	winter flounder		C	C	O	C
Pleuronectes ferrugineus	yellowtail flounder	--	C	A	R	R
Pleuronectes putnami	smooth flounder		R	R		C
Pollachius virens	pollock	C	C	C	C	O
Pomatomus saltatrix	bluefish				O	O
Prionotus carolinus	northern searobin	--	--	O	R	
Prionotus evolans	striped searobin	--	--	R		
Prionotus spp.	searobin	O	R	--	--	--
Pungitius pungitius	ninespine stickleback				C	
Raja spp.[g]	skate			C	R	
Salmo trutta	brown trout					O
Salvelinus fontinalis	brook trout					R
Scomber japonicus	chub mackerel				R	
Scomber scombrus	Atlantic mackerel	A	A	R	C	R
Scophthalmus aquosus	windowpane	C	C	C	R	O
Sebastes spp.[h]	redfish		O			
Sphoeroides maculatus	northern puffer			R		R
Squalus acanthias	spiny dogfish		R	C		
Stenotomus chrysops	scup		R	O	R	
Stichaeus punctatus	Arctic shanny		O			
Syngnathus fuscus	northern pipefish		C	O	R	O
Tautoga onitis	tautog	--	C		R	
Tautogolabrus adspersus	cunner	--	A	O	O	R
Torpedo nobiliana	Atlantic torpedo		R			
Triglops murrayi	moustache sculpin		O	R		
Ulvaria subbifurcata	radiated shanny		C	O		
Urophycis spp.[i]	hake	A	C	A	O	C

Footnotes: See next page.

Footnotes:

[a] Names are according to Robins et al. (1991). Taxa usually identified to a different level are not included in this list to avoid duplication (e.g., Gadidae, *Enchelyopus/Urophycis*, *Myoxocephalus* sp., *Urophycis chuss*)

[b] Occurrence of each species is indicated by its relative abundance or frequency of occurrence for each life stage or gear type:

A = abundant (≥10% of total catch over all years)
C = common (occurring in ≥10% of samples but <10% of total catch)
O = occasional (occurring in <10% and ≥1% of samples)
R = rare (occurring in <1% of samples)
-- = not usually identified to this taxonomic level at this life stage

[c] Predominantly *Fundulus heteroclitis*, mummichog, but may include a small number of *Fundulus majalis*, striped killifish.

[d] Two species of *Gasterosteus* have been identified from seine samples: *G. aculeatus*, threespine stickleback; and *G. wheatlandi*, blackspotted stickleback (both occurring commonly).

[e] May also include a small number of tautog as well as cunner.

[f] Three species of *Liparis* have been identified from trawl samples: *L. atlanticus*, Atlantic seasnail; *L. coheni*, gulf snailfish; and *L. inquilinus* inquiline snailfish.

[g] Four species of *Raja* have been identified from trawl samples: *R. radiata*, thorny skate (common); *R. erinacea*, little skate (common); *R. ocellata*, winter skate (occasional); and R. *eglanteria*, clearnose skate (rare).

[h] *Sebastes norvegicus* (previously called *S. marinus*), golden redfish; *S. mentella*, deepwater redfish; and *S. fasciatus*, Acadian redfish, have been reported to occur in the northwest Atlantic. *Sebastes* in coastal New Hampshire waters are probably *S. fasciatus* (Dr. Bruce B. Collette, U.S. National Museum, pers. comm. April 1982), but larval descriptions are insufficient to allow distinction among the three species.

[i] Three species of *Urophycis* have been identified from trawl samples: *U. chuss*, red hake (common); *U. tenuis*, white hake (common); and *U. regia*, spotted hake (rare).

APPENDIX TABLE 5-2. SPECIES COMPOSITION, ANNUAL TOTALS, AND 4-yr TOTAL OF FINFISH AND AMERICAN LOBSTER IMPINGED AT SEABROOK STATION FROM 1990 THROUGH 1993. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	1990	1991	1992	1993	TOTAL
Winter flounder	18	116	209	141	484
Pollock	69	124	231	32	456
Windowpane	52	150	96	102	400
Lumpfish	69	93	29	118	309
Longhorn sculpin	67	54	88	37	246
Sea raven	38	42	55	98	233
Atlantic silverside		8	67	156	231
Rainbow smelt		12	67	80	159
Grubby	11	26	54	67	158
Atlantic cod	18	28	26	37	109
Little skate	6	96			102
Shorthorn sculpin	4	47	17	28	96
Herrings	44	8	22	19	93
Northern pipefish		6	2	83	91
Rock gunnel	14	11	40	25	90
Skates			48	35	83
Hakes	16	33	15	3	67
Cunner	21	2	13	13	49
Wrymouth	5	15	16	12	48
American lobster	4	29	8	1	42
Flounders		7		32	39
American sand lance	3		28	3	34
Tautog	3	9	9	3	24
Searobins	10	12	1	1	24
Threespine stickleback		3	3	17	23
Snailfishes		3	6	13	22
Silver hake		22			22
Atlantic mackerel	4	13	3		20
Sea lamprey	1	5	3	6	15
Clearnose skate	6	9			15
Unidentified fish	4	4	5		13
Yellowtail flounder		11			11
Sculpins			1	7	8
Fourspot flounder	2	2	1	1	6
Ocean pout	1	2	3		6
American eel	1	1	3		5
Radiated shanny	4	1			5
Spiny dogfish	1	2	1		4
Smooth flounder	3				3
Summer flounder		3			3
Rough scad		3			3
Red hake			1	2	3
Butterfish			2		2
Alewife		1		1	2
Cusk		1	1		2
Wolffish		1			1
White perch	1				1
American plaice				1	1
Conger eel		1			1
Striped anchovy	1				1
Oyster toadfish	1				1
Goosefish	1				1
Scup		1			1
Black sea bass		1			1
Northern kingfish		1			1
ALL SPECIES	503	1019	1174	1174	3870

APPENDIX TABLE 5-3. SPECIES COMPOSITION AND CUMULATIVE MONTHLY TOTALS OF FINFISH AND AMERICAN LOBSTER IMPINGED AT SEABROOK STATION FROM 1990 THROUGH 1993. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Winter flounder	51	24	55	31	6	5			21	52	11	228	484
Pollock	3		4	2	21	117	26		28	54	52	149	456
Windowpane	19	15	14	44	88	13	2		5	27	32	141	400
Lumpfish	11	18	47	49	43	86	34	5		2		14	309
Longhorn sculpin	11	3	17	42	21	8	3	5	2	13	43	78	246
Sea raven	2	3	8	36	60	26	6	7	3	19	21	42	233
Atlantic silverside	6	5	2	4	2					2	3	207	231
Rainbow smelt	8	13	2	4	2				1	1	1	127	159
Grubby	16	14	25	7	4	2		1	1	5	6	77	158
Atlantic cod	1		5	13	16	7	7	3	4	11	8	34	109
Little skate	21	2	7	6	1				7	40	10	8	102
Shorthorn sculpin	6	9	11	14	12	15	1			1	7	20	96
Herrings	1	1	2	9	20	3		6	2	11	16	22	93
Northern pipefish	1	2	1	6								81	91
Rock gunnel	4	2	5	20	20	3	3	3	4	3	2	21	90
Skates	12	1	4	1		1					4	60	83
Hakes	2	1		8				1	8	16	8	23	67
Cunner	1	2		4	19	14	1	4	1	1	2		49
Wrymouth	9	1	2		1				2	8	1	24	48
American lobster		1				4	1	1	1	5	20	9	42
Flounders	1	3	13	22									39
American sand lance	1	1	1	3							1	27	34
Tautog				1	8	9	1	1	1	1	1	1	24
Searobins	1		2	5				3	4	8		1	24
Threespine stickleback		2	7	8								6	23
Silver hake									2	11	9		22
Snailfishes		1	9	3						2	1	6	22
Atlantic mackerel						6				5	8	1	20
Clearnose skate	1	4		8							1	1	15
Sea lamprey			4	10	1								15
Unidentified fish					4			1	3			5	13
Yellowtail flounder	4	6	1										11
Sculpins				5	2							1	8
Fourspot flounder		1		2	2	1							6
Ocean pout				3		2						1	6
American eel						1						4	5
Radiated shanny		1			3						1		5
Spiny dogfish							2		2				4
Red hake						1			1	1			3
Rough scad		2	1										3
Smooth flounder				3									3
Summer flounder				3									3
Alewife	1									1			2
Butterfish												2	2
Cusk	1								1				2
American plaice			1										1
Black sea bass												1	1
Conger eel				1									1
Goosefish					1								1
Northern kingfish										1			1
Oyster toadfish												1	1
Scup											1		1
Striped anchovy									1				1
White perch						1							1
Wolffish						1							1
ALL SPECIES	195	138	250	377	357	326	87	41	105	301	270	1423	3870

TABLE OF CONTENTS

SUMMARY

Submerged rock surfaces in the vicinity of Seabrook Station intake and discharge structures support rich and diverse communities of attached plants and animals (macrobenthos). An extensive monitoring program was implemented in 1978 to assess the potential population and community level effects of Seabrook Station operation on this habitat. Studies were designed to monitor two types of potential impacts; those associated with exposure to elevated water temperatures from the discharge thermal plume, most likely affecting intertidal and shallow subtidal communities, and those associated with increased turbidity and sedimentation from transport of suspended solids and entrained organisms to deeper water communities near the discharge. Thermal impacts, such as shifts in abundance or occurrence of typically cold-water or warm-water species (i.e., decreases or increases, respectively), were not evident at nearfield intertidal or shallow subtidal sites. Overall, community parameters (biomass, number of taxa, etc.) and analyses of community structure (numerical classification) indicated little change in nearfield intertidal or shallow subtidal communities. Of the selected taxa studied in these zones, only two (the amphipod *Ampithoe rubricata* and the kelp *Laminaria digitata*) exhibited significant shifts (decreases) specifically in the nearfield area. In both cases, these trends began in recent preoperational years and their continuation was attributed to natural cycles in environmental or climatic processes rather than to plant operation. Impacts associated with increased turbidity, such as shifts in community dominance to species tolerant of increases in shading, sedimentation rates, and organic loading were not evident at mid-depth or deep stations in the nearfield area. Analyses of community parameters and overall structure revealed remarkable consistency of nearfield and farfield communities in both depth zones over both preoperational and operational periods, reflecting the more stable natural environmental conditions characteristic of deeper benthic habitats. This stability was also exhibited by abundance patterns of selected dominant taxa. Only two of the six taxa showed significant changes in abundance during the operational period relative to preoperational abundances; a significant decrease in abundance of the amphipod *Pontogeneia inermis* was detected, but only at the farfield station, and a significant increase in mussel (Mytilidae) abundance was noted at the nearfield station, with no difference at the farfield station. None of the above-mentioned shifts represents a change beyond what would be expected from the inherent natural variability of balanced indigenous communities, and no evidence exists to suggest that thermal or turbidity-related impacts have occurred to local macrobenthic communities since Seabrook Station began operation in 1990.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

6.0 MARINE MACROBENTHOS

6.1 INTRODUCTION

The predominant benthic marine habitat in the vicinity of Seabrook Station intake and discharge structures is rocky substrata, primarily in the form of bedrock ledge and boulders. These rock surfaces, as with similar habitats in the Gulf of Maine and other northern temperate coastal areas, support rich and diverse communities of attached plants and animals (macrobenthos), which are important and integral parts of coastal ecosystems. In fact, hard-bottom coastal communities are among the most productive regions in the world (Mann 1973). This diversity and productivity is accomplished through modification of the typically two-dimensional substratum by the attached plants and animals, i.e., habitat-formers that create a multi-tiered community and substantially enhance the number of potential biological niches.

One of the most obvious and productive features of the shore and near-shore biota in the Gulf of Maine is an extensive canopy of brown macroalgae, e.g., rockweeds (fucoids) intertidally (Menge 1976; Topinka et al. 1981; Keser and Larson 1984), and kelps subtidally (Sebens 1986; Witman 1987). Generally, several understory layers occur beneath these canopies, and are comprised of secondary levels of foliose and filamentous algae and upright attached macroinvertebrates over a layer of encrusting algal and faunal species, which occupy much of the remaining primary rock surfaces (Menge 1976; Sebens 1985; Ojeda and Dearborn 1989). Also, many of the niches created in and around this attached biota are occupied by mobile predator and herbivore species such as fish, snails, sea urchins, starfish, and amphipods (Menge 1979, 1983; Ojeda and Dearborn 1991).

Another important aspect of these species assemblages is the distinct zonation patterns exhibited by the biota, which throughout the North Atlantic are most obvious in the intertidal zone (Stephenson and Stephenson 1949; Lewis 1964; Chapman 1973), but are also apparent subtidally (Hiscock and Mitchell 1980; Sebens 1985). These patterns of community organization are formed by, and reflect, a variety of interacting physical (e.g., desiccation, water movement, temperature and light) and biological (e.g., herbivory, predation, recruitment, inter- and intraspecific competition for space) mechanisms, which vary over spatial and temporal scales.

Because these coastal hard-bottom communities are ecologically important, are well documented as effective integrators of environmental conditions, and are potentially vulnerable to localized coastal anthropogenic impacts, studies of these communities have been and continue to be part of ecological monitoring programs associated with coastal nuclear power plants (Vadas et al. 1976; Wilce et al. 1978; Osman et al. 1981; Schroeter et al. 1993; BECO 1994; NUSCO 1994). Similarly, Seabrook Station marine macrobenthos studies continue to be part of an extensive environmental monitoring program whose primary objective is to determine whether differences that exist among communities at sites in the Hampton-Seabrook area can be attributed to power plant construction and operation. Potential impacts on the local macrobenthos from Seabrook Station operation include temperature-related community alteration to areas directly exposed to the discharge thermal plume, most likely sites in the upper portion of the water column (intertidal and shallow subtidal zones). Thermal impacts are unlikely in deeper areas; however, increased turbidity in discharge water resulting from transport of suspended solids and entrained organisms could increase shading and sedimentation rates. To assess these potential impacts, studies were implemented to identify the attached plant and animal species occupying nearby intertidal and subtidal rock surfaces, to describe temporal and spatial patterns of occurrence of these species, to identify physical and biological factors that induce variability in rocky intertidal and subtidal communities, and finally, relate these to Seabrook Station operation to determine impact, should it occur.

6.2 METHODS

6.2.1 Field Methods

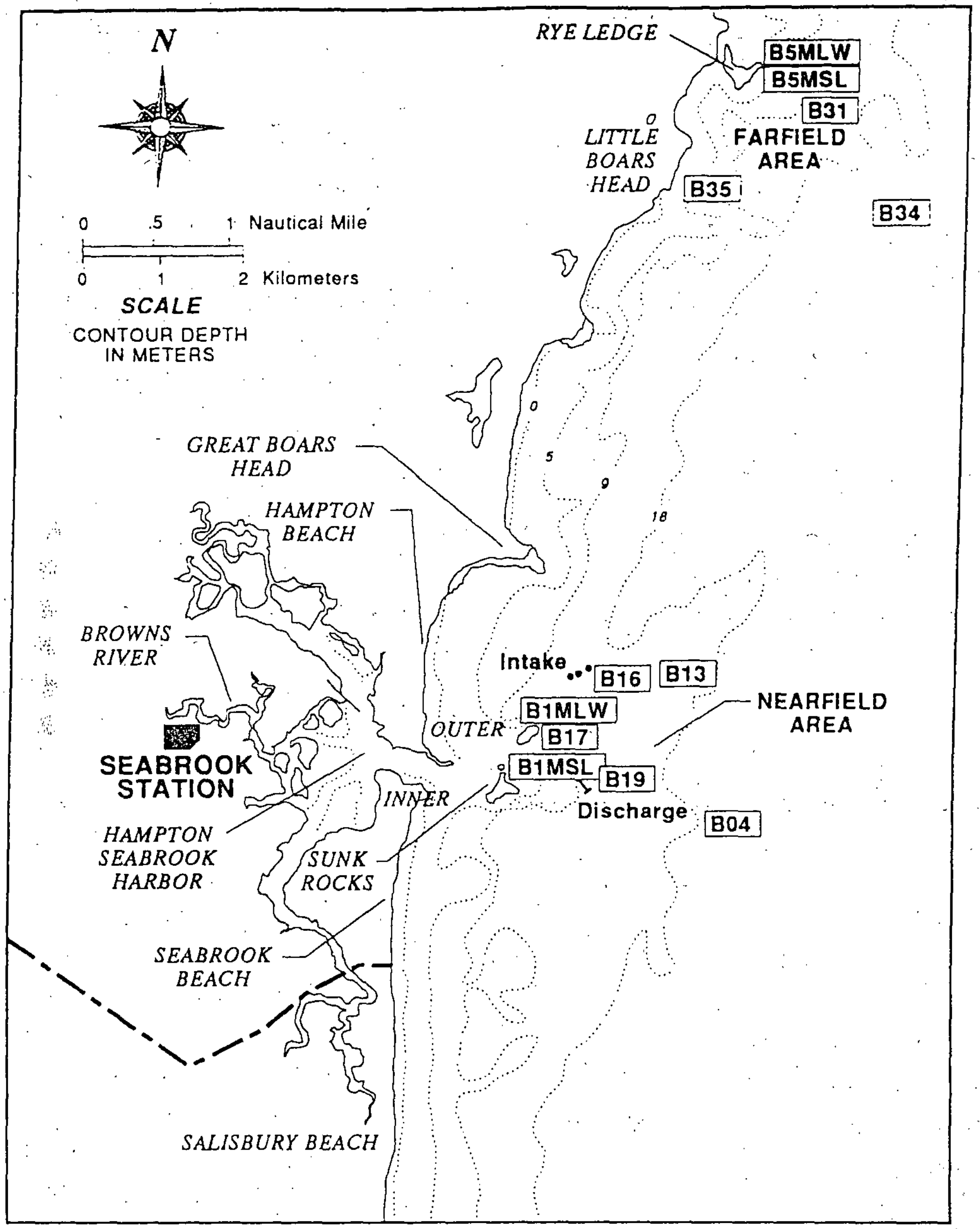
Quantitative (destructive) macrofaunal and macroalgal samples were collected three times a year (May, August and November) at six benthic stations (Fig. 6-1); three nearfield-farfield station pairs were established at lower intertidal (B1MLW, B5MLW), shallow subtidal (4-5 m; B17, B35) and mid-depth (9-12 m; B19, B31) locations. Four additional stations were sampled in August only: one mid depth intake station (B16) and three deep water (18-21 m) stations (nearfield-B13 and B04, and farfield-B34). This sampling program began in 1978 with five nearfield stations (B1, B04, B13, B17 and B19) and one farfield station (B31). Nearfield station (B16) was added to the study in 1979. Subsequently, three farfield stations were added, one in 1980 (B34) and two in 1982 (B35 and B5). Epifauna and epiflora were removed by scraping from five randomly selected 0.0625 m^2 areas on rock surfaces. Subtidal collections were drawn through a diver-operated airlift into a 0.79 mm mesh bag, placed in a labeled plastic bag, brought to the surface and sent to the laboratory for preservation and processing (NAI 1991a). Intertidal collections followed a similar procedure, excluding the use of an airlift.

A comprehensive collection of all visible algal species ("general algae") was made in conjunction with destructive sampling at each sampling station. In addition, collections were taken from the mean low water and mean sea level areas (including tide pools) in the intertidal zone.

Beginning in 1982, two intertidal stations (B1MSL and B5MSL; Fig. 6-1) were evaluated nondestructively during April, July and December. Observations were made at permanently marked 0.25 m^2 quadrats at three tidal levels: bare rock zone (approximately mean high water), predominantly *Fucus* spp.-covered zone (mean sea level), and *Chondrus crispus*-covered zone (approximately mean low water). Percent cover of fucoid algae and percent frequency of occurrence for organisms from an established species list of perennial and annual algal species, gastropods (*Acmaea testudinalis*, *Littorina* spp. and *Nucella lapillus*), *Balanus* spp. and Mytilidae were estimated and recorded. General observations for the entire sampling area were recorded and photographs were taken of each tidal zone and each sampling quadrat. Frequency of occurrence of fucoid algae was also recorded along a 9.5 m transect line (NAI 1991a).

Subtidal transects were established in 1978 to monitor larger macroinvertebrates and macroalgae that were not adequately represented in destructive samples. Six randomly placed replicate 1 m x 7 m band-transects were surveyed at nearfield-farfield station pairs in the shallow subtidal (B17, B35) and mid-depth (B19, B31) zones in April, July and October. Percent frequency of occurrence was recorded for dominant "understory" macroalgae (*Chondrus crispus*, *Phyllophora* spp. and *Ptilota serrata*), as well as counts of *Modiolus modiolus*, *Strongylocentrotus droebachiensis* and all kelps.

Information on patterns of recruitment and settlement of sessile benthic organisms was obtained from the bottom panels program. Bluestone panels (60 cm x 60 cm) were placed 0.5 m off the bottom at Stations B19 and B31, beginning in 1982. Stations B04 and B34 were added in 1986. Short-



LEGEND

☐ = benthic samples

Figure 6-1. Marine benthic sampling stations. Seabrook Operational Report, 1993.

term bottom panels were exposed for four months during three exposure periods: December-April, April-August, and August-December. Long-term bottom panels were exposed for one year, deployed in August and collected in August of the following year.

6.2.2 Laboratory Methods

All destructive samples were washed over a 1.0 mm sieve. Algal species from each sample were identified to the lowest practical taxon, dried for 24 hours at 105°C, and weighed. Only fauna previously designated as selected species were identified and counted from May and November macrofaunal samples. Selected species were determined from previous studies to be those species that are the most useful as indicators of overall community type in the study area, based on abundance, trophic level, and habitat specificity. All faunal species collected in August were identified to the lowest possible taxon; non-colonial species were counted and any colonial taxa were listed as present. In addition, abundance of spirorbid polychaetes at subtidal Stations B19 and B31 was estimated from five subsamples of the alga *Phyllophora* spp.

Life history information was obtained for nine macrofaunal taxa at paired nearfield-farfield stations where they were most abundant. These taxa (and their station pairs) were *Ampithoe rubricata* (B1MLW/B5MLW), *Jassa marmorata* (B17/B35), *Pontogenei inermis* (B19/B31), *Cancer irroratus* (B17/B35), *C. borealis* (B17/B35), *Strongylocentrotus drobachiensis* (B19/B31), Asteriidae (B17/B35), *Nucella lapillus* (B1MLW/B5MLW), and Mytilidae (B1MLW/B5MLW, B17/B35, B19/B31).

A subsample of individuals from each station from May, August and November samples was measured to the nearest 0.1 mm and enumerated. Sex of each amphipod was determined and the presence of eggs or brood was recorded.

Macroalgae from general collections were identified to the lowest practical taxon. The complete macroalgal species list was compiled from both general and destructive collections and included crustose coralline algae, collected only in August.

All undisturbed bottom panel faces were first analyzed for *Balanus* spp. and Spirorbidae, and then scraped to remove sessile bivalves and solitary chordates for identification and enumeration. Hydrozoa, Bryozoa and any abundant algal species were analyzed only on long-term panels.

6.2.3 Analytical Methods

6.2.3.1 Community

Macroalgal and macrofaunal community analyses included numerical classification and analysis of variance (ANOVA) of community parameters such as number of taxa and total abundance or biomass from August samples (Table 6-1). The ANOVA design was directed to test for significant Preop-Op X Station interaction; a more detailed description of the ANOVA design can be found in NAI (1992). In addition, the median percent-frequencies of dominant taxa in the intertidal non-destructive program during the operational period were compared to the median and range from the preoperational period. Total number of algal taxa from general collections during 1991, 1992 and 1993 was compared to the median and range from the preoperational period. A comparison of macroalgal and macrofaunal community composition during operational and preoperational periods was carried out using numerical classification methods (Boesch 1977). Bray-Curtis similarity indices were computed for the annual August log-transformed average densities

TABLE 6-1. SELECTED BENTHIC TAXA AND PARAMETERS USED IN ANOVA OR WILCOXON'S SUMMED RANKS TEST. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	PARAMETER	STATION	DATA PERIODS USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCES OF VARIATION IN ANOVAS[b]
Benthic Macroalgae	*Laminaria saccharina* *Laminaria digitata* *Alaria esculenta* *Agarum cribrosum*	B17 B35; B19, B31 B19, B31	1978 - 1993 1982 - 1993 1978 - 1993 (except 1990)	Mean number per sample period and station, no transformation. Wilcoxon's summed ranks by station.	Preop-Op[c]
	Chondrus crispus *Phyllophora* spp. *Ptilota serrata*	B17, B19, B31 B35	1981 - 1993 1982 - 1993 (except 1990)	Mean % frequency per year. No transformation. Wilcoxon's summed ranks test.	Preop-Op
	Chondrus crispus	B17, B1MLW B5MLW, B35	1978 - 1993 1982 - 1993 (except 1990)	Biomass per sample period and replicate. Square root transformation, shallow subtidal; no transformation, intertidal.	Preop-Op, Station, Year, Month
	Number of taxa Total biomass	B1MLW, B17 B19, B31 B5MLW, B35 B13, B04 B34	Aug, 1978 - 1993 1982 - 1993 1978 - 1984, 1986 - 1993 1979 - 1984, 1986 - 1993	Amount per station, year and replicate; no transformation.	Preop-Op, Station, Year
	Ascophyllum nodosum *Fucus vesiculosus* *Fucus distichus* spp. *edentatus* *Fucus distichus* spp. *distichus* *Fucus* sp.	B1MSL, B5MSL	1983 - 1993 (except 1990)	Mean % frequency per sample period and year; no transformation. Wilcoxon's summed ranks test by station.	Preop-Op

(Continued)

TABLE 6-1. (CONTINUED)

COMMUNITY	PARAMETER	STATION	DATA PERIODS USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCES OF VARIATION IN ANOVAS[b]
Benthic Macrofauna	*Ampithoe rubricata*[d] *Nucella lapillus* Mytilidae spat	B1MLW, B5MLW	1978-89, 91-93 1982-89, 91-93	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Jassa marmorata[d] Mytilidae spat	B17, B35	1978-89, 91-93 1982-89, 91-93		
	Asteriidae	B17, B35	1981-89, 91-93 1982-89, 91-93		
	Pontogeneia inermis[d] Mytilidae spat *Strongylocentrotus droebachiensis*	B19, B31	1978-89, 91-93		
	Total density	B1MLW, B5MLW; B17, B35; B19, B31, B16; B04, B34, B13	August, 1978 - 1993 (see algae for years)	Amount per year, station and replicate.	Preop-Op, Station, Year
	Number of taxa	Same as above	Same as above	Number per year, station, and replicate; no transformation.	Preop-Op, Station, Year
	Modiolus modiolus	B19, B31	1980 - 1989, 1991 - 1993	Mean per sample period, Wilcoxon's summed ranks tests, no transformation.	Preop-Op

[a]$Log_{10}(x+1)$ transformation unless otherwise stated.
[b]ANOVAs used except where otherwise noted (e.g., Wilcoxon's tests).
[c]Preop-Op: Preoperational period vs. Operational period.
[d]Life stages determined: juvenile/adult.

(macrofauna) and square-root transformed average biomass (macroalgae). Macroalgal species with less than 1.2% frequency of occurrence and macrofaunal species with less than 10% frequency of occurrence were excluded from the analysis. In all, 38 algal species and 100 faunal taxa were included in the final data sets for which similarity indices were computed. The group average method (Boesch 1977) was used to classify the samples into groups or clusters. The actual computations were carried out by the computer program EBORDANA (Bloom 1980).

6.2.3.2 Selected Species

Comparisons between preoperational and operational periods were made by means of ANOVA or Wilcoxon's summed ranks test (Sokal and Rohlf 1969) on data for the dominant species listed in Table 6-1. ANOVA was used to test for differences in abundance or biomass between periods at nearfield/farfield station pairs. For a description of the ANOVA design, refer to NAI (1992). The adjusted Least Squares Means (LSMEANS, PROC GLM, SAS Institute, Inc. 1985) were used in the t-test to evaluate differences when the Preop-Op X Station interaction term was significant at $\alpha \leq 0.05$. To further facilitate interpretation of these differences, the adjusted LS means for operational and preoperational periods were plotted by station. The Wilcoxon's test was used to test for significant differences in percent-frequency or abundance between preoperational and operational periods at each station.

6.3 RESULTS AND DISCUSSION

6.3.1 Marine Macroalgae

6.3.1.1 Horizontal Ledge Communities

Number of Taxa

Assessment of spatial and temporal patterns in number of algal taxa has proven useful as an indicator of impacts associated with several nuclear power plants in New England (Vadas et al. 1976; Wilce et al. 1978; Schneider 1981; NUSCO 1994). To assess algal community diversity at Seabrook study sites, number of algal taxa was determined in two ways. Numbers of taxa from general collections were used to qualitatively characterize the overall floristic composition at a given study site. The destructive sampling program provided quantitative information on algal diversity (i.e., number of taxa per unit of area), data which are more amenable to statistical analysis. In these facets combined, a total of 121 taxa has been collected during the 16-year study (Appendix Table 6-2).

Number of Taxa: General Collections

Seventy-eight algal taxa were collected over the 1993 sampling year, which was similar to totals from previous operational and preoperational years (NAI 1992, 1993). No new taxa were added in 1993 to the overall recorded flora (Appendix Table 6-2). Composition of the flora during 1993, based on the proportions of the three major taxonomic divisions, was 52% red algae (Rhodophyta), 26% brown (Phaeophyta) and 22% green (Chlorophyta). These proportions were similar to other operational years (NAI 1992, 1993), to the overall preoperational period (51% red, 27% brown, 22% green), and consistent with other New Hampshire studies (Mathieson and Hehre 1986).

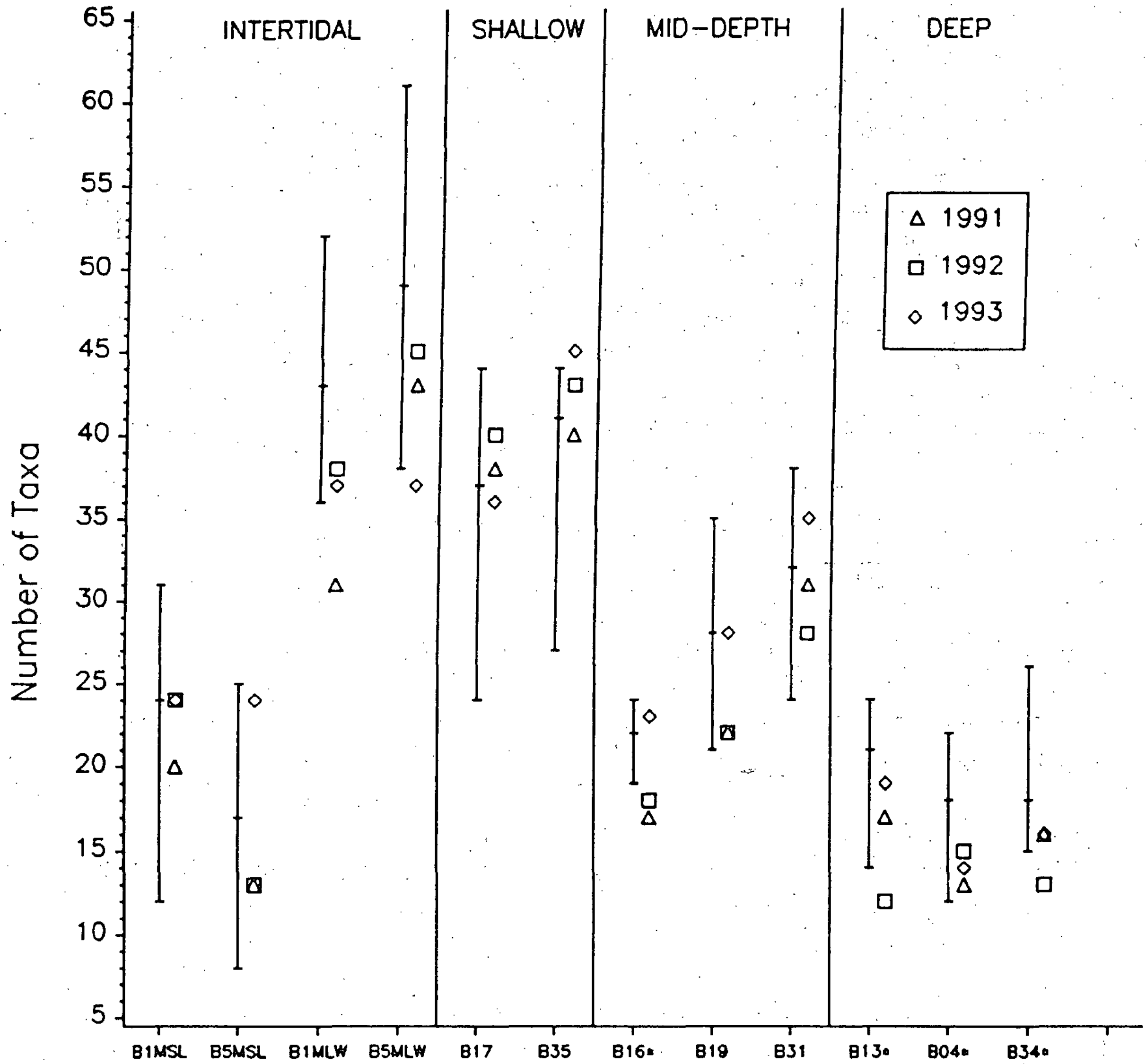


Figure 6-2. Preoperational (through 1989) median and range, and 1991-1993 values for number of taxa collected in triannual general algae collections at Stations B1MSL, B1MLW, B17, B19, B31 (1978-1993), B5MSL, B5MLW, B35 (1982-1993), and annual (August only) collections at Stations marked with '*', i.e., B16 (1980-1984; 1986-1993), B13, B04 (1978-1984; 1986-1993) and B34 (1979-1984; 1986-1993). Seabrook Operational Report, 1993.

As with previous operational years, numbers of taxa from general collections in 1993 were within the range of annual numbers from preoperational years at most stations (Fig. 6-2). Two stations had 1993 totals that were only slightly (by one taxon) outside the preoperational range; those were B5MLW (below) and B35 (above). The 1993 totals were also comparable to other operational years.

Relationships for numbers of taxa among depth zones during 1993 were, in general, consistent with those of previous years (Fig. 6-2). Typically, the most taxa were collected at low intertidal (B1MLW and B5MLW) and shallow subtidal (B17 and B35) sites, with intermediate numbers at mid-depth stations (B16, B19 and B31), and lowest numbers at mid intertidal (B1MSL and B5MSL) and deep (B04, B13 and B34) sites. This zonal pattern was consistent with studies conducted elsewhere on the New Hampshire coastline (Mathieson et al. 1981).

Differences within nearfield/farfield station pairs were not apparent at either intertidal level, as the same number of taxa were collected within each pair in 1993 (24 taxa at both MSL sites and 37 taxa at both MLW sites). When differences in number of taxa between corresponding stations did occur during 1993, such as within shallow subtidal, mid-depth and deep station groups, relationships among stations were consistent with previously observed trends. For example, in the mid-depth group, annual totals have typically been lowest at intake station B16, highest at farfield station B31 and intermediate at nearfield station B19, regardless of plant operation status. Similarly, nearfield station B17 (shallow subtidal) generally had fewer taxa than its farfield station counterpart B35. Consistently lower values at B16 were likely due to less frequent collections at that site (1/yr) than at B19 and B31 (3/yr).

Number of Taxa: Quantitative Samples

Numbers of algal taxa based on August quantitative samples, in general, followed a pattern similar to that from qualitative sampling. Most taxa were typically collected at shallow subtidal and intertidal stations, with fewer taxa at mid-depth stations and lowest numbers at deep stations (Table 6-2). Mean numbers of taxa for 1993 were lower than both preoperational and operational means at intertidal stations B1MLW and B5MLW. Conversely, at all shallow subtidal, mid-depth and deep stations, 1993 means were higher than both preoperational and operational means. Although ANOVA results (Table 6-3) indicated some significant differences between operational periods (for the intertidal depth zone) or among stations within depth zones (for all except the deep zone), no significant ($p \leq 0.05$) preoperational-operational period (Preop-Op) X Station interaction was observed for any zone.

Total Biomass

Total algal biomass (g/m^2) has exhibited a distinct pattern over depth zones during 1993, as well as over both preoperational and operational periods, similar to that described previously for number of taxa (Table 6-2). Biomass in August was consistently highest at shallow subtidal and intertidal stations, and lowest at deep stations. Based on ANOVA results, total algal biomass during the operational period was significantly less than biomass during the preoperational period for three of the four depth zones (intertidal, mid-depth and deep; Table 6-3). No significant difference between operational and preoperational periods was detected for algal biomass in the shallow subtidal zone, and no significant Preop-Op X Station interaction was apparent.

TABLE 6-2. ARITHMETIC MEANS AND ASSOCIATED VARIABILITY (CV) FOR NUMBER OF ALGAL TAXA, TOTAL ALGAL BIOMASS, AND *CHONDRUS CRISPUS* BIOMASS AT VARIOUS DEPTHS AND STATIONS DURING 1993 AND DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER	DEPTH ZONE	STATIONS	PREOPERATIONAL[a] 1978 - 1989 MEAN	CV[b]	REPORT YEAR 1993 MEAN	OPERATIONAL 1991 - 1993 MEAN	CV
Number of taxa[c] (no. per 0.0625 m^2)	Intertidal	B1MLW	11.0	9.2	8.0	9.3	6.9
		B5MLW	18.1	7.9	13.0	14.1	4.6
	Shallow subtidal	B17	11.4	4.4	12.4	11.1	4.2
		B35	15.3	5.3	16.8	13.4	11.1
	Mid-depth	B19	10.1	3.7	10.8	9.6	5.9
		B31	10.9	3.3	12.8	10.9	8.8
		B16	9.0	2.7	11.8	9.6	8.5
	Deep	B04	7.6	3.1	8.0	7.4	4.1
		B13	7.9	2.7	8.8	7.8	6.4
		B34	7.7	2.5	7.8	7.5	3.2
Total biomass[c] (g/m^2)	Intertidal	B1MLW	1300.5	9.4	863.7	994.8	14.7
		B5MLW	1198.0	9.7	967.4	1028.6	5.5
	Shallow subtidal	B17	1208.4	3.7	1303.9	1233.9	6.6
		B35	1170.0	7.5	1032.0	1083.8	6.6
	Mid-depth	B19	308.6	7.4	352.8	380.7	9.7
		B31	471.2	7.9	379.4	373.7	8.7
		B16	779.8	9.3	587.3	549.2	9.5
	Deep	B04	99.7	9.1	122.7	92.8	11.9
		B13	96.0	9.7	29.6	86.8	31.3
		B34	71.4	22.5	54.7	36.0	21.0
Chondrus crispus biomass[d] (g/m^2)	Intertidal	B1MLW	908.7	8.0	954.3	989.7	7.4
		B5MLW	787.8	9.5	966.6	752.6	14.6
	Shallow subtidal	B17	644.1	5.4	685.2	614.4	5.8
		B35	477.3	3.8	466.4	394.6	9.6
	Mid-depth	B19	1.6	35.3	0.5	1.4	35.1
		B31	98.1	12.4	151.2	120.1	36.5

[a]Stations B1MLW, B17, B19, B31: 1978 - 1989; Stations B5MLW B35: 1982 - 1989; Station B16: 1980 - 1989; Station B13, B04: 1978 - 1984, 1986 - 1989; B34: 1979 - 1984, 1986 - 1989. Means of annual means.
[b]Coefficient of variability of the mean (standard error of the mean, divided by the mean and multiplied by 100).
[c]August only.
[d]Sampled three times annually at intertidal, shallow and mid-depth subtidal only. Rarely collected at deep stations.

TABLE 6-3. ANAYSIS OF VARIANCE RESULTS FOR NUMBER OF TAXA (per $^{1}/_{16}$ m^2) AND TOTAL BIOMASS (g per m^2) OF MACROALGAE COLLECTED IN AUGUST AT INTERTIDAL, SHALLOW SUBTIDAL, AND DEEP STATIONS, 1978-1993. SEABROOK *OPERATIONAL REPORT, 1993.*

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	1	26.14	11.41 **	Op<Preop
		Station[b]	1	150.28	65.59 **	
		Year (Preop-Op)[c]	14	16.95	7.40 **	
		Preop-Op X Station[d]	1	1.12	0.49 NS	
		Error	10	2.29		
	Shallow Subtidal (B17, B35)	Preop-Op	1	3.08	1.42 NS	
		Station	1	41.94	19.34 **	
		Year (Preop-Op)	14	5.53	2.55 NS	
		Preop-Op X Station	1	1.36	0.63 NS	
		Error	10	2.17		
	Mid-depth (B16, B19, B31)	Preop-Op	1	0.02	0.01 NS	
		Station	2	7.78	6.47 **	
		Year (Preop-Op)	14	2.40	2.00 NS	
		Preop-Op X Station	2	0.99	0.82 NS	
		Error	25	1.20		
	Deep (B04, B34, B13)	Preop-Op	1	0.16	0.60 NS	
		Station	2	0.43	1.63 NS	
		Year (Preop-Op)	13	0.96	3.63 **	
		Preop-Op X Station	2	<.01	0.20 NS	
		Error	25	0.26		

(Continued)

TABLE 6-3. (CONTINUED)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
Total Biomass	Intertidal (B1MLW, B5MLW)	Preop-Op	1	485,435	6.26 *	Op<Preop
		Station	1	470,847	6.07 *	
		Year (Preop-Op)	14	989,173	12.76 **	
		Preop-Op X Station	1	738,343	9.52 **	B1-Pre B5-Op B5-Pre B1-Op
		Error	118	77,525		
	Shallow Subtidal (B17, B35)	Preop-Op	1	34,396	0.43 NS	
		Station	1	188,817	2.37 NS	
		Year (Preop-Op)	14	210,193	2.64 **	
		Preop-Op X Station	1	111,371	1.40 NS	
		Error	118	79,718		
	Mid-depth (B16, B19, B31)	Preop-Op	1	307,475	8.14 **	Op<Preop
		Station	2	1,547,078	40.98 **	
		Year (Preop-Op)	14	121,416	3.22 **	
		Preop-Op X Station	2	323,754	8.57 **	B16-Pre B16-Op B31-Pre B19-Op B31-Op B19-Pre
		Error	200	37,756		
	Deep (B04, B34, B13)	Preop-Op	1	12,015	5.34 *	Op<Preop
		Station	2	32,128	14.29 **	
		Year (Preop-Op)	13	5,132	2.29 **	
		Preop-Op X Station	2	3,191	1.42 NS	
		Error	201	2,249		

[a]Preop-Op compares 1978-1989 to 1990-1993 regardless of station.
[b]Stations within depth zone.
[c]Year nested within preoperational and operational periods regardless of area.
[d]Interaction of the two main effects, Preop-Op and Station.
[e]NS = Not significant ($p>0.05$); * = Significant ($0.05\geq p>0.01$); ** = Highly significant ($p\leq 0.01$).
[f]Underlining indicates that t-tests showed no significant differences ($\alpha\leq 0.05$) among the underlined least squares means.

A significant Preop-Op X Station interaction was detected for intertidal and mid-depth zones (Table 6-3). Total algal biomass at nearfield intertidal station B1MLW was significantly lower during the operational period than during the preoperational period, while biomass levels at the farfield intertidal counterpart (B5MLW) were not significantly different between periods (Fig. 6-3, Table 6-2). For the mid-depth zone station group, operational period total algal biomass was significantly lower than preoperational biomass only at intake station B16; comparisons of preoperational and operational means at both the nearfield (B19) and farfield (B31) stations indicated no significant between-period difference (Fig. 6-3, Table 6-2).

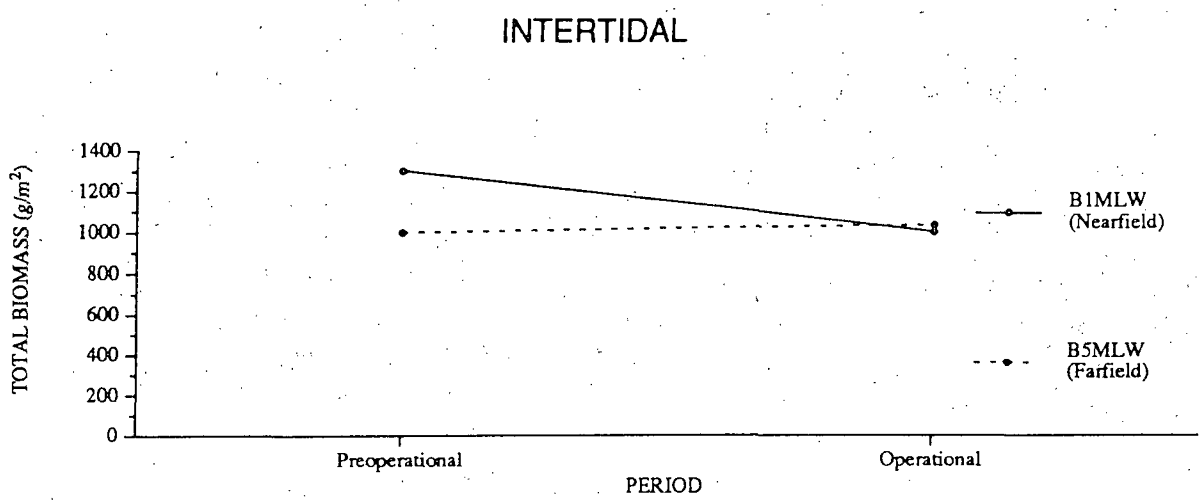
As mentioned above, algal biomass in the deep zone was lower during the operational period than during previous years; however, this trend occurred consistently at all deep stations (i.e., no significant Preop-Op X Station interaction; Table 6-3), indicating an area-wide phenomenon, at least in deep water.

Macroalgal Community Analysis

Multivariate community analysis techniques were used in this study to quantify the degree of similarity among all August collections made at the macrobenthic sampling stations since 1978. In this case, 145 station/year collections, represented by square-root transformed biomass values of 38 macroalgal taxa, were grouped into clusters according to Bray-Curtis similarity indices. A power plant-induced impact to the macroalgal community could be inferred from the failure of recent years' collections at a station (operational collections; 1990-1993) to cluster with collections from preoperational years (1989 and earlier) at that station. However, collections invariably clustered first by station, then by depth zone (Fig. 6-4); each cluster was distinguished from the others by the abundance of a characteristic macroalgal species assemblage. For example, the initial separation of collections occurred at approximately 23% similarity into a group consisting of all three deep water (18-21 m) stations (Fig. 6-4; Cluster II, Groups 6 and 7, stations B04, B34 and B13) and a larger group (Cluster I) containing all other stations (intertidal, shallow subtidal and mid-depth, Groups 1-5). The deep water group was segregated from the other stations on the basis of low macroalgal biomass (<100 g/m^2; Table 6-4); it was further divided into Cluster IIa (Group 6, discharge and farfield deep water stations, dominated by *Ptilota*, with lesser amounts of *Phyllophora* and *Corallina*) and Cluster IIb (Group 7, intake deep water station, dominated by *Phyllophora*, with smaller contribution by *Ptilota* and *Phycodrys*).

Among the other groupings, the intertidal stations (B1MLW and B5MLW) comprised a discrete entity (Cluster Ia; Group 1, within-group similarity 66%), not very similar to the other groups (between-group similarity 32%); the distinguishing characteristics of this group were high biomass values for *Chondrus* and *Mastocarpus* (this was the only group that included *Mastocarpus*), and absence of *Phyllophora* (Table 6-4). Similarly, the shallow subtidal stations (Cluster Ib, Group 2, stations B17 and B35) were characterized by high *Chondrus* and *Phyllophora* abundance, but very low *Phycodrys* biomass. The assemblage at all of the mid-depth stations (Cluster Ic, Groups 3, 4 and 5; stations B31, B19 and B16, respectively) was dominated by *Phyllophora* (ca. 150-400 g/m^2, representing 42-65% of the macroalgal biomass at these sites); each was distinguished from the others by the presence and abundance of a suite of other species (Table 6-4).

The community analysis techniques described above used biomass values from a large number of algal taxa (38 out of a total of 62; all those with an



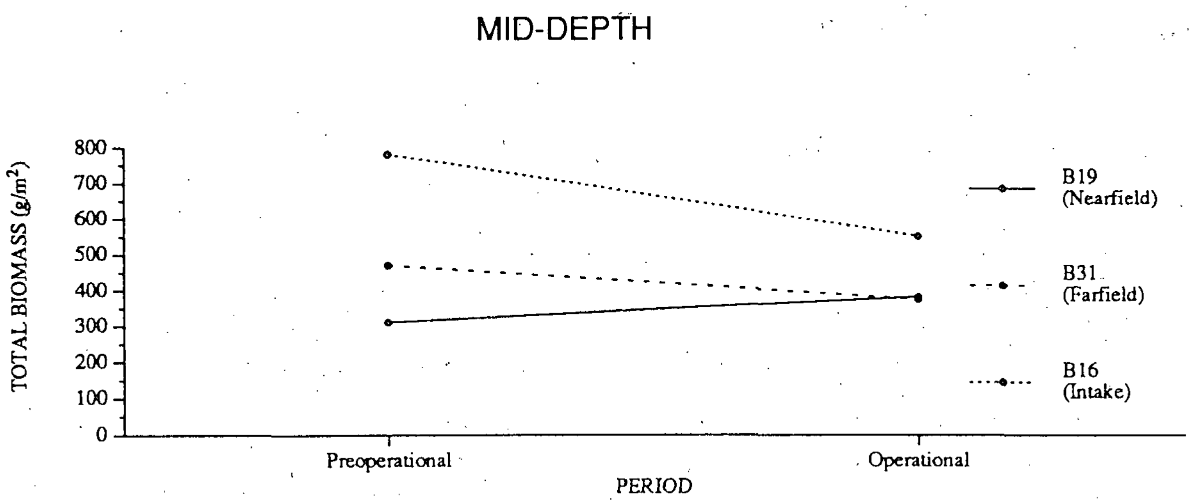


Figure 6-3. Comparisons among stations for mean total **macroalgal** biomass during the preoperational (1978-1989) and operational (1991-1993) periods for depth zones with a significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-3). Seabrook Operational Report, 1993.

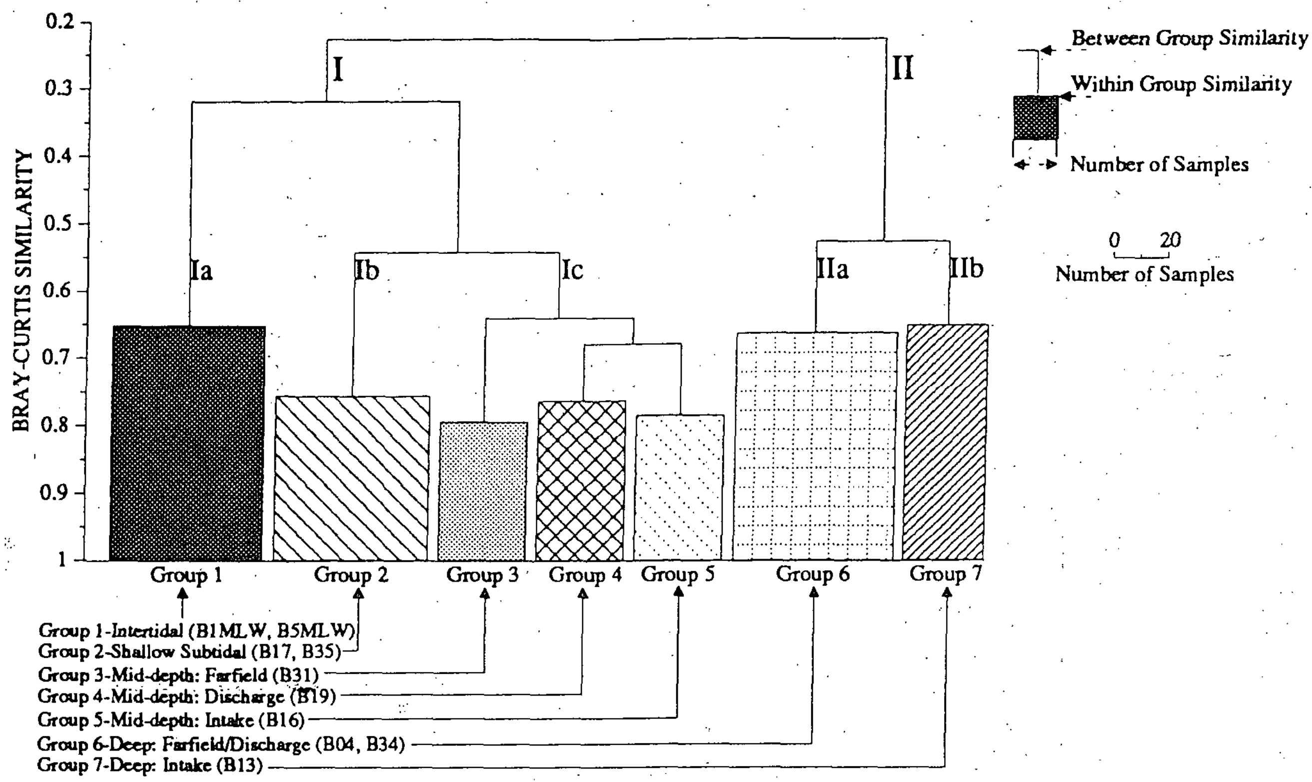


Figure 6-4. Dendrogram and station groups formed by numerical classification of August collections of marine benthic algae, 1978-1993. Seabrook Operational Report, 1993.

overall frequency of occurrence of at least 1.2%). However, by their nature, these analyses are influenced most strongly by commonly found species with high total biomass; small, rarely found taxa contribute little to the Bray-Curtis similarity indices. Therefore, a further community analysis was performed, examining rare species (overall frequency of occurrence less than 4%). Of the 32 species that met this criterion (Table 6-5), eight were found in both preoperational (1989 and earlier) and operational (1990-1993) periods, but relatively more frequently in the preoperational period; five species were found in both periods, but have become relatively more frequent since Seabrook Station began operation. Sixteen species were found in preoperational years, but have not yet been collected in the operational period; only three species have been identified for the first time since Seabrook Station start-up. None of the 32 rare species was considered a major component of the local macroalgal flora (average biomass was <0.10 g/m^2), nor were the reductions or increases of occurrence during the operational period considered to represent a significant alteration of the established algal community.

Another monitoring study, evaluating the impacts associated with construction and operation of a nuclear power plant on the attached macroalgal flora (NUSCO 1994), documented that incursion of a thermal effluent to nearby rocky shore sites caused an alteration of the algal community at those sites. Specifically, there was an increased frequency of occurrence (i.e., extended growing season) for species requiring or tolerant of warm water, and an absence or reduced frequency of occurrence for

TABLE 6-4. SUMMARY OF SPATIAL ASSOCIATIONS IDENTIFIED FROM NUMERICAL CLASSIFICATION (1978 - 1993) OF BENTHIC MACROALGAE SAMPLES COLLECTED IN AUGUST. SEABROOK OPERATIONAL REPORT, 1993.

DEPTH ZONE	STATION	MEAN DEPTH (m)	YEARS INCLUDED	WITHIN/ BETWEEN GROUP SIMILARITY	DOMINANT TAXA	GROUP BIOMASS (g/m^2) PREOP[a] MEAN[b]	PREOP[a] CI[b]	OP[c] MEAN	OP[c] CI
Intertidal	B1MLW	MLW	1978 - 1993	.66/.32	*Chondrus crispus*	986.18	189.73	780.69	307.69
	B5MLW	MLW	1982 - 1993		*Mastocarpus stellatus*	215.23	108.66	206.36	185.66
					Corallina officinalis	51.25	31.30	20.29	24.10
Shallow Subtidal	B17	4.6	1978 - 1993	.76/.55	*Chondrus crispus*	774.22	111.65	660.74	194.00
	B35		1982 - 1993		*Phyllophora* spp.	204.73	61.90	251.18	136.50
					Ceramium rubrum	69.29	20.72	75.44	27.09
					Cystoclonium purpureum	56.59	41.12	85.11	50.74
					Corallina officinalis	51.58	23.24	35.02	13.38
Mid-depth Intake	B16	9.4	1980 - 1984; 1986 - 1993	.79/.68	*Phyllophora* spp.	404.45	99.80	297.82	111.18
					Phycodrys rubens	188.86	71.00	119.51	102.17
					Chondrus crispus	56.97	30.43	19.21	40.81
					Cystoclonium purpureum	44.50	26.48	31.98	35.95
					Ceramium rubrum	34.99	20.70	37.38	75.36
					Callophyllis cristata	32.46	8.64	26.55	22.45

(Continued)

TABLE 6-4. (CONTINUED)

DEPTH ZONE	STATION	MEAN DEPTH (m)	YEARS INCLUDED	WITHIN/ BETWEEN GROUP SIMILARITY	DOMINANT TAXA	GROUP BIOMASS (g/m²) PREOP[a] MEAN[b]	CI[b]	OP[c] MEAN	CI
Mid-depth Discharge	B19	12.2	1978 - 1993	.77/.68	*Phyllophora* spp.	201.85	38.26	220.53	85.60
					Phycodrys rubens	50.16	19.30	110.71	52.96
					Corallina officinalis	15.17	4.41	6.69	6.19
					Callophyllis cristata	12.52	5.71	14.32	12.33
					Ptilota serrata	16.01	6.33	10.06	8.47
					Cystoclonium purpureum	5.97	4.42	9.02	9.20
Mid-depth Farfield	B31	9.4	1978 - 1993	.80/.64	*Phyllophora* spp.	209.50	64.66	158.77	106.24
					Corallina officinalis	96.83	26.70	88.37	33.27
					Chondrus crispus	113.11	42.26	83.06	100.26
					Phycodrys rubens	22.51	5.49	24.45	28.92
Deep Intake	B13	18.3	1978 - 1984; 1986 - 1993	.65/.53	*Phyllophora* spp.	68.85	23.77	67.88	79.56
					Ptilota serrata	11.54	3.96	6.72	9.78
					Phycodrys rubens	5.82	2.95	4.84	6.96
Deep Discharge/ Farfield	B04	18.9 - 21.0	1978 - 1984; 1986 - 1993	.67/.53	*Ptilota serrata*	64.00	18.27	45.54	19.73
					Phyllophora spp.	10.97	5.04	8.70	7.56
	B34		1979 - 1984; 1986 - 1993		*Corallina officinalis*	6.86	3.59	1.52	1.83

[a]Preop = preoperational, 1978-1989 period (Stations B1MLW, B17, B19, B31: 1978 - 1989; Stations B5MLW, B35: 1982-1989; Station B16: 1980 - 1984, 1986-1989; Stations B13, B04: 1978-1984, 1986 - 1989; B34: 1979 - 1984, 1986-1989).
[b]Mean and 95% confidence interval.
[c]Op = 1990, 1991, 1992 and 1993.

TABLE 6-5. A COMPARISON OF PERCENT FREQUENCY OF OCCURRENCE OF RARELY FOUND (OVERALL FREQUENCY OF OCCURRENCE <4%) SPECIES IN AUGUST DESTRUCTIVE SAMPLING DURING PREOPERATIONAL (1978-1989), OPERATIONAL (1990-1993), AND OVERALL (1978-1993) PERIODS OF SAMPLING. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	PREOPERATIONAL	OPERATIONAL	OVERALL
Ectocarpus fasciculatus	5.5	0.5	3.9
Gymnogongrus crenulatus	4.4	3.0	3.9
Polyides rotundus	4.1	3.0	3.7
Bonnemaisonia hamifera	1.8	6.5	3.3
Desmarestia virdis	0.6	7.0	2.5
Leathesia difformis	3.0	0.5	2.3
Ulvaria obscura (v. blyttii)	2.0	0.5	1.5
Cladophora sericea	1.7	1.0	1.4
Petalonia fascia	0.4	3.5	1.4
Ectocarpus siliculosus	1.2	1.5	1.3
Porphyra miniata	1.3	1.0	1.3
Monostroma grevillei	1.7	.	1.2
Palmaria palmata	1.3	.	0.9
Pilayella littoralis	1.3	.	0.9
Spongomorpha spinescens	1.2	.	0.8
Giffordia granulosa	1.1	.	0.7
Sphacelaria cirrosa	0.8	0.5	0.6
Polysiphonia harveyi	0.7	.	0.5
Dumontia contorta	0.6	.	0.4
Ceramium deslongchampii	0.6	.	0.4
Enteromorpha prolifera	0.5	.	0.4
Scytosiphon lomentaria	0.3	0.5	0.3
Spongonema tomentosum	0.5	.	0.3
Chordaria flagelliformis	.	1.0	0.3
Enteromorpha linza	0.3	.	0.2
Bryopsis plumosa	.	0.5	0.2
Polysiphonia denudata	0.3	.	0.2
Isthmoplea sphaerophora	.	0.5	0.1
Ulvaria oxysperma	0.2	.	0.1
Enteromorpha intestinalis	0.2	.	0.1
Plumaria elegans	0.2	.	0.1
Entocladia viridis	0.2	.	0.1

species with cold water affinities. If similar trends were observed in the macroalgal community near Seabrook Station, it could be considered evidence of a power plant impact. However, of the three species that showed significant increases from preoperational to operational periods (Table 6-5; *Bonnemaisonia hamifera*, from 1.8% of the preoperational collections to 6.5% of the operational period collections, *Desmarestia viridis*, from 0.6 to 7.0%, and *Petalonia fascia*, from 0.4 to 3.5%), the latter two are associated with cold water, and typically found in late winter/early spring (Taylor 1957). *Leathesia difformis* is described as a summer plant, but decreased in frequency of occurrence from 3.0% in the preoperational period to 0.5% in the operational period. Both these trends are the converse of the expected response to a thermal incursion. The macroalgal community in the vicinity of Seabrook Station is typical of those reported elsewhere in northern New England (e.g., Mathieson et al. 1981; Mathieson and Hehre 1986); no impact on this community as a result of construction or operation of the power plant has been observed to date.

Kelp and Understory Species

Extensive canopies of several kelp species commonly occur in coastal subtidal zones (4-18 m) in the northwestern Atlantic, and can account for up to 80% of total algal biomass (Mann 1973). In the Gulf of Maine, *Laminaria* spp. (mostly *L. saccharina* and *L. digitata*) are most common in the shallow subtidal zone (4-8 m), while a mixture of *Agarum cribrosum*, *Laminaria* spp. and *Alaria esculenta* are found in deeper zones (Sebens 1986; Witman 1987; Ojeda and Dearborn 1989).

A similar distribution of kelp species was found at Seabrook study sites. While *Laminaria* spp. were commonly found in both shallow and mid-depth zones, *L. saccharina* was the dominant kelp species at shallow subtidal stations (B17 and B35), with dominance switching to *L. digitata* at mid-depth stations (B19 and B31). *Agarum cribrosum* was a codominant at mid-depth stations, where relatively moderate amounts of *Alaria esculenta* were also observed (Table 6-6). In general, kelp densities (no. plants/100 m^2) during 1993 were consistent with means from both preoperational and operational periods for all species except *L. digitata* (described below). Although some year-to-year fluctuations in abundance have been observed for *L. saccharina*, *A. cribrosum* and *A. esculenta* populations, results of Wilcoxon's summed rank tests indicated that overall operational means for these species were not significantly different ($p \leq 0.05$) from corresponding preoperational means (Table 6-6). Mean abundance of *L. digitata* during the operational period was significantly lower than during preoperational years at three of four sampling sites: nearfield stations B17 (shallow subtidal) and B19 (mid-depth), and farfield mid-depth station B31. The lower operational means at these sites resulted from a general decline in abundance of *L. digitata* that began prior to power plant start-up (e.g., 1988 at B19, 1989 at B17 and Spring 1990 at B31; NAI 1993) and was further exacerbated by Hurricane Bob in 1991, when large scale removal of several kelp species, particularly *L. digitata* at B19, was noted (NAI 1992b).

Patterns of occurrence and abundance of some understory species can be influenced by the degree of kelp canopy cover (Johnson and Mann 1988). Common understory species in the Seabrook area, occurring beneath and adjacent to kelp canopies, include the foliose red algae *Chondrus crispus*, *Phyllophora* spp. and *Ptilota serrata*. Mean percent frequencies of occurrence of the three dominant understory algae during 1993, and during preoperational and operational periods are presented in Table 6-6. Patterns of distribution of these species in fixed transects were similar to those

TABLE 6-6. PREOPERATIONAL AND OPERATIONAL MEANS AND 95% CONFIDENCE LIMITS, AND 1993 MEANS, AND RESULTS OF WILCOXON'S SUMMED RANKS TEST COMPARING DENSITIES OF FOUR KELP SPECIES (#/100 m²) AND PERCENT FREQUENCIES OF THREE UNDERSTORY TAXA BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATONAL[a]			1993	OPERATIONAL[b]				
TAXON	STATION	LCL	MEAN	UCL	MEAN	LCL	MEAN	UCL	n	Z[c]
KELPS (#/100 m²)										
Laminaria digitata	B17	141.5	213.9	286.4	36.5	20.1	32.0	43.9	15	-2.49 *
	B35	96.5	155.8	215.1	122.2	25.3	131.7	238.2	11	-0.51 NS
	B19	81.5	139.9	198.3	22.2	12.9	19.8	25.8	15	-2.53 *
	B31	401.6	500.2	598.7	257.0	191.0	252.1	313.2	15	-2.53 *
Laminaria saccharina	B17	272.5	415.1	557.7	508.5	-193.7	336.5	866.7	15	0.00 NS
	B35	210.9	325.7	440.5	381.0	72.0	288.4	504.8	11	-0.10 NS
	B19	2.0	59.1	116.3	18.2	10.1	16.1	22.2	15	-1.51 NS
	B31	59.6	95.5	131.3	82.5	39.3	73.8	108.0	15	-0.36 NS
Alaria esculenta	B19	-2.3	2.4	7.2	10.3	-7.4	6.3	20.1	15	1.57 NS
	B31	19.9	75.2	130.5	58.0	-58.2	69.3	196.8	15	0.22 NS
Agarum cribrosum	B19	613.5	786.6	959.6	525.0	390.7	641.7	892.6	15	-1.22 NS
	B31	280.2	366.4	452.6	250.0	213.3	272.2	331.2	15	-0.94 NS
UNDERSTORY (% FREQUENCY)										
Chondrus crispus	B17	67.6	71.9	76.2	64.3	54.3	71.8	89.3	12	0.00 NS
	B35	46.8	54.2	61.7	47.3	30.9	61.2	91.6	11	0.71 NS
	B19	0.5	4.3	8.1	6.0	-5.8	6.7	19.2	12	0.83 NS
	B31	14.4	21.1	27.8	20.7	13.0	24.8	36.6	12	0.92 NS
Phyllophora sp.	B17	14.6	20.4	26.1	17.7	0.8	22.8	44.8	12	0.18 NS
	B35	11.2	20.0	28.7	30.3	-7.0	28.4	63.9	11	0.92 NS
	B19	28.6	34.1	39.7	30.7	28.7	36.7	44.6	12	0.28 NS
	B31	25.6	31.8	38.1	16.7	5.4	26.4	47.5	12	-0.65 NS
Ptilota serrata	B17	0.1	0.9	1.7	1.0	-2.5	1.3	5.1	12	0.47 NS
	B35	0.0	0.6	1.2	0.0	-0.8	0.7	2.1	11	0.11 NS
	B19	28.6	35.6	42.6	33.3	10.4	36.6	62.7	12	0.00 NS
	B31	9.4	13.2	16.9	6.0	-17.3	8.9	35.1	12	-1.30 NS

[a]Mean of annual means. Years for kelps - Stations B17, B19, B31: 1978-1989; Station B35: 1982-1989. For understory species-Stations B17, B19, B31: 1981-1989; Station 35: 1982-1989. LCL = lower confidence limit. UCL = upper confidence limit.
[b]1991-1993.
[c]Wilcoxon's test: NS = not significant (p>0.05); * = significant (0.05≥p>0.01); ** = highly significant (p≤0.01).

observed from biomass collections (Table 6-4). The shallow subtidal zone (B17/B35) was dominated by extensive turfs of the perennial red alga *Chondrus crispus* (ca. 50-70%), with moderate occurrences of *Phyllophora* spp. (20-30%). Understory dominance shifted to *Phyllophora* spp. in the mid-depth zone (B19/B31; 25-35%), with *Ptilota serrata* as a secondary dominant (10-35%). Relationships in patterns of occurrence between depth zones and between nearfield-farfield stations have remained remarkably consistent over the study period; operational means were not significantly different from preoperational means for all species, at all stations (Table 6-6). These consistent patterns of occurrence are likely due to the perennial habit of each of these species (Taylor 1957), which allows populations to maintain dominance once established.

Intertidal Communities (Non-destructive Monitoring Program)

Macroalgal species abundance patterns on intertidal rock exhibit striking patterns of zonation, which result from factors directly and indirectly related to tidal water movement (Lewis 1964; Chapman 1973; Menge 1976; Lubchenco 1980; Underwood and Denley 1984). To effectively monitor macroalgal species abundance in the intertidal zone and characterize these zonation patterns at each site over time, permanently marked quadrats were established at three tidal levels and sampled three times annually at nearfield and farfield sites.

Physical stress (e.g., desiccation, temperature extremes) resulting from long emersion time is an important structuring mechanism on macroalgae in the high intertidal zone (Lewis 1964; Schonbeck and Norton 1978). Other factors related to biological processes, such as grazing pressure (Cubit 1984; Keser and Larson 1984) and recruitment (Underwood and Denley 1984; Gaines and Roughgarden 1985; Menge 1991), can also be seasonally important.

At Seabrook intertidal study sites, much of the high intertidal zone, denoted as Bare Ledge, consists of bare rock with seasonal and perennial populations of *Fucus* spp., and seasonally abundant ephemeral green algal turfs (mostly an association of *Urospora penicilliformis* and *Ulothrix flacca*). *Fucus* spp. was absent from sampling quadrats at nearfield station B1 in April and July 1993; however, a heavy set of *Fucus* germlings occurred after that time, resulting in high frequency of occurrence (81%) of young fucoids by December (Table 6-7). This annual cycle of *Fucus* abundance has been observed consistently over the operational period (NAI 1992b, 1993), and has also been noted during some preoperational years. In general, fluctuations in *Fucus* abundance at B1 have been high over the entire study period, and likely reflect variability in recruitment, and in conditions for new recruit survival characteristic of the high intertidal (Keser and Larson 1984; NUSCO 1992). Frequency of occurrence of *Fucus* in the high intertidal at farfield station B5 has historically (including 1993) been higher than that at B1 (often at levels of 90% or more; Table 6-7), with populations there often persisting year round. The ephemeral green algal association of *Urospora penicilliformis/Ulothrix flacca* exhibited a consistent annual cycle of abundance at both nearfield and farfield stations, occurring only during the April sampling period in 1993 and all previous years in both operational periods. Conditions for establishment and growth of these species on high intertidal surfaces are most favorable in late winter and early spring. Both physical stress (related to temperature extremes and desiccation) and snail grazing pressure (e.g., by *Littorina littorea* and *L. saxatilis*; Keser and Larson 1984) are least intense during this period (Cubit 1984). These stress mechanisms appear to be less severe at farfield station B5 than at nearfield B1 (due to site

TABLE 6-7. PERCENT COVER AND PERCENT FREQUENCY OF DOMINANT PERENNIAL AND ANNUAL MACROALGAL SPECIES OCCURRENCE AT FIXED INTERTIDAL NON-DESTRUCTIVE SITES DURING THE PREOPERATIONAL AND OPERATIONAL PERIOD. SEABROOK OPERATIONAL REPORT, 1993.

ZONE[a] TAXA	DATA TYPE[b] (%)	STATION	PERIOD/ YEAR[c]	APR	JUL	DEC
Bare Ledge						
Fucus spp.	Frequency	Nearfield	Preoperational	6	19	6
		(B1)	(range)	(0-81)	(0-94)	(0-94)
			Operational	0	0	56
			1993	0	0	81
		Farfield	Preoperational	82	97	100
		(B5)	(range)	(0-100)	(12-100)	(0-100)
			Operational	94	94	94
			1993	94	100	100
Urospora penicilliformis/ Ulothrix flacca	Frequency	Nearfield	Preoperational	45	0	0
		(B1)	(range)	(0-99)	(0)	(0)
			Operational	44	0	0
			1993	44	0	0
		Farfield	Preoperational	73	0	0
		(B5)	(range)	(0-100)	(0)	(0)
			Operational	42	0	0
			1993	82	0	0
Fucoid Ledge						
Fucus spp.	Cover	Nearfield	Preoperational	93	93	68
		(B1)	(range)	(25-98)	(60-100)	(25-95)
			Operational	78	75	62
			1993	45	46	60
		Farfield	Preoperational	94	94	93
		(B5)	(range)	(60-98)	(65-100)	(2-98)
			Operational	77	91	93
			1993	100	100	94
Fucus spp.	Frequency	Nearfield	Preoperational	94	88	88
		(B1)	(range)	(69-100)	(75-100)	(69-94)
			Operational	77	87	81
			1993	56	81	100
		Farfield	Preoperational	85	85	91
		(B5)	(range)	(62-100)	(69-100)	(31-100)
			Operational	83	88	86
			1993	88	88	88

(Continued)

TABLE 6-7. (CONTINUED)

ZONE TAXA	DATA TYPE (%)	STATION	PERIOD/ YEAR	APR	JUL	DEC
<u>Chondrus Zone</u>						
Chondrus crispus	Frequency	Nearfield	Preoperational	45	34	45
		(B1)	(range)	(20-53)	(20-38)	(28-53)
			Operational	36	12	35
			1993	17	3	43
		Farfield	Preoperational	45	48	41
		(B5)	(range)	(0-72)	(41-55)	(39-48)
			Operational	48	60	41
			1993	49	55	31
Mastocarpus stellatus	Frequency	Nearfield	Preoperational	47	66	48
		(B1)	(range)	(21-69)	(65-71)	(32-67)
			Operational	35	16	42
			1993	38	42	37
		Farfield	Preoperational	47	51	44
		(B5)	(range)	(0-53)	(41-63)	(43-56)
			Operational	45	47	39
			1993	49	55	31
Corallina officinalis	Frequency	Nearfield	Preoperational	0	0	0
		(B1)	(range)	(0)	(0)	(0)
			Operational	0	0	0
			1993	0	0	0
		Farfield	Preoperational	30	52	52
		(B5)	(range)	(15-57)	(33-61)	(31-65)
			Operational	57	61	60
			1993	52	60	65

[a]Bare Ledge: approximately mean high water. Fucoid ledge: approximately mean sea level. *Chondrus* Zone: approximately mean low water.
[b]Data Type (%): <u>Frequency</u> - percentage of occurrence based on point contact line sampling.
<u>Cover</u> - percentage of substratum coverage based on fixed quadrats of 0.25 m^2.
[c]Preoperational: 1982-1989 median and range; Operational: 1991-1993 median; 1993: annual mean.

topography and degree of exposure to waves), as frequency of occurrence of this green algal association was typically higher there in 1993 (82% vs. 44%) and over the entire preoperational period (medians of 73% vs. 45%; Table 6-7).

A distinct horizontal band of rockweeds (*Fucus* spp. and *Ascophyllum nodosum*) delineates the mid intertidal zone (Fucoid Ledge) at Seabrook study sites. Habitat conditions for these species are ideal in the mid intertidal, as longer immersion time results in a longer period for zygospore settlement (cf. Underwood and Denley 1984), and reduces physical stress compared to that in the high intertidal; new recruits are able to grow rapidly in this zone and develop physical and chemical defenses against grazing (Geiselman and McConnell 1981; Lubchenco 1983). *Fucus* spp. was the dominant taxon in mid intertidal quadrats at both nearfield and farfield stations over the entire study period (1983-1993), both in terms of percentage of substratum cover and percent-frequency of occurrence (Table 6-7). In 1993 and during preoperational and operational periods, consistently high and comparable levels of abundance of *Fucus* spp. have been recorded at B1 and B5.

Fucoid abundance in the mid intertidal zone at B1 and B5 was also estimated using fixed-line transects located at mean sea level. Overall, a consistently dominant taxon at both study sites (particularly in recent years) was *Ascophyllum nodosum*. Mean percent-frequencies of occurrence of *A. nodosum* during 1993 and the operational period were comparable at both nearfield and farfield sites, ranging from 37% to 41% (Table 6-8). Mean percent-frequency during the operational period was significantly higher than the preoperational mean at B1, whereas the period means at B5 were not significantly different. A concomitant significant decrease in abundance of *Fucus vesiculosus* was observed at B1 during operational years, where mean percent-frequency levels decreased from 47% to 2%. No significant difference was detected at B5 for this species. *Fucus distichus* subsp. *edentatus* was a persistent component of the rockweed community at both stations at lower abundance levels than fucoids discussed above, and these levels remained consistent over the entire study period (i.e., no significant between-period differences were detected). Between-period differences in abundance were identified for *Fucus distichus* subsp. *distichus*, which did not occur at either study site during preoperational years, but established small populations (and significantly higher levels of occurrence) at both sites during the operational period, and persisted through 1993. Significantly higher frequency of occurrence of juvenile *Fucus* sp. was detected at farfield station B5 during the operational period, while no differences were observed at nearfield station B1.

The low intertidal or *Chondrus* zone was monitored non-destructively in fixed quadrats only at the mean low water level. These areas are typically dominated by perennial red algal turfs composed of *Chondrus crispus* and *Mastocarpus stellatus*, which, once established, competitively exclude other algae such as *Fucus* spp. (Lubchenco 1980). Overall operational period percent-frequencies for *Chondrus* and *Mastocarpus* typically exceeded 30% during most sampling periods, with levels comparable between stations and, in most cases, between preoperational and operational periods (Table 6-7). At nearfield station B1, low percent-frequencies were recorded in 1993 for *C. crispus* (April and July) and for *M. stellatus* (July); however, median percent-frequencies were generally similar between preoperational and operational periods. The coralline red alga *Corallina officinalis* can be a locally abundant understory species in the low intertidal zone. Percent-frequency of occurrence of this species generally exceeded 30% in all seasons at farfield station B5 throughout preoperational and operational years, but was absent from the nearfield

TABLE 6-8. PREOPERATIONAL AND OPERATIONAL MEANS WITH 95% CONFIDENCE LIMITS, AND 1993 MEANS, AND RESULTS OF WILCOXON'S SUMMED RANKS TEST COMPARING PERCENT FREQUENCIES OF FUCOID ALGAE AT TWO FIXED TRANSECT SITES IN THE MEAN SEA LEVEL ZONE BETWEEN THE PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATONAL[a]			1993	OPERATIONAL[b]				
TAXON	STATION	LCL	MEAN	UCL	MEAN	LCL	MEAN	UCL	n	Z^c
Ascophyllum nodosum	B1	26.4	32.0	37.6	38.3	34.5	40.1	45.7	10	2.29 *
	B5	31.1	41.2	49.4	40.7	27.9	37.0	46.1	10	-0.68 NS
Fucus vesiculosus	B1	25.7	47.4	69.0	2.3	-0.5	1.7	3.9	10	-2.28 *
	B5	17.3	27.0	36.6	13.7	5.6	15.4	25.3	10	-1.36 NS
Fucus distichus subsp. *edentatus*	B1	6.0	16.2	26.4	17.7	7.1	18.4	29.7	10	0.91 NS
	B5	-5.1	3.6	12.3	0.7	-16.9	5.6	28.0	10	1.12 NS
Fucus distichus subsp. *distichus*	B1	-	0.0	-	3.3	-16.2	7.4	31.1	10	2.80 **
	B5	-	0.0	-	2.7	-1.5	4.5	10.7	10	2.80 **
Fucus spp. (juveniles)	B1	-2.9	7.6	18.1	15.7	3.1	23.8	44.5	10	1.60 NS
	B5	-0.9	0.6	2.1	10.7	-3.2	7.7	18.5	10	2.31 **

[a]Mean of annual means, 1983-1989; LCL, UCL = upper and lower 95% confidence limits.
[b]1991-1993.
[c]Wilcoxon's test: NS = not significant ($p>0.05$); * = significant ($0.05 \geq p > 0.01$); ** = highly significant ($p \leq 0.01$).

(B1) area throughout our studies (Table 6-7).

6.3.1.2 Selected Species

Chondrus crispus

Low intertidal and shallow subtidal horizontal rock surfaces in the vicinity of Seabrook discharge and intake support dense stands of the red alga *Chondrus crispus*. As discussed in the previous section, the tough perennial habit of this species allows extensive populations to continue to dominate suitable rock surfaces to the exclusion of most other species. Similar, nearly monospecific turfs of *Chondrus* are common throughout the North Atlantic (Mathieson and Prince 1973); North American distribution occurs from New Jersey to southern Labrador (Taylor 1957). Owing to its predominance in the Seabrook area, *Chondrus* was selected for further, more detailed analyses. *Chondrus* biomass (g/m^2) at Seabrook study sites was typically highest at the intertidal sites, at times approaching 1000 g/m^2 (Table 6-2). During 1993, biomass levels at intertidal stations were similar, although historically, levels at farfield station B5MLW have been lower than those at nearfield station B1MLW. Operational mean biomass levels were significantly higher than those during the preoperational period (Table 6-9). Regardless of these overall between-station and between-period differences, ANOVA results revealed no significant Preop-Op X Station interaction for intertidal sites, suggesting that any shifts were not related to power plant operation. Substantial, although somewhat smaller, amounts of *Chondrus* were found at shallow subtidal stations, with biomass levels often exceeding 400 g/m^2. Biomass at nearfield station B17 was higher than that at the corresponding farfield station B35 in 1993; this relationship between stations was consistent with those observed during both preoperational and operational periods (Table 6-2). Consequently, no significant between-period (Preop-Op) difference or Preop-Op X Station interaction was detected for shallow subtidal *Chondrus* biomass, based on ANOVA results (Table 6-9).

6.3.2 Marine Macrofauna

6.3.2.1 Horizontal Ledge Communities

Number of Taxa and Total Density

Many attached and slow-moving invertebrate species comprise the marine macrofaunal community on local intertidal and subtidal rock surfaces. Macrofaunal community parameters similar to those used for macroalgal monitoring (i.e., number of taxa, total density) have consistently been monitored as part of Seabrook studies since 1978, and have proven useful elsewhere for assessing potential ecological impacts from coastal nuclear power plants (Osman et al. 1981; NUSCO 1992, 1994; BECO 1994). Overall species richness, as determined by the mean number of taxa, generally increased with increasing depth, with lowest numbers of taxa at intertidal stations (B1MLW and B5MLW) and highest numbers mid-depth (B16, B19 and B31) and deep stations (B04, B13 and B34; Table 6-10). Conversely, total faunal density decreased with increasing depth, with highest densities at intertidal stations, and lowest densities at deep stations.

Mean numbers of taxa at intertidal sites in 1993 were comparable to those recorded over the operational period (1990-93), with fewer taxa collected at B1MLW (nearfield) than at B5MLW (farfield) over that period (Table 6-10). Overall, operational means were significantly lower than preoperational means (Table 6-11). This decrease, however, was most pronounced at B1MLW, and resulted in a significant Preop-Op X Station interaction for the intertidal station group (Table 6-

TABLE 6-9. ANALYSIS OF VARIANCE RESULTS FOR *CHONDRUS CRISPUS* BIOMASS (g/m^2) AT INTERTIDAL AND SHALLOW SUBTIDAL STATION PAIRS FOR THE PREOPERATIONAL (1978 - 1989) AND OPERATIONAL (1991 - 1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

TAXON	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISON OF ADJUSTED MEANS[g] (Ranked in decreasing order)
Chondrus crispus	Intertidal (B1, B5)	Preop-Op[a]	1	585,734	5.64 *	Op>Preop
		Year (Preop-Op)[b]	13	1,024,295	9.86 **	
		Month (Year)[c]	30	525,298	5.06 **	
		Station[d]	1	4,328,746	41.66 **	
		Preop-Op X Station[e]	1	45,215	0.44 NS	
		Error	303	103,898		
	Shallow Subtidal (B17, B35)	Preop-Op	1	163.5	3.87 NS	
		Year (Preop-Op)	13	58.4	1.38 NS	
		Month (Year)	30	179.3	4.24 **	
		Station	1	1129.6	26.73 **	
		Preop-Op X Station	1	2.8	0.07 NS	
		Error	303	42.3		

[a]Preop-Op compares 1978 - 1989 to 1990-1993 regardless of station.
[b]Year nested within preoperational and operational periods regardless of station.
[c]Month nested within year regardless of year, station or period.
[d]Station pairs nested within a depth zone: intertidal = B1MLW, B5MLW; shallow subtidal = B17, B35, regardless of year or period.
[e]Interaction of the two main effects, Preop-Op and Station.
[f]NS = Not significant ($p>0.05$); * = Significant ($0.05 \geq p > 0.01$); ** = Highly significant ($p \leq 0.01$).
[g]The > or < signs indicate a significant difference between two LS means.

TABLE 6-10. PREOPERATIONAL AND OPERATIONAL MEANS (WITH COEFFICIENTS OF VARIABILITY), AND 1993 MEANS OF THE NUMBER OF TAXA AND GEOMETRIC MEAN DENSITY FOR THE TOTAL DENSITY (NON-COLONIAL MACROFAUNA) SAMPLED IN AUGUST AT INTERTIDAL, SHALLOW SUBTIDAL, MID-DEPTH AND DEEP STATIONS. SEABROOK OPERATIONAL REPORT, 1993.

DEPTH ZONE	STATION	PREOPERATIONAL[a]		1993	OPERATIONAL[b]	
		MEAN	CV[c]	MEAN	MEAN	CV
MEAN NO. OF TAXA (per 0.0625 m^2)						
Intertidal	B1MLW	48	17.3	35	37	11.5
	B5MLW	47	17.6	44	42	10.4
Shallow subtidal	B17	56	17.4	65	64	4.3
	B35	52	14.3	61	54	10.6
Mid-depth	B16	67	15.2	78	70	9.7
	B19	64	19.8	71	72	14.2
	B31	49	16.2	55	53	24.6
Deep	B04	62	17.5	66	67	7.9
	B13	53	14.7	44	55	25.7
	B34	62	25.7	63	60	11.8
TOTAL DENSITY (#/m^2)						
Intertidal	B1MLW	122795	5.3	66408	87909	6.7
	B5MLW	68684	5.1	126729	93942	4.6
Shallow subtidal	B17	23373	4.6	40696	31081	3.5
	B35	28372	4.6	106260	40050	6.6
Mid-depth	B16	31590	5.9	42565	15835	7.5
	B19	12424	6.1	24128	16726	7.2
	B31	16240	11.4	25593	14878	5.4
Deep	B04	4936	5.7	5407	4278	2.6
	B13	6073	10.5	29826	12816	7.3
	B34	5523	9.3	5145	5131	4.3

[a]Preoperational period extends through 1989 (Stations B1MLW, B17, B19, B31: 1978-1989; Stations B5MLW, B35: 1982-1989; Station B16: 1980-1984, 1986-1989; Stations B13, B04: 1978-1984, 1986-1989; Station B34: 1979-1984,1986-1989).
[b]Operational period: 1990-1993.
[c]Coefficient of variability of the mean (standard error of the mean divided by the mean and multiplied by 100).

TABLE 6-11. ANAYSIS OF VARIANCE RESULTS FOR NUMBER OF TAXA (per 0.0625 m^2) AND TOTAL DENSITY (per m^2) OF MACROFAUNA COLLECTED IN AUGUST AT INTERTIDAL, SHALLOW, MID-DEPTH, AND DEEP SUBTIDAL STATIONS, 1978 - 1993. SEABROOK OPERATIONAL REPORT, 1993.

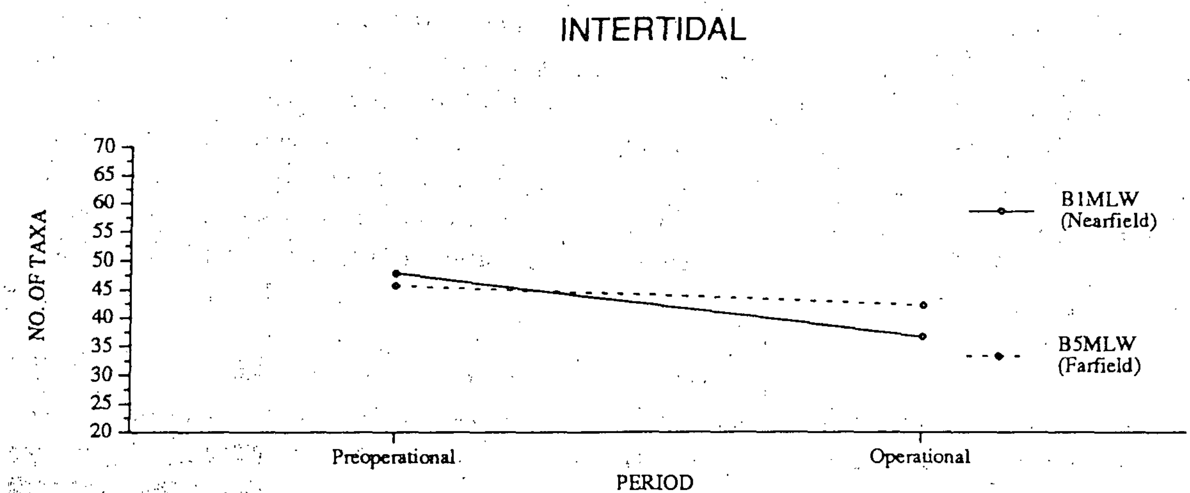
PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	1	1416.12	21.17 **	Op<Preop
		Station[b]	1	81.11	1.21 NS	
		Year (Preop-Op)[c]	14	457.79	6.84 **	
		Preop-Op X Station[d]	1	396.73	5.93 *	B1-Pre B5-Pre B5-Op B1-Op
		Error	118	66.88		
	Shallow Subtidal (B17, B35)	Preop-Op	1	509.23	6.64 *	Op>Preop
		Station	1	827.65	10.79 **	
		Year (Preop-Op)	14	421.24	5.49 **	
		Preop-Op X Station	1	384.48	5.01 *	B17-Op B17-Pre B35-Op B35-Pre
		Error	118	76.69		
	Mid-depth (B16, B19, B31)	Preop-Op	1	1157.49	9.04 **	Op>Preop
		Station	2	5682.09	44.37 **	
		Year (Preop-Op)	14	913.94	7.14 **	
		Preop-Op X Station	2	47.03	0.37 NS	
		Error	200	128.06		
	Deep (B04, B34, B13)	Preop-Op	1	241.09	1.85 NS	
		Station	2	1623.53	12.44 **	
		Year (Preop-Op)	13	1403.60	10.76 **	
		Preop-Op X Station	2	171.65	1.32 NS	
		Error	201	130.47		

(Continued)

TABLE 6-11. (CONTINUED)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
Total Density	Intertidal (B1MLW, B5MLW)	Preop-Op	1	<.01	0.05 NS	
		Station	1	0.31	5.25 *	
		Year (Preop-Op)	14	0.48	8.22 **	
		Preop-Op X Station	1	0.50	8.40 **	B1-Pre B5-Op B1-Op B5-Pre
		Error	118	0.06		
	Shallow Subtidal (B17, B35)	Preop-Op	1	0.45	8.33 **	Op>Preop
		Station	1	0.27	5.11 *	
		Year (Preop-Op)	14	0.30	5.63 **	
		Preop-Op X Station	1	<.01	0.03 NS	
		Error	118	0.05		
	Mid-depth (B16, B19, B31)	Preop-Op	1	0.20	2.07 NS	
		Station	2	0.57	5.85 **	
		Year (Preop-Op)	14	0.84	8.62 **	
		Preop-Op X Station	2	0.62	6.33 **	B16-Pre B19-Op B16-Op B31-Pre B31-Op B19-Pre
		Error	200	0.10		
	Deep (B04, B34, B13)	Preop-Op	1	0.30	3.13 NS	
		Station	2	1.32	13.89 **	
		Year (Preop-Op)	13	0.72	7.59 **	
		Preop-Op X Station	2	0.65	6.82 **	B13-Op B13-Pre B34-Pre B34-Op B04-Pre B04-Op
		Error	201	0.10		

[a]Pre-Op compares 1978 - 1989 to 1990 - 1993 regardless of station.
[b]Nearfield = Stations B1MLW, B17, B16, B04, B13; farfield = Stations B5MLW, B35, B31, B34, regardless of year/period.
[c]Year nested within preoperational and operational periods regardless of station.
[d]Interaction of the two main effects, Preop-op and Station.
[e]Wilcoxon's test: NS = not significant (p>0.05); * = significant (0.05≥p>0.01); ** = highly significant (p≤0.01).
[f]Underlining indicates that t-tests showed no significant differences (α≤0.05) among the underlined least squares means. The > or < signs indicate a significant difference between two LS means.



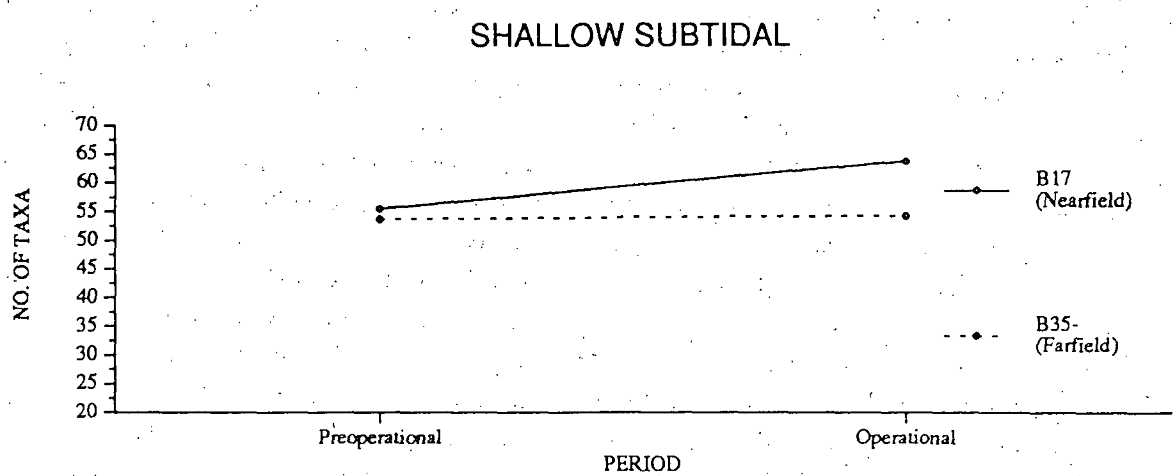


Figure 6-5. Comparisons between stations of mean number of **macrofaunal** taxa during the preoperational (1978-1989) and operational (1990-1993) periods for depth zones with a significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-11). Seabrook Operational Report, 1993.

11, Fig. 6-5). This general decrease in number of taxa at B1MLW during operational years was mirrored by a decline in total faunal density at that site in 1993 and over the operational period (Table 6-10). The opposite trend was apparent at the farfield station (B5MLW), with densities increasing during the operational period, particularly in 1993. These opposing trends (Fig. 6-5) resulted in a significant Preop-Op X Station interaction, based on ANOVA results (Table 6-11).

In contrast to between-period differences in number of taxa at intertidal stations, a significant increase in number of taxa for the shallow subtidal station group (B17 and B35) was apparent during operational years, compared to previous years (Tables 6-10 and 6-11). Numbers of taxa in 1993 strongly influenced this overall trend, as they were higher than both preoperational and operational means. The increase in number of taxa during operational years was most obvious at the nearfield site (B17). ANOVA revealed that this disproportional increase in number of taxa at B17 resulted in a significant Preop-Op X Station interaction for the shallow subtidal station group (Table 6-11, Fig. 6-5). Total faunal density for the overall shallow subtidal station group was also significantly higher during the operational period than during previous years (Tables 6-10 and 6-11). This was due, in large part, to the high densities recorded at both stations in 1993. The increase in total density during the operational period was similar for both stations, and therefore, ANOVA results indicated no significant Preop-Op X Station interaction (Table 6-11).

Similar to the shallow subtidal group, the mid-depth station group had higher numbers of taxa during operational years than during preoperational years (Tables 6-10 and 6-11). Mean numbers of taxa in 1993 at mid-depth stations were generally consistent with overall operational means. The overall increase in numbers of taxa appeared to be an area-wide phenomenon, as it was observed at all mid-depth stations (i.e., ANOVA results revealed no significant Preop-Op X Station interaction). ANOVA results did identify a significant Preop-Op X Station interaction for total faunal densities at mid-depth stations (Table 6-11), which was attributed to shifts in density at the intake station B16. Densities at nearfield (B19) and farfield (B31) stations were generally similar to each other and consistent over preoperational and operational periods (Fig. 6-6). However, at intake station B16, mean density decreased ca. 50% from the preoperational to the operational period (Table 6-10), in spite of a high annual mean for the most recent sampling year (1993).

At deep stations, preoperational, operational and 1993 mean numbers of taxa were generally comparable among all stations, with the exception of a low mean in 1993 at intake station B13, compared to preoperational and operational means for that site (Table 6-10). ANOVA indicated no significant between-period (Preop-Op) differences and no significant Preop-Op X Station interaction for numbers of taxa at the deep stations. Total faunal densities at both the nearfield and farfield deep stations (B04 and B34, respectively) were remarkably similar to each other over the entire study period, including 1993 (Table 6-10). However, as with the mid-depth station group, shifts in total density were apparent in the vicinity of the intakes (B13), where a twofold increase in mean total density was observed during the operational period, compared to the preoperational mean. Based on ANOVA results, this increase in total density at B13, coupled with relative consistency at both B04 and B34, resulted in a significant Preop-Op X Station interaction for the deep station group (Table 6-11; Fig. 6-6).

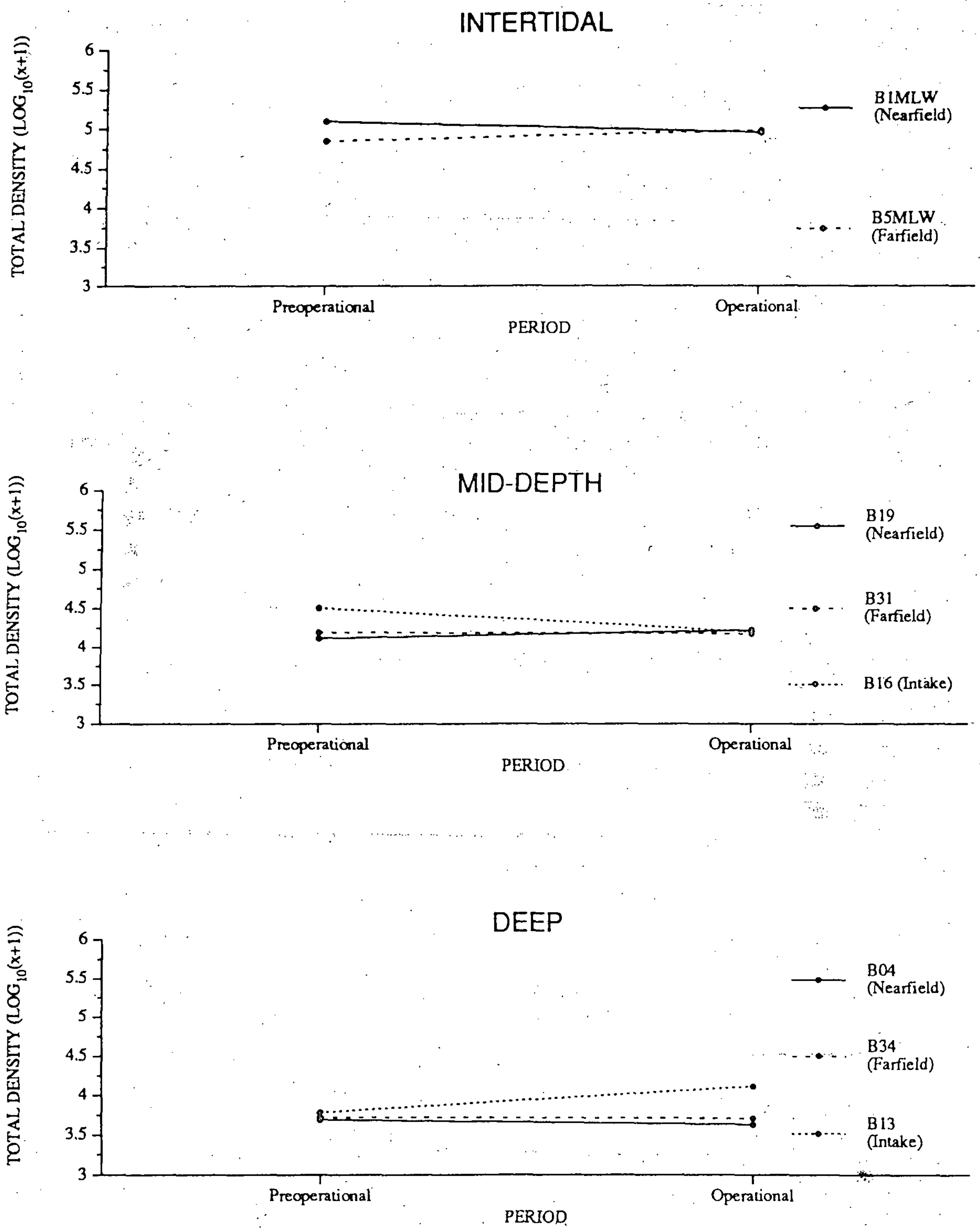


Figure 6-6. Comparisons among stations of mean total **macrofaunal** density ($\log_{10}(x+1)$) during the preoperational (1978-1989) and operational (1990-1993) periods for depth zones with a significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-11). Seabrook Operational Report, 1993.

Macrofaunal Community Analysis

The noncolonial macrofauna associated with hard substrata in the vicinity of Seabrook Station comprise a rich and diverse community; over 400 taxa have been collected in August destructive samples since 1978, some with densities of over 100,000 individuals/m^2. Very few of these animals are 'habitat formers' (cf. macroalgal section), and most are motile; therefore, the faunal species assemblages are not as distinct as those of the algae. However, multivariate macrofaunal community analyses, similar to those performed on macroalgae, facilitate the separation of annual collections at each station into groupings based on Bray-Curtis similarity indices, as well as the determination of within- and between-group relationships. These analyses were applied to log-transformed macrofaunal density data for the top 100 taxa, in terms of frequency of occurrence over the entire study period. The groupings of the 145 station/year collections are illustrated in Figure 6-7.

As with the macroalgal collections (Fig. 6-4), the intertidal stations (B1MLW and B5MLW; Group 1) comprise a distinct entity (Fig. 6-7), characterized by extremely high densities of Mytilidae spat (ca. 70,000 individuals/m^2; Table 6-12). These mussels accounted for about 70-80% of the individuals collected at the intertidal sites; the isopod *Jaera marina*, gastropods *Lacuna vincta* and *Nucella lapillus*, bivalves *Turtonia minuta* and *Hiatella* sp., oligochaetes, and the amphipod *Gammarus oceanicus* were also commonly found intertidally, but at much lower densities; none of these taxa accounted for more than about 5% of the individuals collected. In addition to the high densities of Mytilidae, and the presence of primarily intertidal species *Jaera marina*, *Nucella lapillus* and *Turtonia minuta*, this grouping separated from other clusters because of very low densities of the gammaridean amphipod *Pontogeneia inermis*, which was much more abundant at the deeper water stations.

Collections from the shallow subtidal stations (B17 and B35) also comprise a discrete cluster (Group 2; within-group similarity 68%/ between-group similarity 29%; Fig. 6-7 and Table 6-12). Mytilidae were also dominant at these stations (ca. 5,000-6,000/m^2), but mussel densities were more than an order of magnitude lower than at the intertidal sites. *Lacuna vincta* was the most abundant species at the shallow subtidal stations, in terms of number of individuals (ca. 5,400-10,700/m^2), and became significantly more abundant in the operational period. This small herbivorous snail is a dominant grazer on the kelp *Laminaria saccharina*, and also feeds on many other attached and drift algae. Since the food resource is quite patchy, the abundance of *Lacuna* is also variable. Other species abundant at the shallow subtidal stations (isopods *Idotea phosphorea* and *I. balthica*, gammaridean amphipods *Pontogeneia inermis* and *Jassa marmorata*) exhibited very consistent densities between preoperational and operational periods (Table 6-12).

Group 3 includes all collections from station B16 (mid-depth intake) and several from station B19 (mid-depth discharge; termed 'recent', although preoperational years 1986 and 1987 are included, while operational year 1990 is not). As reported earlier, subtidal zonation becomes less distinct with increasing depth; as the macroalgae (and associated epifauna) become increasingly patchy, collections exhibit less tendency to cluster together and stations/depths often overlap. The 95% confidence limits for all numerically dominant taxa (Mytilidae, amphipods *Pontogeneia inermis*, *Caprella septentrionalis* and *Caprella* sp., molluscs *Hiatella* sp., *Lacuna vincta* and *Anomia* sp. and the pycnogonid (sea spider) *Achelia* sp.) overlapped between preoperational and operational periods (Table 6-12); however, the wide range of values indicates a high degree of variability in the data.

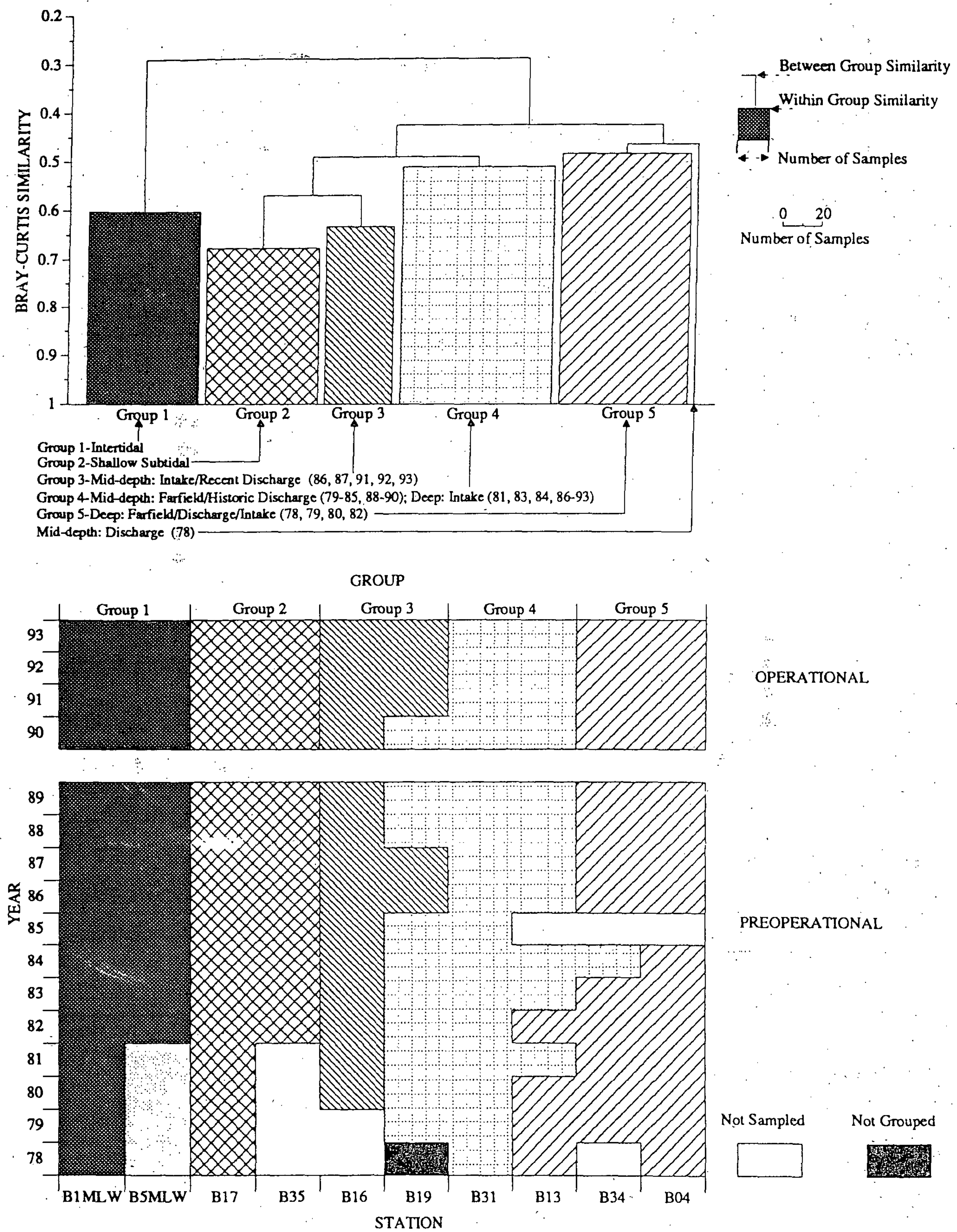


Figure 6-7. Dendrogram and station groups by year formed by numerical classification of August collections of marine macrofauna, 1978-1993. Seabrook Operational Report, 1993.

TABLE 6-12. STATION GROUPS FORMED BY CLUSTER ANALYSIS WITH PREOPERATIONAL AND OPERATIONAL (1990-1993) GEOMETRIC MEAN DENSITY AND 95% CONFIDENCE LIMITS (LOWER, LCL, AND UPPER, UCL) OF ABUNDANT MACROFAUNAL TAXA (NON-COLONIAL) COLLECTED ANNUALLY IN AUGUST FROM 1978 THROUGH 1993. SEABROOK OPERATIONAL REPORT, 1993.

GROUP NO.	NAME/ LOCATION (STATION/YEARS)	SIMILARITY (WITHIN/ BETWEEN GROUP)	DOMINANT TAXA	PREOPERATIONAL			OPERATIONAL		
				LCL	MEAN	UCL	LCL	MEAN	UCL
1	Intertidal/	.604/.291	Mytilidae	47979	69205	99823	37349	70118	131644
	Nearfield		*Jaera marina*	2117	3626	6217	690	1242	2239
	(B1MLW; 1978-93)		*Lacuna vincta*	2036	3209	5061	2474	3888	6114
	Farfield		*Turtonia minuta*	1368	2707	5361	683	1850	5016
	(B5BLW; 1982-93)		*Hiatella* sp.	1465	2604	4632	297	840	2378
			Oligochaeta	1204	2030	3424	182	837	3860
			Nucella lapillus	926	1501	2433	530	1437	3901
			Gammarus oceanicus	242	564	1320	743	1731	4038
2	Shallow Subtidal/	.679/.571	*Lacuna vincta*	3762	5379	7695	8182	10698	13991
	Nearfield		Mytilidae	2906	4758	7794	1520	5829	22359
	(B17; 1978-93)		*Idotea phosphrea*	1696	2166	2768	1603	2136	2850
	Farfield		*Pontogeneia inermis*	1249	1773	2519	814	1680	3470
	(B35; 1982-93)		*Jassa marmorata*	1098	1572	2255	822	1900	4393
			Idotea balthica	509	890	1560	280	659	1552
3	Mid-depth	.636/.571	Mytilidae	662	4034	24608	1396	3779	10238
	Intake		*Pontogeneia inermis*	495	2600	13657	451	1420	4474
	(B16; 1980-93)		*Caprella septentrionalis*	404	1995	9868	1061	2475	5775
	'Recent' Discharge		*Lacuna vincta*	150	601	2412	195	503	1303
	(B19; 1986, 1987, 1991-93)		*Anomia* sp.	116	489	2063	121	264	579
			Caprella sp.	134	485	1758	594	1011	1726
			Achelia spinosa	103	376	1375	532	735	1020
			Hiatella sp.	94	316	1065	385	609	967

(Continued)

TABLE 6-12. (CONTINUED)

GROUP NO.	NAME/ LOCATION (STATION/YEARS)	SIMILARITY (WITHIN/ BETWEEN GROUP)	DOMINANT TAXA	PREOPERATIONAL			OPERATIONAL		
				LCL	MEAN	UCL	LCL	MEAN	UCL
4	Mid-depth/ 'Historic' Discharge (B19; 1979-85, 1988-90) Farfield (B31; 1978-93) and Deep/ Intake (B13; 1981, 1983-84, 1986-93)	.511/.493	Mytilidae	1975	3491	6176	2193	5587	14238
			Balanus crenatus	535	776	1127	687	1106	1783
			Anomia sp.	503	719	1029	224	530	1259
			Hiatella sp.	425	632	942	417	1041	2603
			Pontogeneia inermis	324	438	593	161	311	605
			Caprella septentrionalis	68	218	711	923	2153	5026
5	Deep/ Discharge (B04; 1978-84, 1986-93) Intake (B13; 1978, 1979, 1980, 1982) Farfield (B34; 1979-83, 1986-93)	.487/.468	*Pontogeneia inermis*	135	246	452	67	148	330
			Caprella sp.	129	227	405	60	121	251
			Asteriidae	113	191	325	210	297	423
			Anomia sp.	90	167	313	248	407	671
			Caprella septentrionalis	78	137	244	60	121	250
			Tonicella rubra	81	127	202	59	85	125
			Musculus niger	63	110	197	86	109	140
			Mytilidae	57	109	212	68	127	241
			Hiatella sp.	47	92	185	50	153	473
			Thelepus cincinnatus	9	20	51	132	207	329

Since such variability was evident before Seabrook Station began operation, it was not attributed to the power plant.

Similarly, Group 4 represents a relatively indistinct assemblage, including all collections from station B31 (mid-depth farfield), most collections from stations B19 (mid-depth discharge), most collections from station B13 (deep intake), and even one year from station B34 , the deep farfield site (1984). It should be noted that the slight difference between the within-group (49%) and between-group (51%) similarities is an indication that the cluster is not well defined, and groupings can be expected to change from year to year. Of the numerically dominant taxa in this group (Mytilidae, *Anomia* sp., *Pontogeneia inermis*, *Hiatella* sp., *Caprella septentrionalis*, and the barnacle *Balanus crenatus*), only *C. septentrionalis* exhibited a significant change in density (from a mean of 218/m^2 in preoperational collections to 2,153/m^2 in operational collections; Table 6-12). The final major cluster, Group 5, was composed exclusively of deep water collections: all those from station B04 (discharge), almost all those from station B34 (farfield; excluding 1984), and several from B13 (intake). These collections were characterized by very low densities of all taxa (ca. 100-400/m^2); the bivalves Mytilidae, *Anomia* sp. and *Hiatella* sp. were particularly scarce, relative to densities in shallower water (Table 6-12). No significant changes in density were seen (from preoperational to operational periods) except for the tube-building fan worm *Thelepus cincinnatus*, which increased from a mean of 20/m^2 to over 200/m^2. However, this increase was noted at both nearfield and farfield stations, and does not appear to represent either a major alteration of the macrofaunal community or a power plant impact.

In general, collections from operational years (1990-93) at each station clustered with at least some of those from preoperational years, indicating that no changes to the macrofaunal community have resulted from operation of Seabrook Station.

Intertidal Communities (Non-destructive Monitoring Program)

Patterns of faunal abundance on local rocky shores exhibit patterns of zonation similar to those discussed previously for intertidal macroalgae (Lewis 1964; Menge 1976; Underwood and Denley 1984). Common intertidal fauna occurring in non-destructive sampling quadrats included barnacles, mussels, snails and limpets. Spatial (among zones, between stations) and temporal (among seasons, between operational periods) abundance patterns of these species for nearfield and farfield study sites are described below.

Barnacles (especially *Semibalanus balanoides*) commonly occur on high intertidal (Bare Ledge) rock surfaces in the Seabrook area and throughout the North Atlantic (Connell 1961; Menge 1976; Grant 1977; Bertness 1989). Although generally common, intertidal barnacle populations typically exhibit high seasonal and year-to-year variability (Menge 1991; Minchinton and Sheibling 1991; NUSCO 1994); similar temporal variability in barnacle abundance has been observed in Seabrook study quadrats (Table 6-13). Barnacle abundances (based on percent-frequency of occurrence estimates) during April were the lowest recorded during the operational period for both nearfield and farfield stations, but frequencies in subsequent months (July and December) were the highest recorded for that period, indicating good conditions for settlement and growth of barnacles after April. Because year-to-year variability is so high, between period, within station comparisons are best made by examining ranges of annual frequencies. Taking this approach, operational ranges (both monthly and averages for all seasons), although smaller, fall within preoperational

TABLE 6-13. MEDIAN PERCENT FREQUENCY OF OCCURRENCE BY SEASON AND OVER ALL SEASONS OF THE DOMINANT FAUNA WITHIN PERMANENT 0.25 m^2 QUADRATS AT THE UPPER (BARE ROCK), MID- (FUCOID ZONE), AND LOWER (*CHONDRUS* ZONE) INTERTIDAL ZONES AT NEARFIELD (OUTER SUNK ROCKS) AND FARFIELD (RYE LEDGE) DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS, AND MEAN PERCENT FREQUENCY OF OCCURRENCE DURING 1993. SEABROOK OPERATIONAL REPORT, 1993.

ZONE[a] TAXON	STATION	PERIOD/ YEAR[b]	APR	JUL	DEC	ALL SEASONS[c]
Bare Ledge						
Barnacles	Nearfield	Preoperational	61	51	9	40
	(B1)	(range)	(4-100)	(9-88)	(0-88)	(0-100)
		Operational	41	76	74	68
		(range)	(41-51)	(46-98)	(48-81)	(41-98)
		1993	41	98	81	73
	Farfield	Preoperational	89	85	72	82
	(B5)	(range)	(58-100)	(24-100)	(5-100)	(5-100)
		Operational	70	67	50	58
		(range)	(36-95)	(60-67)	(11-54)	(11-95)
		1993	36	67	54	52
Littorina saxatilis	Nearfield	Preoperational	7	57	16	27
	(B1)	(range)	(0-44)	(0-88)	(0-88)	(0-88)
		Operational	37	81	75	60
		(range)	(25-50)	(81-100)	(0-100)	(0-100)
		1993	50	100	100	83
	Farfield	Preoperational	50	66	75	64
	(B5)	(range)	(0-100)	(38-94)	(0-100)	(0-100)
		Operational	31	50	50	50
		(range)	(0-81)	(6-69)	(19-81)	(0-81)
		1993	0	69	81	50
Fucoid Zone						
Mytilidae	Nearfield	Preoperational	82	76	78	79
	(B1)	(range)	(37-100)	(27-100)	(43-100)	(27-100)
		Operational	83	93	52	70
		(range)	(23-91)	(29-99)	(19-95)	(19-99)
		1993	23	29	52	35
	Farfield	Preoperational	8	1	5	5
	(B5)	(range)	(2-100)	(0-100)	(0-100)	(0-100)
		Operational	9	13	0	8
		(range)	(5-10)	(0-19)	(0-11)	(0-19)
		1993	10	13	0	8

(Continued)

TABLE 6-13. (CONTINUED)

ZONE TAXON	STATION	PERIOD/ YEAR	APR	JUL	DEC	ALL SEASONS
Fucoid Zone (continued)						
Littorina obtusata	Nearfield	Preoperational	3	10	6	6
	(B1)	(range)	(0-6)	(0-25)	(6-19)	(0-25)
		Operational	6	6	12	12
		(range)	(0-6)	(0-19)	(0-44)	(0-44)
		1993	0	6	44	17
	Farfield	Preoperational	3	16	7	9
	(B5)	(range)	(0-25)	(0-44)	(0-44)	(0-44)
		Operational	6	31	37	27
		(range)	(0-12)	(25-50)	(12-56)	(0-56)
		1993	6	50	56	37
Chondrus Zone						
Mytilidae	Nearfield	Preoperational	90	89	65	81
	(B1)	(range)	(54-95)	(71-95)	(15-85)	(15-95)
		Operational	77	76	66	79
		(range)	(67-95)	(72-95)	(63-93)	(63-95)
		1993	77	72	66	72
	Farfield	Preoperational	49	63	26	46
	(B5)	(range)	(10-72)	(23-80)	(0-49)	(0-80)
		Operational	21	53	49	41
		(range)	(0-57)	(27-92)	(8-87)	(0-92)
		1993	57	92	87	79
Nucella lapillus	Nearfield	Preoperational	75	100	56	77
	(B1)	(range)	(13-100)	(100)	(31-88)	(13-100)
		Operational	25	100	37	61
		(range)	(19-81)	(94-100)	(19-69)	(19-100)
		1993	19	94	69	61
	Farfield	Preoperational	94	38	69	67
	(B5)	(range)	(75-100)	(13-56)	(56-81)	(13-100)
		Operational	94	50	31	58
		(range)	(37-100)	(37-94)	(19-75)	(19-100)
		1993	37	94	75	69

(Continued)

TABLE 6-13. (CONTINUED)

ZONE TAXON	STATION	PERIOD/ YEAR	APR	JUL	DEC	ALL SEASONS
Chondrus Zone (continued)						
Littorina littorea	Nearfield	Preoperational	0	0	0	0
	(B1)	(range)	(0)	(0-13)	(0-6)	(0-13)
		Operational	0	6	12	12
		(range)	(0-19)	(0-25)	(12-50)	(0-50)
		1993	0	0	50	17
	Farfield	Preoperational	81	100	88	90
	(B5)	(range)	(75-100)	(94-100)	(44-94)	(44-100)
		Operational	94	100	62	85
		(range)	(81-100)	(100)	(9-75)	(9-100)
		1993	100	100	75	92
Acmaea testudinalis	Nearfield	Preoperational	13	13	13	13
	(B1)	(range)	(6-38)	(0-25)	(6-81)	(0-81)
		Operational	12	12	12	11
		(range)	(0-19)	(6-12)	(0-81)	(0-81)
		1993	0	6	81	29
	Farfield	Preoperational	0	0	0	0
	(B5)	(range)	(0-44)	(0-13)	(0-25)	(0-44)
		Operational	12	6	6	8
		(range)	(6-12)	(0-12)	(0-44)	(0-44)
		1993	6	0	44	7

[a]Bare Ledge station is at upper edge of mean sea level (MSL) zone, approximately mean high water. Fucoid Zone station is approximately MSL. *Chondrus* Zone station is approximately mean low water.
[b]Preoperational period extends from 1982 - 1989, except for *Chondrus* Zone, where sampling began in April 1985. Operational period extends from 1991 - 1993.
[c]Average of three seasonal medians.

ranges with one exception (B1 in July), indicating overall stability of barnacle populations at both stations. The herbivorous snail, *Littorina saxatilis*, is an important grazer in the high intertidal zone. Abundance of *L. saxatilis* in the high intertidal was generally lowest in early spring (April; Table 6-13), providing a temporal refuge for ephemeral algae (see Table 6-7). As with high intertidal barnacles, considerable overlap of preoperational and operational ranges of monthly and all-seasons estimates of *L. saxatilis* abundance were noted for both nearfield and farfield stations.

The dominant faunal taxon in the mid-intertidal (Fucoid) zone has been Mytilidae (primarily the blue mussel *Mytilus edulis*), which can continually dominate certain rocky shores in New England (Lubchenco and Menge 1978; Petraitis 1991) and elsewhere in the North Atlantic (Seed 1976). Mytilidae were most abundant at the nearfield station (B1), with median percent-frequencies (both preoperational and operational) exceeding 50% for all sampling periods (Table 6-13); somewhat lower abundances were observed at this station in 1993. The 1993 and period median frequencies were all less than 13% at farfield station B5, although considerably higher abundances have been observed there occasionally. Mussels are typically outcompeted by barnacles at this site (NAI 1993). At both sites, operational ranges generally fall within preoperational ranges. The herbivorous snail *Littorina obtusata* was a common mid-intertidal resident at both stations. Overall, operational abundances have generally been higher than those during preoperational years, a trend which was apparent at both nearfield and farfield stations (Table 6-13).

High mussel abundances were also typical of the low intertidal or *Chondrus* zone, with only small differences between nearfield and farfield stations, relative to those in the mid-intertidal (Table 6-13). Frequency of occurrence estimates during 1993 at nearfield station B1 were consistent with those from preoperational and operational periods. At the farfield station (B5), high abundances were observed in 1993 and over the operational period, relative to preoperational years. However, considerable overlap of preoperational and operational ranges was apparent for both stations. The carnivorous snail *Nucella lapillus* commonly preys on mussels and barnacles, and can have considerable influence on low intertidal community structure (Connell 1961; Menge 1983, 1991; Petraitis 1991). At Seabrook study sites, *N. lapillus* can be locally abundant, at times reaching frequency of occurrence levels of 100% (Table 6-13). Over the entire study, occurrence of this species has been very consistent, both between nearfield and farfield stations and between periods. Of the herbivorous littorine snails occurring in the Gulf of Maine, *Littorina littorea* has the most pronounced effect on intertidal community structure, particularly in the low intertidal zone (Lubchenco 1983; Petraitis 1983). In the Seabrook study area, *L. littorea* was most common at the farfield station (B5), often exceeding 80% frequency of occurrence during both periods (Table 6-13). Frequencies at the nearfield station (B1) never exceeded 50% during our studies, and many times, *L. littorea* was absent from the study areas. Abundances of *L. littorea* at B1 tended to be lower during the preoperational years (<13%) than during the operational period, when the highest monthly estimates were recorded. Another low intertidal grazer, the limpet *Acmaea testudinalis*, occurred in low to moderate frequencies in most years at nearfield station B1, and occasionally at similar levels at farfield station B5 (Table 6-13). Operational ranges for individual sampling periods were generally similar to preoperational ranges, and preoperational and operational ranges for all seasons combined at each station were identical (0-81% at B1, 0-44% at B5).

Subtidal Fouling Community (Bottom Panel Monitoring Program)

Recruitment success and annual patterns of settlement for sessile macroinvertebrates were assessed by the bottom panel study using short-term exposure periods (three sequential four-month exposure periods a year). Although the type of substratum, length of exposure period and deployment strategies can all influence the patterns of community colonization (Zobell and Allen 1935; Fuller 1946; Schoener 1974; Osman 1977; Sutherland and Karlson 1977), these factors may be standardized to allow comparisons between nearfield and farfield sites during these different periods of the year (January-April, May-August, and September-December). Four-month exposure periods provide the minimum duration for larval stages to settle, metamorphose, and grow into juveniles or young adults that can be effectively identified. Of the organisms collected on these panels, four taxa (*Balanus*, *Anomia*, *Hiatella*, and Mytilidae) have been collected in sufficient frequency and numbers to allow comparisons of long-term trends in densities within and between nearfield and farfield stations for assessing power plant effects (Table 6-14).

Subtidal barnacles in the Seabrook area are represented primarily by two species of *Balanus* (mainly *B.crenatus*, and *B. balanus*). Peak settlement usually occurred in early spring, resulting in highest densities in the April exposure period (Table 6-14). However settlement is protracted, and variable from year to year; substantial densities of barnacles were found in August, and occasionally (notably in 1993), barnacles recruited to bottom panels in the September-December exposure period. Typically, barnacle densities were higher at the farfield station (B31) than at the nearfield station (B19) over both preoperational and operational periods.

Anomia spp. (jingle shells), which consistently have peak settlement during the September to December exposure period, a period when water temperatures are rapidly cooling (cf. Fuller 1946). Preoperational densities of these bivalves were similar between the nearfield and farfield stations (Table 6-14). Operational densities at the nearfield station have tended to be higher in April and December than those during the preoperational period. The 1993 December density estimates at the nearfield station were the highest observed during the operational period and were over twice as high as the operational mean (2600 individuals/0.25 m^2) reported last year (NAI 1993). Densities at the farfield station, though generally lower during the operational than the preoperational period, have remained fairly stable since 1991.

Another species of interest is the small crevice-seeking bivalve, *Hiatella*, which has historically settled during the August exposure period at both stations. Settlement has normally been highest in August at the farfield station, where densities in excess of 10,000 individuals per 0.25 m^2 were commonly reported. This trend changed in 1993, when only 1,266 individuals per 0.25 m^2 were collected at the farfield station. At the nearfield station, August settlement (5399 individuals/0.25 m^2) was similar to those reported in past years (ranging from 3868 to 7473 individuals/0.25 m^2 during the period extending from 1984 to 1993).

Mytilidae (mostly blue mussel, *Mytilus edulis*) are an important component of the local macrofaunal community, and are discussed in more detail in the following section. Recruitment to bottom panels followed a pattern similar to that described for *Hiatella*, i.e., peak recruitment occurred during the August exposure period and densities were consistently highest at the farfield station. Similar to recruitment trends for *Hiatella*, the August 1993 recruitment of Mytilidae spat at the farfield station

TABLE 6-14. ESTIMATED DENSITY (per 0.25 m^2) OF SELECTED SESSILE TAXA ON HARD-SUBSTRATE BOTTOM PANELS EXPOSED FOR FOUR MONTHS AT STATIONS B19 AND B31 SAMPLED TRIANNUALLY (APRIL, AUGUST, DECEMBER) FROM 1981 - 1993 (EXCEPT 1985 AND 1990). SEABROOK OPERATIONAL REPORT, 1993.

			APRIL		AUGUST		DECEMBER		ALL SEASONS	
TAXON	STATION	PERIOD/YEAR	MEAN	CV[c]	MEAN	CV	MEAN	CV	MEAN	CV
Balanus spp.	Nearfield (B19)	Preop[a]	17053	81	6403	78	9	144	7822	110
		Op[b]	13406	113	8861	71	28	171	7432	92
		1993	3433	-	1683	-	83	-	1733	-
	Farfield (B31)	Preop	40962	55	7917	78	14	121	16298	133
		Op	19683	53	10194	53	106	173	9994	98
		1993	12650	-	16233	-	317	-	9733	-
Anomia spp.	Nearfield (B19)	Preop	<1	<1	31	219	1232	92	421	167
		Op	85	113	79	90	3905	68	1356	163
		1993	8	-	72	-	6516	-	3410	-
	Farfield (B31)	Preop	0	0	36	117	993	125	343	164
		Op	7	71	140	124	537	18	228	121
		1993	4	-	18	-	498	-	173	-
Hiatella spp.	Nearfield (B19)	Preop	1	200	3966	65	27	115	1331	171
		Op	3	100	5488	38	9	144	1833	173
		1993	0	-	5399	-	24	-	1808	-
	Farfield (B31)	Preop	<1	<1	11659	91	16	131	3892	173
		Op	3	100	14801	81	114	151	4973	171
		1993	1	-	1266	-	312	-	526	-
Mytilidae	Nearfield (B19)	Preop	2	150	367	67	58	98	142	139
		Op	89	121	2951	88	51	16	1030	161
		1993	1	-	2610	-	42	-	884	-
	Farfield (B31)	Preop	8	138	5035	200	36	100	1693	171
		Op	24	112	4484	81	59	92	1522	169
		1993	0	-	408	-	60	-	156	-

[a]Preop: 1981 - 1984 (*Balanus* and *Anomia*, B19); 1982 - 1984 (*Balanus* and *Anomia*, B31); 1983 - 1984 (*Hiatella* and Mytillidae, B19 and B31); Dec. 1986 - 1989 (all taxa and stations).
[b]Op = 1991 - 1993.
[c]Coefficient of variability of the mean (standard error of the mean divided by the mean and multiplied by 100).

was depressed by an order of magnitude over that observed in past years. At the nearfield station, the 1993 settlement was more consistent with those reported for other operational years. A trend for higher densities of mussels on panels during operational years, relative to preoperational years, occurred at the nearfield, but not the farfield station. This trend was evident in both the August data and the combined seasonal data.

6.3.2.2 Selected Benthic Species

Mytilidae

Representatives of the order Mytilidae (mytilids) are common in the North Atlantic, found attached to intertidal and shallow subtidal rocky substrata, but occasionally recorded from deeper water (Seed 1976). Important as prey for marine carnivores such as the dogwinkle *Nucella lapillus* in the intertidal zone (Menge 1991; Petraitis 1991), and starfish, lobsters, crabs and fish subtidally (Menge 1979; Witman 1985; Ojeda and Dearborn 1991), mytilid shell surfaces and interstices within mytilid aggregates also provide attachment and habitat areas for many algal and faunal species (Dayton 1971; Seed 1976).

At Seabrook study sites, Mytilidae (primarily the blue mussel *Mytilus edulis*) was, by far, the dominant taxon in terms of density (no./m^2) in the intertidal zone (Table 6-15). Annual Mytilidae abundances have been variable over the preoperational period (NAI 1991b), and similar variability has become apparent over the operational period. High year-to-year variability in mytilid recruitment is typical for the Gulf of Maine (Petaitis 1991). For example, while densities have been low during the operational period in previous years, relative to preoperational densities, 1993 densities were higher than other operational years. In spite of these high densities in 1993, overall mean operational densities have remained significantly lower than preoperational densities (ANOVA results; Table 6-16). During 1993 and over both preoperational and operational periods, mytilid densities (Table 6-16) have been consistently higher at the nearfield station (B1MLW) than at the farfield station (B5MLW). Because this between-station relationship has been so consistent over the entire study period (reflecting an area-wide pattern of recruitment), ANOVA results indicated no significant Preop-Op X Station interaction for intertidal mytilid densities (Table 6-16).

Mytilidae were also among the dominant taxa at shallow subtidal stations, and the high recruitment in 1993 discussed previously for the intertidal zone was also apparent; mytilid densities in 1993 at shallow subtidal stations were considerably higher than either preoperational or operational means (Table 6-15). As in the intertidal zone, previous operational means had been significantly lower than preoperational means (NAI 1993); however, high densities in 1993 have resulted in no significant between-period differences (ANOVA results; Table 6-16). The dramatic increase in mytilid abundance in 1993 was most pronounced at the farfield station (B35), with 1993 mean density approximately an order of magnitude higher than either preoperational or operational mean. Although farfield densities have consistently been higher than those at the nearfield station (B17) over the entire study period, the greater difference between nearfield and farfield station means in the operational period (due, in large part, to exceptionally high densities at the farfield station in 1993) has, based on ANOVA, resulted in a significant Preop-Op X Station interaction for the shallow subtidal station pair (Table 6-16, Fig. 6-8).

Mytilids were also abundant at mid-depth stations, relative to other taxa collected at those sites. As noted in the other depth zones, densities recorded in

TABLE 6-15. GEOMETRIC MEAN DENSITIES (#/M^2) OF SELECTED BENTHIC MACROFAUNAL SPECIES DURING PREOPERATIONAL AND OPERATIONAL PERIODS, AND DURING 1993. SEABROOK OPERATIONAL REPORT, 1993.

TAXON	STATION[a]	PREOPERATIONAL[b] MEAN	PREOPERATIONAL[b] CV[d]	1993 MEAN	OPERATIONAL[c] MEAN	OPERATIONAL[c] CV
Mytilidae	B1MLW	121297	4.0	113424	87852	7.4
	B5MLW	72831	2.8	95743	57606	6.7
	B17	2580	10.8	9187	2195	17.5
	B35	4449	9.8	55420	8335	18.9
	B19	1876	16.0	11413	4644	10.3
	B31	6196	14.7	8495	5981	9.9
Nucella lapillus	B1MLW	1970	7.4	1208	947	3.1
	B5MLW	905	3.7	773	554	4.6
Asteriidae						
	B17	590	9.0	561	588	5.8
	B35	184	16.4	81	96	34.4
Pontogeneia inermis	B19	599	5.6	941	747	8.7
	B31	404	8.3	320	259	11.4
Jassa marmorata	B17	1045	10.4	1124	1443	4.7
	B35	1888	9.6	4464	3782	2.0
Ampithoe rubricata	B1MLW	19	88.3	2	1	74.2
	B5MLW	3	117.3	108	144	6.5
Strongylocentrotus droebachiensis	B19	65	23.3	156	69	18.1
	B31	31	28.0	59	31	16.2
Modiolus modiolus[e]	B19	100	22.9	71	79	13.5
	B31	89	30.8	62	68	28.3

[a]Nearfield = B1MLW, B17, B19; Farfield = B5MLW, B35, B31.
[b]Preoperational = mean of annual means, 1978-1989 (B1MLW, B17, B19, B31) or 1982-1989 (B5MLW, B35).
[c]Operational mean = mean of annual means, 1991-1993, for all stations.
[d]Coefficient of variability of the mean (standard error of the mean divided by the mean and multiplied by 100).
[e]Arithmentic mean of annual means. Preop = 1980-1989, Op = 1991-1993.

TABLE 6-16. ANALYSIS OF VARIANCE RESULTS COMPARING LOG-TRANSFORMED DENSITIES OF SELECTED BENTHIC TAXA AT NEAR- AND FARFIELD STATION PAIRS (B1MLW/B5MLW, B17/B35, B19/B31) DURING PREOPERATIONAL (1978 - 1989) AND OPERATIONAL (1991 - 1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

			SAMPLED IN MAY, AUGUST, NOVEMBER			
TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	df	MS	F[g]	MULTIPLE COMPARISON[h] (Ranked in decreasing order)
Mytilidae (<25 mm)	Intertidal (B1, B5)	Preop-Op[b]	1	0.88	7.50 **	Op<Preop
		Year (Preop-Op)[c]	13	0.88	7.51 **	
		Month (Year)[d]	30	0.84	7.13 **	
		Station[e]	1	2.75	23.39 **	
		Preop-Op X Station[f]	1	0.05	0.39 NS	
		Error	303	0.12		
	Shallow Subtidal (B17, B35)	Preop-Op	1	0.61	2.18 NS	
		Year (Preop-Op)	13	3.64	12.97 **	
		Month (Year)	30	2.17	7.75 **	
		Station	1	10.03	35.78 **	
		Preop-Op X Station	1	1.87	6.67 *	B35-Op B35-Pre B17-Pre B17-Op
		Error	295	0.28		
	Mid-Depth (B19, B31)	Preop-Op	1	2.46	6.55 *	Op>Preop
		Year (Preop-Op)	13	5.42	14.42 **	
		Month (Year)	30	1.19	3.17 **	
		Station	1	7.06	18.79 **	
		Preop-Op X Station	1	3.03	8.05 **	B31-Pre B31-Op B19-Op B19-Pre
		Error	355	0.38		

(Continued)

TABLE 6-16. (CONTINUED)

TAXA	DEPTH ZONE (STATION)	SOURCE OF VARIATION	SAMPLED IN MAY, AUGUST, NOVEMBER df	MS	F	MULTIPLE COMPARISON (Ranked in decreasing order)
Nucella lapillus	Intertidal (B1MLW, B5MLW)	Preop-Op	1	5.18	40.52 **	Op<Preop
		Year (Preop-Op)	13	0.55	4.31 **	
		Month (Year)	30	0.97	7.61 **	
		Station	1	4.32	33.79 **	
		Preop-Op X Station	1	0.06	0.47 NS	
		Error	303	0.13		
Asteriidae	Shallow Subtidal (B17, B35)	Preop-Op	1	1.95	12.94 **	Op<Preop
		Year (Preop-Op)	13	2.10	13.95 **	
		Month (Year)	30	0.84	5.58 **	
		Station	1	22.86	152.06 **	
		Preop-Op X Station	1	1.84	12.22 **	B17-Pre B17-Op B35-Pre B35-Op
		Error	295	0.15		
Pontogeneia intermis	Mid-Depth (B19, B31)	Preop-Op	1	0.16	0.73 NS	
		Year (Preop-Op)	13	0.95	4.25 **	
		Month (Year)	30	1.16	5.16 **	
		Station	1	7.39	32.96 **	
		Preop-Op X Station	1	1.25	5.60 *	B19-Op B19-Pre B31-Pre B31-Op
		Error	355	0.22		
Jassa marmorata	Shallow Subtidal (B17, B35)	Preop-Op	1	2.71	8.96 **	Op>Preop
		Year (Preop-Op)	13	1.26	4.04 **	
		Month (Year)	30	0.79	2.55 **	
		Station	1	7.01	22.48 **	
		Preop-Op X Station	1	0.39	1.26 NS	
		Error	295	0.31		

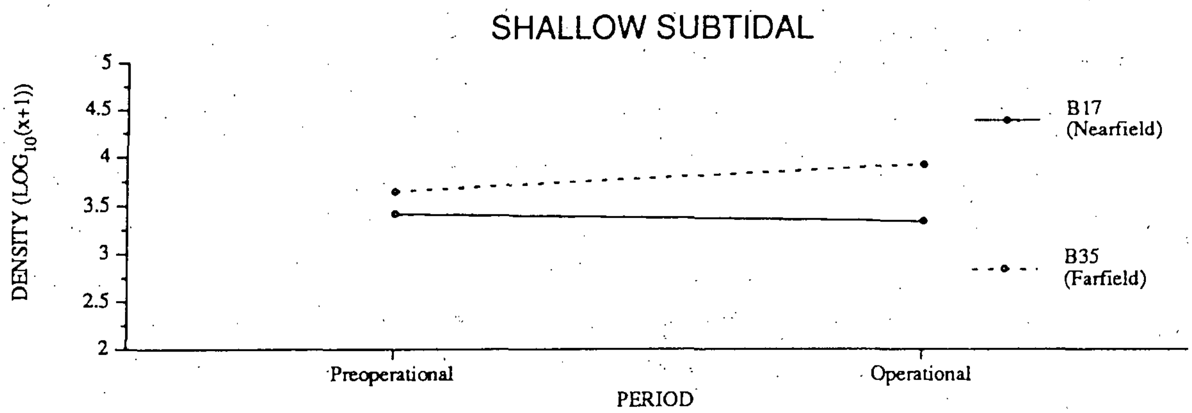
(Continued)

TABLE 6-16. (CONTINUED)

TAXA	DEPTH ZONE (STATION)	SOURCE OF VARIATION	SAMPLED IN MAY, AUGUST, NOVEMBER df	MS	F	MULTIPLE COMPARISON (Ranked in decreasing order)
Ampithoe rubricata	Intertidal (B1, B5)	Preop-Op	1	0.50	1.31 NS	
		Year (Preop-Op)	13	18.16	47.21 **	
		Month (Year)	30	1.09	2.38 **	
		Station	1	58.29	151.50 **	
		Station X Preop-Op	1	52.99	137.73 **	B5-Op B5-Pre B1-Pre B1-Op
		Error	303	0.38		
Strongylocentrotus droebachiensis	Mid-Depth (B19, B31)	Preop-Op	1	0.01	0.02 NS	
		Year (Preop-Op)	13	3.51	7.34 **	
		Month (Year)	30	1.75	3.65 **	
		Station	1	8.44	17.65 **	
		Station X Preop-Op	1	0.00	0.00 NS	
		Error	355	0.48		
Modiolus modiolus (adults)	Mid-Depth (B19, B31)	Preop-Op	1	672,939	36.21 **	Op<Preop
		Year (Preop-Op)	11	135,019	7.26 **	
		Month (Year)	26	34,900	1.88 **	
		Station	1	112	0.01 NS	
		Station X Preop-Op	1	4,286	0.23 NS	
		Error	888	18,585		

[a] $\log_{10}$ (x+1) density, except for *M. modiolus* adults, which were sampled semi-quantitatively and therefore rank densities were used.
[b] Preop-Op compares 1978-1989 to 1990-1993 regardless of station.
[c] Year nested within preoperational and operational periods regardless of station.
[d] Month nested within year regardless of year, station or period.
[e] Station pairs nested within a depth zone: Intertidal = nearfield (B1MLW), farfield (B5MLW); Shallow subtidal = nearfield (B17), farfield (B35); Mid-depth = nearfield (B19), farfield (B31); regardless of year or period.
[f] Interaction of the two main effects, Preo-Op and Station.
[g] NS = not significant (p>0.05); * = significant (0.05≥p>0.01); ** = highly significant (p≤0.01).
[h] Underlining indicates that t-tests showed no significant differences (α≤0.05) among the underlined least squares means; multiple comparisons listed in decreasing order. The > or < signs indicate a significant difference between two LS means.

MYTILIDAE



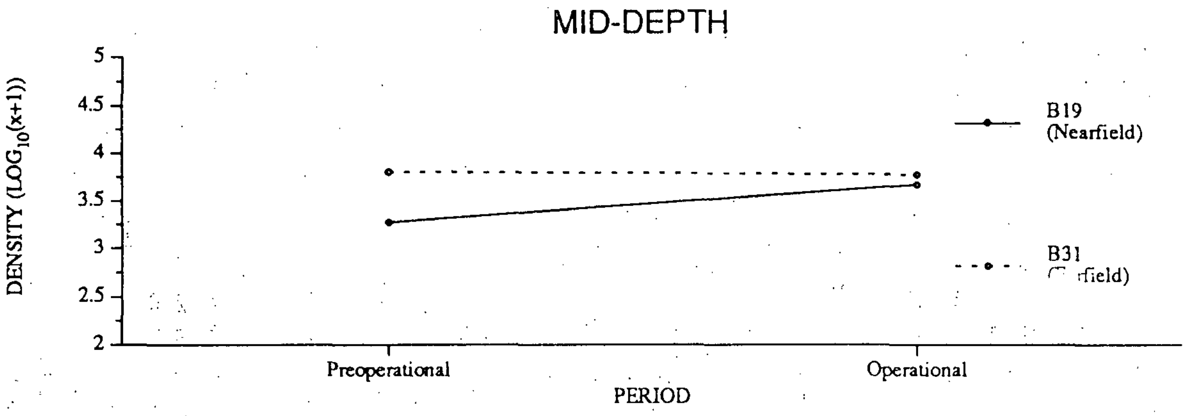
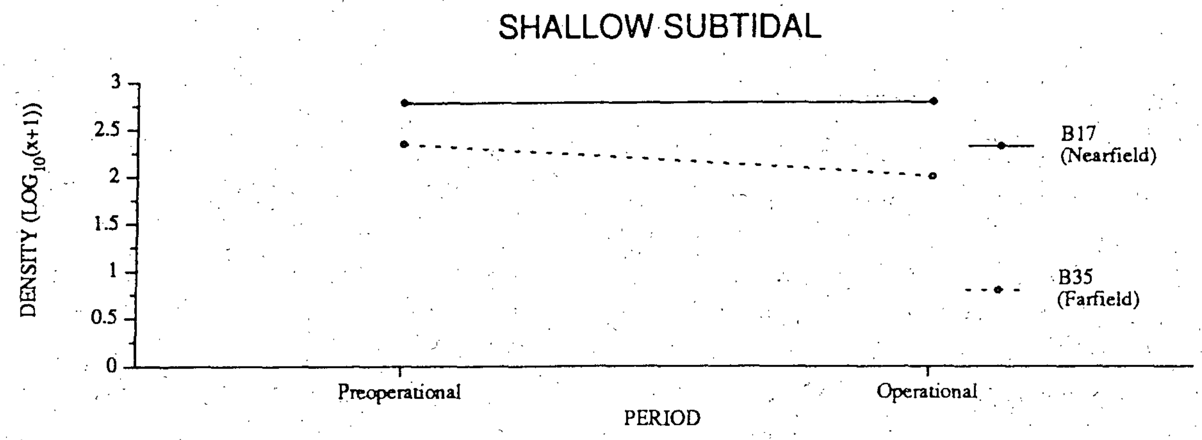
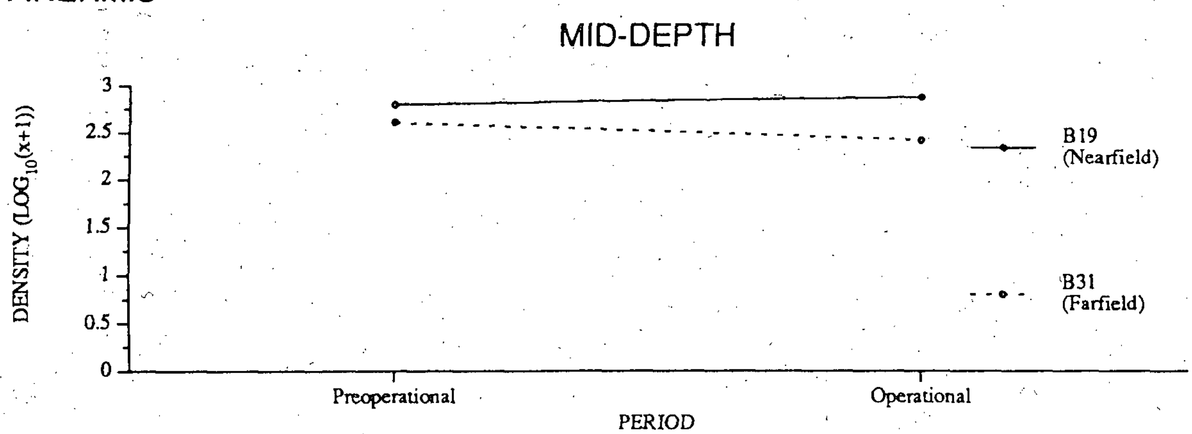


Figure 6-8. Comparisons between stations of mean density ($\log_{10}(x+1)$) of selected **macrofaunal** taxa during the preoperational (1978-1989) and operational (1991-1993) periods for depth zones with a significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-18). Seabrook Operational Report, 1993.

ASTERIDAE



P. INERMIS



A. RUBRICATA

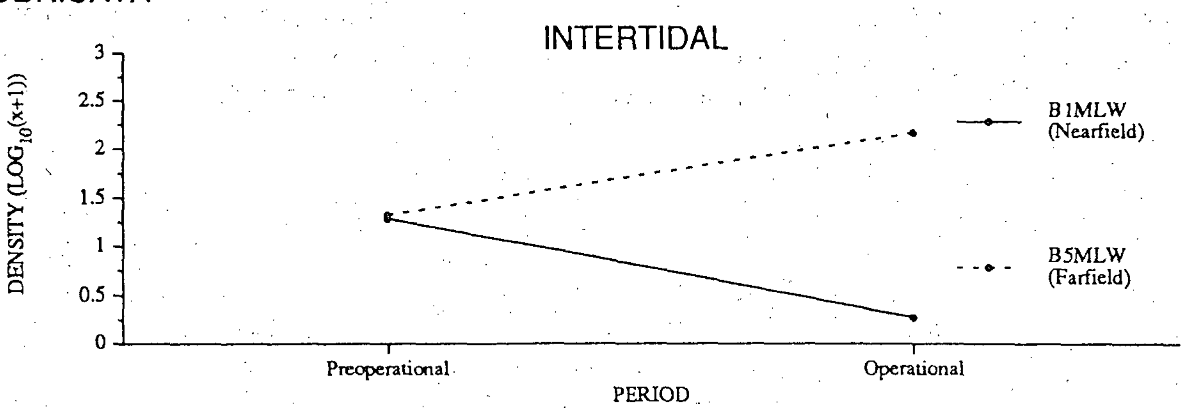


Figure 6-8. (continued)

1993 were higher than both preoperational and operational means, providing further evidence for high recruitment in 1993 (Table 6-15). These higher 1993 densities contributed to the significantly higher overall operational mean density, compared to the overall preoperational mean (ANOVA results; Table 6-16). High recruitment in 1993 was most notable at the nearfield station B19, and resulted in a relatively higher operational mean at that site, compared to the operational mean at the farfield station (B31). ANOVA results indicated that this shift in the relationship between mytilid densities at nearfield and farfield stations (Fig. 6-8) was significant (i.e., a Preop-Op X Station interaction; Table 6-16).

The most common mytilid collected at Seabrook study sites, the blue mussel *Mytilus edulis*, can reach lengths up to 100 mm (Gosner 1978). However, most mytilids collected during our study ranged from 1 to 25 mm, with the majority collected as newly settled spat measuring 2-3 mm. A summary of mytilid lengths over preoperational and operational years is presented in Table 6-17. Mytilid lengths have generally been greatest in the intertidal zone, a trend which has been consistent over both periods. Intertidal mytilids typically have been larger at the farfield station (B5MLW) than at the nearfield station (B1MLW) over both preoperational and operational periods, with a considerable between-station difference noted in 1993 (4.5 mm vs. 3.0 mm). Mytilids were slightly larger during operational years at both intertidal stations, compared to preoperational years.

Mytilids were generally smaller in the subtidal zones than those in the intertidal, with preoperational means ranging from 2.3 to 2.8 mm. During 1993 and over both operational periods, mytilid lengths were smaller at the nearfield stations (B17 and B19), than at the farfield counterparts (B35 and B31, respectively). Mean mytilid lengths were larger in 1993 and during the operational period than during preoperational years at both nearfield and farfield shallow subtidal stations (B17 and B35, respectively). At nearfield mid-depth station B19, mytilids were generally smaller during the operational period and during 1993, relative to the preoperational mean. Mytilid lengths at the mid-depth farfield station have been consistent over the entire study period, including 1993.

<u>*Nucella lapillus*</u>

The only common intertidal predator in the Seabrook area is the dogwinkle, *Nucella lapillus*, preying primarily on mussels and barnacles (Connell 1961; Menge 1976; Petraitis 1991). At Seabrook study sites, *N. lapillus* abundances at nearfield station B1MLW were nearly twofold higher than abundances at the farfield station (B5MLW) in both preoperational and operational periods and during 1993 (Table 6-15). Densities in 1993 were lower than the preoperational means, and ANOVA results indicated that overall means for the operational period were significantly lower than the preoperational mean (Table 6-16). Because the relationship between *N. lapillus* densities at nearfield and farfield intertidal stations has remained relatively consistent and proportional over the study period, ANOVA results also indicated no significant Preop-Op X Station interaction.

Nucella lapillus length measurements were also conducted as part of life history studies. *N. lapillus* can reach lengths of up to 51 mm (Abbott 1974), but typically ranged from 3-12 mm during this study (NAI 1993). Average lengths were greater at the nearfield station (B1MLW) than at the farfield station (B5MLW) in 1993, a trend that has been observed over preoperational and operational periods (Table 6-17). Operational mean lengths at both stations were below the respective preoperational

TABLE 6-17. MEAN LENGTH (mm) AND LOWER (LCL) AND UPPER (UCL) 95% CONFIDENCE LIMITS DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS, AND MEAN LENGTHS DURING 1993 OF SELECTED BENTHIC SPECIES AT NEARFIELD-FARFIELD STATION PAIRS. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATONAL[a]			1993	OPERATIONAL[b]		
TAXON	STATION	LCL	MEAN	UCL	MEAN	LCL	MEAN	UCL
Mytilidae[c]	B1MLW	3.1	3.1	3.2	3.0	3.2	3.3	3.4
	B5MLW	3.2	3.3	3.3	4.5	3.4	3.5	3.6
	B17	2.3	2.3	2.4	2.6	2.5	2.6	2.7
	B35	2.4	2.5	2.5	3.1	2.6	2.7	2.7
	B19	2.3	2.4	2.4	2.2	2.0	2.0	2.1
	B31	2.7	2.8	2.9	2.7	2.7	2.7	2.8
Nucella lapillus	B1MLW	6.7	6.9	7.0	7.9	6.0	6.2	6.5
	B5MLW	5.8	6.0	6.2	4.4	4.9	5.2	5.5
Asteriidae	B17	4.8	5.0	5.1	4.7	4.7	4.8	5.0
	B35	6.4	6.7	7.1	7.7	5.7	6.1	6.6
Pontogeneia inermis	B19	5.0	5.1	5.3	5.8	5.2	5.4	5.5
	B31	5.2	5.3	5.4	5.4	5.3	5.4	5.5
Jassa marmorata	B17	4.1	4.2	4.2	4.1	4.2	4.4	4.5
	B35	3.9	3.9	4.0	3.5	3.9	4.0	4.1
Ampithoe rubricata	B1MLW	6.7	7.0	7.3	6.7	5.6	7.2	8.8
	B5MLW	7.4	7.8	8.2	5.9	6.7	7.1	7.4
Strongylocentrotus droebachiensis	B19	1.8	1.9	2.0	1.3	1.4	1.5	1.7
	B31	1.8	1.9	2.0	2.1	2.1	2.6	3.1

[a]Preoperational = mean of annual means, 1982-1989. Annual mean is sum of lengths of all individuals collected in May, August, and November divided by the total number of individuals measured.
[b]Operational = mean of annual means, 1991-1993.
[c]Individuals measuring >25 mm were excluded.

means and their 95% confidence limits.

Asteriidae

Asteriidae (starfish) is another predatory taxon that can occur in the low intertidal zone, but are most abundant in the shallow subtidal. Although two genera of starfish occur in the Gulf of Maine, *Asterias* and *Leptasterias* (Gosner 1978), two species of the former, *Asterias forbesii* and *A. vulgaris* are the most common in this study. Predation by *Asterias* spp. on mussels can be locally intense, and this feeding activity is believed to have considerable influence on both intertidal and subtidal community structure (Menge 1979; Sebens 1985). Abundance patterns of Asteriidae in the Seabrook area were examined in detail in the shallow subtidal zone, where they were most abundant. Over the entire study period, Asteriidae densities have been highest at the nearfield shallow subtidal station (B17), with densities consistently approaching 600/m^2 during both preoperational and operational periods and during 1993 (Table 6-15). This may be due to higher densities of the prey taxon Mytilidae at that site. Densities have been more variable at the farfield station (B35) over the study periods; operational and 1993 means were approximately half the preoperational mean, resulting in a significant decrease in Asteriidae density for the operational period at this station, relative to preoperational years (Table 6-16). When examined with ANOVA (Table 6-16), this decreasing trend at the farfield station coupled with relative consistency at the nearfield station (Fig. 6-8), caused a significant Preop-Op X Station interaction.

The sizes of Asteriidae collected over the study period have been consistently small, and indicate that the vast majority of individuals collected were juveniles. A consistent relationship between Asteriidae sizes at nearfield and farfield stations has been observed; Asteriidae have generally been larger at the farfield station (B35; means ranging from approximately 6 to 7 mm), while means at nearfield station B17 are typically smaller (around 5 mm) (Table 6-17). For both stations, operational and preoperational means were similar, with overlapping 95% confidence limits.

Pontogeneia inermis

The amphipod *Pontogeneia inermis* is a numerically dominant macrofaunal species in benthic habitats in the Gulf of Maine, where it clings to submerged algae in the intertidal and subtidal zones to depths of more than 10 m, and can also occur in pelagic waters (Bousfield 1973). At Seabrook study sites, *P. inermis* was a dominant taxon at all subtidal stations, but occurred most consistently in the mid-depth zone. Historically, and during recent years including 1993, *P. inermis* densities have been higher at the nearfield station (B19) than at the farfield station (B31; Table 6-15). Mean densities at B19 have typically been higher during the operational period, and in particular during 1993, than during the preoperational period. The opposite trend was apparent at farfield station B31; the preoperational mean was higher than both 1993 and operational means. Based on ANOVA, these shifts in *P. inermis* densities at mid-depth stations during the operational period (i.e., increasing densities at the nearfield station, decreasing densities at the farfield station; Fig. 6-8) resulted in a significant Preop-Op X Station interaction (Table 6-16).

Pontogeneia inermis can reach lengths of up to 11 mm (Bousfield 1973); however, at Seabrook mid-depth stations, average lengths were approximately 5 mm (Table 6-17). Mean lengths at nearfield (B19) and farfield (B31) stations were similar to each other. Although a relatively high mean for 1993 was recorded at B19, preoperational and operational means were comparable, with overlapping 95% confidence limits. In 1993, moderate numbers of juveniles measuring 1-3 mm were collected in August at both mid-depth stations. In previous years, most juveniles were collected in May (NAI 1993). Historically, low numbers of reproductive females were collected from January through summer (NAI 1993); however, no reproductive females were collected in 1993 at either B19 or B31 (NAI 1994).

Jassa marmorata

The tube-building amphipod *Jassa marmorata* is a common member of the local fouling community. Populations of this species can dominate primary space on hard surfaces, often outcompeting encrusting species by forming a mat "complex" composed of numerous tubes made from sediment and detritus (Sebens 1985). Primarily a suspension feeder (Nair and Anger 1979), *J. marmorata* also preys on small crustaceans and ostracods (Bousfield 1973). In the Seabrook study area, *J. marmorata* is most abundant at shallow subtidal stations, where it is among the dominant taxa (Table 6-12). During preoperational and operational periods and 1993, *J. marmorata* mean densities (Table 6-15) were higher at the farfield shallow subtidal station (B35) than at the nearfield station (B17). Annual mean densities during 1993 were higher than preoperational means at both stations but most notably at B35, and consistent with the overall operational means. Based on ANOVA, operational densities of *J. marmorata* were significantly higher than preoperational densities, and because comparable increases during the operational period were observed at both nearfield and farfield stations, no significant Preop-Op X Station interaction was detected (Table 6-16).

Jassa marmorata can reach a maximum length of up to 9 mm (Bousfield 1973), and growth rate and molting frequency of this species is strongly related to temperature (Franz 1989). Lengths of *J. marmorata* in our study averaged approximately 4 mm, with mean lengths slightly higher at the nearfield station (B17) than at the farfield station (B35) over both periods and during 1993 (Table 6-17). Comparisons of preoperational and operational means revealed little between-period difference at either site. Individuals measuring 1-3 mm were numerous in subtidal samples in August and November 1993, consistent with previous years (NAI 1994). No reproductive females were collected in 1993 at either B17 or B35 (NAI 1994).

Ampithoe rubricata

Another amphipod occasionally common to benthic habitats in the Seabrook area is *Ampithoe rubricata*. This species is most abundant in the intertidal zone, building nests among fucoids and in mussel beds (Bousfield 1973). Occurrence and abundance patterns of *A. rubricata* have been unpredictable over the entire study period, with relatively high densities noted in some years, and absence or near-absence observed in other years. For example, *A. rubricata* was the dominant intertidal crustacean in 1982, but was rarely collected during the period 1984-89 (NAI 1991b). Because of this extended period of low abundance, overall preoperational mean densities for this species were low (Table 6-15). This trend of low abundance has continued through 1990 and all operational years, including 1993, at nearfield station B1MLW. However, a dramatic increase in *A. rubricata* abundance has occurred at the farfield station (B5MLW) during operational years, a trend which has continued through 1993. Continued low densities during operational years at B1MLW and continued high densities at B5MLW for that period, when examined with ANOVA, resulted in a significant Preop-Op X Station interaction (Table 6-16, Fig. 6-8).

Ampithoe rubricata can reach a maximum size of 20 mm (Bousfield 1973). During our studies, average lengths generally ranged from 7 to 8 mm (Table 6-17), with a variety of size classes observed. At nearfield station B1MLW, *A. rubricata* mean lengths have been fairly consistent over both periods and during 1993. *A. rubricata* have generally been smaller during the operational period, including 1993. This trend may be the result of high recruitment observed over recent years at B5MLW (i.e., more young individuals). Indeed, moderate numbers of individuals measuring 1-3 mm were observed in August at B5MLW, while no juveniles were collected at B1MLW in 1993 (NAI 1994). Ovigerous females have been rare over the study period, and none were collected during the operational period, including 1993 (NAI 1994).

Strongylocentrotus droebachiensis

The green sea urchin, *Strongylocentrotus droebachiensis*, is well documented as having considerable influence on low intertidal and subtidal community structure (Lubchenco 1980; Witman 1985; Novaczek and McLachlan 1986; Johnson and Mann 1988). Most common in the subtidal zone, grazing by locally dense aggregates of *S. droebachiensis* can effectively eliminate populations of foliose algae (Breen and Mann 1976; Witman 1985), preferentially *Laminaria saccharina* and *L. longicruris* (Larson et al. 1980; Mann et al. 1984). What remains after this severe grazing is a barren grounds of primarily crustose coralline algae. *S. droebachiensis* is susceptible to disease-induced local extinction, allowing foliose algae to recolonize denuded areas. Sea urchin abundance cycles and subsequent habitat modification have been linked to shifts in local lobster landings (Breen and Mann 1976); however, this relationship is still unclear and remains a source of controversy (Elner and Vadas 1990).

Sea urchins collected in destructive samples were small (Table 6-17), and not considered a dominant factor in structuring communities at any depth zone. Sea urchins were most abundant in the mid-depth zone (Table 6-15), with higher densities at the nearfield station (B19) than at the farfield station (B31). This relationship between stations was consistent over both periods and during 1993. Operational mean densities were remarkably similar to preoperational means at both stations; ANOVA results indicated no significant between-period difference, and no significant Preop-Op X Station interaction term (Table 6-16).

Most sea urchins collected were juveniles with average lengths generally around 2 mm during the preoperational period at both nearfield and farfield stations (Table 6-17). During the operational period and the 1993 sampling year, mean lengths at nearfield station B19 were smaller than the preoperational mean, while somewhat larger sea urchins were collected at the farfield station (B31) during the operational period than during preoperational years.

Densities of adult sea urchins were also estimated during subtidal transect sampling, and have been relatively low since sampling began in 1985 (Table 6-18). Annual mean densities during the preoperational period never exceeded $1.3/m^2$, and were typically $<0.5/m^2$. At shallow subtidal stations, operational and 1993 means were within the range of preoperational means for both nearfield and farfield stations (B17 and B35, respectively). Conversely, considerably higher densities have been recorded at both mid-depth stations during the operational period and, in particular, during 1993. In fact, the highest densities to date were observed in that depth zone in 1993, exceeding 6 urchins/m^2 at the farfield station (B31), and $1.3/m^2$ at the nearfield station (B19).

TABLE 6-18. MEAN DENSITIES (PER m^2) AND RANGE DURING PREOPERATIONAL (1985-1989) AND OPERATIONAL (1991-1993) PERIODS, AND DURING 1993 OF ADULT SEA URCHINS IN SUBTIDAL TRANSECTS. SEABROOK OPERATIONAL REPORT, 1993.

	PREOPERATIONAL		1993	OPERATIONAL	
STATION	MEAN	RANGE	MEAN	MEAN	RANGE
B17	0.20	0.00-1.30	0.01	0.02	0.01-0.05
B35	0.10	0.00-0.50	0.21	0.07	0.00-0.21
B19	0.09	0.02-0.20	1.36	0.71	0.01-1.36
B31	0.04	0.00-0.24	6.14	2.07	0.00-6.14
ALL STATIONS	0.11	0.00-1.30	1.93	0.72	0.00-6.14

Modiolus modiolus

Beds of the northern horse mussel *Modiolus modiolus* are often extensive in subtidal habitats in the Gulf of Maine, providing additional hard substratum for benthic algae (Sebens 1985), and sheltering a diverse group of invertebrates in spaces between individual mussels (Witman 1985; Ojeda and Dearborn 1989). Large sea stars (*Asterias* spp.) actively prey on *Modiolus*, while another common subtidal predator, the omnivorous sea urchin *Strongylocentrotus droebachiensis*, appears to choose foliose macroalgae over *Modiolus* (Briscoe and Sebens 1988). Urchin activity may actually enhance *Modiolus* abundance by grazing kelps off mussels and decreasing the risk of mussel dislodgement (Witman 1987).

Overall mean densities of *Modiolus* during the operational period and during 1993 were lower than mean densities for the preoperational period (Table 6-15), and the between-period (Preop-Op) difference was significant (Table 6-16). However, the relationship between *Modiolus* densities at nearfield (B19) and farfield (B31) stations (i.e., higher densities at B19 than those at B31) has remained consistent over both periods. Therefore, based on ANOVA results, no significant Preop-Op X Station interaction was detected (Table 6-16). Overall lower densities during the operational period may be due to removal by storms, similar and perhaps related to that previously discussed for kelps (Section 6.3.1.1).

6.4 CONCLUSIONS

6.4.1 Introduction

Thermal and hydrodynamic changes in physical conditions, created by operation of the Seabrook Station condenser cooling water system, could potentially impact the local hard-bottom macrobenthic communities in several ways. The most obvious type of impact is temperature-related community alteration, resulting from direct exposure to the discharge thermal plume. This type of impact could produce significant changes to nearby attached communities, depending on the proximity of these habitats to the discharge, and the hydrodynamic characteristics of the thermal plume itself. These changes are most likely to occur in surface and near surface waters, due to the buoyant nature of most thermal plumes. Such impacts are well-documented for intertidal and shallow subtidal communities during monitoring studies for coastal nuclear power plants elsewhere, and include elimination or reduced abundance of cold-water species, and increased abundance of warm-water tolerant and/or opportunistic species, leading to the development of communities distinct from those seen prior to thermal incursion and from those on nearby unaffected coasts (Vadas et al. 1976; Wilce et al. 1976; BECO 1994; NUSCO 1994).

Another less common impact resulting from coastal nuclear power plants is related more to altered water circulation patterns than to thermal incursion. Specifically, the introduction (discharge) of turbid water to an area of historically lower levels of turbidity can decrease light penetration and increase sedimentation rates. Sources of this turbidity include suspended inorganic and organic particles from higher energy areas, such as wave-swept shores (Osman et al. 1981; NUSCO 1988; Schroeter et al. 1993), and potentially, increased detrital deposition resulting from settlement of entrained organisms. Turbidity impacts would be most pronounced in areas where levels of water movement and physical disturbance are low, such as in deeper water. Turbidity effects detrimental to macrobenthic plants and animals include shading or burial, and an increased community dominance by suspension-feeding organisms and organisms more tolerant of higher sedimentation rates (Hiscock and Mitchell 1980; Schroeter et al. 1993).

Because the type of impact a community is vulnerable to appears to be related to its relative position in the water column (i.e., temperature effects for shallow water sites, turbidity effects at deeper water sites), potential impacts associated with construction and operation of Seabrook Station on communities in each of these depth zones will be examined separately and discussed below.

6.4.2 Evaluation of Potential Thermal Plume Effects on Intertidal/Shallow Subtidal Benthic Communities

6.4.2.1 Background

Nearfield sampling sites used for the Seabrook intertidal and shallow subtidal macrobenthos studies were selected because they occur within, and best represent, the shallow water communities that are most susceptible to incursion by the Seabrook Station discharge thermal plume. Hydrodynamic modeling, conducted prior to plant start-up to predict the areal extent of the thermal plume under various meteorological and current regimes, indicated that thermal incursion to these sites would be minimal, with temperature increases of <1°F (Teyssandier et al. 1974). Subsequent field studies, conducted after Seabrook began commercial operation, verified these predictions by measuring no temperature increases at the intertidal sampling site, and increases of <1°F at shallow subtidal site (Padmanabhan and Hecker 1991).

6.4.2.2 Intertidal Benthic Community

While several parameters used to evaluate certain aspects of benthic intertidal communities indicated significant differences between preoperational and operational periods, analyses of overall community structure showed that nearfield macroalgal and macrofaunal communities have changed little since Seabrook began operation (Table 6-19). For example, significant decreases during the operational period at the nearfield station were detected for total algal biomass, number of faunal taxa and total faunal density, and significant overall decrease in number of algal taxa was observed at both nearfield and farfield stations. However, numerical classification of macroalgal and macrofaunal data, an analysis technique that incorporates abundances of all

TABLE 6-19. SUMMARY OF EVALUATION OF POTENTIAL THERMAL PLUME EFFECTS ON BENTHIC COMMUNITIES IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	AREA/DEPTH ZONE	PARAMETER[a]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[b]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[c]
Macroalgae	Intertidal	No. of taxa	Op<Preop	Yes
		Total biomass	Op<Preop	NF: Op<Preop FF: Op=Preop
		Community structure	Yes	Yes
	Shallow subtidal	No. of taxa	Yes	Yes
		Total biomass	Yes	Yes
		Community structure	Yes	Yes
Macrofauna	Intertidal	No. of taxa	Op<Preop	NF: Op<Preop FF: Op=Preop
		Total density	Yes	NF: Op<Preop FF: Op=Preop
		Community structure	Yes	Yes
	Shallow subtidal	No. of taxa	Op>Preop	NF: Op>Preop FF: Op=Preop
		Total density	Op>Preop	Yes
		Community structure	Yes	Yes

[a]Abundance, no. of taxa, biomass, total density, evaluated using ANOVA; community structure evaluated using numerical classification by year and station.
[b]Operational period = 1990-1993 (August only).
[c]NF = nearfield; FF = farfield.

TABLE 6-20. SUMMARY OF EVALUATION OF POTENTIAL THERMAL PLUME EFFECTS ON REPRESENTATIVE IMPORTANT BENTHIC TAXA IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	AREA/DEPTH ZONE	SELECTED TAXON	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[a]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[b]
Macroalgae	Intertidal	*Chondrus crispus*	Op>Preop	Yes
	Shallow Subtidal	*Chondrus crispus*	Yes	Yes
	Shallow Subtidal	*Laminaria saccharina*	Yes	Yes
	Shallow Subtidal	*Laminaria digitata*	Op<Preop	NF: Op<Preop FF: Op=Preop
Macrofauna	Intertidal	*Ampithoe rubricata*	Yes	NF: Op<Preop FF: Op>Preop
	Intertidal	*Nucella lapillus*	Op<Preop	Yes
	Intertidal	Mytilidae	Op<Preop	Yes
	Shallow Subtidal	*Jassa marmorata*	Op>Preop	Yes
	Shallow Subtidal	Asteriidae	Op<Preop	NF: Op=Preop FF: Op<Preop
	Shallow Subtidal	Mytilidae	Yes	NF: Op=Preop FF: Op>Preop

[a]Conclusions derived from analysis of variance or nonparametric analysis for Preoperational versus Operational periods.
[b]NF = nearfield; FF = farfield.

important components of these communities, revealed that annual collections invariably clustcred by station or depth zone first, with no evidence of groupings by preoperational or operational period. This suggests that the important structuring mechanisms creating differences between stations and among years are most likely natural factors unrelated to power plant operation.

Patterns of abundance and occurrence of individual taxa in the intertidal zone were monitored in several ways. In high, mid and low intertidal quadrats, frequency of occurrence of dominant taxa, including barnacles, snails, mussels, fucoids and *Chondrus crispus*, generally remained consistent over both preoperational and operational periods (Tables 6-7 and 6-13). Some changes during operational years were observed in fucoid abundances at nearfield fixed transect sites (e.g., increased dominance by *Ascophyllum nodosum*, decreased abundance of *Fucus vesiculosus*) However, since *A. nodosum* is reportedly less tolerant of temperature increases than is *F. vesiculosus* (Vadas et al. 1976; NUSCO 1994), this change is most likely a natural successional shift, and not a power plant impact.

Destructive sampling allowed more detailed monitoring of abundance patterns of selected dominant intertidal taxa. More rigorous statistical tests (i.e., ANOVA) could be applied to these data to examine differences between preoperational and operational periods and among stations. These analyses indicated that, of the four taxa studied, only one (the amphipod *Ampithoe rubricata*) had significant changes in the relationship between nearfield and farfield stations during the operational period (Table 6-20). For all other selected taxa (*Chondrus crispus*, *Nucella lapillus* and Mytilidae), significantly lower abundances were recorded dunng the operational period; however, this trend occurred at both nearfield and farfield stations for all three of these taxa, indicating area-wide shifts unrelated to power plant operation.

Operational period shifts in abundance of *Ampithoe rubricata*, relative to the preoperational abundance, were not consistent between stations (significant decrease at the nearfield station; significant increase at the farfield station). However, examination of annual abundances revealed that these shifts began before power plant start-up. Once a dominant at intertidal stations prior to 1986, *A. rubricata* disappeared from both stations until recolonization was observed in 1988 at the farfield station (NAI 1989). Abundances at the farfield station have continued to increase through 1993, but no recolonization has occurred at the nearfield station since 1986. Temporally patchy abundances of *A. rubricata* have been typical of the entire study period, suggesting that highly unpredictable environmental/climatic processes, and not power plant impacts, may have produced local extinction and subsequent recolonization.

6.4.2.3 Shallow Subtidal Benthic Community

Community parameters used to evaluate shallow subtidal benthic communities indicated that, in most cases, no changes have occurred that could be related to power plant operation (Table 6-19). Only a significant change in number of faunal taxa was detected (increase during the operational period at the nearfield station, no change at the farfield station). Numerical classification of macroalgal and macrofaunal data revealed no substantive changes in species composition and overall community structure at shallow subtidal stations, with clusters determined by station and/or depth zone, rather than by preoperational and operational periods.

Specific analyses on abundances of selected important taxa in the shallow subtidal zone (ANOVA) revealed consistent relationships between nearfield and farfield stations over both preoperational and operational periods (i.e., no impact) for three of six selected taxa (*Chondrus crispus*, *Laminaria saccharina* and *Jassa marmorata*; Table 6-20). Of the remaining three selected taxa, two exhibited significant preoperational to operational period shifts only at the farfield station (Asteriidae decreased during the operational period, Mytilidae increased during that period). These trends may be related; since Asteriidae prey almost exclusively on mussels (Menge 1979; Sebens 1985), reductions of starfish at the farfield site during the operational period may have enhanced the local mussel population. Regardless of this possible relationship, this shift was observed only at the farfield station, and therefore, was not attributable to power plant operation.

A significant reduction in abundance of *Laminaria digitata* was observed at the nearfield station during the operational period, while farfield abundance levels remained relatively consistent. This decline at the nearfield station actually began prior to power plant start-up (1989). A similar decline in *L. digitata* abundance was also observed at both mid-depth stations (Table 6-6), indicating an area-wide shift in abundance likely related to the susceptibility of this species to removal by storms (Kitching 1937), such as Hurricane Bob in 1991, and subsequent natural factors affecting the degree of recolonization, such as increased abundance of sea urchins noted in recent years in both nearfield and farfield study areas.

6.4.3 Evaluation of Potential Turbidity Effects on the Mid-Depth/Deep Benthic Communities

6.4.3.1 Background

Nearfield mid-depth and deep study sites represent macrobenthic communities in closest proximity to the Seabrook Station discharge. However, due to their position in the water column relative to the thermal plume (depths 9-21 m), temperature effects at these sites are unlikely. Higher sedimentation rates resulting from increased levels of suspended particles in discharge waters relative to the surrounding waters could potentially impact nearfield deeper water benthic communities. Higher sedimentation rates (and impacts to nearby macrobenthic communities) associated with a thermal effluent have been documented for a nuclear power plant in California (Osman et al. 1981; Schroeter et al. 1993), with the major source of turbidity being fine inorganic sediments transported from inshore waters where intakes for the plant were located. The organic component of these sediments contributed little to the overall flux of sediments, and no indications of organic enrichment were observed at sites near the discharge. The Seabrook intake is located well offshore and draws in relatively low turbidity water, similar to that near the discharge. Therefore, transport of fine inorganic particles is unlikely and any increase in sedimentation would be the result of settlement of organic material from entrained organisms. However, plankton densities are also lower in deeper offshore waters near the intake structure, compared to those in more productive inshore waters, thereby reducing the likelihood of any organic loading to benthic habitats near the discharge.

6.4.3.2 Mid-Depth Benthic Community

All assessments of community parameters and overall community structure indicated no changes to the nearfield mid-depth community during Seabrook operational years (Table 6-21). Significant decreases in both measures of community abundance (total algal biomass and total faunal density) were observed at the mid-depth intake station during the

TABLE 6-21. SUMMARY OF EVALUATION OF POTENTIAL TURBIDITY EFFECTS ON BENTHIC COMMUNITIES IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	AREA/DEPTH ZONE	PARAMETER[a]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[b]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[c]
Macroalgae	Mid-depth	No. of taxa	Yes	Yes
		Total biomass	Op<Preop	Discharge, FF: Op=Preop Intake: Op<Preop
		Community structure	Yes	Yes
	Deep	No. of taxa	Yes	Yes
		Total biomass	Op<Preop	Yes
		Community structure	Yes	Yes
Macrofauna	Mid-depth	No. of taxa	Op>Preop	Yes
		Total density	Yes	Discharge, FF: Op=Preop Intake: Op<Preop
		Community structure	Yes	Yes
	Deep	No. of taxa	Yes	Yes
		Total density	Yes	Discharge, FF: Op=Preop Intake: Op>Preop
		Community structure	Yes	Yes

[a]Abundance, no. of taxa, biomass, and total density evaluated using ANOVA; community structure evaluated using numerical classification by year and station.
[b]Operational period = 1990-1993 (August only).
[c]NF = nearfield; FF = farfield.

TABLE 6-22. SUMMARY OF EVALUATION OF POTENTIAL TURBIDITY EFFECTS ON REPRESENTATIVE IMPORTANT BENTHIC TAXA IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	AREA/DEPTH ZONE	SELECTED TAXON	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[a]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[b]
Macroalgae	Mid-depth	*Laminaria digitata*	Op<Preop	Yes
		Laminaria saccharina	Yes	Yes
Macrofauna	Mid-depth	*Pontogeneia inermis*	Yes	NF: Op=Preop FF: Op<Preop
		Modiolus modiolus	Op<Preop	Yes
		Mytilidae	Op>Preop	NF: Op>Preop FF: Op=Preop
		Strongylocentrotus droebachensis	Yes	Yes

[a]Conclusions derived from ANOVA or nonparametric analysis for Preoperational versus Operational periods.
[b]NF = nearfield; FF = farfield.

operational years, while consistent levels for both parameters were observed at nearfield and farfield sites over the entire study period. We have no explanation for these shifts at the intake station; however, because impacts associated with intakes are greatly minimized by locating these structures well above the bottom, we feel these changes were not related to power plant operation. Numerical classification characterized overall algal and faunal community structure at mid-depth sites, and revealed high similarity of annual collections within depth zone, and no evidence of separate groupings based on operational and preoperational periods. In other words, no substantive changes in community composition have occurred at any mid-depth site since Seabrook began commercial operation.

Detailed analyses of selected mid-depth benthic taxa abundance patterns are summarized in Table 6-22. Four of the six selected taxa showed no significant changes over the operational period that would indicate a power plant impact. Two of these taxa (*Laminaria digitata* and *Modiolus modiolus*, often found attached to each other) exhibited area-wide decreases during the operational period, which may be related to the susceptibility of these species to removal by storms (Kitching 1937; Witman 1987). Another kelp, *Laminaria saccharina* exhibited consistent patterns of occurrence over both periods, as did the green sea urchin *Strongylocentrotus droebachiensis*. Record high densities of adult sea urchins were found in both nearfield and farfield transect areas in 1993, perhaps indicating area-wide movement of this species into the Seabrook area. Such mass migration has been observed previously at the nearby Isles of Shoals (Witman 1985).

Two other species exhibited significant changes in patterns of abundance during the operational period. A significant decrease in abundance of the amphipod *Pontogeneia inermis* was detected during the operational period, but only at the farfield station. Nearfield abundances of *P. inermis* were comparable over both periods. Mytilids were significantly more abundant during the operational period at the nearfield station, while no significant between-period change was observed at the farfield station. The high operational mean at the nearfield station is, in large part, due to exceptionally high mytilid densities during a single operational year (1993), when conditions for recruitment at this station were apparently near-optimal, but unlikely related to power plant operation.

6.4.3.3 Deep Benthic Community

Measurement of various aspects of deep water macrobenthic communities (numbers of algal and faunal taxa, total algal biomass and total faunal density) and assessment of overall community structure (through numerical classification) revealed that nearfield and farfield communities have remained remarkably stable over both preoperational and operational periods (Table 6-21). The only significant between-period shift at deep water stations occurred at the intake station, where an increase in total faunal density was observed during the operational period. Overall, deep water macrobenthic communities in the Seabrook area appear unaffected by power plant operation.

6.4.4 Overall Effect of Seabrook Operation on the Local Marine Macrobenthos

These extensive monitoring studies have documented that balanced indigenous macrobenthic communities continue to occupy intertidal and subtidal rocky habitats in the vicinity of the Seabrook discharge, with little change beyond that expected from natural variability. While some changes have been detected over the operational period, most were either part of an area-wide trend (occurring at both nearfield and farfield stations), part of an historical trend that began prior to commercial operation of Seabrook, or restricted to a site (intake) where little potential for impacts exists. There is no evidence to suggest that thermal impacts or impacts associated with increased organic loading on the local macrobenthos have occurred since the start-up of Seabrook Station in 1990.

6.5 REFERENCES CITED

Abbott, R.T. 1974. American seashells. 2nd ed., Van Nostrand Reinhold, New York.

BECO (Boston Edison Company). 1994. Benthic Algal Monitoring at the Pilgrim Nuclear Power Station. Pages 1-23 *in* Marine ecology studies related to operation of Pilgrim Station. Semi-Ann. Rep. No. 43.

Bertness, M.D. 1989. Intraspecific competition and facilitation in a northern acorn barnacle population. Ecology 70:257-268.

Bloom, S.A. 1980. A package of computer programs for benthic community analyses. Univ. Florida.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Environmental Protection Agency, Ecological Research Report Agency, Ecol. Res. Rep. 114 pp.

Bousfield, E.L. 1973. Shallow water gammaridean Amphipoda of New England. Comstock Pub., Ithaca, NY. 312 pp.

Breen, P.A., and K.H. Mann. 1976. Changing lobster abundance and destruction of kelp beds by sea urchins. Mar. Biol. 34:137-142.

Briscoe, C.S., and K.P. Sebens. 1988. Omnivory in *Strongylocentrotus droebachiensis* (Müller) (Echinodermata: Echinoidea): predation on subtidal mussels. J. Exp. Mar. Biol. Ecol. 115:1-24.

Chapman, A.R.O. 1973. A critique of prevailing attitudes towards to control of seaweed zonation on the sea shore. Bot. Mar. 16:80-82.

Connell, J.H. 1961. Effects of competition, predation by *Thais lapillus*, and other factors on natural populations of the barnacle *Balanus balanoides*. Ecol. Monogr. 31:61-104.

Cubit, J.D. 1984. Herbivory and the seasonal abundance of algae on a high intertidal rocky shore. Ecology 65:1904-1917.

Dayton, P.K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. 41:351-389.

Elner, R.W., and R. L. Vadas. 1990. Inference in ecology: the sea urchin phenomenon in the northwestern Atlantic. Am. Nat. 136:108-125.

Franz, D.R. 1989. Population density and demography of a fouling community amphipod. J. Exp. Mar. Biol. Ecol. 125:117-136.

Fuller, J.L. 1946. Season of attachment and growth of sedentary marine organisms at Lamoine, Maine. Ecology 27:150-158.

Gaines, S., and J. Roughgarden. 1985. Larval settlement rate: a leading determinant of structure in an ecological community of the marine intertidal zone. Proc. Natl. Acad. Sci. USA

82:3707-3711.

Geiselman, J.A., and O.J. McConnell. 1981. Polyphenols in brown algae *Fucus vesiculosus* and *Ascophyllum nodosum*: chemical defenses against the marine herbivorous snail, *Littorina littorea*. J. Chem. Ecol. 7:1115-1133.

Gosner, K.L. 1978. A Field Guide to the Atlantic seashore. Houghton Mifflin Co., Boston. 329 pp.

Grant, W.S. 1977. High intertidal community organization on a rocky intertidal headland in Maine, USA. Mar. Biol. 44:15-25.

Hiscock, K., and R. Mitchell. 1980. The description and classification of sublittoral epibenthic ecosystems. Pages 323-370 *in* J.H. Price, D.E.G. Irvine and W.F. Farnham (eds.) The Shore Environment, Vol. 2: Ecosystems. Academic Press, London and New York. 945 pp.

Johnson, C.R., and K.H. Mann. 1988. Diversity, patterns of adaptation, and stability of Nova Scotian kelp beds. Ecol. Monogr. 58:129-154.

Keser, M., and B.R. Larson. 1984. Colonization and growth dynamics of three species of *Fucus*. Mar. Ecol. Prog. Ser. 15:125-134.

Kitching, J.A. 1937. Studies in sublittoral ecology II. Recolonization at the upper margin of the sublittoral region; with a note on the denudation of *Laminaria* forests by storms. J. Ecol. 25:482-495.

Larson, B.R., R.L. Vadas, and M. Keser. 1980. Feeding and nutrition ecology of the green sea urchin, *Strongylocentrotus droebachiensis* in Maine, U.S.A. Mar. Biol. 59:49-62.

Lewis, J.R. 1964. The Ecology of Rocky Shores. English Univ. Press, London. 323 pp.

Lubchenco, J. 1980. Algal zonation in the New England rocky intertidal community: an experimental analysis. Ecology 61:333-344.

__________. 1983. *Littorina* and *Fucus*: effects of herbivores, substratum heterogeneity, and plant escapes during succession. Ecology 64:1116-1123.

Lubchenco, J., and B.A. Menge. 1978. Community development and persistence in a low rocky intertidal zone. Ecol. Monogr. 48:67-94.

Mann, K.H. 1973. Seaweeds: their productivity and strategy for growth. Science 182:975-981.

Mann, K.H., L.C. Wright, B.E. Welsford, and E. Hatfield. 1984. Responses of the sea urchin *Strongylocentrotus droebachiensis* (O.F. Muller) to waterborne stimuli from potential predators and potential food algae. J. Exp. Mar. Biol. Ecol. 79:233-244.

Mathieson, A.C., E.J. Hehre, and N.B. Reynolds. 1981. Investigations of New England marine algae. II: The species composition, distribution and zonation of seaweeds in the Great Bay estuary system and the adjacent open coast of New Hampshire. Bot. Mar. 24:533-545.

Mathieson, A.C., and E.J. Hehre. 1986. A synopsis of New Hampshire seaweeds. Rhodora 88:1-139.

Mathieson, A.C., and J.S. Prince. 1973. Ecology of *Chondrus crispus* Stackhouse. Pages 53-79 *in* M.J. Harvey and J. MacLachlan (eds.) *Chondrus crispus*. Nova Scotian Inst. Sci., Halifax.

Menge, B.A. 1976. Organization of the New England rocky intertidal community: role of predation, competition, and environmental heterogeneity. Ecol. Monogr. 46:355-393.

_________. 1979. Coexistence between the seastars *Asterias vulgaris* and *A. forbesii* in a heterogeneous environment: a non-equilibrium explanation. Oecologia 41:245-272.

_________. 1983. Components of predation intensity in the low zone of the New England rocky intertidal region. Oecologia 58:141-155.

_________. 1991. Relative importance of recruitment and other causes of variation in rocky intertidal community structure. J. Exp. Mar. Biol. Ecol. 146:69-100.

Minchinton, T.E., and R.E. Scheibling. 1991. The influence of larval supply and settlement on the population structure of barnacles. Ecology 72:1867-1879.

NAI (Normandeau Associates, Inc.). 1989. Seabrook Environmental Studies. 1988. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1988. A preoperational study for Seabrook Station. Tech. Rep. XX-II.

_________. 1991a. Seabrook Environmental Studies. 1990 Data Report. Tech. Rep. XXII-I.

_________. 1991b. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

_________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

_________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-I

_________. 1994. Seabrook Environmental Studies. 1993 Data. Unpublished Data Tables.

Nair, K.K.C., and K. Anger. 1979. Experimental studies on the life cycle of *Jassa falcata* (Crustacea, Amphipoda). Helgo. Wiss. Meeres. 37:444-452.

Novaczek, I., and J. McLachlan. 1986. Recolonization by algae of the sublittoral habitat of Halifax County, Nova Scotia, following the demise of sea urchins. Bot. Mar. 29:69-73.

NUSCO (Northeast Utilities Service Company). 1988. Benthic Infauna. Pages 58-117 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Three-unit operational studies 1986-1987.

_________. 1992. Rocky Intertidal Studies. Pages 237-292 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Ann. Rep., 1991.

_________. 1994. Rocky Intertidal Studies. Pages 51-79 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Ann. Rep., 1993.

Ojeda, F.P., and J.H. Dearborn. 1989. Community structure of macroinvertebrates inhabiting the rocky subtidal zone in the Gulf of Maine: seasonal and bathymetric distribution. Mar. Ecol.

Prog. Ser. 57:147-161.

__________. 1991. Feeding ecology of benthic mobile predators: experimental analyses of their influence in rocky subtidal communities of the Gulf of Maine. J. Exp. Mar. Biol. Ecol. 149:13-44.

Osman, R.W. 1977. The establishment and development of a marine epifaunal community. Ecol. Monogr. 47:37-63.

Osman, R.W., R.W. Day, J.A. Haugsness, J. Deacon, and C. Mann. 1981. The effects of the San Onofre Nuclear Generating Station on sessile invertebrate communities inhabiting hard substrata (including experimental panels). Hard Benthos Project, Marine Science Institute, University of California, Santa Barbara. Final Rep., 223 pp.

Padmanabhan, M., and G.E. Hecker. 1991. Comparative evaluation of hydraulic model and field thermal plume data, Seabrook Nuclear Power Station. Alden Research Laboratory, Inc. 12 pp.

Petraitis, P.S. 1983. Grazing patterns of the periwinkle and their effect on sessile intertidal organism. Ecology 64:522-533.

Petraitis, P.S. 1991. Recruitment of the mussel *Mytilus edulis* L. on sheltered and exposed shores in Maine, USA. J. Exp. Mar. Biol. Ecol. 147:65-80

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 edition. SAS Inst., Inc., Cary, N.C. 956 pp.

Schneider, C.W. 1981. The effect of elevated temperature and reactor shutdown on the benthic marine flora of the Millstone thermal quarry, Connecticut. J. Therm. Biol. 6:1-6.

Schoener, A. 1974. Experimental zoogeography: colonization of marine mini-islands. Am. Nat. 108:715-738.

Schonbeck, M.W., and T.A. Norton. 1978. Factors controlling the upper limits of fucoid algae on the shore. J. Exp. Mar. Biol. Ecol. 31:303-313.

Schroeter, S.C., J.D. Dixon, J Kastendiek, and R.O. Smith. 1993. Detecting the ecological effects of environmental impacts: a case study of kelp forest invertebrates. Ecol. Appl. 3:331-350.

Sebens, K.P. 1985. The ecology of the rocky subtidal zone. Am. Sci. 73:548-557.

__________. 1986 Community ecology of vertical walls in the Gulf of Maine. USA: small scale processes and alternative community states. Pages 346-371 *in* P.G. Moore and R. Seed (eds.). The Ecology of Rocky Coasts. Columbia Univ. Press, New York.

Seed, R. 1976. Ecology. Pages 13-65 *in* B.L. Bayne (ed.), Marine Mussels: Their Ecology and Physiology. Cambridge Univ. Press, Cambridge.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. 775 pp.

Stephenson, T.A., and A. Stephenson. 1949. The universal features of zonation between tidemarks on rocky coasts. J. Ecol. 38:289-305.

Sutherland, J.P., and R.H. Karlson. 1977. Development of stability of the fouling community at Beaufort, North Carolina. Ecol. Monogr. 47:425-446.

Taylor, W.R. 1957. Marine algae of the northeastern coast of North America. University of Michigan Press, Ann Arbor. 509 pp.

Teyssandier, R.G., W.W. Durgin, and G.E. Hecker. 1974. Hydrothermal studies of diffuser discharge in the coastal environment: Seabrook Station. Alden Research Laboratory Rep. No. 86-124.

Topinka, J., L. Tucker, and W. Korjeff. 1981. The distribution of fucoid macroalgal biomass along the central coast of Maine. Bot. Mar. 24:311-319.

Underwood, A.J., and E.J. Denley. 1984. Paradigms, explanations and generalizations in models for the structure of intertidal communities of rocky shores. Pages 151-180 *in* D.R. Strong, Jr., D. Simberloff, L.G. Abele and A.B. Thistle (eds.), Ecological Communities: Conceptual Issues and the Evidence. Princeton Univ. Press, Princeton N.J.

Vadas, R.L., M. Keser, and P.C. Rusanowski. 1976. Influence of thermal loading on the ecology of intertidal algae. Pages 202-251 *in* G.W. Ecsh and R.W. MacFarlane (eds.) Thermal Ecology II. ERDA Symp. Ser., Augusta GA.

Wilce, R.T., J. Foertch, W. Grocki, J. Kilar, H. Levine, and J. Wilce. 1978. Flora: Marine Algal Studies. Pages 307-656 *in* Benthic Studies in the Vicinity of Pilgrim Nuclear Power Station, 1969-1977. Sum. Rep. Boston Edison Co.

Witman, J.D. 1985. Refuges, biological disturbance, and rocky subtidal community structure in New England. Ecol. Monogr. 55:421-445.

__________. 1987. Subtidal coexistence: storms, grazing, mutualism, and the zonation of kelps and mussels. Ecol. Monogr. 55:421-445.

Zobell, C.E., and E.C. Allen. 1935. The significance of marine bacteria in fouling of submerged surfaces. J. Bacter. 29:239-251.

APPENDIX TABLE 6-1. NOMENCLATURAL AUTHORITIES FOR MACROFAUNAL TAXA CITED IN THE MARINE MACROBENTHOS SECTION. SEABROOK OPERATIONAL REPORT, 1993.

- Mollusca
  - Polyplacophora
    - *Tonicella rubra* (Linnaeus 1767)
  - Gastropoda
    - *Lacuna vincta* (Montagu 1803)
    - *Littorina littorea* (Linnaeus 1758)
    - *Littorina obtusata* (Linnaeus 1758)
    - *Littorina saxatilis* (Olivi 1792)
    - *Nucella lapillus* (Linnaeus 1758)
  - Bivalvia
    - Mytilidae
    - *Musculus niger* (J.E. Gray 1824)
    - *Modiolus modiolus* (Linnaeus 1758)
    - *Anomia* sp.
    - *Turtonia minuta* (Fabricius 1780)
    - *Hiatella* sp.
- Annelida
  - Polychaeta
    - *Thelepus cincinnatus* (Fabricius 1780)
  - Oligochaeta
- Arthropoda
  - Pantopoda
    - *Achelia spinosa* (Stimpson 1853)
  - Crustacea
    - *Balanus* sp.
    - *Balanus crenatus* Bruguiere 1789
    - *Idotea balthica* (Pallas 1772)
    - *Idotea phosphorea* Harger 1873
    - *Jaera marina* (Fabricius 1780)
    - *Ampithoe rubricata* (Montagu 1808)
    - *Gammarus oceanicus* Segerstråle 1947
    - *Jassa marmorata* (Holme 1903)
    - *Pontogeneia inermis* Krøyer 1842
    - *Caprella* sp.
    - *Caprella septentrionalis* Krøyer 1838
- Echinodermata
  - Echiniodea
    - *Strongylocentrotus droebachiensis* (Müller 1776)
  - Stelleriodea
    - Asteridae

APPENDIX TABLE 6-2. THE OCCURRENCE OF MACROALGAE FROM TRIANNUAL GENERAL COLLECTIONS AND DESTRUCTIVE SAMPLING AT ALL SUBTIDAL AND INTERTIDAL DESTRUCTIVE STATIONS, 1978-1993.**
SEABROOK OPERATIONAL REPORT, 1993.

CHLOROPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
BLIDINGIA MINIMA (Naeg. ex Keutz.) Kylin	X		X	X	X	X	X	X	X							
BRYOPSIS PLUMOSA (Hudson) Agardh							X								X	X
CHAETOMORPHA BRACHYGONA Harvey	X				X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA LINUM (O.F. Muell.) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA MELAGONIUM (F. Weber et Mohr) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA PICQUOTIANA Mont. ex Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA SP.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CLADOPHORA REFRACTA (Roth) Kuetz.														X		X
CLADOPHORA SERICEA (Hudson) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ENTEROMORPHA COMPRESSA (L.) Grev.													X			
ENTEROMORPHA INTESTINALIS (L.) Link		X		X	X	X		X					X			
ENTEROMORPHA LINZA (L.) J. Agardh	X	X		X	X	X	X	X								
ENTEROMORPHA PROLIFERA (O.F. Muell.) J. Agardh		X	X		X	X	X	X		X		X				
ENTEROMORPHA SP.				X			X		X	X	X					
MONOSTROMA FUSCUM (Postels et Rupr.)					X	X	X	X	X							
MONOSTROMA GREVILLEI (Thuret) Wittr.	X	X		X	X	X	X	X	X	X	X	X	X	X		X
MONOSTROMA PULCHRUM Farlow	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
MONOSTROMA SP.																X
PSEUDENDOCLONIUM SUBMARINUA Wille					X											
RHIZOCLONIUM TORTUOSUM (Dillwyn) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SPONGOMORPHA ARCTA (Dillwyn) Kuetz.	X	X		X	X	X	X		X			X		X	X	
SPONGOMORPHA SP.	X															
SPONGOMORPHA SPINESCENS Kuetz.	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
ULOTHRIX FLACCA (Dillwyn) Thuret				X							X					
ULOTHRIX SP.																X
ULVA LACTUCA L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ULVARIA OBSCURA V. BLYTTII (Aresch.) Bliding	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
ULVARIA OXYSPERMA (Kuetz.) Bliding	X	X	X		X					X						
UROSPORA PENICILLIFORMIS (Roth) Aresch.						X	X			X				X		X
UROSPORA WORMSKJOLDII (Mert.) Rosenv.						X										

**Stations B1MLW, M1MSL (general collection only), B17, B19, B31 sampled 1979-1993;
B5MLW, B5MSL (general collection only), B35 sampled 1982-1993;
B16 sampled 1980-1984 and 1986-1993;
B13, B04 sampled 1978-1984 and 1986-1993;
B34 sampled 1979-1984 and 1986-1993.
Stations B04, B13, B16, B34 sampled in August only.

APPENDIX TABLE 6-2. THE OCCURRENCE OF MACROALGAE FROM GENERAL COLLECTIONS AND DESTRUCTIVE SAMPLING AT ALL SUBTIDAL AND INTERTIDAL DESTRUCTIVE STATIONS, 1978-1993. SEABROOK OPERATIONAL REPORT, 1993.

PHAEOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
AGARUM CRIBROSUM (Mert.) Bory	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ALARIA ESCULENTA (L.) Grenville	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ASCOPHYLLUM NODOSUM (L.) LeJolis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHORDARIA FLAGELLIFORMIS (Muell.) Agardh	X	X	X	X	X	X				X	X	X		X	X	X
DESMARESTIA ACULEATA (L.) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DESMARESTIA VIRIDIS (Muell.) Lamouroux	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
ECTOCARPUS FASCICULATUS Harvey					X	X	X	X	X	X	X			X	X	X
ECTOCARPUS SILICULOSUS (Dillwyn) Lyngbye	X		X	X	X	X	X		X	X	X	X	X	X	X	X
ECTOCARPUS SP.												X	X			
ELACHISTA FUCICOLA (Velley) Aresch.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS DISTICHUS SSP. DISTICHUS*	X	X	X				X					X	X	X	X	X
FUCUS DISTICHUS SSP. EDENTATUS (Bach. Pyl.) Powell	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS DISTICHUS SSP. EVANESCENS Agardh			X		X	X	X	X	X	X		X	X	X		X
FUCUS SP.	X	X		X		X			X	X	X	X	X	X	X	X
FUCUS VESICULOSUS L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS VESICULOSUS V. SPIRALIS L.						X							X			
GIFFORDIA GRANULOSA (Sm.) Hamel						X	X									
ISTHMOPLEA SPHAEROPHORA (Carm. ex Harv.) Kjell.												X	X			
LAMINARIA DIGITATA (Hudson) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LAMINARIA SACCHARINA L. Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LAMINARIA SP.			X		X		X		X		X					
LAMINARIOCOLAX TOMENTOSOIDES (Farlow) Kylin															X	
LEATHESIA DIFFORMIS (L.) Aresch.	X	X		X	X	X	X	X	X		X	X	X	X		
PETALONIA FASCIA (Muell.) O. Kuntze	X	X		X		X	X	X	X	X	X	X	X	X	X	X
PETALONIA ZOSTERIFOLIA (Reinke) O. Kuntze									X							
PETRODERMA MACULIFORME (Wollny) Kuck.							X									
PILAYELLA LITTORALIS Kjellman	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PSEUDOLITHODERMA EXTENSUM (P.Crou. et H.Crou.) S.Lund										X						
SACCORHIZA DERMATODEA (Bach. Pyl.) J. Agardh	X			X												
SCYTOSIPHON LOMENTARIA (Lyngbye) Link	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
SORAPION KJELLMANNI (Wille) Rosensv.								X								
SPHACELARIA CIRROSA (Roth) Agardh		X		X	X	X	X	X	X		X		X			
SPHACELARIA PLUMOSA Lyngbye							X	X		X		X				
SPHACELARIA RADICANS (Dillwyn) Agardh						X	X	X								
SPONGONEMA TOMENTOSUM Kuetzing			X	X		X	X	X	X	X		X	X	X	X	X

*name in question

6-71

APPENDIX TABLE 6-2. THE OCCURRENCE OF MACROALGAE FROM GENERAL COLLECTIONS AND DESTRUCTIVE SAMPLING AT ALL SUBTIDAL AND INTERTIDAL DESTRUCTIVE STATIONS, 1978-1993. SEABROOK OPERATIONAL REPORT, 1993.

RHODOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
ACROCHAETIUM FLEXUOSUM*					X	X	X									
ACROCHAETIUM SP.	X	X		X												
AHNFELTIA PLICATA (Hudson) Fries	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ANTITHAMNIONELLA FLOCCOSA (Muell.) Whitt.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AUDOUINELLA DAVIESII (Dillwyn) Woelk.														X		
AUDOUINELLA MEMBRANACEA (Magnus) Papenf.															X	X
AUDOUINELLA PURPUREA (Lightf.) Woelk.							X		X	X						
AUDOUINELLA SP.												X				
BANGIA ATROPURPUREA (Roth) Agardh						X	X									X
BONNEMAISONIA HAMIFERA Hariot	X	X			X				X	X	X	X	X	X	X	X
CALLITHAMNION SP.			X													
CALLITHAMNION TETRAGONUM (With.) S.F. Gray		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CALLOPHYLLIS CRISTATA (Agardh) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CERAMIUM DESLONGCHAMPII Chauvin					X	X										
CERAMIUM RUBRUM (Hudson) Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CERATOCOLAX HARTZII Rosenv.	X	X	X	X	X	X	X	X	X							
CHONDRIA BAILEYANA (Mont.) Harvey	X															
CHONDRUS CRISPUS Stackhouse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHOREOCOLAX POLYSIPHONIAE Reinsch					X	X	X		X	X	X	X	X		X	
CLATHROMORPHUM CIRCUMSCRIPTUM (Stroemf.) Foslie	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
CLATHROMORPHUM COMPACTUM (Kjellm.) Foslie				X								X			X	
COLACONEMA SECUNDATA*	X	X	X													
CORALLINA OFFICINALIS L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CYSTOCLONIUM PURPUREUM (Hudson) Batters	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DERMATOLITHON PUSTULATUM (Lamour.) Foslie	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DEVALERAEA RAMENTACEUM (L.) Guiry						X	X	X		X		X				
DUMONTIA CONTORTA (S. Gmelin) Rupr.				X		X	X	X	X	X	X	X	X	X	X	X
ERYTHROTRICHIA CARNEA (Dillwyn) Agardh	X	X			X	X										
FIMBRIFOLIUM DICHOTOMUM (Lepechin) G. Hansen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FOSLIELLA FARINOSA (Lamour.) Howe	X															
FOSLIELLA LEJOLISII*	X	X	X	X	X	X	X	X	X	X		X				
GIGARTINALES					X											
GLOIOSIPHONIA CAPILLARIS (Hudson) Carmich. ex Berk.						X	X									
GYMNOGONGRUS CRENULATUS (Turner) J. Agardh	X		X	X	X	X	X	X	X	X	X		X	X	X	X
HILDENBRANDIA RUBRA (Sommerf.) Mengh			X			X	X		X	X	X					
LEPTOPHYTUM FOECUNDUM (Kjellman) Adey	X	X		X	X	X	X		X	X		X	X	X	X	
LEPTOPHYTUM LAEVE (Stroemf.) Adey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LEPTOPHYTUM SP.														X		
LITHOPHYLLUM CORALLINAE (Crouan frat.) Heydr.	X					X										
LITHOTHAMNION GLACIALE Kjellman	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MASTOCARPUS STELLATUS (Stack.) Guiry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MEMBRANOPTERA ALATA (Hudson) Stackhouse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

*name in question

(continued)

APPENDIX TABLE 6-2. (Continued)

RHODOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
PALMARIA PALMATA (L.) O. Kuntze	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PEYSSONNELIA ROSENVINGII Schmitz	X	X	X	X	X	X	X	X	X	X	X	X			X	
PHYCODRYS RUBENS (L.) Batters	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA PSEUDOCERANOIDES (S. Gnelin) Newr.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA SP.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA TRAILLII Holmes ex Batters.								X	X							
PHYLLOPHORA TRUNCATA (Pallas) A. Zin.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYMATOLITHON LAEVIGATUM (Foslie) Foslie			X		X	X	X	X	X	X	X	X	X	X	X	X
PHYMATOLITHON LENORMANDII (Aresch.) Adey	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYMATOLITHON RUGULOSUM Adey		X		X	X		X	X				X	X	X	X	X
PLUMARIA ELEGANS (Bonhem.) Schmitz			X		X	X	X	X	X	X		X				
POLYIDES ROTUNDUS (Hudson) Greville	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA DENUDATA (Dillwyn) Grev. ex Harvey										X						
POLYSIPHONIA FLEXICAULIS (Harvey) F. Collins	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA HARVEYI J. Bailey						X	X	X	X	X	X	X		X		
POLYSIPHONIA LANOSA (L.) Tandy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA NIGRA (Hudson) Batters			X		X	X	X		X		X			X		X
POLYSIPHONIA NIGRESCENS (Hudson) Grev.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA SP.			X													
POLYSIPHONIA URCEOLATA (Lightf. ex Dillwyn) Grev.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORPHYRA LEUCOSTICTA Thuret	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORPHYRA LINEARIS Greville														X		
PORPHYRA MINIATA (Agardh) Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORPHYRA SP.												X	X	X	X	X
PORPHYRA UMBILICALIS (L.) J. Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PTILOTA SERRATA Keutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RHODOMELA CONFERVOIDES (Hudson) Silva	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RHODOPHYSEMA ELEGANS (P. Cruan et H. Cruan) P. Dixon		X			X		X	X		X	X					
SCAGELIA CORALLINA (Rupr.) Hansen*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TURNERELLA PENNYI (Harvey) Schmitz		X		X												

*name in question

TABLE OF CONTENTS

SUMMARY

The fouling community settling and developing on surface panels has shown predictable seasonal patterns throughout the study. Most measures of community structure (biomass, abundance, number of taxa) and abundances and frequencies of individual taxa showed significant differences among years, a reflection of year to year variability in recruitment. Measures that indicate fouling community settlement (on panels exposed for one month) and development (on panels exposed for increasing time periods, 1-12 months) showed significant differences between preoperational and operational periods that were consistent between nearfield and farfield stations, suggesting area wide trends. Some parameters measured on the year end fouling community (panels exposed for one year) indicated changes during the operational period that were not consistent between nearfield and farfield areas. This observation is complicated by the weather-related loss of panels at the nearfield station in 1992, reducing the number of observations during the operational period. These parameters will continue to be monitored closely.

LIST OF FIGURES

LIST OF TABLES

7.0 SURFACE PANELS

7.1 INTRODUCTION

The surface fouling panels program was designed to study both settlement patterns and community development in the discharge plume area and in corresponding farfield areas. The program is based on the hypothesis that the balanced indigenous fouling community should not be adversely influenced due to exposure to the thermal plume. Short-term panels, submerged for one month, provide information on the temporal sequence of settlement activity, while monthly sequential panels, exposed from one to twelve months, provide information on species growth and patterns of community development.

7.2 METHODS

7.2.1 Field Methods

Fouling panels (10.2 cm x 10.2 cm roughened plexiglass plates) were collected monthly from January through December at two mid-depth stations (nearfield B19, depth 12.2 m and farfield B31, depth 9.4 m) and two deep stations (nearfield B04, depth 18.9 m and farfield B34, depth 21 m; Figure 7-1). The designations mid-depth and deep stations are based on the surface to bottom depth in relation to more shallow stations sampled for other programs in this study (i.e., benthos, macroalgae). Panel depths below the water surface ranged from 3 to 6 m depending on the tidal stage. Collections were made at Stations B04, B19 and B31 from 1978 to 1984, at Station B34 from 1982 to 1984, and at all stations (B04, B19, B31 and B34) from July 1986 through 1993.

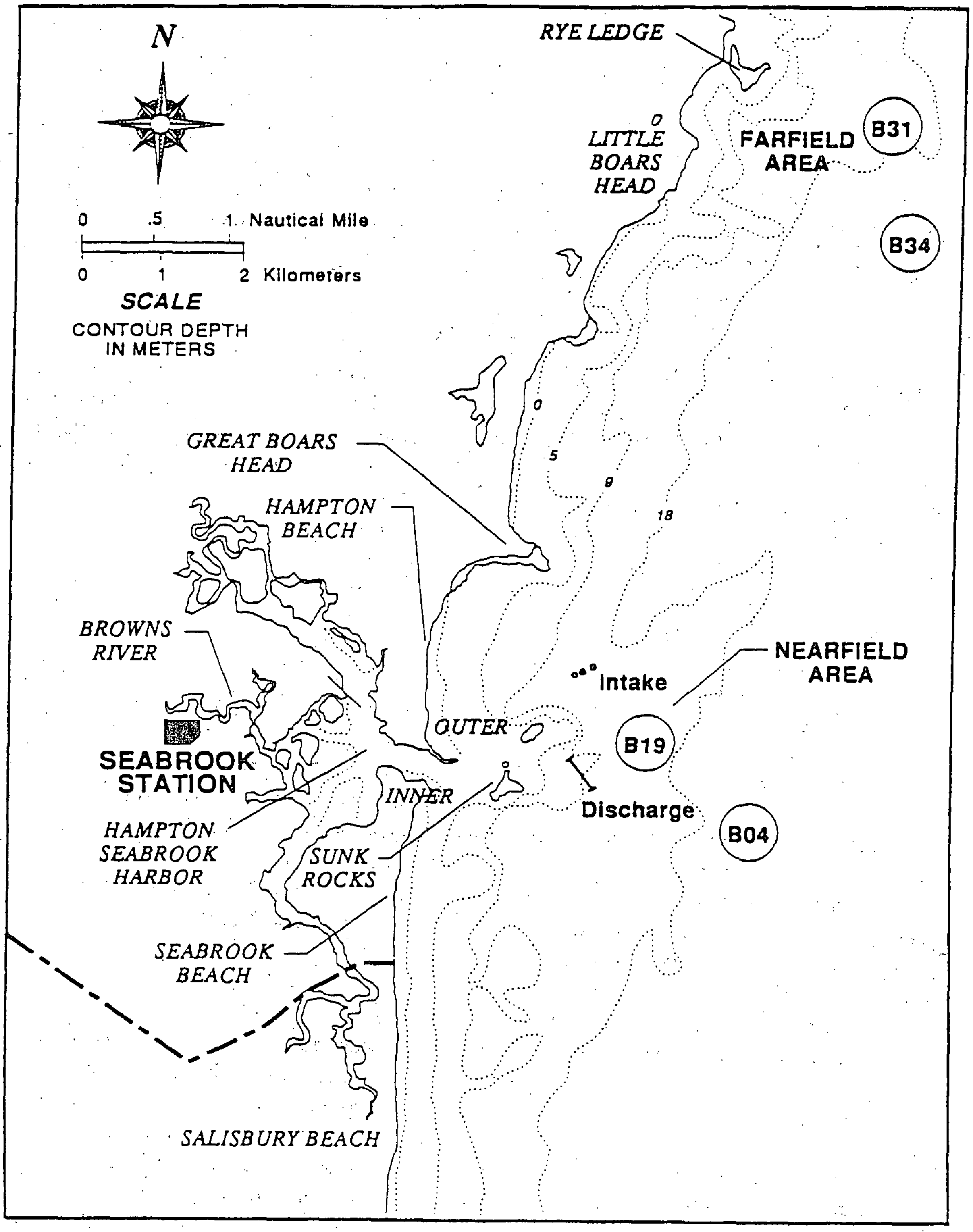
Two different panel types were employed at each station: short-term (ST) panels, exposed for one month, and monthly sequential (MS) panels, exposed for increasing time periods from 1-12 months. Two replicate short-term panels and one monthly sequential panel were collected monthly at each of the four stations. In December, an additional MS panel was collected at each station.

7.2.2 Laboratory Methods

In the laboratory, each panel was dismantled and the panel face photographed. The fouling material was scraped off the wood block and panel support apparatus, and rinsed over a 0.25 mm mesh sieve prior to storage or processing. The wood blocks from all MS panels were dried, split, and examined for the presence of wood-boring organisms.

All noncolonial species collected monthly on both ST replicates and one December MS replicate were identified and enumerated. When high abundances of Mytilidae, *Hiatella* sp. and *Anomia* sp. occurred, organisms were enumerated from subsamples generated using a Folsom plankton splitter (NAI 1990). Colonial animals, diatoms and macroalgae on ST panels were quantified by determining the percent frequency of occurrence on the panel face (Mueller-Dombois and Ellenberg 1974; Rastetter and Cooke 1979; NAI 1990). Colonial animals, diatoms, and macroalgal species were recorded as "P" (present, but not quantified) when found in the sample, but not directly on the panel face. For MS panels, the percent frequency of occurrence of selected dominants (colonial and noncolonial), and diatom and macroalgal species were estimated using the procedure cited above. Counts were estimated for noncolonial species and an abundance class was recorded. Abundance classes, assigned 1 through 5, consist of ranges of numbers of individuals (1-10, 11-100, ..., >10,000). Colonial and noncolonial dominants, diatoms, and macroalgae were recorded as "P" (present, but not quantified) when found in the sample, but not directly on the panel face.

Random samples of ≥200 Mytilidae and ≥100 *Jassa marmorata* Holmes 1903 individuals found on MS panels and in the residue were measured and recorded



LEGEND

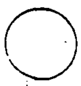

= surface panels

Figure 7-1. Surface panel sampling stations. Seabrook Operational Report, 1993.

in 0.1 mm increments (NAI 1990). All *J. marmorata* and Mytilidae individuals less than 1.0 mm were recorded as <1.0 mm and estimated at 0.5 mm in calculations of mean lengths.

Dry-weight biomass from one of each pair of ST replicates and all MS panels was determined after taxonomic processing by drying all faunal and floral material to a constant weight at 105°C.

7.2.3 Analytical Methods

Analysis of Variance

Recruitment on ST panels, measured by the number of all taxa, the abundance of noncolonial organisms, and biomass, indicated the potential for fouling community development. Monthly biomass levels on MS panels give an indication of observed community development. Multiway analyses of variance (variables Preop-Op, Year, Station and Month) were used to compare fouling community settlement potential (as exemplified by species richness, abundance, biomass and selected dominant species) as well as community development (biomass) between preoperational (generally 1978-1984 and 1986-1989) and operational (1991-1993) years at paired nearfield (B19, B04) and farfield (B31, B34) stations. Log (x+1) transformed monthly mean values were used in the ANOVAs for short-term noncolonial total abundance and all selected species abundances (*Jassa marmorata* and Mytilidae), or frequency of occurrence (*Tubularia* sp.). ANOVA models treated all variables as fixed and were more conservative (more likely to detect significant differences) than alternate models that treated some sources of variation such as YEAR as random variables. Non-transformed monthly mean values were used in the multiway analyses of variance for short-term and monthly sequential biomass and short-term number of taxa. A significant difference in the interaction (Preop-Op X Station) was investigated by comparing the least square means with a paired *t*-test (SAS 1985).

t Test

Community development was also assessed by examining biomass, species richness, and abundance on surface panels exposed for one year. A comparison was made between preoperational (generally 1982-1984 and 1986-1989) and operational (1991-1993) periods at each station using paired *t* tests (SAS 1985). Selected dominant species (Mytilidae and *Jassa marmorata*) lengths were also compared using paired *t* tests to determine if average annual lengths varied between nearfield and farfield station pairs in 1993.

7.3 RESULTS

7.3.1 Short-Term Panels

Short-term panels provided information on the seasonal cycles of settlement activity. Seasonal cycles in faunal richness in 1993 and during the operational period were similar to the preoperational trend. In 1993, as in the preoperational years, the number of taxa increased during May and June and remained high through September at both B19 and B04 (Figure 7-2). The average number of taxa during the operational period was higher than the preoperational average at all four stations (Table 7-1). In addition, ANOVA results indicate the operational period was significantly greater than the preoperational period for both sets of nearfield-farfield station pairs, indicating an area-wide pattern (Preop-Op term; Table 7-2). Significant differences were also noted among months and years.

The seasonal pattern of faunal abundance at mid-depth Stations B19 and B31 and deep Stations B04 and B34 during the operational years was similar to that of preoperational years. Historically, abundances remained low from January to May, increased in June and July, then declined from August to December (Figure 7-2). During 1993, the monthly abundances remained high in summer, with a slightly bimodal pattern, declining in the fall. Total mean abundance

TABLE 7-1. MEANS (PER PANEL) AND COEFFICIENT OF VARIATION (%) FOR SELECTED PARAMETERS AND SPECIES ABUNDANCES AT STATIONS B19, B31, B04, AND B34 OVER THE PREOPERATIONAL AND OPERATIONAL PERIODS (1991-1993), AND 1993 MEANS. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER/ TAXON	PANEL[a] TYPE	STATION	PREOPERATIONAL[b] $\overline{x}^c$	PREOPERATIONAL[b] CV	1993 $\overline{x}^c$	OPERATIONAL $\overline{x}^c$	OPERATIONAL CV
Total no. of taxa	ST	B19	11.3	30.4	11.3	13.6	15.0
		B31	10.8	25.2	12.1	12.7	4.4
		B04	10.2	32.9	11.3	12.1	9.5
		B34	11.7	18.7	10.6	12.2	16.2
Total noncolonial abundance	ST	B19	42.3	20.5	134.4	69.2	16.0
		B31	53.9	20.5	153.3	61.5	19.8
		B04	27.6	21.1	84.9	40.6	22.1
		B34	38.4	20.6	63.8	38.6	26.0
Total biomass (g)	ST	B19	0.8	40.8	0.3	0.6	66.7
		B31	0.6	67.5	0.5	0.4	44.4
		B04	0.6	47.8	0.4	0.5	83.0
		B34	1.0	46.7	0.5	0.5	70.4
Mytilidae	ST	B19	30.4	22.6	91.7	37.3	26.2
		B31	39.6	21.1	111.0	31.2	32.9
		B04	19.3	20.7	58.4	21.5	35.9
		B34	21.6	28.0	38.9	16.9	4.2
Jassa marmorata	ST	B19	3.0	29.0	2.3	2.1	9.7
		B31	3.9	30.4	6.3	2.9	45.6
		B04	2.3	43.1	2.0	1.3	72.8
		B34	2.2	23.2	1.9	1.7	56.4
Tubularia spp.	ST	B19	1.9	51.2	2.1	1.7	11.2
		B31	1.1	73.6	0.3	0.3	76.8
		B04	1.5	59.1	0.7	1.0	55.6
		B34	2.6	51.2	0.5	0.6	103.4
Biomass (g)	MS	B19	207.8	106.6	327.3	225.6	55.3
		B31	236.8	90.0	314.2	225.3	34.6
		B04	203.1	118.4	252.4	177.4	41.9
		B34	199.6	78.8	344.7	263.9	31.9

[a]ST = short term MS = monthly sequential
[b]Preoperational = 1978-1984; Jul 1986-Dec 1989 except B34, which was first sampled in 1982
[c]Geometric mean for total abundance, and Mytilidae and *J. marmorata* abundance
Percent frequency of occurrence for *Tubularia* sp. Preop. and Op. means are means of annual means.

TABLE 7-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING MONTHLY TOTAL NUMBER OF TAXA, NONCOLONIAL FAUNAL ABUNDANCE, TOTAL BIOMASS, AND SELECTED SPECIES ABUNDANCE OR PERCENT FREQUENCY ON SHORT TERM PANELS AT MID-DEPTH (B19, B31) AND DEEP (B04, B34) STATION PAIRS DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1993) PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER	STATIONS	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISONS[g] (ranked in decreasing order)
Total number of taxa	B19, B31	Preop-Op[a]	1	260.50	39.73***	Op>Preop
		Year (Preop-Op)[b]	12	164.30	25.06***	
		Month (Year)[c]	147	76.16	11.62***	
		Station[d]	1	23.32	3.56 NS	
		Preop-Op X Station[e]	1	2.92	0.45 NS	
		Error	156	6.56		
	B04, B34	Preop-Op	1	223.10	36.45***	Op>Preop
		Year (Preop-Op)	12	112.33	18.35***	
		Month (Year)	147	55.39	9.05***	
		Station	1	0.31	0.05 NS	
		Preop-Op X Station	1	1.78	0.29 NS	
		Error	112	6.12		
Noncolonial faunal abundance	B19, B31	Preop-Op	1	1.10	12.88**	Op>Preop
		Year (Preop-Op)	12	2.43	28.58***	
		Month (Year)	147	2.02	23.74***	
		Station	1	0.05	0.64 NS	
		Preop-Op X Station	1	0.32	3.76 NS	
		Error	156	0.09		
	B04, B34	Preop-Op	1	0.98	12.20***	Op>Preop
		Year (Preop-Op)	12	1.78	22.18***	
		Month (Year)	147	1.57	19.55***	
		Station	1	0.00	0.02 NS	
		Preop-Op X Station	1	0.01	0.17 NS	
		Error	112	0.08		

(continued)

TABLE 7-2. (Continued)

PARAMETER	STATIONS	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISONS[g] (ranked in decreasing order)
Biomass	B19, B31	Preop-Op	1	4.26	4.77*	Op<Preop
		Year (Preop-Op)	10	1.85	2.07*	
		Month (Year)	125	2.39	2.68***	
		Station	1	2.02	2.27 NS	
		Preop-Op X Station	1	0.00	0.00 NS	
		Error	134	0.89		
	B04, B34	Preop-Op	1	6.46	9.76**	Op<Preop
		Year (Preop-Op)	10	2.54	3.84***	
		Month (Year)	125	4.01	6.06***	
		Station	1	1.76	2.66 NS	
		Preop-Op X Station	1	2.08	3.14 NS	
		Error	112	0.66		
Mytilidae	B19, B31	Preop-Op	1	0.00	0.02 NS	
		Year (Preop-Op)	12	2.64	23.93***	Pre Op Op Pre
		Month (Year)	147	2.59	23.51***	B31 B19 B31 B19
		Station	1	0.02	0.19 NS	
		Preop-Op X Station	1	0.51	4.59*	
		Error	156	0.11		
	B04, B34	Preop-Op	1		0.22 NS	
		Year (Preop-Op)	12	2.10	23.80***	
		Month (Year)	147	1.88	21.34***	
		Station	1	0.08	0.96 NS	
		Preop-Op X Station	1	0.17	1.87 NS	
		Error	11	0.09		

(continued)

TABLE 7-2. (Continued)

PARAMETER	STATIONS	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISONS[g] (ranked in decreasing order)
Jassa marmorata	B19, B31	Preop-Op	1	0.56	6.11*	Op<Preop
		Year (Preop-Op)	12	0.63	6.90***	
		Month (Year)	147	0.68	7.42***	
		Station	1	0.46	4.96*	B31>B19
		Preop-Op X Station	1	0.00	0.04 NS	
		Error	156	0.09		
	B04, B34	Preop-Op	1	0.49	4.42*	Op<Preop
		Year (Preop-Op)	12	0.66	5.96***	
		Month (Year)	147	0.46	4.16***	
		Station	1	0.01	0.06 NS	
		Preop-Op X Station	1	0.22	1.96 NS	
		Error	112	0.11		
Tubularia sp.	B19, B31	Preop-Op	1	0.75	4.84*	Op<Preop
		Year (Preop-Op)	12	0.79	5.11***	
		Month (Year)	147	0.65	4.22***	
		Station	1	2.76	17.90***	B19>B31
		Preop-Op X Station	1	0.49	3.19 NS	
		Error	156	0.15		
	B04, B34	Preop-Op	1	1.22	14.71***	Op<Preop
		Year (Preop-Op)	12	1.02	12.27***	
		Month (Year)	147	0.68	8.28***	
		Station	1	0.08	1.01 NS	
		Preop-Op X Station	1	0.13	1.55 NS	
		Error	112	0.08		

[a]Preop-Op = 1991-1993 v. previous years (1978-84; July 1986-December 1989 except B34, which began in 1982) regardless of station
[b]Year nested within preoperational and operational periods regardless of station
[c]Month nested within year regardless of station
[d]Station regardless of year or period
[e]Interaction between main effects Station and Preop-Op
[f]NS = Not significant ($p \geq 0.05$)
  * = Significant ($0.05 \geq p > 0.01$)
  ** = Highly significant ($.01 \geq p > 0.001$)
  *** = Very highly significant ($0.001 \geq p$)
[g]Underlining indicates no significant differences ($\alpha \leq 0.05$) in least square means using a paired t test.

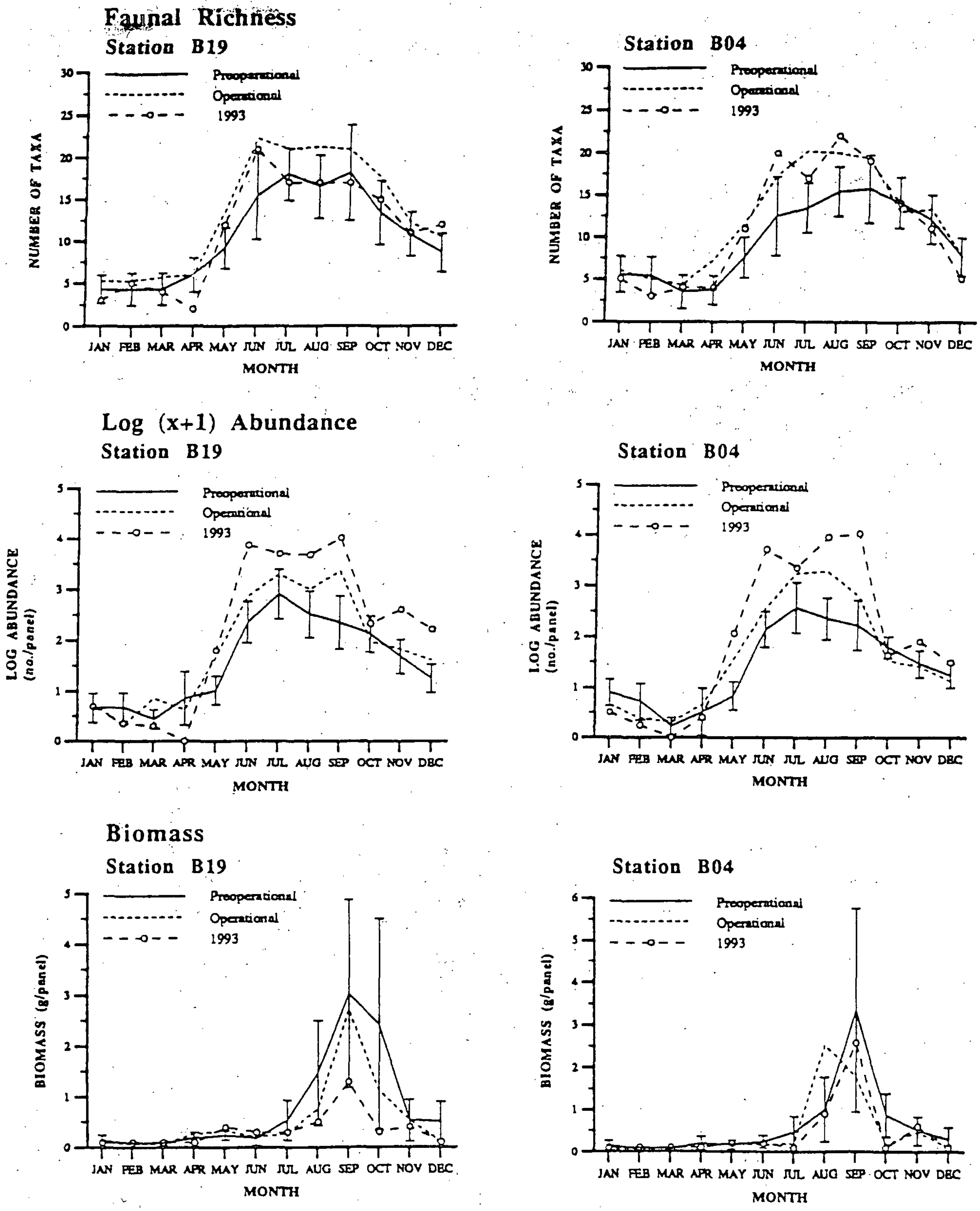


Figure 7-2. Monthly faunal richness (number of faunal taxa on two replicate panels), abundance, and biomass on short-term panels at nearfield Stations B19 and B04. The operational period (1991-1993) and 1993 compared to the means and 95% confidence limits during the preoperational period (1978-1984 and July 1986-December 1989). Seabrook Operational Report, 1993.

at all four stations during 1993 exceeded all previous operational years (NAI 1992a, 1993, Table 7-1), contributing to the highly significant differences in annual mean faunal abundances between the operational and preoperational periods for both sets of station pairs based on ANOVA results (Table 7-2). However, there were no significant differences between the nearfield/farfield stations for both station pairs, and the interaction of the main effects was not significant (Preop-Op X Station). Significant differences were also noted among years and months.

Seasonal settling patterns for the entire fouling community (motile fauna, colonial organisms, macroalgae) were best demonstrated by changes in biomass. The 1993 seasonal trend for biomass at station B19 followed a pattern similar to the preoperational and operational periods. Seasonal trends were characterized by a significant difference among months (Table 7-2). Biomass was low during 1993 with a small late summer peak (Figure 7-2) coincident with increased numbers of bivalves [Mytilidae (Figure 7-3), *Anomia* sp. and *Hiatella* sp. (NAI 1994)] and high percent cover of *Tubularia* sp. (Figure 7-3). Biomass levels in 1991 at B19 were not significantly different from preoperational levels (NAI 1992b); however, biomass levels at Station B19 declined in both 1992 and 1993 (NAI 1993) resulting in a significant difference between operational and preoperational years (Op < Preop; Table 7-2). Biomass at Station B19 was not significantly different from its farfield counterpart B31 (Table 7-2, NAI 1993). Additionally, the interaction of the main effects was not significant.

The 1993 seasonal biomass pattern at B04 was similar to the preoperational trend. Biomass levels were consistently low throughout the year with the exception of a late summer (September) increase (Figure 7-2). Peak biomass during the operational period, however, occurred in August, approximately one month earlier than during the preoperational period. This difference is the result of atypical seasonal biomass patterns occurring during the two previous operational years, beginning with the extreme August peak in 1991 followed by 1992 when biomass levels were low throughout the year and did not display a marked seasonal increase (NAI 1992b, 1993). ANOVA results indicated that although the biomass levels at both Stations B04 and B34 were significantly lower during the operational period than in preoperational years, the levels were not significantly different between the nearfield-farfield station pairs (Preop-Op X Station; Table 7-2).

Several dominant taxa on short-term panels were monitored to determine their long-term recruitment patterns. Historically, Mytilidae (mainly *Mytilus edulis* Linné 1758 spat) was the most abundant noncolonial taxon. Seasonally, the recruitment pattern for Mytilidae during 1993 closely followed the operational and preoperational seasonal trends at both stations. Low to moderate settlement occurred throughout the year, but was most intense from June through September (Figure 7-3), coincident with larval availability (Section 4.0). In 1993, the June-September period of increased abundance was bimodal at both Stations B19 and B04 with the peaks occurring in June and September. The 1993 summer abundances at both stations were higher than the operational and preoperational averages from June through September. ANOVA results for the mid-depth stations indicated that there were no significant differences in abundance between stations or between the operational and preoperational periods (Table 7-2). For the mid-depth station pair (B19/B31), the interaction term was significant. The two stations displayed opposite trends. Abundance increased at nearfield Station B19 and decreased at farfield Station B31 between the preoperational and operational periods (Figure 7-4). At the deep stations there were no significant differences in abundance between the operational and preoperational periods nor between the nearfield and farfield station pairs. The interaction of the main effects was not significant. Significant differences were noted between months and years for both station pairs (Tables 7-1,2).

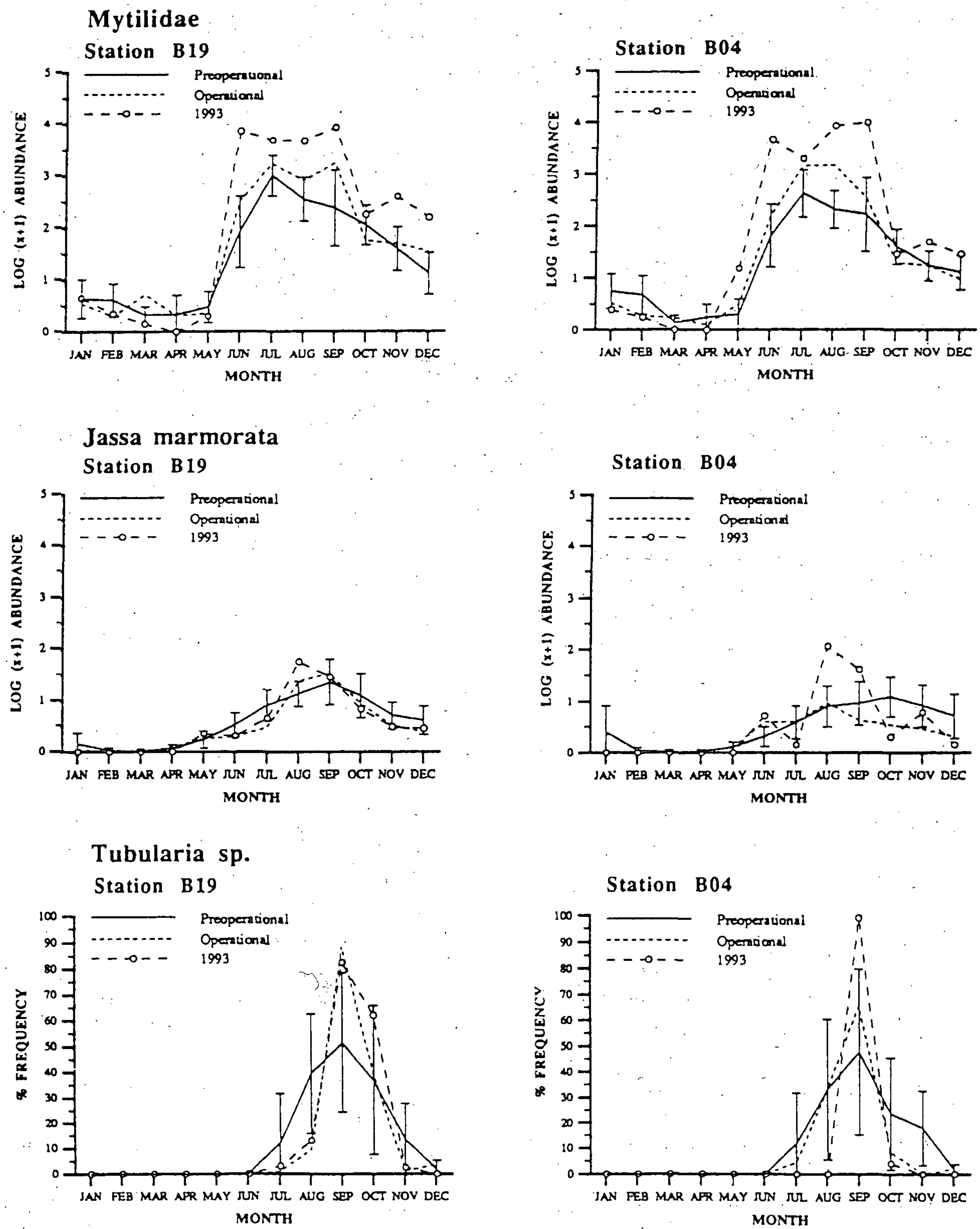


Figure 7-3. Log abundance (no. per panel) of **Mytilidae**, and monthly mean percent frequency of ***Jassa marmorata***, and ***Tubularia*** sp. on short-term panels at nearfield Stations B19 and B04. The operational period (1991-1993) and compared to the mean abundance or percent frequency and 95% confidence limits during the preoperational period (1982-1984 and July 1986-December 1989). Seabrook Operational Report, 1993.

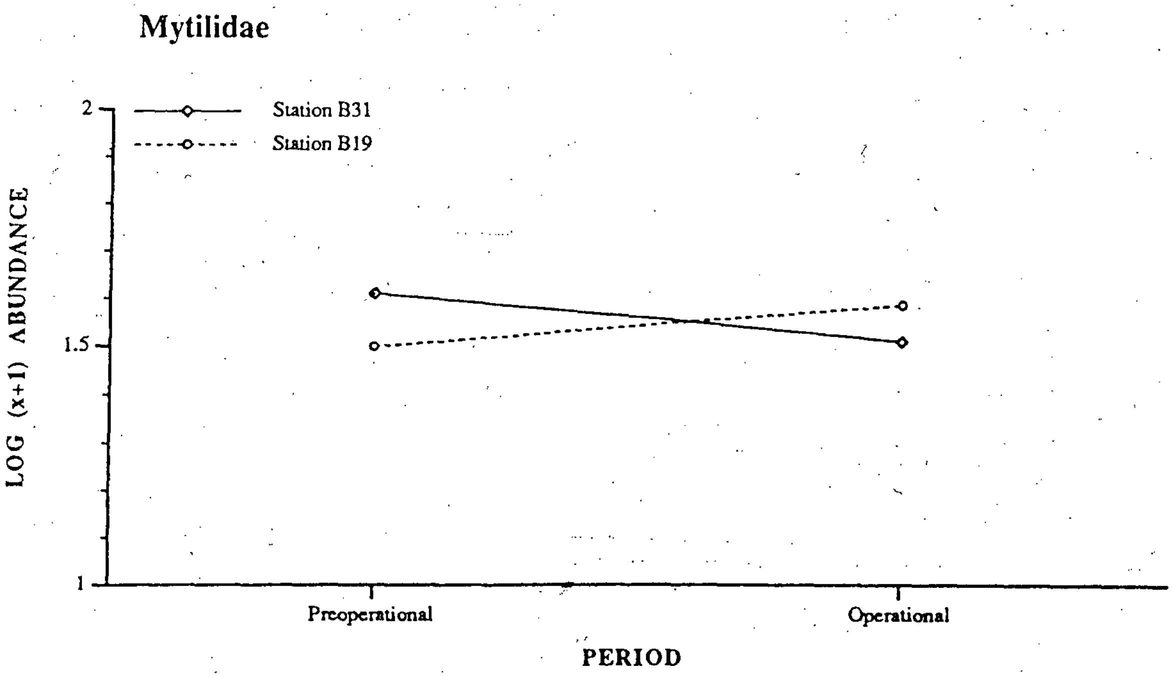


Figure 7-4. A comparison of the Log (x+1) abundance of Mytilidae on short-term panels at the nearfield/farfield mid-depth station pair (B19/B31) during the preoperational (1978-1984, 1986-1989) and operational (1991-1993) periods when the interaction term (Preop-op X Station) of the ANOVA model was significant (Table 7-2). Seabrook Operational Report, 1993.

The amphipod *Jassa marmorata* (formerly known as *J. falcata* and revised by Conlan 1990) is a common fouling organism (Barnard 1957). This species lacks a larval stage, so recruitment occurs through dispersal of juveniles or adults through the water column (Bousfield 1973). In 1993 at B19, *J. marmorata* abundances were low throughout the year with a small late summer increase, which closely follows the established seasonal pattern for operational and preoperational periods (Figure 7-3). There was slightly more monthly variability in 1993 at station B04, but essentially the established seasonal pattern was followed. ANOVA results indicated densities at all four stations were significantly lower during the operational period compared to the preoperational period. *J. marmorata* abundances were not significantly different between the nearfield and farfield deep stations, but at the mid-depth stations, B19 was significantly lower than the farfield counterpart B31. The interaction of the main effects for both station pairs was not significant. Significant differences were noted among years and months (Tables 7-1,2).

The hydroid *Tubularia* sp. is a dense summer colonizer. It is important because of its voluminous growth habits, which can provide a substrate (Field 1982) and food source (Clark 1975) for epifaunal taxa. In previous years, *Tubularia* sp. reached peak cover between July and September (NAI 1992b). At Stations B19 and B04, the peak percent cover occurred in September during 1993 and was coincident with the preoperational peaks (Figure 7-3). Although the 1993 September peak frequencies at both stations were greater than the preoperational means, the overall annual means were similar (Table 7-1). The operational mean percent frequency was significantly lower than the preoperational mean at all four stations. Frequencies at mid-depth Station B31 were significantly lower than B19, but there was no significant difference between the nearfield-farfield deep station pair B04/B34. The interaction of the main effects for both station pairs was not significant. Significant differences were noted among years and months (Table 7-2).

7.3.2 Monthly Sequential Panels

Monthly sequential panels provide information on growth and successional patterns of development within the fouling community. Seasonal patterns of community development were assessed by examining the monthly biomass levels. At Station B19, the 1993 biomass levels remained low through June, but the increase, beginning in July, reached an initial high point in October, declined in November and reached the yearly peak in December (Figure 7-5). The seasonal pattern of monthly means in 1993 was similar to preoperational years at Station B04 (Figure 7-5). Historically, biomass levels remained low through June, then increased steadily, peaking in October. Seasonal variability was underscored by a significant difference among months at both station pairs. At the mid-depth stations, average biomass during the operational period was significantly greater than the preoperational average with no significant difference between nearfield and farfield stations (Table 7-3). There was no significant difference between operational and preoperational means at the deep stations. However, biomass at the farfield Station B34 was significantly greater than at nearfield B04 (Table 7-3). The interaction of the main effects was not significant for either station pair.

Seasonal patterns of abundance of the community dominants in 1993 were similar to those observed during the preoperational period in most cases. Mytilidae spat settled heavily on panels in June at both nearfield stations, one month earlier than usual (Figure 7-5). Frequency of occurrence in 1993 generally remained at 100% from June through December at both B19 and B04, continuing a trend which began during the preoperational period (NAI 1988, 1990, 1991b, 1992b, 1993). Mytilidae frequencies at both nearfield stations during the operational period and 1993 were greater than the preoperational average from June through December.

Mytilidae spat measurements from monthly sequential panels in 1993 were compared to determine if mean

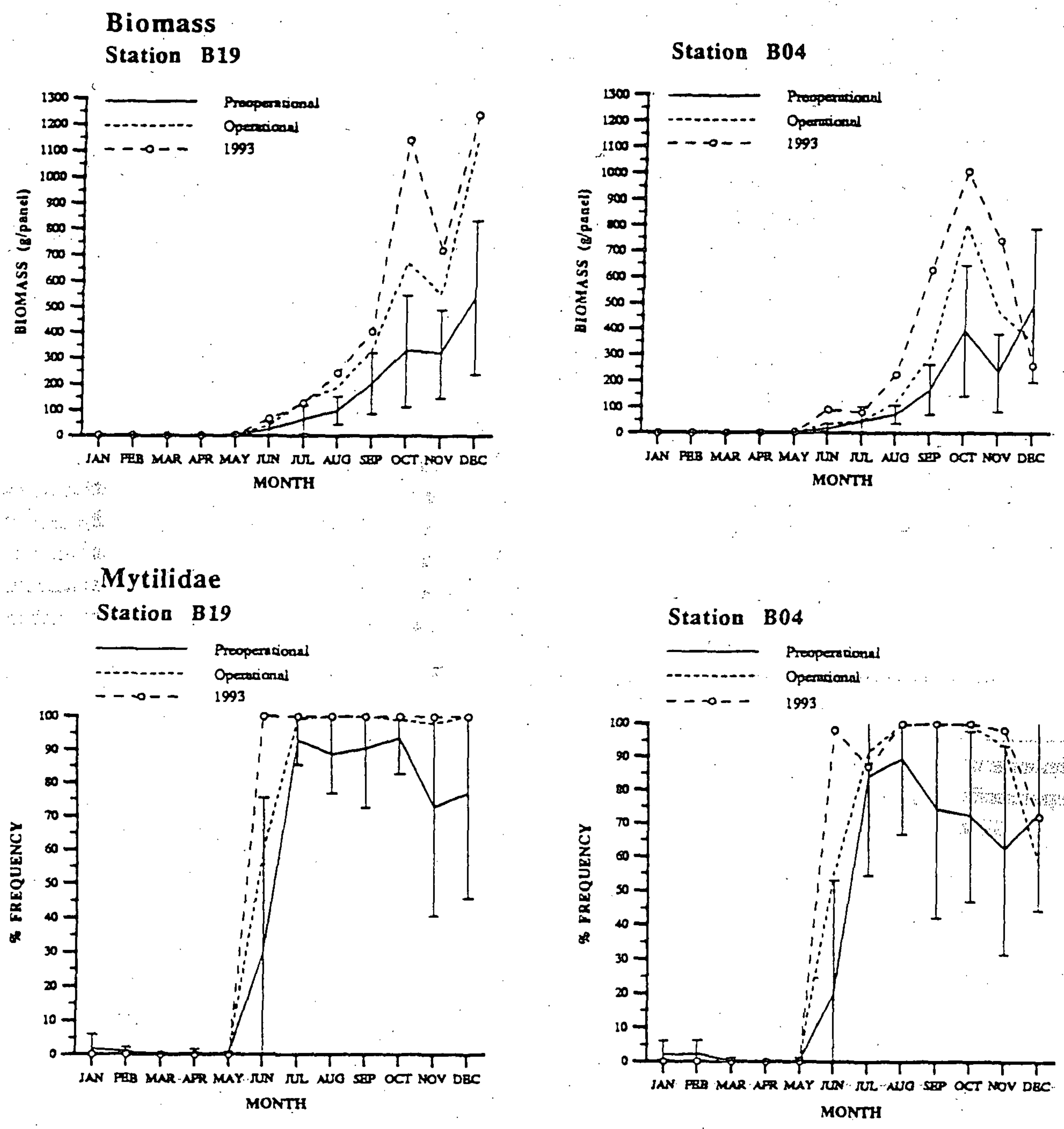


Figure 7-5. Mean biomass (g/panel) and Mytilidae spat (percent frequency of occurrence) during the operational period (1991-1993) and in 1993 compared to mean and 95% confidence limits during the preoperational period (Stations B19 and B04 from 1978-1984 and July-December 1986-1989) on monthly sequential panels. Seabrook Operational Report, 1993.

TABLE 7-3. ANOVA RESULTS COMPARING MONTHLY SEQUENTIAL PANEL BIOMASS AT MID-DEPTH (B19, B31) AND DEEP (B04, B34) STATION PAIRS DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1993) PERIODS. *SEABROOK OPERATIONAL REPORT, 1993.*

STATIONS	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISON (ranked in decreasing order)
Mid-depth	Preop-Op[a]	1	63,544.3	5.13*	Op>Preop
B19, B31	Year (Preop-Op)[b]	12	294,193.1	23.74***	
	Station[c]	1	3,268.2	0.26 NS	
	Month (Year)[d]	135	141,519.0	11.42***	
	Preop-Op X Station[e]	1	29,461.3	2.38 NS	
	Error	146	12,392.0		
Deep	Preop-Op	1	36,544.3	2.15 NS	
B04, B34	Year (Preop-Op)	12	271,200.8	15.98***	
	Station	1	181,476.8	10.69**	B34>B04
	Month (Year)	135	137,087.6	8.08***	
	Preop-Op X Station	1	32,883.2	1.94 NS	
	Error	112	16,970.7		

[a]Preop-Op = 1991-1993 v. previous years (1978-84; July 1986-December 1989 except B34, which began in 1982)
[b]Year nested within preoperational and operational periods regardless of station
[c]Station regardless of year or period
[d]Month nested within year regardless of station
[e]Interaction between main effects
[f]NS = Not significant (.05>p)
 * = Significant (.01<p≤.05)
 ** = Highly significant (.001<p≤.01)
*** = Very highly significant (p≤.001)

lengths differed between nearfield-farfield station pairs. Mytilid annual mean lengths ranged from 1.6 to 2.9 mm in 1993 at all four stations (Table 7-4). Annual averages of Mytilidae spat lengths were not statistically different between nearfield and farfield station pairs B19 and B31 ($t=0.18$, $t_{alpha=0.01,n=22} = 2.35$) and B04 and B34 ($t=0.42$, $t_{alpha=0.01,n=18} = 1.72$; Sokal and Rohlf 1969).

Jassa marmorata Holmes 1903 frequencies at mid-depth Station B19 during 1993 were seasonally quite variable with a summer peak occurring in July (Figure 7-6). Seasonally, *J. marmorata* frequencies at Station B19 during the operational period were similar to the preoperational period. In 1993, *J. marmorata* percent frequencies remained low at Station B04 throughout the year, maintaining a level below both preoperational and operational averages. The operational monthly average percent frequencies approximated those of the preoperational period from January through September, but were much lower from October to December. Average lengths of *Jassa marmorata* individuals colonizing monthly sequential panels ranged from 2.5 to 3.2 mm in 1993 (Table 7-4). A *t* test indicated that there were no significant length differences at nearfield-farfield station pairs B19 and B31 ($t=0.20$, $t_{alpha=0.01,n=15} = 2.77$) or B04 and B34 ($t=0.06$, $t_{alpha=0.01,n=15} = 5.25$; Sokal and Rohlf 1969).

In 1993, *Balanus* sp. (including *Balanus* spp. and *Semibalanus balanoides* L.) appeared at nearfield stations B19 in April and B04 in May, similar to previous years (Figure 7-6). In contrast to previous years, frequencies remained high at both stations throughout the spring to autumn season; April-November at B19 and May-October at B04. With few exceptions, the operational monthly means at both stations were greater than the preoperational means.

In 1993, at the nearfield stations, *Tubularia* sp. first appeared in July at B19 and in August at B04 (Figure 7-6). Seasonally, 1993 occurrences of *Tubularia* sp. were similar to the historical levels. The peak percent frequency occurred in September at both nearfield stations. The percent frequency of *Tubularia* sp. at Station B04 was lower than the preoperational average throughout the year. At Station B19, *Tubularia* sp. frequencies were below historical levels with the exception of September and December.

TABLE 7-4. NEARFIELD/FARFIELD COMPARISON OF ANNUAL MEAN AND STANDARD DEVIATION OF *JASSA MARMORATA* AND MYTILIDAE SPAT LENGTHS (mm) FROM MONTHLY SEQUENTIAL PANELS COLLECTED IN 1993. SEABROOK OPERATIONAL REPORT, 1993.

		MYTILIDAE SPAT		*JASSA MARMORATA*	
STATION		MEAN LENGTH (mm)	STANDARD ERROR	MEAN LENGTH (mm)	STANDARD ERROR
Mid-depth	B19	1.6	0.48	3.0	0.60
	B31	1.6	0.30	2.5	0.32
Deep	B04	1.8	0.57	3.2	0.53
	B34	2.9	0.87	2.5	0.26

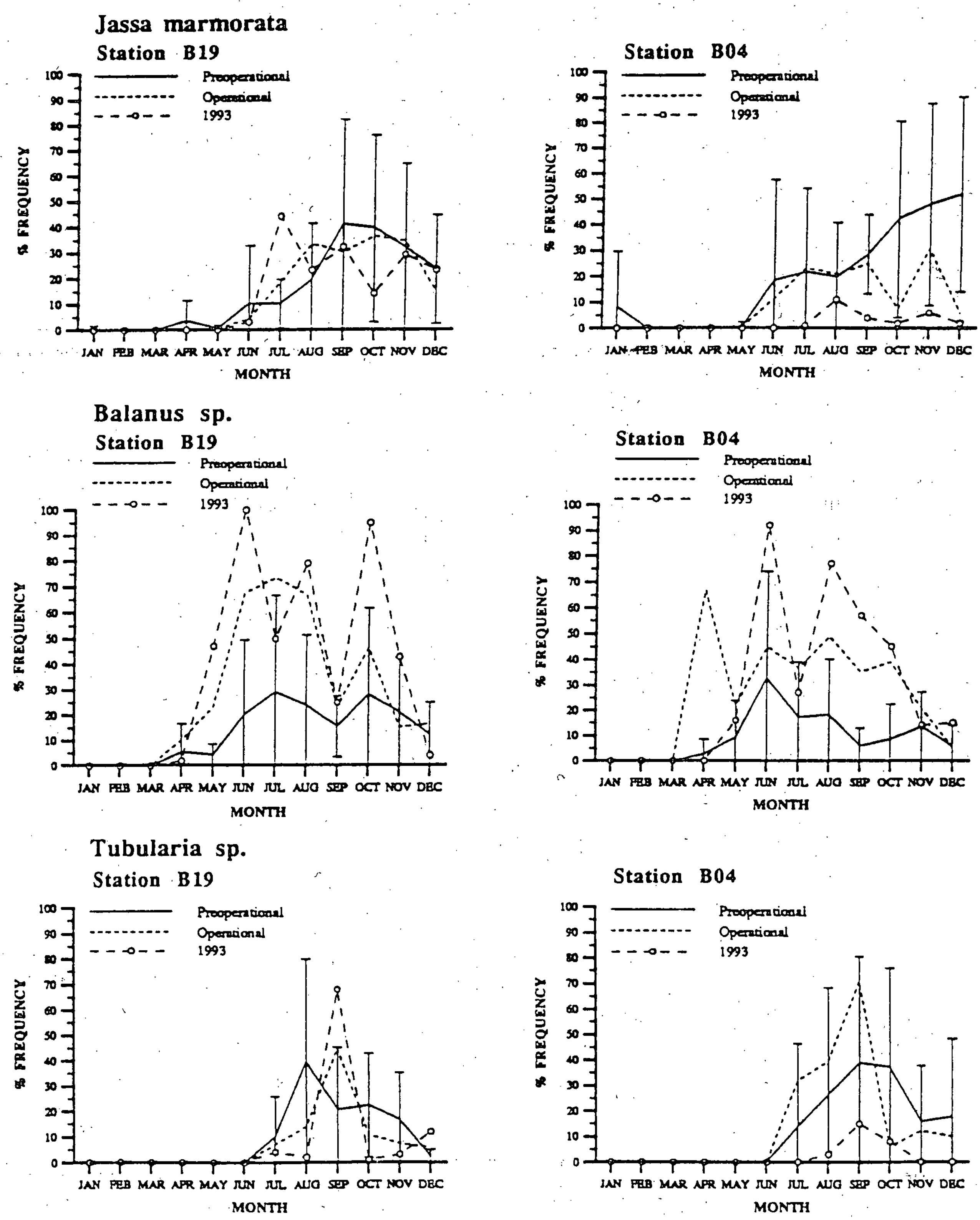


Figure 7-6. Monthly mean percent frequency of occurrence on monthly sequential panels for *Jassa marmorata*, *Balanus* sp., and *Tubularia* sp. at Stations B19 and B04 during the operational period (1991-1993) and in 1993, compared to mean and 95% confidence limits during the preoperational period (1982-1984 and July 1986-December 1989). Seabrook Operational Report, 1993.

7.3.3 One Year Panels

Community development was also assessed by examining biomass, species richness and abundance on surface panels exposed for one year. Year-end biomass values during the operational period were significantly greater than the preoperational means only at Station B19 (Table 7-5).

TABLE 7-5. DRY WEIGHT BIOMASS, NONCOLONIAL NUMBER OF TAXA, ABUNDANCE, AND *LAMINARIA* SP. COUNTS ON SURFACE FOULING PANELS SUBMERGED FOR ONE YEAR AT STATIONS B19, B31, B04, AND B34. MEAN AND STANDARD DEVIATION FOR THE PREOPERATIONAL PERIOD (1982-1984 AND 1986-1989) AND MEAN FOR 1993, AND THE OPERATIONAL PERIOD (1991-1993). SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL		OPERATIONAL	
	STATION	MEAN	S.D.	1993	MEAN
BIOMASS (g/panel)	B19	661.5	476.88	1235.4	1145.8 *
	B31	708.9	523.86	695.4	681.5 NS
	B04	600.9	474.66	258.4	351.7 NS
	B34	823.2	570.39	1150.8	1059.0 NS
NUMBER OF NON-COLONIAL TAXA (No./panel)	B19	21.3	4.42	34.0	33.5 *
	B31	25.9	4.60	26.0	36.7 *
	B04	23.6	4.16	27.0	30.0 *
	B34	22.9	5.05	24.0	35.7 NS
NONCOLONIAL ABUNDANCE (No./panel)	B19	13,905.1	7,046.48	63,030.0	38,581.0 NS
	B31	21,967.6	18,398.27	110,497.0	75,753.3 *
	B04	19,386.0	15,063.89	30,891.0	22,163.7 NS
	B34	19,221.7	19,986.38	23,371.0	24,661.7 NS
LAMINARIA SP.** (No./panel)	B19	24.3	36.91	0.0	0.0 NS
	B31	39.3	29.24	0.0	7.7 *
	B04	14.1	34.40	0.0	0.0 NS
	B34	15.9	26.83	0.0	0.3 NS

*$.01 < p \leq .05$ when preoperational and operational means tested for equality with a single sample *t* test (SAS 1985)

**not determined to species due to juvenile condition of most plants

The mean number of non-colonial taxa identified in 1993 and operationally was greater than the preoperational mean at all four stations (Table 7-5). The differences were significant at nearfield Stations B19 and B04 and farfield Station B31. There was no significant difference at Station B34. The trend toward increasing numbers of taxa began during the preoperational period (NAI 1991, 1992b).

The noncolonial abundance in 1993 was substantially higher than the preoperational mean abundance at all four stations (Table 7-5). However, the difference between the operational and preoperational means was significant only at Station B31.

Laminaria sp. blade counts on one-year panels have been low during most years of this study. At mid-depth nearfield Station B19 and both deep stations (B04 and B34), *Laminaria* sp. did not occur at least 3 of the 7 years of the preoperational period (NAI 1991b, 1992b, 1993). *Laminaria* sp. did occur during each preoperational year at mid-depth farfield Station B31. During 1993, *Laminaria* sp. did not occur at any of the four stations (Table 7-5). Elevated abundances of non-colonial taxa, specifically Mytilidae, may have resulted in diminished surface area for *Laminaria* sp. juveniles to attach. Differences between operational and preoperational means were significant only at Station B31.

7.4 DISCUSSION

The surface panels program was established to document the temporal and spatial patterns in the recruitment and development of the fouling community and to monitor the effects of Seabrook Station's operation on the community. The characteristics of Seabrook Station's thermal plume have been estimated from hydrothermal modeling studies (Teyssandier et al. 1974) and confirmed in recent field studies (Padmanabhan and Heckler 1991). Results from field studies generally confirmed initial model results, indicating that the discharge plume area was relatively small under the conditions tested. For example, the isotherm of a surface temperature increase of 3°F (1.7°C) covered a relatively small 32-acre area in the vicinity of the discharge area.

The community settling and developing on surface panels has shown predictable seasonal patterns throughout the study, as evidenced by both measures of community structure (biomass, abundance, and number of taxa) and abundance or percent frequency of occurrence of dominant taxa. Most measures showed significant differences between operational and pre-operational periods, a reflection of year-to-year variability in recruitment (Table 7-6). These differences were consistent among nearfield and farfield station pairs with one exception. Abundances of Mytilidae at nearfield Station B19 increased during the operational period in comparison to the preoperational period, whereas numbers decreased at its farfield counterpart, Station B31 These differences, which were not statistically significant, were due mainly to exceptionally low numbers of Mytilids in 1991 at B31 (NAI 1992a). Numbers in the subsequent years, although higher than average, indicated a nearfield-farfield difference that was similar to previous years. Thus there is no indication, in any of the parameters measured in the monthly (ST and MS) surface panels program, of any effect of Seabrook Station on the community.

The year-end values for parameters measured for surface panels exposed for twelve months are a reflection of the seasonal changes in recruitment and growth of organisms over the year on MS panels. Some community parameters indicated differences during the operational period that were not consistent among nearfield-farfield station pairs. This assessment is

TABLE 7-6. SUMMARY OF EVALUATION OF DISCHARGE PLUME EFFECTS ON THE FOULING COMMUNITY IN VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY	DEPTH ZONE[a]	PARAMETER[b]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[c]
Fouling community: Settlement[d]	Mid-depth	Abundance	Op>Preop	yes
		No. of taxa	Op>Preop	yes
		Biomass	Op<Preop	yes
	Deep	Abundance	Op>Preop	yes
		No. of taxa	Op>Preop	yes
		Biomass	Op<Preop	yes
Fouling community: Development-MS[d]	Mid-depth	Biomass	Op>Preop	yes
	Deep	Biomass	yes	yes
Fouling community: Development-year end[d]	Mid-depth	Abundance	no	NF:Op=Preop FF:Op>Preop
		No. of taxa	Op>Preop	yes
		Biomass	no	NF:Op>Preop FF:Op=Preop
	Deep	Abundance	yes	yes
		No. of taxa	no	NF:Op>Preop FF:Op=Preop
		Biomass	yes	yes
Fouling community: Settlement[d]	Mid-depth	Mytilidae	yes	NF:Op=Preop FF:Op=Preop
	Deep		yes	yes
	Mid-depth	Jassa marmorata	Op<Preop	yes
	Deep		Op<Preop	yes
	Mid-depth	Tubularia sp.	Op<Preop	yes
	Deep		Op<Preop	yes

[a]Mid-depth = Stations B19, B31. Deep = Stations B04, B34
[b]Abundance, number of taxa, biomass, and total density evaluated using ANOVA, or *t* test
[c]NF = nearfield FF = farfield
[d]Settlement = short term panels; Development = MS panels; MS = Monthly sequential; year end = one year exposure

complicated by the weather-related loss of the nearfield mid-depth panel in 1992. Total biomass was significantly higher at the mid-depth nearfield Station B19 during the operational period, while other stations showed no significant difference (Table 7-6). Elevated biomass also occurred on monthly sequential panels at both mid-depth stations during the operational period. This parameter will continue to be monitored closely. Numbers of non-colonial taxa were elevated at all four stations during the operational period, paralleling the trend noted on short-term panels. These differences were significant at both mid-depth stations, but at the deep stations, the difference was significant only at the nearfield station. Non-colonial abundances on year-end panels in the mid-depth region were substantially elevated during the operational period, similar to the trend observed for short-term panels. The increase was significant only at Station B31. These parameters will continue to be monitored closely. The algal species *Laminaria* sp. did not appear in 1993 at any station, continuing a decline which began during the preoperational years (NAI 1991). However, the differences in abundance of *Laminaria* during the operational period were significant only at the mid-depth farfield Station B31. There is no indication that this effect is due to Seabrook Station operation, since the decline occurred at both nearfield and farfield stations and began prior to the operation of Seabrook Station.

7.5 REFERENCES CITED

Barnard, J. Laurens. 1957. Amphipod crustaceans as fouling organisms in Los Angeles-Long Beach Harbors, with reference to the influence of seawater turbidity. California Department of Fish and Game. Contribution No. 212. Allan Hancock Foundation.

Bousfield, E.L. 1973. Shallow-Water Gammaridean Amphipoda of New England. Comstock Pub. Ithaca, NY. 312 pp.

Clark, K.B. 1975. Nudibranch life cycles in the northwest Atlantic and their relationship to the ecology of fouling communities. Helgo. Wiss. Meere. 27-28-69.

Conlan, Kathleen E. 1990. Revision of the crustacean amphipod; genus *Jassa* Leach (Corophioidea: Ischyroceridae. Can. J. Zool. 68:2031-2075.

Field, B. 1982. Structural analysis of fouling community development in the Damariscotta River estuary, Maine. J. Exp. Biol. Ecol. 57:25-33.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, NY. 547 pp.

Normandeau Associates Inc. 1988. Seabrook Environmental Studies. 1987. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1987. A preoperational study for Seabrook Station. Tech. Rep. XIX-II.

__________. 1990. Seabrook Environmental Studies. 1989 Data Report. Tech. Rep. XXI-I.

__________. 1991. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

__________. 1992a. Seabrook Environmental Studies. Unpub. 1991 data.

__________. 1992b. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during operation of Seabrook Station. Tech. Rep. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-I.

__________. 1994. Seabrook Environmental Studies. Unpub. 1993 data.

Padmanabhan, M., and G.E. Hecker. 1991. Comparative evaluation of hydraulic model and field thermal plume data. Seabrook Nuclear Power Station. Alden Res. Lab., Inc. 12 p.

Rastetter, E.B. and W.J. Cooke. 1979. Response of marine fouling communities to sewage abatement in Kaneohe Bay, Oahu, Hawaii. Mar. Biol. 53:271-280.

SAS Institute, Inc. 1985. User's Guide: Statistics, Version 5 Edition. SAS Inst. Inc. Cary, NC 956 pp.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. xxi + 776 pp.

Sutherland, John P., and Ronald H. Karlson. 1977. Development and stability of the fouling community at Beaufort, North Carolina. Ecol. Monog. 47:425-446.

Teyssandier, R.G., W.W. Durgin, and G.E. Hecker. 1974. Hydrothermal studies of diffuser discharge in the coastal environment: Seabrook Station. Alden Res. Lab. Rep. No. 86-24.

TABLE OF CONTENTS

SUMMARY

Epibenthic crustacea in the study area include the American lobster and rock and Jonah crabs, important invertebrate predators in the region. Lobster larvae have historically been relatively rare in the study area, averaging less than 1 per 1000 square meters. The larvae, predominantly stage IV, typically had peak abundances in July and August. Larval abundance during the operational period was significantly greater than during the preoperational period at all three stations. Adult lobster catches (all sizes) were typically highest from August through November. A similar seasonal cycle was observed during the operational period, but catches showed a significant decline that was most pronounced at the farfield station. The decrease is thought to be related to intense commercial fishing as well as decreased bottom temperatures. Catches of legal sized lobsters remained unchanged during the operational period. There was no evidence of an effect from Seabrook Station.

Cancer crab larvae were most abundant in the study area from June through September. Average densities during the operational period were significantly higher than during the preoperational period at all three stations. The adult Jonah crab catch during the operational period showed differences between nearfield and farfield stations. Operational catches increased at the nearfield station (by 1.6 crabs/15 traps to 13.9) but decreased at the farfield station (by 2.0 crabs to 7.4 CPUE). Rock crabs were less abundant than their congener, likely due to preference for sandy substrate, which is less common in the study area than hard substrate. No differences in rock crab catch were observed during the operational period in comparison to the preoperational period. There was no evidence of an effect of Seabrook station, with the exception of Jonah crab catches. All species will continue to be monitored closely.

LIST OF FIGURES

LIST OF TABLES

8.0 EPIBENTHIC CRUSTACEA

8.1 INTRODUCTION

The objective of the epibenthic crustacea monitoring program was to determine the monthly, spatial, and annual trends in larval density and catch per unit effort for the juvenile and adult stages of American lobster (*Homarus americanus* Milne-Edwards 1837), Jonah crab (*Cancer borealis* Stimpson 1859), and rock crab (*Cancer irroratus* Say 1817). Analyses were done to determine if the discharge from Seabrook Station had any measurable effect on the epibenthic crustacea. The planktonic larval stages of *Cancer* species may potentially be impacted by entrainment within the cooling system of the plant where mechanical damage or temperature increase may cause death or stress. Lobster larvae may be entrained in the buoyant discharge plume, which may affect survival, successful molting, and settlement to the bottom. The benthic (bottom dwelling) stages may be impinged at the intake or be subject to possible discharge effects such as increased turbidity.

8.2 METHODS

8.2.1 Field Methods

Lobster Larvae (Neuston)

To monitor the distribution of American lobster larvae, neuston samples were collected once a week, during the day, from May through October along horseshoe-shaped tows approximately 1/2 mile (800 m) long on a side. These tows were centered on the intake (P2), discharge (P5), and farfield (P7) stations (Figure 8-1). Collections began in 1978 at Station P2, in 1982 at Station P7, and in 1988 at Station P5. Collections were made with a 1-mm mesh net (1 m deep x 2 m wide x 4.5 m long) fitted with a General Oceanics® flowmeter and a 40-lb depressor. Thirty minute surface tows were taken with the bottom of the net mouth approximately 0.5 m below the surface. The area sampled averaged about 3732 m^2 (generally ranging from 2874 to 4300 m^2).

Cancer spp. Larvae (Macrozooplankton)

Cancer spp. larvae (*C. borealis* and *C. irroratus*) and other macrozooplankton were sampled four times per month from January through December. On each date, four replicate (two paired-sequential) oblique tows were made at night with 1-m diameter, 0.505-mm mesh nets at the intake (P2), discharge (P5), and farfield (P7) stations (Figure 8-1). Collections began in 1978 at Station P2 and in 1982 at Station P7. Collections at Station P5 occurred from 1978-1981, July-December 1986, and from 1987 to the present. No collections were made in 1985 at any station. The nets with depressors were set off the stern and towed for 10 minutes while varying the boat speed, causing the net to sink to approximately 2 m off the bottom and to rise to the surface at least twice during the tow. If nets became clogged due to plankton blooms, tows were shortened to 6 minutes. The volume filtered was determined with a General Oceanics® digital flowmeter. Upon retrieval, each net was thoroughly washed down with filtered seawater and the contents preserved in 5-10% borax-buffered formalin.

Juveniles and Adults (Lobster Traps)

American lobster, Jonah crab and rock crab were collected at the nearfield discharge station (L1) and a farfield station located off Rye Ledge (L7) (Figure 8-1). Collections began at Station L1 in 1975 and at Station L7 in 1982. Fifteen 25.4 mm (1 in) mesh experimental lobster traps without escape vents were retrieved at two-day intervals, approximately three times per week from June through November. Lobster carapace lengths were recorded in the field in the following 12.7 mm (1/2 in) size classes:

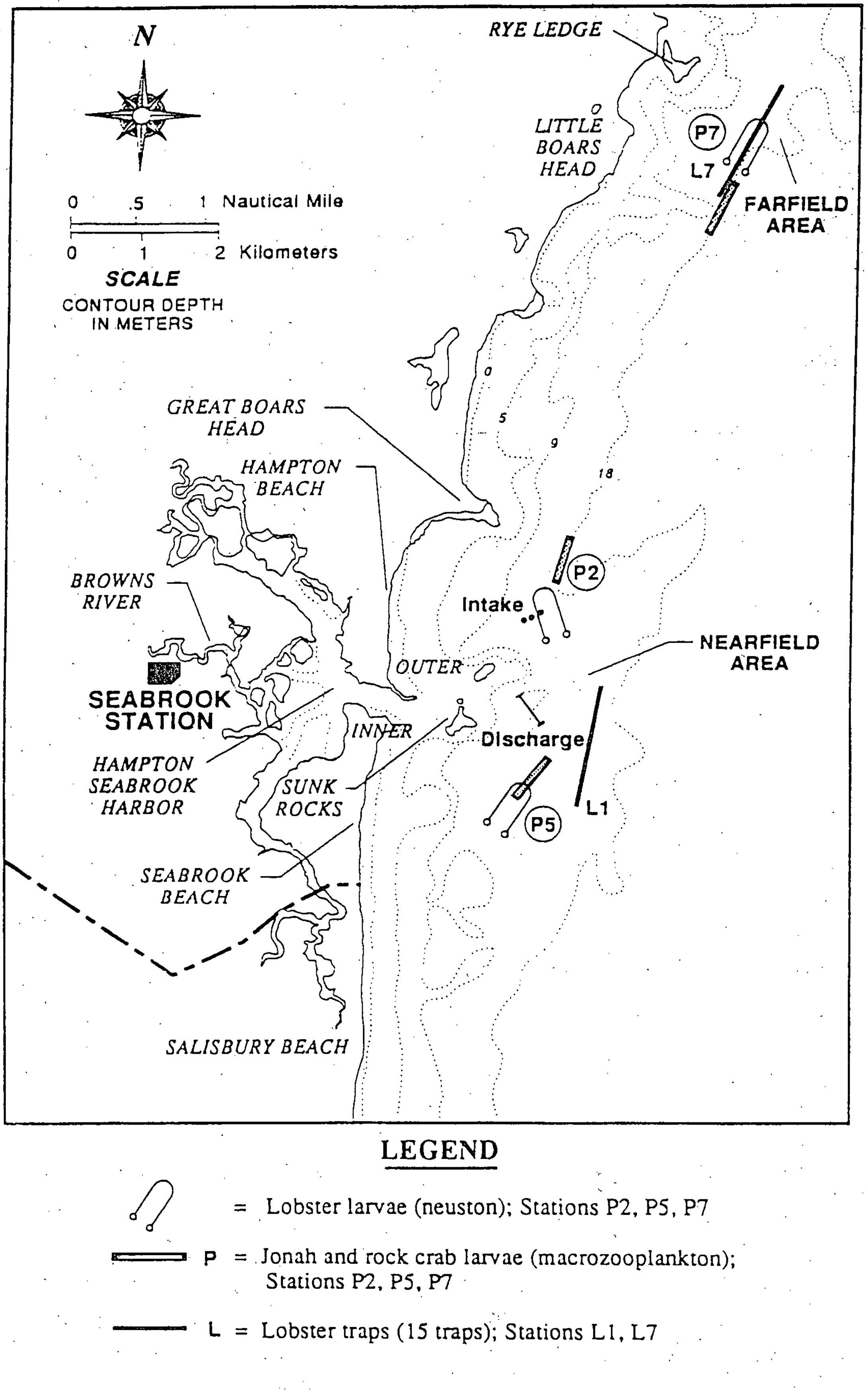


Figure 8-1. Epibenthic crustacea (American lobster, Jonah and rock crabs) sampling stations. Seabrook Operational Report, 1993.

Size Class (mm)	Range (inches)
<54	<2-1/8
54-67	2-1/8 to 2-5/8
68-79	>2-5/8 to 3-1/8
80-92	>3-1/8 to 3-5/8
93-105	>3-5/8 to 4-1/8
>105	>4-1/8

Lobsters in the 80-92 mm (>3-1/8 to 3-5/8 in) class were classified in two groups separating the legal and sublegal lobsters based on the current State of New Hampshire regulations. Beginning in 1990, lobsters measuring greater than 83 mm (3-1/4 in) were classified as legal. The total numbers of males, females, and egg-bearing females were also recorded.

8.2.2 Laboratory Methods

In the laboratory, lobster larvae (neuston) samples were rinsed through a 1-mm mesh sieve, and sorted. The live lobster larvae (Stages I-IV) were enumerated and released into Hampton Harbor. Those samples that were not processed the day of collection were preserved in 6% formalin (NAI 1991).

Cancer spp. larvae from macrozooplankton samples were analyzed from three of the four tows (randomly selected) at each station for two of the four sampling periods each month (usually the first and third weeks). In the laboratory, each sample was split with a Folsom plankton splitter into fractions that provided counts of at least 30 individuals of *Cancer* spp. larvae. A maximum of 100 milliliters of settled plankton, generally 1/4 of the original sample volume, was analyzed. *Cancer* spp. larvae were identified to developmental stage and enumerated (NAI 1991).

In the laboratory, juvenile and adult *Cancer* spp. were identified, enumerated and sexed, and the carapace width was measured to the nearest millimeter. In addition, the number of egg-bearing females was recorded.

8.2.3 Analytical Methods

An analysis of variance (SAS 1985) was used on log (x +1) transformed densities of lobster and *Cancer* spp. larvae to determine differences between the average abundances for the operational (1991-1993) and recent preoperational (1988-1989, when all three stations were sampled concurrently) periods at the nearfield, intake, and farfield stations. Weekly geometric means were analyzed for lobster larvae and biweekly (twice a month) geometric means were used for *Cancer* spp. larvae. The untransformed monthly arithmetic mean CPUE (no. per 15 traps) was used for juvenile and adult lobsters and crabs for the preoperational (1982-1989) and operational (1991-1993) periods.

All sources of variation in the analysis of variance model were assumed to be fixed variables. This was a conservative model since it was more likely to detect significant differences than alternate models that assume some of the sources of variation to be random. When the F value was significant for the interaction term (Preop-Op X Station), or class variable (Station, Preop-Op), the least squares means procedure (SAS 1985) was used to evaluate differences among least squares means with a t-test at alpha ≤ 0.05.

8.3 RESULTS

8.3.1 American Lobster

Lobster Larvae

Annual mean densities in 1993 continued the trends observed in 1991 and 1992 (NAI 1991, 1992). Lobster larvae densities during 1993 were higher than preoperational (1988-1989) densities at each station (Table 8-1). Average larval densities during the three-year opera-

TABLE 8-1. GEOMETRIC MEAN ABUNDANCE (LARVAE: LOBSTER = NO./1000 m^2; *CANCER* SPP. = NO./1000 m^3) OR ARITHMETIC MEAN CATCH PER UNIT EFFORT (NO./15 TRAPS) AND THE COEFFICIENT OF VARIATION (CV,%) OF EPIBENTHIC CRUSTACEA AT NEARFIELD (P2, P5, L1) AND FARFIELD (P7, L7) STATIONS DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND IN 1993. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES (period sampled)	STATION	PREOPERATIONAL[a] MEAN	PREOPERATIONAL[a] CV	1993[b] MEAN	OPERATIONAL[c] MEAN	OPERATIONAL[c] CV
Lobster larvae (May-Oct)	P2	0.4	22.7	0.8	1.0	22.5
	P5	0.4	33.3	0.7	0.9	17.3
	P7	0.6	28.0	0.7	1.2	26.4
Lobster, total (Jun-Nov)	L1	70.7	20.4	49.5	58.2	15.4
	L7	87.2	16.9	56.5	58.1	6.4
Lobster, legal (Jun-Nov)	L1	6.0	29.6	2.8	2.4	15.1
	L7	6.0	37.2	1.8	2.0	22.4
Lobster, female (Jun-Nov)	L1	39.0	19.4	28.3	31.5	18.4
	L7	47.2	17.0	31.3	31.3	11.6
Lobster, egg-bearing (Jun-Nov)	L1	0.6	17.1	0.6	0.5	19.9
	L7	0.6	31.8	1.0	0.8	20.6
Cancer spp. larvae (May-Sep)[d]	P2	9532.4	5.2	11123.1	19285.8	6.2
	P5	5063.9	5.6	8755.5	13498.3	4.0
	P7	8426.2	5.7	8630.6	17189.1	6.2
Jonah crab, total (Jun-Nov)	L1	12.3	52.7	14.4	13.9	20.4
	L7	9.4	31.4	5.8	7.4	33.4
Jonah crab, female (Jun-Nov)	L1	9.5	50.6	10.2	9.8	17.3
	L7	6.7	30.1	3.4	4.7	45.5
Rock crab, total (Jun-Nov)	L1	2.4	78.9	2.9	4.1	60.9
	L7	1.5	133.5	2.0	3.5	41.9
Rock crab, female (Jun-Nov)	L1	0.5	119.4	0.2	0.9	104.9
	L7	0.3	148.7	0.2	0.9	119.7

[a]Preoperational: Lobster larvae from Sta. P2-1978-89; Sta. P5-1988-1989; Sta. P7-1982-89; *Cancer* spp. larvae from Sta. P2-1978-84, 1986-89; Sta. P5-1982-84 + Jul-Dec 1986 + 1987-89; Sta. P7 1982-84 + 1987-89; all others 1982-89.

[b]1993 mean; mean of the total number of samples collected during the period sampled.

[c]Operational: 1991-93, mean of annual means.

[d]Sampled year-round but abundance computed for peak period (May - September).

tional period were significantly higher than the average densities during the preoperational period (Table 8-2). Significant differences were also found among weeks and years. There were no significant differences among the three stations during the 1988-1993 study period. Increases between the preoperational and operational periods were consistent among stations.

Monthly trends in 1993 were similar to previous years (Figure 8-2). In 1993, high densities of lobster larvae occurred at the nearfield station in July and August, while low densities occurred in May, June and October. The occurrence of peak abundances of lobster larvae during the preoperational period was consistent with other studies in New England, indicating that peak abundances occur sometime from June through August (Fogarty and Lawton 1983). Other studies relate first appearance of lobster larvae with a surface temperature of 12.5°C (Harding et al. 1983), which typically occurs in June or July in the study area (Section 2.0).

Density increases in 1993 were due mainly to increases in Stage IV larvae, historically the most numerous of the four larval stages (Figure 8-2). Stage I larvae were the second-most abundant, both in 1993 and during the preoperational period. Stage II and Stage III larvae have historically been least abundant. Stage I lobster predominated in the majority of other studies, mainly from southern New England, as reviewed by Fogarty and Lawton (1983). Stage IV lobsters, however, were most numerous in some years in Cape Cod and Buzzards Bay, and Long Island Sound (Fogarty and Lawton 1983), as well as in collections from the coast of southwestern Nova Scotia to New Hampshire (Harding et al. 1983). These Stage IV larvae, including those in the study area, are hypothesized to originate, at least in part, offshore in the warm southwestern waters of the Gulf of Maine and Georges Bank (Harding et al. 1983, Harding and Trites 1988).

Total Catch: Legal- and Sublegal-Sized

The 1993 total catch per unit effort (CPUE) for lobster was lower than the CPUE during the operational period (1991-93) at both the nearfield (L1) and farfield (L7) stations (Table 8-1). Both stations showed a significant decline in the catch between the preoperational and operational periods (Table 8-1); however, the decline was greater at the farfield station when compared to the nearfield station, resulting in a significant Preop-Op X Station interaction term (Table 8-2, Figure 8-3).

In 1993, the monthly trend in total CPUE was similar to that observed during the preoperational period. The monthly total catch peaked in October, but was below the operational and preoperational averages for the other months (Figure 8-2). The monthly pattern during the operational period (1991-93) was similar to the preoperational period, but monthly operational averages were usually below preoperational averages (Figure 8-2). Significant differences were noted among months (Table 8-2). Monthly variations in lobster catch were due in part to regional temperature changes. Warmer temperatures tend to increase the activity level of adults, in turn enhancing the likelihood of being caught (McLeese and Wilder 1958, Dow 1969). In addition, temperature may affect seasonal lobster migrations (Campbell 1986). In New Hampshire, adult lobsters are thought to move inshore in spring and summer and offshore in fall and winter (NHFG 1992). In 1993, the average bottom water temperature at the nearfield station was lower than the previous year for the second year in a row (Section 2.0). The decline in water temperature may have caused a decrease in lobster activity, resulting in a decreased catch at both stations during the operational period (1991-93).

Legal-sized Lobster

During 1993, legal-sized lobsters were 6% of the total catch at the nearfield station and 3% at the farfield

TABLE 8-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING DENSITIES OF LOBSTER AND *CANCER* SPP. LARVAE COLLECTED AT INTAKE, NEARFIELD, AND FARFIELD STATIONS, AND CATCHES OF TOTAL AND LEGAL-SIZED LOBSTERS, JONAH CRAB, AND ROCK CRAB AT THE NEARFIELD AND FARFIELD STATIONS. SEABROOK OPERATIONAL REPORT, 1993.

SPECIES	SOURCE OF VARIATION[a]	df	MS	F[b]	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Lobster larvae (May-Oct)	Preop-Op	1	2.04	53.34 ***	Op>Preop
	Station	2	0.00	0.06 NS	
	Year (Preop-Op)	3	0.20	5.25 **	
	Week (Preop X Op)	95	0.32	8.36 ***	
	Preop-Op X Station	2	0.03	0.74 NS	
	Error	223	0.04		
Lobster (total catch) (Jun-Nov)	Preop-Op	1	81,414.47	96.48 ***	
	Station	1	18,972.84	22.48 ***	
	Year (Preop-Op)	9	17,775.88	21.07 ***	
	Month (Year X Preop-Op)	54	27,428.32	32.50 ***	
	Preop-Op X Station	1	14,781.37	17.52 ***	7 Pre 1 Pre <u>7 Op 1 Op</u>
	Error	1323	843.84		
Lobster (legal size) (Jun-Nov)	Preop-Op	1	3,273.81	316.00 ***	Op<Preop
	Station	1	8.51	0.82 NS	
	Year (Preop-Op)	9	406.51	39.24 ***	
	Month (Year X Preop-Op)	54	132.54	12.79 ***	
	Preop-Op X Station	1	15.22	1.49 NS	
	Error	1323	15.40		
Cancer spp. larvae (May-Sep)	Preop-Op	1	4.59	5.48 *	Op>Preop
	Station	2	0.60	0.71 NS	
	Year (Preop-Op)	4	0.95	1.14 NS	
	Month (Year X Preop-Op)	24	6.99	8.35 ***	
	Preop-Op X Station	2	0.12	0.14 NS	
	Error	146	0.84		

(continued)

TABLE 8-2. (Continued)

SPECIES	SOURCE OF VARIATION[a]	df	MS	F[b]	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Jonah Crab (Jun-Nov)	Preop-Op	1	3.31	0.04 NS	
	Station	1	6,276.74	73.45 ***	
	Year (Preop-Op)	9	1,847.52	21.62 ***	
	Month (Year X Preop-Op)	54	1,305.64	15.28 ***	
	Preop-Op X Station	1	902.79	10.56 ***	1 Op>1 Pre>7 Pre>7 Op
	Error	1301	85.46		
Rock Crab (Jun-Nov)	Preop-Op	1	443.77	23.26 ***	Op>Preop
	Station	1	155.53	8.15 **	
	Year (Preop-Op)	9	382.92	20.07 ***	
	Month (Year X Preop-Op)	54	115.64	6.06 ***	
	Preop-Op X Station	1	6.26	0.33 NS	
	Error	1300	19.07		

[a]Preop-Op = Preoperational period (Lobster and *Cancer* spp. larvae, all stations: 1988, 1989; Adult lobster and crabs: 1982-1989); Operational period: 1991-93 regardless of station or month.
Station = Station differences (Lobster and *Cancer* spp. larvae: P2, P5, P7; all others: Discharge (L1) and Rye Ledge (L7)) regardless of year, month or period.
Preop-Op X Station = Interaction of main effects.
Year (Preop-Op) = Year nested within preoperational and operational periods regardless of year, month or station.
Month (Year) or Week (Year) = Month or week nested within year, regardless of station.
[b]NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very Highly Significant ($0.001\geq p$)
[c]Underlining signifies no significant differences ($\alpha\leq0.05$) among least squares means with a paired t-test.

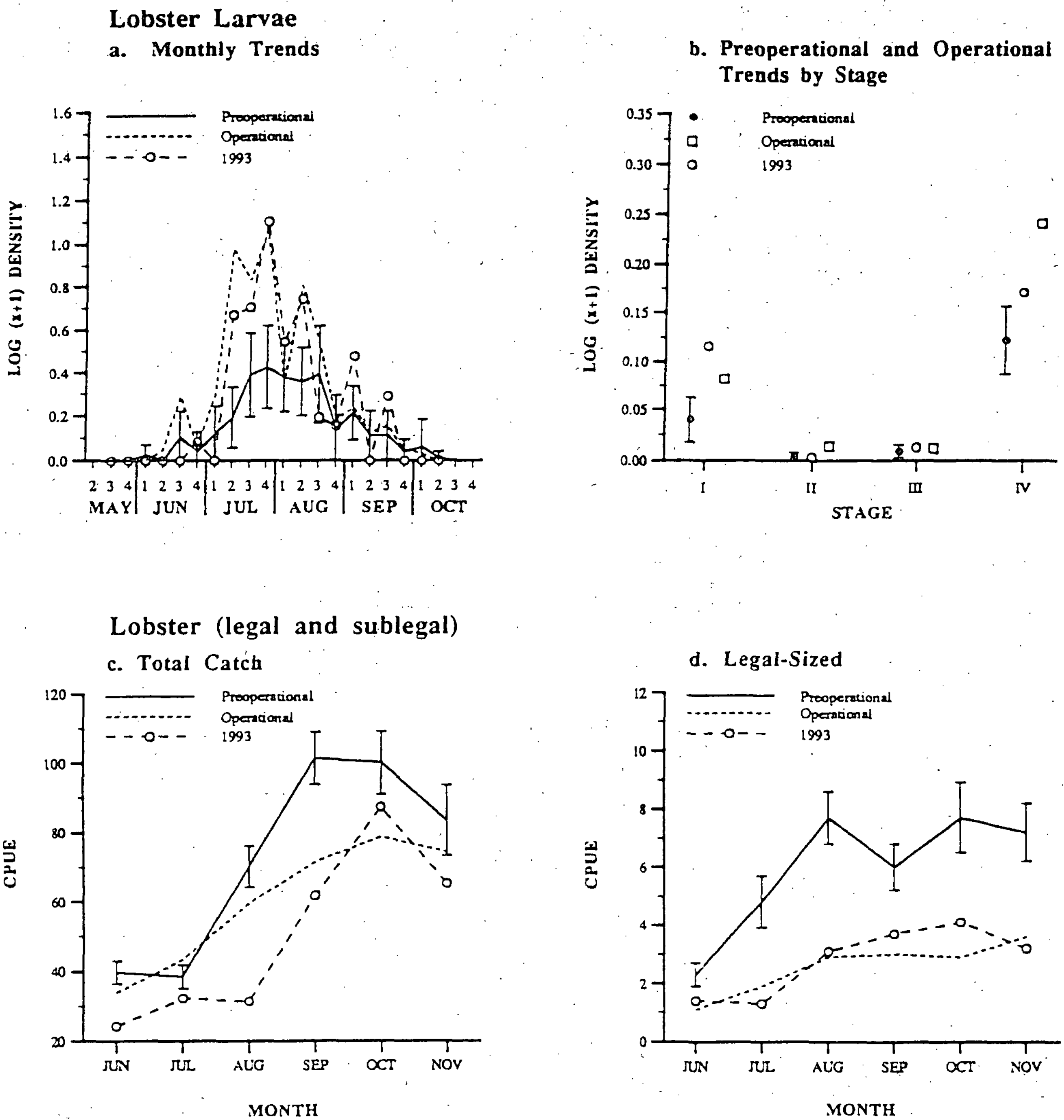


Figure 8-2. Preoperational mean and 95% confidence limits and 1993 and operational means of a. weekly density (no./1000m^2) of lobster larvae at Station P2, b. lobster larvae density by lifestage at P2, c. monthly CPUE (15 traps) of total (legal and sublegal) lobster at Station L1, and d. monthly CPUE (15 traps) of legal-sized lobster at Station L1. Seabrook Operational Report, 1993.

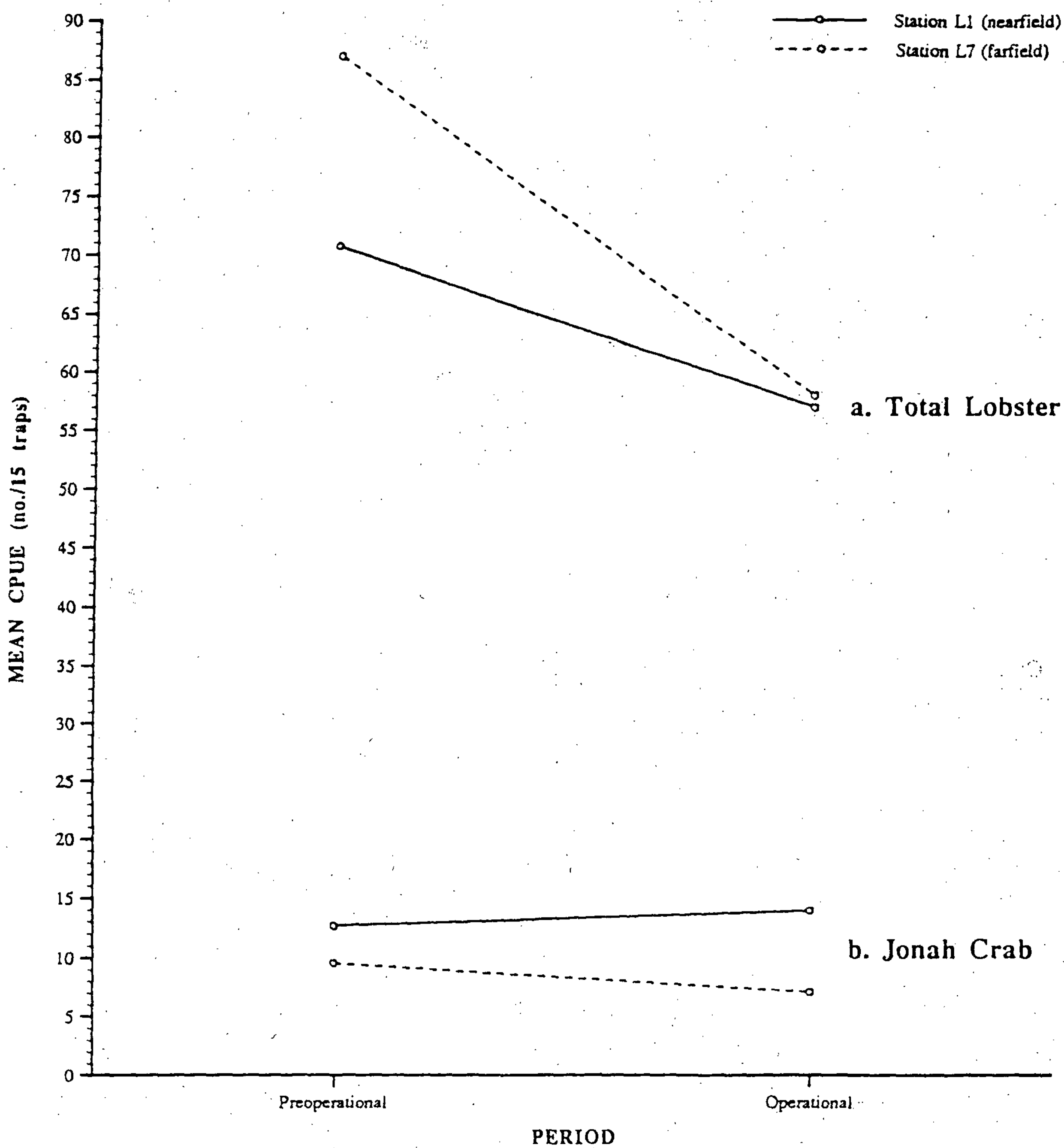


Figure 8-3. A comparison of the mean catch per unit effort (no. per 15 traps) for **a. total lobster** and **b. Jonah crab** by station during the preoperational (1982-1984 + 1986-1989) and operational (1991-1993) periods when the interaction term (Preop-Op x Station) of the ANOVA model was significant (Table 8-2). Seabrook Operational Report, 1993.

station, slightly lower than the preoperational averages of 8% and 7%, respectively (Table 8-1). During the three-year operational period, the average annual catch at both stations was significantly lower than the preoperational average, paralleling trends in total catch (Tables 8-1,2). There was no significant difference in CPUE between the nearfield and farfield stations, and the decrease between the operational and preoperational periods was consistent between stations.

The monthly pattern of legal-sized lobster catches in 1993 showed an October peak, similar to monthly patterns observed during the preoperational period (Figure 8-2). Significant differences were noted among months and years (Table 8-2).

Catches of legal-sized lobsters were affected by fisheries regulations and environmental factors such as water temperature. The legal-size limit for lobsters was increased in 1984, 1989, and in 1990, and is currently defined as a carapace length of 83 mm (3-1/4 in). Each increase in the legal size proportionally reduced the catch of legal-sized lobsters (Figure 8-4).

Size Class and Sex Distribution

The majority of lobsters collected at the nearfield station in 1993 were in the 68-79 mm (2-5/8 - 3-1/8 in) carapace length size class, as was true in previous years beginning in 1980. Lobsters measuring 54-67 mm (2-1/8 -2-5/8 in) ranked second in abundance in 1993, as in previous years (Figure 8-4). Catches (CPUE) during 1993 in the 80-92 mm size class, which includes both legal-sized and sublegal-sized lobsters, were the lowest since 1983. The decline may be due to lower water temperatures in 1992 and 1993 (Section 2.0), which may decrease catchability (McLeese and Wilder 1958, Dow 1969). A similar decline in catch in 1992 was noted in Maine by other investigators (Addison and Fogarty 1993). In a 1991 study of New Hampshire coastal areas, the majority of lobsters were also sublegal-size, and measured between 77 and 80 mm, with an average length of 78 mm (NHFG 1992).

In 1993, the female lobster catch averaged 28.3 CPUE at the nearfield station in 1993, 57% of the total lobster population (Table 8-1). During the preoperational period, the proportion of females was 55% at the nearfield station. The proportion was similar at the farfield Rye Ledge Station, both in 1993 (55%) and during the preoperational period (54%). NHFG studies found that females were 52% of the total legal-sized population in the New Hampshire coastal area (Grout et al. 1989).

Egg-bearing female lobsters represented a small component of the lobster population. In 1993, they averaged 0.6 CPUE at the nearfield station, representing 1.2% of the total catch. Catches of egg-bearing females at Rye Ledge were slightly higher and averaged 1.0 CPUE, 1.8% of the total catch (Table 8-1). During the preoperational period, egg-bearing females composed 0.8% of the total catch at the nearfield station, and 0.7% at the farfield station. NHFG studies (Grout et al. 1989) found that 0.4% of the total lobsters examined during lobster surveys of New Hampshire coastal waters from 1983-1985 were egg-bearing.

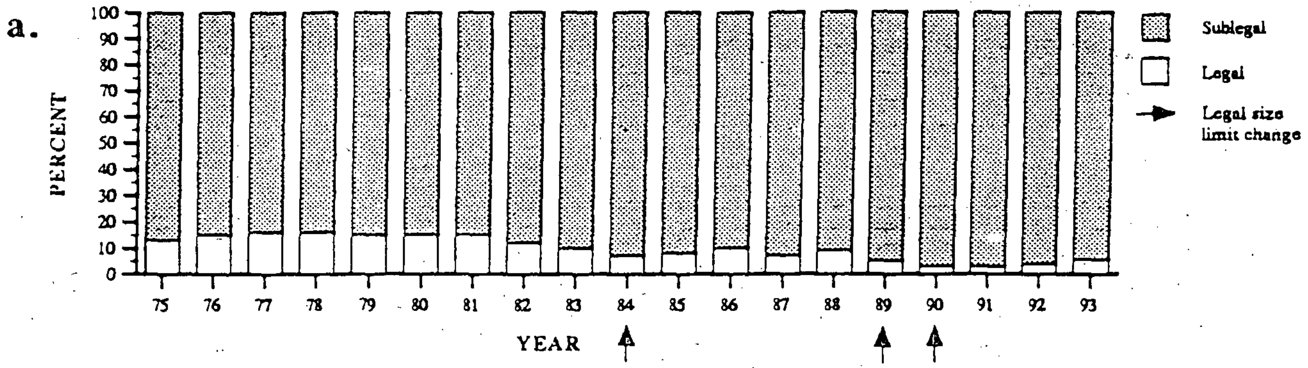
Impingement

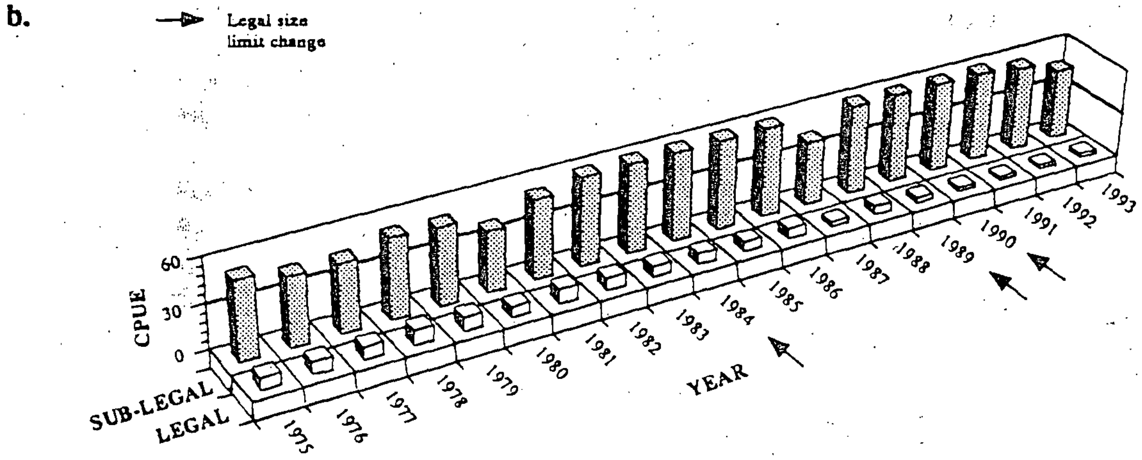
In 1993, one lobster measuring 220 mm in total length was impinged in the plant's cooling water system. Four lobsters were impinged in 1990, 29 were impinged in 1991 and 6 in 1992 (NAI 1993). Sixty-six percent of those impinged in 1991 were found in November following a severe northeastern storm.

8.3.2 Jonah and Rock Crabs

Larvae

Cancer spp. (*Cancer borealis* and *Cancer irroratus*) larvae had slightly higher peak period abundances in





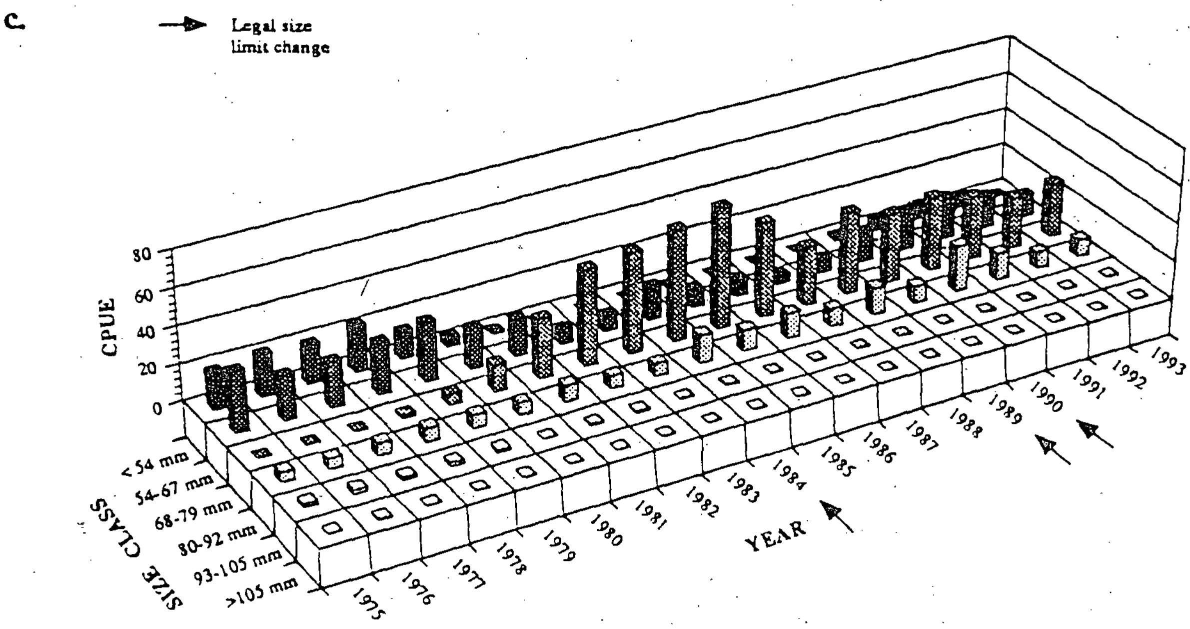


Figure 8-4. a. Percentage and b. catch (per 15 trap effort) of legal-sized and sublegal-sized lobster at Station L1 and c. size-class distribution at Station L1 from 1975-1993. Seabrook Operational Report, 1993.

1993 than during the preoperational period at all three stations (Table 8-1). During the three-year operational period, the average density was significantly higher than the preoperational average at each station (Tables 8-1, 8-2). Since the increase occurred at both the nearfield and farfield stations, it reflects an area-wide increase and is not due to plant operation. The seasonal trend of occurrence at nearfield Station P2 in 1993 and for the average operational period was similar to preoperational years. Densities were low from January through April, peaked from May or June through September, then decreased from October through December (Figure 8-5). Monthly differences were significant (Table 8-2).

Total Catch: Juveniles and Adults

The 1993 mean CPUE for Jonah crab (*Cancer borealis*) at the nearfield station was higher than the preoperational average (Table 8-1). In contrast, the 1993 CPUE at the farfield station declined, and was lower than the preoperational average. Highest catches in 1993 at the nearfield station occurred in August and were above the preoperational monthly means from August through November (Figure 8-5).

Trends in mean CPUE during the operational period differed between the nearfield and farfield stations, and the Preop-Op X Station interaction term was significant (Table 8-2, Figure 8-3). At the nearfield station, CPUE increased during the operational period. However, at the farfield station, CPUE decreased during the operational period.

Changes in female Jonah crab CPUE paralleled those of total catch. Female crab catches in 1993 were 71% and 59% of the total catches at the nearfield and farfield stations, respectively. During the preoperational period the proportion has varied from year to year, and averaged 77% and 72% at the near- and farfield stations, respectively (Table 8-1).

In 1993 the rock crab (*Cancer irroratus*) CPUE at the nearfield and farfield stations decreased from the high catches observed in 1992 (NAI 1993), but were above the preoperational averages (Table 8-1). The 1993 and the operational years catches at the nearfield site were highest in June, but decreased in July (Figure 8-5). During the preoperational period, abundance peaked in August. Differences between stations were significant (Tables 8-1, 8-2), with more crabs occurring at the nearfield station. Rock crab catches were significantly higher during the operational period at both stations, representing an area-wide increase.

Female rock crab CPUE decreased in 1993 to levels that were lower than the preoperational means. Female crabs composed approximately 20% of the total catch at each station during the preoperational period. The proportion increased slightly to 22-26% at each station during the operational period (Table 8-1). Rock crab catches were less abundant than Jonah crab in the study area (Table 8-1), probably a result of this species' preference for sandy habitat rather than the cobble-rock that predominates in the study area (Jefferies 1966) as well as intra-specific competition (Richards et al. 1983).

8.4 DISCUSSION

8.4.1 American Lobster

Eggs and newly-hatched larvae require a sea water temperature above 10°C (50°F) to survive (Mariano 1993). Larvae spend roughly one month in the water column, molting three times before they settle to the bottom. The frequency of molting and growth rate may increase with temperature (Mariano 1993).

Lobster larvae have traditionally been thought of as strictly neustonic, although recent research suggests that they migrate vertically in waters above the theromocline (Harding et al. 1987, Boudreau 1991). Lobster larvae could be exposed to the discharge plume,

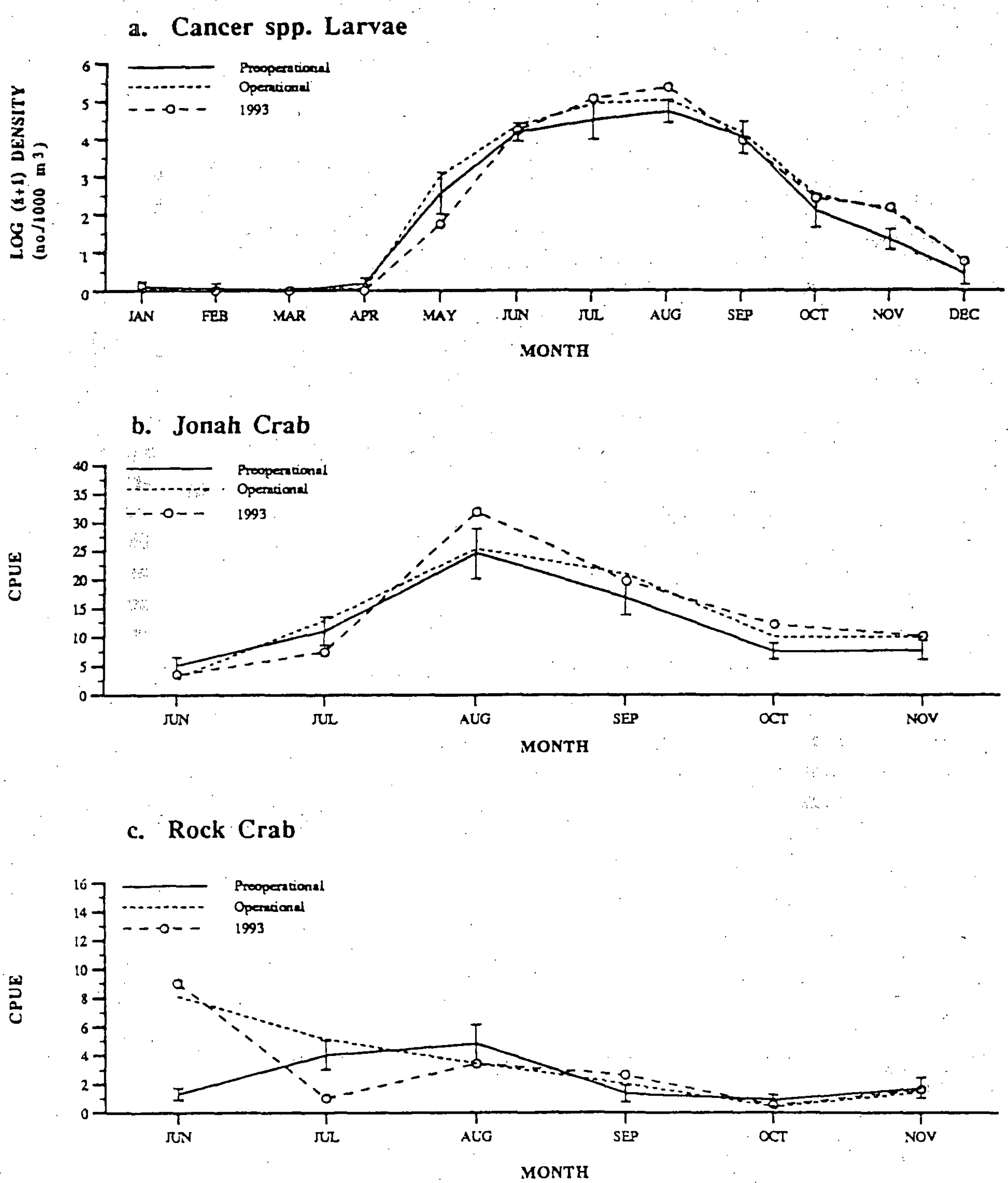


Figure 8-5. Monthly means and 95% confidence intervals of log (x+1) density (no./1000 m^3) of **a.** ***Cancer*** **spp.** larvae at Station P2, and monthly mean catch per unit effort (15 traps) of **b. Jonah** and **c. Rock crabs** at Station L1 during the preoperational period (1978-1984 + 1986-1989: larvae, 1975-1984 + 1986-1989: adults) and monthly means during the operational period (1991-1993) and in 1993. Seabrook Operational Report, 1993.

which may influence larval survival, molting and successful bottom settlement of Stage IV lobster. Juvenile lobsters in the study area are recruited from Stage IV larvae (the stage prior to benthic settlement), some of which are believed to originate offshore from the southwest waters of the Gulf of Maine and Georges Bank (Harding et al. 1983). Although the level of juvenile recruitment has been correlated with abundances of Stage IV larvae (Harding et al. 1982, Harding et al. 1983), others have failed to demonstrate this relationship (Fogarty and Idoine 1986). Recent research indicates that successful benthic recruitment of larval lobsters is affected more by habitat availability for the early benthic phase than by larval abundance (Wahle and Steneck 1991).

Lobster larvae have historically been relatively rare in the study area, averaging less than 1 per 1000 m^2. Lobster larvae density during the operational period was significantly higher than the preoperational average at all three stations (Table 8-1, Figure 8-2). Thus, increased densities appear to be part of an area-wide trend rather than an effect of plant operation. Densities of both Stage I and Stage IV larvae increased during the operational period. These density increases, particularly for Stage I larvae, may be related to the small increase in the percentage of egg-bearing females (Table 8-1, Figure 8-2). Distribution of Stage I larvae has been linked to brood stock distribution for the first time in Jaddore Harbor, Nova Scotia (Dibacco and Pringle 1992). Regional fishing regulations have increased

TABLE 8-3. SUMMARY OF POTENTIAL PLANT EFFECTS ON ABUNDANCE OF EPIBENTHIC CRUSTACEA. SEABROOK OPERATIONAL REPORT, 1993.

PARAMETER MEASURED	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD[a]	DIFFERENCES BETWEEN PREOPERATIONAL AND OPERATIONAL PERIODS CONSISTENT AMONG STATIONS[b]
Lobster: Larvae	Op>Preop	Yes
Lobster: Total Catch	Op<Preop	nearfield: Op<Preop farfield: Op<Preop
Lobster: Legal-Sized Catch	Op<Preop	Yes
Cancer spp.: Larvae	Op>Preop	Yes
Jonah Crab: Total Catch	Yes	nearfield: Op>Preop farfield: Op<Preop
Rock Crab: Total Catch	Op>Preop	Yes

[a]based on Preop-Op term of ANOVA model (Table 8-2)
[b]based on the interaction term (Preop-Op X Station) of the ANOVA model and multiple comparison test at $\alpha \leq 0.05$ (Table 8-2)

protection of the lobster population over the past decade, prohibiting harvest of egg-bearing females and V-notched females (marked while egg-bearing). The minimum legal size has been increased three times during the study period (1975-93). Even so, most females that are legal-sized (minimum carapace width of 83 mm) have not attained sexual maturity (90-100 mm, NH Fish and Game 1974, Mariano 1993). Despite this fact, the regulations may have helped to cause the slight increase in the proportion of egg-bearing females, and in turn resulted in increased numbers of larvae, especially Stage I, during the operational period.

Bottom dwelling juvenile and adult lobsters would most likely be susceptible to the potential effects of plant operation due to changes in their food sources that might result from the effects of increased detritus around the discharge area. Temperature in general can affect lobster activity, likelihood of capture, and migratory behavior (Dow 1969, Campbell 1986). However, changes in bottom temperature resulting from Seabrook Station are unlikely to occur because of the design of the discharge diffuser and the buoyancy of the discharge plume.

Decreases in lobster landings have been correlated with temperature decreases both in the current year and after a six-year lag period (Fogarty 1988, Campbell et al. 1991). The average annual bottom temperature at all three stations increased slightly in 1991, but declined in 1992 and declined further in 1993 (Section 2.0). The decline in CPUE at both stations during the 1991-93 operational period may be due to this decrease. Preliminary results from other studies have documented a similar decrease in catch coinciding with decreased water temperature in 1992 (Addison and Fogarty 1993).

The total catch of lobster was significantly lower at both stations during the operational period (as compared to the preoperational period) (Table 8-3), but the decline was greater at the farfield station. The decrease is not likely related to plant operation because it occurred at both the nearfield and farfield stations, as well as regionally (NOAA 1993).

The area-wide decline in total lobster CPUE observed in this study coincides with a regional decline. NOAA (1993) changed the status of the entire inshore/offshore population of lobster throughout its range, Gulf of Maine (71% of landings) through the mid-Atlantic, from "fully exploited" (NOAA 1992) to "over exploited." Intense commercial fishing may in part account for the significant decline in total lobster catch at both stations during the operational period. In 1992, the federal Autumn Survey Index (kg per trawl tow) decreased, as did the commercial landings. In response to the recent increases in legal-size limits, fishermen increased the number of pots fished inshore, as well as the areas fished (NOAA 1993). The inshore landings decreased by 13% between 1991 and 1992 (NOAA 1993), in spite of increased effort. NHFG (1993) also reported an overall decrease in the abundance of lobster sampled with lobster traps between 1992 and 1993 along the New Hampshire coast within three miles of shore.

In Maine, newly recruited legal-sized lobsters are almost completely harvested in the same year (Fogarty 1988). Historically, in this study, percentages of legal-sized lobsters have decreased with each increase in the legal-size limit, as would be expected. No difference was found between operational and preoperational catches of legal-sized lobsters at the nearfield and farfield stations (Table 8-3). Proportions of female lobsters were also consistent with previous years. The proportion of egg-bearing lobsters increased slightly (Table 8-3).

Impingement of lobsters in the cooling water system was not expected because of the off-bottom intake location. A total of 40 lobsters were impinged during the operational period (1990-93); nearly half (19) were sub-legal sized lobsters impinged after a severe north-easter in November, 1991. This level of impingement does not pose a threat to the local lobster population.

8.4.2 Jonah and Rock Crabs

Cancer spp. larvae abundance more than doubled during the operational period, compared to the preoperational period at each of the three stations (Table 8-1). Annual abundances were higher in 1991 (NAI 1992) and 1992 (NAI 1993) than in 1993. The changes indicate an area-wide trend that is unrelated to plant operation.

Jonah and rock crabs are taken incidentally in lobster traps and could be subject to the same potential for impact as lobsters. The Jonah crab catch in the operational period increased at the nearfield (L1) station during the operational period but decreased at the farfield (L7) station. The interaction between stations by period was significant (Table 8-3, Figure 8-3). At the nearfield station mean CPUE between the preoperational and operational periods increased by 1.6 crabs/15 traps, and at the farfield station mean CPUE decreased by 2.0 crabs/15 traps. These small changes may have been statistically significant in part due to the conservative nature of the analysis of variance model and may not be due to plant operation. These trends should be monitored closely in future reports.

Rock crab are less prevalent than their congener in the study area, probably because of their preference for sandy substrate (Jefferies 1966). Annual catches of rock crab were similar during the operational and preoperational periods at both near- and farfield stations (Table 8-3).

8.5 REFERENCES CITED

Addison, J. and M. Fogarty. 1993. Juvenile lobster habitat limitation: what can landings tell us. The Lobster Bull. 6(2):2.

Boudreau, B., Y. Simard and E. Bourget. 1991. Behavioral responses of the planktonic stages of the American lobster *Homarus americanus* to thermal gradients, and ecological implications. Mar. Ecol. Prog. Ser. 76:13-23.

Campbell, A. 1986. Migratory movements of ovigerous lobsters, *Homarus americanus*, tagged off Grand Manan, eastern Canada. Can. J. Fish. Aquat. Sci. 43:2197-2205.

Campbell, A., O.J. Noakes and R.W. Elmer. 1991. Temperature and Lobster, *Homarus americanus*, yield relationships. Can. J. Fish. Aquat. Sci. 48:2073-2082.

Dibacco, C. and J.D. Pringle. 1992. Larval lobster (*Homarus americanus*, H. Milne Edwards, 1837) distribution in a protected Scotian Shelf bay. J. Shell. Res. II(1):81-84.

Dow, R. 1969. Cyclic and geographic trends in seawater temperature and abundance of American lobster. Science 164:1060-1063.

Fogarty, M.J. 1988. Time series models of the Maine lobster fishery: the effect of temperature. Can. J. Fish. Aquat. Sci. 45:1145-1153.

Fogarty, M.J., and J.S. Idoine. 1986. Recruitment dynamics in an American lobster (*Homarus americanus*) population. Can. J. Fish. Aquat. Sci. 43:2368-2376.

Fogarty, M.J., and R. Lawton. 1983. An overview of larval American lobster *Homarus americanus*, sampling programs in New England during 1974-70. pp 9-14. In. M.J. Fogarty (ed.) Distribution and Relative Abundance of American Lobster, *Homarus americanus*, Larvae: New England Investigations During 1974-79, NOAA Tech. Rep. NMFS SSRF-775.

Grout, D.E., D.C. McInnes and S.G. Perry. 1989. Impact evaluation of the increase in minimum carapace length on the New Hampshire lobster fishery. N.H. Fish and Game Dept.

Harding, G.C., K.F. Drinkwater, and W.P. Vass. 1983. Factors influencing the size of American lobster (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. Can. J. Fish. Aquat. Sci. 40:168-184.

Harding, G.C., J.D. Pringle, W.P. Vass, S. Pearre, and S. Smith. 1987. Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. Mar. Ecol. Prog. Ser. 41:29-41.

Harding, G.C., and R.W. Trites. 1988. Dispersal of *Homarus americanus* larvae in the Gulf of Maine from Brown's Bank. Can. J. Fish. Aquat. Sci. 45:416-425.

Harding, G.C., W.P. Vass, and K.F. Drinkwater. 1982. Aspects of larval American lobster (*Homarus americanus*) ecology in St. Georges Bay, Nova Scotia. Can. J. Fish. Aquat. Sci. 39:1117-1129.

Jefferies, H.P. 1966. Partitioning of the estuarine environment by two species of *Cancer*. Ecology 47(3):477-481.

McLeese, D., and D.G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Bd. Can. 15:1345-1354.

Mariano, M. 1993. American lobster. NH Fish and Game and NOAA Agreement #M9270R0188-01. 4p.

New Hampshire Fish and Game Department. 1974. Investigation of American Lobsters (*Homarus americanus*) in New Hampshire Coastal Waters. 34 pp.

__________. 1992. Monitoring of the American lobster resource and fishery in New Hampshire - 1991. Performance Rep. subm Nat. Mar. Fish. Serv. Management Div. under contract no. NA16FI-0353-02. 28 pp.

__________. 1993. Monitoring of the American lobster resource and fishery in New Hampshire - 1991. Performance report submitted to the Nat. Mar. Fish. Serv. Management Div. under contract no. NA16FI-0353-02. 35 pp.

NOAA. 1992. Status of the fishery resources of the northeastern United States for 1992. NOAA Tech. Memo. NMFS-F/NEC-95. 133 p.

__________. 1993. Status of the fishery resources of the northeastern United States for 1993. NOAA Tech. Memo NMFS-F/NEC-101. 140 pp.

Normandeau Associates Inc. 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Rep. XXII-I.

__________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

Richards, R.A., J.S. Cobb, and M.J. Fogarty. 1983. Effects of behavioral interactions on the catchability of American lobster, *Homarus americanus*, and two species of Cancer crab. Fish. Biol. 81(1):51-60.

SAS Institute, Inc. 1985. User's Guide: Statistics, Version 5 edition. SAS Inst., Inc. Cary, N.C. 956 pp.

Wahle, R.A. and R.S. Steneck. 1991. Recruitment habitats and nursery ground of the American lobster *Homarus americanus*: a demographic bottleneck? Mar. Ecol. Prog. Series. 69:231-243.

TABLE OF CONTENTS

SUMMARY

Since 1978, the benthic macrofaunal communities in the Hampton-Seabrook area have been characterized in terms of species composition and abundance of dominant taxa in order to identify spatial and temporal patterns in community structure and to assess whether observed changes could be attributed to construction and operation of the Seabrook Station. The discharge of effluent from the plants' waste water treatment settling basin into Browns River had the potential to be a measurable impact on estuarine benthic communities. As in other temperate areas, spatial and temporal patterns of abundance, numbers of species and dominant taxa in intertidal and subtidal communities were largely controlled by the physical environment, and the most numerous species were those that tolerated fluctuating water temperature and salinity and changing sedimentary conditions. Macrofaunal species composition in Browns River nearby the outfall during 1993 was similar to that in Mill Creek, a control site located away from the influence of the settling basin discharge. The dominant taxa collected at both sites included the polychaetes *Streblospio benedicti*, *Capitella capitata*, and *Hediste diversicolor* and oligochaetes; all these organisms are classified as opportunists and have also predominated in previous study years. Total density, mean number of taxa and density of dominant taxa during 1993 were within the ranges reported since 1978 in the Seabrook study areas, suggesting that the settling basin discharge has not impacted the indigenous benthic community.

LIST OF FIGURES

PAGE

LIST OF TABLES

LIST OF APPENDIX TABLES

9.0 ESTUARINE STUDIES

9.1 INTRODUCTION

Environmental studies conducted in Hampton Harbor since 1978 have included monitoring of physical parameters (temperature and salinity), fish populations, benthic macrofauna, and juvenile and adult soft-shelled clams (*Mya arenaria*). Long-term data are needed to distinguish impacts of human activities on marine environments from the inherent variability of estuarine systems (Holland 1985; Nichols 1985; Holland et al. 1987; Warwick 1988; Rees and Eleftheriou 1989). Impact assessments, in general, are often difficult because of our lack of understanding of how physical and biological factors control the structure and function of benthic communities (Diaz and Schaffner 1990). To aid in our understanding, a time-series of data have been collected since 1978 at sites potentially affected by Seabrook Station (nearfield), and at sites in the estuary beyond power plant influence (farfield).

Among the possible impacts on estuarine benthic communities in the Hampton-Seabrook estuary related to the construction and operation of Seabrook Station, the effluent from the power plant waste water treatment settling basin into the Browns River had the potential to be a measurable impact. Outfall from this settling basin usually contained the freshwater discharge from the Station's sewage treatment plant and runoff from rainfall. During the construction of the Seabrook intake and discharge tunnels (1979-1983), the outfall became more saline due to dewatering of the tunnels, and volume of the discharge increased greatly. The effluent also contained higher than average levels of organic material, nutrients (nitrate, nitrite, and phosphate) and suspended solids, which consisted mainly of granite rock flour from tunnel drilling (NAI 1980a, 1981). Bioassays using undiluted effluent from the settling basin indicated that such effluent adversely affected sand shrimp (*Crangon septemspinosa*), but not soft-shelled clams (*Mya arenaria*; NAI 1979, 1980b). Once the tunnels were completed in 1983, the volume of water discharged from the settling basin diminished and has had no saline component.

Current estuarine monitoring efforts are directed to identify potential effects from either settling basin discharge or Seabrook Station operation. One of the main environmental issues in the Hampton-Seabrook estuary related to plant operation was whether the offshore intake and discharge could impact the adult soft-shell clam population in Hampton Harbor. The specific impact from entrainment of *Mya* larvae is discussed later in Section 10.0. The objectives of the estuarine benthos studies are to characterize the macrofaunal communities in the Hampton Harbor estuary in terms of abundance and species composition, to identify spatial and temporal patterns in community structure and abundance, and to assess whether observed changes are related to the construction and operation of Seabrook Station.

9.2 METHODS

9.2.1 Field and Laboratory

Surface temperature (°C) and salinity (ppt) were measured weekly during slack water at high and low tide at the Browns River Station (BR) and Hampton Harbor Station (HH; Figure 9-1). Precipitation was recorded continuously at the Seabrook Station meteorological tower.

Invertebrate sampling stations were located at Browns River (nearfield), just downstream from the settling pond outfall and Mill Creek (farfield), a tidal creek located southeast of the outfall (Figure 9-1). Macrofaunal samples were collected in subtidal (Browns River Station 3, Mill Creek Station 9) and intertidal areas at mean low water (Browns River

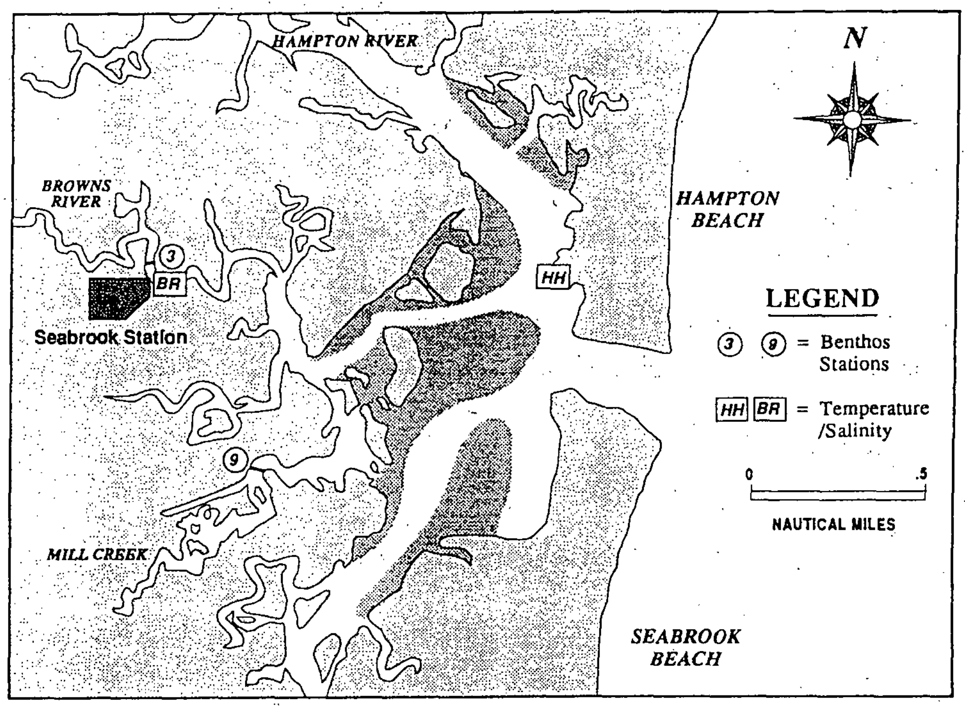


Figure 9-1. Hampton-Seabrook estuary temperature/salinity and benthos sampling stations. Seabrook Operational Report, 1993.

Station 3MLW, Mill Creek 9MLW) in May, August, and November since 1978 (excluding 1985, when sampling was suspended). SCUBA divers collected five samples (25 cm^2 x 10.2 cm deep) using an airlift system fitted with a 0.79 mm mesh bag. In the laboratory, all samples were washed through a 1.0 mm mesh sieve, preserved in 6% buffered formalin and sorted under dissecting microscopes. All non-colonial organisms were identified to the lowest possible taxon and counted (NAI 1990).

9.2.2 Analytical Methods

Weekly measurements of surface water salinity and temperature were averaged by month, and patterns of monthly and annual means were examined. Annual mean densities (no./m^2) of the total number of individuals and of dominant macrofaunal taxa were computed by averaging the $\log_{10}(x+1)$ transformed seasonal densities. The number of taxa in each season was computed by pooling all five samples collected by the divers; the three seasonal values (May, August, November) were averaged to calculate the annual mean. A one-way ANOVA was used to test for differences among years in total macrofaunal density, number of taxa, and density of individual dominant taxa. Significant differences ($\alpha \leq 0.05$) between multiple pairs of years were evaluated using the Waller-Duncan k-ratio t-test (SAS Institute Inc. 1988).

9.3 RESULTS AND DISCUSSION

9.3.1 Physical Environment

Salinity, Temperature, and Precipitation

Monthly averages of surface water salinity and temperature at high and low slack tides in Brown River and Hampton Harbor were used to examine seasonal and annual patterns of these parameters in the Hampton-Seabrook estuary. Monthly and annual patterns of precipitation were investigated using rainfall data collected at the Seabrook Station meteorological tower. The mean monthly salinity at low tide in Browns River during 1993 ranged from 17.9 ppt in March to 29.5 ppt in August. This pattern was similar to long-term averages, where monthly salinities were consistently lowest in April and highest in August (Figure 9-2). The monthly range in salinity at Hampton Harbor during 1993 was somewhat smaller (20.8 in April to 29.7 in July; Figure 9-2). The seasonal pattern of salinity corresponded to the seasonal variations in precipitation. On average, precipitation was highest in Spring (March and April) and Fall (October and November; Figure 9-2). Mean monthly precipitation at Seabrook Station during 1993 was highest in April (6.19 in), similar to long-term trends where precipitation was highest in April (4.58 in; Figure 9-2). Monthly rainfall values from May through August 1993 were among the lowest recorded since 1980. Total annual precipitation during 1993 was 39.3 inches, which was within the range of annual precipitation values reported since 1980 (28.7 to 46.3 in).

Salinities at both Browns River and Hampton Harbor were consistently lower at low tide than at high tide. During 1993, the mean salinities were 23.6 and 27.0 during low tide, and 29.7 and 29.6 during high tide at Browns River and Hampton Harbor, respectively (Table 9-1). At each site in 1993, the annual average salinities during both tidal stages were within the ranges of values reported since 1980. Relatively high salinities observed in the early 1980s were attributed to the dewatering of the intake and discharge tunnels during Seabrook Station construction, whereas the relatively high values in 1993 (particularly at low tide) were attributed to the unusually dry summer.

Mean monthly temperatures at Browns River, measured at low tide during 1993, ranged from 0.0°C in January to 27.0°C in July. The temperature range was smaller at Hampton Harbor (0.3°C in February to 19.8°C in August; Figure 9-3). At both sites, the monthly water temperatures during 1993 were similar to the monthly values reported since 1979.

In contrast to the lower salinity values recorded during low tide relative to those at high tide at each site, water temperatures were higher at low tide. Annual mean temperatures during 1993 were 12.1 and 9.5°C during low tide, and 10.4 and 8.7°C during high tide at Browns River and Hampton Harbor, respectively (Table 9-1). Temperatures at each site and tidal stage during 1993 were within the ranges of annual average temperatures reported since 1980.

When the two sites were compared, the ranges of water temperatures and salinities were consistently larger at Browns River than at Hampton Harbor during low tide. Over all years, water temperature averaged 11.4°C during low tide at Browns River, and 10.1°C at Hampton Harbor (Table 9-1). Conversely, the overall salinity at Browns River during low tide (21.3 ppt) was considerably lower than at Hampton Harbor (27.6 ppt; Table 9-1). Both patterns have resulted from the relative position of the sampling stations in the estuary, i.e., Browns River is located farther up the estuary, and more influenced by freshwater runoff, while Hampton Harbor is nearer the mouth of the estuary, and more influenced by Gulf of Maine water.

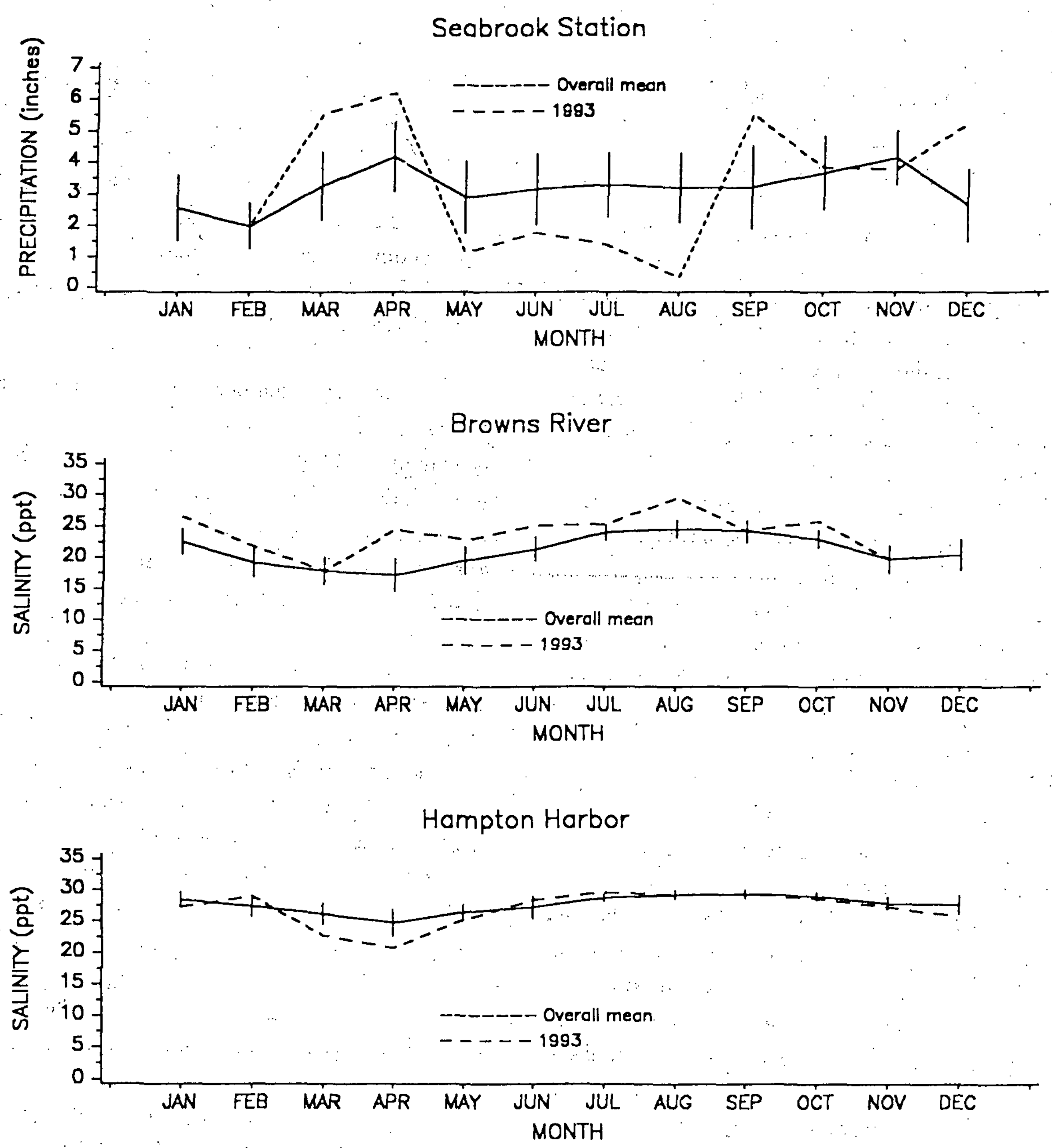


Figure 9-2. Monthly means and 95% confidence limits for precipitation measured at Seabrook Station from 1980-1992 (excluding 1984-1986) and surface salinity measured at low tide in Browns River and Hampton Harbor from May 1979-December 1992 and monthly means in 1993. Seabrook Operational Report 1993.

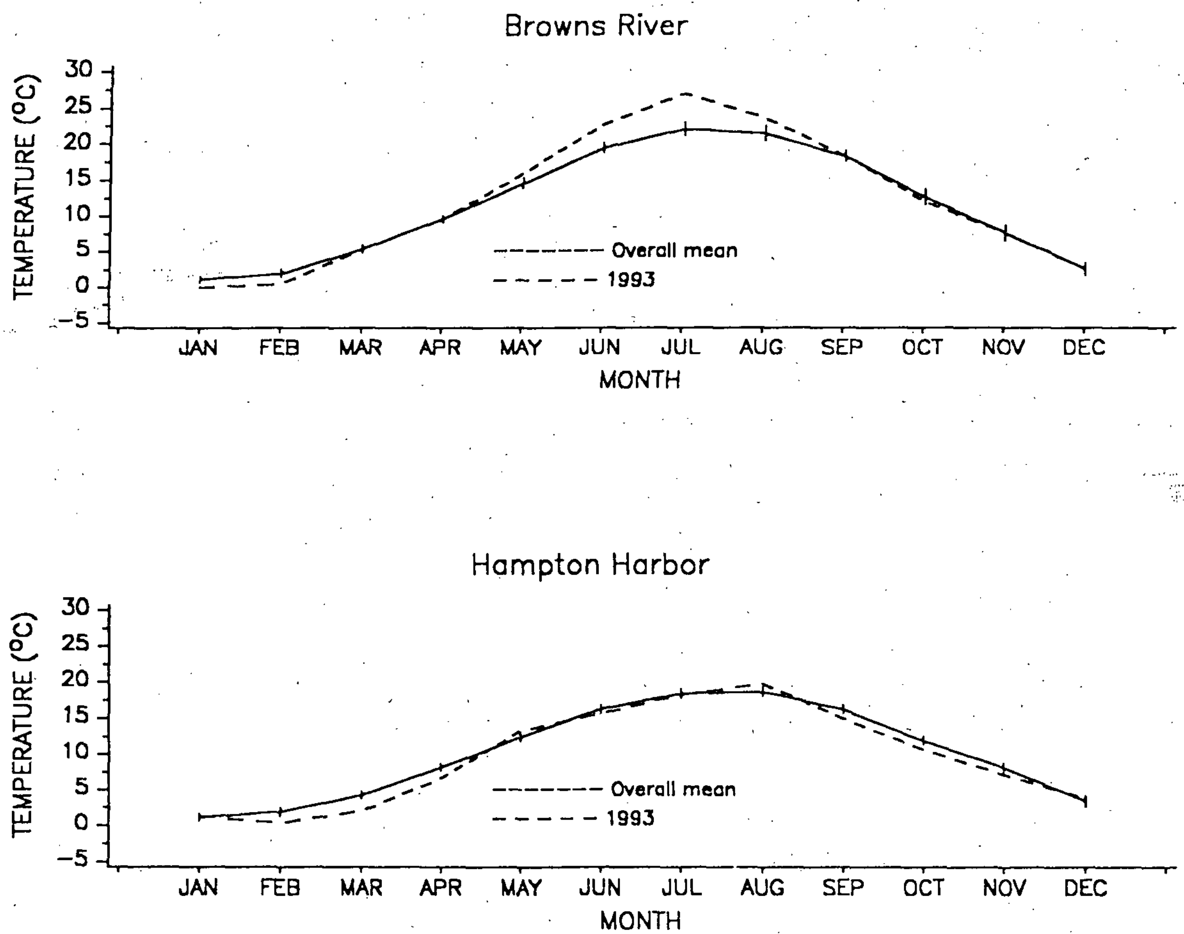


Figure 9-3. Monthly means and 95% confidence limits for temperature measured at low tide in Browns River and Hampton Harbor from May 1979-December 1992 and monthly means in 1993. Seabrook Operational Report 1993.

TABLE 9-1. ANNUAL MEAN WITH 95% CONFIDENCE INTERVAL FOR SALINITY (ppt) AND TEMPERATURE (^{o}C) TAKEN AT BOTH HIGH AND LOW SLACK TIDE IN BROWNS RIVER AND HAMPTON HARBOR DURING 1980-1993. SEABROOK OPERATIONAL REPORT, 1993.

SALINITY

	BROWNS RIVER		HAMPTON HARBOR	
	LOW TIDE	HIGH TIDE	LOW TIDE	HIGH TIDE
1980	25.1 ± 1.9	31.0 ± 1.6	29.9 ± 1.4	32.0 ± 0.5
1981	25.5 ± 1.6	30.0 ± 1.7	28.9 ± 1.1	31.5 ± 0.4
1982	22.8 ± 1.8	30.0 ± 1.2	27.3 ± 1.5	31.2 ± 0.6
1983	19.4 ± 3.6	28.0 ± 1.9	25.5 ± 2.4	30.1 ± 0.9
1984	18.1 ± 3.3	28.4 ± 1.8	25.8 ± 2.3	30.2 ± 0.9
1985	21.7 ± 2.1	30.6 ± 0.7	29.1 ± 1.0	32.2 ± 0.3
1986	20.4 ± 3.1	30.2 ± 0.9	27.7 ± 1.3	31.5 ± 0.4
1987	20.3 ± 2.7	28.9 ± 1.8	27.5 ± 2.2	30.7 ± 0.9
1988	20.5 ± 2.2	29.8 ± 0.7	27.8 ± 1.0	31.3 ± 0.4
1989	20.2 ± 2.5	30.0 ± 0.7	28.0 ± 1.2	31.4 ± 0.7
1990	19.5 ± 2.7	29.6 ± 1.4	27.2 ± 1.2	31.3 ± 0.6
1991	19.4 ± 1.9	29.6 ± 1.3	28.0 ± 0.9	30.9 ± 0.4
1992	21.9 ± 1.5	29.6 ± 0.8	27.2 ± 1.6	29.4 ± 1.6
1993	23.6 ± 2.1	29.7 ± 1.1	27.0 ± 1.8	29.6 ± 1.1
ALL	21.3 ± 0.6	29.7 ± 0.3	27.6 ± 0.4	31.0 ± 0.2

TEMPERATURE

	BROWNS RIVER		HAMPTON HARBOR	
	LOW TIDE	HIGH TIDE	LOW TIDE	HIGH TIDE
1980	10.9 ± 5.2	9.6 ± 4.4	9.6 ± 4.4	9.1 ± 3.6
1981	10.6 ± 4.4	10.3 ± 4.6	10.1 ± 4.4	9.3 ± 3.8
1982	10.7 ± 4.5	9.9 ± 4.2	10.2 ± 4.1	9.2 ± 3.5
1983	11.9 ± 5.0	11.0 ± 4.2	10.4 ± 4.3	9.9 ± 3.4
1984	11.9 ± 5.1	10.6 ± 3.9	10.4 ± 4.1	9.4 ± 3.1
1985	11.3 ± 5.0	10.1 ± 4.4	10.6 ± 4.2	10.1 ± 3.3
1986	10.3 ± 4.8	9.6 ± 4.0	10.0 ± 3.9	9.4 ± 3.0
1987	11.5 ± 5.1	9.7 ± 4.1	10.0 ± 4.3	8.9 ± 3.5
1988	10.6 ± 5.1	10.3 ± 4.0	9.7 ± 3.9	9.2 ± 3.3
1989	11.5 ± 5.4	10.1 ± 3.9	10.2 ± 4.4	9.2 ± 3.3
1990	12.6 ± 5.3	11.0 ± 4.4	10.3 ± 4.3	9.7 ± 3.6
1991	12.4 ± 5.0	11.7 ± 4.1	11.1 ± 4.0	9.8 ± 3.1
1992	11.7 ± 5.2	11.1 ± 3.7	9.1 ± 4.0	8.6 ± 2.9
1993	12.1 ± 5.9	10.4 ± 3.8	9.5 ± 4.4	8.7 ± 3.5
ALL	11.4 ± 1.2	10.4 ± 1.0	10.1 ± 1.0	9.3 ± 0.8

9.3.2 Macrofauna

The general macrobenthic community structures at both nearfield (Browns River 3 and 3MLW) and farfield (Mill Creek 9 and 9MLW) stations in the vicinity of Seabrook Station were typical for East Coast estuarine areas with fine-grained sediments (Watling 1975; McCall 1977; Whitlatch 1977; Santos and Simon 1980; Whitlatch and Zajac 1985). Sediments at subtidal stations were generally fine sand with organic carbon ranging from 1.0 to 2.7%; at intertidal stations the sediments usually varied between fine sand and silt with organic carbon ranging from 1.6 to 5.9% (NAI 1985). Wide temporal and spatial fluctuations were observed in the total density of macrofauna inhabiting the soft-bottom habitats of the Hampton-Seabrook estuary. Species abundance and dominance in the estuary are generally controlled by the physical environment, and the most numerous species are those that tolerate fluctuating water temperature and salinity and a changing sedimentary environment (Flint 1985; Diaz and Schaffner 1990).

Total macrofaunal density averaged 4062 individuals/m^2 at all sites during 1993, and was within the range of densities reported since 1978 (995-8424/m^2; Table 9-2). More organisms were collected during 1993 at intertidal nearfield (3MLW-4774/m^2) and farfield (9MLW-5461/m^2) sites than were collected at subtidal sites (3955/m^2 and 2641/m^2 at 3 and 9, respectively; Table 9-2). Total macrofaunal densities during 1993 at Browns River and Mill Creek intertidal sites (3MLW and 9MLW, respectively) were within the 95% confidence limits calculated for the 15 year time-series. Farfield subtidal (Station 9) macrofaunal density during 1993 was also within the 95% confidence limits; however, the 1993 nearfield (Station 3) subtidal density of 3955 individuals/m^2 was the fifth largest reported since 1978 and well above the upper 95% CL of 3474/m^2 (Table 9-2). Significant annual differences were observed in total density at all four stations (Table 9-3). In general, faunal densities at all sites were highest from 1980 to 1982 and results of the one-way ANOVAs indicated that total densities from 1980 through 1982 were significantly higher than those during other study years (Table 9-3).

Mean number of taxa collected at subtidal sites during 1993 was higher at Browns River (n=38) than at Mill Creek (n=26); mean numbers of taxa collected at the corresponding intertidal sites (3MLW and 9MLW) were 24 and 27, respectively (Table 9-2). With the exception of the Browns River subtidal site, mean numbers of taxa at all other sites during 1993 were below the lower 95% CL computed for the 15-year time-series (Table 9-2). Similarly, results of ANOVAs indicated significant variation in the annual mean number of taxa collected at all sites except Browns River subtidal (Table 9-3). Annual values for mean taxa followed a pattern similar to that observed for total density. Mean numbers of taxa were highest during 1980-1982, when settling basin discharges were also highest.

Streblospio benedicti, a small deposit-feeding polychaete, is widespread on the western and eastern coasts of North America and in Europe. Characterized as an opportunist (Grassle and Grassle 1974), *S. benedicti* is able to rapidly colonize perturbated estuarine environments, and high abundance of this species has also been suggested as an indicator of organic enrichment (Wass 1967). This polychaete was the most abundant species in the Hampton-Seabrook estuary and accounted for 7% of the total faunal density at subtidal and 16% at intertidal stations over the 16-year study period. During 1993, densities of *S. benedicti* were substantially higher at the nearfield Browns River stations (293/m^2 and 1977/m^2 at subtidal and intertidal areas, respectively) than at the farfield Mill Creek stations (76/m^2 and 27/m^2, respectively; Table 9-2). *S. benedicti* density at Browns River subtidal

TABLE 9-2. MEAN NUMBER OF TAXA AND GEOMETRIC MEAN DENSITY (No./m²) FOR EACH YEAR AND OVER ALL YEARS WITH 95% CONFIDENCE LIMITS FROM ESTUARINE STATIONS AT BROWNS RIVER SUBTIDAL (3) AND INTERTIDAL (3MLW) AND MILL CREEK SUBTIDAL (9) AND INTERTIDAL (9MLW) SAMPLED FROM 1978 THROUGH 1993 (EXCLUDING 1985). SEABROOK OPERATIONAL REPORT, 1993.

																	ALL YEARS[c]		
	Station	1978	1979	1980	1981	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	MEAN	UCL[d]	LCL[d]
Total	3	3170	4616	4978	5360	9331	2635	1244	1182	1198	3472	2583	1707	1889	2253	3955	2771	3474	2210
Density[a]	9	3619	2209	14,767	11,277	4335	4533	620	2819	726	4764	1878	2488	5373	2178	2641	3095	4286	2235
	3MLW	4260	6136	5695	6833	8022	2723	2187	5632	1727	3936	6940	1778	6834	4842	4774	4338	5320	3537
	9MLW	3120	4512	6947	12,189	11,383	11,151	5131	4203	653	6115	7525	3845	3572	4997	5461	5063	6808	3765
	ALL	3514	4099	7344	8424	7796	4364	1715	2980	995	4467	3990	2321	3967	3301	4062	3704	4251	3228
Mean No.	3	35	41	38	42	47	32	27	38	33	38	38	35	32	34	38	36	39	34
of Taxa[b]	9	26	34	47	44	34	36	21	36	21	27	25	31	30	31	26	31	34	28
	3MLW	28	37	31	38	35	28	18	32	23	31	31	28	25	26[b]	24	29	31	27
	9MLW	28	35	35	41	36	33	21	36	16	29	29	36	25	33	27	31	33	28
	ALL	29	37	38	41	38	32	22	35	23	31	31	33	28	31	29	32	33	31
Streblospio	3	367	123	193	525	1064	552	239	99	66	550	181	56	462	160	293	240	347	166
benedicti	9	106	26	2396	525	81	538	16	161	49	744	167	400	1612	296	76	202	377	108
	3MLW	439	505	1010	928	3584	525	535	1421	316	1306	3227	259	3301	1635	1977	1006	1441	703
	9MLW	566	434	466	2700	2354	3215	1560	1299	11	744	399	1023	604	231	27	525	964	286
	ALL	314	163	684	912	925	842	242	415	58	794	445	278	1105	366	187	400	524	306
Oligochaeta	3	242	270	204	651	2189	556	225	95	133	768	301	156	233	421	392	322	452	230
	9	16	100	2910	969	1058	1603	162	528	131	272	233	260	525	293	140	317	503	199
	3MLW	87	186	318	320	350	292	382	968	215	322	409	48	197	428	334	267	385	184
	9MLW	574	810	1067	861	565	2877	572	742	161	351	2888	362	610	2024	1680	802	1228	523
	ALL	119	253	671	646	823	931	298	437	157	392	537	163	348	572	419	384	474	312
Capitella	3	11	63	123	473	889	216	66	73	57	105	72	16	33	153	268	94	153	58
capitata	9	238	29	2453	277	291	376	28	808	113	1530	262	259	479	220	1042	302	478	191
	3MLW	17	29	138	244	540	208	124	197	26	46	27	24	10	57	62	65	98	43
	9MLW	279	45	125	320	276	800	303	234	19	1068	173	466	143	181	208	211	328	136
	ALL	60	40	269	318	443	341	91	228	42	299	98	84	71	137	245	141	179	110

(continued)

TABLE 9-2. (Continued)

	Station	1978	1979	1980	1981	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	ALL YEARS[c] MEAN	UCL[d]	LCL[d]
Hediste diversicolor	3	83	172	158	352	452	45	50	52	43	128	52	38	64	50	342	96	133	69
	9	21	29	41	205	41	7	7	43	2	33	29	8	45	35	82	26	40	17
	3MLW	800	1343	1169	1613	975	220	296	987	150	523	1235	199	1906	1105	1120	710	1026	491
	9MLW	170	164	101	241	135	57	513	184	6	29	93	18	30	25	89	74	115	48
	ALL	125	183	167	410	223	45	89	143	18	90	115	33	115	84	230	107	140	82
Mya arenaria	3	69	158	92	181	132	75	31	21	30	12	35	64	7	17	49	45	67	30
	9	265	427	299	246	148	168	157	34	53	83	69	208	48	32	82	116	165	81
	3MLW	106	224	26	179	117	103	22	13	27	12	73	25	22	31	91	48	73	31
	9MLW	100	328	62	400	141	70	86	13	73	39	425	266	102	107	309	117	172	80
	ALL	118	265	82	237	134	98	55	19	42	26	93	98	30	37	103	74	90	60
Spio setosa	3	38	39	65	155	159	120	113	151	171	244	447	334	376	267	254	156	212	114
	9	50	59	287	346	170	16	3	75	6	315	236	110	158	66	42	71	125	40
	3MLW	7	9	8	6	4	8	2	46	25	46	24	26	8	2	5	10	16	6
	9MLW	54	59	43	78	48	30	8	65	2	32	41	117	46	5	3	27	47	15
	ALL	30	33	51	72	51	26	10	76	16	104	102	103	70	22	21	42	56	31
Caulleriella sp. B	3	330	221	835	1	2	3	12	9	1	101	7	6	24	10	103	20	40	10
	9	10	40	46	292	136	35	7	10	3	16	4	4	75	27	34	22	44	11
	3MLW	106	174	607	3	23	52	44	255	87	244	80	28	4	9	90	54	95	31
	9MLW	8	298	48	43	1634	278	325	307	1	21	3	8	8	22	6	37	79	17
	ALL	42	147	183	17	64	37	34	53	5	54	10	9	16	15	38	31	43	22

[a] Yearly mean density = mean of three seasonal means (where seasonal mean = mean of five replicates).
[b] Yearly mean number of taxa = mean of three seasonal totals (where seasonal total = total number in all five 1/16 m^2 replicates combined). In August 1992 at Station 3MLW, the total number of replicates was four, not five.
[c] Mean of all years = mean of 45 seasonal means (3 seasons x 15 years).
[d] Upper and lower 95% confidence limits.

TABLE 9-3. RESULTS OF ONE-WAY ANALYSIS OF VARIANCE AMONG YEARS FOR MEAN TOTAL DENSITY (No./m^2), MEAN NUMBER OF TAXA (per 5/16 m^2) AND LOG10 (x+1) TRANSFORMED DENSITY (No./m^2) OF THE MOST ABUNDANT ESTUARINE SPECIES OF MACROFAUNA COLLECTED AT FOUR ESTUARINE STATIONS FROM 1978 THROUGH 1993 (EXCLUDING 1985). SEABROOK OPERATIONAL REPORT, 1993.

PARMETER[a]	STATION	F[b]	MULTIPLE COMPARISONS[c] - SUBTIDAL STATIONS
Mean Density (All spp.)	3	3.63**	82>78,83,84,86,87,89-92; 81>84,86,87,90; 79,80,93>84,86,87
	9	3.09**	80>79,84,86,87,89,90,92,93; 81>84,87,89,92; 82,83,88,91>84,87
Mean Number of Taxa	3	1.66 NS	
	9	4.86**	80>78,79,82-84,86-93; 81>78,84,87-93; 79,82,83,86,>84,87
Streblospio benedicti	3	1.84 NS	
	9	1.85 NS	
Oligochaeta	3	1.91 NS	
	9	4.13**	80>78-79,84,87-90,92,93; 83>78,79,84,87,93; 81,82>78,79; 88-90,92>78; 84,87-93>78
Capitella capitata	3	2.14*	82>78,87,90,91; 81,93>78,90; 83>78
	9	3.80*	80>78,79,81,82,84,87,89,90,92; 88,93>79,84,87; 78,81-83,86,89-91>79,84
Hediste diversicolor	3	2.89**	82>78,83,84,86,87,89-92; 81,93>83,84,86,87,89-92
	9	2.38*	81>83,84,87,90; 93>83,87; 79,80,82,86,88,89,91,92>87
Mya arenaria	3	2.19*	79,81>88,91,92; 82>88,91; 78,80,83>91
	9	1.87 NS	
Spio setosa	3	2.34*	89,91>78-80; 88,90,92,93>78,79
	9	2.15*	80-82,88,89,91>84,87; 90>84
Caulleriella sp. B	3	5.41**	80>81-84,86,87,89-92; 78,79>81-84,86,87,89,90,92; 88,93>81-83,87
	9	1.01 NS	

(continued)

TABLE 9-3. (Continued)

PARMETER[a]	STATION	F[b]	MULTIPLE COMPARISONS[c] - INTERTIDAL STATIONS
Mean Density (All spp.)	3MLW	2.50*	81-82,89,91>84,87,90; 79,80,86>90,87
	9MLW	2.09*	81-86,88-93>87
Mean Number of Taxa	3MLW	3.03**	79,81>84,87,91-93; 82>84,87,93; 80,86,88,89>84
	9MLW	2.70*	81>84,87,91; 79,80,82,86,90>84,87; 83,88,92>87
Streblospio benedicti	3MLW	2.14*	82,91>78,87,90; 89>87,90; 93>90
	9MLW	3.02**	78,81-84,86,88,90,91>87,93; 79,80,89,92>87
Oligochaeta	3MLW	0.96 NS	
	9MLW	0.95 NS	
Capitella capitata	3MLW	4.16**	82>78,79,87-93; 81,83,86>78,79,87,89-91; 80,84>78,91; 83,88>79,87; 78,81,82,84,90>87
	9MLW	1.70 NS	
Hediste diversicolor	3MLW	1.62 NS	
	9MLW	3.11**	84>83,87,88,90-92; 81>87,90,92; 78,86>87,90; 79,80,82,89,93>87
Mya arenaria	3MLW	1.72 NS	
	9MLW	2.40*	79,81,89,>86,88; 82,90,93>86
Spio setosa	3MLW	1.06 NS	
	9MLW	1.41 NS	
Caulleriella sp. B	3MLW	3.15**	80>81,82,90-92; 79,86,88>81,91,92; 78,87,89,93>81,91
	9MLW	3.64**	82>78,80,81,87-93; 79,84,86>78,87,89-91,93

[a] Degrees of freedom for the model (years) = 14; Degrees of freedom for the error = 30;
[b] NS = Not significant (p>0.05); * = Significant (0.05≥p>0.01); ** = Highly significant (p≤0.01);
[c] Multiple comparison test is Waller-Duncan k-ratio t test with alpha = 0.05. Groups are in order of decreasing abundance. Statistically similar groups that include either the years of highest or lowest values are separated by (;). Intermediate years may overlap with the highest and/or lowest groups.

during 1993 was within the 95% CL for all years; However, the 1993 intertidal density was higher than the upper CL value of $1441/m^2$. Densities of this species at both Mill Creek sites were below the lower 95% CL for the 15-year time-series (Table 9-2). Because of the high population fluctuations of *S. benedicti*, particularly at Mill Creek intertidal (e.g., $3215/m^2$ in 1983 to $11/m^2$ in 1987), significant annual differences were observed at both nearfield and farfield intertidal sites; by contrast, annual variation in *S. benedicti* abundance was not significant at Browns River or Mill Creek subtidal sites (Table 9-3).

Oligochaetes are small deposit feeding annelids that can be very abundant in organically enriched shallow-water marine habitats, feeding on microbes that colonize organic detritus (Soulsby et al. 1982; Hull 1987). As the amount of detrital material varies both spatially and temporally, oligochaete abundance can exhibit rapid and large fluctuations (Giere 1975; Price and Hylleberg 1982). Oligochaetes were the second most abundant taxon collected, comprising on average 11% of the total number of individuals collected at both intertidal and subtidal stations. Densities of oligochaetes during 1993 at Browns River subtidal ($392/m^2$) and intertidal ($334/m^2$) were similar and within the 95% CL of previous study years (Table 9-2). At the Mill Creek subtidal site, however, oligochaete density during 1993 was $140/m^2$, which was considerably lower than the 1680 individuals/m^2 collected intertidally (9MLW) and below the subtidal lower CL of $199/m^2$ for the past 16 years (Table 9-2). Significant annual differences in oligochaete density were observed at the Mill Creek subtidal site over the 16-year study period (Table 9-3). Although the 1993 density of oligochaetes at Mill Creek intertidal was above the upper 95% CL, there were no significant differences among the annual mean densities during the study period (Table 9-3), and no significant annual differences in oligochaete densities were observed at either Browns River site.

The polychaete genus *Capitella* occurs worldwide (Hartman 1969; Wade 1972) and, as an opportunist, is a good indicator of a wide variety of environmental stresses (Wass 1967). *C. capitata*, a sedentary tube-dwelling deposit-feeding polychaete, is commonly found in oxygen-depleted estuaries and harbors where sedimentation rates are high (Reish 1967). *C. capitata* was also present in high numbers at Seabrook estuarine study sites. During 1993, *C. capitata* densities at Browns River and Mill Creek subtidal sites were 268 and $1042/m^2$, respectively, the third largest values reported at each site since 1978 and above the upper 95% CL computed for the 15-year time series (Table 9-2). Intertidal densities for *C. capitata* at both the nearfield and farfield sites during 1993 were within the 95% CL of previous study years. Differences among annual densities of *C. capitata* were significant at all stations except the Mill Creek intertidal site (9MLW; Table 9-3).

The clam worm *Hediste diversicolor* inhabits near-shore marine sediments from the North Atlantic and North Sea to the Mediterranean (Gosner 1971). This relatively large polychaete has often been identified as an "indicator of organic pollution" because of its frequent abundance in nutrient rich areas (Hull 1987). *H. diversicolor* is a common member of the macrofaunal community in Hampton-Seabrook estuary, with densities during these studies averaging just over $100/m^2$. During 1993, mean densities of *H. diversicolor* at the nearfield Browns River subtidal and intertidal sites were 342 and $1120/m^2$, respectively, and were considerably higher than the densities at the farfield Mill Creek sites ($82/m^2$ and $89/m^2$; Table 9-2). With the exception of the Mill Creek intertidal station, the 1993 densities of *H. diversicolor* at all stations were above the upper 95% CL computed for previous study years (Table 9-2). Significant differences among years occurred at all stations except Browns River intertidal (3MLW), where *H. diversicolor* was consistently most abundant (ANOVA results; Table 9-3).

The soft-shelled clam *Mya arenaria* is harvested in great numbers from mud flats in New England (Abbott 1974). In Hampton Harbor, *M. arenaria* had important commercial value until 1989, when flats were closed to shellfishing due to coliform contamination (NAI 1993). The predominant life stage of *M. arenaria* collected in estuarine samples were young-of-the-year (spat <5 mm) and juvenile clams (<12 mm). Mean clam densities during 1993 at Browns River subtidal ($49/m^2$) and intertidal sites ($91/m^2$) were lower than the densities at Mill Creek subtidal ($82/m^2$) and intertidal sites ($309/m^2$). The 1993 subtidal densities of *M. arenaria* at the nearfield and farfield sites were within the 95% CL of previous study years; however, both intertidal densities were above the upper 95% CL. Significant annual differences in *Mya* density occurred only at Stations 3 and 9MLW (Table 9-3).

The tube-dwelling polychaete *Spio setosa* is most common in sandy, shelly subtidal areas where it feeds on suspended particles (Dauer et al. 1981). In the Hampton-Seabrook estuary, *S. setosa* was more common in subtidal collections, particularly at Browns River, and uncommon in intertidal collections. During 1993, mean densities of *S. setosa* at Browns River subtidal ($254/m^2$) were above the upper 95% CL of previous studies. *S. setosa* mean densities at Mill Creek subtidal were within the 95% CL, while densities at both intertidal sites were below the lower 95% CL. No significant differences in *S. setosa* density occurred among years at either of the intertidal stations; however, densities at both subtidal stations exhibited significant annual variability (Table 9-3).

The polychaete *Caulleriella* sp. B, occasionally abundant in the Hampton-Seabrook estuary, has exhibited wide density fluctuations from one year to the next since 1980 at both nearfield and farfield sites (e.g., 835 to $1/m^2$ at Station 3 from 1980 to 1981 and 43 to $1634/m^2$ at Station 9MLW from 1981 to 1982; Table 9-2). Densities of *Caulleriella* sp. B during 1993 were higher at Browns River ($103/m^2$ subtidal and $90/m^2$ intertidal) than at Mill Creek ($34/m^2$ and $6/m^2$ for subtidal and intertidal sites, respectively; Table 9-2). Although subtidal densities of this species at Browns River (Station 3) during 1993 were above the upper 95% CL, densities at Mill Creek (Station 9) were within the 95% CL of previous study years (Table 9-2). At the intertidal stations, *Caulleriella* sp. B densities during 1993 were within the 95% CL at 3MLW and below the lower CL at 9MLW. Significant annual differences in abundance occurred at all stations except the Mill Creek subtidal station (Table 9-3).

9.4 CONCLUSIONS

9.4.1 Physical Environment

Physical factors such as temperature and salinity are important in controlling and structuring soft-bottom communities in the Hampton-Seabrook estuary. The predictable seasonal cycles of temperature and salinity provide valuable information for interpreting changes in macrofaunal abundance and community composition. Maximum temperatures usually occur in July or August, with minima in January or February. Temperatures in Browns River from June to August 1993 were warmer than average, but the overall annual average was near the 16-year mean temperature. Salinity levels had a less distinct seasonal cycle than did temperatures, but were usually lowest in Spring coincident with increased runoff, and highest in Summer due to decreased precipitation. The Summer of 1993 was particularly dry, and as a result, monthly salinities in Browns River were above average. During a three year period from

1980 to 1982, salinities in Browns River were among the highest observed in this study (especially at low water), and coincided with low precipitation and highest discharge volume from the Seabrook Station settling basin. This was the period when the maximum dewatering of the intake and discharge tunnels took place, causing the salinity of the pond's discharge water to be relatively high. Since the decrease of discharge volumes in 1983, salinity levels in Browns River have also decreased and remained at levels typical of estuarine environments.

9.4.2 Macrofauna

The benthic macrofaunal community in the Hampton-Seabrook estuary was representative of other communities reported throughout New England. Species composition in Browns River (Stations 3 and 3MLW) and Mill Creek (Stations 9 and 9MLW) was similar to that described in other estuaries along the Atlantic Coast (Watling 1975; McCall 1977; Whitlatch 1977; Santos and Simon 1980; Whitlatch and Zajac 1985). As in most other temperate areas, spatial and temporal patterns of abundance, numbers of species, and dominant taxa comprising intertidal and subtidal communities were largely determined by physical and chemical characteristics of the soft bottom (Rhoads et al. 1978; Flint 1985). The small sedentary deposit feeders, *Streblospio benedicti, Capitella capitata, Hediste diversicolor*, and oligochaetes have predominated in the macrofaunal collections since 1978. These organisms have been classified as opportunists and are characterized by rapid development, several reproductions per year, and high recruitment and mortality (Grassle and Grassle 1974; McCall 1977; Rhoads et al. 1978). As a result of these life history strategies and the natural variability in physical and chemical properties of this estuary, significant annual variation was observed in total macrofaunal density, mean number of taxa, and density of most of the dominant organisms. Changes such as these are typical of those in marine benthic communities following disturbance (Kaplan et al. 1974; Sanders et al. 1980; Swartz et al. 1980; Nichols 1985; NUSCO 1987, 1993; Berge 1990).

The number of species collected and macrofaunal densities were highest from 1980 to 1982, most likely due to a combination of low precipitation and higher discharge rates from the settling basin. Also during this period, the discharge contained higher than average levels of nutrients, organic matter and suspended solids (NAI 1980a, 1981). The increased volume of discharge water during 1980-1982 may have disturbed the established faunal community in Browns River, which was rapidly colonized by opportunist species such as *S. benedicti, C. capitata, H. diversicolor*, and oligochaetes. However, since changes in total density and density of dominants occurred simultaneously at Browns River and Mill Creek, they were probably related to area-wide changes in natural abiotic (precipitation, temperature, salinity) and/or biotic (predation, competition) factors. Nevertheless, settling basin discharge volumes were lower in 1983 and this was followed by lower total density and the lowest number of taxa in 1984. Macrofaunal density increased by 1986 and then decreased again in 1987. These rapid changes were apparently related to high precipitation and low salinity (NAI 1988, 1992). The macrofaunal community recovered within one to two years, and since then, total density and number of taxa have been less variable (NAI 1993).

Although mean total macrofaunal density and mean number of taxa collected at each station during 1993 were within the range of annual values reported since 1978, the 1993 mean total density and number of taxa were outside the 95% confidence limits computed for the 16-year time series. Although not extremes in the 16-year time-series, 1993 macrofaunal densities were higher than in many

TABLE 9-4 SUMMARY OF EVALUATION OF EFFECTS OF SEABROOK STATION OPERATION ON BENTHIC MACROFAUNA OF HAMPTON HARBOR ESTUARY. SEABROOK OPERATIONAL REPORT, 1993.

COMMUNITY/ SPECIES	WAS 1993 SIMILAR TO PREVIOUS YEARS?[a]
Number of taxa	Yes
Total density	Yes
Streblospio benedicti	Yes
Oligochaeta	Yes
Capitella capitata	Yes
Hediste diversicolor	Yes
Mya arenaria	Yes
Caulleriella sp. B	Yes
Spio setosa	Yes

[a] Results based on ANOVA (see Table 9-3).

previous years. Densities of the opportunistic species *C. capitata* and *H. diversicolor* increased at all sites from 1992 to 1993 and the density of *S. benedicti* at Browns River also increased in 1993. These changes were probably related to higher than average precipitation in March and April 1993, which increased freshwater inputs and likely resuspended sediments in the estuary. Similar correlations between sediment resuspension, as mediated by waterflow, and macrofaunal colonization by opportunistic species has been demonstrated in another New England estuary (Alewife Cove, New London CT; Zajac and Whitlatch 1982). In that study, a strong seasonal pulse of sedimentation due to increased ice melt and runoff coincided with an increase in faunal density one to two months later. In Seabrook study areas, although the densities of some species increased in 1993 relative to 1992, densities of the dominant species were within the density ranges reported since 1978. Additionally, the 1993 increases occurred at both the nearfield Browns River and farfield Mill Creek stations, and the results of ANOVAs of total density, number of taxa, and density of selected species indicated that 1993 data were similar to previous years (Tables 9-3 and 9-4). Furthermore, since 1986, the discharge volume has been reduced to approximately 10% of the volume discharged during 1980-1982. This suggests that the settling basin discharge into Browns River has not negatively impacted the indigenous benthic community. Also, the settling basin discharge was diverted to open ocean via the circulating water system in April 1994 (R. Sher, NAESCO, pers. comm.).

In general, the data on estuarine macrofaunal abundance collected during these studies from 1978 to 1990 do not support the hypothesis of measurable effects related to settling basin discharge during Seabrook Station construction. Similarly, data patterns and ANOVA results since 1990, when Seabrook Station began operating, do not provide any support for possible plant operational effects on the local estuarine macrofaunal assemblages.

9.5 REFERENCES CITED

Abbott, R.T. 1974. American Seashells. The marine Mollusca of the Atlantic and Pacific Coasts of North America. Van Nostrand Reinhold Co., New York. 663 pp.

Berge, J.A. 1990. Macrofaunal recolonization of subtidal sediments. Experimental studies on defaunated sediment contaminated with crude oil in two Norwegian fjords with unequal eutrophication status. I. Community responses. Mar. Ecol. Prog. Ser. 66:103-115.

Dauer, D.M., C.A. Maybury, and R.M. Ewing. 1981. Feeding behavior and general ecology of several spionid polychaetes from the Chesapeake Bay. J. Exp. Mar. Biol. Ecol. 54:21-38.

Diaz, R.J., and L.S. Schaffner. 1990. The functional role of estuarine benthos. Pages 25-56 *in* Contribution 1595. College of William and Mary, Virginia Inst. of Mar. Sci.

Flint, R.W. 1985. Long-term estuarine variability and associated biological response. Estuaries 8:158-169.

Giere, O. 1975. Population structure, food relations and ecological role of marine oligochaetes, with special reference to meiobenthic species. Mar. Biol. 31:139-156.

Gosner, K.L. 1971. Guide to Identification of Marine and Estuarine Invertebrates. Wiley-Interscience. John Wiley and Sons, Inc., New York. 693 pp.

Grassle, J.F., and J.P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. J. Mar. Res. 32:253-284.

Hartman, O. 1969. Atlas of the Sedentariate Polychaetous Annelids from California. Los Angeles, Allan Hancock Fnd., Univ. S. Cal. 812 pp.

Holland, A.F. 1985. Long-term variation of macrobenthos in a mesohaline region of Chesapeake Bay. Estuaries 8:93-113.

Holland, A.F., A.T. Shaughnessy, and M.H. Hiegel. 1987. Long-term variation in mesohaline Chesapeake Bay macrobenthos: spatial and temporal patterns. Estuaries 10:227-245.

Hull, S.C. 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. and Shelf Sci. 25:519-532.

Kaplan, E.H., J.R. Welker, and M.G. Kraus. 1974. Some effects of dredging on populations of macrobenthic organisms. Fish. Bull., U.S. 72:445-480.

McCall, P.L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. 35:221-266.

NAI (Normandeau Associates, Inc.). 1979. Effects of the settling basin effluent on survival of selected marine invertebrates: *in situ* bioassay. Prepared for Public Service Company of New Hampshire. 8 pp.

_________. 1980a. A report to the Public Service Company of New Hampshire concerning nutrient and phytoplankton concentrations in the Seabrook Station sewage lagoons. 5 pp.

_________. 1980b. Effects of Seabrook station's settling basin effluent on survival of selected marine invertebrates. Tech. Rep. XI-4 Seabrook Ecological Studies, 1979.

_________. 1981. Seabrook Environmental Studies. 1979 Seabrook benthic report. Tech. Rep. XI-5.

_________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook area, 1975-1984. Tech. Rep. XVI-II.

_________. 1988. Seabrook Environmental Studies. 1987 data report. Tech. Rep. XIX-I.

_________. 1990. Seabrook Environmental Studies, 1989 data report. Tech. Rep. XXI-I.

_________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-1.

_________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

Nichols, F.H. 1985. Abundance fluctuations among benthic invertebrates in two Pacific estuaries. Estuaries 8:136-144.

NUSCO (Northeast Utilities Service Company). 1987. Benthic Infauna. Pages 1-51 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Summary of studies prior to Unit 3 operation. Annual Report 1986.

_________. 1993. Benthic Infauna. Pages 115-150 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1992.

Price, L.H., and J. Hylleberg. 1982. Algal-faunal interactions in a mat of *Ulva fenestrata* in False Bay, Washington. Ophelia 21:75-88.

Rees, H.L., and A. Eleftheriou. 1989. North Sea benthos: a review of field investigations into the biological effects of man's activities. J. Cons. int. Explor. Mer 45:284-305.

Reish, D.J. 1967. Relationship of the polychaetous annelid *Capitella capitata* (Fabricius) to waste discharges of biological origin. Pages 195-200 *in* C.M. Tarzwell, ed. Biological problems in water pollution. U.S. Health Service.

Rhoads, D., P.L. McCall, and T.Y. Yingst. 1978. Disturbance and production in the estuarine seafloor. Amer. Sci. 66:577-586.

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge

"Florida" off West Falmouth, Massachusetts. J. Mar. Res. 38:265-380.

Santos, S.L., and J.L. Simon. 1980. Response of soft-bottom benthos to annual catastrophic disturbance in a South Florida estuary. Mar. Ecol. Prog. Ser. 3:347-356.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, N.C. 1028 pp.

Soulsby, P.G., D. Lowthion, and M. Houston. 1982. Effects of macroalgal mats on the ecology of intertidal mudflats. Mar. Poll. Bull. 13:162-166.

Swartz, R.C., W.A. DeBen, F.A. Cole, and L.C. Bentsen. 1980. Recovery of the macrobenthos at a dredge site in Yaquina Bay, Oregon. Pages 391-408 *in* R.A. Baker, ed. Contaminants and Sediments, Vol. 2. Ann Arbor Science Publisher, Inc., Ann Arbor, Mich.

Wade, B.A. 1972. A description of a highly diverse soft-bottom community in Kingston Harbor, Jamaica. Mar. Biol. 13:57-69

Warwick, R.M. 1988. Effects on community structure of a pollutant gradient-introduction. Mar. Ecol. Prog. Ser. 46:149.

Wass, M.L. 1967. Biological and physiological basis of indicator organisms and communities II. Indicators of pollution. Pages 271-283 *in* T.A. Olsen, and E.J. Burgers, eds. Pollution and Marine Ecology. Interscience Publ., New York.

Watling, L. 1975. Analysis of structural variations in a shallow estuarine deposit-feeding community. J. Exp. Mar. Bio. Ecol. 19:275-313.

Whitlatch, R.B. 1977. Seasonal changes in the community structure of the macrobenthos inhabiting the intertidal sand and mudflats of Barnstable Harbor, MA. Biol. Bull. 152:275-294.

Whitlatch, R.B., and R.N. Zajac. 1985. Biotic interactions among estuarine infaunal opportunistic species. Mar. Ecol. Prog. Ser. 21:299-311.

Zajac, R.N., and R.B. Whitlatch. 1982. Responses of estuarine infauna to disturbance. I. Spatial and temporal variation of initial recolonization. Mar. Ecol. Prog. Ser. 10:1-14.

APPENDIX TABLE 9-1. NOMENCLATURAL AUTHORITIES FOR TAXA CITED IN THE ESTUARINE BENTHOS SECTION. SEABROOK OPERATIONAL REPORT, 1993.

Oligochaeta

Polychaeta

Capitella capitata (Fabricius 1780)
Caulleriella sp.
Hediste diversicolor (Müller 1776)
Spio setosa (Verrill 1875)
Streblospio benedicti Webster 1879

Mollusca

Mya arenaria Linnaeus 1758

TABLE OF CONTENTS

PAGE

SUMMARY

Since Hampton-Seabrook estuary contains the majority of New Hampshire's stock of the recreationally important soft-shell clam, an extensive program has been undertaken to characterize the population of all life stages. Larvae have typically been abundant in June and July, with a second, larger peak in late August and September. Larval densities during the operational period showed a seasonal cycle that was similar to previous years, but abundances were lower than average at both nearfield and farfield stations. Adult soft-shell clam densities have been highly variable during the preoperational period, a result of varying recruitment success, variable predation levels, and the presence of disease. The closure of Hampton Harbor to recreational clamming in 1989, a result of coliform contamination, has eliminated a substantial source of mortality. Young of the year densities were higher than average in 1993. However, average densities during the operational period were lower than average at Flats 2 and 4, but showed no change at Flat 1. Spat and juvenile densities during the operational period were significantly lower than the preoperational average throughout the estuary. Adult densities showed some recovery at Flat 4 during the operational period, but showed no change at Flats 1 and 4 in comparison to the preoperational average.

LIST OF FIGURES

PAGE

LIST OF TABLES

10.0 SOFT-SHELL CLAM (*MYA ARENARIA*)

10.1 INTRODUCTION

The objectives of the soft-shell clam (*Mya arenaria* Linnaeus 1758) monitoring programs are to determine the spatial and temporal patterns of abundance of various life stages of soft-shell clams in the vicinity of Hampton Harbor, NH. Planktonic larval stages may be subject to impacts from Seabrook Station due to entrainment into the circulating water system, which would originate at the offshore intake structure. Benthic stages (after settlement to the bottom) in the Hampton-Seabrook estuary may be subject to impacts from the station's settling pond discharge. Other factors that affect the adult density, such as predation and disease, have been considered. Nearfield/farfield comparisons of clam densities are made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich MA.

10.2 METHODS

10.2.1 Bivalve Larvae

The spatial and temporal distributions of 12 species of umboned bivalve larvae, including *Mya arenaria*, were monitored using a 0.5-m diameter, 0.076-mm mesh net. Samples were collected weekly from mid-April through October at Hampton Harbor (P1), intake (P2), discharge (P5) and farfield (P7) stations (Figure 10-1). Sampling began at Station P2 in July 1976, Station P7 in July 1982, and at Station P1 in July 1986. Collections were made at Station P5 from July-December 1986 and April 1988 to the present. Two simultaneous two-minute oblique tows were taken at each station. Upon recovery, net contents were preserved with 1-2% borax-buffered formalin (with sugar added to enhance color preservation) and refrigerated. In the laboratory, samples were split when the total umboned bivalve larvae count exceeded 300 specimens and two subsample fractions were enumerated from each sample. A more detailed description of methods can be found in NAI (1991).

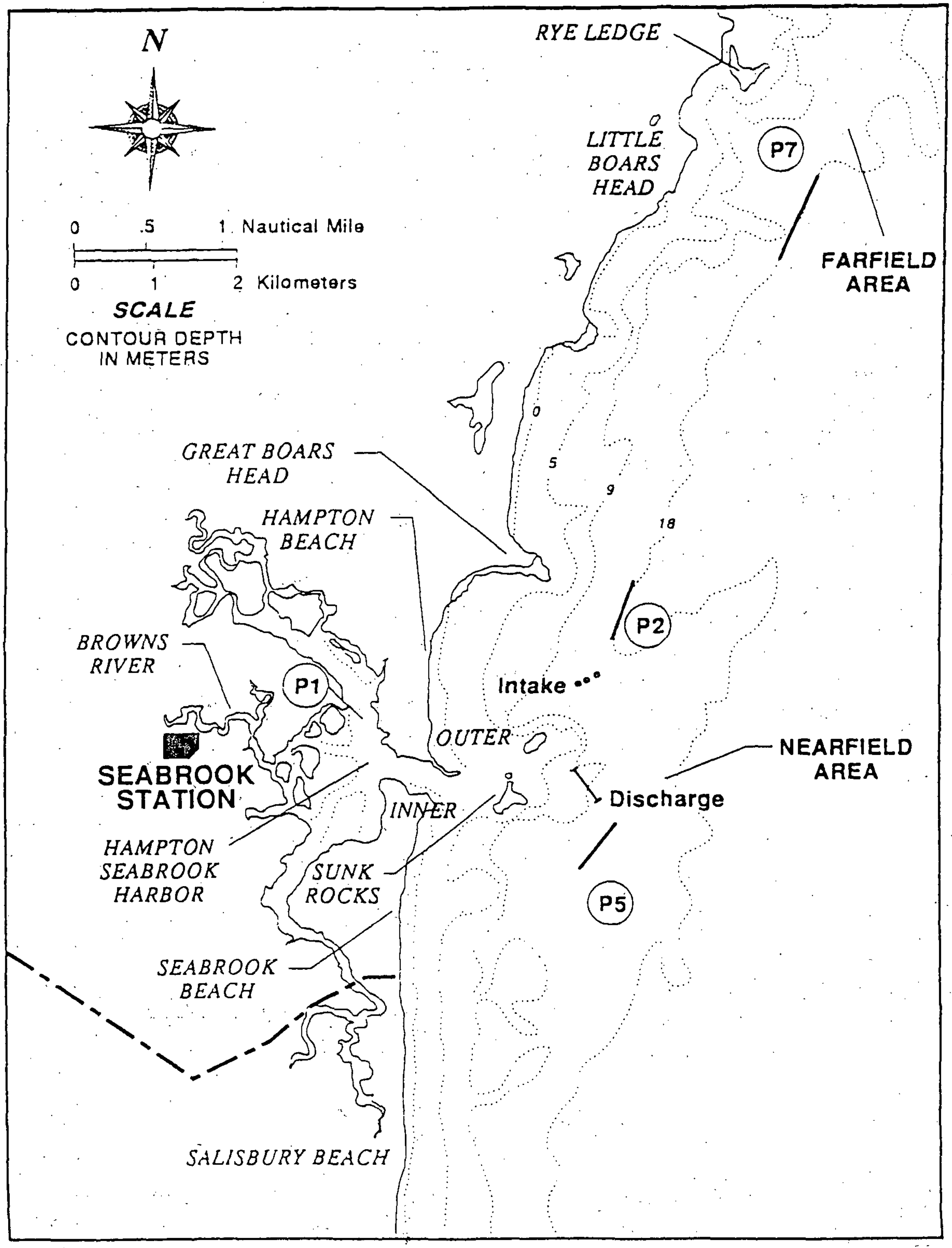
10.2.2 Hampton Harbor Survey

The five largest flats in the Hampton-Seabrook estuary (Figure 10-2) were surveyed in the late fall from 1974-1993 to obtain information on clams measuring at least 1 mm. Sampling sites within each flat were chosen randomly. The number of stations sampled on each flat was proportional to the variance in density observed at that flat historically. Flats 3 and 5 were not sampled for clams greater than 25 mm in length, since the density has historically been extremely low.

A sample for 1-25 mm clams consisted of three 10.2-cm diameter x 10.2-cm deep cores (4-in diameter x 4-in deep) taken within a 30-cm x 61-cm quadrat (1-ft x 2-ft). Samples were sieved with a 1-mm mesh sieve, and clams were enumerated, measured, and released. A sample for clams >25 mm consisted of one quadrat dug to a depth of 45 cm (1.5-ft) with a clam fork. Large clams were removed from the sediment in the field, enumerated, measured, and released.

10.2.3 Nearfield/Farfield Study

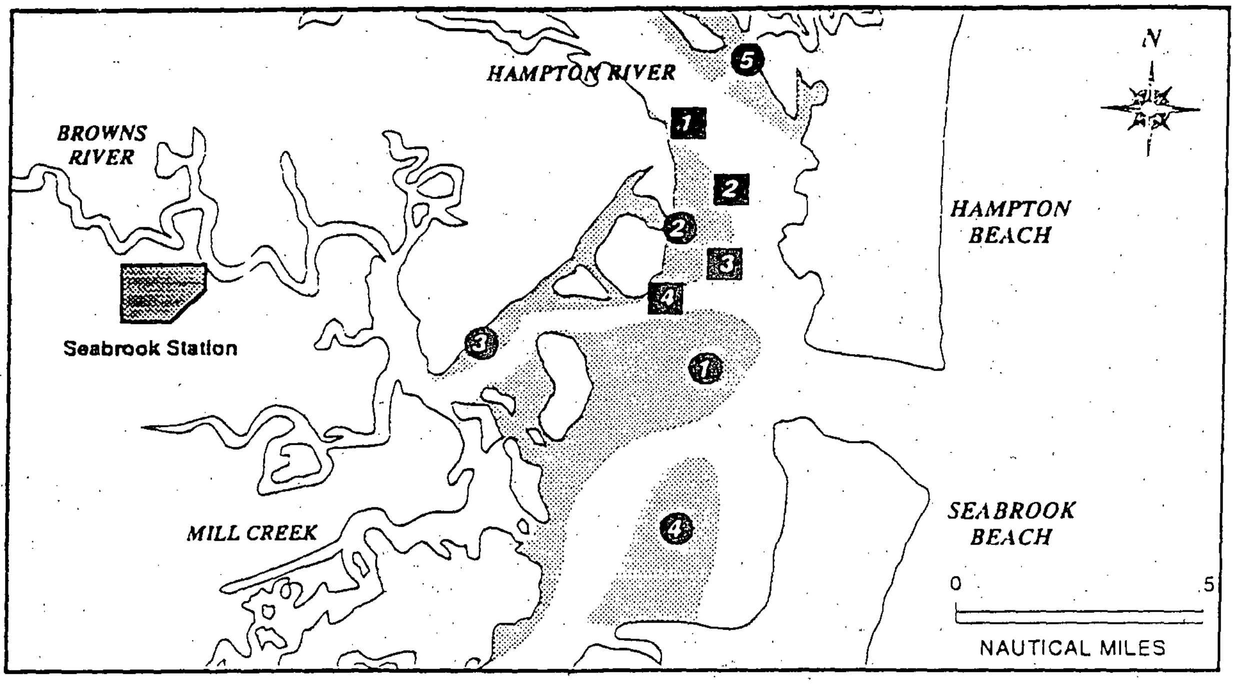
To compare seed clam densities (1-12 mm), surveys were conducted in the fall at 10 sites in both Hampton Harbor (Flats 2 and 4) and Plum Island Sound beginning in 1976. Collections were also made in Ogunquit, ME from 1976-1984. Three cores were taken per station and processed using the same methods employed in the Hampton Harbor survey described above. An additional 1-cm deep x 35-mm diameter core was taken for analysis of newly-set soft-shell clam spat (<1.0 mm). Sampling sites were fixed at locations where the abundance of clams has been high historically.



LEGEND

—— = Bivalve Larvae Stations P1, P2, P5, P7

Figure 10-1. Bivalve larvae (including *Mya arenaria*) sampling stations. Seabrook Operational Report, 1993.



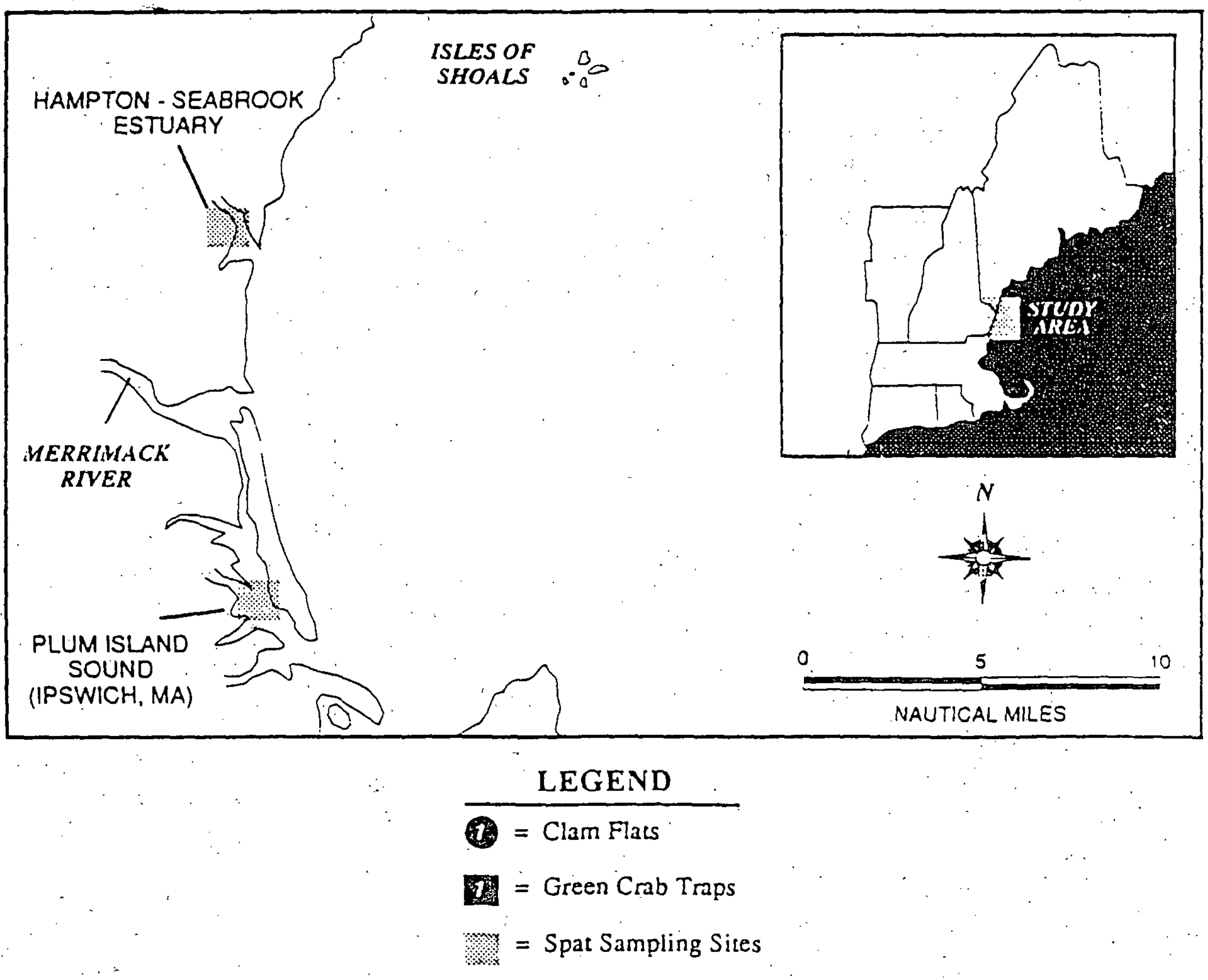


Figure 10-2. Hampton-Seabrook estuary and Plum Island Sound soft-shell clam (*Mya arenaria*) and green crab (*Carcinus maenas*) sampling areas. Seabrook Operational Report, 1993.

10.2.4 Green Crab (*Carcinus maenas*)

Beginning in 1983, green crabs (*Carcinus maenas* Linnaeus 1758) were collected at four estuarine locations on the perimeter of Flat 2 in Hampton Harbor (Figure 10-2). The traps were set twice a month for 24 hours year-round except for February and March, when historically no crabs have been found. Two 13-mm mesh, baited crab traps were set at each station so that they were awash at mean low tide (NAI 1991).

10.2.5 Analytical Methods

Annual geometric mean density was computed based on the number of samples taken during any given year (n = number of samples). Preoperational and operational geometric mean densities were based on the annual means (n = number of years sampled), to avoid variation caused by an uneven number of samples per year. Means were plotted graphically and examined for trends.

An analysis of variance (ANOVA) was used on log (x+1) transformed density (n=number of samples) to determine differences for the following main effects: spatial (among stations or areas/flats), temporal (among weeks (larvae only) and years), and periodic (between preoperational and operational periods) variation. In addition, the interaction between station or area and period was investigated. If the interaction term (Preop-Op X Area) was found significant ($\alpha \leq 0.05$), the least squares means procedure (SAS 1985) was used to evaluate differences among means at the $\alpha \leq 0.05$ level, and significant interactions were presented graphically. All sources of variation were considered to be fixed variables. The model was conservative and more likely to detect significant differences than alternative models that assume some sources of variation are random. ANOVA used weekly means of log (x+1) density for larvae collected from 1988-1993, when all three stations were sampled concurrently. The ANOVA model used log (x+1) densities from the total number of samples taken for benthic stages sampled from 1974-1993 in the Hampton Harbor survey, and from 1987-93 for the nearfield/farfield survey.

10.3 RESULTS

10.3.1 Larvae

Mya arenaria larvae occurred most weeks from late May through October during preoperational years at nearfield Station P2 (Figure 10-3). Maximum densities were typically recorded in late summer or early fall, although a secondary peak usually occurred in early summer. Peak abundances in 1993 occurred in September and October and were above the preoperational average. However, the overall operational mean larval abundance at all three stations was significantly less than the preoperational mean (Tables 10-1, 10-2). The decrease during the operational period was consistent at each of the three stations, and the difference among stations was not significant (Tables 10-1, 10-2).

Sexual maturity in *Mya arenaria* is primarily a function of size rather than age, with clams larger than 20 mm in shell length capable of spawning (Coe and Turner 1938). Clams north of Cape Cod usually began to spawn once per year when the water temperature reached 4-6°C. Factors which affect spawning in addition to temperature include adult condition and food availability (Newell and Hidu 1986). Larval abundance is dependent upon the number of adults spawning, the location of spawning sites, larval behavior, coastal currents, water column stratification and other environmental conditions. Length of life spent in the larval state is approximately 12 days at 20°C, but lasts up to 21 days under cooler conditions (Turner 1949). Planktonic larvae settle to the bottom after this period to become young-of-the-year (seed clams).

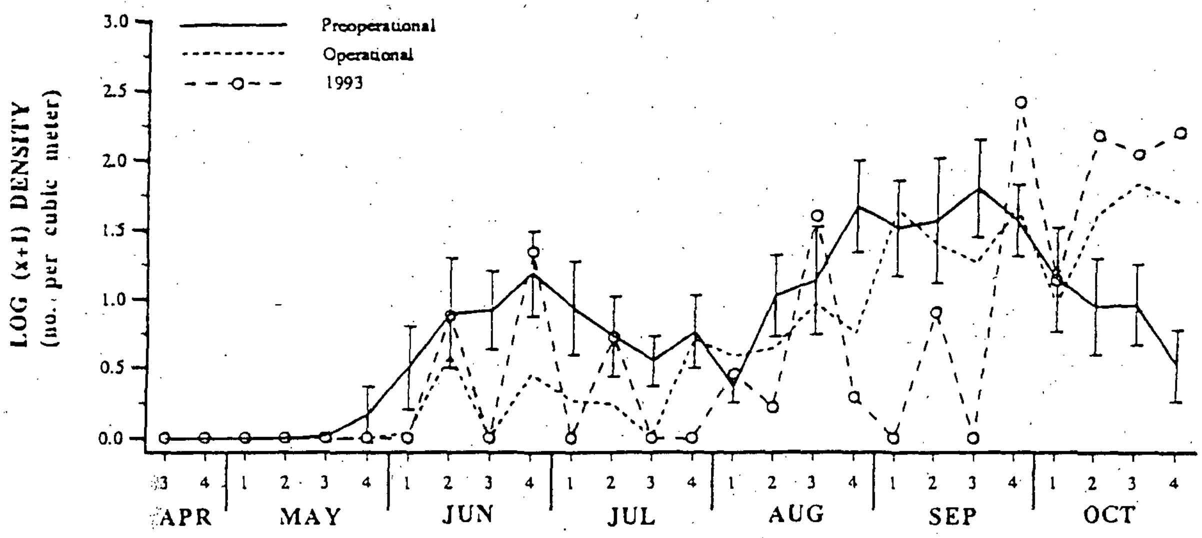


Figure 10-3. Weekly mean and 95% confidence interval of log (x+1) density (no. per cubic meter) of *Mya arenaria* larvae at Station P2, during the preoperational (1978-1989) and operational (1991-1993) periods and in 1993. Seabrook Operational Report, 1993.

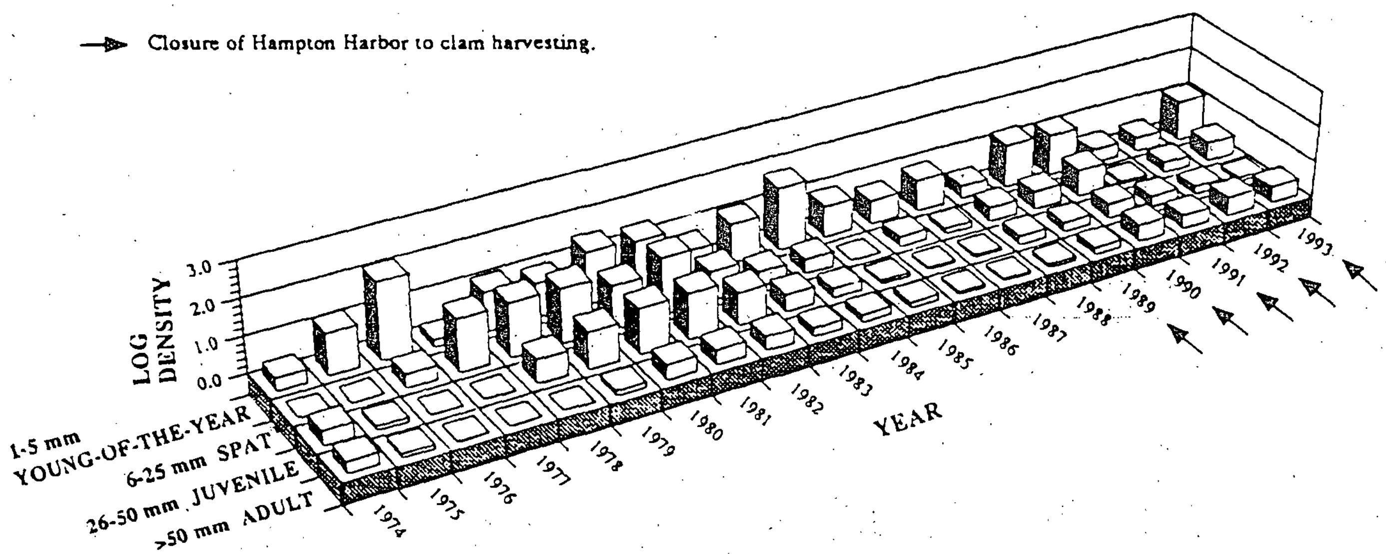


Figure 10-4. Annual mean log (x+1) density (number per square foot) of **young-of-the-year** (1-5 mm), **spat** (6-25 mm), **juvenile** (26-50 mm), and **adult** (>50 mm) *Mya arenaria* at Hampton-Seabrook Harbor Flat 4 from 1974-1993. Seabrook Operational Report, 1993.

TABLE 10-1. GEOMETRIC MEAN DENSITY (NUMBER OF LARVAE PER CUBIC METER; NUMBER OF JUVENILES/ADULTS PER SQUARE FOOT) AND THE COEFFICIENT OF VARIATION (CV) OF *MYA ARENARIA* COLLECTED DURING PREOPERATIONAL AND OPERATIONAL YEARS AND IN 1993. SEABROOK OPERATIONAL REPORT, 1993.

		PREOPERATIONAL[a]		1993	OPERATIONAL[a]	
LIFESTAGE	AREA	MEAN[b]	CV	MEAN[b]	MEAN[b]	CV
Larvae	P2	5.5	17.68	3.3	3.5	5.25
	P5	5.0	11.99	2.0	3.3	32.88
	P7	5.7	13.04	2.4	3.4	18.27
1-5 mm young-of-the-year	HH-1	3.5	48.45	4.2	3.6	53.08
	HH-2	8.6	58.77	9.5	5.2	45.35
	HH-4	10.5	43.78	11.8	4.6	56.41
	All	6.4	49.04	6.8	4.3	48.93
6-25 mm spat	HH-1	1.7	127.81	0.7	0.9	101.92
	HH-2	0.7	153.46	0.6	0.4	70.09
	HH-4	3.4	89.73	2.3	1.6	70.83
	All	1.8	108.48	0.9	0.8	81.71
26-50 mm juveniles	HH-1	1.6	108.64	0.2	0.4	47.50
	HH-2	0.4	115.59	<0.1	0.1	64.77
	HH-4	1.7	100.43	0.3	0.8	46.34
	All	1.2	97.41	0.1	0.3	40.80
>50 mm adults	HH-1	0.6	76.61	0.7	0.6	19.10
	HH-2	0.4	96.53	0.2	0.2	49.86
	HH-4	0.5	78.19	1.8	1.8	12.29
	All	0.5	76.51	0.6	0.6	19.38
1-12 mm seed clams	Hampton Harbor	5.7	70.81	13.7	6.0	81.62
	Plum Is. Sound	17.1	68.54	7.8	9.3	81.45

[a]Larvae PREOP = 1988, 1989; OP = 1991-93. Hampton Harbor (HH) PREOP = 1974-1989; OP = 1990-1993. Hampton Harbor-Plum Is. PREOP = 1987-1989; OP = 1990-1993

[b]PREOP and OP means = mean of annual means. 1993 mean = mean of the number of samples.

TABLE 10-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING *MYA ARENARIA* LARVAL, SPAT, JUVENILE AND ADULT DENSITIES DURING PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1993.

MYA ARENARIA LIFESTAGE	STATION/FLAT	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS[i] (in decreasing order)
larvae[a]	NEARFIELD (P2, P5) FARFIELD (P7)	Preop-Op[c,d]	1	3.27	15.41***	Op<Pre
		Year (Preop-Op)[e]	3	0.68	3.23*	
		Week (Preop-Op X Year)[f]	122	1.41	6.66***	
		Station[g]	2	0.09	0.44 NS	
		Preop-Op X Station[h]	2	0.02	0.10 NS	
		Error	249			
1-5 mm[b] young-of-the-year	HAMPTON HARBOR 1, 2, 4	Preop-Op	1	9.07	20.44***	
		Year (Preop-Op)	18	11.07	24.94***	
		Area	2	9.33	21.02***	4 Pre 2 Pre 2 Op 4 Op 1 Op 1 Pre
		Preop-Op X Area	2	3.03	6.84***	
		Error	1570	0.44		
6-25 mm[b] spat	1, 2, 4	Preop-Op	1	7.48	32.48***	Op<Pre
		Year (Preop-Op)	18	10.99	47.72***	
		Area	2	8.03	34.87***	4 1 2
		Preop-Op X Area	2	0.51	2.23 NS	
		Error	1570	0.23		
26 -50 mm[b] juvenile	1, 2, 4	Preop-Op	1	15.37	100.75***	
		Year (Preop-Op)	18	10.71	70.19***	
		Area	2	9.14	59.91***	
		Preop-Op X Area	2	0.63	4.16*	4 Pre 1 Pre 4 Op 2 Pre 1 Op 2 Op
		Error	2737	0.15		
>50 mm adult, legal	1, 2, 4	Preop-Op	1	1.74	29.74***	
		Year (Preop-Op)	18	1.97	33.80***	
		Area	2	5.80	99.28***	
		Preop-Op X Area	2	4.11	70.33***	4 Op 1 Op 1 Pre 4 Pre 2 Pre 2 Op
		Error	2737	0.06		
1-12 mm[b]	NEARFIELD/FARFIELD Hampton Harbor Plum Island Sound	Preop-Op	1	0.42	0.78 NS	
		Year (Preop-Op)	5	1.03	1.89 NS	
		Area	1	3.10	5.69 NS	
		Preop-Op X Area	1	0.58	1.07 NS	
		Error	131	0.55		

[a]Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1988, 89 and op = 1991-93.
[b]For Hampton Harbor Survey preop = 1974-89 and op = 1990-93. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-93.
[c]Commercial operation began in August 1990, therefore the operational period includes 1990 for spat, juveniles, and adults, but not for larvae.
[d]Operational versus preoperational period regardless of area.
[e]Year nested within preoperational and operational periods, regardless of area.
[f]Week nested within year regardless of area.
[g]Station or flat, regardless of year or period.
[h]Interaction of main effects.
[i]Underlining signifies no significant differences among least square means at alpha ≤ 0.05

NS = Not significant (p>0.05)
* = Significant (0.05≥p>0.01)
** = Highly significant (0.01≥p>0.001)
*** = Very highly significant (0.001≥p)

Gonadal studies demonstrate that the onset of spawning in Hampton Harbor and Plum Island Sound (late May-June) usually followed the appearance of larvae in offshore tows (early-mid May)(NAI 1985). Therefore, the spring and early summer larvae population may in part originate in areas farther south. Historically, the late-summer peaks generally were coincident with northward-flowing currents. Recruitment of larvae of non-local origin is likely due to current patterns in the Gulf of Maine, which may move water masses and their entrained larvae significant distances before larval settlement (NAI 1979).

10.3.2 Hampton Harbor Survey

Young-of-the-year (1-5 mm). This size class contains recently settled clams that have not yet survived a winter. In 1993, average density of 1-5 mm clams was slightly higher than the preoperational and operational averages at all three flats (Table 10-1). Densities in 1993 were higher than the previous two years (NAI 1993). Historically, spat density has been highly variable, and 1993 was within the range of previous years (Figure 10-4 and NAI 1990). Average abundances for the operational period were significantly lower than the preoperational average at Flats 2 and 4, but were not different at Flat 1 (Table 10-2, Figure 10-5).

Spat (6-25 mm) and Juveniles (26-50 mm). Trends in the 6-25 mm size class indicate the survival success of young-of-the-year (1-5 mm spat) that have overwintered, and may also include some fast-growing young-of-the-year. During 1993, recruitment into the 6-25 mm size class increased over the previous year at each flat, but remained below the preoperational mean at all three flats (Table 10-1, Figure 10-4; NAI 1993). The average density of 6-25 mm clams during the operational period was significantly lower than preoperational average (Tables 10-1, 10-2). Differences among years and flats were also significant. Flats 1 and 4 had significantly higher densities of 6-25 mm clams than Flat 2.

Juvenile (26-50 mm) mean densities in 1993 remained lower than the preoperational means, and have declined since the late 1980s (Table 10-1). The 1993 densities at Flat 2 were the lowest since 1988, although no juveniles were collected in 1975 or 1977 (NAI 1990). Spatial differences between the preoperational and operational periods (Preop-Op X Area) were significant. There was a significant decrease in mean density between the preoperational and operational periods at all three flats (Table 10-2, Figure 10-5).

Adults (>50 mm). Clams measuring more than 50 mm are at least 4 years of age (Ayer 1968) and considered adults in this study. In 1993, densities of adults were similar to the operational means at all three flats and above the preoperational means at Flats 1 and 4 (Table 10-1). The interaction term (Preop-Op X Area) was significant. Adult clam densities increased significantly at Flat 4 during the operational period relative to the preoperational period, but no significant differences occurred during the operational period at Flat 1 (Table 10-2, Figure 10-5). At Flat 2, the preoperational density was significantly higher than the operational density.

10.3.3 Nearfield/Farfield Study

In 1993, the density of seed clams in the nearfield area (Hampton Harbor) was the highest collected since the study began in 1987 (Table 10-1; NAI 1990). Another good set occurred in Hampton Harbor in 1989. In the farfield area (Plum Island Sound) in 1993, density increased only slightly over 1992 levels (NAI 1993). In both locations, annual densities of seed clams were variable, with occasional good sets. The interaction between Preop-Op X Area was not significantly different at the nearfield or farfield areas (Table 10-2).

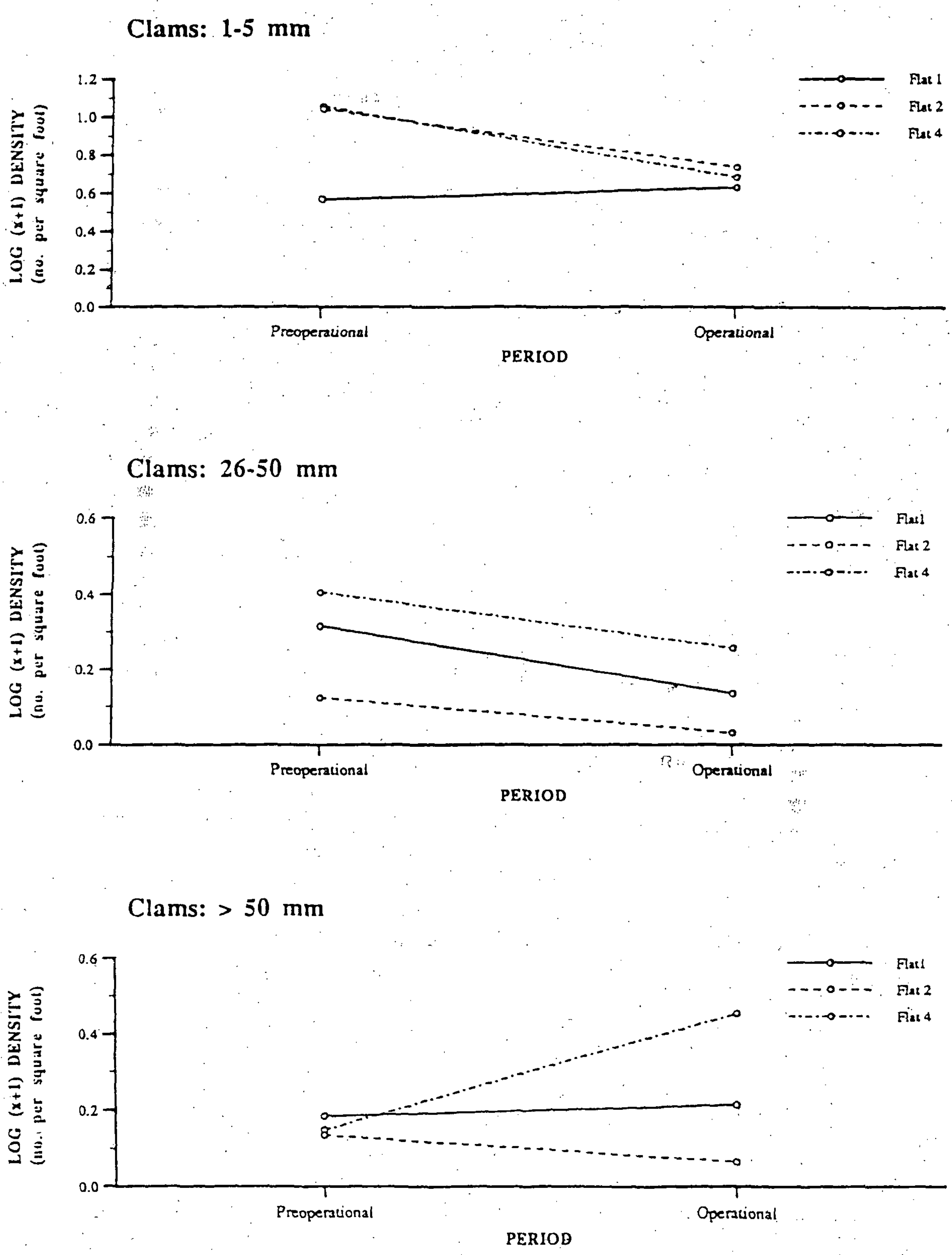


Figure 10-5. A comparison of the mean log (x+1) density (number per square foot) among flats during the preoperational (1974-1989) and operational (1990-1993) periods when the interaction term (Preop-op X Area) of the ANOVA model is significant (Table 10-2). Seabrook Operational Report, 1993.

10.3.4 Effects of Predation and Perturbation

Clams in Hampton Harbor have historically been subjected to predation from two major sources: green crab (*Carcinus maenas*), which consume clams up to about 50 mm in length (Ropes 1969), and humans who dig adult *Mya* and also cause mortality to smaller clams following flat disturbance. Sea gulls are also predators, as they are commonly observed picking over clam digger excavations for edible invertebrates.

Clams are a major source of food for green crab, particularly in the fall (Ropes 1969). Maximum green crab abundance usually occurred in the late fall (Figure 10-6). Mean monthly densities during the 1991-1993 operational period were lower than preoperational densities except during January and December.

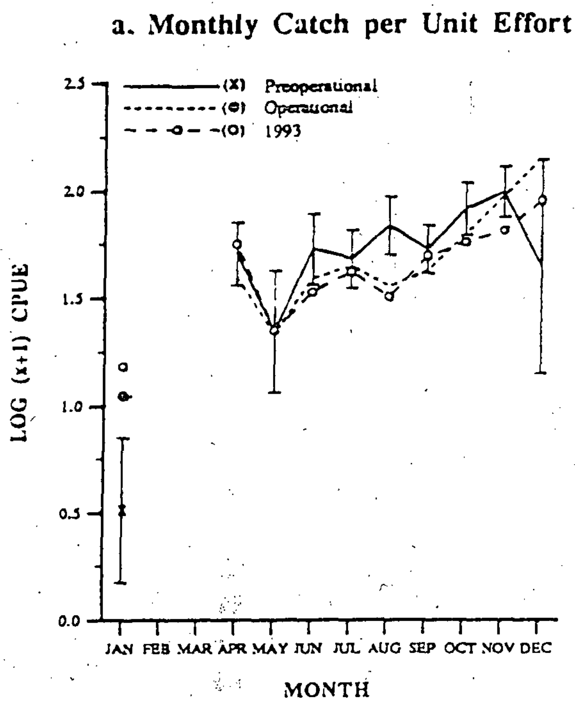
Welch (1969) and Dow (1972) found that green crab abundance increased markedly following relatively warm winters. Data from Hampton Harbor from the past 15 years for the most part corroborate their findings (Figure 10-6) although there are exceptions. During the winters when the minimum temperature was relatively high (1983-1989), green crab abundance in the following fall was also high (Figure 10-6). In 1993, when the minimum winter temperature was low, green crab abundance declined from the previous year. However, in 1992 the minimum temperature was low, but the fall green crab abundance was at its highest level to date. It is likely that other factors such as competition are involved in controlling the green crab population size. Green crabs were not found in New England before the early 1900s (Gosner 1983), and the local population has generally increased since the late 1970s (Figure 10-6).

Recreational clam digging on the Hampton Harbor flats was a significant source of mortality for adult clams (>50 mm) through April 1989. The perturbation it caused was probably a source of mortality to smaller clams as well. Hampton Harbor flats were closed to clam digging from April 1989 through December 1993 by the New Hampshire Department of Health and Human Services due to coliform contamination. The size class of clams greater than 50 mm in length greatly increased from 1990 through 1992 on Flat 4 (Figure 10-4). With the Hampton Harbor flats closed, the harvesting pressure on the adult clam population was removed, and the estimated number of bushels per acre in 1992 was the highest during the study period (Figure 10-7). However, in 1993, the estimated bushels per acre declined slightly. The decrease may be due to illegal harvesting, but the extent to which this occurs is unknown (Bruce Smith, NHFG, Durham, NH; Pers. Comm. April 1994).

Clam seeding was another anthropogenic influence on the Hampton Harbor clam population. Attempts by the New Hampshire Fish and Game Department to augment natural recruitment by seeding juvenile clams at Flat 5 in 1987 and 1988 were not successful (NHFG 1990). During the fall of 1988, the local 4-H organization planted 30,000 seed (approximately 12 mm) clams on Flat 4 (47.9 acres), which can be converted to roughly 0.01 clams/sq.ft. In late November, 1989, the 4-H again planted 100,000 seed clams on Flat 4, or roughly 0.05/sq.ft. No population increase was evident shortly after the planting (R.Wojtusik, 4-H; UNH Cooperative Extension, Durham, NH; Pers. Comm. June 1992).

10.3.5 Effect of Disease

Sarcomatous neoplasia, a lethal form of leukemia in *Mya arenaria*, was identified in a limited number of samples taken from Hampton Harbor *Mya* populations (Hillman 1986, 1987). A virus similar to the B-type retroviruses is known to initiate the disease in *Mya* (Oprandy et al. 1981). Although the infection has been observed in relatively pristine waters, the rate of infection may also be enhanced by pollution-mediated deterioration of the environment (Reinisch et al. 1984). The infection rate in some *Mya* populations may reach



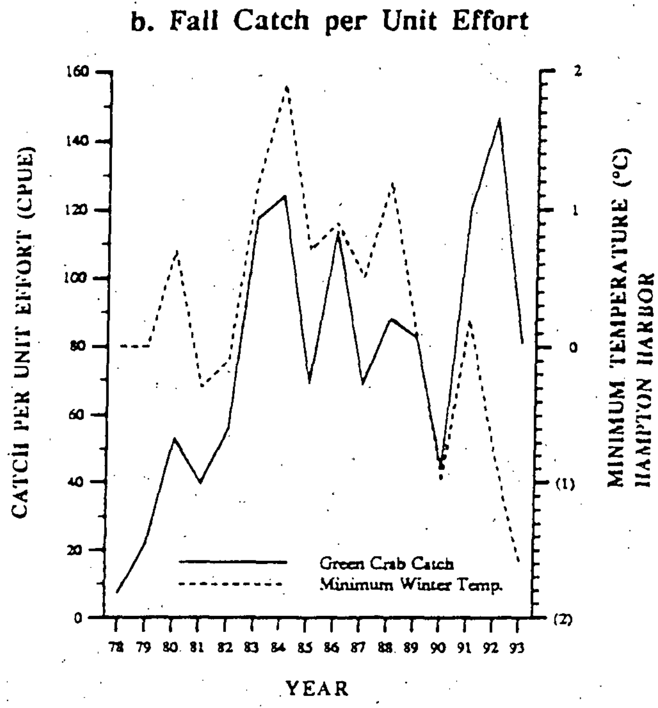


Figure 10-6. a. Mean monthly catch per unit effort log (x+1) and 95% confidence intervals of green crabs (*Carcinus maenas*) collected during preoperational years (1983-1989) and operational years (1991-1993) and b. Mean fall (October-December) catch per unit effort of green crabs in Hampton-Seabrook Harbor and its relationship to minimum winter temperature from 1978-1993. Seabrook Operational Report, 1993.

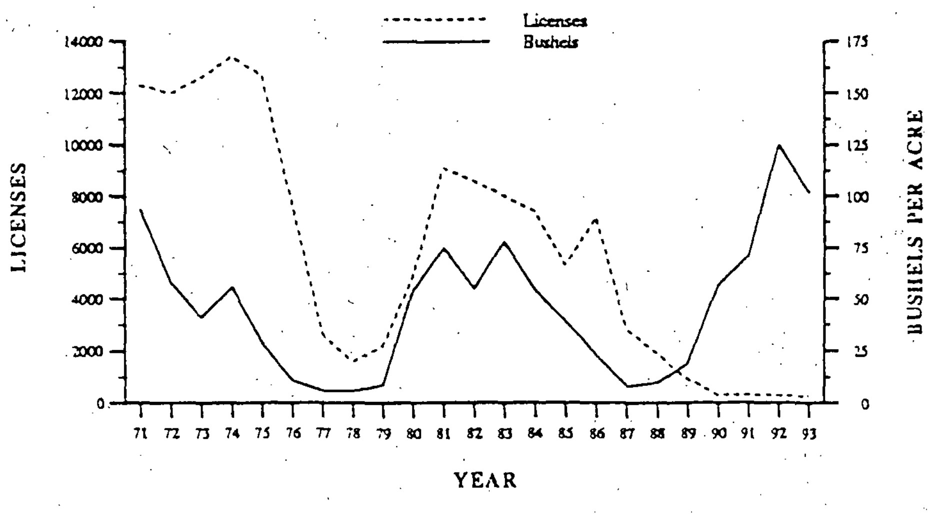


Figure 10-7. Number of clam licenses issued and the estimated bushels per acre of adult (>50 mm) clams in Hampton-Seabrook estuary, 1971-1993. Seabrook Operational Report, 1993.

100 percent with 100 percent mortality of infected clams (Farley et al. 1986). The incidence of sarcomatous neoplasms in the Hampton Harbor *Mya* population was observed in October 1986 and February 1987 (Hillman 1986, 1987). Neoplastic infections were more prevalent in February, reaching 6% at Flat 1 and 27% at Flat 2. Infections were absent from Flat 4. Assuming 100 percent mortality of infected clams (Farley et al. 1986), Flats 1 and 2 may have suffered substantial disease-related reductions in clam production. In 1987, clam flat surveys indicated that juvenile and adult densities fell by over 50% at Flat 1 and Flat 2, while Flat 4 remained unchanged from the previous year. In November 1989, fifteen large (>40 mm) clams were taken from Flat 2, and 80% had neoplastic cells (verified by D.J. Brousseau, Ph.D.; Fairfield University; Fairfield, CT). At Flat 4 during the 1990-1993 operational period, adults >50 mm have more than tripled their preoperational abundance in comparison to other flats, which showed no increase (Table 10-1). The absence of neoplasia may have contributed to these spatial differences.

10.4 DISCUSSION

Since the Hampton-Seabrook estuary contains the majority of New Hampshire's stock of the recreationally-important soft-shell clam, an extensive sampling program was undertaken to characterize the variability in the population for all lifestages.

Recruitment and survival of the soft-shell clam population in Hampton Harbor is affected by a variety of factors, including physical and biological factors, that must be considered in impact assessment. Recruitment from larvae to young-of-the-year is not well understood, but is apparently unrelated to the abundance levels of larval stages (NAI 1982). Successful young-of-the-year sets have occurred throughout the preoperational period as well as during 1990 and 1993 (Figure 10-4, NAI 1992). Young-of-the-year densities in 1993 were above the preoperational (1974-1989) average at each of the three flats. Young-of-the-year densities for the operational period (1990-1993) were similar to the preoperational average at Flat 1, and lower than the preoperational average at Flats 2 and 4 (Table 10-3). In the nearfield/farfield comparison study of 1-12 mm clams, average densities during the preoperational and operational periods were not significantly different (Table 10-3).

Survival of the young-of-the-year set depends on a number of factors including the level of predation and disease. The preoperational period includes the extremes of a "boom and bust" cycle of spat, juvenile and adult clams, in part dictated by a classic predator-prey relationship, at least for the smaller size classes. The preoperational densities are elevated by the high densities that began in the mid-1970s and ended in the early 1980s, similar to trends noted in Maine and Massachusetts (Crago 1993). As a result, densities of spat and juveniles from the operational period (1990-93), even though similar to recent years, were lower than the preoperational average (Table 10-3, Figure 10-4). The reasons for the recent mortality of young-of-the-year sets and their decreased survival since 1984 are complex, but certainly include changes in abundance of its major predator, green crab *Carcinus maenas*. Warm winter temperatures from 1984 through 1989 may have enhanced green crab survival, coinciding with decreased densities of spat and juvenile clams. Lower green crab catches in 1990 corresponded to increases in spat and juvenile clams on some flats (NAI 1991). In 1991 and 1992, when green crab catches were high, densities of spat and juvenile clams were below average (Figures 10-4, 10-6). In 1993, when green crab abundance was low, spat densities were above the operational average on two of three flats, but juveniles were rare.

Another factor likely to affect growth and survival of juvenile and adult clams was the presence of sarcomatous neoplasia, a lethal form of blood cancer in the soft-shell clam. During 1986 and 1987, the incidence of neoplasia in Hampton Harbor was restricted

TABLE 10-3. SUMMARY OF EVALUATION OF EFFECTS OF OPERATION OF SEABROOK STATION ON SOFT-SHELL CLAM. SEABROOK OPERATIONAL REPORT, 1993.

STUDY	LIFESTAGE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD[a]	SPATIAL DIFFERENCES CONSISTENT BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS[b]
NEARFIELD (P2,P5)/ FARFIELD (P7)	Larvae	Op<Preop	Yes
HAMPTON HARBOR	Young-of-year (1-5mm)	No	Flats 2, 4 Op<Preop Flat 1 Op=Preop
	Spat (6-25mm)	Op<Preop	Yes
	Juvenile (26-50mm)	No	Flats 1, 2, 4 Op<Preop
	Adult (>50mm)	No	Flats 1, 2 Op=Preop Flat 4 Op>Preop
HAMPTON HARBOR/ PLUM ISLAND SOUND	Young-of-year (1-12mm)	Yes	Yes

[a]Operational period for larvae = 1991-93; 1->50 m size classes = 1990-93; preoperational period for larvae = 1988, 1989; preoperational period for nearfield farfield = 1987-89; preoperational period for Hampton Harbor = 1974-89; results based on Op-Preop term of ANOVA model, when Preop-Op x Area is not significant.

[b]Results based on interaction term (Preop-Op X Area) of ANOVA model and LS means multiple comparisons at alpha ≤ 0.05.

to Flats 1 and 2 (Hillman 1986, 1987). Significant increases in adult clam densities in the 1990-1993 operational period in comparison to previous years occurred primarily at Flat 4, where neoplasia was apparently absent. Neoplasia is suggested as a cause for declining catches in New England (Crago 1993).

Another factor in the evaluation of long-term trends is human predation by clam diggers. Each digging (with a 4-tined clam fork) causes a total reduction of 80% of the harvestable adults and 50% of the smaller size classes (Medcof and MacPhail 1964). The number of clam licenses sold dropped sharply beginning in 1977, coinciding with the reduced numbers of adults available to harvest (estimated bushels per acre). The decrease in clamming resulted in an increase in the numbers of adult clams throughout Hampton Harbor (Figure 10-7). In 1989, the clam flats were closed due to coliform contamination, and the estimated standing crop increased through 1992. In 1993, the estimated bushels per acre declined slightly from the previous year, but were higher than any other year since the study began in 1971. Closure of the flats likely increased survival, particularly of the adult size class. Flat 4 historically has been heavily used by recreational clammers (NAI 1988). The most notable change in the clam population structure during the operational period was a sharp increase of adult clams in Hampton Harbor, primarily at Flat 4. The operational mean density of clams increased sharply (3.6 times) over the preoperational period of Flat 4, but was the same or slightly lower at Flats 1 and 2. Flat 4 was also the only area where historically no evidence of the lethal disease neoplasia was detected.

Mya arenaria population changes during the operational period are indicated by visual inspection of graphs and by the interaction term of the ANOVA model. Differences between the preoperational and operational means were consistent at nearfield and farfield areas for larvae and seed clams, 1-12 mm in length (Table 10-3). This indicates the operation of Seabrook Station has not affected larvae or seed clam densities. Intensive fall surveys within the nearfield area (Hampton Harbor) found the differences between preoperational and operational means were not consistent among the three flats. The differences are due to a variety of physical and biological variables that occur within the nearfield area. The most notable change to occur (a significant increase in the number of adults at Flat 4 during the operational period) was probably due to the closure of flats to clam harvesting. The absence of neoplasia was likely a contributing factor.

The key to monitoring the effects of plant operation (1990-1993) on the soft-shell clam population is understanding its long-term cycle and the multitude of factors that affect it. Average seed clam (1-12 mm) density during the operational period in Hampton Harbor followed the same trend as that of a neighboring estuary, indicating that Seabrook Station was not affecting larval settlement (Table 10-3). In Hampton Harbor, average spat densities from 1990-1993 at each flat were lower than the preoperational average. However, the 15-year preoperational period includes extremely successful periods of clam recruitment and survival, when densities of its major predator were low, as well as periods of very low clam density, leading to a significant difference in density among years. Given the high variability among years, and the complexity of factors affecting clam recruitment, there is no indication that Seabrook Station has had a positive or negative effect on the Hampton Harbor population.

10.5 REFERENCES CITED

Ayer, W.C. 1968. Soft-shell clam population study in Hampton-Seabrook Harbor, New Hampshire. New Hampshire Fish and Game Dept. 39 pp.

Coe, W.R. and H.J. Turner. 1938. Development of the gonads and gametes of the soft shell clam *Mya arenaria*. J. Morph. 62:91-111.

Crago, T.I. 1993. Getting to why. Understanding leukemia in soft shell clams. Nor'easter 5(1):20-23.

Dow, R. 1972. Fluctuations in Gulf of Maine sea temperature and specific molluscan abundance. J. Cons. Int. Explor. Mer 34(3):532-534.

Farley, C.A., S.A. Otto, and C.L. Reinisch. 1986. New occurrence of epizootic sarcoma in Chesapeake Bay soft shell clams, *Mya arenaria*. Fish. Bull., U.S. 84(4):851-857.

Hillman, R.E. 1986. Summary report on determination of neoplasia in soft-shell clams, *Mya arenaria*, near the Seabrook Nuclear Plant. Battelle study no. N-0954-9901 to YAEC. 6 pp.

__________. 1987. Final report on determination of neoplasia in soft-shell clams *Mya arenaria* near the Seabrook Nuclear Plant. Battelle study no. N-0954-9901 to YAEC. 7 pp.

Newell, C.R., and H. Hidu. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) -- softshell clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.53). U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

NHFG. 1990. Enhancement of soft-shell clam (*Mya arenaria*) stocks in the Hampton/Seabrook Estuary. Fin. Rept. 6 pp.

Normandeau Associates, Inc. 1979. Soft-shell clam, *Mya arenaria*, study. Tech. Rept. X-3.

__________. 1982. Seabrook Environmental Studies, 1981. Soft-shell clam, *Mya arenaria* study. Tech. Rept. XIII-II.

__________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rept. XVI-II.

__________. 1988. Seabrook Environmental Studies, 1987 Data Report. Tech. Rept. XIX-1.

__________. 1990. Seabrook Environmental Studies, 1989. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1989. Tech. Rept. XXI-II.

__________. 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Rept. XXII-1.

__________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rept. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rept. XXIV-1.

Medcof, J.C. and J.S. MacPhail. 1964. Fishing efficiency of clam hacks and mortalities incidental to fishing. Proc. Natl. Shellfish. Assoc. 55:53-72.

Oprandy, J.J., P.W. Chang, A.D. Promovost, K.R. Cooper, R.S. Brown, and V.J. Yates. 1981. Isolation of a viral agent causing hematopoietic neoplasia in the soft-shell clam, *Mya arenaria*. J. Invert. Pathol. 38:45-51.

Ropes, J.W. 1969. The feeding habits of the green crab *Carcinus maenas* (L.) U.S. Fish Wildl. Serv. Fish. Bull. 67:183-203.

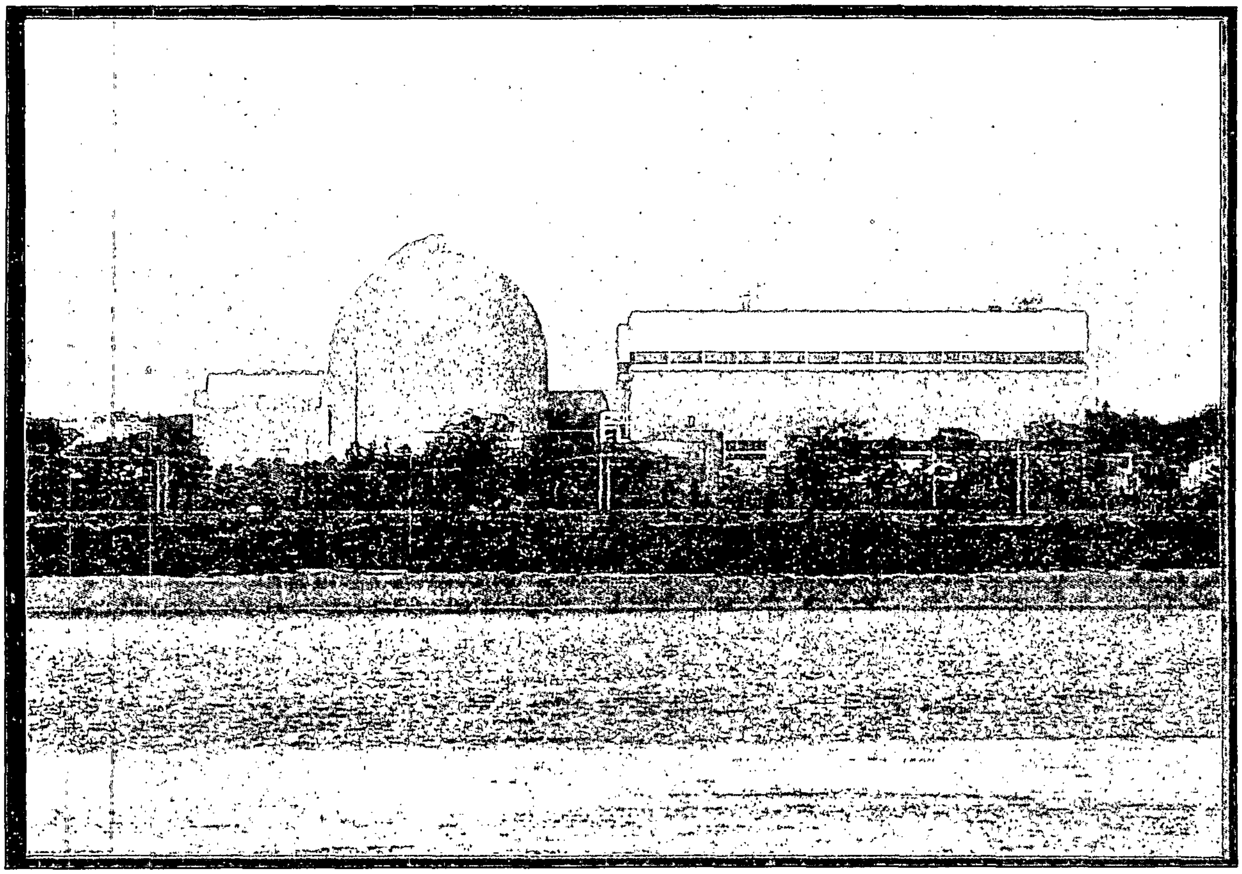
Reinisch, C.L., A.M. Charles, and A.M. Stone. 1984. Epizootic neoplasia in soft-shell clams collected from New Bedford Harbor. Hazardous Waste 1:73-81.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics Version.5 edition. SAS Inst., Inc., Cary, N.C. 956 pp.

Turner, H.J., Jr. 1949. The soft-shell clam industry of the east coast of the United States. App. I. Report on investigations of the propagation of the soft-shell clam, *Mya arenaria*. WHOI collected reprints 1948, Contrib. No. 462, pp. 11-42.

Welch, W.R. 1969. Changes in abundance of the green crab, *Carcinus maenas* (L.) in relation to recent temperature changes. U.S. Fish Wild. Serv. Fish. Bull. 67:337-345.

SEABROOK STATION
1994 ENVIRONMENTAL STUDIES
IN THE HAMPTON-SEABROOK AREA



A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS

North Atlantic

The Northeast Utilities System

SEABROOK STATION 1994 ENVIRONMENTAL STUDIES IN THE HAMPTON-SEABROOK AREA A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS DURING THE OPERATION OF SEABROOK STATION

Prepared for

NORTH ATLANTIC ENERGY SERVICE CORPORATION
P.O. Box 300
Seabrook Station
Seabrook, New Hampshire 03874

Prepared by

NORMANDEAU ASSOCIATES
25 Nashua Road
Bedford, New Hampshire 03310-5500

Critical reviews of this report were provided by:

The Seabrook Station Ecological Advisory Committee:

Dr. John Tietjen, Chairman (City University of New York)
Dr. W. Huntting Howell (University of New Hampshire)
Dr. Bernard McAlice (University of Maine)
Dr. Saul Saila (emeritus, University of Rhode Island)
Dr. Robert Wilce (emeritus, University of Massachusetts)

The staff of the Northeast Utilities Environmental Laboratory at Millstone Nuclear Power Station

October 1995

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

1.1 APPROACH

Environmental monitoring studies were conducted to determine whether Seabrook Station, which became operational in August of 1990, had an effect on the "Balanced Indigenous Populations of Fish, Shellfish and Wildlife" in the nearfield coastal waters of New Hampshire. A biological monitoring program established under the National Pollutant Discharge Elimination System (NPDES) permit, jointly issued by the Environmental Protection Agency and the state of New Hampshire, forms the framework for study.

A systematic approach of impact assessment was used to determine whether the operation of Seabrook Station affected the aquatic biota. This approach incorporated both temporal and spatial components for each biological community evaluated (Figure 1-1). Potential operational effects could be ruled out if: (1) results from the operational period were similar to previous (preoperational) years, given the natural variability in the system, or (2) differences within the operational period were observed in both nearfield and farfield areas. In addition, other potential sources of change have been investigated before the conclusions specified within this report were drawn. This study design was modeled after objectives discussed by Green (1979), which have been described previously in more detail (NAI 1991).

The validity of the impact assessment model is based on comparisons between nearfield stations within the influence of Seabrook Station and at farfield stations beyond its influence. Modeling studies, as well as operational validation, clearly indicate this to be true for thermal effects in relation to the thermal plume. The extent of a +3°F (1.7°C) isotherm has been shown to cover a relatively small 32-acre surface area (Padmanabhan and Hecker 1991). Due to the buoyant nature of the thermal discharge, temperature differences do not extend below the thermocline. Due to its location within the water column, the intake is also expected to have only a localized effect. This is characterized by the entrainment and impingement sampling programs.

A basic assumption in the monitoring program is that there are two major sources of natural-occurring variability: (1) that which occurs among different areas or stations, i.e., spatial, and (2) that which varies in time, from daily to weekly, monthly or annually, i.e., temporal. In the experimental design and analysis, the Seabrook Environmental program has focused on the major source of variability in each community type and then determined the magnitude of variability in each community. The frequency and spatial distribution of the sampling effort were determined based on the greatest sources of variability for each parameter (NAI 1991).

Biological variability was measured on two levels: species and community (Table 1-1). A species' abundance, recruitment, size and growth are important for understanding operational impact, if any, should changes occur in these parameters between stations or over time. These parameters were monitored for selected species from each community type. Selected species were chosen for more intensive study based on either their commercial or numerical importance, sensitivity to temperature, potential as a nuisance organism, or habitat preference. Overall community structure of the biota, e.g., the number and type of species, total abundance and the dominance structure, was also reviewed to determine potential plant impact. Trends in these parameters were reviewed against the natural variation in community structure.

A previous Summary Report (NAI 1977) concluded that the balanced indigenous community in the Seabrook study area should not be adversely influenced by loss of individuals due to entrapment in the Circulating Water System (CWS), exposure to the thermal plume, or exposure to increased particulate material (dead organisms) settling from the discharge. The current

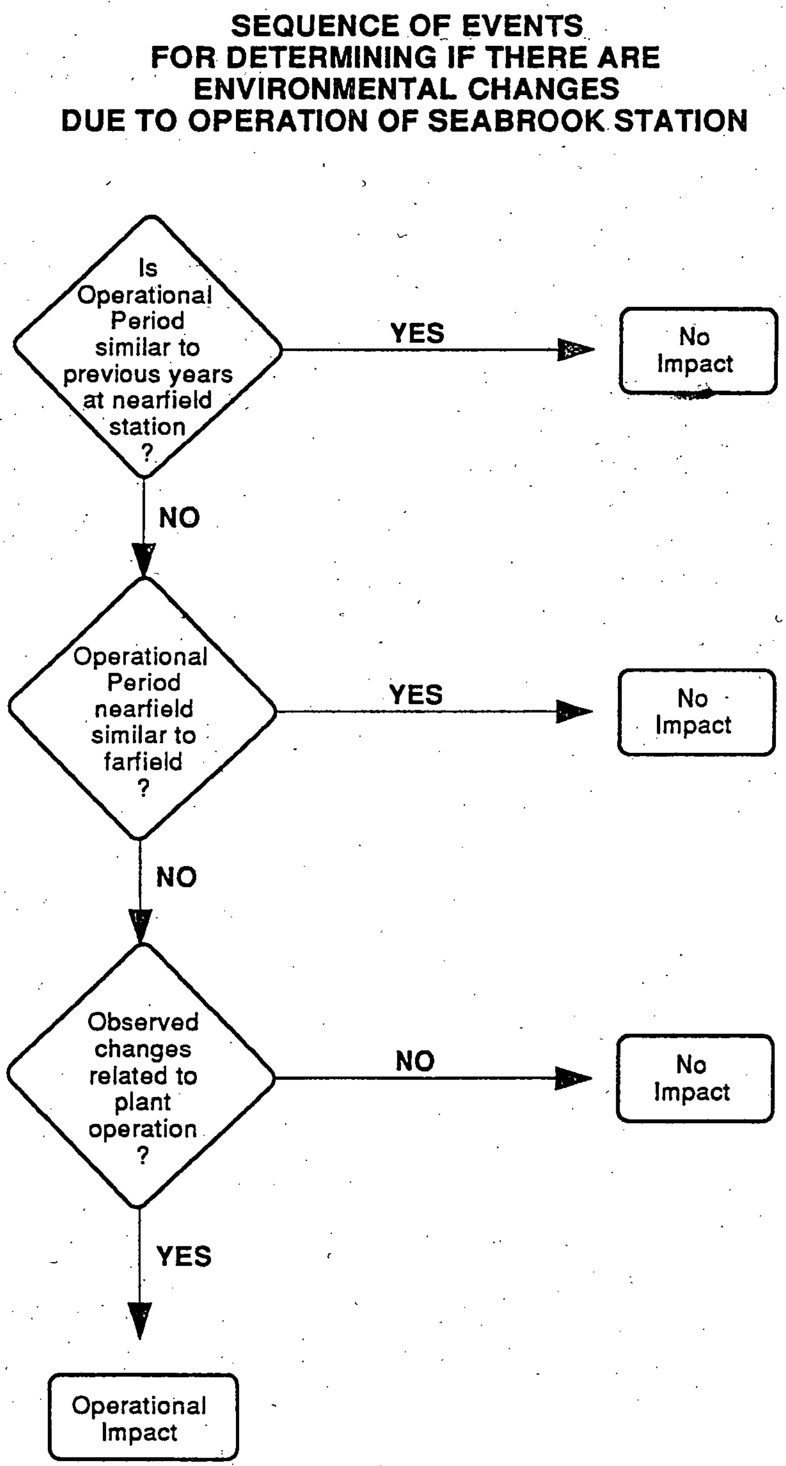


Figure 1-1. Sequence of events for determining if there are environmental changes due to the operation of Seabrook Station. Seabrook Operational Report, 1994.

TABLE 1-1. SUMMARY OF BIOLOGICAL COMMUNITIES AND TAXA MONITORED FOR EACH POTENTIAL IMPACT TYPE. SEABROOK OPERATIONAL REPORT, 1994.

MONITORING AREA	IMPACT TYPE	SAMPLE TYPE	LEVEL MONITORED: COMMUNITY	LEVEL MONITORED: SELECTED SPECIES/ PARAMETERS
Intake	Entrainment	Microzooplankton	x	x
		Macrozooplankton	x	x
		Fish eggs	x	
		Fish larvae	x	x
		Soft-shell clam larvae	[a]	
		Cancer crab larvae	[a]	x
				x
	Impingement	Juvenile/Adult fish	x	x
		Lobster adults		x
Discharge	Thermal Plume	Nearshore water quality		x
		Phytoplankton	x	x
		Lobster larvae		x
		Intertidal/shallow subtidal macroalgae and macrofauna	x	x
		Subsurface fouling community	x	x
	Turbidity (Detrital Rain)	Mid-depth/deep macrofauna and macroalgae	x	x
		Bottom fouling community		x
		Demersal fish	x	x
		Lobster adults		x
		Cancer crab adults		x
Estuary	Cumulative Sources	Estuarine temperature		x
		Soft-shell clam spat and adults		x
		Estuarine fish	x	x

[a]No samples collected in 1994. See Executive Summary pages 1-8.

study continues to focus on the likely sources of potential influence from plant operation, and the sensitivity of a community or parameter to that influence within the framework of natural variability (Table 1-1). A community or species within the study area might be affected by more than one aspect of the CWS. Results from this monitoring program will be discussed in light of that aspect of the cooling water system that has the greatest potential for affecting that particular component of the biological community. Entrainment and impingement were addressed through in-plant monitoring of the organisms entrapped in the CWS.

The effects on the balanced indigenous populations of aquatic biota in the vicinity of the CWS intake and discharge structures were evaluated through continued monitoring at sampling stations established during the preoperational period, with statistical comparison of the results at both the community and the species levels. The null hypothesis in all tests is that there as been no change in community structure or selected species abundance or biomass that is restricted to the nearfield area. This in turn would indicate, based on the approach outlined in Figure 1-1, that the balanced indigenous populations have not been affected.

1.2 STUDY PERIODS

Environmental studies for Seabrook Station began in 1969 and focused on plant design and siting questions. Once these questions were resolved, a monitoring program was designed to assess the temporal (seasonal and yearly) and spatial (nearfield and farfield) variability during the preoperational period as a baseline against which conditions during station operation could be evaluated. This report focuses on the preoperational data collected from 1976 through 1989 for fisheries studies and from 1978 through 1989 for most plankton and benthic studies; during these years sampling design had consistently focused on providing the background to address the question of operational effects.

Commercial operation of Seabrook Station began intermittently in July and August 1990, and continued for periods of approximately three weeks in September and October. Therefore, August 1990 is considered the beginning of the operational period for the purposes of this environmental assessment. After operation at 100% for less than a week at the beginning and end of November, the plant operated nearly continuously from December 1990 through July 1991 when it was shut down for routine maintenance. Resumption of full power operation began again in October 1991 and continued through a second maintenance outage in late September 1992. Full power operation began again in November 1992 and continued with only minor interruptions throughout 1993. In 1994 the plant was operational from January through early April, and August through December (Figure 1-2). Monthly characteristics of the Circulating Water System operation throughout 1990-1994 are presented in Table 1-2.

1.3 SUMMARY OF FINDINGS

Water Quality

Water quality parameters were collected to aid in interpreting information obtained from the biological monitoring program, as well as to determine whether the operation of the Seabrook Station Circulating Water System had a measurable effect on the physical or chemical characteristics of the water column. Water quality samples were obtained within the vicinity of Seabrook's intake and discharge structures, and at farfield locations outside of the influence of operation. Measured parameters included temperature, salinity, dissolved oxygen, and nutrients (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia).

Potential impacts related to the operation of Seabrook Station include: (1) temperature changes resulting from the discharge of a heated cooling water from the Station condensers, (2) the discharge of chlorine (sodium hypochlorite) used to prevent the settlement and

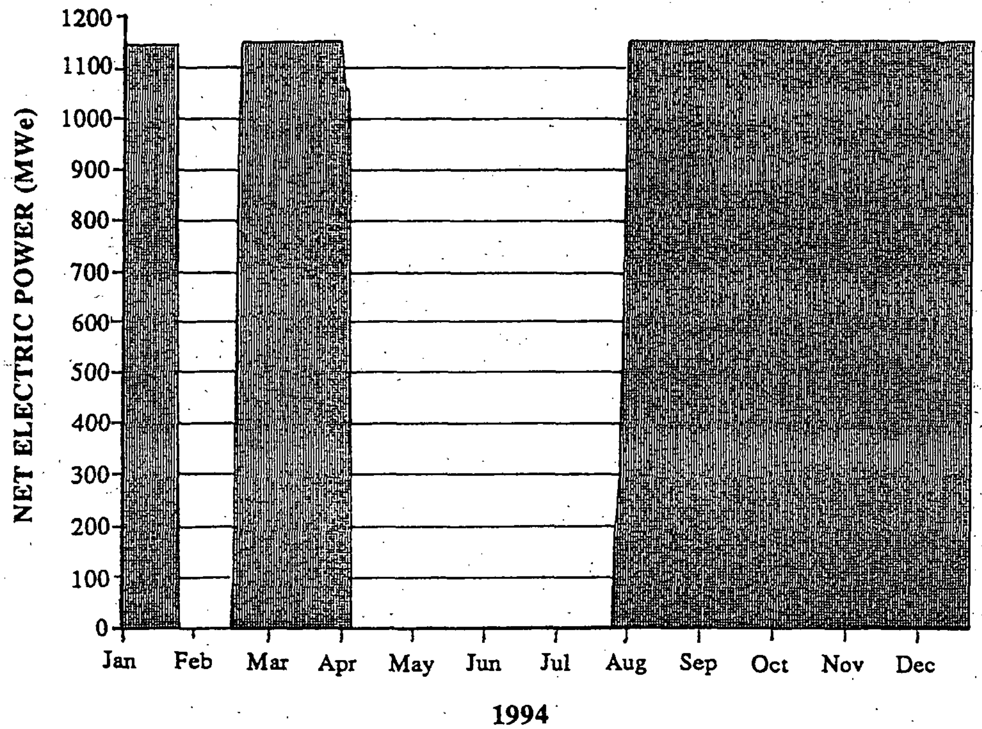


Figure 1-2. Average daily power level at Seabrook Station during 1994. Seabrook Operational Report, 1994.

TABLE 1-2. MONTHLY CHARACTERISTICS OF SEABROOK STATION OPERATION FOR THE PERIOD 1990 THROUGH 1994. SEABROOK OPERATIONAL REPORT, 1994.

	DAYS OF CIRCULATING WATER SYSTEM OPERATIONS					AVERAGE DAILY FLOW (mgd)				
MONTH	1990	1991	1992	1993	1994	1990	1991	1992	1993	1994
Jan	31	31	31	31	25	324	584	585	587	689
Feb	28	28	29	28	12	564	580	578	587	566
Mar	31	31	31	31	31	563	580	581	580	673
Apr	30	30	30	30	8	563	581	576	579	352
May	31	31	31	31	0	562	581	581	582	242
Jun	30	30	30	30	0	563	578	593	582	212
Jul	31	31	31	31	1	582	535	593	578	331
Aug	31	21	31	31	31	588	253	583	579	681
Sep	30	26	29	30	30	588	257	314	574	695
Oct	31	31	24	31	31	590	552	159	574	690
Nov	30	30	30	30	30	590	590	566	612	692
Dec	31	31	31	31	31	589	591	563	608	628

accumulation of biological fouling organism within the Circulating Water System, and (3) associated changes related to the addition of moribund entrained plankton to the nearshore marine environment.

The annual mean surface and bottom temperatures were significantly different among the three monitoring locations. These among-station differences were consistent at all three stations between the preoperational and operational periods. Mean surface and bottom water temperatures in 1994 were the warmest recorded since 1990. Bottom water temperatures were significantly warmer during the operational period, but these increases were consistent at all stations.

Seasonal patterns of surface and bottom salinity were similar between preoperational and operational periods; however, in 1994 annual mean salinities at each station decreased by approximately 0.4-0.8 ppt compared to the preoperational means. There were no significant differences in surface or bottom salinities between the preoperational and operational periods or among stations.

Surface and bottom dissolved oxygen concentrations exhibited a seasonal pattern in 1994 that was similar to previous years. Average surface dissolved oxygen concentrations decreased between the preoperational and operational period, and the magnitude of the decrease was less at the discharge station than at the intake or farfield stations.

There were no significant differences between the preoperational and operational periods for any of the five nutrient parameters analyzed. Significant differences among stations were detected only for orthophosphate and nitrate. These differences were consistent between the preoperational and operational periods, and not attributed to the operation of Seabrook Station. This is based on the consistency of spatial trends between the two periods, as well as the similarity of seasonal patterns across the years.

Most water quality parameters showed a distinct seasonal cycle that was consistent throughout the monitoring period. Significant differences among years were typical, reflecting high year-to-year variability. Increases or decreases in all parameters were consistent between nearfield and farfield stations except surface dissolved oxygen, indicating that the chemical and physical environments in the study area are dominated by larger regional trends. These appear unrelated to the operation of Seabrook Station.

Phytoplankton

The phytoplankton monitoring program was initiated to identify seasonal, annual, and spatial trends in the phytoplankton community and to determine if the operation of Seabrook Station had a measurable effect on this community. The purpose of the monitoring program is to determine if the balanced indigenous phytoplankton community in the Seabrook area has been adversely influenced, within the framework of natural variability, by exposure to the thermal plume. Specific aspects of the community evaluated included phytoplankton (taxa $\geq$10 μm in size) abundance and species composition; ultraplankton (taxa <10 μm in size) abundance and species composition; community standing crop as measured by chlorophyll *a* concentrations; abundance of selected species (*Skeletonema costatum*); and toxicity levels of paralytic shellfish poison (PSP), as measured in the tissue of the mussel *Mytilus edulis*) in the Hampton-Seabrook area.

Monthly abundances of phytoplankton during 1994 and the operational period showed seasonal patterns that were similar to previous years. On average, diatoms (Bacillariophyceae) dominated the phytoplankton assemblage during January through March and June through December during the operational period, while the yellow-green alga *Phaeocystis pouchetti* dominated during April and May. This pattern of seasonal succession in phytoplankton is well documented in other northern temperate waters. Phytoplankton abundances at the intake station varied by more than an order of magnitude throughout the preoperational and operational periods. The geometric mean abundance in 1994 (192,000 cells/L) was higher than the preoperational and operational means. Geometric mean abundances showed no significant differences between the nearfield and farfield stations. In addition, the abundances of the 15 numerically important taxa were not different among the stations in 1994.

Monthly log (x+1) mean ultraplankton abundances were similar among the three stations in 1994 and all exhibited a weak seasonal pattern. Annual mean geometric abundances were similar among the three stations in 1994, and showed no significant differences during the operational period. As in 1991 through 1993, blue-green algae (Cyanophyceae) was the overwhelmingly dominant taxon and followed a similar pattern of occurrence at each station.

During both the preoperational and operational periods, monthly arithmetic mean total chlorophyll *a* concentrations exhibited an early spring peak. Monthly mean operational concentrations were lower than preoperational concentrations in all months. On an annual basis, there appeared to be no relationship between chlorophyll *a* concentrations and phytoplankton abundances. The lack of a trend is likely due to differences among taxa with respect to cell size and chlorophyll *a* content. Seasonally, preoperational and operational chlorophyll *a* concentrations followed a pattern similar to that of phytoplankton abundances during the same periods.

Skeletonema costatum was chosen as a selected species because of its historic omnipresence and overwhelming dominance during much of the year. There were no significant differences in the abundance of *S. costatum* between the preoperational and operational periods or between stations. During the operational period both spring and fall peaks were larger than the preoperational period but followed the same general pattern. In 1994, *S. costatum* abundances generally followed historic patterns, except in March and September when mean abundances were higher than those typically observed and in June when mean abundances were lower.

During the preoperational period, paralytic shellfish poison (PSP) toxicity levels, commonly known as red tide, were above the detection limit in tissue of the mussel *Mytilius edulis* and above the closure limit during the late spring, early summer, and late summer. In 1991, only two occurrences of PSP above the detection limit were recorded. PSP was not detected during 1992. In 1993 PSP was detected above the closure level in May and June, and July. In 1994 the closure level was exceeded in May through July. Red tide events in New Hampshire coincided with those in adjacent states. There were no outbreaks of red tide that were restricted to New Hampshire, consistent with recent research pointing to a non-local origin.

Zooplankton

Three components of the zooplankton community, microzooplankton, bivalve larvae, and macrozooplankton, were sampled separately to identify spatial and temporal trends at both the community and species level. Initial monitoring characterized the source and magnitude of variations in abundance and species composition in the zooplankton community and provided a template for comparison to data obtained during the operational period. The zooplankton community is currently evaluated to determine whether entrainment within the Circulating Water System (CWS) of Seabrook Station has had a measurable effect on the community or any species. The entrainment of bivalve larvae within the CWS has also been evaluated.

Microzooplankton species composition during the operational period continued to resemble the historical patterns. While the abundances of some taxa were different between the operational and preoperational periods, these differences were generally consistent between stations. Patterns of seasonal variation recorded during the operational years (1991-1994) for the selected microzooplankton species were generally similar to those observed during the preoperational period. Operational differences, if they occurred, were observed at both nearfield and farfield stations.

The species composition of bivalve larvae during the operational and preoperational periods was similar to previous years. Seasonal appearances of dominant species were similar to previous years. However, average abundances for four of the species during the operational periods were less than abundances during the preoperational period. These decreases occurred at both the nearfield and farfield stations and suggest an area-wide trend unrelated to the operation of Seabrook Station. Two taxa, *Hiatella* sp., one of the dominants, and *Teredo navalis*, a relatively rare species, showed trends among stations that differed between the preoperational and operational periods. For both of these taxa, the trends at least one of the nearfield stations paralleled trends the farfield station.

Entrainment collections provide a measure of the actual number of organisms directly affected by Station entrainment. No entrainment samples for bivalve larvae were collected in 1994 due to a scheduled plant outage and collection scheduling deficiencies. Consistent with previous refueling outages, ichthyoplankton and bivalve larvae entrainment samples were not taken during the April 9 to July 31 refueling outage when there was insufficient circulating water flow to operate the entrainment sampling equipment. Refurbishment of the entrainment sampling equipment was not completed during the outage as originally scheduled and as a result on-site entrainment sampling was not resumed until mid September when the equipment was returned to service. However, when ichthyoplankton sampling was resumed, bivalve larvae sampling was not resumed. As a result of the outage which began in April and the failure to resume bivalve entrainment sampling in September, no bivalve larvae samples were taken in 1994 during the April to October sampling period. These on-site entrainment sampling deficiencies have been addressed by reassigning the responsibility for entrainment sampling to the organization that provides oversight of the off-site environmental monitoring program. Monthly entrainment of all taxa was less in 1991 and 1992 in comparison to 1990 and 1993. Reduced CWS flow during outage periods in the summer when larvae typically reach their peak abundance levels in the local coastal waters may have led to reduced entrainment in 1991 and 1992. Abundances of *Mytilus edulis* larvae in collections from all stations in 1991 and 1992 were also reduced when compared to 1990 and 1993, contributing to reductions in entrainment. Entrainment within the CWS has not affected the balanced indigenous bivalve larvae community based on data from 1990-1993. The seasonal pattern of the bivalve larvae *Mytilus edulis* during the operational period was similar to recent preoperational years.

Plankton that spend all or a portion of their life in the water column (holo- and meroplankton) were similar to those in other portions of the Gulf of Maine. The seasonal change in the holo- and meroplankton community composition at both nearfield and farfield stations were consistent during the past six years. However, the abundances of many of the dominant species were elevated in the operational period compared to the preoperational period. Increased abundances generally occurred at all three stations, suggesting an area-wide change. One exception was in the abundance of *Calanus finmarchicus* adults, which showed a significant decrease at the farfield station during the operational period while the intake and discharge stations showed a corresponding increase. Comparisons of annual means showed these differences to be slight.

Tychoplankton are those plankton that inhabit both the substrate and the water column as a result of excursions related to light, lunar cycle, storm events, reproduction or nonspecific aggregation. Tychoplankton exhibited greater spatial variability than either the holo-or meroplankton. Seasonal changes in species composition were generally similar between the operational and preoperational periods. Substrate differences between the nearfield and farfield stations account for some of the variability observed in the tychoplankton assemblages.

Differences between the spatial and temporal components of the tychoplankton assemblages have been consistent throughout the study. Abundance differences between the preoperational and operational periods have occurred at both the nearfield and farfield stations. Spatial patterns of tychoplankton have been similar both in the preoperational and operational periods.

There has essentially been no change in the abundances or seasonality in most of the macrozooplankton selected species. With the exception of *Canalus finmarchicus* adults, changes in abundances between the preoperational and operational periods were consistent at all stations.

Fish Population

Finfish studies at Seabrook Station began in 1975 to investigate all life stages of fish, including ichthyoplankton (eggs and larvae), juveniles, and adults. Potential impacts of Seabrook Station operation on local populations include the entrainment of eggs and larvae through the Circulating Water System and the impingement of larger specimens on travelling screens within the Circulating Water pumphouse. Local distribution could also potentially be affected by the thermal plume, with some eggs and larvae being subjected to thermal shock due to plume entrainment upon discharge from the system diffusers. The main objective of the finfish studies is to assess whether the operation of Seabrook Station has had any measurable effect on the nearshore fish population.

Ichthyoplankton analyses focused on seasonal assemblages of both eggs and larvae, as well as on the collection of selected larval species. Consistent temporal (among months and years) and spatial (among stations) egg and larval assemblages identified through the monitoring programs suggest that the operation of Seabrook Station has not altered the seasonal spawning time nor the distribution of eggs in the Hampton-Seabrook area. Although the temporal occurrence of fish larvae, both monthly and annually, was less consistent than for eggs, spatial parameters were consistent. Ichthyoplankton composition at all three stations was very similar within each year and month. Temporal changes in assemblage abundances were consistent at all three stations.

Among the selected larval species, changes in density were consistent between the preoperational and operational periods at all stations, except for Atlantic sand lance. Density of Atlantic sand lance increased at the farfield station, but there were no significant differences at the two at the other nearfield stations. These changes in density are probably not due to plant operation because density of sand lance larvae has generally been increasing at all stations during the operational period.

Entrainment of eggs and larvae in 1994 were the lowest recorded since the plant became operational, primarily due to an extended outage from April through July that included the period of greatest abundance for many eggs and larvae. Taxa entrained in 1994 were also common in previous years, but their relative abundances were different due to the extended outage that reduced entrainment for several species that were historically more abundant.

In the pelagic fish community, Atlantic herring, blueback herring, silver hake and pollock were dominant during the preoperational period. During the operational period, Atlantic herring, pollock, Atlantic mackerel and spiny dogfish were dominant. The change in the species composition of dominant pelagic fish reflected larger changes in the pelagic fish community in the Gulf of Maine. The spiny dogfish has become increasingly abundant during the operational period. Together with skates, spiny dogfish now compose about 75% of the fish biomass of the Georges Bank.

The geometric mean CPUE of demersal fish at all stations combined in 1994 decreased compared to 1993 and was the second lowest since sampling began in 1976. Dominant demersal fish in the operational period were winter flounder, longhorn sculpin, yellowtail flounder and skates. Catches of nearly all species declined from the preoperational to the operational period, particularly for the yellowtail flounder. Differences in CPUE and species composition were apparent among stations. This may be due to the fact that the discharge station is located in shallow water off the mouth of Hampton-Seabrook Harbor where the substrate has a tendency to be inundated with drift algae. The farfield stations were located in deeper water with sandier bottoms. Changes in CPUE of adult fish between the preoperational and operational periods were consistent at all stations with the exception of rainbow smelt and winter flounder. The decrease in winter flounder abundance at the nearfield station began prior to plant operation. Similar decreases in rainbow smelt CPUE at the nearfield station were also observed in the preoperational period. Therefore, it is not likely that these decreases in CPUE were due to the operation of Seabrook Station.

The geometric mean CPUE for estuarine fish caught at all stations during 1994 increased from the average in 1993. Catches generally were smaller during 1987-1994 compared to 1976-1984. Average catches were less for the operational period than observed during the preoperational period. However, this declining trend began in advance of Station operation. The Atlantic silverside dominated catches in all years sampled. Winter flounder, killifishes (mummichog and striped killifish), ninespine stickleback, and rainbow smelt also contributed to the catch. Trends in the CPUE paralleled fluctuations in catch of the dominant species, Atlantic silverside.

During 1994 an estimated 19,221 fish were impinged on the travelling screens at Seabrook Station. Since the Station began operation, a total of 23,022 fish and 73 American lobsters have been reported. During the 4-year operational period, Atlantic silverside, hakes, grubby, pollock and winter flounder, Atlantic silverside made up 66% of the estimated impingement.

In October 1994, Seabrook Station identified the fact that it had not accurately counted the number of small fish impinged on Seabrook Station's travelling screens prior to the fourth quarter of 1994. Small fish, concealed in screen wash debris had been overlooked by plant personnel responsible for separating fish from debris. Therefore, impingement data prior to the fourth quarter of 1994 cannot be considered to be as reliable as data after this time frame. The impingement monitoring program was enhanced in the fourth quarter of 1994 to separate all readily visible fish from seaweed, and beginning in 1995, biologists began to conduct the weekly impingement evaluation.

The design of the Seabrook Station offshore intake with a mid-water intake fitted with a velocity cap has resulted in fewer numbers of fish being impinged when compared to other coastal power plants.

A number of differences were found between the preoperational and operational periods for adult fish assemblages in general, and for most selected species in particular. In nearly all cases where differences were found, abundance during the operational period was significantly lower than during the preoperational period. However, in many instances, the declines began in the early or mid-1980s. Several of the decreases reflect long-term declining trends of overexploited commercial fishes, including Atlantic cod, winter flounder, and yellowtail flounder.

Marine Macrobenthos

The predominant benthic marine habitat within the vicinity of Seabrook Station's intake and discharge is rocky substrate in the form of ledge and boulders. These rocky surfaces support rich and diverse communities of attached plants and animals (macrobenthos). Because these hard-bottom communities are ecologically important, and are potentially vulnerable to localized coastal anthropogenic impacts, studies of these communities have been an important part of the ecological monitoring program. The program has been designed to determine whether differences exist among communities at sites within the Hampton-Seabrook area that can be attributed to the operation of Seabrook Station. Potential impacts include temperature-related community alteration to areas directly exposed to the thermal discharge plume. This would occur at shallow subtidal sites due to the buoyant nature of a thermal plume. Thermal impacts are unlikely in deeper areas; however, increased turbidity resulting from the transport of suspended solids and entrained organisms could increase shading and sedimentation.

Studies were implemented to identify plant and animal species occupying nearby intertidal and subtidal rock surfaces and at those at farfield control locations. The studies also describe temporal and spatial patterns of species occurrence, identify physical and biological factors that induce variability in these communities, and relate these to the operation of Seabrook Station.

Potential Thermal Plume Effects

Hydrodynamic modeling and subsequent field studies indicated that intertidal benthic locations experienced no temperature increase; shallow subtidal sites experienced increases of <1°F (Padmanabhan and Hecker 1991). Overall, intertidal benthic community parameters (biomass, number of taxa, etc.) and community structure indicated little change in nearfield intertidal or shallow subtidal communities. Of the selected taxa studied in these zones, only the kelp *Laminaria digitata* exhibited a significant decrease specifically in the nearfield area. This trend began in recent preoperational years and its continuation was attributed to natural environmental processes rather than to plant operation.

Abundance patterns of selected dominant intertidal taxa indicated that of the four taxa studied, only one taxon, *Ampithoe rubricata*, exhibited a change in abundance during the operational period that differed between the nearfield and farfield stations. Abundance of *A. rubricata* was significantly lower in the nearfield area and higher in the farfield; however, these changes began prior to Station operation.

In the shallow subtidal benthic communities, no changes have occurred that can be related to the operation of Seabrook Station. Numerical classification of macroalgal and macrofaunal collections revealed no substantive changes in species composition or overall community structure. Abundances of selected taxa were consistent between nearfield and farfield stations over both the preoperational and operational periods for *Chondrus crispus, Laminaria saccharina, Jassa marmorata,* Asteriidae and Mytilidae.

Potential Turbidity Effects

Assessments of community parameters and overall community structure indicate no changes in the nearfield mid-depth community during the operation of Seabrook Station. There were no significant differences in measures of community structure between the preoperational and operational periods for the mid-depth macroalgae or macrofauna communities. High similarity in annual collections within the mid-depth zone was characteristic for the overall faunal and algal community structure.

Of the six selected taxa, only two, *Laminaria digitata* and *L. saccharina* exhibited area wide decreases during the operational period. These decreases occurred at both the nearfield and farfield stations, and were not attributed to plant operation. Densities of selected macrofauna, *Pontogeneia inermis*, *Modiolus modiolus*, Mytlidae, and *Strongylocentrotus droebachiensis* were not significantly different between the preoperational and operational periods.

Collections in the deep water macrobenthic communities and assessment of the overall community structure revealed that nearfield and farfield communities have remained stable over the preoperational and operational periods. Overall, the macrobenthic communities appear unaffected by Station operation.

Surface Panels

The surface fouling panels program was designed to study settlement patterns and community development in the discharge plume and in farfield areas. Panels provide information on the temporal sequence of settlement activity, as well as on species growth and patterns of community development.

The settlement of the fouling community was monitored through the short term panels program, where panels are exposed for one month each month of the year. Settlement of fouling organisms on short term monthly panels did not appear to be affected by plant operation because there were no significant differences in the trends between stations, or between the preoperational and operational periods in the abundance, number of taxa, or biomass of the fouling community. Similarly, there was no apparent effect due to plant operation on the settlement of selected species: Mytilidae, *Jassa marmorata*, and *Tubularia* sp.

Fouling community development was assessed through a monthly sequential panel program where panels were exposed for increasing periods of time ranging from 1 to 12 months. Seasonal patterns of development were similar between the preoperational and operational periods. Average annual biomass on monthly sequential panels was similar between the preoperational and operational periods at all stations. For the year-end panels exposed for 12 months, biomass and abundance were similar between the preoperational and operational periods at both nearfield and farfield stations. The number of taxa increased at the nearfield station between the preoperational and operational periods, but was not significantly different at the farfield station.

In 1994, panels were also exposed for three, six, nine and 12 month periods. Results from these quarterly panels were similar to the monthly sequential panels for parameters that were comparable between the two programs. Since this is the first year for quarterly sequential panels, there were no preoperational data for comparison.

The community settling and developing on surface panels has shown predictable seasonal patterns throughout the study, as evidenced both by measures of community structure (biomass, abundance, and number of taxa) and by abundance or percent frequency of occurrence of dominant taxa. Few measures showed significant differences between operational and preoperational periods, and these differences were consistent among nearfield and farfield stations, with the exception of the number of taxa on the year-end monthly sequential panel.

Epibenthic Crustacea

The objective of the epibenthic crustacea monitoring program was to determine the seasonal, spatial, and annual trends in larval density and catch per unit effort (CPUE) for juvenile and adult stages of American lobster (*Homarus americanus*), Jonah crab (*Cancer borealis*) and rock crab (*Cancer irroratus*). Analyses were done to determine if the discharge from Seabrook Station had any measurable effect on these species.

Annual mean densities of lobster larvae in 1994 continued the trends observed in 1991 through 1993. Lobster larvae densities during 1994 were higher than during the preoperational period (1988-1989) at each station. Average larval densities during the four year operational period were significantly higher than the average densities during the preoperational period. There were no significant differences among the three stations during the 1988-1994 monitoring period. Monthly trends were similar to those observed in previous years. Increases in densities during 1994 were due mainly to increases in Stage I and Stage IV larvae, historically the most numerous of the four stages. Stage IV larvae are hypothesized to originate, at least in part, offshore in the warm southwestern waters of the Gulf of Maine and Georges Bank. The decline in lobster abundance in the study area parallels an overall decline in lobster abundance in the Gulf of Maine (NOAA 1992).

The 1994 CPUE for adult lobster was lower than the preoperational and operational means. CPUE declined between the preoperational and operational periods, but the decline was significantly greater at the farfield station. The monthly trend of CPUE in 1994 was similar to that observed during the preoperational period. Legal sized lobsters in 1994 were 5% of the total catch at the nearfield station and 3% at the farfield station, slightly lower than the preoperational averages of 8% and 7% respectively. The decrease in the percentage of legal sized lobsters in the operational period is likely due to the increases in the legal size limit.

In 1994, 31 lobsters were impinged in the Station's Circulating Water System. Four were impinged in 1990, 29 in 1991, 6 in 1992, and one in 1993. The current level of impingement does not pose a serious threat to the indigenous population.

Cancer spp. larvae had slightly lower abundances in 1994 than during the preoperational period at all stations. The average density during the four year operational period was not significantly different from the preoperational average. The 1994 mean CPUE for both Jonah crab and rock crab was lower than the preoperational and operational periods at both the nearfield and farfield stations. There were no significant differences between the preoperational and operational periods or among stations for either of these species. Rock crabs have been less prevalent than Jonah crabs throughout the study area, probably because of their preference for sandy substrata, which are rare in the study area.

Estuarine Benthos

Environmental studies conducted in Hampton Harbor since 1978 have included monitoring of the physical parameters (temperature and salinity), fish populations, benthic macrofauna, and juvenile and adult soft-shell clams (*Mya arenaria*). Current estuarine monitoring efforts are directed to identify potential effects from either the Settling Basin discharge or Seabrook Station operation. The objectives of the estuarine benthos studies are to characterize the macrofaunal communities in the Hampton estuary in terms of abundance and species composition, to identify spatial and temporal patterns in community structure and abundance, and to assess whether observed changes are related to the operation of Seabrook Station. In April 1994, the settling basin discharge was diverted offshore via the cooling water discharge tunnel.

The mean monthly salinity at low tide in Browns River during 1994 was lowest in spring, due to runoff, and highest in the summer when precipitation was lowest, a pattern similar to previous years. Salinities at both Browns River and Hampton Harbor were consistently lower at low tide than at high tide. Seasonal patterns of salinity corresponded to variations in precipitation. Mean monthly precipitation in 1994 highest in March and September.

Mean monthly temperatures at Browns River at low tide during 1994 ranged from a low in February to a high in July, similar to previous years. Temperature ranges in Hampton Harbor were narrower. At both sites the monthly water temperatures during 1994 were similar to the monthly values reported since 1979.

Salinity and water temperature data were collected in January through May 1995 at Browns River. Salinity and water temperatures for the first five months of 1995 were within ranges for these months during previous years.

The general macrobenthic community structures at both nearfield (Browns River) and farfield (Mill Creek) stations in the vicinity of Seabrook Station were typical for East Coast estuarine areas with fine-grained sediments. Species abundances and dominance in the estuary are generally controlled by the physical environment, and the most numerous species are those that tolerate fluctuating water temperatures and salinity and a changing sedimentary environment. Macrofaunal species composition in Browns River near the outfall was similar to Mill Creek, a control site located away from the influence of the settling basin discharge. The dominant taxa collected at both sites included the polychaetes *Streblospio benedicti*, *Capitella capitata*, *Hediste diversicolor* and oligochaetes; all these organisms are classified as opportunists and have also predominated in previous study years. In general, total density, mean number of taxa and density of dominant taxa in 1994 were within ranges reported since 1978.

The total macrofaunal density at the intertidal station in the Browns River in 1994 was the highest recorded during the study period. Densities of both *C. capitata* and *H. diversicolor* increased in 1994, continuing a trend that started in 1992. Densities of *H. diversicolor* and *S. benedicti* in 1994 were within the range of previous years. Results of ANOVA tests did not show 1994 to be significantly different from previous years at any station for any variable. There were no apparent impacts on estuarine water quality or benthic community due to the cessation of the discharge from the settling basin in April of 1994.

Soft-Shell Clam

The objectives of the soft-shell clam (*Mya arenaria*) monitoring programs are to determine the spatial and temporal pattern of abundance of various life stages of *Mya arenaria* in the vicinity of Hampton Harbor. Pelagic life stages may be subject to impacts from Seabrook Station operation due to entrainment into the Circulating Water System. Benthic stages (after settlement to the bottom) in the Hampton-Seabrook estuary may be subject to impacts from discharges from the Station's Settling Basin, which were eliminated in 1994. Nearfield/farfield comparisons of clam densities are also made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich, MA.

Mya arenaria larvae occurred most weeks from May through October during the preoperational years. Peak abundances in 1994 were seen in June and September and were above the preoperational average. However, the overall operational mean larval abundance at all three stations was not significantly different than the preoperational means at both nearfield and farfield stations.

Mean density in 1994 of young-of-the-year (1-5 mm) clams on all three flats was less than the preoperational mean and equal to the operational mean density. Juvenile (26-50 mm) mean density in 1994 was less than the preoperational and operational mean densities. Spat (6-25 mm) and adult (>51 mm) mean densities in 1994 were greater than the operational and preoperational mean densities. There were no significant differences in densities of young-of-the-year, spat and juveniles between the preoperational and operational periods. However, the Preop-Op X Area term was significant for adults, which indicated differing trends between the preoperational and operational periods among flats. Adult clam densities increased significantly at Flat 4, and decreased significantly at Flat 2 between the preoperational and operational periods. No changes occurred at Flat 1.

In 1994, the mean density of seed clams (1-12 mm) in Hampton Harbor (nearfield area) was lower than the record set of 1993. Densities of seed clams in 1994 in Plum Island Sound (farfield area) were lower than the preoperational mean density and similar to the operational mean. No significant differences were observed between the two areas, suggesting that settlement has been unaffected by Seabrook Station.

Clams in Hampton Harbor have historically been subjected to predation from green crabs (*Carcinus maenas*) and human clam digging. Mean densities of green crabs during the 1991-1994 operational period were lower than preoperational densities for most of the year. Recreational clam digging resumed on Flats 1 and 3 in October of 1994. Despite intensive digging, the effects of harvesting were not apparent as densities of adult and juvenile clams were similar to 1993 densities.

1.4 LITERATURE CITED

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, N.Y. 257 pp.

NOAA. 1992. Status of the fishery resources of the northeastern United States for 1992. NOAA Tech. Memo. NMFS-F/NEC-95. 133 p.

Normandeau Associates Inc. (NAI). 1977. Summary document: assessment of anticipated impacts of construction and operation of Seabrook Station on the estuarine, coastal and offshore waters of Hampton-Seabrook, New Hampshire.

__________. 1991. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

Padmanabhan M. and Hecker, G.E. 1991. Comparative Evaluation of Hydraulic Model and Field Thermal Plume Data, Seabrook Nuclear Power Station. Alden Research Laboratory, Inc.

TABLE OF CONTENTS

PAGE

SUMMARY

Water quality measurements collected in 1994 were similar to those collected in previous years, although temperatures fluctuated over a wider range between winter and summer than in any previous year. On average, temperatures were warmer in 1994 than in 1992-1993, but cooler than in 1991. Salinities and dissolved oxygen concentrations were also lower during summer and fall than in previous years. Monthly mean levels of orthophosphate in 1994 were generally lower than the preoperational means, while total phosphorus levels were generally higher. Monthly mean levels of nitrate, nitrite and ammonia were both above and below the preoperational means.

All water quality parameters showed a distinct seasonal pattern that was consistent throughout the monitoring program. With the exception of bottom temperatures, there were no significant preoperational-operational differences (operational bottom temperatures were significantly warmer than preoperational bottom temperatures). Small but significant differences among stations were observed in surface and bottom temperatures and in orthophosphate and nitrate concentrations, although in each case relationships were consistent between the preoperational and operational periods.

Although surface dissolved oxygen concentrations declined at each of the three stations between the preoperational and operational periods, they declined more steeply at Stations P2 and P7 than at P5, as indicated by a significant interaction term in the ANOVA model. This outcome does not appear to be temperature related, since there was no significant difference between preoperational and operational surface temperatures, and temperatures at P5 were actually slightly warmer than at P2 and P7.

LIST OF FIGURES

LIST OF TABLES

PAGE

2.0 WATER QUALITY

2.1 INTRODUCTION

Water quality parameters were collected to aid in interpreting information obtained from the biological monitoring program and to determine whether the operation of the Seabrook Station Circulating Water System has had a measurable effect on the physical and chemical characteristics of the water column. To provide information on the physical environment, water quality samples were collected in the vicinity of the Seabrook Station intake and discharge, as well as at a farfield location outside of the influence of Station operation. Parameters measured included temperature, salinity, dissolved oxygen, and nutrients. Potential impacts related to the cooling water system include both that of temperature, through the discharge of a heated effluent from the condensers, and the application of sodium hypochlorite as a biofouling control measure.

Seabrook Station employs a once-through Circulating Water System. Ambient ocean water is drawn into the system from approximately 7,000 feet offshore through three intake structures and returned through a multiport diffuser system approximately 5,500 feet offshore. All discharges are controlled under the Station's National Pollutant Discharge and Elimination System (NPDES) Permit issued by the State of New Hampshire and the Environmental Protection Agency (EPA). This permit specifies that the temperature rise shall not exceed 5°F (3°C) within the nearfield jet mixing region. This applies at the surface of the receiving waters within 300 feet of the submerged diffuser in the direction of discharge.

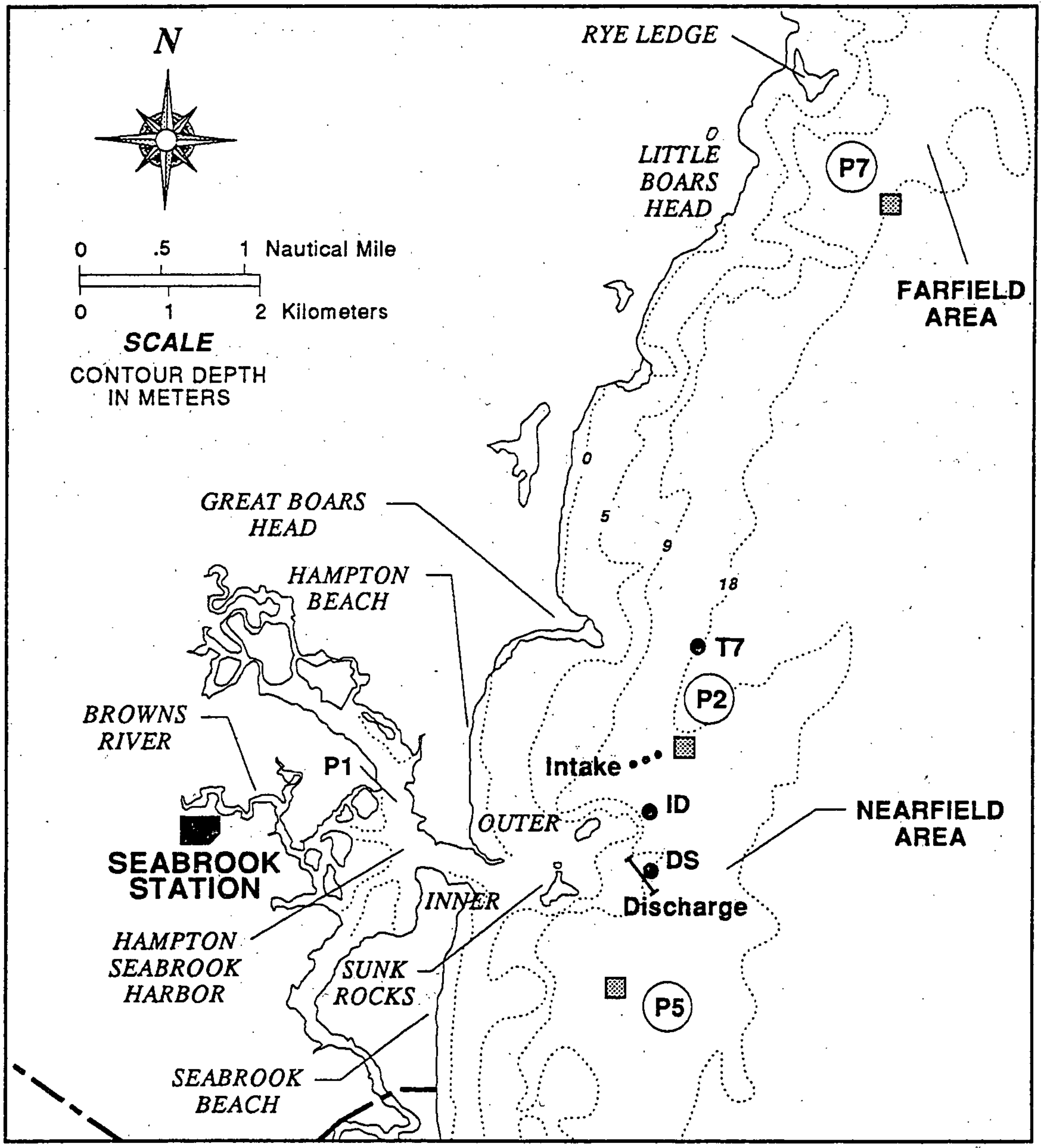
Seabrook Station utilizes continuous low level chlorination in the Circulating and Service Water Systems to control biofouling. Information was gathered through the Chlorine Minimization Program, which assessed the effectiveness of chlorine application in preventing biofouling while utilizing the least amount of chlorine. Residual levels of chlorine at the diffusers, when measured, have been below detection limits.

2.2 METHODS

2.2.1 Field Methods

Near-surface (-1 m) water samples for nutrient analysis were collected during daylight hours using a General Oceanics® 8-L water sampler from the intake (Station P2, 16.8 m depth, MLW), discharge (Station P5, 16 m depth, MLW), and farfield (P7, 18.3 m depth, MLW) sampling locations (Figure 2-1). Nutrient sampling commenced at Stations P2 and P5 in 1978 and at Station P7 in 1982. Sampling continued until 1981 at P5 and until 1984 at P2 and P7. Sampling resumed at all three stations in July 1986, and continued to the present. Water samples were taken once in January, February, and December and twice monthly from March through November, in conjunction with the phytoplankton and microzooplankton sampling, and within 24 hours of the weekly macrozooplankton and ichthyoplankton sampling.

Temperature, dissolved oxygen, and salinity measurements began in 1979 at Stations P2 and P5, and in 1982 at Station P7. Sampling at P2 and P7 continued to the present; sampling at P5 was interrupted from January 1982 until July 1986, but was sampled concurrently with P2 and P7 from July 1986 until the present. At all stations, temperature and salinity profiles were taken in 2 m increments four times per month during January through December with a Beckman® Thermistor Salinometer (through March 1989) or a YSI® (Model 33) S-C-T Meter within 24 hours of the weekly macrozooplankton and ichthyoplankton sampling. Duplicate dissolved oxygen samples were also collected at near-surface (-1 m) and near-bottom (1 m above bottom) depths. Samples were fixed in the field with manganese sulfate and alkaline iodide-azide, and analyzed by titration within eight hours of collection. Additionally, continuous operational



LEGEND

▩ = water quality stations

● = continuous temperature monitoring stations

Figure 2-1. Water quality sampling stations. Seabrook Operational Report, 1994.

temperature data from the discharge (Station DS), nearfield (Station ID) and farfield (Station T7) areas were collected beginning in August 1990 by Ocean Surveys Inc. (OSI) as part of Seabrook Station's NPDES permit compliance program (Figure 2-1). The results of this monitoring are included in this section.

2.2.2. Laboratory Methods

Water quality samples were analyzed for five nutrients (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia) using a Technicon® Autoanalyzer II system. All analyses were performed according to EPA Methods for Chemical Analyses of Water and Wastes (USEPA 1979) and Standard Methods (APHA 1989).

2.2.3 Analytical Methods

Results from these collection efforts were used to describe the seasonal, temporal, and spatial characteristics of the water column within the nearshore waters off Seabrook Station. Analyses used data from all stations, but focused on Station P2 since it was sampled for a longer period of time than Stations P5 and P7. Any values that were less than the detection limits were assigned a value equal to one-half of the detection limit for computational purposes (Gilbert 1987). Seasonal trends were analyzed using monthly arithmetic mean temperatures and dissolved oxygen, salinity, and nutrient concentrations. Monthly means for the preoperational and operational periods were calculated from the monthly arithmetic means for each year within each period, resulting in a sample size equal to the number of years in each period. Monthly means for 1994 were calculated as the arithmetic average of all samples taken within a given month.

Among-year and between-period trends were evaluated using annual or period (preoperational, operation) means. Annual means of 1994 collections were calculated as the arithmetic mean of all observations within the year. The means of preoperational and operational collections were calculated as arithmetic means of annual means over all years within each period, which varied among stations and parameters. The precision of the mean was described by its coefficient of variation (Sokal and Rohlf 1981). The preoperational periods for the different analyses are listed on the appropriate tables and figures; in all cases the operational period consists of collections from 1991-1994. Collections from 1990 were not included in these analyses since the year was divided between the preoperational and operational periods, and the inclusion of partial years in each period would bias the means.

Operational/preoperational and nearfield/farfield differences in monthly means were evaluated using a multi-way analysis of variance procedure (ANOVA), using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. A mixed model ANOVA developed by Northeast Utilities, based on recent review of the BACI model by Underwood (1994) and Stewart-Oaten (1986), was used with all effects considered random, except operational status (Preop-Op). Time and location of sampling were considered random factors because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). The preoperational period for each analysis was specified as 1987-1989, which was the period during which all three stations were sampled concurrently (thus maintaining a balanced model design). These results were evaluated in conjunction with means calculated over all available preoperational years to help distinguish between recent trends and long-term trends.

2.3 RESULTS

2.3.1 Physical Environment

Temperature

Monthly mean surface water temperatures at Station P2 followed a similar seasonal pattern during both the preoperational and operational periods (Figure 2-2). In 1994 specifically, surface temperatures were coolest in February (2°C cooler than in January), then warmed by an additional 3.5°C by the end of April. The largest consecutive monthly change in temperature occurred between June and July, when the average temperature increased by 6°C. The annual maximum temperature occurred in August. Warm temperatures continued into September, but then began to cool, and declined by 2.5-4.0°C per month through December.

Monthly mean surface temperatures recorded in 1994 at Station P2 were lower than preoperational lower 95% confidence limits in January through April and in June, similar to the preoperational mean in May, then greater than preoperational upper 95% confidence limits by an average of 1.3°C through the last six months of the year (Figure 2-2). This is reflected in the range of temperatures observed in 1994 (0.1°C to 20.3°C), which was 2.3°C wider than the average range of temperatures in the preoperational period (Table 2-1), and the widest of all individual preoperational or operational years (Figure 2-3). Surface temperatures in 1994 at Stations P5 and P7 followed the same seasonal pattern as observed at P2 (Figure 2-2). Temperatures at P2 and P5 were slightly greater than at P7, as was observed in the preoperational period (Table 2-1).

Average annual surface temperatures in 1994 were warmer at each station compared to recent preoperational years (1987-1989) and over all preoperational years (Table 2-1). Temperatures in 1994 reversed a cooling trend observed in 1992 and 1993 compared to 1991, when the mean annual surface temperature at P2 (10.1°C) was the highest recorded during the fifteen year study period (Figure 2-3). Differences between stations were small but significant, and Preop-Op differences were not significant (Table 2-2). Differences in surface temperatures between preoperational and operational periods were consistent among all three stations, as indicated by the non-significant interaction term in the ANOVA model (Table 2-2).

As noted for surface temperatures, monthly mean bottom temperatures at each station were generally cooler during the winter and warmer during the summer in 1994 compared to preoperational monthly mean temperatures (Figure 2-2). This is reflected in the wider range of temperatures observed in 1994 compared to the average range of temperatures recorded during the preoperational period (Table 2-1). Average annual bottom temperatures were slightly warmer at Station P5 compared to P2 and P7 (by 0.2-0.4°C), as in the preoperational period. Annual mean bottom temperatures were warmer at each station in 1994 compared to the entire and recent preoperational averages. Differences between operational and preoperational temperatures were significant (Op>Preop), as were differences among stations. However, the differences in bottom water temperatures between the preoperational and operational periods were consistent at all three stations (i.e., no significant interaction term; Table 2-2).

Monthly mean differences between surface and bottom temperatures (surface - bottom; Figure 2-4) indicated that the water column at each station was essentially isothermal (ΔT = -1°C to +1°C) during six to seven of twelve months, during both operational and preoperational periods. A weak temperature stratification began to develop in May in 1994, with a ΔT of approximately 3°C. The maximum surface-bottom difference of 6.6°C occurred in July. Temperature differences then began to decline to approximately 3-4°C by September. The water column returned to isothermal conditions by late October. Average surface-bottom temperature differences at P2 were similar to preoperational differences in all months

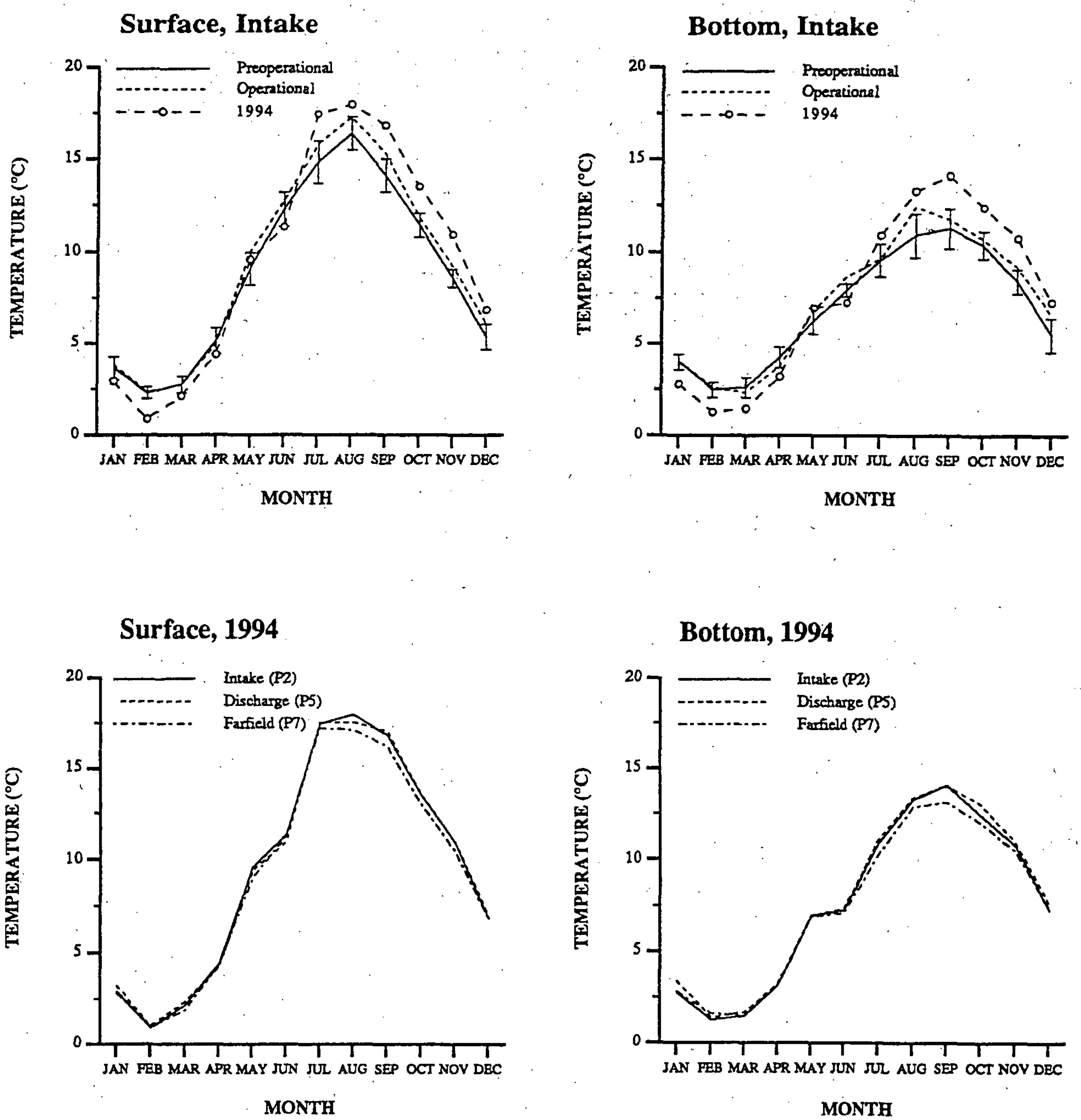


Figure 2-2. Surface and bottom **temperature** (°C) at nearfield Station P2, monthly means and 95% confidence intervals over the preoperational period (1979-1989) and the operational period (1991-1994), and monthly means of surface and bottom temperature at Stations P2, P5, and P7 in 1994. Seabrook Operational Report, 1994.

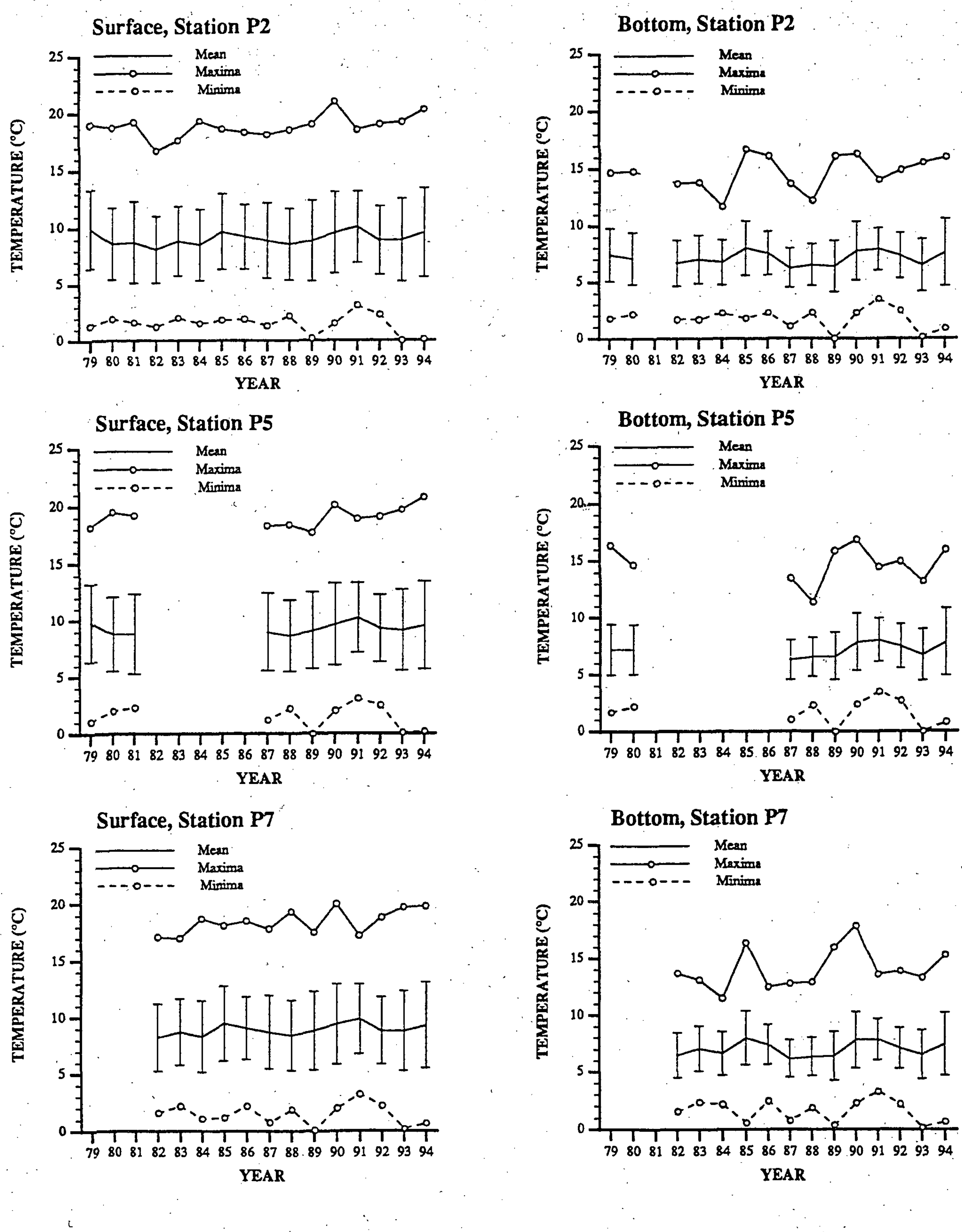


Figure 2-3. Time-series of annual means and 95% confidence intervals and annual minima and maxima of **surface and bottom temperatures** at Stations P2, P5 and P7, 1979-1994. Seabrook Operational Report, 1994.

TABLE 2-1. ANNUAL MEANS AND COEFFICIENTS OF VARIATION (CV,%) AND AVERAGE MINIMA AND MAXIMA FOR WATER QUALITY PARAMETERS MEASURED DURING PLANKTON CRUISES AT STATIONS P2, P5, P7 OVER PREOPERATIONAL[a] AND OPERATIONAL (1991-1994) YEARS, AND THE ANNUAL MEAN, MINIMUM AND MAXIMUM IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

	PREOPERATIONAL														
	ALL YEARS[a]				RECENT YEARS[b]				OPERATIONAL				1994		
PARAMETER	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	MIN	MAX
TEMPERATURE (°C)															
Surface															
P2	9.1	8.0	1.5	18.5	9.0	3.0	1.2	18.5	9.4	5.4	1.4	19.3	9.6	0.1	20.3
P5	9.9	10.7	2.0	18.5	9.2	3.7	1.1	18.1	9.6	4.3	1.5	19.6	9.6	0.2	20.8
P7	8.7	6.3	1.4	18.0	8.8	3.6	0.9	18.2	9.2	4.8	1.6	18.9	9.3	0.7	19.8
Bottom															
P2	7.1	8.8	1.7	14.4	6.6	2.7	1.1	14.0	7.4	7.5	1.8	15.1	7.7	0.9	16.0
P5	7.5	16.9	2.2	14.1	6.7	3.7	1.1	13.6	7.6	6.9	1.8	14.7	7.9	0.8	16.0
P7	6.9	9.3	1.6	13.6	6.4	3.1	1.0	13.9	7.2	6.9	1.6	14.0	7.5	0.7	15.3
SALINITY (ppt)															
Surface															
P2	31.6	1.4	28.4	33.3	31.6	1.1	26.9	33.4	31.5	1.5	28.1	33.6	30.9	27.2	33.1
P5	31.7	0.9	28.2	33.7	31.5	1.1	25.5	34.4	31.4	1.3	26.7	33.5	30.9	27.6	33.0
P7	31.5	1.3	26.7	33.6	31.4	1.0	25.0	33.5	31.5	1.3	27.8	33.6	31.0	26.8	32.8
Bottom															
P2	32.3	0.8	30.6	33.5	32.1	0.9	30.1	33.7	32.1	1.0	29.4	33.5	31.7	29.2	33.1
P5	32.2	0.6	31.0	33.5	32.1	0.7	30.5	33.6	32.1	1.1	28.0	33.5	31.6	28.8	33.0
P7	32.2	0.8	30.5	33.5	32.2	0.8	30.5	33.6	32.2	1.3	28.5	34.0	31.6	26.5	33.2
DISSOLVED OXYGEN (mg/L)															
Surface															
P2	9.7	3.1	7.4	12.5	9.7	1.0	7.4	12.3	9.6	1.0	7.5	12.0	9.5	7.4	12.2
P5	9.6	4.6	7.6	11.6	9.7	1.0	7.6	12.3	9.7	1.0	7.6	12.1	9.6	7.9	12.3
P7	9.7	1.0	7.3	12.7	9.7	1.3	7.4	12.2	9.5	1.0	7.4	11.8	9.5	6.9	12.1
Bottom															
P2	9.2	4.6	6.6	12.0	9.2	4.2	6.6	11.7	9.1	3.8	6.4	11.8	8.8	5.4	11.8
P5	9.0	6.8	6.7	11.2	9.2	4.5	6.8	11.9	9.2	2.5	6.5	11.8	9.0	5.9	11.8
P7	9.1	2.5	6.1	12.5	9.1	4.4	6.4	11.7	9.1	3.3	6.4	11.7	8.7	5.4	11.6

(continued)

TABLE 2-1. (Continued)

PARAMETER	PREOPERATIONAL								OPERATIONAL				1994		
	ALL YEARS[a]				RECENT YEARS[b]										
	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	CV	MIN	MAX	$\bar{x}$	MIN	MAX
SURFACE NUTRIENTS (µg/L)															
Orthophosphate															
P2	13.0	27.4	2.4	27.1	14.9	14.7	2.8	32.0	13.8	11.5	3.4	31.8	11.9	2.0	33.5
P5	12.1	22.7	1.9	34.9	14.6	12.2	2.3	37.7	13.5	13.2	3.3	29.9	11.2	2.0	34.5
P7	15.9	10.2	2.3	32.8	15.6	11.4	2.5	33.7	14.3	8.2	4.4	32.4	12.8	2.0	34.5
Total Phosphorus															
P2	25.8	18.8	9.1	52.0	29.2	11.8	11.7	53.3	27.0	7.7	14.4	51.3	28.9	11.0	44.0
P5	27.5	22.6	10.1	56.9	29.7	5.9	16.7	56.7	26.5	11.1	14.9	46.1	27.0	14.0	43.5
P7	29.1	12.2	11.3	56.8	31.0	13.2	13.3	60.0	27.5	9.5	11.9	53.5	29.6	10.0	65.0
Nitrite															
P2	2.1	30.9	0.6	5.5	2.1	16.2	0.5	6.0	2.3	9.5	0.6	6.0	2.4	0.5	5.0
P5	2.1	26.0	0.6	6.3	2.0	13.6	0.5	6.7	2.1	25.6	0.6	5.3	2.9	0.5	5.5
P7	1.9	32.3	0.5	5.8	2.2	17.5	0.5	7.3	2.6	21.3	0.6	7.4	3.4	0.5	9.0
Nitrate															
P2	40.0	20.9	5.5	156.5	44.0	24.5	5.0	170.0	40.0	17.3	3.1	148.8	38.3	2.5	160.0
P5	39.8	19.9	5.7	150.0	42.2	26.2	5.0	163.3	36.6	28.0	3.1	142.5	32.6	2.5	150.0
P7	42.1	24.4	5.0	157.8	47.4	22.5	5.0	166.7	42.2	14.6	3.1	153.8	41.7	2.5	150.0
Ammonia[c]															
P2	6.4	10.7	5.0	20.0	--	--	--	--	6.8	49.3	3.3	22.5	6.3	2.5	30.0
P5	6.1	25.0	5.0	12.5	--	--	--	--	6.2	49.8	3.3	16.3	5.8	2.5	25.0
P7	7.6	18.8	5.0	25.0	--	--	--	--	6.9	47.1	3.3	21.3	5.2	2.5	25.0

[a]Mean of annual means, minima and maxima for preoperational years:
Water quality parameters: P2 = 1979-1989; P5 = 1979-1981, 1987-1989; P7 = 1982-1989
Nutrients: P2 = 1978-1984, 1987-1989; P5 = 1978-1981, 1987-1989; P7 = 1982-1984, 1987-1989

[b]1987-1989; preoperational period specified in ANOVA (Table 2-2), mean of annual means.

[c]Because analytical methods for ammonia changed in April 1988, preoperational period for ammonia is April 1988 - December 1989.

TABLE 2-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING WATER QUALITY CHARACTERISTICS AMONG STATIONS P2, P5, AND P7 DURING RECENT PREOPERATIONAL YEARS (1987-1989) AND OPERATIONAL (1991-1994) YEARS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[h] (ranked in decreasing order)
Surface Temperature	Preop-Op[b,c]	1	21.88	3.47 NS	
	Year (Preop)[d]	5	6.31	0.08 NS	
	Month (Year)[e]	77	83.38	1473.00***	
	Station[f]	2	2.62	45.01*	Non-est.[h]
	Preop-Op X Station[g]	2	0.06	0.91 NS	
	Station X Year (Preop)	10	0.06	1.13 NS	
	Error	154	0.06		
Bottom Temperature	Preop-Op	1	58.95	7.66*	Op>Preop
	Year (Preop)	5	7.69	0.23 NS	
	Month (Year)	77	33.32	397.69***	
	Station	2	1.47	21.72*	Non-est.
	Preop-Op X Station	2	0.07	1.08 NS	
	Station X Year (Preop)	10	0.06	0.75 NS	
	Error	154	0.08		
Surface Salinity	Preop-Op	1	<0.01	<0.01 NS	
	Year (Preop-Op)	5	7.65	1.49 NS	
	Month (Year)	77	5.17	62.91***	
	Station	2	0.32	1.89 NS	
	Preop-Op X Station	2	0.17	2.86 NS	
	Station X Year (Preop)	10	0.06	0.72 NS	
	Error	154	0.08		
Bottom Salinity	Preop-Op	1	0.11	0.03 NS	
	Year (Preop)	5	4.32	2.36*	
	Month (Year)	77	1.80	36.50***	
	Station	2	0.30	9.47 NS	
	Preop-Op X Station	2	0.03	0.40 NS	
	Station X Year (Preop)	10	0.08	1.59 NS	
	Error	154	0.05		

(continued)

TABLE 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[h] (ranked in decreasing order)
Surface Dissolved Oxygen	Preop-Op	1	1.61	4.05 NS	
	Year (Preop)	5	0.36	0.12 NS	
	Month (Year)	77	3.01	170.73***	
	Station	2	0.12	2.84 NS	
	Preop-Op X Station	2	0.04	8.72**	PreP5 PreP2 PreP7>OpP5>OpP2 OpP7[i]
	Station X Year (Preop)	10	<0.01	0.27 NS	
	Error	154	0.02		
Bottom Dissolved Oxygen	Preop-Op	1	0.73	0.18 NS	
	Year (Preop)	5	4.00	0.79 NS	
	Month (Year)	77	5.04	190.80***	
	Station	2	0.30	4.27 NS	
	Preop-Op X Station	2	0.07	1.92 NS	
	Station X Year (Preop)	10	0.04	1.37 NS	
	Error	154	0.03		
Orthophosphate	Preop-Op	1	71.12	0.76 NS	
	Year (Preop-Op)	5	96.98	0.44 NS	
	Month (Year)	77	218.54	73.86***	
	Station	2	10.73	39.86*	Non-est.
	Preop-Op X Station	2	0.30	0.08 NS	
	Station X Year (Preop)	10	3.70	1.25 NS	
	Error	154	2.96		
Total Phosphorus	Preop-Op	1	519.40	1.73 NS	
	Year (Preop-Op)	5	303.53	0.96 NS	
	Month (Year)	76	310.89	13.92***	
	Station	2	45.60	1.82 NS	
	Preop-Op X Station	2	25.06	0.87 NS	
	Station X Year (Preop)	10	28.69	1.28 NS	
	Error	152	22.33		

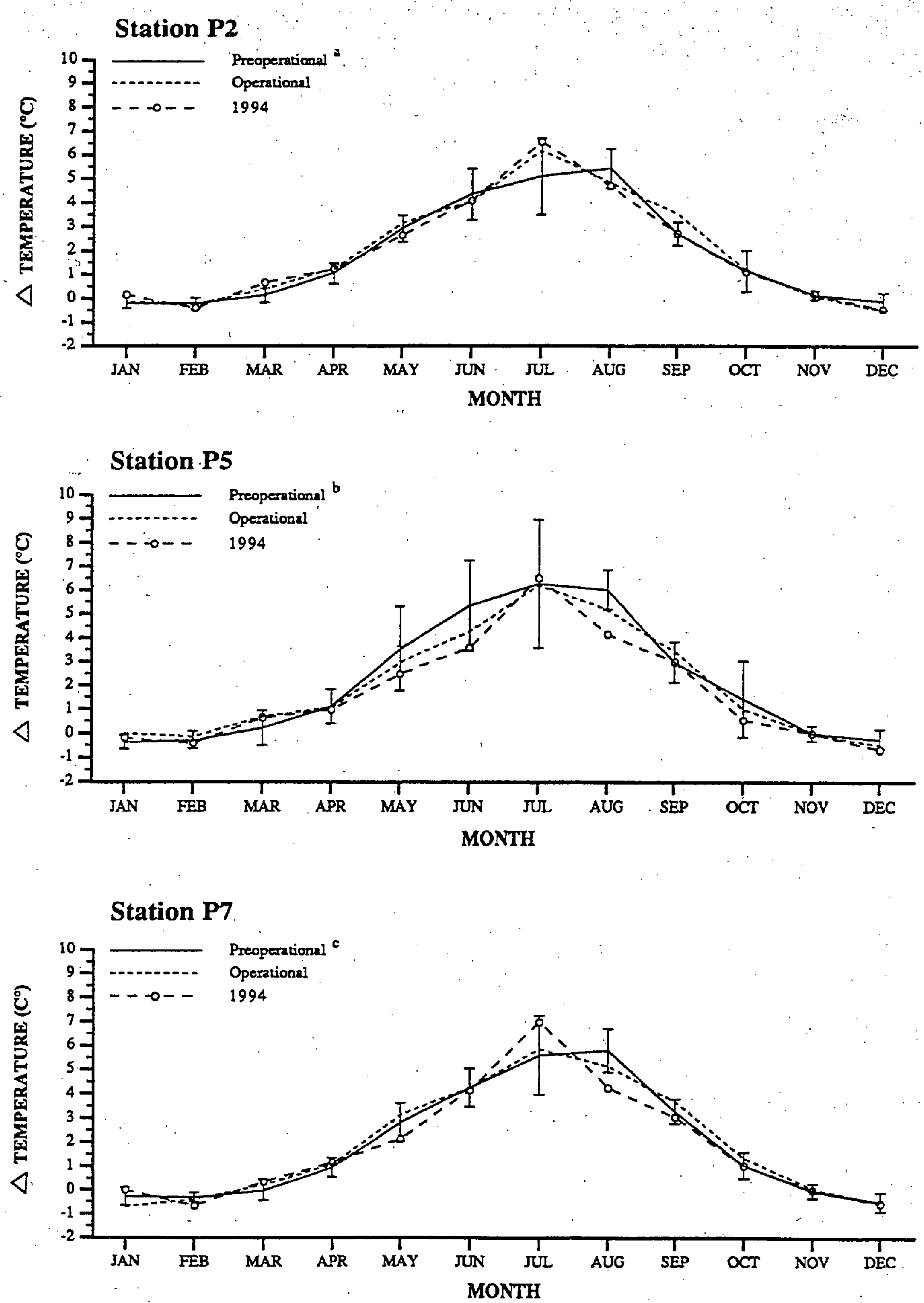
(continued)

TABLE 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[h] (ranked in decreasing order)
Nitrate	Preop-Op	1	1554.67	0.49 NS	
	Year (Preop-Op)	5	3227.35	0.32 NS	
	Month (Year)	77	9992.97	246.65***	
	Station	2	428.07	34.62*	Non. est.
	Preop-Op X Station	2	12.89	0.19 NS	
	Station X Year (Preop)	10	69.27	1.71 NS	
	Error	154	40.51		
Nitrite	Preop-Op	1	3.49	0.83 NS	
	Year (Preop-Op)	5	4.70	0.60 NS	
	Month (Year)	77	7.33	17.93***	
	Station	2	2.12	4.83 NS	
	Preop-Op X Station	2	0.44	0.48 NS	
	Station X Year (Preop)	10	0.92	2.24*	
	Error	154	0.41		
Ammonia	Preop-Op	1	0.89	<0.01 NS	
	Year (Preop-Op)	4	320.25	10.03***	
	Month (Year)	63	33.96	6.39***	
	Station	2	15.31	4.88 NS	
	Preop-Op X Station	2	3.18	0.93 NS	
	Station X Year (Preop)	8	3.28	0.62 NS	
	Error	126	5.31		

[a]Based on averaged monthly collections for all parameters
[b]Preoperational years: 1987-1989 at each station for all parameters except ammonia, which was April 1988 through December 1989
[c]Preoperational versus operational period, regardless of station
[d]Year nested within preoperational and operational periods, regardless of station
[e]Month nested within year nested within preoperational and operational periods, regardless of station
[f]Station P2 versus P5 versus P7, regardless of year
[g]Interaction between main effects
[h]LSMEANS test for differences among stations was non-estimable
[i]Underlining indicates no significant difference based on a test of H_0: LSMEAN(i)=LSMEAN(j).

NS = not significant ($p \geq 0.05$)
* = significant ($0.05 \geq p > 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)



[a] Preoperational years = 1979-1989

[b] Preoperational years = 1979-1981, 1987-1989

[c] Preoperational years = 1982-1989

Figure 2-4. Monthly mean difference and 95% confidence intervals between surface and bottom temperatures (°C) at Stations P2, P5, and P7 for the preoperational period (1979-1989) and monthly means for the operational period (1991-1994) and 1994. Seabrook Operational Report, 1994.

in 1994 except July, when the mean difference was nearly equal to the upper 95% confidence limit of the July preoperational mean difference.

Although Seabrook Station was off-line for four months in 1994 (April-July), continuous surface temperatures recorded at Stations DS (discharge) and T7 (farfield) by OSI in 1994 showed a similar seasonal pattern as temperatures recorded at the water quality stations, including a distinct August peak that was 1°C (T7) to 3°C (DS) cooler than in 1993 (Figure 2-5). The annual mean temperature at DS decreased between 1991 and 1993 (Table 2-3). Temperatures measured in 1994 at both T7 and DS were cooler than during

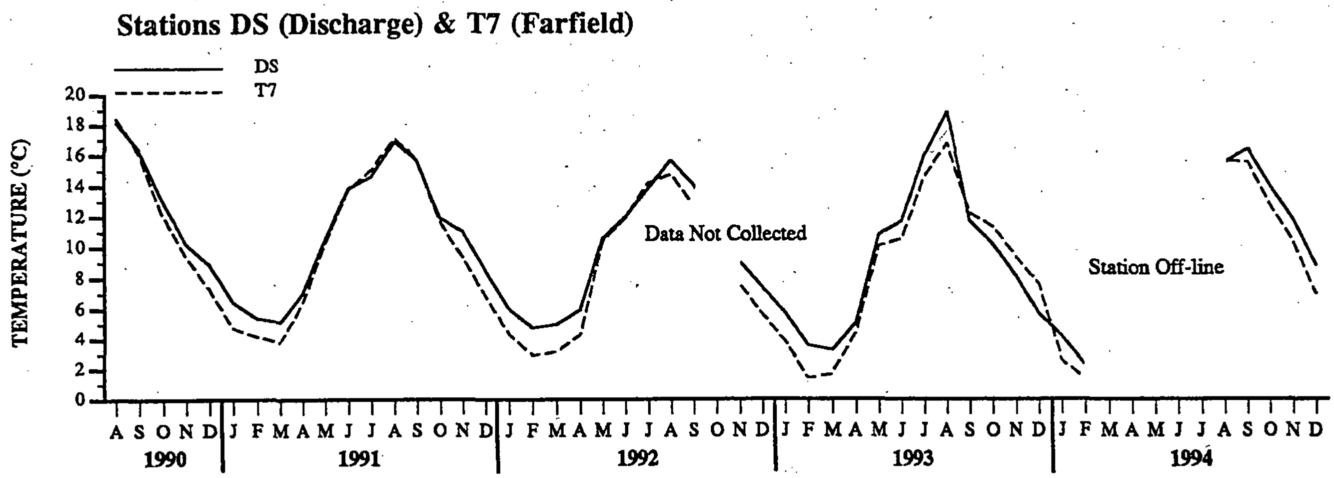


Figure 2-5. Comparison of monthly averaged **continuous temperature** (°C) data collected at the surface at discharge (DS) and farfield (T7) stations during commercial operation, August 1990-August 1994. Seabrook Operational Report, 1994.

TABLE 2-3. ANNUAL MEAN SURFACE TEMPERATURES[a] AND COEFFICIENTS OF VARIATION (CV,%) AT STATIONS DS AND T7 DURING OPERATIONAL MONITORING CONDUCTED BY YAEC. SEABROOK OPERATIONAL REPORT, 1994.

	STATION DS		STATION T7	
YEAR	MEAN	CV	MEAN	CV
1991	10.6	38.9	9.9	48.1
1992	9.4	41.9	8.3	54.6
1993	9.2	53.3	8.6	57.4
1994	9.4	61.6	8.3	72.4

[a]mean of monthly means; n=12 in 1991 and 1993; n=11 in 1992; n=8 in 1994.

the three previous years during January, February, March and August (Table 2-4). Temperatures were about average in September, but were then warmer than usual during the fourth quarter.

Monthly mean temperatures at DS were generally 1-2°C warmer than at T7 in all months in 1994 except in August, when temperatures at the two stations were nearly equal (Table 2-4). These average monthly ΔT values (DS-T7) showed full compliance with the Station's NPDES permit, which has been the case throughout the operational period.

Salinity

Monthly average surface salinities followed a distinct seasonal pattern (Figure 2-6) that was related to freshwater influx and precipitation, air temperatures and winds, and tides and currents. Several major freshwater sources influence salinities observed in the nearshore area off Hampton Harbor, including the Androscoggin and Kennebec Rivers in Maine (Franks and Anderson 1992), the Piscataqua River in New Hampshire and the Merrimack River in Massachusetts (NAI 1977). Salinities were typically highest during the colder months due to low precipitation and runoff. Salinities declined to their lowest levels of the year when freshwater influx reached its peak level in the spring, due to spring storms combined with snow melt. Bottom salinities exhibited a similar but less pronounced seasonal pattern. Waters within the study area are relatively shallow, thus storms and strong currents can, at times, affect the entire water column (NAI 1979). However, bottom waters in 1994 generally exhibited a more stable temperature and salinity structure compared to surface waters, i.e., temperature and salinity changed at a faster rate and to a larger degree over the course of the year in surface waters when compared to bottom waters.

Two types of meters were used to measure salinity over the sixteen year monitoring period: a Beckman salinometer from 1979-1989, and a YSI CTD meter from 1989-1994. A distinct downward trend in annual mean salinities was observed during 1989-1993 (NAI and NUS 1994). A laboratory verification program was undertaken in 1994 to determine if this decline was related to meter performance. Although the field meter consistently passed quality control procedures as outlined in NAI (1994), analyses of duplicate samples from September-December by the Estuarine Chemistry Lab at the University of New Hampshire (UNH) revealed that the observed decline was, at least in part, a function of meter drift. Further inspection of results from 1989-1994 revealed that the drift was approximately 0.029 ppt/month. These observations were corrected by applying a drift correction, a simple, progressive linear addition of the fraction of the total drift applicable to each weekly salinity value within the time period of March 27, 1989 to December 27, 1993. Salinity measurements taken in 1994 were corrected against the duplicate samples processed by UNH. A regression equation relating field and lab measurements for September-December in 1994 was developed, then used to adjust field measurements from January-August sampling. September-December salinity measurements from UNH were used in combination with the adjusted January-August measurements for analytical purposes.

Seasonal patterns of surface and bottom salinity were similar between preoperational and operational periods, although salinities measured at Station P2 during summer months in 1994 were 1-3 ppt lower than preoperational monthly means and summer bottom salinities were 1-2 ppt lower than preoperational monthly means (Figure 2-6). Differences between operational and preoperational salinities were not significant at either surface or bottom depths (Table 2-2). Over both the preoperational (all years and recent years) and operational periods, both mean surface and

TABLE 2-4. MONTHLY MEAN SURFACE TEMPERATURES (°C) AND TEMPERATURE DIFFERENCES (ΔT,°C) BETWEEN DISCHARGE (DS) AND FARFIELD (T7) STATIONS COLLECTED FROM CONTINUOUSLY-MONITORED TEMPERATURE SENSORS, JULY 1990-DECEMBER 1994. SEABROOK OPERATIONAL REPORT, 1994.

	1990			1991			1992			1993			1994		
MONTH	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT
DISCHARGE - FARFIELD (SURFACE)															
JAN	--[b]	--	--	6.47	4.71	1.76	6.02	4.32	1.70	5.69	3.80	1.89	4.12	2.57	1.55
FEB	--	--	--	5.38	4.17	1.21	4.74	2.92	1.82	3.52	1.38	2.14	2.23	1.32	0.91
MAR	--	--	--	5.11	3.78	1.33	4.94	3.16	1.78	3.26	1.63	1.63	2.69	1.73	0.96
APR	--	--	--	6.99	6.37	0.62	5.93	4.26	1.67	5.04	4.44	0.60	--	--	--
MAY	--	--	--	10.43	10.21	0.22	10.52	10.32	0.20	10.74	10.02	0.72	--	--	--
JUN	--	--	--	13.81	13.70	0.11	11.94	11.84	0.10	11.65	10.53	1.12	--	--	--
JUL	14.54	14.63	-0.08	14.58	15.02	-0.44	13.81	14.16	-0.35	15.92	14.54	1.39	--	--	--
AUG[a]	18.16	18.36	-0.20	16.86	17.06	-0.20	15.61	14.69	0.92	18.77	16.69	2.08	15.44	15.53	-0.09
SEP	16.31	16.09	0.22	15.66	15.69	-0.03	14.03	12.69	1.34	11.62	12.19	-0.57	16.33	15.47	0.86
OCT	13.04	12.11	0.93	11.87	11.68	0.19	--	--	--	10.13	11.27	-1.14	13.94	12.69	1.25
NOV	10.24	9.44	0.80	11.00	9.33	1.67	9.01	7.59	1.42	8.03	9.33	-1.30	11.77	10.37	1.40
DEC	8.91	7.32	1.59	8.45	6.81	1.64	7.32	5.61	1.71	5.64	7.55	-1.91	8.74	6.90	1.84

[a]Commercial operation began in August, 1990.
[b]Data either not collected, or an equipment failure occurred.
[c]Seabrook Station was offline April-July.

NOTE: ID (surface, mid-depth, bottom) and T7 (mid-depth and bottom) sensors decommissioned July 1, 1993. See 1993 Seabrook Operational Report for data summary.

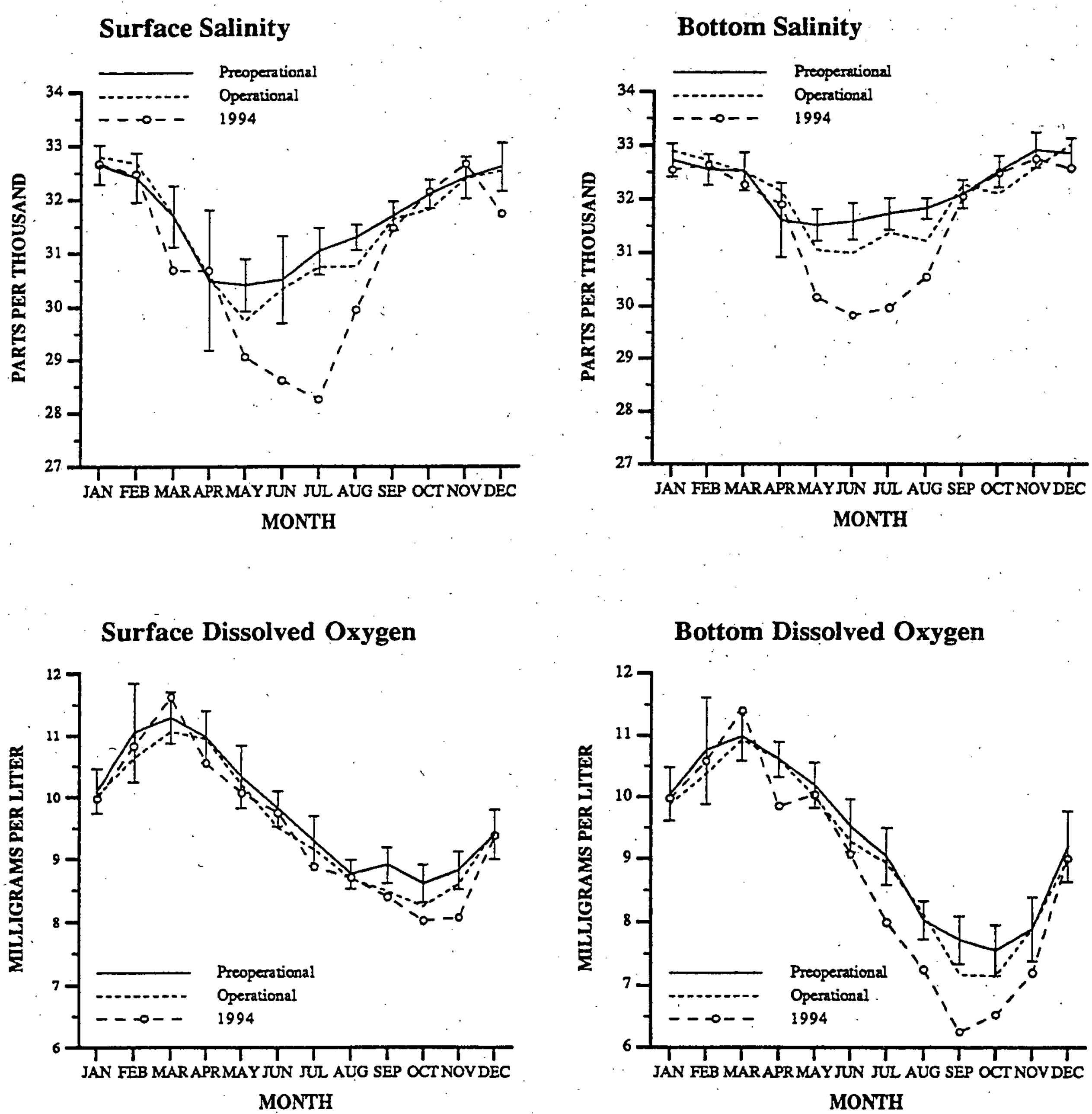


Figure 2-6. Surface and bottom **salinity** (ppt) and **dissolved oxygen** (mg/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1989) and monthly means for the operational period (1991-1994) and 1994. Seabrook Operational Report, 1994.

mean bottom salinities have been similar among the three stations (Table 2-1). These relationships have remained consistent regardless of the operational status of Seabrook Station (Table 2-2).

Even with the drift correction, long-term annual salinity means suggest the presence of downward trends at all stations and at both depths (Figure 2-7), particularly over the last four years. A similar phenomenon was observed at the Maine Department of Marine Resources West Boothbay Harbor long term environmental monitoring station. This station is fairly comparable to the Seabrook water quality stations; although in a more protected location, there is relatively little freshwater input to the harbor. Long term (1966-1985) annual mean surface salinities (taken at -5.5 feet MLW) at the West Boothbay Harbor station ranged between 30 and 32 ppt (MDMR 1987), and in recent years annual mean salinity has declined from 30.7 ppt in 1990 to 29.2 ppt in 1993 (MDMR 1991, 1992, 1993, 1994). Boothbay harbor salinities rebounded slightly in 1994, to an annual mean of 29.8 ppt (MDMR 1995).

Dissolved Oxygen

Surface and bottom dissolved oxygen concentrations exhibited a seasonal pattern in 1994 similar to previous years (Figure 2-6). Dissolved oxygen concentrations were highest during the cooler winter months, and peaked in late winter (February and March); concentrations were lowest during August through October when temperatures reached the annual maximum (Figure 2-2). Operational and 1994 mean surface concentrations were within preoperational 95% confidence limits during all months except for July (1994 < LCL), September and October (Op and 1994 < LCL) and November (1994 < LCL). Mean bottom concentrations in 1994 were lower than preoperational confidence limits in April and June through November. The March 1994 mean bottom dissolved oxygen concentration was the only observation that was higher than the preoperational upper 95% confidence limit.

Preoperational-operational differences in mean surface and bottom dissolved oxygen concentrations were small (≤0.2 mg/L, Table 2-1). The interaction between the Preop X Op and Station terms was significant for surface dissolved oxygen concentrations (Table 2-2). Operational concentrations at P5 were significantly greater than concentrations at P2 and P7, while there were no differences among the stations during the recent preoperational period.

This interaction term is illustrated in Figure 2-8, and shows that the significant interaction occurred because surface DO concentration decreased more steeply between the recent preoperational and operational periods at Stations P2 and P7 compared to Station P5. In general, the decrease in DO concentrations at each station may be due to the overall increase in temperature between recent preoperational years and operational years (although Op-Preop differences were not statistically significant for surface temperature). As temperature uniformly increased at all three stations, it is unlikely that the steeper decrease in surface DO at P2 and P7 was related to temperature.

2.3.2 Nutrients

Phosphorus Species

Monthly mean surface orthophosphate concentrations followed a distinct seasonal pattern in 1994 that was typical of earlier years (Figure 2-9). Concentrations were highest during late-fall to late-winter, and lowest during summer months. This pattern, typical of nutrients in northern temperate waters in general, is

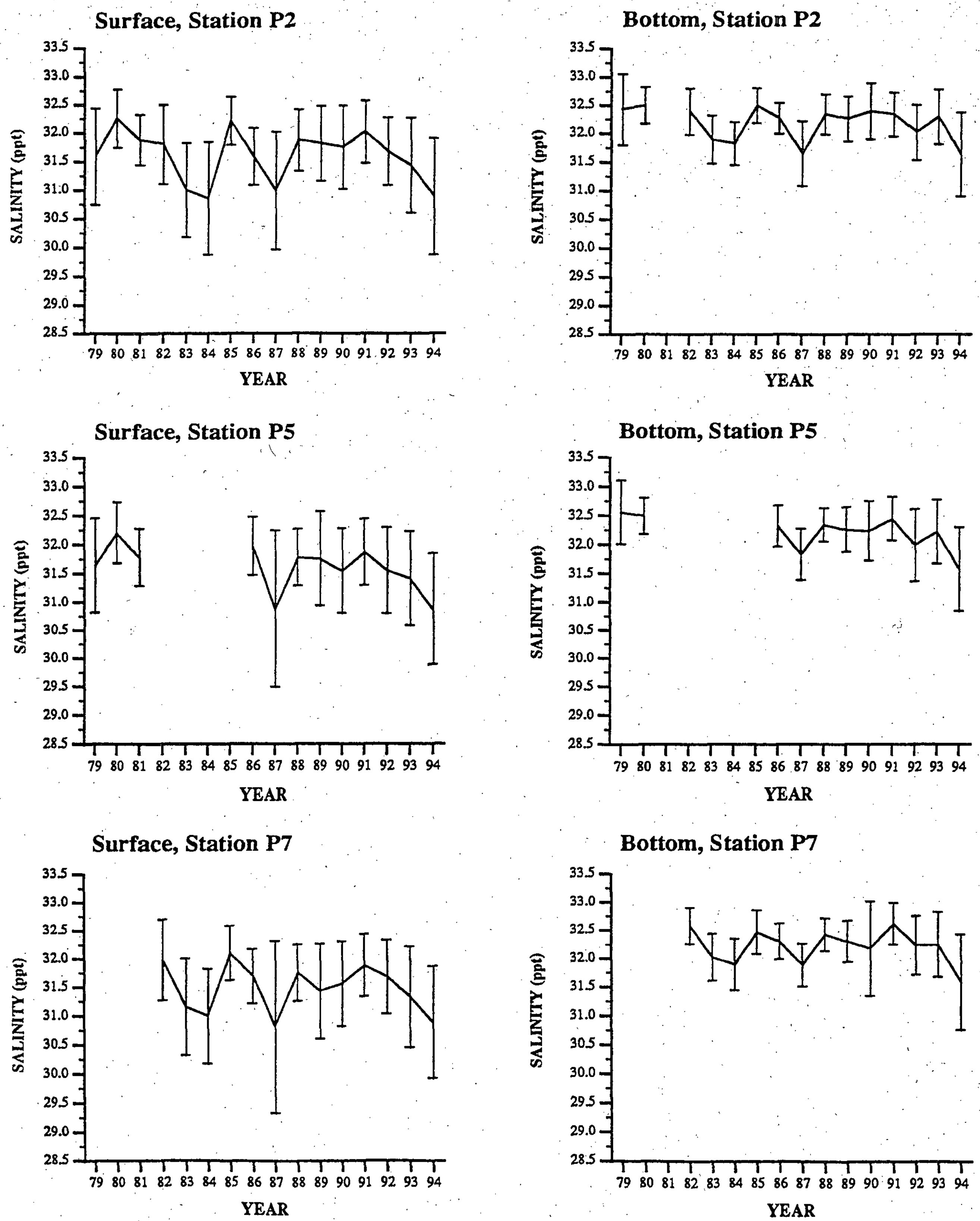


Figure 2-7. Time-series of annual means and 95% confidence intervals of surface and bottom salinity (ppt) at Stations P2, P5, and P7, 1979-1994. Seabrook Operational Report, 1994.

Surface Dissolved Oxygen (mg/L)

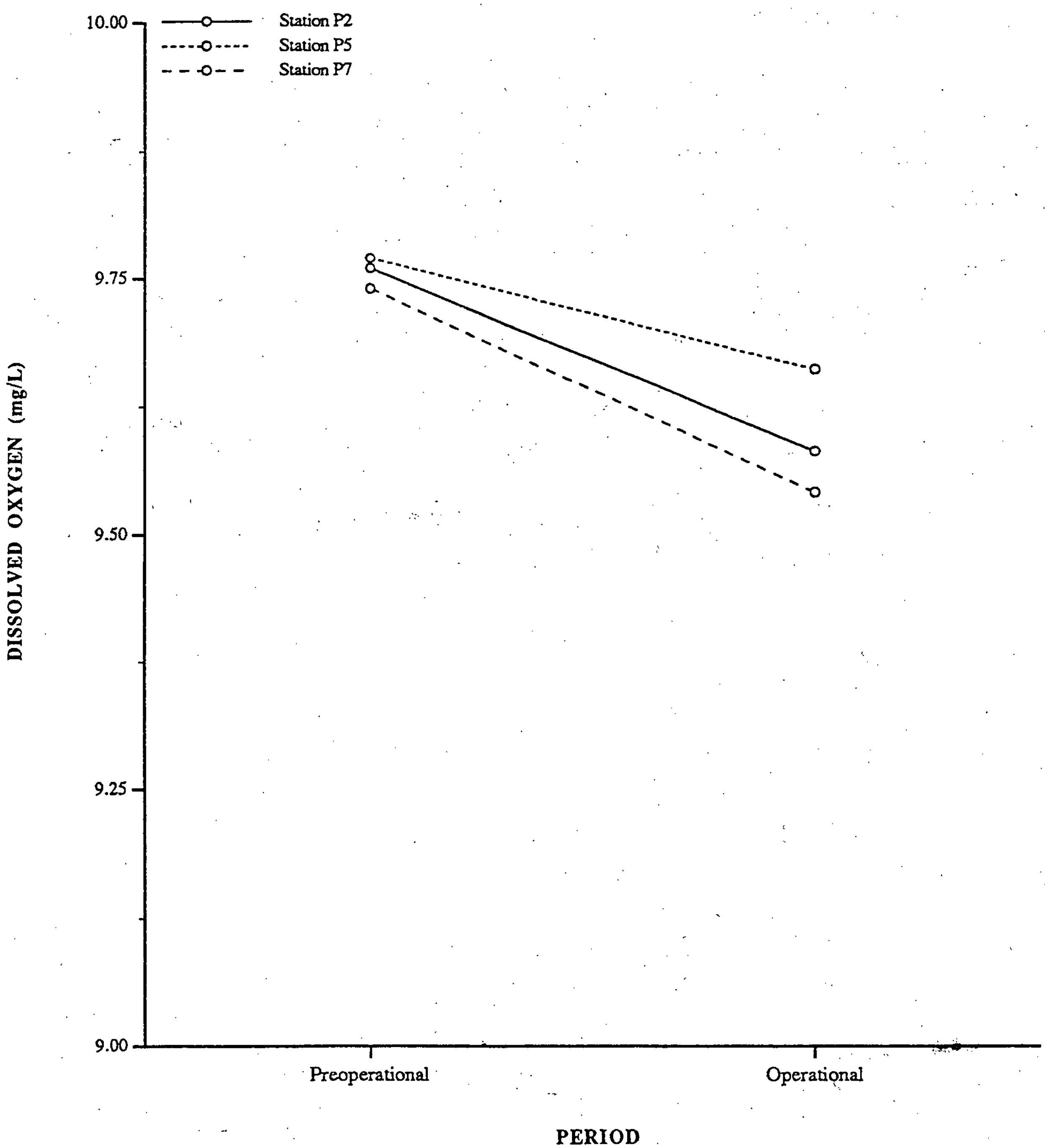


Figure 2-8. A comparison among stations of annual mean **surface dissolved oxygen** (mg/L) during recent preoperational years (1987-1989) and operational years (1991-1994) for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 2-2). Seabrook Operational Report, 1994.

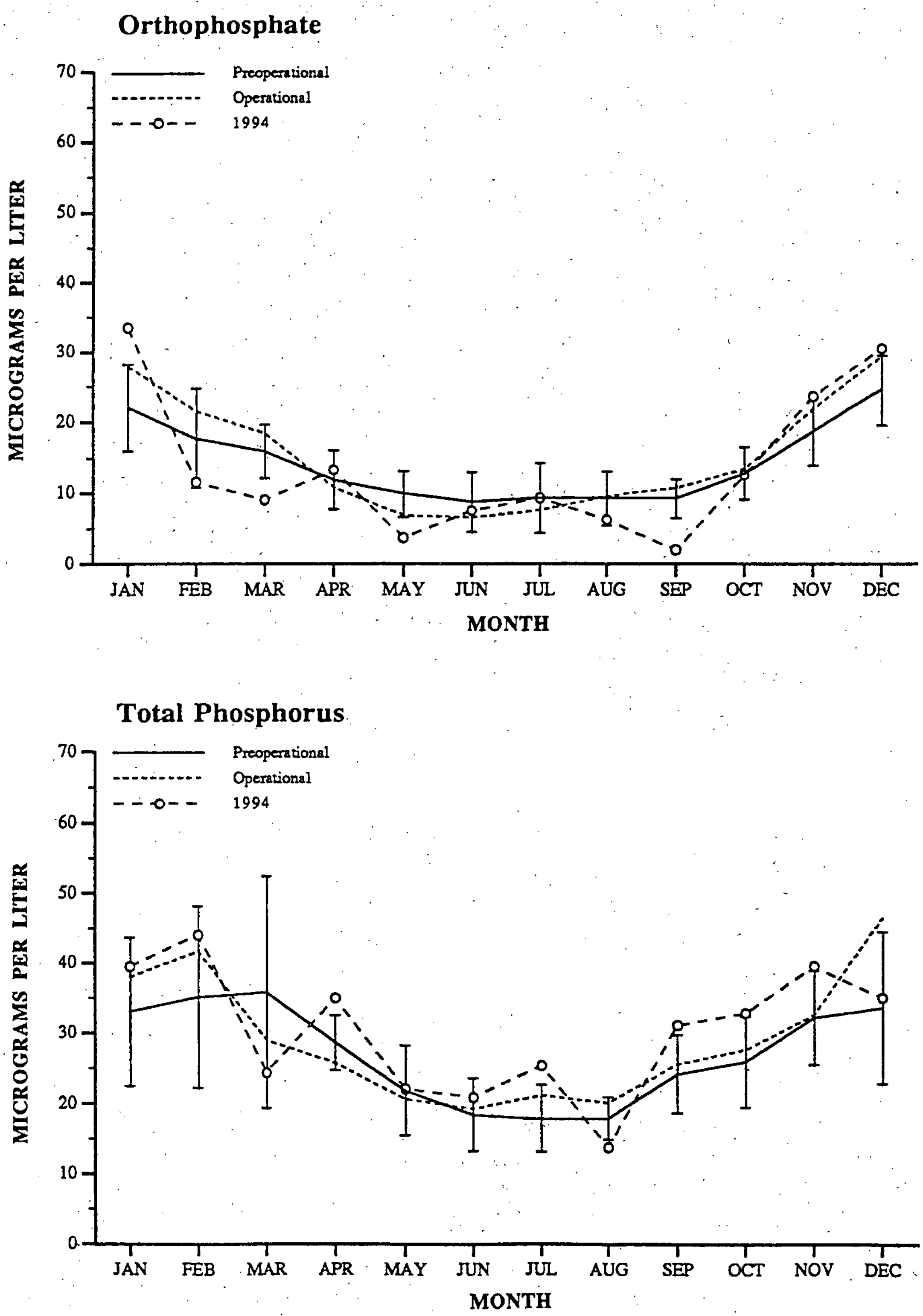


Figure 2-9. Surface orthophosphate and total phosphorus concentrations (µg P/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-1989), and monthly means for the operational period (1991-1994) and 1994. Seabrook Operational Report, 1994.

caused largely by the uptake of phosphorus during the warmer months by primary producers (Section 3.0).

Orthophosphate concentrations during January, November and December in 1994 exceeded preoperational upper 95% confidence limits, but monthly mean concentrations in March, May and September were lower than preoperational lower 95% confidence limits. Annual mean orthophosphate concentrations in 1994 were approximately 1.0-3.5 mg/L lower than preoperational (all years and recent years) means. Operational-preoperational (recent years) mean differences ranged from 0.8 to 1.1 mg/L (Table 2-1), and were not statistically significant (Preop-Op term, Table 2-2). Differences between stations, during both periods, were also not significant, nor was the interaction of main effects (Preop-Op X Station, Table 2-2).

Trends in total phosphorus concentrations were similar to trends in orthophosphate on a seasonal basis (Figure 2-9). Monthly mean total phosphorus concentrations observed in 1994 fell within the 95% confidence limits of preoperational monthly means during only six months of the year. Monthly means in 1994 exceeded preoperational upper 95% confidence limits in April, July, September, October and November. The August 1994 mean concentration was lower than the preoperational lower 95% confidence limit. Both the operational and 1994 mean concentrations were lower than preoperational means (all years and recent years), at all three stations (Table 2-1). However, there were no significant differences between operational and preoperational mean concentrations (Table 2-2).

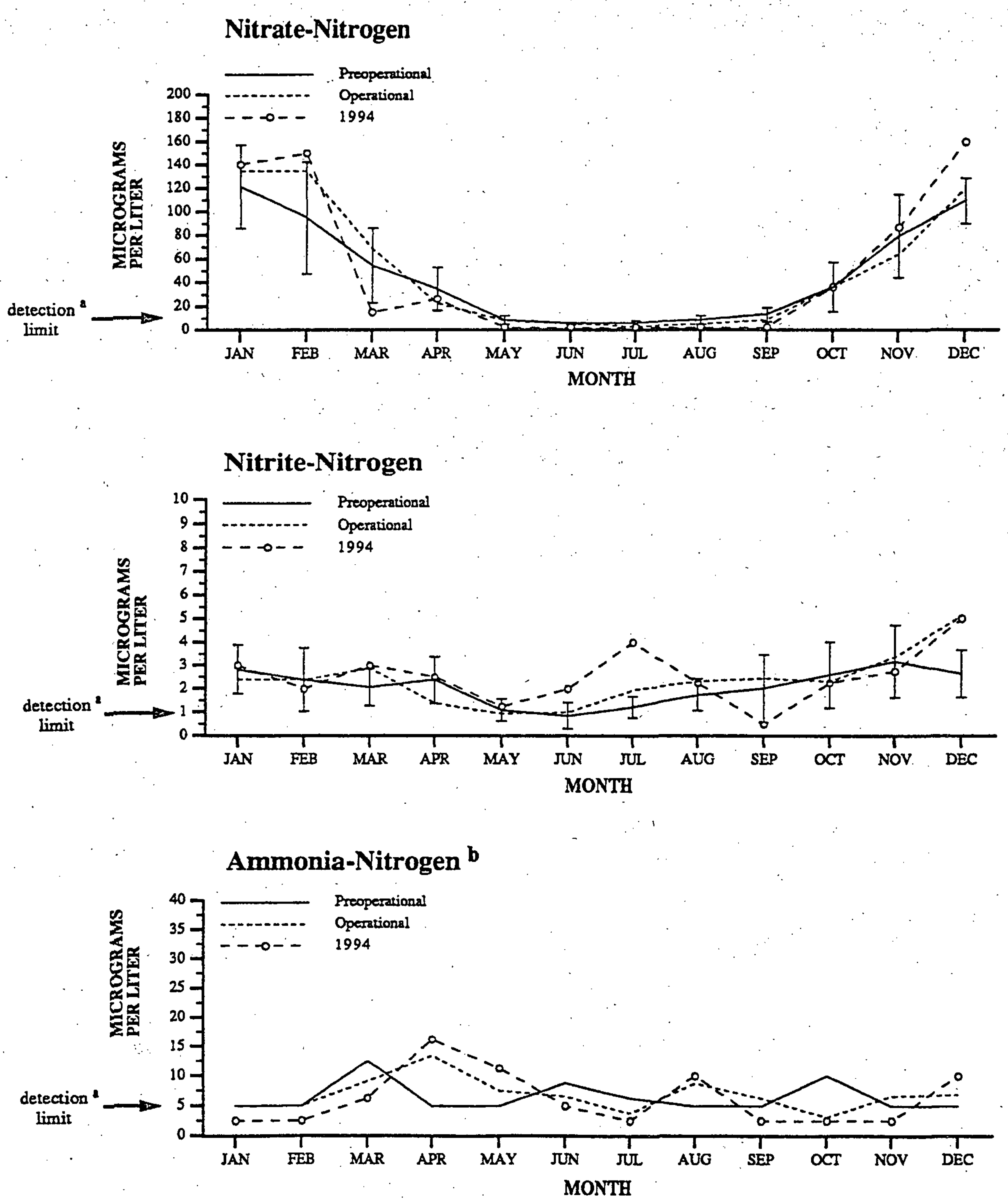
Over all operational years, mean total phosphorus concentrations differed on an annual basis by no more than 1 mg/L among the three stations (Table 2-1). Over all preoperational years, among-station differences as large as 3.3 mg/L were observed. Over the period of 1987-1994, however, differences among stations were not significant, nor was the interaction of the main effects (Table 2-2).

Nitrogen Species

Nitrate concentrations exhibited the same strong seasonality observed in phosphorus concentrations (Figure 2-10). Monthly mean concentrations in 1994 were within preoperational 95% confidence limits in only four months (January, April, October and November). Monthly means in 1994 exceeded upper confidence limits in February and December, but were lower than lower confidence limits in the remaining six months. The annual mean concentration observed in 1994 was less than during the period 1987-1989 at each station (Table 2-1). Operational means were lower at each station compared to the recent preoperational years (Table 2-1), although these differences were not significant (Table 2-2). Station differences were small but significant over all years, but the interaction between main effects was not significant.

Nitrite concentrations exhibited a weaker monthly (seasonal) pattern compared to other nutrients (Figure 2-10). Over the whole year, monthly mean concentrations in 1994 were variable, and exceeded preoperational upper 95% confidence limits in some months (March, June, July, December) and were less than preoperational lower 95% confidence limits in September. Operational and preoperational annual mean concentrations were not significantly different, nor were station differences (Table 2-2). As with other nutrients, the interaction term was not significant.

Ammonia concentrations did not show the distinct seasonality observed in other nutrients (Figure 2-10). Monthly mean concentrations in 1994 were higher than preoperational monthly means in April, May, August



[a] For the purpose of calculating monthly means, data points reported as "below detection limit" were given a value of one-half the detection limit.

[b] Preoperational period for ammonia is April 1988-December 1989; confidence intervals not calculated for this period.

Figure 2-10. Surface nitrite-nitrogen, nitrate-nitrogen and ammonia-nitrogen concentrations (µg N/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-1989), and monthly means for the operational period (1991-1994) and 1994. Seabrook Operational Report, 1994.

and December (Figure 2-10). Operational-preoperational differences over all stations were not significant nor were station differences, nor was the interaction term (Table 2-2).

2.4 DISCUSSION

The seasonal cycles of all 1994 water quality parameters were consistent with those of preoperational years. For some parameters, however, the magnitude of the seasonal cycle was greater than in past years. For example, 1994 winter temperatures were cooler than usual (i.e., versus all preoperational years), while summer temperatures were warmer than usual. Temperature fluctuated over a wider range in 1994 than in any previous year. The year on average was warmer than 1992-1993, but cooler than 1991, the warmest year of the entire monitoring period.

Overall, operational water quality parameters were not significantly different from recent preoperational averages. One exception was bottom temperatures. Operational bottom temperatures were significantly warmer than recent preoperational bottom temperatures. In 1994, average operational bottom temperatures were 0.8-0.9°C warmer than average recent preoperational temperatures, but only 0.1-0.3°C warmer than the average preoperational temperatures over all preoperational years. This reflects the cyclical nature of the long term water temperature measurements. Long term salinity measurements also showed a cyclical pattern, with a downward trend evident beginning in 1990, in part related to changes in instrumentation.

Water quality measurements have generally remained similar among the three stations. Small but significant station differences were detected in surface and bottom temperatures and in orthophosphate and nitrate concentrations. In each case, however, these differences were consistent between the preoperational and operational periods.

One parameter showed differing trends between nearfield and farfield stations during the operational period. Surface dissolved oxygen concentrations declined at each station between the preoperational and operational periods, although they declined more steeply at Stations P2 and P7 compared to P5. This decline most likely occurred in response to increasing temperatures during the operational period (particularly in 1991 and 1994), although there was not a significant difference between operational and preoperational surface temperatures. This unequal decline resulted in a significant interaction term in the ANOVA model. Surface temperatures at Station P5 were slightly warmer than P2 and P7 during both periods; thus the decrease in dissolved oxygen does not appear to be temperature related. If the unequal decline in dissolved oxygen concentrations was due solely to temperature, temperatures at P5 would be expected to be lower than at the other two stations.

The results of the analyses of water quality parameters highlight the cyclical and variable nature of these parameters. With the exception of surface dissolved oxygen, all preoperational and operational patterns have remained consistent (Table 2-5). Overall, no localized effects due to the operation of Seabrook Station were observed.

TABLE 2-5. SUMMARY OF POTENTIAL EFFECTS OF SEABROOK STATION ON AMBIENT WATER QUALITY. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH	OPERATIONAL PERIOD SIMILAR TO RECENT PRE-OPERATIONAL PERIOD?[a]	SPATIAL TRENDS CONSISTENT WITH PREVIOUS YEARS[b]
Temperature	surface	yes	yes
	bottom	Op>Preop	yes
Salinity	surface	yes	yes
	bottom	yes	yes
Dissolved oxygen	surface	no	no; P2,P7: Op=Preop P5: Op<Preop
	bottom	yes	yes
Nitrite	surface	yes	yes
Nitrate	surface	yes	yes
Ammonia	surface	yes	yes
Orthophosphate	surface	yes	yes
Total phosphate	surface	yes	yes

[a]based on ANOVA for 1987-1994, when all 3 stations were sampled concurrently

[b]PREOP-OP X STATION term in ANOVA model

2.5 REFERENCES CITED

APHA (American Public Health Association). 1989. Standard methods for the examination of water and wastewater, 17th edition.

Franks, P.J.S. and D.M. Anderson. 1992. Alongshore transport of a toxic phytoplankton bloom in a buoyancy current: *Alexandrium tamarense* in the Gulf of Maine. Marine Biology 112(153-164).

Gilbert, Richard O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold Co. Inc., New York.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York, NY. 257 p.

Maine Department of Marine Resources (MDMR). 1991. Boothbay Harbor Environmental Data, 1990. West Boothbay Harbor, Maine.

__________. 1992. Boothbay Harbor Environmental Data, 1991. West Boothbay Harbor, Maine.

__________. 1993. Boothbay Harbor Environmental Data, 1992. West Boothbay Harbor, Maine.

__________. 1994. Boothbay Harbor Environmental Data, 1993. West Boothbay Harbor, Maine.

__________. 1995. Boothbay Harbor Environmental Data, 1994. West Boothbay Harbor, Maine.

Normandeau Associates (NAI). 1977. Summary Document: Assessment of anticipated impacts of construction and operation of Seabrook Station on the estuarine, coastal and offshore waters; Hampton-Seabrook, NH. Prepared for Public Service Co. of New Hampshire.

__________. 1979. Annual Summary Report for 1977 Hydrographic Studies off Hampton Beach, New Hampshire. Tech. Rep. X-I. Preoperational Ecol. Monit. Stud. for Seabrook Station.

__________. 1994. Seabrook Environmental Studies: Quality Program and Standard Operating Procedures. Revision 3, Change 6. June 20, 1994.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area During the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co., San Francisco, CA. 859 p.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "pseudo-replication in time?" Ecology, 67:929-940.

USEPA (United States Environmental Protection Agency). 1979. Methods for chemical analyses of water and wastes. EPA-600/4-79-020. EMSL, Cincinnati, OH.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4(1):3-15.

TABLE OF CONTENTS

SUMMARY

The phytoplankton community historically has been highly variable in species composition and abundance. This trend has continued during the operational period. Taxa of the class Bacillariophyceae (diatoms) dominated the community numerically throughout the operational period and in 1994, although in 1992 the Prymnesiophyceae taxon *Phaeocystis pouchetii* was dominant because of its spring bloom. Such shifts between diatoms and *P. pouchetii* were also observed during the preoperational period. Total community abundance and abundance of the selected species (the diatom *Skeletonema costatum*) varied year to year during the operational period. Chlorophyll *a* concentration was also variable year to year, but was independent of abundance. For example, during 1992 the increase in abundance without a corresponding increase in chlorophyll *a* concentration was likely due to the exceptionally high numbers of *Phaeocystis pouchetii,* a small-celled form. No significant differences in phytoplankton abundance, chlorophyll *a* concentration, or abundance of *Skeletonema costatum* were observed between the preoperational and operational periods. Community composition during the operational period was relatively similar to that observed historically. Any differences observed during the operational periods occurred at both the nearfield and farfield stations. Thus there was no indication of an impact resulting from the operation of Seabrook Station.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

3.0 PHYTOPLANKTON

3.1 INTRODUCTION

The phytoplankton monitoring program was initiated to identify seasonal, annual, and spatial trends in the phytoplankton community, to determine if the balanced indigenous phytoplankton community in the Seabrook area has been adversely influenced, within the framework of natural variability, by exposure to the thermal plume. Specific aspects of the community evaluated included phytoplankton (taxa ≥ 10 µm in size) abundance and species composition; ultraplankton (taxa < 10 µm in size) abundance and species composition; community standing crop as measured by chlorophyll *a* concentrations; abundance of the selected species (*Skeletonema costatum*); and toxicity levels of paralytic shellfish poison (PSP) as measured in the tissue of the mussel *Mytilus edulis* in the Hampton-Seabrook area.

3.2 METHODS

3.2.1 Field Methods

Near-surface (-1 m) water samples for phytoplankton and chlorophyll *a* analyses were collected during daylight hours at Stations P2 (intake), P5 (discharge) and P7 (farfield) (Figure 3-1) using an 8-L Niskin bottle. Collections were taken once per month in January, February and December, and twice monthly from March through November. Sampling occurred at Station P2 from 1978-1984; from 1978-1981 at Station P5; and from 1982-1984 at Station P7. Chlorophyll *a* collections resumed at all three stations in July 1986 and phytoplankton collections resumed in April 1990. These collections continued on this schedule through December 1994. From each whole water collection, two one-quart (0.946 L) jars containing 10 mL of a modified Lugol's iodine fixative were filled for phytoplankton taxonomic analyses and one gallon (3.785 L) was reserved for chlorophyll *a* analyses. Weekly paralytic shellfish poison (PSP) toxicity levels from mussels collected in Hampton Harbor were provided by the State of New Hampshire.

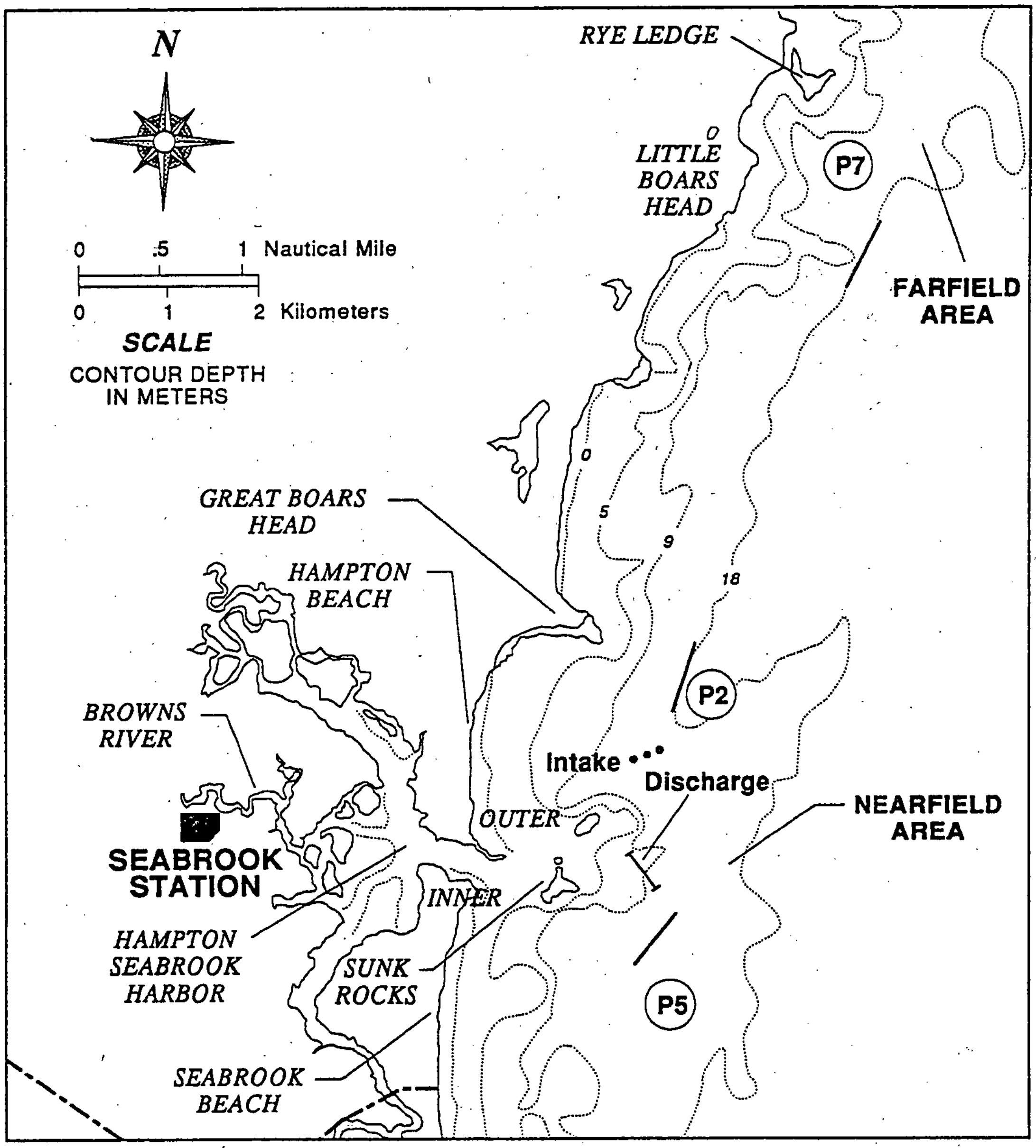
3.2.2 Laboratory Methods

Phytoplankton samples were prepared for analysis following the steps outlined in NAI (1991). One randomly-selected replicate from each station and sample period was analyzed for all taxa and a second replicate was analyzed for the selected species *Skeletonema costatum* only. Two 0.1-mL subsamples from each replicate were withdrawn and placed in Palmer-Maloney nanoplankton counting chambers. For those replicates selected for taxonomic analyses, the entire contents of the chamber were enumerated and identified to the lowest possible taxon, usually species.

Procedures for preparation of chlorophyll *a* water samples followed steps outlined in NAI (1991). Following the extraction of the plant pigment, fluorescence was determined and chlorophyll *a* concentrations (µg/L) were computed.

3.2.3 Analytical Methods

Members of the phytoplankton community were classified into two size fractions as defined by Marshall and Cohen (1983): ultraplankton (<10 µm) and phytoplankton (≥10 µm). These groups were analyzed separately. During the earlier years of the Seabrook program, ultraplankton forms were only partially identified (the picoplankton size fraction, or forms <2.0 µm in size, were generally not identified). Beginning in the mid-1980s, an effort to identify these smaller forms was initiated throughout the scientific community (Stockner 1988). This effort plus use of an improved identification technique (phase contrast microscopy) was undertaken on this project when the phytoplankton program was re-initiated in 1990. These issues and



LEGEND

—— = phytoplankton stations

Figure 3-1. Phytoplankton sampling stations. Seabrook Operational Report, 1994.

their impacts on ultraplankton enumeration were discussed in more detail in NAI (1992b). Since the ultraplankton have been enumerated in greater detail during the operational period than during the preoperational period, an impact assessment that relies on comparisons between the two periods was not appropriate. Therefore, analyses focused only on nearfield-farfield comparisons during the operational period.

Seasonal abundance patterns of the phytoplankton assemblages during the preoperational and operational periods were compared graphically using log (x+1)-transformed monthly mean abundances for ultraplankton, total phytoplankton and the selected species (*Skeletonema costatum*; Table 3-1). A decision was made to move the dinoflagellate *Oxytoxum* sp. from the ultraplankton group to the phytoplankton group in 1994 based on new information concerning the size range of the genus. Slight changes in preoperational mean abundances resulted. The log (x+1) transformation was performed on the sample period mean prior to calculating monthly means. Temporal (preoperational-operational) patterns in species abundances were evaluated using geometric means and community composition was evaluated by examining the percent composition of dominant (>1%) taxa. Chlorophyll *a* temporal and seasonal comparisons were based on untransformed monthly and yearly arithmetic mean concentrations. The similarity among the three stations with respect to species composition of the dominant phytoplankton taxa was evaluated statistically using a multivariate analysis of variance procedure (MANOVA, Harris 1985). Operational/preoperational and nearfield/farfield differences in total abundances of *S. costatum* and phytoplankton and mean chlorophyll *a* concentrations were evaluated using a multi-way analysis of variance procedure (ANOVA, SAS Institute, Inc. 1985). A mixed model ANOVA developed by Northeast Utilities, based on recent reviews of the BACI model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random except operational status (Preop-Op). Time and location of sampling were considered random because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). Preoperational periods for each analysis are listed on the appropriate figures and tables. For all preoperational comparisons, the focus was on intake Station P2 because it had the longest time series of data. In all cases the operational period evaluated in this report includes collections from 1991-1994.

Weekly mean PSP toxicity levels were arithmetically averaged over the preoperational and operational periods and examined graphically.

3.3 RESULTS

3.3.1 Total Community

3.3.1.1 Phytoplankton

Seasonal Trends at Station P2

Monthly abundances during 1994 and the operational period were within the 95% confidence intervals established for the preoperational period with the exception of the early spring (March and April) and early fall (September)(Figure 3-2). The increased abundances during 1994 consisted of high counts of *Phaeocystis pouchetii* (Prymnesiophceae) and chain forming diatoms (Bacillariophyceae). Seasonally, during both preoperational and operational periods, the most distinct period of peak abundance occurred in the fall (September/October).

On average, diatoms (Bacillariophyceae) dominated the phytoplankton assemblage during 10 of 12 months during the preoperational period, while colonies of the Prymnesiophyceae taxon *Phaeocystis pouchetii* dominated during April and May and composed a minor portion of the assemblage in August (Figure 3-2). This pattern of seasonal succession in phytoplankton is well documented in other northern temperate coastal waters

TABLE 3-1. SUMMARY OF METHODS USED IN EVALUATION OF THE PHYTOPLANKTON COMMUNITY. SEABROOK OPERATIONAL REPORT, 1994.

ANALYSIS	TAXA	STATIONS	DATES USED IN ANALYSIS[a]	DATA CHARACTERISTICS	SOURCE OF VARIATION
PHYTOPLANKTON					
Percent Composition	All	P2	1978-1984; 1991-1994	Monthly and annual arithmetic mean abundances	--
		P2,P5,P7	1994	Monthly arithmetic mean abundances	--
Abundance	All	P2,P5,P7	1978-1984; 1991-1994	Monthly log (x+1) and annual geometric mean abundances	--
	Skeletonema costatum	P2	1978-1984; 1991-1994	Monthly log (x+1) and annual geometric mean abundances	--
MANOVA	18 dominants	P2,P5,P7	1994	Monthly log (x+1) mean abundances; species <1% of total abundance not included	Station
ANOVA	All	P2,P7	1982-1984; 1991-1994	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
	Skeletonema costatum	P2,P7	1982-1984; 1991-1994	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
		P2,P5	1979-1981; 1991-1994	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station

(continued)

TABLE 3-1. (Continued)

ANALYSIS	TAXA	STATIONS	DATES USED IN ANALYSIS[a]	DATA CHARACTERISTICS	SOURCE OF VARIATION
ULTRAPLANKTON					
Percent Composition	All	P2,P5,P7	1994	Monthly arithmetic mean abundances	--
Abundance	All	P2,P5,P7	1991-1994	Monthly log (x+1) and annual geometric mean abundances	--
ANOVA	All	P2,P5,P7	1991-1994	Monthly log (x+1) mean abundances	Year, Month, Station
CHLOROPHYLL *a*					
Concentration	--	P2	1978-1989; 1991-1994	Monthly arithmetic mean concentrations	--
		P2,P5,P7	1978-1984; 1987-1989; 1991-1994	Annual arithmetic mean concentrations	--
ANOVA	--	P2,P5,P7	1987-1989; 1991-1994	Monthly arithmetic mean concentrations	Preop-Op, Year, Month, Station
PSP TOXICITY	--	--	1983-1989; 1991-1994	Weekly arithmetic mean concentrations	--

[a]PREOPERATIONAL PERIOD:

A. PHYTOPLANKTON
- P2 = 1978-1984
- P5 = 1978-1981
- P7 = 1982-1984

B. CHLOROPHYLL *a*
- P2 = 1978-1984, 1987-1989
- P5 = 1978-1981, 1987-1989
- P7 = 1982-1984, 1987-1989

OPERATIONAL PERIOD: 1991-1994, all stations and parameters

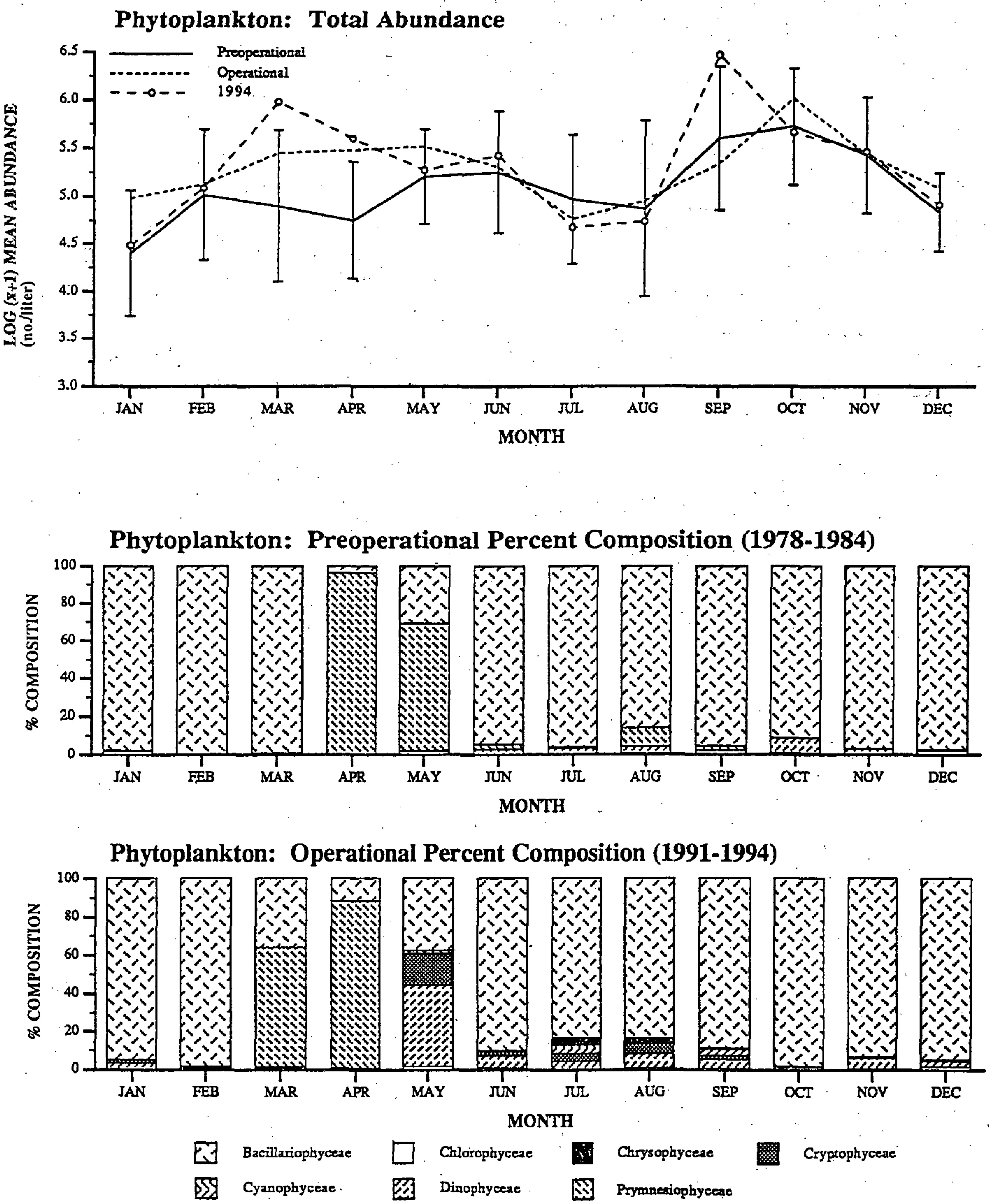


Figure 3-2. Monthly mean log (x+1) total abundance (no./L) of **phytoplankton (≥10 μm)** at nearfield Station P2, monthly means and 95% confidence intervals over all preoperational years (1978-1984), and monthly means over operational years (1991-1994); and percent composition by division for preoperational and operational periods. Seabrook Operational Report, 1994.

(Cadée and Hegeman 1986; Peperzak 1993). Other groups, primarily the dinoflagellates (Dinophyceae), were present in low numbers throughout the summer during the preoperational period. Seasonal succession during the operational period showed a similar pattern, with diatoms dominant in all months except March and April, when *P. pouchetii* was dominant and during May when Dinophyceae (particularly *Oxytoxum* sp.) and Bacillariophyceae were co-dominant. The dominance of *P. pouchetii* in operational averages was due to the extremely high numbers encountered in 1992 and 1994 (NAI 1993a, NAI 1995). This is in contrast to a nearly complete absence of *P. pouchetii* in 1991 (NAI 1992b) and 1993 (NAI 1994).

Among-Year Trends at Station P2

Phytoplankton abundances at Station P2 showed large shifts from year-to-year throughout both the preoperational and operational periods (Figure 3-3). The operational geometric mean abundance (192,000 cells/L) was higher than the preoperational mean abundance (119,000 cells/L; Table 3-2). This was due in large part to the high annual mean abundance during 1992 (361,600 cells/L), which was higher than in any individual preoperational year (Figure 3-3). The geometric mean abundance in 1993 (123,700 cells/L) was the lowest of the operational period and lower than in five of the seven preoperational years (Figure 3-3).

TABLE 3-2. GEOMETRIC MEAN ABUNDANCE (x 10^4 cells/L) OF PHYTOPLANKTON ($\geq 10\mu m$), *SKELETONEMA COSTATUM*, AND CHLOROPHYLL *a* CONCENTRATIONS (mg/m^3) AND COEFFICIENT OF VARIATION (CV,%) FOR THE PREOPERATIONAL AND OPERATIONAL (1991-1994) PERIODS, AND 1994 GEOMETRIC MEANS. SEABROOK OPERATIONAL REPORT, 1994.

	PREOPERATIONAL			OPERATIONAL		1994
STATION	$\bar{x}$[a]	CV	(YEARS)[b]	$\bar{x}$[a]	CV	$\bar{x}$
PHYTOPLANKTON						
P2	11.86	4.9	(78-84)	19.20	3.9	20.35
P5	12.60	4.0	(78-81)	23.47	4.3	21.13
P7	9.95	4.3	(82-84)	17.50	3.5	25.89
SKELETONEMA COSTATUM						
P2	0.21	45.1	(78-84)	0.79	30.1	0.86
P5	0.11	69.0	(78-81)	0.62	32.9	0.46
P7	0.19	32.6	(82-84)	0.50	37.7	0.61
CHLOROPHYLL *a*						
P2	0.78	68.1	(87-89)	0.80	69.8	1.06
P5	0.88	70.8	(87-89)	0.82	63.9	0.96
P7	0.75	63.4	(87-89)	0.77	59.8	0.95

[a]Mean of annual means.
[b]( ) = preoperational years.

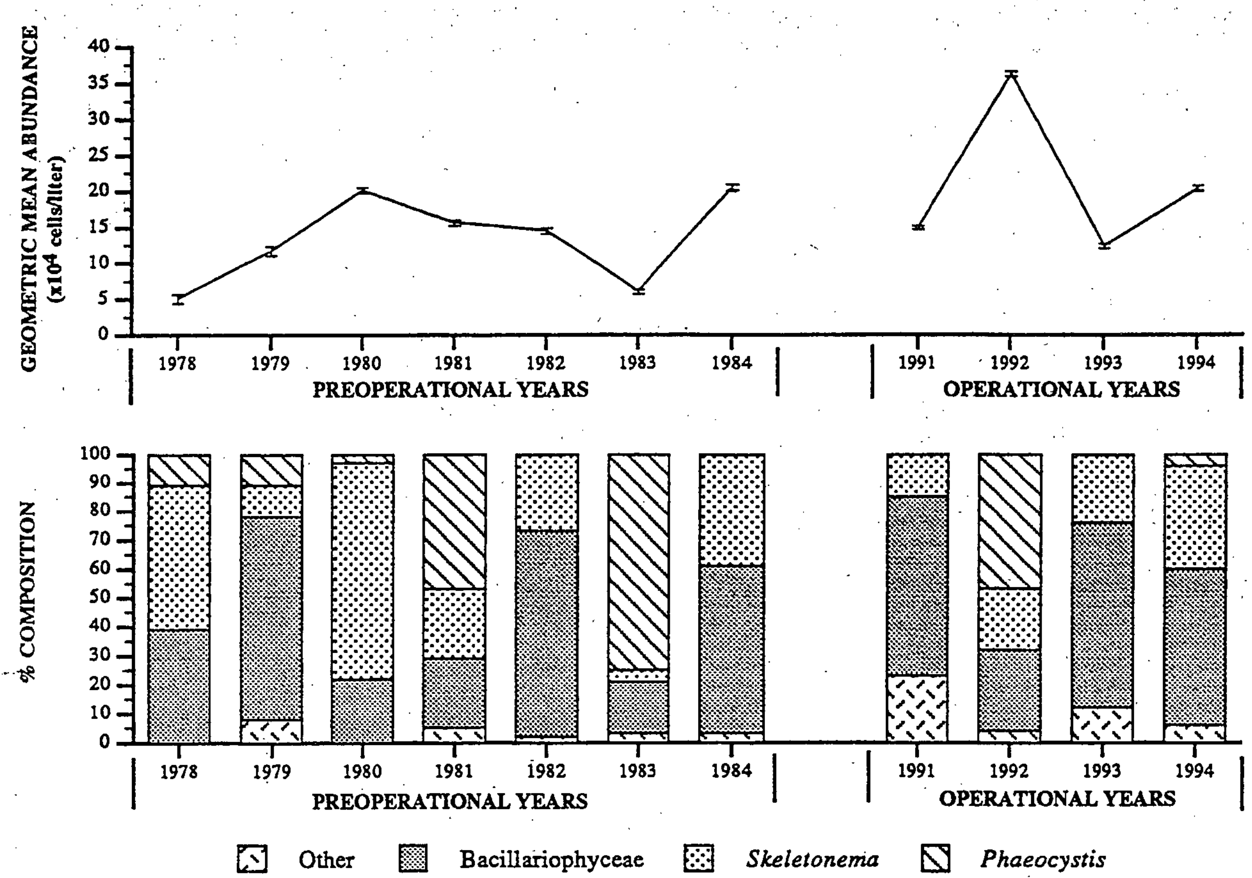


Figure 3-3. Geometric mean abundances (x 10^4 cells/L) and 95% confidence intervals of annual assemblages, and percent composition of four selected phytoplankton groupings at Station P2 during each year of the preoperational and operational periods. Seabrook Operational Report, 1994.

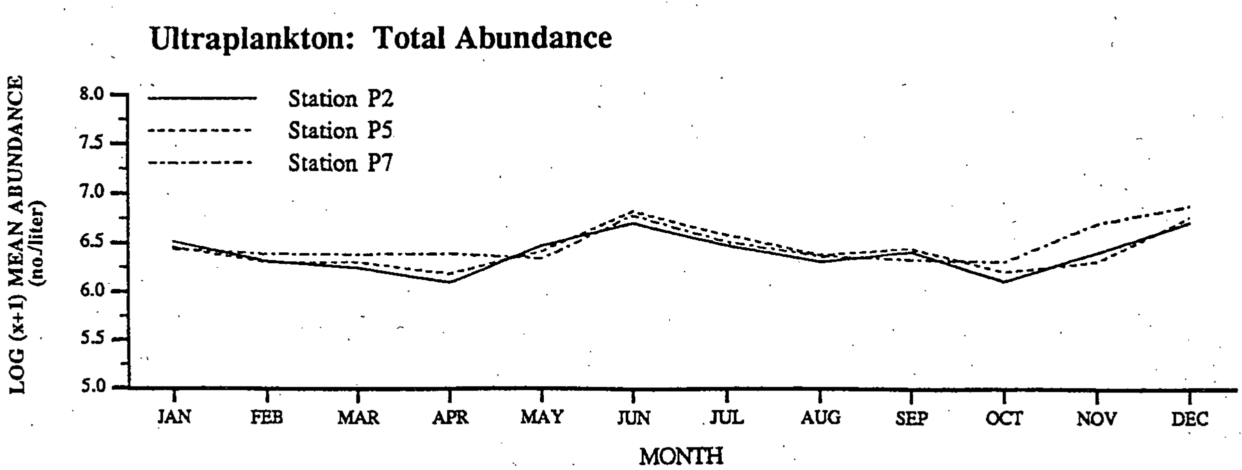


Figure 3-4. Monthly mean log (x+1) total abundance of **ultraplankton** (<10µm) at Stations P2, P5 and P7 during 1994. Seabrook Operational Report, 1994.

Based on historical data, the annual phytoplankton community at Station P2 can be divided into four major components: *Skeletonema costatum* (Bacillariophyceae), all other diatom taxa, *Phaeocystis pouchetii*, and all remaining taxa. Although these groupings are descriptive of both the preoperational and operational periods, the relative importance of each group or species, as well as individual abundances, varied considerably on a year-to-year basis (Figure 3-3). However, diatoms (including *S. costatum*) were the dominant phytoplankton throughout this study with the exception of 1981 and 1992, when diatoms and *P. pouchetii* were co-dominant.

Diatoms (including *Skeletonema costatum*) as a group formed approximately 77% of the preoperational assemblage, 66% of the operational assemblage, and 88% of the 1994 assemblage (Figure 3-3). *Skeletonema costatum* alone accounted for 35% of the preoperational assemblage, 25% of the operational assemblage, and 36% of the 1994 assemblage. Within the preoperational period, the relative abundance of *Skeletonema costatum* varied from 4% in 1983 to 75% of total abundance in 1980 (Figure 3-3). Within the operational period, the relative abundance of *Skeletonema costatum* varied from 15% in 1991 (NAI 1992b) to 36% in 1994.

Phytoplankton community composition is inherently variable from year to year. This is evident in the relative importance of species during each period of this study. *Skeletonema costatum* was the dominant diatom (Bacillariophyceae) taxon during each year of this study. Diatom taxa other than *S. costatum* that were important during the preoperational period were *Chaetoceros socialis* and *Rhizosolenia delicatula/fragilissima* (Table 3-3). During the operational period three different secondary taxa were important (*Leptocylindrus danicus, Leptocylindrus minimus* and *Nitzschia* sp.), and during 1994 three other taxa were secondarily important (*Thalassionema nitzschioides, Thalassiosira* spp. and *Chaetoceros socialis*).

Further evidence of the variability within the phytoplankton community is the range of abundances of *Phaeocystis pouchetii* that have occurred during this study. During the preoperational period the range was less than 1% in 1982 and 1984 to 76% in 1983 (Figure 3-3). During the four operational years, *P. pouchetii* ranged from less than 1% in 1991 and 1993 to 47% of the 1992 assemblage. During 1994 *P. pouchetii* accounted for approximately 4% of the population. The exceptionally high abundances in 1992 caused this species to represent 25% of the overall operational assemblage.

All remaining species accounted for 3% of the preoperational, 7% of the operational and 6% of the 1994 community composition (Figure 3-3). Two Dinophyceae taxa, *Prorocentrum micans* and *Oxytoxum* sp. accounted for 1% preoperationally, 3% operationally and 2% during 1994. *Cryptomonas* sp. (Cryptophyceae) was marginally important only during the operational period (2%) (Table 3-3).

Spatial Trends

Phytoplankton abundance and community composition were evaluated in the nearfield (Stations P2 and P5) and farfield (Station P7) areas to determine whether historical spatial relationships were maintained during the operational period. Preoperational geometric mean abundances were similar between Stations P2 (1978-1984) and P5 (1978-1981; Table 3-2), while abundances at Station P2 were higher than abundances at P7 (1982-1984). Abundances at each station were higher during the operational period and 1994 compared to the preoperational period. A comparison of phytoplankton abundances using analysis of variance was performed on Stations P2 and P7 (Table 3-4). There was no significant difference for preoperational vs operational periods, among years or between stations, indicating no apparent effect on abundances due to the operation of Seabrook Station (Table 3-4).

TABLE 3-3. ARITHMETIC MEAN ABUNDANCE (x 10^4 cells/L) AND PERCENT COMPOSITION OF DOMINANT PHYTOPLANKTON TAXA DURING THE PREOPERATIONAL PERIOD (1978-1984), OPERATIONAL PERIOD (1991-1994), AND 1994 AT NEARFIELD STATION P2. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL		OPERATIONAL		1994	
CLASS	TAXON	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION
Dinophyceae	*Prorocentrum micans*	0.79	1.15	0.15	<1.00	0.07	<1.00
	Oxytoxum sp.	0.01	0.02	1.93	3.42	1.26	2.25
Cryptophyceae	*Cryptomonas* spp.	<0.01	<1.00	0.94	1.67	0.48	<1.00
Prymnesiophyceae	*Phaeocystis pouchetii*	11.80	17.09	14.18	25.12	2.32	4.14
Bacillariophyceae	Bacillariophyceae	0.77	1.11	1.05	1.86	1.45	2.58
	Asterionella glacialis	0.05	<1.00	1.55	2.75	<.01	<1.00
	Cerataulina bergonii	0.95	1.39	0.14	<1.00	0.55	0.98
	Chaetoceros debilis	2.12	3.08	0.39	<1.00	0.58	1.03
	Chaetoceros decipiens	0.02	<1.00	0.63	1.12	0.75	1.34
	Chaetoceros socialis	6.50	9.45	1.86	3.30	3.61	6.43
	Chaetoceros spp.	1.19	1.74	1.80	3.20	1.59	2.84
	Cylindrotheca closterium	0.07	<1.00	0.84	1.50	0.91	1.62
	Leptocylindrus danicus	0.40	<1.00	3.55	6.30	3.13	5.57
	Leptocylindrus minimus	1.00	1.46	3.06	5.43	1.63	2.91
	Nitzschia spp.	3.20	4.65	2.30	4.07	1.95	3.48
	Rhizosolenia delicatula/fragilissima	9.89	14.38	1.75	3.10	1.82	3.24
	Skeletonema costatum	24.35	35.40	14.02	24.85	20.22	36.03
	Thalassionema nitzschioides	1.33	1.94	2.26	4.00	6.21	11.06
	Thalassiosira spp.	1.89	2.74	2.09	3.71	5.04	8.98

[a]Mean abundance over all year(s) in each period; species accounting for <1% of total abundance not presented, therefore percent composition as shown does not sum to 100.

TABLE 3-4. RESULTS OF ANALYSIS OF VARIANCE COMPARING ABUNDANCES OF TOTAL PHYTOPLANKTON, ULTRAPLANKTON AND *SKELETONEMA COSTATUM*, AND CHLOROPHYLL *a* CONCENTRATIONS AMONG STATIONS P2, P5 AND P7 DURING PREOPERATIONAL AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

SOURCE OF VARIATION	df	MS	F
PHYTOPLANKTON: P2 VS P7 (PREOP = 1982-1984; OP = 1991-1994)[a]			
Preop-Op[b]	1	1.28	1.15 NS
Year (Preop-Op)[c]	5	1.16	1.78 NS
Month (Year)[d]	77	0.60	22.82***
Station	1	0.14	4.67 NS
Station X Year (Preop-Op)[f]	5	0.08	3.14*
Preop-Op X Station[e]	1	0.03	0.37 NS
Error	77	0.03	
CHLOROPHYLL *a*: P2, P5, P7 (PREOP = 1987-1989; OP = 1991-1994)[a]			
Preop-Op[b]	1	<.01	<.01 NS
Year (Preop-Op)[c]	5	1.26	1.85 NS
Month (Year)[d]	77	0.70	12.30***
Station	2	0.17	3.74 NS
Station X Year (Preop-Op)	10	0.04	0.69 NS
Preop-Op X Station[e]	2	0.05	1.17 NS
Error	154	0.06	
***SKELETONEMA COSTATUM*: P2 VS. P7 (PREOP = 1982-1984; OP = 1991-1994)[a]**			
Preop-Op[b]	1	9.68	4.53 NS
Year (Preop-Op)[c]	5	2.22	0.77 NS
Month (Year)[d]	77	2.79	14.72***
Station	1	0.69	3.60 NS
Station X Year (Preop-Op)	5	0.28	1.48 NS
Preop-Op X Station[e]	1	0.19	0.69 NS
Error	77	0.19	
***SKELETONEMA COSTATUM*: P2 VS. P5 (PREOP = 1979-1981; OP = 1991-1994)[a]**			
Preop-Op[b]	1	12.19	9.54 NS
Year (Preop-Op)[c]	5	1.64	0.36 NS
Month (Year)[d]	76	4.38	13.68***
Station	1	0.87	14.65 NS
Station X Year (Preop-Op)	5	0.44	1.37 NS
Preop-Op X Station[e]	1	0.06	0.14 NS
Error	76	0.32	
ULTRAPLANKTON: P2, P5, P7 (Operational period only, 1991-1994)			
Year	3	0.25	0.67 NS
Month (Year)[d]	44	0.35	11.13***
Station	2	0.05	0.92 NS
Year X Station[e]	6	0.06	1.82 NS
Error	88	0.03	

[a]ANOVA based on mean of twice-monthly collections Mar-Nov and monthly collections Dec-Feb; only years when collections at these stations were concurrent are included; analyses include only years when all 12 months were sampled.
[b]Preoperational versus operational period regardless of station.
[c]Year, regardless of preop-op.
[d]Month nested within year regardless of station or year.
[e]Interaction between main effects.
[f]Interaction between station and year nested within preoperational and operational periods.
NS = not significant ($p \geq 0.05$)
* = significant ($0.05 > p \geq 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)

Of all species present with abundance >1% during 1994, five phytoplankton classes are represented (Table 3-5). Percent composition for each class was similar among stations with the exception of Prymnesiophyceae for which percent composition at Stations P5 and P7 was 4-5 times greater than P2. Overall, the abundances of the 18 numerically important taxa (Table 3-3) were not significantly different among the three stations in 1994 ($p = 0.83$, Wilkes' Lambda as computed by the MANOVA).

3.3.1.2 Ultraplankton

Monthly mean ultraplankton abundances were similar among Stations P2, P5, and P7 in 1994, and exhibited a weak seasonal pattern at each station (Figure 3-4). Annual geometric mean abundances showed no significant differences among the three stations or years throughout the operational period (Tables 3-4 and 3-6).

The ultraplankton assemblage was similar among the three stations in 1994 (Table 3-5). As in all previous operational years, Cyanophyceae were overwhelmingly dominant at each station (approximately 70-75% of the assemblage); mean abundance followed a similar seasonal pattern of occurrence at each station (Figure 3-4, NAI 1992a, 1993a, 1994).

For reasons discussed in Section 3.2.3, it was not possible to test preoperational-operational differences in the ultraplankton community. However, the lack of nearfield-farfield differences in the ultraplankton assemblage indicates that there was no effect caused by the operation of Seabrook Station.

3.3.1.3 Chlorophyll *a* Concentrations

During both the preoperational and operational periods, monthly arithmetic mean total chlorophyll *a* concentrations exhibited an early spring peak, mid-summer decline, and fall peak (Figure 3-5). Monthly mean operational concentrations were lower than preoperational concentrations in all months, and below the lower 95% confidence limits of the preoperational means in June and October through December. The 1994 monthly mean concentrations were highly variable and less than the preoperational lower 95% confidence limits in April, June and October through December.

In 1994, chlorophyll *a* annual mean concentration at each station increased by nearly two times compared to 1993. However, the ANOVA results indicated no significant differences between the preoperational and operational periods or among years or stations (Tables 3-2, 3-4).

On an annual basis, chlorophyll *a* concentrations and phytoplankton abundances appear to be unrelated, rather than directly related as expected. The differences observed in trends between phytoplankton abundances and chlorophyll *a* concentrations were likely due to differences among taxa with respect to cell size and chlorophyll *a* content. For example, the unusually high annual mean phytoplankton abundance in 1992 was influenced by high abundances of *Phaeocystis pouchettii* on several dates (Figure 3-3). While *P. pouchetii* had a large effect on phytoplankton abundances, it had only a minor effect on chlorophyll *a* concentrations (NAI 1992b) since it is a small-celled taxon (Lee 1980). Evidence for the relationship between chlorophyll *a* concentrations and phytoplankton abundances exists in the comparison of seasonal patterns. Preoperational and operational chlorophyll *a* concentrations followed a pattern similar to that of phytoplankton abundances during the same periods (Figure 3-5).

3.3.2 Selected Species

Skeletonema costatum was chosen as a selected species because of its historic omnipresence and overwhelming dominance during much of the year. At Station P2, peak abundances generally occurred in

TABLE 3-5. 1994 PHYTOPLANKTON ($\geq 10 \mu m$) AND ULTRAPLANKTON ($<10 \mu m$) SPECIES COMPOSITION BY STATION. SEABROOK OPERATIONAL REPORT, 1994.

CLASS	TAXA	P2	P5	P7
PHYTOPLANKTON[a]				
Cyanophyceae	*Oscillatoria* sp.	<1.00	0	1.32
Cryptophyceae	*Cryptomonas* sp.	<1.00	1.26	<1.00
Dinophyceae	*Oxytoxum* sp.	2.25	2.67	1.03
Bacillariophyceae				
	Bacillariophyceae	2.58	<1.00	1.54
	Cerataulina bergonii	<1.00	5.50	<1.00
	Chaetoceros debilis	1.03	<1.00	<1.00
	Chaetoceros decipiens	1.34	1.23	1.61
	Chaetoceros socialis	6.43	5.46	4.24
	Chaetoceros sp.	2.84	2.60	1.56
	Cylindrotheca closterium	1.62	1.47	1.56
	Leptocylindrus danicus	5.57	7.90	8.87
	Leptocylindrus minimus	2.91	2.43	4.21
	Nitzschia sp.	3.48	2.94	3.01
	Rhizosolenia delicatula/fragilissima	3.24	2.45	3.58
	Skeletonema costatum	36.03	21.62	32.31
	Thalassionema nitzschioides	11.06	7.80	8.91
	Thalassiosira spp.	8.98	10.50	8.76
Prymnesiophyceae	*Phaeocystis pouchetti*	4.14	19.52	14.06
ULTRAPLANKTON[b]				
Chlorophyceae	Alga; Flagellate	4.12	3.92	3.73
	Alga; Unicellular	20.65	18.98	18.44
Cryptophyceae	*Chroomonas* sp.	4.45	5.15	3.60
Cyanophyceae	Cyanophyceae; Total[c]	70.79	71.94	74.23

[a]Presents only taxa accounting for ≥1% of total abundance
[b]All ultraplankton taxa presented
[c]Includes all chroococcoid forms

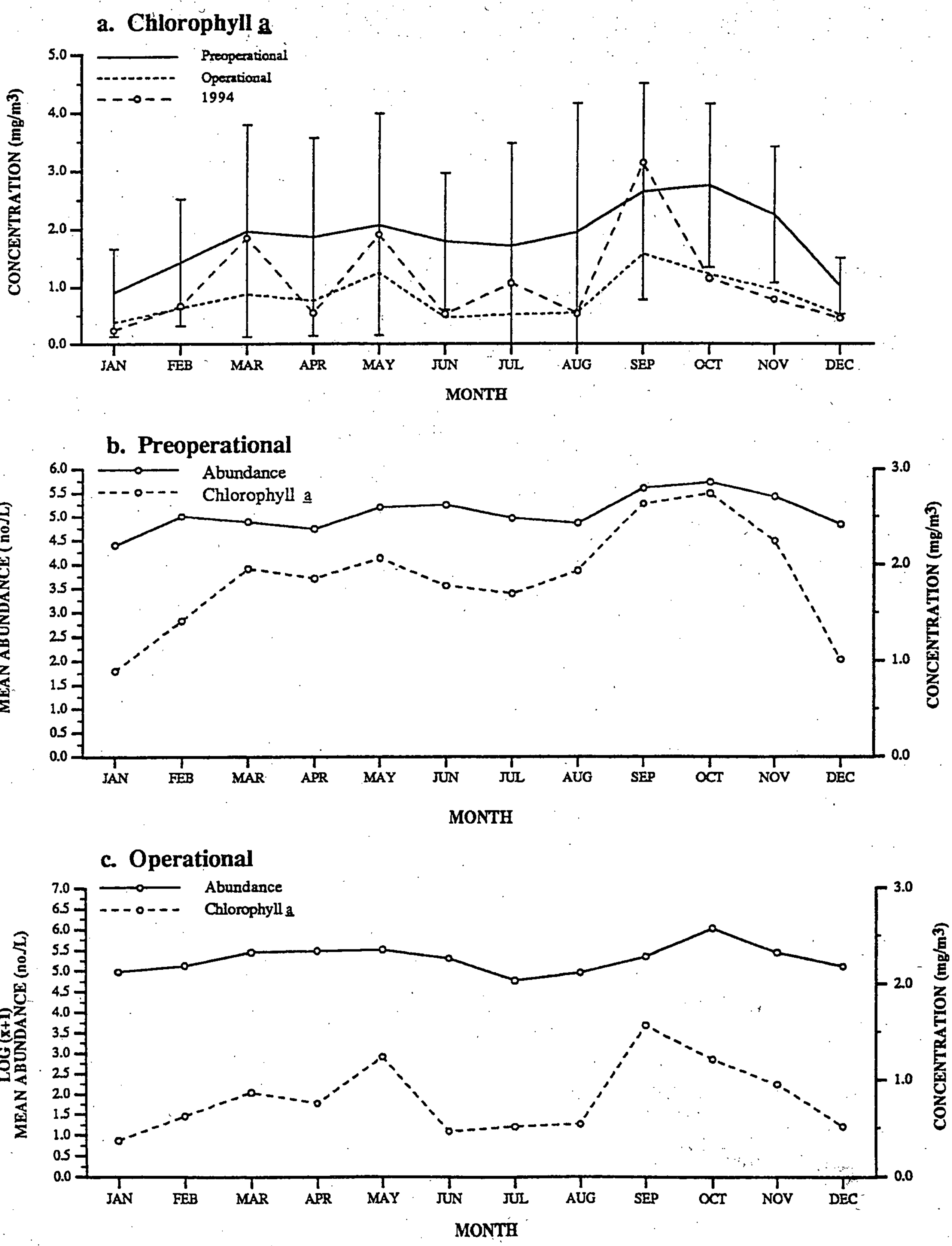


Figure 3-5. Mean monthly **chlorophyll *a*** concentrations and 95% confidence intervals at Station P2 over preoperational years (1979-1989) and monthly means over operational years (1991-1994) (a); and mean monthly chlorophyll a concentrations and phytoplankton log (x+1) abundances during the preoperational (b) and operational (c) periods. Seabrook Operational Report, 1994.

TABLE 3-6. GEOMETRIC MEAN ABUNDANCE (10^4 CELLS/L) AND COEFFICIENT OF VARIATION (CV, %) OF ULTRAPLANKTON AT STATIONS P2, P5 AND P7 DURING THE OPERATIONAL PERIOD. SEABROOK OPERATIONAL REPORT, 1994.

	STATION					
	P2		P5		P7	
YEAR[a]	MEAN	CV	MEAN	CV	MEAN	CV
1991	353.86	6.0	290.31	7.2	292.86	5.6
1992	187.21	8.9	189.58	8.5	283.90	8.2
1993	286.74	2.9	377.96	4.1	337.75	2.9
1994	242.00	3.1	260.77	3.1	294.87	30
OP MEAN[b]	260.38	1.8	271.39	1.9	301.65	0.5

[a]Annual means are means of monthly means, n = 12.
[b]Operational means are means of annual means, n = 4.

the spring and fall during the preoperational period (Figure 3-6). During the operational period both the spring and fall peaks were larger but followed the same general seasonal pattern of the preoperational period. Operational mean abundances were higher than preoperational means in all months except September, and exceeded preoperational upper 95% confidence limits during January, April and May. In 1994, *S. costatum* abundances generally followed historical patterns (Figure 3-6).

S. costatum abundances were evaluated in two separate ANOVA tests since Stations P5 and P7 were not sampled concurrently during the preoperational period (Table 3-2). For both tests (P2 versus P7 and P2 versus P5), there were no significant differences between the preoperational and operational periods or among individual years regardless of station (Table 3-4). No differences in abundances were detected between the nearfield (Station P2) and the farfield (Station P7) areas or between Stations P2 and P5 in the nearfield area. The interaction of main effects was not significant for either pairing, indicating no effect due to the operation of Seabrook Station (Table 3-4).

3.3.3 PSP Levels

During the preoperational period, average weekly PSP toxicity levels were above the detection limit of 44 μg PSP/100 g tissue of the mussel *Mytilus edulis* and periodically above the closure limit in effect then (80 μg PSP/100 g tissue) during the late spring, early summer and late summer (Figure 3-7). PSP toxicity was rarely detected during the operational period, however. During the first two years of the operational period, the State of New Hampshire recorded two occurrences of PSP levels above the detection limit, both in 1991 (NAI 1992b, 1993b), and during 1993 and 1994 occurrences were recorded only during May and early June (NAI and NUS 1994, Figure 3-7). Although the PSP levels observed in 1991 were below the current closure level of 68 μg/L, New Hampshire's coastal shellfish beds were closed as a precautionary

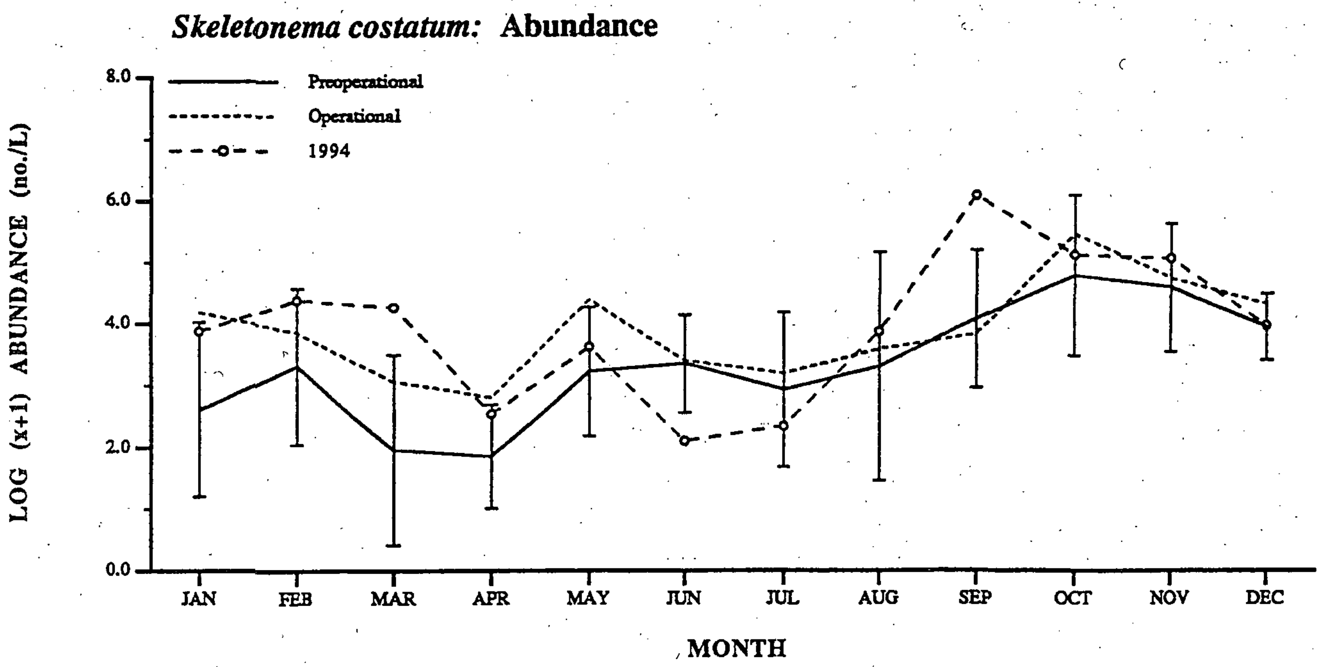
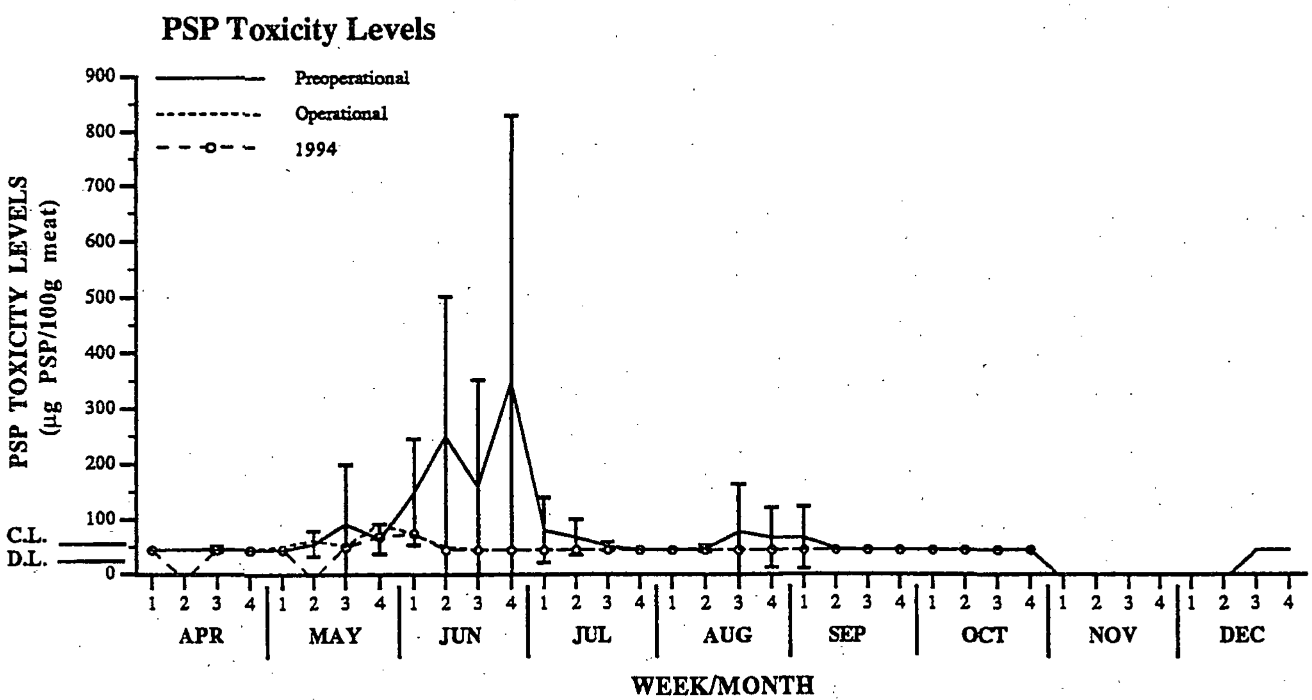


Figure 3-6. Log (x+1) abundance (no./L) of *Skeletonema costatum* at nearfield Station P2; monthly means and 95% confidence intervals over all preoperational years (1978-1984) and monthly means for the operational period (1991-1994) and 1994. Seabrook Operational Report, 1994.



C.L. = closure level of 68 µg PSP/100 g meat
D.L. = method detection limit of 44 µg PSP/100 mg meat
No PSP detected in 1992

Figure 3-7. Weekly **paralytic shellfish poisoning (PSP)** toxicity levels in *Mytilus edulis* in Hampton Harbor, mean and 95% confidence intervals over preoperational years (1983-1989) and operational years (1991-1994). Data provided by the State of New Hampshire. Seabrook Operational Report, 1994.

measure from June 14 until September 19, 1991 because of high PSP levels reported in shellfish from Maine and Massachusetts during this period (NAI 1992b). In 1994 shellfish bed closure was initiated on May 27 based on the rising PSP levels which reached 68 μg/100g and the knowledge that the State of Maine had closed their coastline adjacent to the New Hampshire border. The coast was reopened on July 20. The widespread occurrence of PSP toxicity in the coastal areas of northern New England (NAI 1993b) indicates that the occurrence of PSP toxicity in the project area was unrelated to the operation of Seabrook Station.

3.4 DISCUSSION

3.4.1 Community Interactions

The operation of Seabrook Station has had no demonstrable effect on the phytoplankton community. The seasonal patterns of total abundance, chlorophyll *a* concentrations and the occurrence of dominant taxa in the phytoplankton assemblage were similar between the preoperational and operational periods, and among stations (Table 3-7). The phytoplankton assemblage was dominated by diatoms (Bacillariophyceae) both annually and seasonally during both periods. In some years, however, the Prymnesiophyceae species *Phaeocystis pouchetii* accounted for as high a proportion of the community at each station as did total diatoms (Figure 3-3). On average, *P. pouchetii* composed a greater proportion of the operational assemblage (25%) than the preoperational assemblage (17%; Table 3-3), due to its high abundances during the spring of 1992 and 1994.

With the exception of *Phaeocystis pouchetii*, the group of taxa that accounted for the majority of the community changed little between the preoperational and operational periods (Figure 3-3). On a year-to-year basis, however, assemblages differed considerably. For this reason, the phytoplankton study included an analysis of parameters that were expected to be more predictable indicators of community status than species composition, such as the abundance of the selected species (*Skeletonema costatum*), or total biomass as estimated by chlorophyll *a* concentrations. Seasonal patterns for these parameters between the two periods remained similar, and no nearfield/farfield differences were detected (Table 3-4). Mean chlorophyll *a* concentration during the operational period was similar to the preoperational period and on a monthly basis chlorophyll *a* concentrations closely tracked phytoplankton abundance. In 1994, peaks in chlorophyll *a* concentration corresponded to two peaks in phytoplankton abundance, March (dominated by *Thalassiosira decipiens* and *Chaetoceros socialis*) and September (dominated by *Skeletonema costatum* and *Thalassionema nitzschioides*). The two-fold difference in chlorophyll *a* concentration between 1993 and 1994 may be a reflection of the two-fold difference in *S. costatum* abundance that also occurred. Both parameters fell within the variability observed in the preoperational period. There were no significant interactions between operational status and station for total phytoplankton abundance, *Skeletonema costatum* abundance, or chlorophyll *a* concentrations (Table 3-4).

The focus of the investigation of the ultraplankton assemblage was an examination of nearfield-farfield differences during the operational period, as identification techniques and information availability substantially improved after preoperational collections ended in 1984. During 1994, the ultraplankton assemblage was dominated by Cyanophyceae, particularly colonials (Table 3-5). Percent composition of each of the ultraplankton taxa, and the seasonal occurrences of total abundances, were similar among the three stations. Other studies conducted in the Gulf of Maine indicated that these forms were prominent throughout the region during both the preoperational and operational periods (Shapiro and Haugen 1988; Haugen 1991).

Only minor occurrences of PSP toxicity have been documented in the study area during the operational

TABLE 3-7. SUMMARY OF POTENTIAL EFFECTS (BASED ON ANOVA) OF OPERATION OF SEABROOK STATION ON THE PHYTOPLANKTON COMMUNITY. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PRE-OPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
Phytoplankton	Op=Preop	yes
Skeletonema costatum	Op=Preop	yes
Chlorophyll *a*	Op=Preop	yes

period. The occurrence of PSP toxicity in this portion of the Gulf of Maine was first documented in 1972 (NAI 1985), possibly as the result of the transport of the PSP-producing dinoflagellate *Alexandrium* spp. (formerly called *Gonyaulax* sp.) from the Bay of Fundy following Hurricane Carrie (Franks and Anderson 1992a). With few exceptions, PSP has been recorded seasonally in this region of the western Gulf of Maine ever since, although not always at toxic levels. It is currently thought that *Alexandrium* spp. blooms are transported to this region on coastally-trapped buoyant plumes derived from the Androscoggin and/or Kennebec Rivers (Maine)(Franks and Anderson 1992a). This theory is consistent with the generally observed north-to-south seasonal progression of occurrence of this dinoflagellate and the PSP levels (Franks and Anderson 1992b). Local sources of dinoflagellates may also contribute to the blooms as well. Thus, occurrences of PSP toxicity in New Hampshire have been associated with larger regional occurrences in southern Maine and northern Massachusetts, and are not a localized occurrence.

3.4.2 Effects of Plant Operation

The high variability of the phytoplankton community both temporally and spatially during the whole of the study period is an inherent characteristic. The high variability in density levels and community structure from year-to-year was due to the influence of both physical and chemical factors, some cyclical and some transitory, and to the rapid turnover rate of phytoplankton populations. Thus, it has been difficult to succinctly describe the long-term temporal community structure (NAI 1985). However, all documented characteristics of the phytoplankton community in the vicinity of Seabrook Station indicate that, although some community changes occurred over time, these changes occurred at all three stations. In some cases (i.e. the apparent increase of certain Cyanophyceae forms), these changes were widely documented in the Gulf of Maine. Therefore there is no evidence indicating that the operation of Seabrook Station had a demonstrable effect on any aspect of the local phytoplankton community.

3.5 REFERENCES CITED

Cadée, G.C. and J. Hegeman. 1986. Seasonal and annual variation in *Phaeocystis pouchetii* (Haptophyceae) in the westernmost inlet of the Wadden Sea during the 1973 to 1985 period. Neth. J. Sea Res. 20(1):29-36.

Franks, P.J.S. and D.M. Anderson. 1992a. Alongshore transport of a toxic phytoplankton bloom in a buoyant current: *Alexandrium tamarense* in the Gulf of Maine. Mar. Biol. 112:153-164.

Franks, P.J.S. and D.M. Anderson. 1992b. Toxic phytoplankton blooms in the southwestern Gulf of Maine: testing hypotheses of physical control using historical data. Mar. Biol. 112:165-174.

Harris, R.J. 1985. A primer of multivariate statistics. Acad. Press, Orlando. 575 pp.

Haugen, E. 1991. Unpublished phytoplankton data filed with MWRA, Deer Island offshore outfall monitoring studies, 1990.

Lee, R.E. 1980. Phycology. Cambridge University Press, New York. 478 pp.

Marshall, H.G. and M.S. Cohen. 1983. Distribution and composition of phytoplankton in northeastern coastal waters of the United States. Estuar. Coast. and Shelf Sci. 17:119-131.

Normandeau Associates Inc. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rep. XVI-II.

_________. 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Report XXII-I.

_________. 1992a. Seabrook Environmental Studies. Unpubl. 1991 Data.

_________. 1992b. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

_________. 1993a. Seabrook Environmental Studies. Unpubl. 1992 Data.

_________. 1993b. Seabrook Environmental Studies, 1992. A characterization environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XIV-I.

_________. 1994. Seabrook Environmental Studies. Unpub. 1993 Data.

_________. 1995. Seabrook Environmental Studies. Unpub. 1994 Data.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A characterization of Environmental Conditions in the Hampton-Seabrook Area during the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

Peperzak, Louis. 1993. Daily irradiance governs growth rate and colony formation of *Phaeocystis* (Prymnesiophyceae). J. Plank. Res. 15(7):809-821.

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 edition. SAS Inst., Inc. Cary, N.C. 956 pp.

Shapiro, L.P. and E. M. Haugen. 1988. Seasonal distribution and temperature tolerance of *Synechococcus* in Boothbay Harbor, Maine. Estuar. Coast. Shelf Sci. 26:517:525.

Stockner, J.G. 1988. Phototrophic picoplankton: an overview from marine and freshwater ecosystems. Limnol. Oceanogr. 33:765-775.

Stewart-Oaten, A., W.M. Murdoch and K.R. Parker. 1986. Environmental impact assessment: "Pseudo-replication" in time? Ecology. 67:920-940.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4 (1):3-15.

APPENDIX TABLE 3-1. CHECKLIST OF PHYTOPLANKTON TAXA CITED IN THIS REPORT. SEABROOK OPERATIONAL REPORT, 1994.

BACILLARIOPHYCEAE	*Asterionella glacialis* Castracane (syn. *A. japonica* Cleve)
	Cerataulina bergonii H. Péragallo
	Chaetoceros debilis Cleve
	Chaetoceros decepiens Cleve
	Chaetoceros socialis Lauder
	Cylindrotheca closterium (Ehrenberg) Reimann. and Lewin
	Leptocylindrus danicus Cleve
	Leptocylindrus minimus Gran
	Nitzschia sp.
	Rhizosolenia delicatula Cleve
	Rhizosolenia fragilissima Bergon
	Skeletonema costatum (Greville) Cleve
	Thalassionema nitzschioides Hustedt
	Thalassiosira sp.
CRYPTOPHYCEAE	*Cryptomonas* sp.
	Chroomonas sp.
DINOPHYCEAE	*Oxytoxum* sp.
	Prorocentrum micans Ehrenberg
PRYMNESIOPHYCEAE	*Phaeocystis pouchettii* (Hariot) Lagerheim

TABLE OF CONTENTS

PAGE

PAGE

SUMMARY

Microzooplankton have historically shown distinct seasonal changes that relate to changing abundances of dominant taxa, including the copepods *Pseudocalanus* sp. and *Oithona* sp., bivalve larvae, and copepod nauplii. Seasonal patterns during the operational period were similar to those observed during the preoperational period, although abundances of one key taxon (*Pseudocalanus/Calanus* nauplii) showed significant differences. No differences in abundance were observed between nearfield and farfield areas, indicating that there is no evidence of an effect related to Seabrook Station.

The umboned bivalve larval assemblage is defined by varying abundances of dominants such as *Hiatella* sp., *Mytilus edulis*, and *Anomia squamula*. Seasonal appearances of dominant species were similar to previous years. However, average abundances for four of the species during the operational period were diminished in comparison to the preoperational average. Since decreased abundances occurred at both nearfield and farfield stations, they suggest an areawide trend unrelated to the operation of Seabrook Station. Abundances of *Teredo navalis* increased at Station P2 and decreased at Stations P5 and P7. The increase in abundance of *Hiatella* sp. during the operational period was significantly greater at Station P2. The level of entrainment of bivalve larvae changed with the abundance of larvae in the surrounding waters. No entrainment samples were collected in 1994 due to a scheduled plant outage, equipment being out of service for refurbishment, and personnel scheduling conflicts. Consistent with previous refueling outages, ichthyoplankton and bivalve larvae entrainment samples were not taken during the April 9 to July 31 refueling outage when there was insufficient circulating water flow to operate the entrainment sampling equipment. Refurbishment of the entrainment sampling equipment was not completed during the outage as originally scheduled and as a result on-site entrainment sampling was not resumed until mid-September when the equipment was returned to service. However, when ichthyoplankton sampling was resumed, bivalve larvae sampling was not resumed. As a result of the outage which began in April and the failure to resume bivalve entrainment sampling in September, no bivalve larvae samples were taken in 1994 during the April to October sampling period. These on-site entrainment sampling deficiencies have been addressed by reassigning the responsibility for entrainment sampling to the organization that provides oversight of the off-site environmental monitoring program. Previous results show no evidence that larval entrainment has resulted in decreased numbers of bivalve larvae in coastal waters.

The macrozooplankton community is composed of a true planktonic component (defined as holo/meroplankton) including the copepods *Calanus finmarchicus*, *Centropages typicus*, *Pseudocalanus* sp., and *Temora longicornis*, along with larval stages of decapods and barnacles. Amphipods, cumaceans, and mysids occasionally venture into the water column, forming the tychoplanktonic component. The assemblage of species changed seasonally, and, for the most part, has been consistent throughout the study period. However, abundances of many of the dominants were elevated during the operational period. For the holo/meroplankton, increased abundances generally occurred at all three stations, suggesting an areawide change. Differences in the abundance of *Calanus finmarchicus* adults between the recent preoperational and operational periods were not consistent among stations. Comparison of the annual means showed the differences to be slight. Tychoplankton have historically shown nearfield-farfield differences that are related to variations in substrate. These spatial differences have been consistent during both preoperational and operational periods. No changes in the macrozooplankton community have been observed that could be related to the operation of Seabrook Station.

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

4.0 ZOOPLANKTON

4.1 INTRODUCTION

Three components of the zooplankton community, microzooplankton, bivalve larvae and macrozooplankton, were sampled separately to identify spatial and temporal trends at both the community and species level. One station outside the area most likely to be affected by plant operation was selected as a farfield site. Initial monitoring characterized the source and magnitude of variation in each zooplankton community and provided a data base for comparing operational monitoring. Current trends in zooplankton population dynamics were evaluated to determine whether entrainment in Seabrook Station's cooling water system has had a measurable effect on the community or any individual species. In addition, entrainment of bivalve larvae in the plant's cooling water system was estimated.

4.2 METHODS

4.2.1 Field Methods

4.2.1.1 Microzooplankton

Microzooplankton were sampled twice a month from March-November and monthly in December-February at intake (Station P2), discharge (Station P5) and farfield (Station P7) areas (Figure 4-1). Sampling at all three stations occurred from July through December 1986 and from April 1990 through December 1994. In addition, Station P2 was sampled from January 1978 through December 1984 and Station P7 from January 1982 through December 1984. Four replicate samples were collected by pump at both 1 m below the surface and 2 m above the bottom at each station on each sampling date. Discharge from the pumps was directed into a 0.076-mm mesh plankton net (12 cm diameter) set into a specially-designed stand filled with seawater to within 15 cm of the top of the net. Pumping time was recorded to calculate volume filtered based on predetermined pumping rates. Volume filtered averaged 125 liters and ranged from 105-235 liters (NAI 1991a). Microzooplankton were rinsed from the nets into sample containers after pumping and were preserved in borax-buffered 3% formalin.

4.2.1.2 Bivalve Larvae

The spatial and temporal distributions of 12 taxa of umboned bivalve larvae were monitored using a 0.5-m diameter, 0.076-mm mesh net. Samples were collected weekly from mid-April through October at Hampton Harbor (P1), and at Stations P2, P5 and P7 (Figure 4-1). Sampling began at Station P2 in July 1976. Farfield Station P7 was added to the program in 1982, and Station P1 was added in July 1986. Samples were collected at Station P5 from July-December 1986 and April 1988 through October 1993. Two simultaneous two-minute oblique tows were usually taken at each station. In cases when nets were clogged, vertical tows were taken. Volume filtered ranged from 6-13 m^3 and averaged 9 m^3 for oblique tows, and ranged from 2-5 m^3 and averaged 3 m^3 for vertical tows (NAI 1991a). The volume of water filtered was recorded with a General Oceanics® flowmeter. Upon recovery, net contents were preserved with 1-2% borax-buffered formalin (with sugar added to enhance color preservation) and refrigerated.

4.2.1.3 Entrainment

Bivalve larvae entrainment sampling has historically been conducted up to four times a month by NAESCO personnel within the circulating water pumphouse on-site at Seabrook Station from July 1986-June 1987 and June 1990-October 1993. Three replicates were collected during the day on each sampling date. Sampling dates coincided with offshore bivalve larvae sampling whenever possible. Entrainment sampling was not conducted on several scheduled sampling dates,

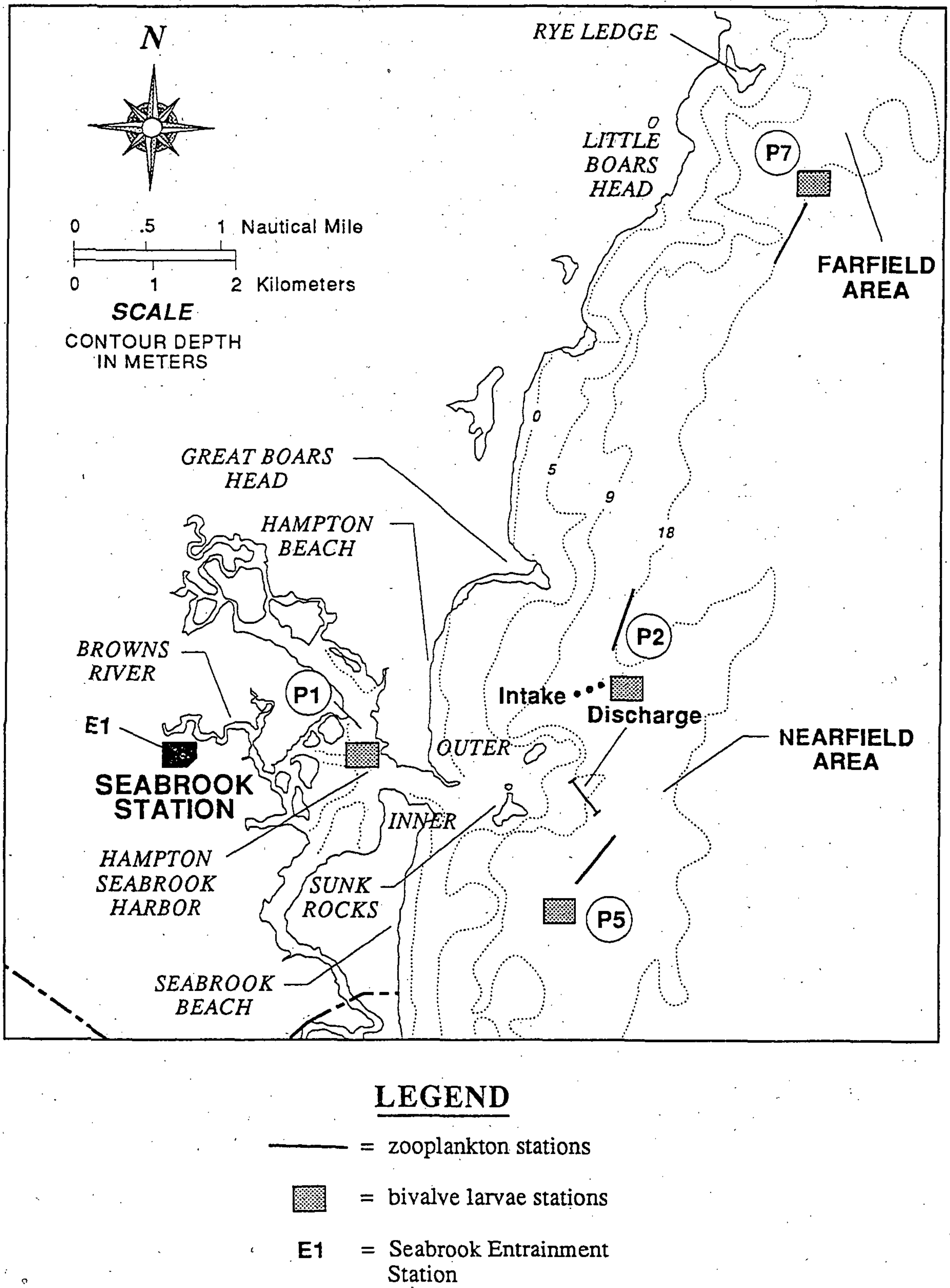


Figure 4-1. Plankton and entrainment sampling stations. Seabrook Operational Report, 1994.

however, due to either station outages or sampling equipment problems. Scheduled station outages occurred from August through November 1991, September through October 1992, and April through August 1994. No bivalve larvae entrainment samples were collected in 1994 due to the scheduled outage, equipment being out-of-service and personnel scheduling conflicts.

Samples were historically taken using a double barrel collection system. A 0.076-mm mesh plankton net was suspended in a 30-gallon drum which, in turn, was suspended in a 55-gallon drum. Water diverted from the cooling water system entered the 55-gallon drum from the bottom and overflowed the 30-gallon drum into the plankton net. After passing through the net, the water discharged through the bottom of both drums. The water supply was adjusted to maintain three to six inches of water above the plankton net at all times. After the water was drained from the system, the sample contents were consolidated and preserved with 1% buffered formalin. Three replicate samples were collected on each sampling date. The volume filtered was measured with an in-line flowmeter and averaged approximately 7 m^3 per replicate.

4.2.1.4 Macrozooplankton

Macrozooplankton were collected from July 1986 through December 1994 at Stations P2, P5, and P7 (Figure 4-1). Station P2 was also sampled from January 1978 through December 1984. Station P5 was also sampled from January 1978 through December 1981. Station P7 was also sampled from January 1982 through December 1984.

Macrozooplankton collections were made at night two times per month, concurrent with ichthyoplankton sampling. On each date, four replicate oblique tows were made with 1-m diameter 0.505-mm mesh nets at each station. The nets were set off the stern and towed for 10 minutes while varying the boat speed, causing the net to sink to approximately 2 m off the bottom and to rise to the surface at least twice during the tow. When nets became clogged due to plankton blooms, tows were shortened to 5 minutes. The volume filtered, determined with a General Oceanics® digital flowmeter, ranged from 408-567 m^3 (averaged 494 m^3) for 10-minute tows, and ranged from 109-280 m^3 (averaged 166 m^3) for 5-minute tows (NAI 1991a). Upon retrieval, each net was rinsed and the contents preserved in 6% buffered formalin.

4.2.2 Laboratory Methods

4.2.2.1 Microzooplankton

Two replicates from each depth and station on all sample dates were analyzed for microzooplankton; the remaining two replicates were archived and stored as "contingency" samples. The sample was concentrated or diluted to a known volume that provided an optimal working number of organisms (ca. 200 per 1-ml subsample). Each sample was agitated with a calibrated bulb pipette to distribute the contents homogeneously. A 1-ml subsample was removed, placed in a Sedgewick-Rafter cell and examined under a compound microscope using magnifications of 40X to 200X. All microzooplankton taxa present in the subsample (generally, all taxa smaller than adult *Calanus finmarchicus* are <4.0 mm) were counted and identified. Most copepods were identified to developmental stages, e.g., nauplii, copepodites or adults (copepodite 6). Two subsamples were analyzed for each replicate. Individual abundances for all taxa (no./m^3) were computed for each subsample and then averaged to provide mean abundances per taxon for each replicate.

4.2.2.2 Bivalve Larvae

Each bivalve larvae sample collected at each station was analyzed. When the total umboned larvae collected ranged from 1-300, the entire sample was processed.

Samples were split when the total umboned bivalve larvae count exceeded 300 specimens and two subsample fractions were examined with a dissecting scope. Umboned larvae were identified from an established species list and enumerated. Specimens of other species were enumerated as Bivalvia. Subsamples (when present) were averaged for each tow. Samples collected in 1985 were analyzed for *Mytilus edulis* and *Mya arenaria* only.

4.2.2.3 Macrozooplankton

Macrozooplankton were analyzed from three of the four tows (randomly selected) at each station. Copepods were analyzed by concentrating or diluting the sample to a known volume from which a subsample of approximately 150 copepods per 1 ml could be obtained. The sample was agitated with a Stempel pipette to homogeneously distribute the contents and 1 ml was removed and examined under a dissecting microscope. Subsampling continued until at least 30 of the dominant copepod taxa and 150 total copepods were counted. If an even distribution of copepods could not be attained, the sample was serially split using a Folsom plankton splitter. Cyclopoids and copepodites of smaller calanoid species (which were not efficiently collected in the macrozooplankton samples) were not included in the copepod counts. For the selected species *Calanus finmarchicus*, both lifestage and sex were identified. After enumeration, subsamples were recombined with the sample.

To enumerate rarer copepods (*Anomalocera opalus*, *Caligus* sp., *Candacia armata*, *Euchaeta* sp., Harpacticoida, Monstrillidae and *Rhincalanus nasutus*) and the remaining macrozooplankton, the sample was placed in a Folsom plankton splitter and serially split into fractions that provided counts of at least 30 individuals of each dominant macrozooplankton taxon (as defined in NAI 1984). A maximum of 100 ml of settled plankton was analyzed. Macrozooplankton taxa were enumerated by species using a dissecting microscope at magnifications between 6x and 150x. Selected species (*Cancer* sp., *Carcinus maenas*, *Crangon septemspinosa*, and *Neomysis americana*) were identified to detailed developmental stage (lifestage and/or sex). Splits were recombined upon completion.

For each sample type, species counts were converted to density by multiplying each species' count by the appropriate scaling ratio (the proportion of the sample analyzed for each particular organism) and dividing by the volume of water filtered during field collection. Microzooplankton and bivalve larvae abundances were reported as no./m^3; macrozooplankton abundances were reported as no./1000 m^3.

4.2.3 Analytical Methods

4.2.3.1 Communities

Community structure of the microzooplankton, bivalve larvae, and macrozooplankton components of the zooplankton community was evaluated by numerical classification, multivariate analysis of variance (MANOVA), and qualitative comparison of log abundances or geometric means for periods (operational, preoperational and 1994, Table 4-1). The macrozooplankton community includes numerous species that exhibit one of three basic life history strategies. The holoplankton species, e.g. copepods, are planktonic essentially throughout their entire life cycle. Meroplankton includes species that spend a distinct portion of their life cycle in the plankton, e.g. larvae of benthic invertebrates. Species that alternate between association with the substrate and rising into the water column on a regular basis are called tychoplankton, e.g. mysids. Because of these behavioral differences, as well as large differences in abundances, macrozooplankton species were categorized into holo/meroplanktonic species or tychoplanktonic species prior to statistical analysis. The same types of analyses were performed on each group of species.

TABLE 4-1. SUMMARY OF METHODS USED IN NUMERICAL CLASSIFICATION AND MULTIVARIATE ANALYSIS OF VARIANCE OF ZOOPLANKTON COMMUNITIES, AND ANALYSIS OF VARIANCE OF ZOOPLANKTON SELECTED SPECIES. SEABROOK OPERATIONAL REPORT, 1994.

ANALYSIS	TAXON	LIFESTAGE	STATIONS	DATES USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN (M)ANOVA
MICROZOOPLANKTON MANOVA	31 dominants	--	P2 P5 P7	1994	Log (x+1) transformation of each "replicate" sample, $\bar{x}$ of surface and bottom; species excluded with frequency of occurrence <20%	Station
ANOVA	Selected species: *Eurytemora* sp. *Eurytemora herdmani* *Pseudocalanus/Calanus* *Pseudocalanus* sp. *Oithona* sp.	 C[b] A N C,A N,C,A	P2 P7	1982-1984; 1991-1994	Monthly mean, surface, and bottom	Preop-Op, Year, Month, Station and Interaction Terms
Numerial classification	35 dominants	--	P2	1978-1984, 7/86-12/86 4/90-12/94	Log (x+1) transformation of each individual (replicate) sample, $\bar{x}$ of surface and bottom; species excluded with frequency of occurrence <9%	--
BIVALVE LARVAE MANOVA	All taxa except Bivalvia	--	P2 P5 P7	1988-1994[c]	Log (x+1) transformation of individual (replicate) sample, then weekly means computed	Preop-Op, Station, Year, Week
ANOVA	Selected species: *Mytilus edulis*	--	P2 P5 P7	1988-1994[c]	Same as above	Preop-Op, Station, Year, Week
Numerical classification	All taxa except Bivalvia	--	P2 P5 P7	1988-1994[c]	Log (x+1) transforamtion of each individual (replicate) sample, half-monthly means calculated from weekly $\bar{x}$	--

(continued)

TABLE 4-1. (Continued)

ANALYSIS	TAXON	LIFESTAGE	STATIONS	DATES USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN (M)ANOVA
MACROZOOPLANKTON						
Numerical classification	Tycho: 22 dominants[d]	--	P2 P5 P7	1986-1994	Monthly $\bar{x}$. Tychoplankton: taxa occurring in ≥4% of P2 preoperational samples except Mysidacea and Amphipoda.	--
	Holo/mero: 50 dominants[e]				Holo/mero: deleted taxa occurring in ≤5% of P2 preoperational samples and general taxa of low abundance.	
MANOVA	Tycho: 22 dominants[d]	--	P2 P5 P7	1987-1994[c]	Sample period $\bar{x}$ sampled twice per month. Tychoplankton: taxa occurring in ≥4% of P2 preoperational samples except Mysidacea and Amphipoda.	Preop-Op, Station, Year, Month
	Holo/mero: 50 dominants[e]				Holo/mero: deleted taxa occurring in ≤5% of P2 preoperational samples and general taxa of low abundance.	
ANOVA	Selected species:					
	Calanus finmarchicus	C,A[b]	P2	1987-1994[c]	Sample period $\bar{x}$, sampled twice per month	Preop-Op, Station, Year, Month
	Cancer sp.[f]	L	P5			
	Carcinus meanas[g]	L	P7			
	Crangon septemspinosa	L				
	Neomysis americana	All				

[a]All data log (x+1) transformed unless otherwise noted
[b]C = copepodite; A = adult; N = nauplii; L = larvae
[c]1990 excluded
[d]Hyperiidae removed, *Mysis stenolepis* added to list in 1994.
[e]Hydrozoa, Gastropoda, Hyperiidae added to list; *Eualus* sp., *Lebbeus* sp. and *Spirontocaris* sp. lumped together as Hippolytidae in 1994.
[f]*Cancer* spp. discussed in Section 8.0
[g]*Carcinus maenas* larvae are essentially absent for 7 of 12 months, therefore a peak period of June-October only was analyzed.

Temporal and spatial changes in the community structure of microzooplankton, bivalve larvae, and the two components of macrozooplankton were evaluated using numerical classification techniques (Boesch 1977). This technique forms groups of stations and/or sampling periods based on similarity levels calculated for all possible combinations of stations/sampling periods and the species that occur there. The Bray-Curtis similarity index (Clifford and Stephenson 1975, Boesch 1977) was used. Values of the indices ranged from 0 for absolute dissimilarity to 1 for absolute similarity. The classification groups were formed using the unweighted pair-group method (UPGMA: Sneath and Sokal 1973). Results were simplified by combining the entities based on their similarity levels, determined by both the within-group and between-group similarity values. Results were presented graphically by dendrograms, which show the within-group similarity value and the between-group similarity (value at which a group links to another group). The groups were characterized by the mean abundance of the dominant taxa. Communities during the operational period (August 1990-December 1994) were judged to be similar to previous years if collections were placed in the same group as the majority of collections taken at the same time during previous years. A potential impact was suggested if community differences occurred solely during the operational period and were restricted to either the near-field or the farfield area. This situation would initiate additional investigations. If community differences occurred at both nearfield and farfield stations, they were assumed to be part of an area-wide trend, and unrelated to plant operation.

Multivariate analysis of variance (MANOVA, Harris 1985) was the statistical test used to assess simultaneously the differences in abundance between periods (preoperational and operational), stations (nearfield and farfield), years and months (microzooplankton, macrozooplankton) or weeks (bivalve larvae, Table 4-1). The interaction term (Station X Period) was used to determine if there was an impact from plant operation for bivalve larvae and macrozooplankton. Microzooplankton collections from 1994 were tested only to determine station differences. Historically, there have been few differences in planktonic species assemblages among nearfield intake and discharge and farfield stations. Continuation of the trend during plant operation would suggest that there were no effects of plant operation on these communities. Probabilities associated with the Wilks' Lambda test statistic (SAS 1985) were reported. Abundance data from each individual (replicate) sample was log (x+1) transformed prior to use in the MANOVA model in order to more closely approximate the normal distribution.

Untransformed densities of bivalve larvae in entrainment samples were multiplied by the month's average daily volume pumped through the circulating water system, and by the number of days represented by each sampling date, and then summed within month to estimate the number of bivalve larvae entrained by Seabrook Station on a monthly basis.

4.2.3.2 Selected Species

Biologically important or numerically dominant taxa were selected for further investigation (Table 4-1). The operational, preoperational, and 1994 geometric means and coefficients of variation (Sokal and Rohlf 1981) were tabulated. Monthly log (x+1) means and 95% confidence limits for the preoperational and operational periods, and 1994 were compared graphically to provide a visual estimate of their magnitude and seasonality. Operational/preoperational and nearfield/farfield differences in monthly means were evaluated using a multi-way analysis of variance procedure (ANOVA), using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. A mixed model ANOVA developed by Northeast Utilities, based on recent review of the BACI model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random, except operational status (Preop-Op). Time (months or weeks) and location (station) of sampling were considered random factors because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). The preoperational period for each analysis was specified as the period during which all three stations were sampled concurrently (thus maintaining a balanced model design). Some species (e.g. all bivalve larvae, *Carcinus maenas*) were common only during part of the year (peak periods). Data from the peak periods were used in analysis of variance and to compute operational, preoperational, and 1994 geometric means.

4.3 RESULTS

4.3.1 Microzooplankton

4.3.1.1 Community Structure

Temporal Characteristics

Temporal variability in species abundances and taxonomic composition of the nearshore microzooplankton community (surface and bottom samples averaged) at Station P2 for all preoperational and operational collections was examined using numerical classification. Collections were grouped into four major groups that corresponded with the annual seasonal progression of dominant species and four smaller groups (one collection date was ungrouped; Figure 4-2). The major seasonal patterns in the microzooplankton community structure were largely delineated by changes in both total abundance and the dominance structure of numerically important taxa. The copepods *Oithona* sp., *Pseudocalanus* sp., and *Pseudocalanus/Calanus* nauplii were the most abundant organisms in virtually every seasonal group during both preoperational and operational periods (Table 4-2). Winter samples (Groups 1 and 2) were characterized by low abundances and high variability of all taxa including *Oithona* sp. and Copepoda nauplii during both periods (preoperational and operational). Increased numbers of these taxa as well as *Pseudocalanus/Calanus* nauplii and *Pseudocalanus* sp. marked the appearance of the winter/spring assemblage (Group 3). The spring assemblage (Group 4) was characterized by the appearance of Tintinnidae during a rarely occurring "bloom." The spring/summer assemblage (Group 5) had peak abundances of *Oithona* sp., Copepoda nauplii, *Pseudocalanus/Calanus* nauplii, *Pseudocalanus* sp., and bivalve veliger larvae. In the fall assemblage (Group 6), numbers of bivalve veligers diminished (<5% of total group abundance) and numbers of *Oithona* sp., *Pseudocalanus* sp., *Pseudocalanus/Calanus* nauplii, and copepod nauplii decreased. The first fall/winter group (Group 7) contained Tintinnidae and *Oithona* sp. This group was only represented in the preoperational period. The second fall/winter group (Group 8) exhibited an abundance of *Oithona* sp. as well as taxa represented in other time periods. The ungrouped sample mean was taken in late May 1982 and had very high abundances of *Oithona* sp. and *Acartia* sp.; Polychaeta larvae and Rotifera were common.

Comparison of the specific sampling periods included within the major cluster groups indicated that differences among years were generally moderate. Collections from the operational period were generally placed into groups containing corresponding dates from the preoperational period, although some collections from summer/fall 1990 showed Group 6 becoming dominant earlier than in other years (Figure 4-2). This is of little consequence, as Group 6 is very similar to Group 5, which was dominant in other years. Group 8 appeared during some operational years (1991 and 1992) in the summer and early fall while it was generally found in winter in preoperational years. Preoperational and operational periods were similar in the rank order of numerically dominant taxa identified from each cluster group (Table 4-2). Differences among groups, in large measure, were attributed to seasonal variability in the abundances of these dominant taxa (Figure 4-2). For example, the fall assemblage (Group 6) was present in August of 1980, 1981, 1982 and 1990, while in most other years it did not appear until

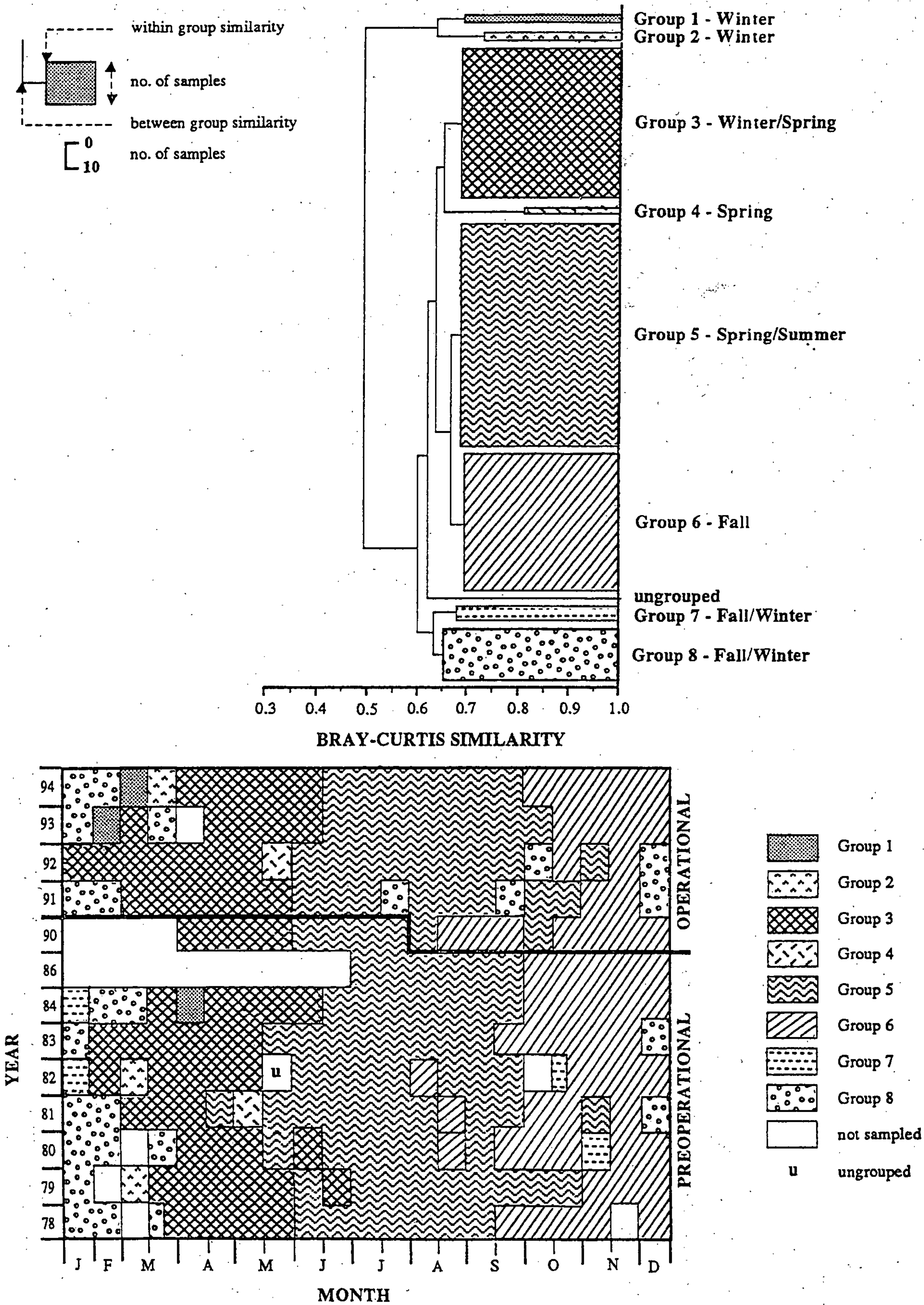


Figure 4-2. Dendrogram and seasonal groups formed by numerical classification of log (x+1) transformed **microzooplankton** abundances (no./m³) at nearfield Station P2, 1978-1984, July-December 1986, April 1990-December 1994. Seabrook Operational Report, 1994.

TABLE 4-2. GEOMETRIC MEANS OF MICROZOOPLANKTON ABUNDANCE (No./m^3), 95% CONFIDENCE LIMITS, AND NUMBER OF SAMPLES FOR DOMINANT TAXA OCCURRING IN SEASONAL CLUSTER GROUPS IDENTIFIED BY NUMERICAL CLASSIFICATION OF COLLECTIONS AT NEARFIELD STATION P2, 1978-84, JULY-DECEMBER 1986, APRIL-DECEMBER 1990, 1991-94. SEABROOK OPERATIONAL REPORT, 1994.

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL PERIOD				OPERATIONAL PERIOD			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1	Foraminifera	1	--	95	--	2	0	52	8.1x10^7
Winter	Copepoda nauplii		--	28	--		0	34	2.1x10^8
(0.66/0.60)	*Oithona* sp.		--	18	--		0	170	26386
	Tintinnidae		--	15	--		0	36	6168
	Microsetella norvegica		--	2	--		0	66	5823
2	*Oithona* sp.	2	6	223	7538	1	--	197	--
Winter	Cirripedia larvae		0	84	7.8x10^7		--	172	--
(0.71/0.60)	*Pseudocalanus/Calanus* nauplii		0	61	7.3x10^7		--	34	--
	Copepoda nauplii		0	31	1054		--	26	--
	Microsetella norvegica		0	9	718		--	41	--
	Polychaeta larvae		0	13	6.7x10^6		--	39	--
3	*Oithona* sp.	40	729	1105	1675	23	1085	1745	2807
Winter/Spring	Copepoda nauplii		596	856	1230		1005	1423	2017
(0.66/0.62)	*Pseudocalanus/Calanus* nauplii		418	621	923		135	299	661
	Pseudocalanus sp.		152	237	369		133	225	379
4	Tintinnidae	1	--	5053	--	1	--	11502	--
Spring	*Oithona* sp.		--	1823	--		--	517	--
(0.78/0.62)									

(continued)

TABLE 4-2. (Continued)

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL PERIOD				OPERATIONAL PERIOD			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
5 Spring/Summer (0.66/0.64)	*Oithona* sp.	64	3447	4194	5103	34	5100	6427	8099
	Copepoda nauplii		2313	3098	4149		2789	3636	4741
	Pseudocalanus/Calanus nauplii		1265	1654	2162		364	577	914
	Pseudocalanus sp.		561	769	1055		337	570	963
	Bivalvia veliger larvae		480	736	1129		266	502	947
6 Fall (0.66/0.64)	*Oithona* sp.	39	1045	1415	1915	20	1075	1469	2007
	Copepoda nauplii		560	753	1013		525	708	953
	Pseudocalanus/Calanus nauplii		442	594	798		65	115	204
	Pseudocalanus sp.		161	246	377		157	225	322
7 Fall/Winter (0.65/0.61)	Tintinnidae	4	63	2005	62805	not represented			
	Oithona sp.		22	228	2233				
8 Fall/Winter (0.62/0.61)	*Oithona* sp.	14	274	423	651	11	376	795	1680
	Copepoda nauplii		129	221	379		160	336	702
	Pseudocalanus/Calanus sp.		83	141	239		13	37	107
	Pseudocalanus sp.		58	102	178		37	81	178

[a]within group similarity/between group similarity
[b]taxa comprising ≥ 5% of total group abundance in either preoperational or operational period

September. Seasonal groups identified by numerical classification generally encompassed collection periods with similar temperature regimes, particularly with respect to the depth and intensity of the thermocline (NAI 1985, NAI 1991b).

Spatial Patterns

Spatial variation in the microzooplankton community structure was examined separately for both the preoperational and operational periods. Historical comparisons of total microzooplankton densities revealed no significant differences between Stations P2 and P7; although some numerically important taxa exhibited large differences in rank order or percent composition between stations, their individual abundances were not significantly different, and confidence intervals of the preoperational and operational abundances generally overlapped (NAI 1985). Similarly, 1994 abundances of the 29 dominant taxa were not significantly different among the three stations when tested with MANOVA Wilks' Lambda=0.32, F=0.75, (p>F=0.87), as was found in previous years (NAI 1991b, 1992, 1993b; NAI and NUS 1994).

4.3.1.2 Selected Species

The copepods *Pseudocalanus* sp. and *Oithona* sp. were selected for further analysis in the microzooplankton program because of their numerical dominance. Their abundance and trophic level make them important members of the marine food web throughout the Gulf of Maine and nearby Atlantic Shelf waters (Sherman 1966, Tremblay and Roff 1983, Davis 1984, Anderson 1990). The third selected species, *Eurytemora herdmani*, although not dominant, has been reported to be an abundant coastal copepod in the northern region of the western Atlantic (Katona 1971). Lifestages of these taxa were identified whenever possible to develop an understanding of the dynamics of population recruitment cycles. In some cases, however, the possible presence of congeneric species made it impossible to routinely identify all lifestages to species level.

Eurytemora sp.

Earlier studies indicated that *Eurytemora* sp. copepodite and *E. herdmani* adult populations in Hampton Harbor and the nearfield Station P2 underwent similar seasonal cycles, but during the spring the population density in the estuary was much higher than the nearfield population density (NAI 1978, 1979). These observations suggest that recruitment to the coastal population may be supplemented by the estuarine population. Other sources of recruitment in the spring might be maturation of, and subsequent reproduction of, overwintering copepodites or hatching of diapause (overwintering) eggs (Grice and Marcus 1981, Marcus 1984).

Eurytemora sp. copepodite monthly mean densities for the operational period and 1994 failed to exhibit the mid-summer density peak that has been observed in the preoperational years (1982-1984) and were well below the preoperational average density from June through October (Figure 4-3). However, mean operational densities displayed (1) a late-spring peak that was somewhat lower than the preoperational mid-summer peak, and (2) a fall peak that was comparable to the fall peak in preoperational years. Abundance peaked only in the fall during 1994. The 1994 annual geometric mean for *Eurytemora* sp. copepodites at Station P2 was below the overall mean and below the mean values for individual years for the preoperational years (Table 4-3, NAI 1991b). ANOVA results indicated that *Eurytemora* sp. copepodite abundances during the operational period were not significantly different than densities from recent preoperational years, and there were no significant differences between stations (Table 4-4). The interaction term (Preop-Op X Area) was not significant, indicating that both stations showed similar trends in density between the preopera-

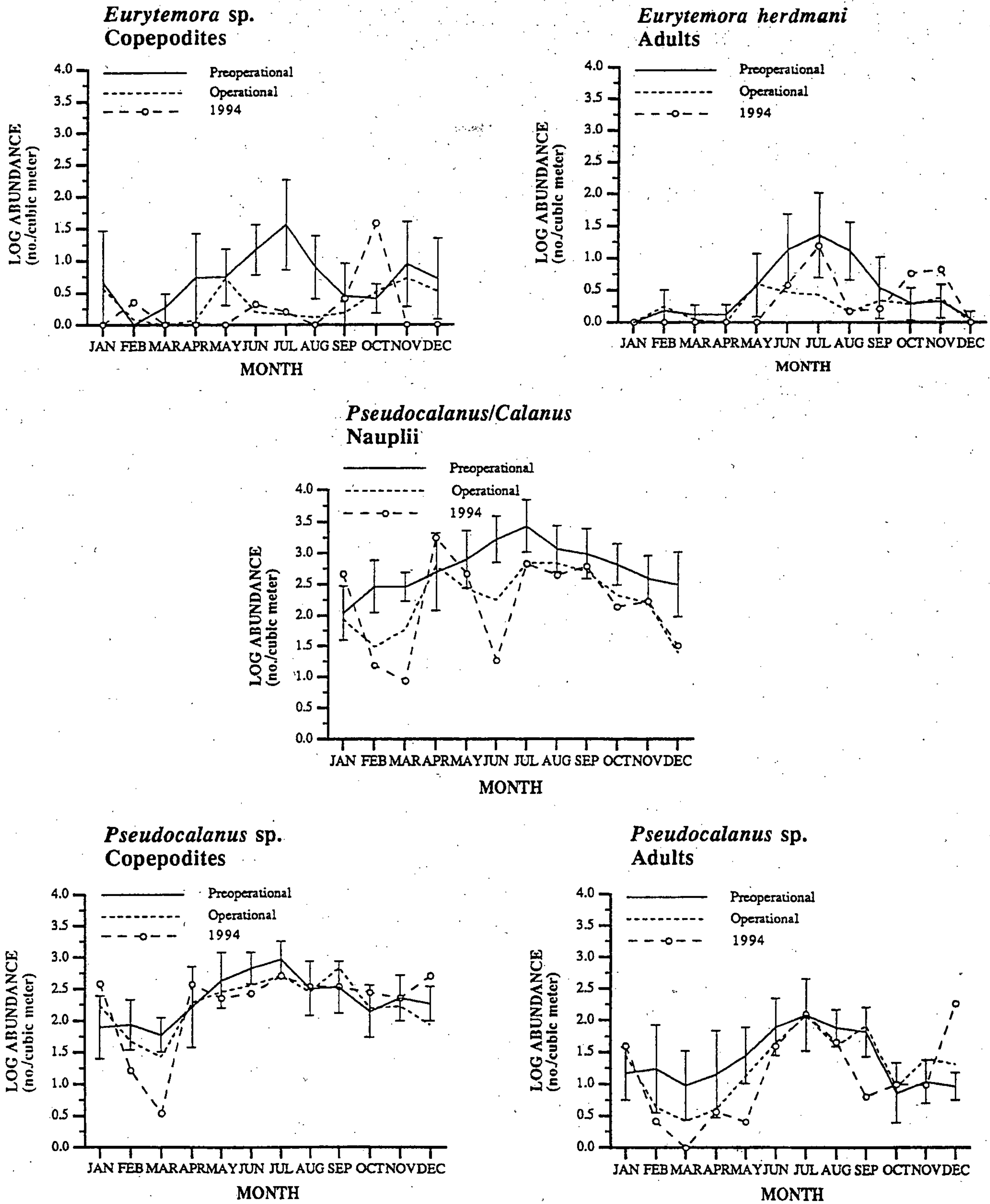


Figure 4-3. Log (x+1) abundance (no./m³) of ***Eurytemora* sp. copepodites** and ***Eurytemora herdmani* adults, *Pseudocalanus/Calanus* sp. nauplii,** and ***Pseudocalanus* sp. copepodites and adults**; monthly means and 95% confidence intervals over all preoperational years (1978-1984 and 1986) and monthly means for 1994 and operational period at nearfield Station P2. Seabrook Operational Report, 1994.

TABLE 4-3. GEOMETRIC MEAN DENSITY (No/m³) AND THE COEFFICIENT OF VARIATION (CV,%) OF SELECTED MICROZOOPLANKTON SPECIES AT STATIONS P2, P5, AND P7 FOR PREOPERATIONAL AND OPERATIONAL PERIODS AND 1994. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL		OPERATIONAL		1994
SPECIES/LIFESTAGE	STATION	MEAN	CV	MEAN[b]	CV	MEAN
Eurytemora sp. copepodites	P2	4	35.1	1	23.2	1
	P5	--	--	1	25.6	1
	P7	4	56.4	1	43.9	<1
Eurytemora herdmani adults	P2	2	50.2	1	37.4	1
	P5	--	--	1	28.9	1
	P7	3	51.2	1	42.5	1
Pseudocalanus/Calanus sp. nauplii	P2	593	7.5	177	7.8	150
	P5	--	--	120	4.9	89
	P7	499	11.2	142	5.1	135
Pseudocalanus sp. copepodites	P2	223	8.6	178	4.2	178
	P5	--	--	146	7.0	129
	P7	193	14.0	155	4.2	153
Pseudocalanus sp. adults	P2	23	17.4	17	14.4	12
	P5	--	--	17	8.7	15
	P7	25	16.4	16	13.0	10
Oithona sp. nauplii	P2	465	11.7	485	6.9	352
	P5	--	--	493	4.7	341
	P7	403	15.1	440	7.0	342
Oithona sp. copepodites	P2	490	10.1	706	4.2	527
	P5	--	--	631	7.2	383
	P7	299	20.1	616	3.4	540
Oithona sp. adults	P2	107	13.5	181	6.3	163
	P5	--	--	169	8.9	144
	P7	98	23.9	154	6.6	143

[a]Preoperational years: P2 = 1978-84, P5 = not sampled, P7 = 1982-84. Mean of annual means.
[b]Operational years = 1991-94; 1990 not sampled during January through March, data not included. Mean of annual means.

TABLE 4-4. RESULTS OF THE ANALYSIS OF VARIANCE OF LOG (X+1) TRANSFORMED DENSITY (No./m^3) OF SELECTED MICROZOOPLANKTON SPECIES AMONG PREOPERATIONAL YEARS (1982-84) AND OPERATIONAL YEARS (1991-94) AND NEARFIELD (STATION P2) VS. FARFIELD (STATION P7) AREAS. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[a]	df	MS	F	MULTIPLE COMPARISONS[b]
Eurytemora sp. copepodite	Preop-Op	1	7.43	3.05NS	
	Year (Preop-Op)	5	2.24	3.78**	
	Month (Year X Preop-Op)	77	0.80	3.30***	
	Area	1	0.10	0.36NS	
	Preop-Op X Area	1	0.27	4.39NS	
	Area X Year (Preop-Op)	5	0.06	0.26NS	
	Error	201	0.24		
Eurytemora herdmani adult	Preop-Op	1	7.32	3.89NS	
	Year (Preop-Op)	5	1.77	2.86*	
	Month (Year X Preop-Op)	77	0.81	3.98***	
	Area	1	0.31	1.80NS	
	Preop-Op X Area	1	0.16	3.22NS	
	Area X Year (Preop-Op)	5	0.05	0.26NS	
	Error	201	0.20		
Pseudocalanus/Calanus sp. nauplii	Preop-Op	1	16.80	9.95*	Op<Preop
	Year (Preop-Op)	5	1.75	1.41NS	
	Month (Year X Preop-Op)	77	1.41	5.68***	
	Area	1	0.29	3.14NS	
	Preop-Op X Area	1	0.09	0.53NS	
	Area X Year (Preop-Op)	5	0.17	0.69NS	
	Error	201	0.25		
Pseudocalanus sp. copepodite	Preop-Op	1	0.49	0.47NS	
	Year (Preop-Op)	5	1.22	1.22NS	
	Month (Year X Preop-Op)	77	1.12	4.38***	
	Area	1	0.12	7.71NS	
	Preop-Op X Area	1	0.02	0.80NS	
	Area X Year (Preop-Op)	5	0.20	0.80NS	
	Error	201	0.25		
Pseudocalanus sp. adult	Preop-Op	1	1.69	1.07NS	
	Year (Preop-Op)	5	1.88	1.46NS	
	Month (Year X Preop-Op)	77	1.32	4.67***	
	Area	1	0.00	1.18NS	
	Preop-Op X Area	1	0.01	0.02NS	
	Area X Year (Preop-Op)	5	0.35	1.23NS	
	Error	201	0.28		

(continued)

TABLE 4-4. (Continued)

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[a]	df	MS	F	MULTIPLE COMPARISONS[b]
Oithona sp. nauplii	Preop-Op	1	0.01	0.00NS	
	Year (Preop-Op)	5	3.15	4.73**	
	Month (Year X Preop-Op)	77	0.90	4.08***	
	Area	1	0.64	327.81NS	
	Preop-Op X Area	1	0.00	0.07NS	
	Area X Year (Preop-Op)	5	0.03	0.13NS	
	Error	201	0.22		
Oithona sp. copepodite	Preop-Op	1	4.96	1.71NS	
	Year (Preop-Op)	5	2.97	2.76*	
	Month (Year X Preop-Op)	77	1.19	7.23***	
	Area	1	0.77	16.22NS	
	Preop-Op X Area	1	0.05	0.38NS	
	Area X Year (Preop-Op)	5	0.13	0.77NS	
	Error	201	0.17		
Oithona sp. adult	Preop-Op	1	2.29	0.65NS	
	Year (Preop-Op)	5	3.55	3.56**	
	Month (Year X Preop-Op)	77	1.23	5.96***	
	Area	1	0.50	1055.00NS	
	Preop-Op X Area	1	<0.00	0.02NS	
	Area X Year (Preop-Op)	5	0.05	0.23NS	
	Error	201	0.21		

NS = Not Significant (P> 0.05)
* = Significant (0.05 ≥ P >0.01)
** = Highly Significant (0.01 ≥ P > 0.001)
*** = Very Highly Significant (P ≤ 0.001)

[a]Preop-Op = preoperational period vs. operational period, regardless of area
Year (Preop-Op) = year nested within preoperational and operational periods, regardless of area
Month (Year X Preop-Op) = month nested within year
Area = nearfield vs. farfield stations
Preop-Op X Area = interaction of main effects
Year X Area (Preop-Op) = interaction of area and year nested within preoperational and operational period.

[b]Least squares means compared with a paired *t*-test

tional and operational periods, and no effect can be attributed to the operation of Seabrook Station.

Temporal changes in the abundance of *Eurytemora herdmani* adults during the operational period followed the same general seasonal pattern as described for *Eurytemora* sp. copepodites with the exception that a fall peak was not detected in *E. herdmani* adult abundances in either the preoperational or operational years, although a fall peak occurred in 1994 (Figure 4-3). The mean abundances of *E. herdmani* adults during the operational period were below the mean abundances for the preoperational years (Table 4-3), but the differences were not significant (Table 4-4). The interaction term (Preop-Op x Area) was not significant indicating no effect due to the plant. Significant differences were noted among years and months.

Pseudocalanus sp.

Historically, *Pseudocalanus/Calanus* sp. nauplii were present year-round at Station P2 in large numbers (Figure 4-3), and were among the numerically dominant taxa composing the microzooplankton community in most seasons (Table 4-2). Seasonal peak abundance occurred during July during preoperational years, and July and August during the operational period (Figure 4-3). The 1994 abundances peaked somewhat earlier than both preoperational and operational averages. Mean densities for the operational period were significantly lower than the preoperational mean at both stations (Tables 4-3, 4-4). However, the differences between periods were consistent between the nearfield and farfield areas, indicating an areawide decrease rather than a localized plant effect. Differences among months and years were significant, while spatial differences were not significant.

Pseudocalanus sp. copepodites and adults were also present throughout the year, with peak abundances occurring from mid-summer through fall (Figure 4-3). Monthly mean abundances in 1994 were lower than the preoperational average in spring and near the preoperational average for the remainder of the year. The mean densities of both copepodites and adults during the operational period were not significantly different from the preoperational (1982-1984) means (Tables 4-3, 4-4). The interaction term (Preop-Op x Area) was not significant, indicating no effect due to plant operation. Significant differences were noted among months, but not between stations.

Oithona sp.

All *Oithona* sp. (mostly *Oithona similis*) lifestages were present year-round and together constituted one of the most abundant microzooplankton taxa throughout the preoperational and operational periods (Tables 4-2 and 4-3). *Oithona* sp. nauplii densities at Station P2 during the operational period and 1994 generally exhibited the same seasonal pattern of abundance as during the preoperational period (Figure 4-4), although in 1994 the spring and summer densities were lower than the preoperational and operational spring and summer densities. Average operational densities were not significantly different from the preoperational (1982-1984) mean (Tables 4-3, 4-4). Significant differences were noted among years and months (Table 4-4).

Oithona sp. copepodites also followed the same general pattern of seasonal abundances during the operational period and 1994 that was evident during the preoperational period (Figure 4-4). The 1994 geometric mean for copepodites at Stations P2 and P7 was larger than the means for the preoperational period (Table 4-3). However, there were no significant differences between the operational and preoperational periods or between stations (Table 4-4). Differences among years and months were significant. Mean densities at the nearfield and farfield stations showed similar trends between the preoperational (1982-1984) and operational periods, indicating no effect due to the plant (Table 4-4).

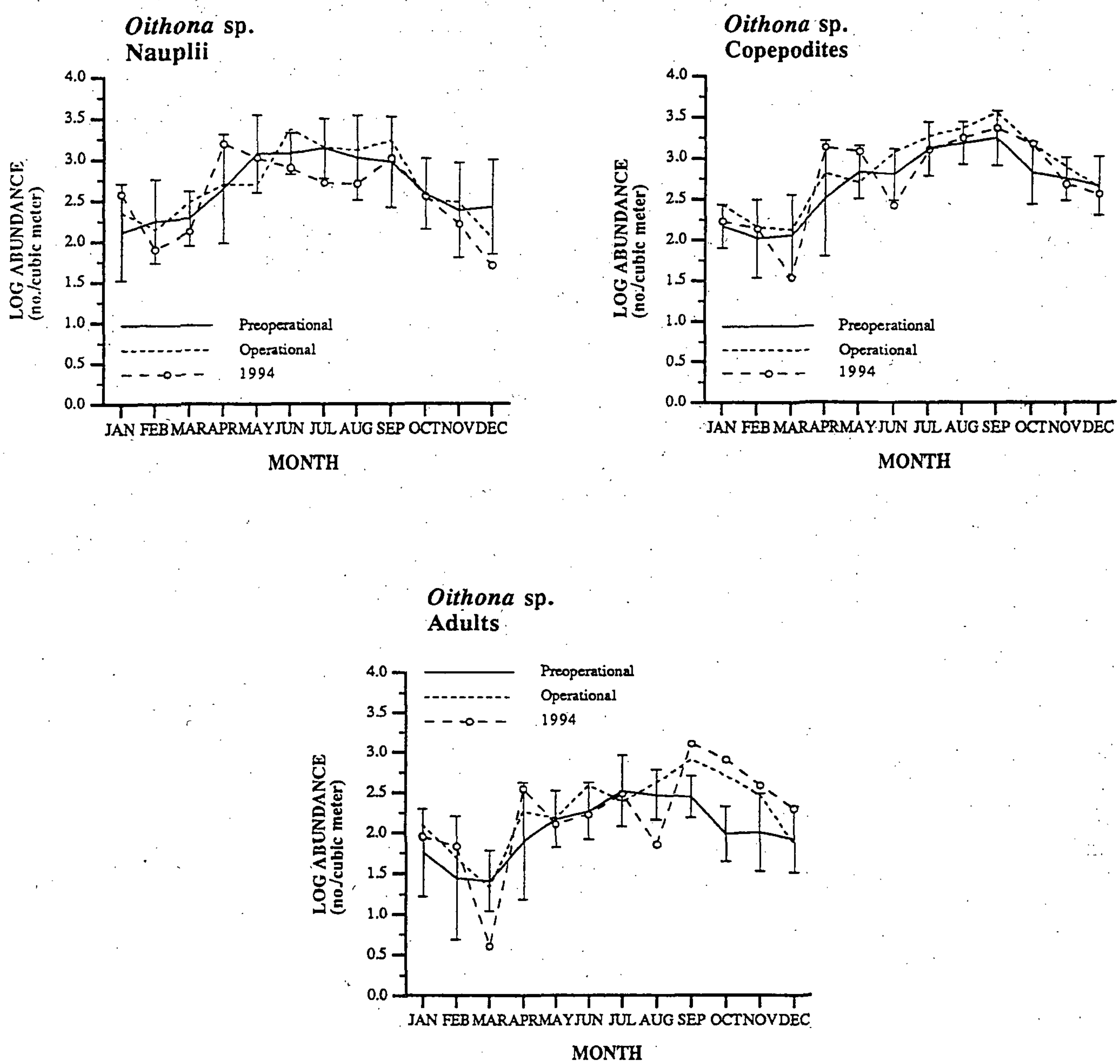


Figure 4-4. Log (x+1) abundance (no./m³) of ***Oithona* sp. nauplii, copepodites and adults;** monthly means and 95% confidence intervals over all preoperational years (1978-1984 and 1986) and monthly means for 1994 and operational period at nearfield Station P2. Seabrook Operational Report, 1994.

Seasonal fluctuations in abundance of *Oithona* sp. adults during the operational period and 1994 were generally similar to those observed during the preoperational period (Figure 4-4), although the spring minimum was slightly lower in 1994 than the preoperational and operational minimum values, while the fall maximum for the operational period and 1994 was somewhat higher than the preoperational value. Geometric mean abundance for adults at Station P2 for 1994 was slightly higher than the mean for all preoperational years (Table 4-3); however, mean operational densities of *Oithona* sp. adults were not significantly greater than the recent preoperational (1982-1984) means at both nearfield and farfield stations (Table 4-4). Mean densities at the nearfield and farfield stations showed no significant differences (Table 4-4). Differences among months were significant. No significant differences were detected between stations, and the interaction term (Preop-Op X Station) was not significant.

4.3.2 Bivalve Larvae

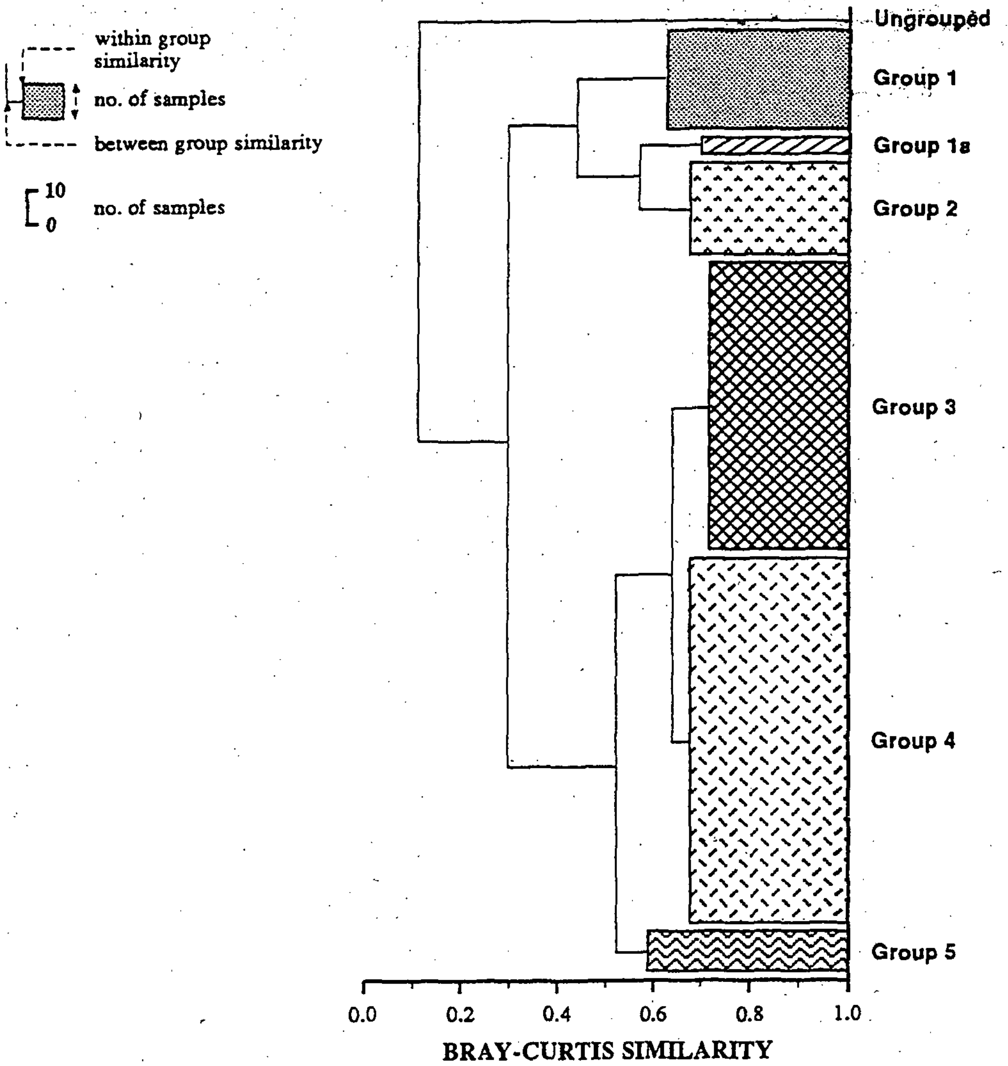
4.3.2.1 Community Structure

Patterns of abundance of the umboned bivalve larvae assemblage were examined using numerical classification to address whether there were differences among stations (spatial patterns) or between the preoperational and operational periods (temporal patterns). This aggregation of meroplanktonic species exhibited strong seasonal patterns that were generally consistent among years and stations, especially for the early spring and spring groups (Figure 4-5). Mean abundances were grouped seasonally, falling into one of six distinct groups. The seasonal structure of the community reflected recruitment of different taxa and their abundance (Table 4-5).

Temporal Patterns

The bivalve larvae assemblage showed predictable seasonal changes that were generally consistent among years. Most operational period collections were classified into groups that occurred preoperationally (Figure 4-5 and Table 4-5). Early spring collections (Group 1) were characterized by low densities of only a single taxon, *Hiatella* sp. In 1994, early spring collections were similar to previous years in that only one taxon, *Hiatella* sp., was present. However, densities were two orders of magnitude higher than typical of Group 1, resulting in a unique assemblage (Group 1a) not observed historically. The transition to the late spring assemblage (Group 2) was marked by peak densities of *Hiatella* sp., the earliest spawner, along with moderate densities of *Mytilus edulis*, *Mya truncata* and Solenidae. Peak mean densities of *M. edulis*, *Anomia squamula*, and *Modiolus modiolus* typified the early summer/fall assemblages, Group 3. This assemblage was followed by a period of low-to-moderate densities of bivalve larvae (Group 4) that occurred in late summer and fall. In some years, a second peak of *M. edulis*, *A. squamula* and *M. modiolus* led to the recurrence of the summer/fall assemblage (Group 3) in late summer or fall. Late summer or fall collections throughout the study period have occasionally contained exceptionally low densities of bivalve larvae, including *Anomia squamula*, *Mytilus edulis* and *Modiolus modiolus* (Group 5). These periods were followed by an increase in densities of the dominants and return to the typical late summer-fall assemblage (Group 4). No single group characterized the bivalve larvae assemblage from August-October every year. The bivalve larvae assemblage during the operational period (beginning in August 1990) was similar to previous years.

In 1994, the typical early spring assemblage (Group 1) occurred only in late April at Station P2. Higher-than-average densities of *Hiatella* sp. (Group 1a) occurred at P5 and P7 in late April; in early May, the unusual early spring assemblage occurred at all three stations. As the spawning season progressed, the bivalve larvae assemblage changed from the early spring (Group 2) in late May to early summer/fall in June



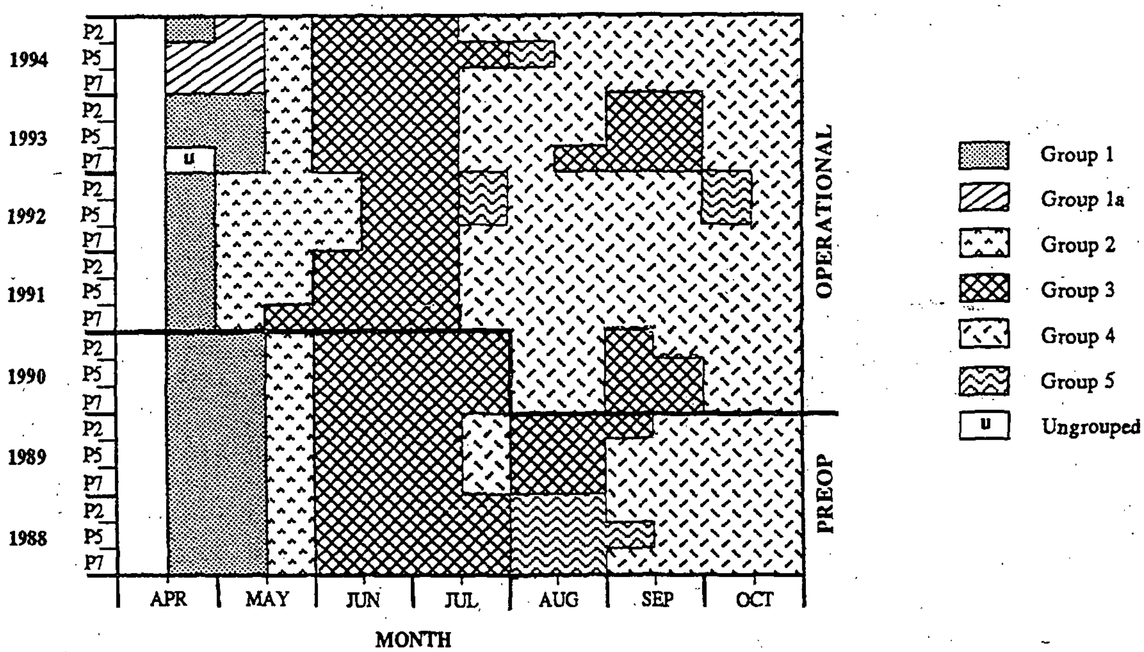


Figure 4-5. Dendrogram and seasonal groups formed by numerical classification of **bivalve larvae** log (x+1) transformed abundances (half monthly means; no./m³) at Seabrook intake (P2), discharge (P5) and farfield (P7) stations, April-October, 1988-1994. Seabrook Operational Report, 1994.

TABLE 4-5. GEOMETRIC MEAN ABUNDANCE (No./m^3), AND THE 95% CONFIDENCE LIMITS OF DOMINANT TAXA AND NUMBER OF COLLECTIONS OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF BIVALVE LARVAE COLLECTIONS AT INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) STATIONS, 1988-1994. SEABROOK OPERATIONAL REPORT, 1994.

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA	PREOPERATIONAL YEARS[b]				OPERATIONAL YEARS[b]			
		N[c]	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1 Early spring (0.64/0.46)	*Hiatella* sp.[d]	18	28	39	55	12	24	50	103
1a Early Spring, 1994 (0.85/0.46)	*Hiatella* sp.[d]	0	--	--	--	5	1511	2694	4805
2 Early spring (0.69/0.58)	*Hiatella* sp.[a]	90	632	1316	2741	20	451	648	933
	Mya truncata[d]		56	112	223		6	10	18
	Solenidae		38	51	69		9	15	25
3 Early Summer/ Fall (0.72/0.65)	*Mytilus edulis*[d]	41	3020	4500	6705	46	3723	5519	8181
	Anomia squamula[d]		297	587	1160		518	885	1512
	Hiatella sp.[d]		234	463	916		430	754	1320
	Modiolus modiolus		153	264	455		44	96	208
	Solenidae		34	55	91		23	48	100
4 Late Summer/ Fall (0.68/0.65)	*Anomia squamula*[d]	24	268	451	758	84	315	387	476
	Modiolus modiolus[d]		100	191	362		16	26	41
	Mytilus edulis[d]		53	103	199		204	283	393
	Spisula solidissima		29	51	92		16	22	29
	Solenidae		23	45	90		6	9	13
5 Fall (0.61/0.54)	*Anomia squamula*[d]	7	13	27	58	6	19	42	89
	Mytilus edulis[d]		10	22	46		5	13	35
	Modiolus modiolus		3	14	51		0	1	1
	Mya arenaria[d]		0	3	10		1	9	40
	Solenidae[d]		0	1	2		0	8	53
Ungrouped (--/0.12)	*Hiatella* sp.[d]	--	--	--	--	1	--	2	--

[a](within-group similarity/between-group similarity)
[b]preoperational = April 1988-July 1990; operational = August 1990-October 1994
[c]N = number of half-monthly means calculated from weekly means (first half-month includes weeks beginning with days 1-15; second half with days 16-31)
[d]those taxa contributing ≥5% of total group abundance in either preoperational or operational period collections

and July (Group 3). In early August a transition to the typical late summer-fall community (Group 4) was observed at Stations P2 and P7. At Station P5, low densities of most taxa were observed in early August (Group 5), which then progressed to the typical fall assemblage (Group 4). Multivariate analysis indicated that operational densities were significantly different from densities in 1988 and 1989 (Wilks' Lambda=0.35, F=47.9, p=0.0001); these differences were not consistent among stations (Preop-Op X Station: Wilks' Lambda=0.88, F=1.59, p=0.04). Four species (*Modiolus modiolus, Spisula solidissima, Mya arenaria*, and *Macoma balthica*) had decreased abundances during the operational period at all three stations. Two taxa, *Hiatella* sp., and *Teredo navalis*, were responsible for the significant Preop-Op X Station interaction (Figure 4-6). Densities of *Hiatella* sp. increased during the operational period; however these increases were greatest at Station P2. Densities of *Teredo navalis*, a relatively uncommon species showed a significant increase at Station P2 during the operational period , and a significant decrease at Stations P5 and P7 (Figure 4-6).

Spatial Patterns

Distribution of bivalve larvae in marine waters was related to several factors: distribution of spawning adults, length of larval existence and local hydrographic conditions. The dominant bivalve larvae collected in coastal waters of New Hampshire were species whose adults were widely distributed along the New England coastline. Duration of larval stage is dependent on temperature, but may be as long as six weeks (Bayne 1965, 1976; Jury et al. 1994). The local hydrography is dominated by tidal and longshore currents (NAI 1980). Stations P2, P5 and P7 are located in waters of similar depth (Figure 4-1) with no physical barriers between them. These conditions tended to create a spatially homogenous bivalve larvae community. It was not unexpected, then, that the species composition was usually similar at each of the three stations (Figure 4-5). During 90% of the sampling periods, assemblages at all three stations were similar, and were grouped together; assemblages at nearfield Stations P2 and P5 were grouped together 95% of the time. In 1994, the assemblage from the earliest samples taken (late April 1994) at Station P2 (nearfield) was not similar to any other group because only extremely low numbers of *Hiatella* sp. were present. By early May 1994, numbers of *Hiatella* sp. increased, making the P2 assemblage similar to that at P5 and P7, the early spring assemblage (Group 1a).

The only other sampling period in 1994 where all three stations were not placed in the same faunal group occurred in early August. Collections from Station P5 (nearfield) were placed in Group 5, the low-density fall assemblage, while collections at Stations P2 (nearfield) and P7 (farfield) were placed in Group 4. By late August, the assemblage at all three stations was similar (Group 4). MANOVA results indicated that two species, *Hiatella* sp. and *Teredo navalis*, showed trends during the operational period that differed among stations (Figure 4-6). However, in both cases the trends at the farfield station were similar to one of the nearfield stations.

4.3.2.2 Selected Species

Mya arenaria was identified as a selected species because of the interest in recreational (locally) and commercial (regionally) harvesting of adults and the concern that impacts to the larval population could decrease the standing stock of harvestable clams (Section 10.0). *Mytilus edulis* has been the most abundant species encountered in bivalve larvae investigations. Temporal and spatial patterns of both species were examined to evaluate whether there was evidence of impacts induced by operation of Seabrook Station.

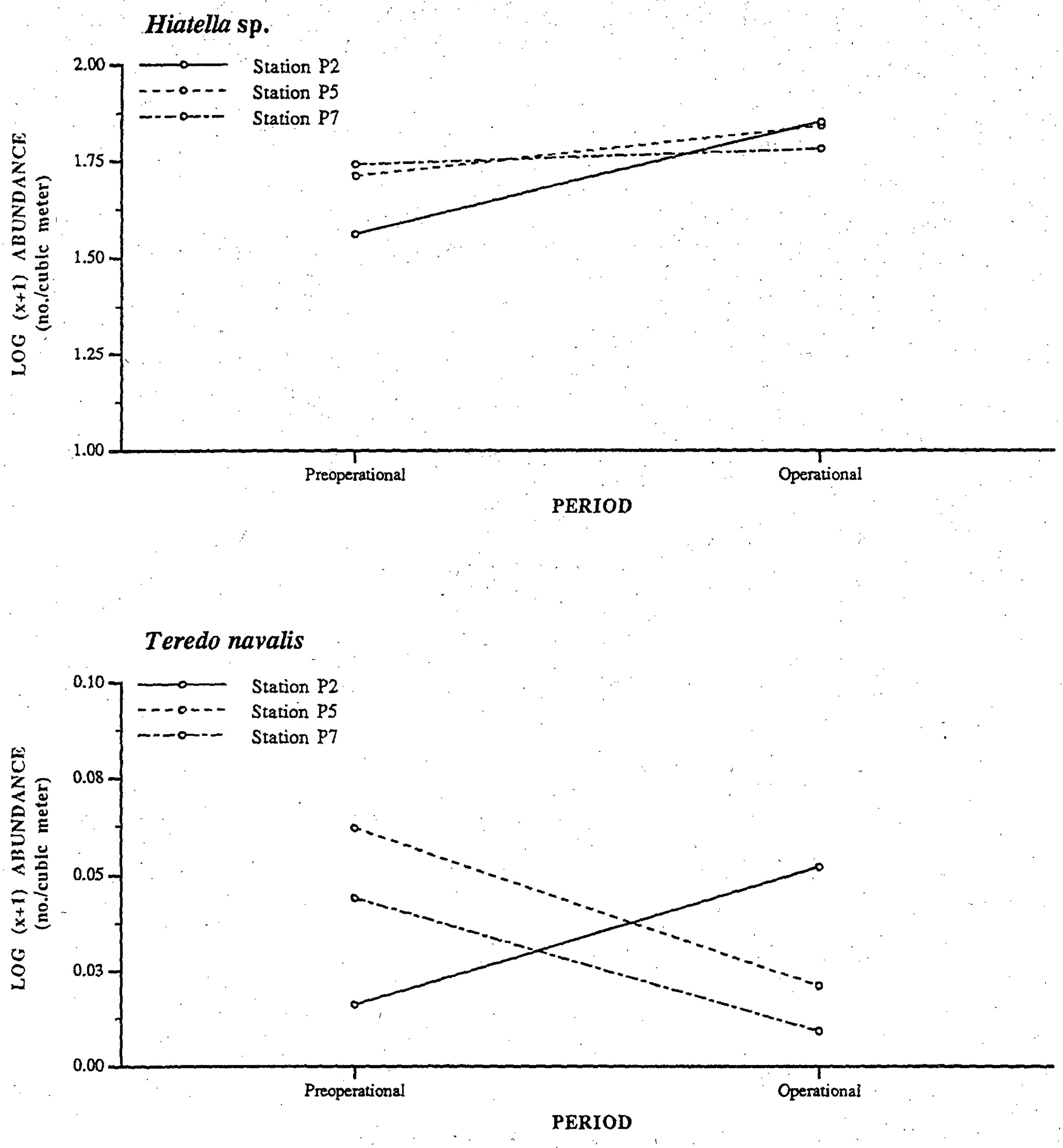


Figure 4-6. A comparison of the mean log (x+1) abundance (number per cubic meter) among Stations P2, P5, and P7 during the preoperational (1988-1989) and operational (1991-1994) periods when the interaction term (Preop-op X Area) of the ANOVA model is significant for a. *Hiatella* sp. and b. *Teredo navalis* (note different scales). Seabrook Operational Report, 1994.

Mya arenaria

This species is discussed in detail in Section 10.0.

Mytilus edulis

Abundances of *Mytilus edulis* peaked in June at Station P2 during the preoperational and operational periods and during 1994. Densities remained relatively abundant through the end of sampling in October (Figure 4-7). Monthly abundances in 1994 increased sharply in mid-June and reached peak abundances in early July, with a secondary peak occurring in late-September/early October. During these times, densities exceeded the upper 95% confidence limits of both the preoperational and operational weekly averages (Figure 4-7).

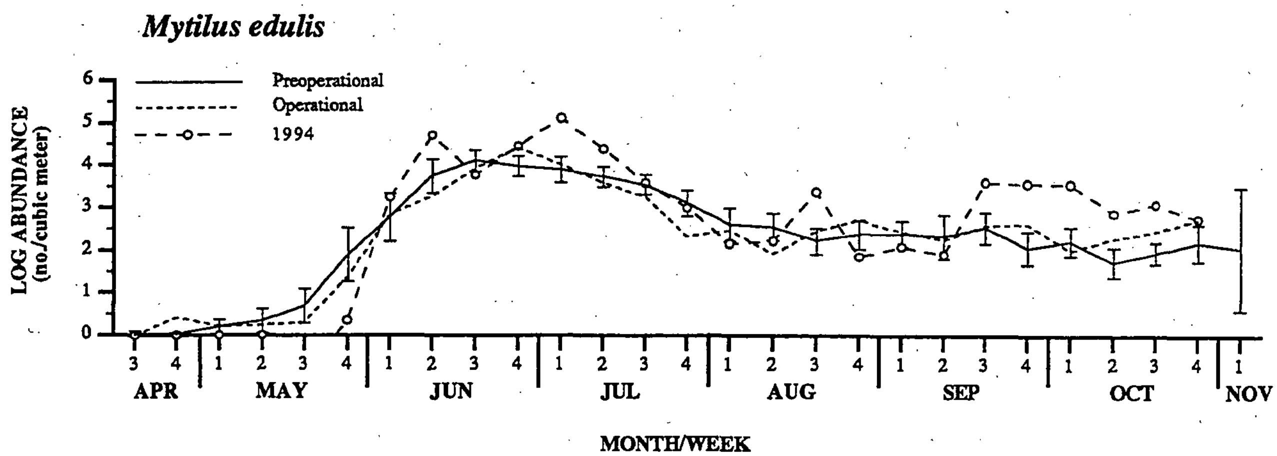


Figure 4-7. Weekly mean log (x+1) abundance (no./m³) of ***Mytilus edulis*** **larvae** at Station P2 during preoperational years (1978-1989, including 95% confidence intervals), and weekly means in the operational period (1991-1994) and in 1994. Seabrook Operational Report, 1994.

The annual abundances at both nearfield and farfield stations during 1994 were at least 50% higher than the operational and preoperational abundances for the second year in a row (Table 4-6, NAI and NUS 1994). Mytilid abundances had been low at all stations in 1992 (NAI 1993b). The average operational abundances at all three stations were not significantly different than recent preoperational (1988-1989) abundances (Table 4-7). Station differences were not significant during the period when collections were made at all three stations, although differences among years and weeks were significant. The interaction term (Preop-Op X Station) was not significant, suggesting that the plant had no effect on the abundance of *Mytilus edulis* larvae.

4.3.2.3 Entrainment

The effects of operation of Seabrook Station on bivalve larvae were monitored primarily through entrainment sampling and secondarily through compar-

TABLE 4-6. GEOMETRIC MEAN ABUNDANCE (No./m^3) WITH COEFFICIENT OF VARIATION (CV) FOR *MYTILUS EDULIS* LARVAE AT STATIONS P2, P5 AND P7 DURING THE PREOPERATIONAL AND OPERATIONAL (1991-1994) YEARS AND THE 1994 MEAN. SEABROOK OPERATIONAL REPORT 1994.

		PREOPERATIONAL		OPERATIONAL		1994
STATION	YEAR	MEAN[a]	CV	MEAN[a]	CV	MEAN
P2	1982-1989	232.4	18.5	193.7	24.2	424.7
P5	1988-1989	184.2	18.0	172.2	20.7	281.4
P7	1982-1984, 1986-1989	250.1	13.2	204.8	23.0	409.8

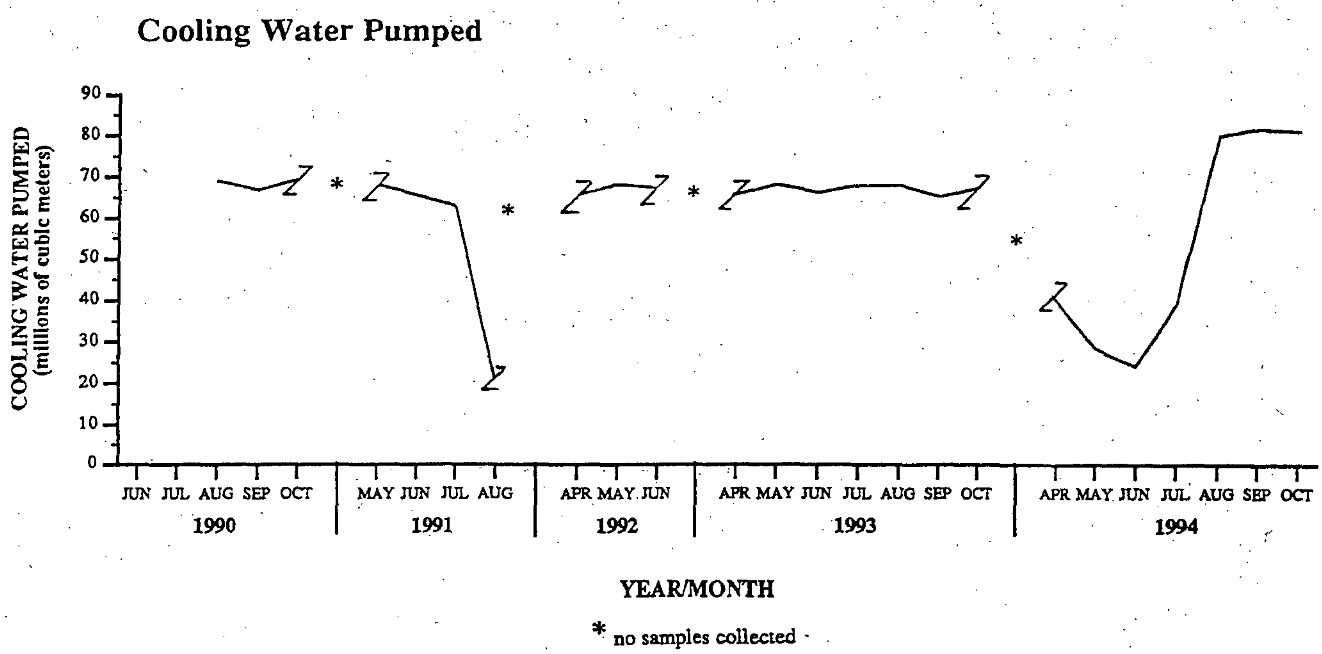
[a]mean of annual means

TABLE 4-7. RESULTS OF ANALYSIS OF VARIANCE COMPARING INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) WEEKLY ABUNDANCES OF MYTILUS EDULIS DURING PREOPERATIONAL (1988-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS
Preop-Op[a]	1	0.62	0.03 NS	
Station	2	0.30	3.21 NS	
Year (Preop-Op)	4	19.69	3.56***	
Week (Preop X Year)	146	5.57	41.83***	
Preop-Op X Station	2	0.093	0.97 NS	
Station X Year (Preop-Op)	8	0.097	0.73 NS	
Error	291	0.13		

NS = Not Significant (P> 0.05)
* = Significant (0.05 ≥ P >0.01)
** = Highly Significant (0.01 ≥ P > 0.001)
*** = Very Highly Significant (P ≤ 0.001)

[a]Preop-Op = preoperational period vs. operational period, regardless of area
Station = nearfield vs. farfield stations
Year (Preop-Op) = year nested within preoperational and operational periods, regardless of area
Week (Year X Preop-Op) = week nested within year
Preop-Op X Area = interaction of main effects
Station X Year (Preop-Op) = interaction of station and year nested within preoperational and operational period.



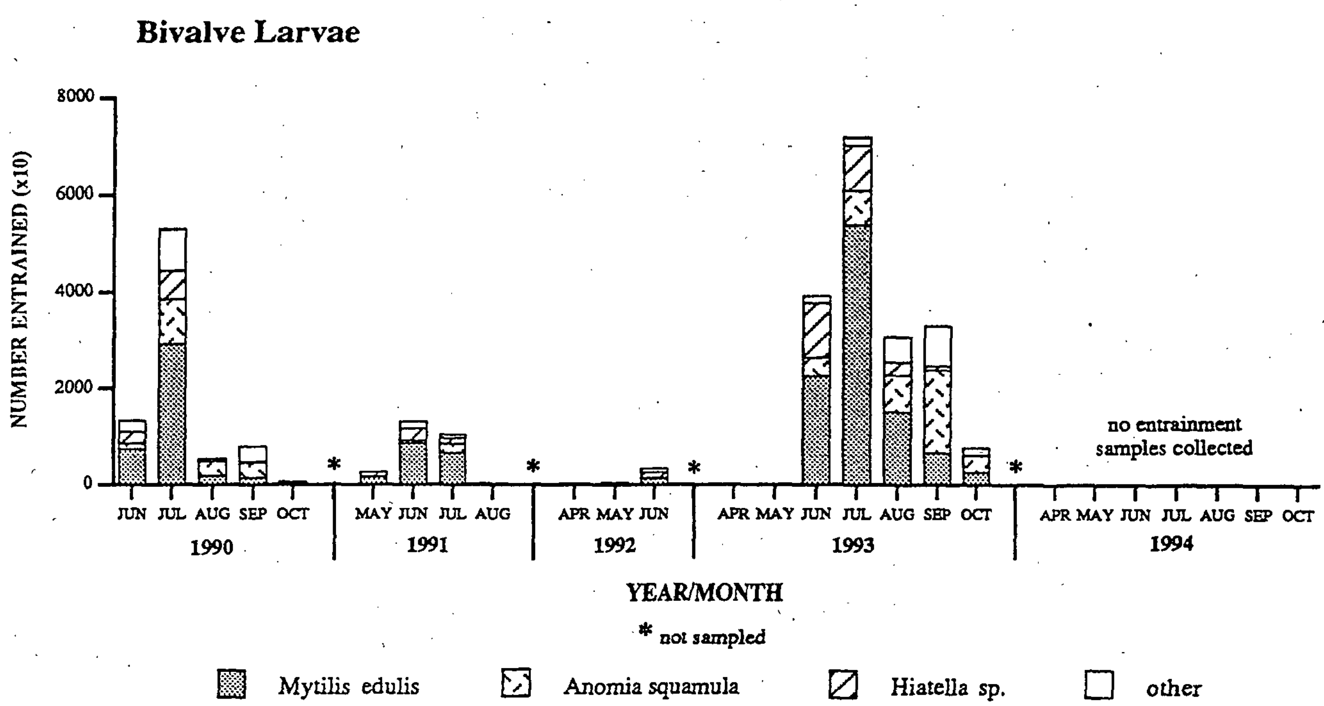


Figure 4-8. Volume of cooling water pumped during the months sampled for **bivalve larvae** and total number of **bivalve larvae** ($x10^9$) entrained by Seabrook Station, 1990-1994. Seabrook Operational Report, 1994.

isons of both community and species abundance characteristics between the preoperational and operational periods. In 1994, no entrainment samples were collected, due to a scheduled plant shutdown and equipment malfunction. Scheduled plant shutdowns occurred from early August through November 1991, in September and October 1992, and from April through August 1994. The total number of bivalve larvae entrained in 1993 was greater than in 1991 and 1992 (Figure 4-8) due to above- average abundances of dominants such as *Mytilus edulis* and *Anomia squamula* in combination with sampling during periods of peak abundance (July-September). In 1993 *Mytilus edulis* accounted for 55% of the total bivalve larvae entrained, while *Anomia squamula* accounted for 22%, *Hiatella* sp. for 13% and *Modiolus modiolus* for 7% (Figure 4-8). Entrainment appeared to be substantially lower in 1991 than during 1990 and 1993 (NAI 1991b), largely as a result of a four-month plant shutdown, which resulted in reduced entrainment of dominants *Mytilus edulis, Hiatella* sp. and *Anomia squamula* (Figure 4-7).

Numbers of larvae entrained reflect the numbers present in the natural environment. In all years, entrainment was highest in June or July, reflecting the natural peak in bivalve larval abundance observed nearshore. For example, *Mytilus edulis* larvae were very abundant in 1993 from late June through the third week of July (NAI and NUS 1994). That period of peak abundance is reflected in the high numbers entrained in July (Figure 4-8). An early fall (September) peak in bivalve larvae entrainment in 1993 was due to high numbers of *Anomia squamula* and other bivalves, primarily *Modiolus modiolus*. *Hiatella* sp., an early spawner, was most abundant in entrainment samples in June and July.

4.3.3 Macrozooplankton

4.3.3.1 Community Structure

Historical analysis (1978-1984 and 1986-1989) of the macrozooplankton assemblage at the nearfield Station P2 showed seasonal changes that were greatly influenced by the population dynamics of the dominant copepods *Centropages typicus* and *Calanus finmarchicus* (NAI 1990). Other taxa, particularly meroplanktonic species, exerted short-term influences, especially during the spring and summer (NAI 1985). Because of their lower abundances, seasonal patterns of tychoplanktonic species, e.g., mysids, amphipods and cumaceans, were not well documented by numerical classification of the entire macrozooplankton assemblage. To identify seasonal patterns more clearly, the tychoplankton assemblage was analyzed separately from the mero- and holoplankton.

The Holo- and Meroplankton Assemblage

The distinct seasonal patterns of the holo- and meroplankton previously observed were again evident when 1994 collections were included in the numerical classification (Figure 4-9, Table 4-8). Groups 1, 6, 7, and 8 occurred for at least one month in every year and together, included 84% of the collections. *Temora longicornis, Sagitta elegans* and *Centropages typicus* dominated periods of low abundance in late fall and early winter (Group 1). *Pseudocalanus* sp., *Tortanus discaudatus* and Larvacea (formerly referred to as *Oikopleura* sp.) were co-dominant at this time. A few of the cooler winter months (Group 2) in 1993 and 1994 were dominated by *Temora longicornis, Sagitta elegans* and *Tortanus discaudatus*. *Temora longicornis* and *Sagitta elegans* dominated February collections in 1990 (Group 3). Late winter and early spring (Group 4) collections were dominated by Cirripedia. *Calanus finmarchicus* and Larvacea were also abundant in late winter and early spring. *C. finmarchicus* with Cirripedia dominated March and April samples in 1989 (Group

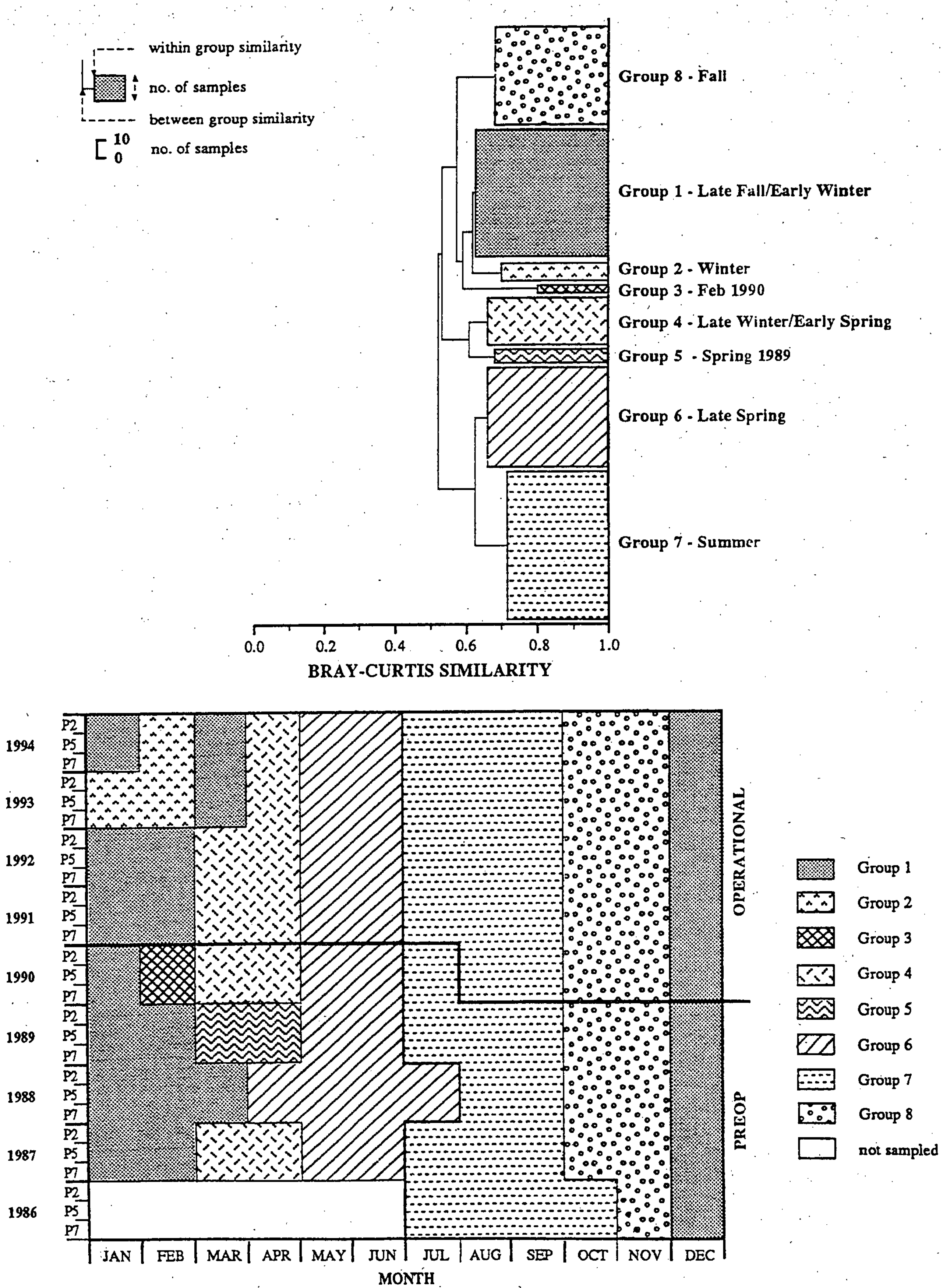


Figure 4-9. Dendrogram and seasonal groups formed by numerical classification of mean monthly log (x+1) transformed abundances (no./1000 m^3) of **holo- and meroplanktonic species** of macrozooplankton at intake Station P2, discharge Station P5 and farfield Station P7, 1986-1994. Seabrook Operational Report, 1994.

TABLE 4-8. GEOMETRIC MEAN ABUNDANCE (No./1000m^3) AND 95% CONFIDENCE LIMITS OF DOMINANT HOLO- AND MEROPLANKTONIC TAXA OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF MACROZOOPLANKTON COLLECTIONS (MONTHLY MEANS) AT INTAKE STATION P2, DISCHARGE STATION P5 AND FARFIELD STATION P7, 1986-1994. SEABROOK OPERATIONAL REPORT, 1994.

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1 Late Fall/Early Winter (0.64/0.63)	*Temora longicornis*	36	1932	2884	4304	36	871	1515	2634
	Sagitta elegans		873	1322	2003		668	918	1261
	Centropages typicus		565	1206	2573		1200	2271	4296
	Pseudocalanus sp.		401	701	1222		201	351	613
	Tortanus discaudatus		216	495	1131		440	836	1588
	Larvacea		73	164	367		238	474	942
2 Winter (0.70/0.63)	*Temora longicornis*	-- not represented --				9	693	2391	8245
	Sagitta elegans						1645	2331	3303
	Tortanus discaudatus						1030	2035	4018
3 Feb 1990 (0.81/0.60)	*Temora longicornis*	3	3226	28662	254624	-- not represented --			
	Sagitta elegans		6896	20601	61540				
4 Late Winter/Early Spring (0.67/0.58)	Cirripedia	12	20260	51170	129237	18	73254	181714	450762
	Calanus finmarchicus		4761	16060	54165		2887	11420	45173
	Larvacea		1906	4562	10912		7898	14485	26568
5 Spring 1989 (0.68/0.58)	*Calanus finmarchicus*	6	4390	7900	14217	-- not represented --			
	Cirripedia		893	3550	14100				

(continued)

TABLE 4-8. (Continued)

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
6	*Calanus finmarchicus*	30	42197	57527	78424	24	65756	109869	183574
Late Spring	*Eualus pusiolus*		3386	4844	6932		1622	2287	3225
(0.67/0.62)	*Evadne* sp.		2358	4491	8552		11285	18565	30540
7	*Centropages typicus*	39	17875	37103	77012	42	37598	66807	118708
Summer	*Calanus finmarchicus*		20821	36214	62988		8864	18999	40721
(0.72/0.62)	*Cancer* sp.		14019	24401	42471		27137	38298	54047
	Eualus pusiolus		3421	6602	12741		3683	6058	9964
	Temora longicornis		1210	2695	5997		6937	11109	17789
8	*Centropages typicus*	21	29419	52173	92524	30	30735	57541	107724
Fall	*Centropages hamatus*		2307	4594	9147		102	276	746
(0.68/0.59)	*Centropages* sp. copepodite		2409	4337	7810		645	1447	32442

[a](within-group similarity/between group similarity)
[b]those taxa contributing ≥5% of total group abundance in either preoperational or operational periods
[c]preoperational period = January 1986-July 1990; operational period = August 1990-December 1994

5). Late spring (Group 6) collections were dominated by *C. finmarchicus*, whose abundance was an order of magnitude greater than the co-dominants *Evadne* sp. and *Eualus pusiolus*. Summer (Group 7) collections were dominated by *Centropages typicus, C. finmarchicus*, and *Cancer* sp. *E. pusiolus* and *T. longicornis* were also abundant in summer. Most meroplanktonic species (e.g., *Carcinus maenas*, Sec. 4.3.3.2), though not dominant, reached their peak abundances during summer months. *C. typicus*, *Centropages hamatus*, and *Centropages* sp. copepodites were dominant in fall (Group 8).

The seasonal shift in dominance among Cirripedia, *Calanus finmarchicus* and *Centropages typicus* observed in 1987 through 1994 was consistent with patterns observed historically (NAI 1990). The seasonal shifts in dominance observed among the copepods *C. finmarchicus, C. typicus* and to a lesser extent, *Pseudocalanus* sp. were consistent with other observations for the Gulf of Maine (Sherman et al. 1988).

Species composition of holo- and meroplankton during the operation of Seabrook Station was generally similar to the preoperational period examined. However, January and February 1993 and February 1994 assemblages were atypical (Figure 4-9). The fall dominant *Centropages typicus* typically declined in abundance each December, but remained a dominant in the low abundance winter assemblage. However, *C. typicus* virtually disappeared in January and February 1993 (NAI 1994) and February 1994 (NAI 1995) at all three stations. These winter samples were dominated by *Temora longicornis, Sagitta elegans*, and *Tortanus discaudatus*, which normally were co-dominant during this time. A slightly delayed Cirripedia peak combined with low copepod abundances and sustained high abundance of *S. elegans* extended the winter community (Group 1) into March 1993 (NAI 1994) and 1994 (NAI 1995). The delay of the spring Cirripedia and *Calanus finmarchicus* peaks, the low abundance of *C. typicus*, and the longevity of the winter group may have been the result of the lower than normal water temperatures during the winters of 1993 and 1994 (Section 2.3.1). A similar reduction in the abundance of *C. typicus* was observed during the cold winter months of 1978 and 1979 in earlier preoperational sampling (NAI 1984b).

Although community composition was generally similar between operational and preoperational periods, geometric mean abundances were generally higher in the operational years than in the preoperational period of 1987-1989, as indicated by a significantly different operational status (p=0.0001) when tested by MANOVA. Of the 50 taxa included in the MANOVA, 8 exhibited significantly higher abundance in the operational period (individual species differences determined by ANOVA). No taxa were lower in abundance. Cirripedia, one of the 13 taxa that dominated the holo- and meroplankton during various parts of the annual cycle, reached higher abundances in the operational period than in the recent preoperational period (1987-1989). Although differences in the operational and preoperational periods were detected, a similar shift was detected at all stations (MANOVA testing Preop-Op X Station, p=0.96) indicating a broadscale trend. Increases of holo- and meroplankton in the operational period could be attributed to a number of environmental factors such as changes in temperature, reduced abundances of ichthyoplankton predators and recruitment of macrozooplankton from other areas (Meise-Munns et al 1990; Kane 1993). Small but significant broadscale increases in temperature have been detected in the bottom waters during the operational period (Section 2.3.1). The abundance of Atlantic herring ichthyoplankton, which feed on macrozooplankton, has declined in the operational period (Section 5.3.1). Copepod abundance in the Gulf of Maine has been increasing (Jossi and Goulet 1993) and New Hampshire coastal waters may be experiencing some of this increase. *Calanus finmarchicus* was reported to have exhibited an increasing trend in the Northwest Atlantic over the past 30 years (Sherman 1991). Jossi (1991) reported that total copepod abundances in the Gulf of Maine were higher in 1990 than in the previous decade.

Previous analyses have suggested that there are no spatial differences in holo- and meroplanktonic assemblages in the study area (NAI 1991b).

Numerical classification of holo- and meroplanktonic abundances from 1986-1994 revealed no spatial differences in community composition among Stations P2, P5 and P7 (Figure 4-9). Collections from all stations were grouped together within each month. Although species composition was similar among stations, differences in species abundances were detected by MANOVA (p=0.0001). Abundances at Station P5 were slightly higher than at Stations P2 and P7. Only six of 50 taxa exhibited significant station differences when tested by ANOVA, including the seasonal dominants *Evadne* sp. and *Eualus pusiolus*. Differences could be related to spatial differences in water quality parameters. Significant station differences in surface and bottom temperature were detected and annual mean temperatures have been higher at Station P5 (Section 2.3.1).

The Tychoplankton Assemblage

Seasonal variation in the tychoplankton species composition was influenced mostly by variations in abundance of the nearly omnipresent dominant taxa *Neomysis americana*, Oedicerotidae and *Pontogeneia inermis* and by the presence of the seasonal dominant *Mysis mixta* (Figure 4-10; Table 4-9). Three seasonal groups (Groups 7, 8 and 9) encompassed 78% of the collections of the tychoplankton (91% of P2 and P5 collections). Oedicerotidae and *Pontogeneia inermis* dominated summer collections (Group 7), particularly in the nearfield area. High abundances of *N. americana* dominated the fall and early winter collections (Group 8). *M. mixta* replaced *N. americana* as the overwhelming dominant in late winter and early spring (Group 9). The offshore migration of *M. mixta* juveniles, which has been linked to surface water temperatures approaching 12°C and the onset of thermal stratification (Grabe and Hatch 1982) occurred in May and June. Two other infrequently occurring communities occurred at all stations. Summer (Group 6) collections were represented by moderate abundances of amphipods (*P. inermis* preoperationally and Oedicerotidae during the operational period) and Harpacticoids. The other in late spring, (Group 10), was characterized by moderate numbers of *P. inermis*, *Ischyrocerus anguipes* and *N. americana*. Episodes of low tychoplankton abundance at Station P7 resulted in the formation of several small groups (Groups 1, 2 and 3) represented by reduced abundances of amphipods, *N. americana*, Harpacticoids and *Diastylis* sp. Moderate abundances of *N. americana* and reduced abundances of amphipods and the cumacean *Diastylis* sp. formed a fall group composed almost entirely of Station P7 (Group 4) collections which was concurrent with the dominance by *N. americana* at the nearfield stations. A fall and winter community (Group 5) dominated by Oedicerotidae and *N. americana* appeared infrequently at Stations P5 and P7.

Seasonal patterns of the tychoplankton assemblage were generally similar between during preoperational and operational periods (Figure 4-10). However, the amphipod dominated community (Group 7) failed to appear in the summer of 1994 at the nearfield stations due to higher than normal abundances of *Neomysis americana* (Section 4.3.3.2), typical of Group 8. Most tychoplanktonic taxa in the nearfield area are ubiquitous, so changes in groups are generally a function of relative abundances. Despite considerable interannual variation in succession of seasonal groups at Station P7, the appearance of seasonal groups in the operational period has generally coincided (within one month) seasonally with the appearance of groups in the preoperational period. MANOVA results indicated that differences in abundance between preoperational (1987-1989) and operational (1991-1994) periods existed (p=0.0001), with abundances higher during operational years than in recent preoperational years. This shift occurred in

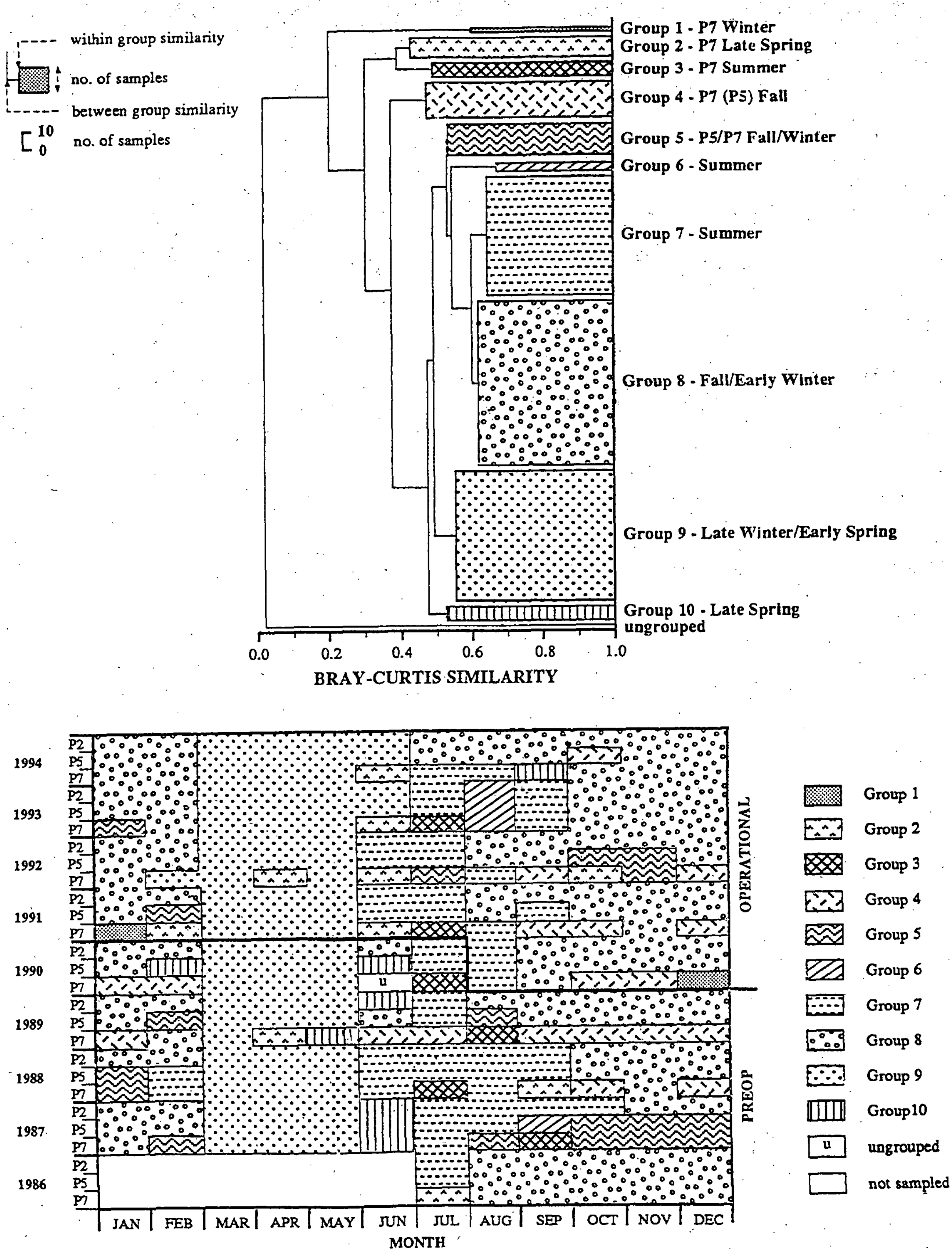


Figure 4-10. Dendogram and seasonal groups formed by numerical classification of mean monthly log (x+1) transformed abundances (no./1000 m^3) of **tychoplanktonic species** of macrozooplankton at intake Station P2, discharge Station P5 and farfield Station P7, 1986-1994. Seabrook Operational Report, 1994.

TABLE 4-9. GEOMETRIC MEAN ABUNDANCE (No./1000m^3) AND 95% CONFIDENCE LIMITS OF DOMINANT TYCHOPLANKTONIC TAXA OCCURRING IN SEASONAL GROUPS FORMED BY NUMERICAL CLASSIFICATION OF MACROZOOPLANKTON COLLECTIONS (MONTHLY MEANS) AT INTAKE STATION P2, DISCHARGE STATION P5 AND FARFIELD STATION P7, 1986-1994. SEABROOK OPERATIONAL REPORT, 1994.

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1	*Diastylis* sp.					2	0	2	110
P7 Winter	*Erythrops erythrophthalma*	-- not represented --					1	2	4
(0.61/0.24)	Oedicerotidae						1	1	1
	Neomysis americana						0	1	14
2	*Pontogeneia inermis*	3	0	4	19	7	1	2	5
P7 Late Spring	Harpacticoida		0	3	18		1	3	9
(0.43/0.39)	*Neomysis americana*		0	2	29		2	3	5
	Diastylis sp.		0	0	7		0	1	5
	Ischyrocerus anguipes		0	0	7		0	1	2
3	Oedicerotidae	4	0	8	73	2	0	23	1.0x10^9
P7 Summer	Harpacticoida		2	7	18		0	6	1961
(0.50/0.39)	*Pontogeneia inermis*		0	2	13		0	1	620
4	*Neomysis americana*	11	31	87	242	8	30	81	215
P7(P5) Fall									
(0.48/0.40)									
5	Oedicerotidae	12	15	40	103	6	2	16	101
P5/P7 Fall/Winter	*Neomysis americana*		9	14	21		6	17	47
(0.54/0.54)	*Pontogeneia inermis*		3	6	12		2	5	12
	Diastylis sp.		2	4	7		0	3	12
	Harpacticoida		1	3	7		4	11	28
6	*Pontogeneia inermis*	3	--	163	--	3	6	8	10
Summer	Harpacticoida		--	97	--		40	101	254
(0.68/0.55)	Oedicerotidae		--	5	--		69	142	291
	Diastylis sp.		--	14	--		0	38	1360

(continued)

TABLE 4-9. (Continued)

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
7	Oedicerotidae	25	104	258	634	21	55	185	611
Summer	*Pontogeneia inermis*		49	77	120		31	58	110
(0.64/0.60)	*Neomysis americana*		23	50	108		33	59	107
	Harpacticoida		25	43	72		43	78	141
8	*Neomysis americana*	49	453	852	1599	69	183	254	352
Fall/Early Winter	*Diastylis* sp.		35	54	82		34	48	69
(0.62/0.60)	*Pontogeneia inermis*		26	41	63		33	49	73
	Oedicerotidae		20	31	48		25	35	50
	Harpacticoida		3	5	8		15	22	33
9	*Mysis mixta*	34	172	435	1099	40	168	345	709
Late Winter/Early	*Neomysis americana*		17	37	79		14	25	44
Spring	*Pontogeneia inermis*		14	23	38		27	45	75
(0.56/0.50)									
10	*Neomysis americana*	7	17	61	221	1	--	31	--
Late Spring	*Pontogeneia inermis*		4	36	272		--	64	--
(0.54/0.49)	*Ischyrocerus anguipes*		3	11	34		--	0	--

[a](within-group similarity/between group similarity)
[b]those taxa contributing ≥5% of total group abundance in either preoperational or operational periods
[c]preoperational period = January 1986-July 1990; operational period = August 1990-December 1994

both nearfield and farfield stations (Figure 4-10; Preop-Op X Station, p=0.36), indicating a broadscale trend.

Differences between the nearfield and farfield areas in tychoplankton assemblages from 1987 through 1994 were apparent from numerical classification. Collections from Stations P2 and P5 were usually grouped together (84% of collections, Figure 4-10). The assemblage at Station P7 was distinct from either of the two nearfield stations in 47% of the collections. Despite the differences at Station P7, farfield communities parallelled the nearfield progression of dominant taxa from *Neomysis americana* in the fall and winter (Group 4) to *Mysis mixta* in the spring (Group 9) to the amphipods in summer (Groups 2,3). The greatest similarity between nearfield and farfield stations occurred during the *Mysis mixta* peak in March, April, and May, and again in November during the *N. americana* peak (Figure 4-10). Although Station P7 generally exhibited similar seasonal patterns to Stations P2 and P5, abundances of dominant taxa, particularly *Pontogeneia inermis*, Oedicerotidae, and *Diastylis* sp. were lower, resulting in the formation of four groups (1,2,3 and 4) composed almost entirely of farfield collections. Results of numerical classification were substantiated by MANOVA, which indicated that there were significant differences among stations in species composition (p=0.0001). Tychoplanktonic species are often strongly associated with particular substrate types. Substrate type and complexity, along with proximity to Hampton-Seabrook estuary, may account for some of the differences observed among tychoplankters. *Neomysis americana, Pontogeneia inermis,* and Oedicerotidae have higher abundances in the heterogeneous sand and rock ledge substrate in the nearfield area than at Station P7, where the substrate is mainly sand.

4.3.3.2 Selected Species

Calanus finmarchicus

Average monthly *Calanus finmarchicus* copepodite abundances at Station P2 have historically exhibited a broad spring through summer peak (Figure 4-11). Operational abundances followed a similar pattern, although abundances were lower in February and March. Abundances in 1994 showed the same monthly pattern as previous years.

The geometric mean annual abundance of copepodites at the nearfield stations have historically been about double that at Station P7. Similar ratios were seen in the operational period and in 1994. Increased abundances in the nearfield area could be due to the proximity to the Hampton Estuary. Slight decreases in abundances were seen in 1994 (Table 4-10). No differences of abundance were detected between the recent preoperational (1987-1989) and operational periods or among stations (Table 4-11). The interaction term (Preop x Station) was not significant indicating no effect from operation of Seabrook Station on populations of *Calanus finmarchicus* copepodites.

The monthly mean abundance of *Calanus finmarchicus* adults during all preoperational years showed a peak period occurring in winter and a larger peak occurring June through September (Figure 4-11). Peak abundances during the operational period were slightly delayed, occurring March through April and July through September. Abundances in 1994 followed preoperational trends except for June and July when adult *Calanus finmarchicus* were absent and again in December when abundances were much greater than pre-vious years (Figure 4-11).

Annual geometric mean abundances of adult *Calanus finmarchicus* (Table 4-10) were similar among stations in the preoperational period (all years). During the operational period, abundance was lower at Station P7 than at the other stations. Although there were no

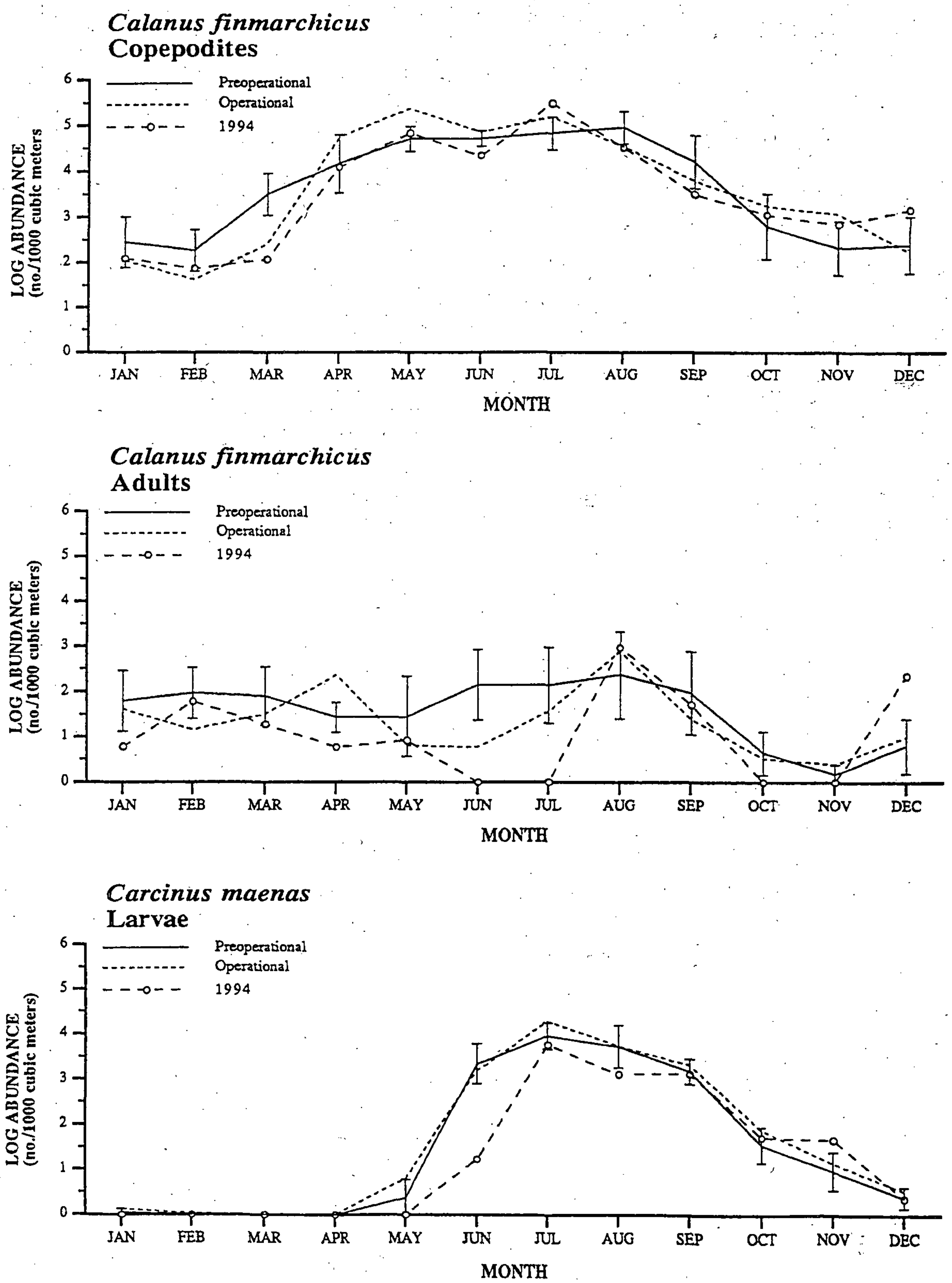


Figure 4-11. Log (x+1) abundance (no./1000 m³) of *Calanus finmarchicus* copepodites and adults and *Carcinus maenas* larvae; monthly means and 95% confidence intervals over all preoperational years (1978-1984, 1986-1989) and monthly means for the operational period (1991-1994) and 1994 at intake Station P2. Seabrook Operational Report, 1994.

TABLE 4-10. GEOMETRIC MEAN ABUNDANCE (No./1000 m^3) AND COEFFICIENT OF VARIATION OF SELECTED MACROZOOPLANKTON SPECIES AT STATIONS P2, P5, AND P7 DURING PREOPERATIONAL AND OPERATIONAL YEARS (1991-1994), AND 1994. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL		OPERATIONAL		1994
SPECIES/LIFESTAGE (peak period)	STATION	MEAN[a]	CV	MEAN[b]	CV	MEAN
Calanus finmarchicus	P2	4,153	6.39	3,984	3.53	3,116
copepodites	P5	5,713	6.99	5,131	3.18	3,936
(January-December)	P7	2,594	7.19	2,416	4.96	1,535
Calanus finmarchicus	P2	36	26.52	20	15.88	10
adults	P5	26	28.88	26	19.57	10
(January-December)	P7	29	28.96	11	23.25	4
Carcinus maenas	P2	3,509	6.73	4,256	15.55	631
larvae	P5	3,615	12.92	5,065	12.93	1,051
(June-September)	P7	4,251	6.24	3,118	11.93	973
Crangon septemspinosa	P2	257	3.66	223	8.47	126
zoeae and postlarvae	P5	233	6.72	195	11.84	78
(January-December)	P7	161	10.42	90	9.90	49
Neomysis americana	P2	151	18.94	179	8.57	285
all lifestages	P5	45	30.73	54	13.45	100
(January-December)	P7	43	22.03	22	19.12	50

[a]Years sampled:
Preoperational: P2 = 1978-1984, 1987-1989
P5 = 1987-1989
P7 = 1982-1984, 1987-1989
Mean of annual means

[b]Mean of annual means, 1991-1994

significant differences in mean abundance between the preoperational and operational periods, or among stations, the interaction term (Preop-Op X Station) was significant, indicating a potential plant effect (Table 4-11). Mean abundance at Station P7 decreased in the operational period while mean abundance increased at Stations P2 and P5 (Figure 4-12). However, trends in the annual mean log (x+1) abundances by year shows that the rank order and direction of change of abundance was consistent for each station each year, regardless of operational status (Figure 4-13). This pattern of similar changes each year among stations is not consistent with the pattern that would be expected if the plant was affecting mean abundance. The significant interaction term is probably a result of the accumulation of yearly small differences in mean abundance between the stations and should be monitored closely in future years.

Carcinus maenas

Green crab, *Carcinus maenas* larvae (zoea and megalopa) during the preoperational years first appeared in May, with peak abundances occurring from June through September, then steadily declining until the larvae disappear from collections in February (Figure 4-11). Operational monthly mean abundances of green crab larvae were almost identical to preoperational abundances. The first occurrence of larvae and the onset of the peak abundances in 1994 were delayed one month. Colder than normal surface and bottom temperatures in January through April 1994 (Section 2.3.1) may have contributed to this delay.

Peak period mean abundances during all preoperational years were similar at all stations. Peak period abundances increased slightly from the preoperational to the operational period at the nearfield stations and declined slightly at Station P7 (Table 4-10). Abundances in 1994 at all stations were a fraction of preoperational abundances due to the exceptionally low abundances in June (Table 4-10; Figure 4-11). Differences in abundance among stations and between the operational and preoperational periods were not significant when tested by ANOVA (Table 4-11). The interaction term (Preop x Station) was not significant indicating no effect due to operation of Seabrook Station on the larvae of *Carcinus maenas.*

Crangon septemspinosa

Peak mean abundance of the zoea and post larvae of the sand shrimp *Crangon septemspinosa* during all preoperational years occurred from June through September (Figure 4-14). Abundances steadily decreased to a low in February. Operational mean abundances were similar to the preoperational period, although September abundances were lower. Abundances in 1994 have followed the operational period pattern except for very low abundances during the winter months when lower than normal temperatures (Section 2.3.1) may have had an effect.

Annual geometric means of *Crangon septemspinosa* larvae have been slightly higher at the nearfield stations than at Station P7 (Table 4-10). The differences in abundance between the nearfield and farfield sites was significant (Table 4-11). Mean annual abundance in 1994 was considerably lower than in both preoperational and operational periods, apparently due to very low winter abundances. The annual geometric mean abundances showed no significant differences during the operational period. Differences in abundance among stations have been consistent between operational status periods (Table 4-11) indicating a broadscale trend and there is no indication of any effect due to operation of Seabrook Station on larval populations of *Crangon septemspinosa.*

Neomysis americana

Monthly geometric mean abundances of *Neomysis americana* (all lifestages combined) during the

TABLE 4-11. RESULTS OF ANALYSIS OF VARIANCE COMPARING ABUNDANCES OF SELECTED MACROZOOPLANKTON SPECIES FROM STATIONS P2, P5, AND P7 DURING PREOPERATIONAL (1987-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES[a]	SOURCE[b]	d.f.	MS	F	MULTIPLE COMPARISONS[i]
Calanus finmarchicus copepodites (January-December)	Preop-Op[c]	1	2.32	1.46NS	
	Year (Preop-Op)[d]	5	1.50	0.14NS	
	Month (Year)[e]	77	11.10	19.14***	
	Station[f]	2	3.00	15.31NS	
	Preop-Op X Station[g]	2	0.19	1.82NS	
	Station X Year (Preop-Op)[h]	10	0.11	0.18NS	
	Error	403	0.58		
Calanus finmarchicus adults (January-December)	Preop-Op	1	0.09	0.02NS	
	Year (Preop-Op)	5	5.43	0.97NS	
	Month (Year)	77	6.47	7.34***	
	Station	2	3.37	10.19NS	
	Preop-Op X Station	2	0.33	6.15*	P5Op P5Pr P2Op P2Pr P7Pr P7Op
	Station X Year (Preop-Op)	10	0.05	0.06NS	
	Error	403	0.86		
Carcinus maenas larvae (June-September)	Preop-Op	1	0.03	0.01NS	
	Year (Preop-Op)	5	3.38	1.44NS	
	Month (Year)	21	2.64	3.69***	
	Station	2	0.36	2.83NS	
	Preop-Op X Station	2	0.13	0.31NS	
	Station X Year (Preop-Op)	10	0.42	0.59NS	
	Error	126	0.72		
Crangon septemspinosa zoeae and post larvae (January-December)	Preop-Op	1	0.66	0.32NS	
	Year (Preop-Op)	5	2.20	0.25NS	
	Month (Year)	88	8.99	29.21***	
	Station	2	5.66	28.66*	P2 P5 > P7
	Preop-Op X Station	2	0.20	0.60NS	
	Station X Year (Preop-Op)	10	0.33	1.07NS	
	Error	403	0.31		
Neomysis americana all lifestages (January-December)	Preop-Op	1	0.34	0.05NS	
	Year (Preop-Op)	5	7.81	3.14*	
	Month (Year)	77	2.70	4.70***	
	Station	2	34.36	18433.00NS	
	Preop-Op X Station	2	0.01	0.01NS	
	Station X Year (Preop-Op)	10	0.37	0.65NS	
	Error	403	0.57		

[a]Based on twice monthly sampling periods. [b]Commercial operation began in August 1990; 1990 data left out of analysis to keep a balanced design in the ANOVA procedure. [c]Preoperational (1987-1989) versus operational (1991-1994) periods, regardless of station; 1987-1989 reflects the period of time that all three stations were sampled coincidentally. [d]Year nested within preoperational and operational periods, regardless of station. [e]Month nested within year, regardless of station. [f]Station P2 vs. station P5 vs. station P7, regardless of year. [g]Interaction between main effects. [h]Interaction of station and year nested within preoperational and operational period.

NS = Not significant ($p > 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

[i]Ranked in decreasing order. Underlines indicate no significant difference in least-squares means ($\alpha \leq .05$).

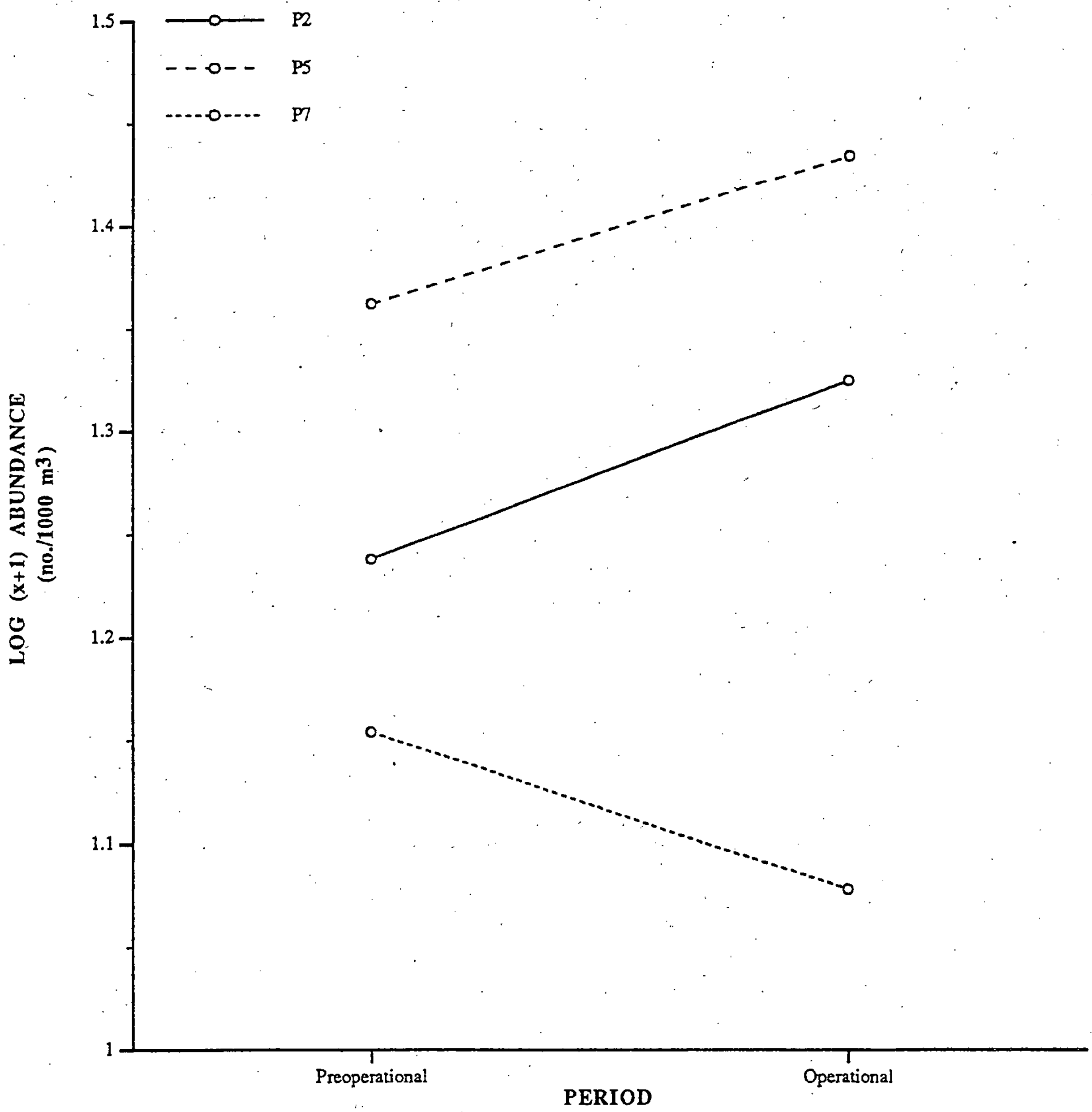


Figure 4-12. A comparison among stations of the mean log (x+1) abundance (no./1000 m³) of *Calanus finmarchicus* adults during preoperational (1987-1989) and operational (1991-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model. Seabrook Operational Report, 1994.

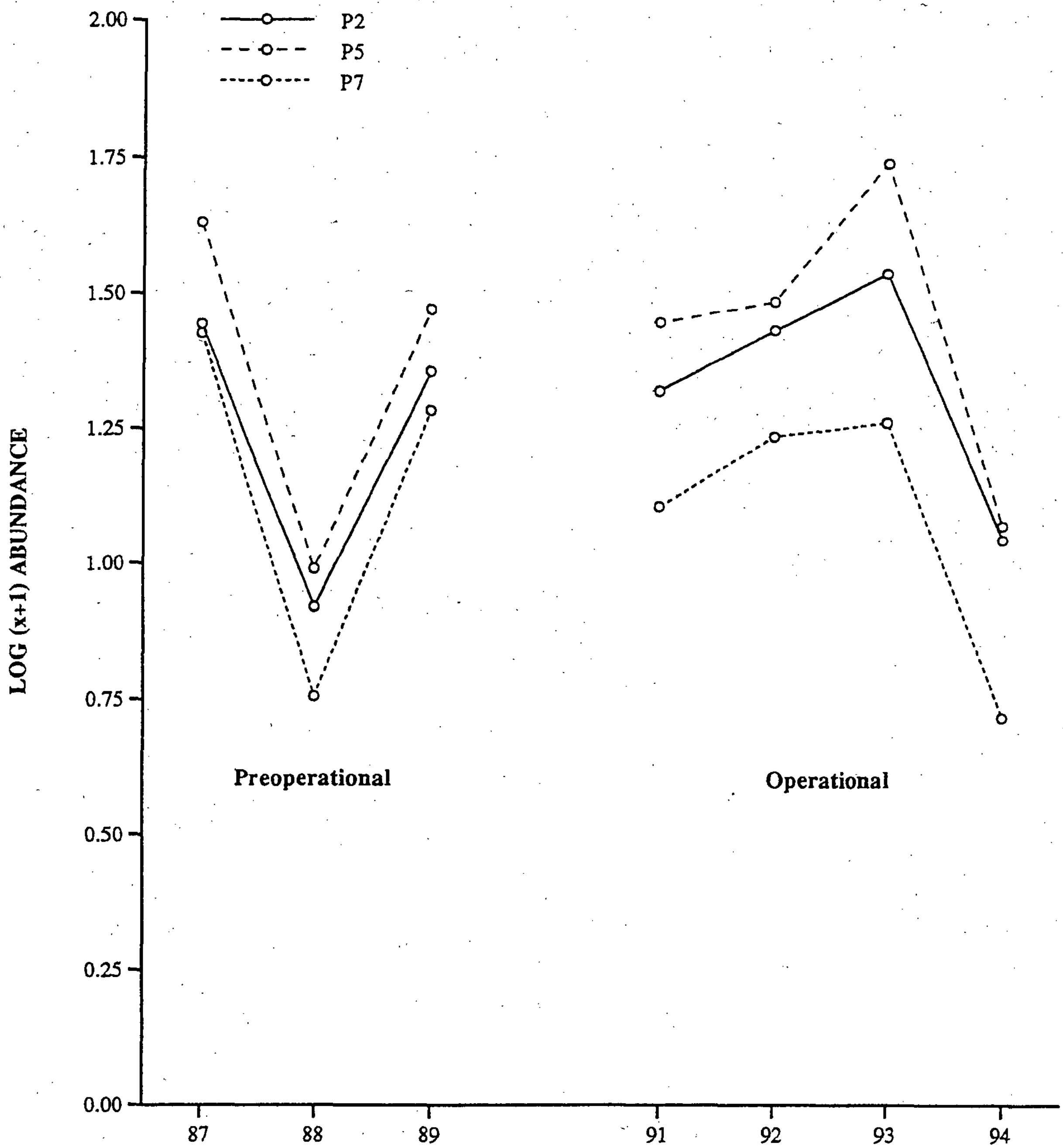
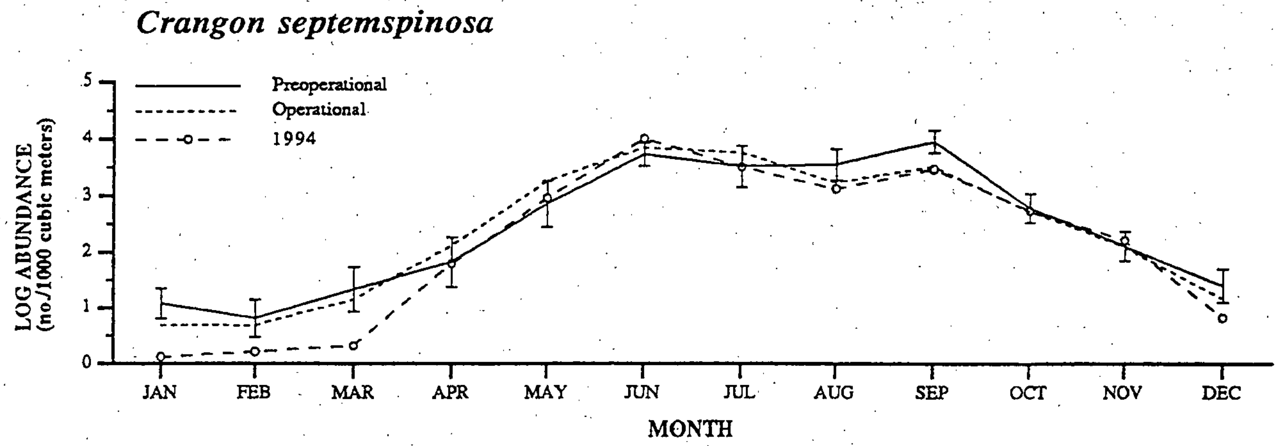
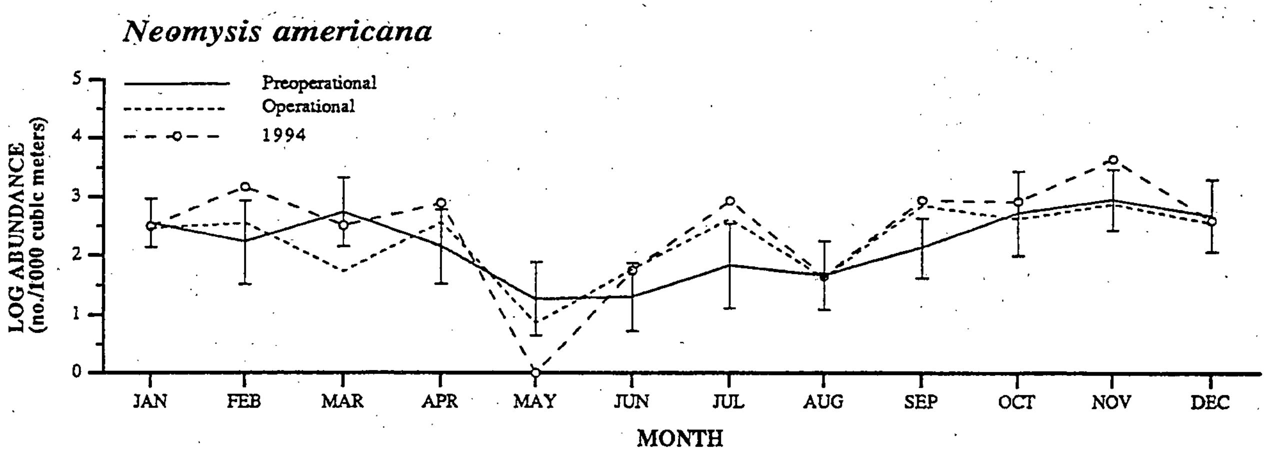


Figure 4-13. Annual mean log (x+1) abundance of *Calanus finmarchicus* adults by station for the recent preoperational (1987-89) and operational periods. Seabrook Operational Report, 1994.





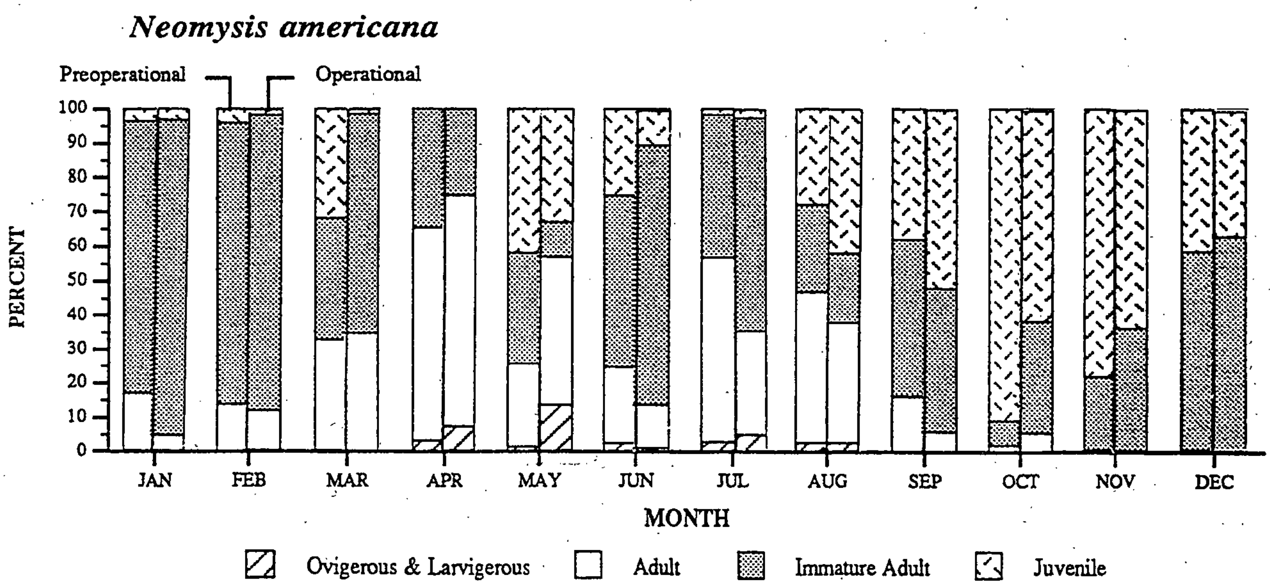


Figure 4-14. Log (x+1) abundance (no./1000 m^3) of *Crangon septemspinosa* (zoea and post larvae) and *Neomysis americana* (all lifestages); monthly means and 95% confidence intervals over all preoperational years (1978-1984, 1986-1989) and monthly means for the operational period (1991-1994) and 1994; and mean percent composition of *Neomysis americana* lifestages over all preoperational years (1978-1984, 1986-1989) and for the operational period (1991-1994) at intake Station P2. Seabrook Operational Report, 1994.

preoperational period were lowest in May and June. Abundances generally increased through the summer to a broad peak lasting through fall and winter (Figure 4-14). Monthly abundances in the operational period show an additional peak, dominated by immature mysids, occurring in mid-summer and reduced abundances in March. Abundances in 1994 followed the operational pattern. The 1994 monthly mean abundance was considerably lower than the preoperational confidence interval in May. Abundances exceeded the confidence interval in February, April, July, September and November.

The average annual abundance in 1994 was somewhat higher than in previous years (Table 4-10). There were no significant differences in abundances among stations or between the recent preoperational (1987-1989) and operational periods and the interaction term (Preop-Op X Station) was not significant indicating no effect from operation of the Seabrook Station on the abundance of *Neomysis americana* (Table 4-11).

The relative abundance of the individual lifestages (Figure 4-14) at Station P2 suggest that *Neomysis americana* produces two generations per year, similar to the life cycle described by Mauchline (1980) and observed by Wigley and Burns (1971) on Georges Bank. Although small differences in the relative abundance of the non-adult stages are apparent (March and October), the same lifecycle appears in both preoperational and operational periods indicating that Seabrook Station has not affected the lifecycle of *Neomysis americana*.

4.4 DISCUSSION

4.4.1 Community

Microzooplankton

Seasonal patterns of the natural assemblage of microzooplankton have historically been dominated by the population dynamics of the copepods *Oithona* sp. and *Pseudocalanus* sp. and the production of early lifestages (nauplius larvae) of other copepods that were present year-round. Seasonally, other taxa such as polychaete larvae, bivalve larvae and tintinnids influenced community structure. Since Seabrook Station began commercial operation, species composition has continued to resemble the historical patterns (Table 4-12). Although abundances of some taxa were occasionally different between the preoperational and operational periods, the differences were consistent among the nearfield and farfield stations. Since the differences occurred areawide, they were not due to the operation of Seabrook Station.

Bivalve Larvae

Varying abundances of *Hiatella* sp., *Mytilus edulis* and *Anomia squamula* defined most seasonal groups identified by the community analysis. The species composition during the operational period was generally similar to previous years according to numerical classification techniques (Table 4-12). One exception was the occurrence of higher-than-average densities of *Hiatella* sp., which occurred at both nearfield and farfield stations. Community structure, according to MANOVA results, was significantly different when compared to the recent preoperational period (1988-89). Despite similar hydrographic conditions, differences were not consistent among stations. Two taxa were responsible for the observed differences. *Teredo navalis* density decreased during the operational period at Stations P5 and P7, but increased at Station P2. Densities of *Hiatella* sp. increased at all three stations, but the increases were more pronounced at Station P2. These differences are not suspected to be a result of entrainment, because densities increased at the intake station. Furthermore, other taxa abundant during the same time period (e.g., *Mya truncata, Mytilus edulis*) did not show a similar pattern.

TABLE 4-12. SUMMARY OF POTENTIAL EFFECTS (BASED ON NUMERICAL CLASSIFICATION AND MANOVA RESULTS) OF OPERATION OF SEABROOK STATION INTAKE ON THE INDIGENOUS ZOOPLANKTON COMMUNITIES. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
MICROZOOPLANKTON		
Community Structure	yes[a]	yes
Abundances	no, variable among taxa[b]	yes
BIVALVE LARVAE		
Community structure	yes, with one exception[a]	yes
Abundances	Op>Preop[c]	yes
Hiatella sp.	no	P2 Op>>Preop P5, P7 Op>Preop
Teredo navalis	no	P2 Op>Preop P5, P7 Op<Preop
MACROZOOPLANKTON		
Holo/meroplankton		
Seasonal occurrence	yes, except for winter 1993, 1994[a]	yes
Abundances	Op>Preop[b,c]	yes
Tychoplankton		
Seasonal occurrence	yes	yes
Abundances	Op>Preop[c]	yes

[a]Based on results of numerical classification
[b]Based on comparisons of group mean abundances
[c]Based on MANOVA results

Entrainment

The focus of monitoring plankton in the intake area was to evaluate the effect of entrainment of organisms by the circulating water system on community structure and population levels in the nearfield area. Due to the limited control of their horizontal movements and often broad vertical distribution in the water column, most types of planktonic organisms could be exposed to entrainment. Estimates of total monthly levels of entrainment were computed (Figure 4-8) to quantify losses of bivalve larvae. Community structure and abundances of selected species in the nearfield area during commercial operation were compared to historical conditions and to farfield conditions. These comparisons addressed the question of whether the balanced, indigenous planktonic populations within the study area have been affected by the plant intake during the commercial operation to date.

Although Seabrook Station operated its circulating water system at varying levels since 1985, no power or heated discharge were produced until August of 1990. Entrainment collections provide a measure of the actual number of organisms directly affected by plant entrainment. No entrainment samples were collected in 1994 due to planned plant outages and equipment malfunction. Three taxa, *Mytilus edulis* (blue mussel), *Anomia squamula* and *Hiatella* sp., accounted for more than 85% of the bivalve larvae entrained each year (Figure 4-8). *Modiolus modiolus* was intermittently entrained during 1990 and 1991 (NAI 1991b, NAI 1992) and was common in entrainment samples in August and September 1993. Monthly entrainment of all taxa was less in 1991 and 1992 in comparison to 1990 and 1993 (Figure 4-8). Reduced CWS flows during outage periods in summer when larvae typically reach their peak abundance levels in local coastal waters led to reduced entrainment in 1991 and 1992. Furthermore, abundances of *M. edulis* larvae observed in local coastal waters (P2, P5, P7) in 1991 and 1992 were reduced when compared to 1990 and 1993 abundances, which contributed to lower entrainment levels.

Holo- and Meroplanktonic Macrozooplankton

The holo- and meroplanktonic component of the macrozooplankton community in the study area was similar to the other portions of the Gulf of Maine (Sherman 1966). In the study area, copepods predominate. The dominant species in the study area, *Calanus finmarchicus, Centropages typicus, Pseudocalanus* sp. and *Temora longicornis* were the dominant copepods in the Gulf of Maine and nearby Scotian Shelf and Georges Bank, occurring in a seasonal pattern similar to the study area (Anderson 1990, Kane 1993, Sameoto and Herman 1992, Tremblay and Roff 1983). The seasonal occurrence of the other groups was also similar to other observations in the Gulf of Maine (Sherman 1966).

The seasonal change in the holo- and meroplankton community composition at both nearfield and farfield stations was consistent during the past nine years. Consistent seasonal changes were observed at Station P2 (nearfield) from 1978 through 1984 and from 1986 through 1990 (NAI 1991b).

In the recent preoperational and operational periods, community composition exhibited the greatest variation among years during the period February through April. This period corresponds to the lowest annual temperatures and the period of greatest variability in salinity in the study area (Section 2.3.1). The community variation in February through April is probably due to combined regional water temperature and salinity effects. Winter water temperatures may be a controlling variable in the composition of the holo- and meroplankton communities. Winter water temperatures approach threshold limits for some species and small differences from year to year may have significant effects on community composition during this period. The occurrence of *Centropages typicus* has been associated with surface water temperatures of 2.2 to 26.6 °C (Grant 1988). Water temperatures in 1993 and 1994 fell below 2.2 °C for an extended period (Section 2.3.1). These lower than normal water temperatures may have reduced the population of *C. typicus*, resulting in the occurrence of an anomalous group that was characterized by its usual co-dominants. Studies have shown both the timing and the magnitude of the spring copepod bloom may be related to water temperature. In the presence of high phytoplankton abundance, cold water temperatures can delay the initiation of egg production and reduce the quantity of eggs produced by *Calanus finmarchicus* (Plourde and Runge 1988). Low temperatures can also reduce growth rates and delay the development of larger copepodites (Anderson 1990). Salinity during the spring bloom may also have accounted for some of the variability in community composition. High variability in salinity among years can be caused by meteorological events. Storms can increase run-off and reduce salinity and can also cause mixing between lower salinity coastal water masses and shelf water masses.

The abundance of holo- and meroplankton was higher during the operational period than the recent (1987-1989) preoperational years. Six taxa experienced order of magnitude changes from the preoperational to the operational periods. Interannual variations of orders of magnitude are common among copepods on Georges Bank (Kane 1993). Jossi and Goulet (1993) suggested that there has been a possible general increase in copepod abundance from 1961 through 1989 for the entire Gulf of Maine. *Calanus finmarchicus* increased in abundance in all regions except the extreme western portion of the Gulf of Maine, which includes coastal New Hampshire.

Although holo- and meroplanktonic community structure was qualitatively similar among Stations P2, P5, and P7, quantitative examination of abundances indicated that spatial differences occurred, and that these differences persisted from preoperational through operational periods (as evidenced by the MANOVA's significant station term and insignificant interaction term). Specific differences were not clearcut. Only six of the 50 taxa examined exhibited significant station differences. Differences may be related to water quality characteristics, as temperature has been higher in the nearfield (P2 and P5) (Section 2.0). The proximity of Stations P2 and P5 to Hampton estuary may partially account for water quality patterns.

Tychoplanktonic Macrozooplankton

The tychoplanktonic community, composed of species that inhabit both the substrate and the water column, exhibited greater spatial variability than the holo- and meroplanktonic community. Excursions into the plankton can be related to such factors as light, lunar cycle, storm events, reproduction and nonspecific aggregation (Mauchline 1980). These factors can influence apparent abundance dramatically.

Seasonal changes in species composition were similar between preoperational and operational years, except December 1990 and January 1991. Very low abundances of a few taxa separated this period from all other collections.

Substrate differences between nearfield and farfield sites may be responsible for differences in tychoplankton abundance between the sites. Tychoplankton species such as mysids (Wigley and Burns 1971; Pezzak and Corey 1979; Mauer and Wigley 1982), amphipods (Bousfield 1973) and cumaceans (Watling 1979) have substrate preferences. A relatively homogeneous substrate of sand exists at the farfield area. Rock ledges are few and generally not near the farfield station. In contrast, the nearfield substrate is heterogeneous. Station P2 is sand and hard sand with numerous nearby rock ledges. Station P5 is sand and rock ledge with considerable amounts of algae. The heterogeneous nature of the nearfield stations may have increased the abundance of various tychoplankton by supplying more diverse habitat. Many amphipods such as *Pontogeneia* *inermis* are associated with submerged plants and algae. Higher concentrations of macroalgae in the nearfield area may provide additional habitat for some amphipods and increase their abundance. Differences in tychoplankton abundance between the nearfield and farfield areas may be due to differences in habitat and not to the operation of Seabrook Station.

While both temporal and spatial differences have been observed in various components of the macrozooplankton community, these differences have been consistent. Although abundances of a number of species have differed between the preoperational and operational periods, similar changes have occurred at nearfield and farfield locations. Other species, particularly tychoplankton, have exhibited spatial patterns that have been consistent from preoperational to operational periods. The long-term consistency in distribution indicates that operation of Seabrook Station's cooling water system has not affected the macrozooplankton community.

4.4.2 Selected Species

Microzooplankton

Patterns of seasonal variation recorded during operational years (1991-1994) for the selected microzooplankton species were similar to patterns observed during the preoperational period at nearfield Station P2 (Figures 4-3, 4-4) for all individual taxa except *Eurytemora* sp. copepodites, which have failed to show a mid-summer peak in abundance in the operational period. ANOVAs detected significantly lower operational mean densities for only *Pseudocalanus/Calanus* sp. nauplii. In no case, however was the interaction (Preop-Op X Area) term significant, indicating that the operational differences were observed at both nearfield and farfield stations and therefore could not be attributed to a plant effect (Table 4-13).

Bivalve Larvae

Umboned larvae of *Mytilus edulis* have been generally present in the water column during all months sampled, but were most abundant from June through August. Their protracted presence was probably due to spawning patterns and the duration of larvae life. In Long Island Sound, spawning occurred over a two-to-three month period and was asynchronous among local populations (Fell and Balsamo 1985). Larval development requires three to five weeks (Bayne 1976), and metamorphosis can be delayed up to 40 days until suitable settling conditions are encountered (Bayne 1965). The seasonal pattern of *M. edulis* larvae in the operational period was similar to recent preoperational years. Average abundances of *M. edulis* larvae were not significantly different during the operational period at each of the three stations (Table 4-13).

Macrozooplankton

There has essentially been no change in the abundances or seasonality of most of the macrozooplankton selected species. With the exception of *Calanus finmarchicus* adults, average abundances of all selected species during the operational period were not significantly different from the recent preoperational period (Table 4-13). One species, *Crangon septemspinosa*, showed significant nearfield-farfield differences between both the preoperational and operational periods. Abundances have remained stable over time, and the relationship of abundances between the three stations has also remained unchanged. Differences in the abundance of *Calanus finmarchicus* adults between the recent preoperational and operational periods were not consistent among stations and warrant close monitoring in the future. Comparison of the annual means showed the differences to be slight.

TABLE 4-13. SUMMARY OF POTENTIAL EFFECTS (BASED ON ANOVA RESULTS) OF OPERATION OF SEABROOK STATION INTAKE ON ABUNDANCES OF SELECTED INDIGENOUS ZOOPLANKTON SPECIES. SEABROOK OPERATIONAL REPORT, 1994.

PLANKTON SELECTED SPECIES AND LIFESTAGES	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL[a] PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
MICROZOOPLANKTON		
Eurytemora sp. copepodites	yes	yes
E. herdmani adults	yes	yes
Pseudocalanus/Calanus nauplii	Op<Preop	yes
Pseudocalanus sp. copepodites	yes	yes
adults	yes	yes
Oithona sp. nauplii	yes	yes
copepodites	yes	yes
adults	yes	yes
BIVALVE LARVAE		
Mytilus edulis larvae	yes	yes
MACROZOOPLANKTON		
Calanus finmarchicus		
copepodites	yes	yes
adults	yes	P5Op>P7Op P5Preop=P7Preop
Crangon septemspinosa larvae	yes	yes
Carcinus maenas larvae	yes	yes
Neomysis americana	yes	yes

[a]recent preoperational years: 1982-1984 for microzooplankton, 1988-1989 for bivalve larvae and 1987-1989 for macrozooplankton

4.5 REFERENCES CITED

Anderson, J.T. 1990. Seasonal development of invertebrate zooplankton on Flemish Cap. Mar. Ecol. Progr. Ser. 67:127-1409.

Bayne, B.L. 1965. Growth and the delay of metamorphosis of the larvae of *Mytilus edulis* (L.) Ophelia 2:1-47.

__________. 1976. The biology of mussel larvae. Chap. 4 in Bayne, B.L., ed. Marine Mussels: Their Ecology and Physiology. IBP 10. Cambridge Univ. Press. pp. 81-120.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Environmental Protection Agency, Ecological Research Report Agency, Ecol. Res. Rep., 114 pp.

Bousfield, E.L. 1973. Shallow-water Gammaridean Amphipoda of New England. Comstock Pub. Assoc. (Cornell University Press; Ithaca, NY and London. 312 pp.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

Davis, C.S. 1984. Interaction of a copepod population with the mean circulation of Georges Bank. J. Mar. Res. 42:573-590.

Fell, P.E. and A.M. Balsamo. 1985. Recruitment of *Mytilus edulis* L. in the Thames Estuary, with evidence for differences in the time of maximal settling along the Connecticut shore. Estuaries 8:68-75.

Grabe, S.A. and E.R. Hatch. 1982. Aspects of the biology of *Mysis mixta* (Lilljeborg 1852)(Crustacea, Mysidacea) in New Hampshire coastal waters. Can. J. Zool. 60(6):1275-1281.

Grant, G.C. 1988. Seasonal occurrence and dominance of *Centropages* congeners in the Middle Atlantic Bight, USA. Hydrobiol. 167/168:227-237.

Grice, G.D. and N.H. Marcus. 1981. Dormant eggs of marine copepods. Oceanogr. Mar. Biol. Ann. Rev. 19:125-140.

Harris, R.J. 1985. A primer of multivariate statistics. Orlando: Acad. Press. 575 p.

Jossi, J.W. 1991. Gulf-of-Maine copepods hit 11-year high. In Northeast Fish. Ctr. End-of-Year Rep. for 1990. NOAA-NMFS.

Jossi, J.W. and J.R. Goulet, Jr. 1993. Zooplankton Trends: U.S. Northeast Shelf Ecosystem and Adjacent Regions Differ from Northeast Atlantic and North Sea. ICES J. Mar. Sci. 50:303-313.

Jury, S.H., J.D. Field, S.L. Stone, D.M. Nelson, and M.E. Monaco. 1994. Distribution and abundance of fishes and invertebrates in North Atlantic estuaries. ELMR Rep. No. 13. NOAA/NOS Strategic Env. Assessments Div., Silver Spring, MD. 221 p.

Kane, J. 1993. Variability of Zooplankton Biomass and Dominant Species Abundance on Georges Bank, 1977-1986. Fishery Bull. 91:464-474.

Katona, S.K. 1971. The developmental stages of *Eurytemora affinis* Poppe, 1880 (Copepoda, Calanoida) raised in laboratory cultures, including a comparison with the larvae of *Eurytemora americana* Williams, 1906, and *Eurytemora herdmani* Thompson and Scott, 1897. Crustaceana 21:5-20.

Marcus, N.H. 1984. Recruitment of copepod nauplii into the plankton: importance of diapause eggs and benthic processes. Mar. Ecol. Prog. Ser. 15:47-54.

Mauchline, J. 1980. The Biology of Mysids: Part I, in The Biology of Mysids and Euphausiids. Adv. Mar. Biol. 18:3-372.

Maurer, D. and R.L. Wigley. 1982. Distribution and ecology of mysids in Cape Cod Bay, MA. Biol. Bull. 163:477-491.

Meise-Munns, C., J. Green, M. Ingham and D. Mountain. 1990. Interannual variability in the copepod populations of Georges Bank and the Western Gulf of Maine. Mar. Ecol. Progr. Ser. 65:225-232.

Normandeau Associates Inc. 1978. Seabrook Environmental Studies, 1976-1977. Monitoring of plankton and related physical-chemical factors. Tech. Rep. VIII-3.

_________. 1979. Seabrook Environmental Studies, July through December 1977. Plankton. Tech. Rep. IX-1.

_________. 1980. Annual summary report for 1978 hydrographic studies off Hampton Beach, New Hampshire. Preoperational ecological monitoring studies for Seabrook Station. Tech. Rep. X-2.

_________. 1984a. Seabrook Environmental Studies. 1983 data report. Tech. Rep. XV-I.

_________. 1984b. Seabrook Environmental Studies, 1983. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1983. Tech. Rep. XV-II.

_________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rep. XVI-II.

_________. 1990. Seabrook Environmental Studies. 1989. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1989. A preoperational study for Seabrook Station. Tech. Rep. XXI-II.

_________. 1991a. Seabrook Environmental Studies, 1990 data report. Tech. Rep. XXII-1.

_________. 1991b. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

_________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

_________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-I.

_________. 1994. Seabrook Environmental Studies. 1993 Data. Unpub. Data Tab.

_________. 1995. Seabrook Environmental Studies. 1994 Data Unpub. Data Tab.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area during the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

Pezzack, D.S. and S. Corey. 1979. The life history and distribution of *Neomysis americana* (Smith) (Crustacea, Mysidacea) in Passamaquoddy Bay. Can. J. Zool. 57:785-793.

Plourde, S. and J.A. Runge. 1993. Reproduction of the Planktonic Copepod *Calanus finmarchicus* in the Lower St. Lawrence Estuary: Relation to the Cycle of Phytoplankton Production and Evidence for a *Calanus* pump. Mar. Ecol. Progr. Ser. 102:217-227.

Sameoto, D.D. and A.W. Herman. 1992. Effect of the outflow from the Gulf of St. Lawrence on Nova Scotia shelf zooplankton. Can. J. Fish. Aquat. Sci. 49:857-869.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics, version 5 edition. SAS Ins., Inc., Cary, N.C. 956 pp.

Sherman, K. 1966. Seasonal and areal distribution of Gulf of Maine coastal zooplankton, 1963. ICNAF Special Publ. No. 6. pp. 611-623.

__________. 1991. Northwest/northeast Atlantic zooplankton show different trends. in Northeast Fish. Center End-of-Year Rep. 1990. NOAA-NMFS.

Sherman, K., M. Grosslein, D. Mountain, D. Busch, J. O'Reilly and R. Theroux. 1988. The continental shelf ecosystem off the northeast coast of the United States. Chapter 9, pp. 279-337. *In* H. Postma and J.J. Zijlstra, Ecosystems of the World 27. Continental Shelves. Elsevier, Amsterdam.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. W.H. Freeman Co., San Francisco. 573 pp.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co., San Francisco, CA. 859 p.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication in time?" Ecology, 67:929-940.

Tremblay, M.J. and J.C. Roff. 1983. Community gradients in the Scotian shelf zooplankton. Can. J. Fish. Aquatic. Sci. 40:598-611.36

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4(1):3-15.

Watling, L. 1979. Marine flora and fauna of the Northeastern United States. Crustacea: Cumacea. NOAA Tech. Rep. NMFS Circular 423. 23 p.

Wigley, R.L. and B.R. Burns. 1971. Distribution and biology of mysids (Crustacea, Mysidacea) from the Atlantic Coast of the United States in the NMFS Woods Hole collection. Fish. Bull. 69(4):717-746

APPENDIX TABLE 4-1. LIST OF ZOOPLANKTON TAXA CITED IN THIS REPORT. SEABROOK OPERATIONAL REPORT, 1993.

Protozoa
- Foraminiferida
- Tintinnidae

Rotifera

Mollusca
- Bivalvia
  - *Anomia squamula* Linnaeus
  - *Hiatella* Bosc 1801
  - *Macoma balthica* Linnaeus 1758
  - *Modiolus modiolus* Linnaeus 1758
  - *Mya arenaria* Linnaeus 1758
  - *Mya truncata* Linnaeus 1758
  - *Mytilus edulis* Linnaeus 1758
  - *Placopecten magellanicus* (Gmelin 1791)
  - Solenidae
  - *Spisula solidissima* (Dillwyn 1817)
  - *Teredo navalis* Linnaeus 1758

Polychaeta

Arthropoda
- Branchiopoda
  - *Evadne* Lovén
- Copepoda
  - *Acartia* Dana 1846
  - *Anomalocera opalus* Penell 1976
  - *Calanus finmarchicus* (Gunnerus 1765)
  - *Caligus* Müller 1785
  - *Candacia armata* (Boeck 1872)
  - *Centropages hamatus* (Lilljeborg 1853)
  - *Centropages* Krøyer 1849
  - *Centropages typicus* Krøyer 1849
  - *Euchaeta* Philippi 1843
  - *Eurytemora herdmani* Thompson and Scott 1897
  - *Eurytemora* Giesbrecht 1881
  - Harpacticoida
  - *Microsetella norvegica* (Boeck)
  - Monstrillidae
  - *Oithona* Baird 1843
  - *Oithona similis* Claus 1866
  - *Pseudocalanus* Boeck 1872
  - *Rhincalanus nasutus* Giesbrecht 1892
  - *Temora longicornis* (Müller 1785)
  - *Tortanus discaudatus* (Thompson and Scott 1897)

(continued)

APPENDIX TABLE 4-1. (Continued)

Cirripedia

Malacostraca
- Mysidacea
  - *Erythrops erythrophthalma* (Gőes 1864)
  - *Mysis mixta* (Lilljeborg 1852)
  - *Mysis stenolepis* S.I. Smith
  - *Neomysis americana* (S.I. Smith 1873)
- Cumacea
  - *Diastylis* Say
- Amphipoda
  - Hyperiidae
  - *Ischyrocerus anguipes* Krøyer 1838
  - Oedicerotidae
  - *Pontogeneia inermis* (Krøyer 1842)
- Decapoda
  - *Cancer* Linnaeus
  - *Carcinus maenas* (Linnaeus 1758)
  - *Crangon septemspinosa* Say 1818
  - *Eualus pusiolus* (Krøyer 1841)
  - *Eualus* Thallwitz 1892
  - *Lebbeus* White 1847
  - Hippolytidae
  - *Spirontocaris* Bate 1888

Chaetognatha
- *Sagitta elegans* Verrill 1873

Chordata
- Larvacea (previous to 1994, identified as *Oikopleura* Mertens)

TABLE OF CONTENTS

PAGE

SUMMARY

Fish of the Hampton-Seabrook area have been sampled since 1975 to assess potential impacts associated with the construction and operation of Seabrook Station on local fish assemblages. Effects include the entrainment of fish eggs and larvae and the impingement of juvenile and adult fish at the station intake; entrainment of fish eggs and larvae into and the avoidance by large fish of the offshore discharge thermal plume; and effects related to the discharge of the plant settling basin into the Browns River within the Hampton-Seabrook estuary. The spatial and temporal abundance of specific fish assemblages were examined along with various life stages of eleven selected fish taxa. Preoperational and operational abundances were compared using multivariate analysis methods for ichthyoplankton assemblages and analysis of variance (ANOVA) for larval, juvenile, and adult stages of the selected taxa. The sampling scheme used to collect data for the ANOVA was designed to meet the Before-After/Control-Impact analysis criteria. Although a number of significant differences were found in the abundance of several species between the preoperational and operational periods, nearly all of these differences can be attributed to large-scale, regional decreases in abundance, particularly for commercially important fishes. Three potential effects were found that could possibly be related to plant operation. These were decreases in rainbow smelt and winter flounder CPUE in the trawl, and an increase in American sand lance larval densities. In October 1994, Seabrook Station identified the fact that it had not accurately counted the number of small fish impinged on Seabrook Station's travelling screens prior to the fourth quarter of 1994. Small fish, concealed in screen wash debris had been overlooked by plant personnel responsible for separating fish from debris. Therefore, impingement data prior to the fourth quarter of 1994 cannot be considered to be as reliable as data after this timeframe. The impingement monitoring program was enhanced in the fourth quarter of 1994 to separate all readily visible fish from seaweed and beginning in 1995 biologists began to conduct the weekly impingement evaluation. In comparison to other New England power plants with marine intakes, Seabrook Station entrains relatively few fish eggs and larvae and impinges fewer juvenile and adult fish. Because the settling basin no longer is discharged into the Browns River, this effluent has been eliminated as a potential source of impact. Based on the small numbers of individuals directly removed by station operation, the general lack of significant differences found between the nearfield and farfield stations, and the large source populations of potentially affected fishes in the Gulf of Maine, the operation of Seabrook Station does not appear to have affected the balanced indigenous populations of fish in the Hampton-Seabrook area.

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

LIST OF APPENDIX TABLES

5.0 FISH

5.1 INTRODUCTION

Finfish studies at Seabrook Station began in July 1975 and have included investigations of all life stages of fish, including ichthyoplankton (eggs and larvae), juveniles, and adults. The initial objectives of these studies were to determine the seasonal, annual, and spatial trends in abundance and distribution of fish in the nearshore waters off Hampton and Seabrook, NH, to establish baseline data suitable for assessing the effects of future plant operation. In addition, the nearshore fish populations in the Hampton-Seabrook estuary were examined to determine if there was any measurable effect due to the construction of Seabrook Station and the discharge from the onsite settling basin into the Browns River. The station began commercial operation in August 1990. Potential impacts of plant operation on local fishes include entrainment of eggs and larvae through the condenser cooling water system and impingement of larger specimens on traveling screens within the circulating water pumphouse. Also, local distribution of fishes could be affected by the thermal plume, and some eggs and larvae could be subjected to thermal shock due to plume entrainment following the discharge of condenser cooling water from the diffuser system.

At present, the main objective of the finfish studies at Seabrook Station is to assess whether power plant operation since 1990 has had any measurable effect on the nearshore fish populations. The following report first presents general information on each finfish collection program and then provides more detailed analyses for those fish species selected because of their dominance in the Hampton and Seabrook area or their commercial or recreational importance. A list of all taxa and their relative abundance in collections from July 1975 through December 1994 by various ichthyoplankton and adult finfish sampling programs are given in Appendix Table 5-1. Both the common and scientific names in that table follow Robins et al. (1991) and common names are used throughout this report.

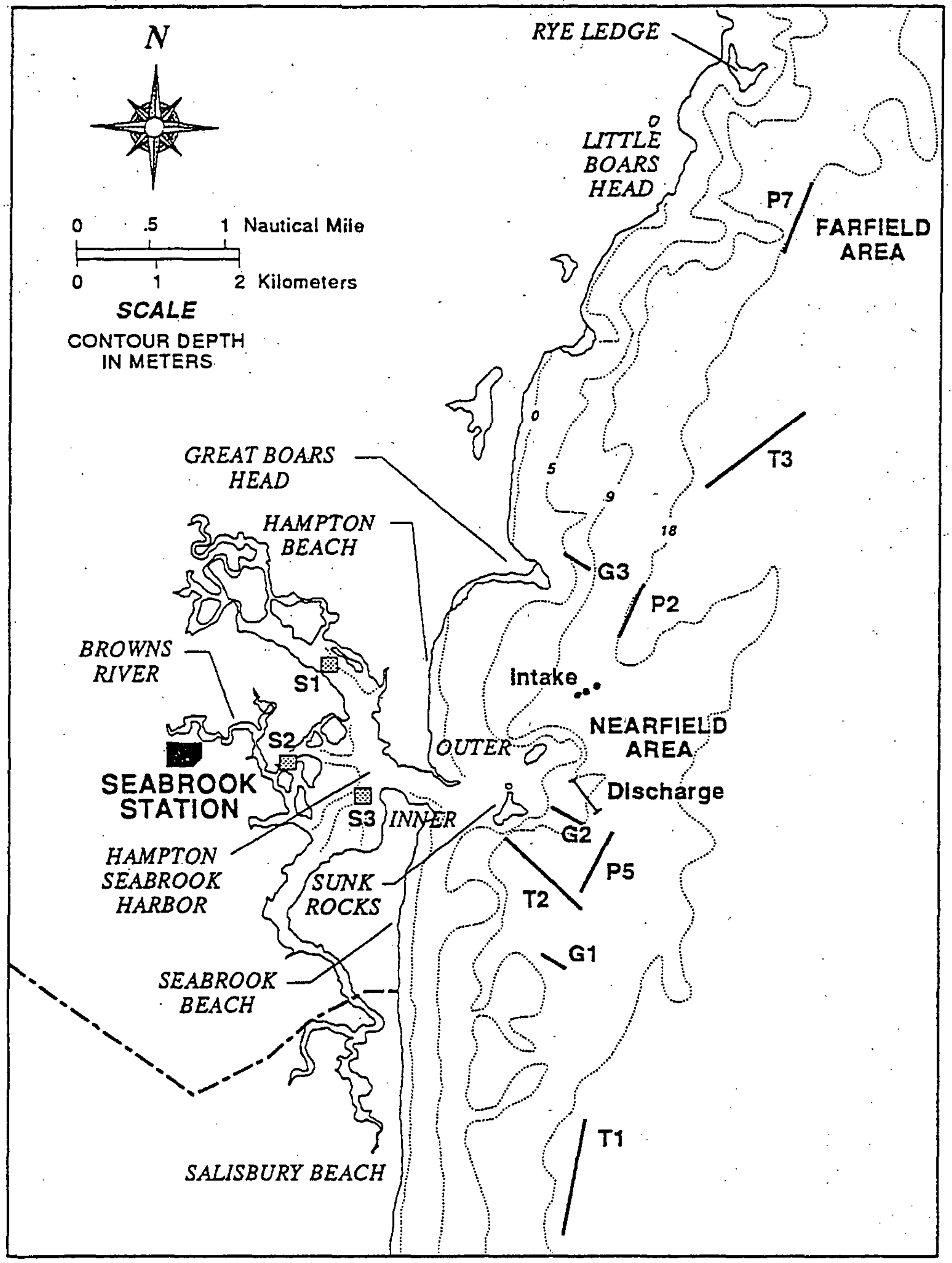
5.2 METHODS

5.2.1 Ichthyoplankton

5.2.1.1 Offshore Sampling

Ichthyoplankton sampling for Seabrook Station has been conducted since July 1975. Several modifications to the sampling methodology and collection frequencies were made as the nature of the ichthyoplankton community and its natural variability became better understood (NAI 1993). Station P2 (nearfield site for the Seabrook intakes) has been sampled consistently since the start of the program (Figure 5-1). Station P5 (nearfield site for the Seabrook discharge) was sampled from July 1975 through December 1981 and from July 1986 through December 1994. Station P7 (farfield station located about 7 km north of the nearfield stations), representing a non-impacted or control site, was sampled from January 1982 through December 1984 and from January 1986 through December 1994. Through June 1976, collections were taken monthly at each station sampled. Subsequently, a second monthly sampling period was added in February through August and in December. Beginning in January 1979, all months were sampled twice. Starting in March 1983, sample collection was increased to the current frequency of four times per month at each station sampled.

On each sampling date and at each station, four samples were collected at night from July 1975 through December 1993. In 1994, four tows per station were collected on the first and third sampling periods each month and two tows were collected on the second and fourth periods. Oblique tows were made using paired 1-m diameter, 0.505-mm mesh nets. Each net, weighted with an 8-kg depressor, was set off the stern and towed for 10 min while varying the boat speed, with the nets



LEGEND

———	P = Ichthyoplankton Tows
———	T = Otter Trawls
———	G = Gill Nets
▩	S = Seine Hauls

Figure 5-1. Ichthyoplankton and adult fish sampling stations. Seabrook Operational Report, 1994.

sinking to approximately 2 m off the bottom and rising obliquely to the surface at least twice during the tow. A standard 10-min tow was occasionally reduced to a 5-min tow to minimize net clogging due to high plankton density. The volume filtered, calculated using data from a calibrated General Oceanics® flowmeter mounted in each net mouth, averaged approximately 500 m^3 for 10-min tows and approximately 250 m^3 for 5-min tows. Upon retrieval, each net was washed down from mouth to codend and the contents preserved in 5% formalin buffered with borax.

5.2.1.2 Entrainment

Ichthyoplankton entrainment sampling was conducted up to four times a month by NAESCO personnel within the circulating water pumphouse on-site at Seabrook Station from July 1986 through June 1987 and June 1990 through December 1994. Sampling dates coincided with offshore ichthyoplankton sampling whenever possible. Three replicate samples were collected during the day on each sampling date. The entrainment data discussed in this report are only those for the operational period of 1990-94.

Seabrook Station's third Refueling Outage took place between April 9, 1994 and July 31, 1994. Consistent with previous outages, ichthyoplankton and bivalve larvae entrainment samples were not taken during the outage when there is insufficient circulating water flow to operate the entrainment sampling equipment. Refurbishment of the entrainment sampling equipment was not completed during the outage as originally scheduled and as a result on-site entrainment sampling was not resumed until mid September when the equipment was returned to service. However, when ichthyoplankton sampling was resumed, bivalve larvae sampling was not resumed. As a result of the outage which began in April and the failure to resume bivalve entrainment sampling in September, no bivalve larvae samples were taken in 1994 during the April to October sampling period. These on-site entrainment sampling deficiencies have been addressed by reassigning the responsibility for entrainment sampling to the Seabrook Station Regulatory Compliance Department, the organization that provides oversight of the off-site environmental monitoring program.

Simultaneous replicate samples were taken using three double-barrel collection devices. In each, a 0.505-mm mesh plankton net was suspended in a 30-gal drum which, in turn, was suspended within a 55-gal drum. Water diverted from the cooling-water system entered each 55-gal drum from the bottom, overflowed into the 30-gal drum, passed through the plankton net, and was discharged through the bottom of both drums. The water supply was adjusted to maintain approximately 8 to 15 cm of water above the plankton nets at all times. Following sampling, water was drained from the system and the contents of each net consolidated, and preserved with 5% buffered formalin. The volume filtered was measured with an in-line flowmeter and averaged approximately 100 m^3 per replicate. Monthly entrainment estimates were determined by calculating the arithmetic mean density for each sampling week, multiplying the mean density by the number days in the sampling week, and by the average daily condenser cooling water volume for the month. These weekly estimates were summed for a monthly estimate. No entrainment estimates were made for the periods of August through November 1991, September through November 1992, or 9 April through 15 September 1994, for the reasons discussed above.

5.2.1.3 Laboratory Methods

Prior to March 1983, all four offshore ichthyoplankton samples per date and station were analyzed, except from January through December 1982, when only one sample per date and station was completely analyzed; only selected taxa were counted from the remaining three samples. Beginning in March 1983, only two of the four offshore samples (one from each pair; Section 5.2.1.1) were analyzed from each station for each sampling date; the remaining two were held as contingency samples. Starting in January 1994, only one of the two duplicate tows was analyzed per date and station, with the remaining held as a contingency sample.

Samples were subsampled with a Folsom plankton splitter and sorted for fish eggs and larvae using a dissecting microscope. Successive aliquots were analyzed until a minimum of 200 eggs and 100 larvae were sorted or until 200-400 mL settled plankton volume was sorted. All eggs and larvae were identified to the lowest practical taxon (usually species) and counted. In some instances when eggs were difficult to identify to species due to their stage of development, they were grouped with eggs of similar appearance (e.g., cunner, tautog, and yellowtail flounder were grouped as cunner/yellowtail flounder eggs; Atlantic cod, haddock, and witch flounder as Atlantic cod/haddock; and hake species and fourbeard rockling as fourbeard rockling/hake). The notochord lengths of at least 20 larvae per sample (if present) were measured to the nearest 0.5 mm for selected taxa, which included Atlantic herring, Atlantic cod, pollock, hakes, cunner, Atlantic mackerel, American sand lance, winter flounder, and yellowtail flounder. Entrainment samples were processed in a similar manner.

5.2.2 Adult Fish

5.2.2.1 Pelagic Fishes

Beginning in July 1975, gill net arrays were set for two consecutive 24-h periods twice each month at stations G1 (farfield), G2 (nearfield), and G3 (farfield) to sample the pelagic fish assemblage (Figure 5-1; Table 5-1). Starting in July 1986, sampling was reduced to once per month. Nets were 30.5 m x 3.7 m and comprised four panels having stretch mesh dimensions of 2.5 cm, 5.1 cm, 10.2 cm, and 15.2 cm. One net array consisting of surface and near-bottom nets was set at each station. All nets were set perpendicular to the isobath (Figure 5-1). All nets were attached between permanent moorings and tended daily by SCUBA divers. Fish collected were identified to their lowest practical taxon (usually species), and measured to the nearest 2 cm.

5.2.2.2 Demersal Fishes

The inshore demersal fish assemblage was sampled monthly beginning in July 1975 by otter trawl at night at one nearfield station, T2, and two farfield stations, T1 and T3 (Figure 5-1; Table 5-1). Four replicate tows were made at each station once per month. Beginning in January 1985, sampling frequency was increased to twice per month and the number of replicate tows was reduced to two. Sampling was conducted with a 9.8-m shrimp otter trawl (3.8-cm nylon stretch mesh body; 3.2-cm stretch mesh trawl bag; 1.3-cm stretch mesh codend liner). The net was towed at approximately 1 $m \cdot sec^{-1}$ for 10 min, with successive tows taken in opposite directions. The volume of drift algae caught in the trawl was also recorded. It was not always possible to collect samples at station T2, particularly from August through October, due to the presence of commercial lobster gear; the frequency of missed samples has increased since 1983. Fish collected were identified to their lowest practical taxon (usually species), and measured to the nearest 2 cm.

5.2.2.3 Estuarine Fishes

Seine samples were taken monthly from April to November at stations S1, S2, and S3, beginning in July 1975 (Figure 5-1; Table 5-1). No samples were collected in 1985 or from April through June of 1986. Duplicate daytime hauls were taken into the tidal current at each station with a 30.5 m x 2.4 m bag seine. The nylon bag was 4.3 m x 2.4 m with 1.4-cm stretch mesh, and each wing was 13.1 m x 2.4 m with 2.5-cm stretch mesh. Fish collected were identified to their lowest

TABLE 5-1. DESCRIPTION OF FINFISH SAMPLING STATIONS. SEABROOK OPERATIONAL REPORT, 1994.

STATION	DEPTH	BOTTOM TYPE	REMARKS
BEACH SEINE			
S1	0-2 m	sand	Affected by tidal currents; approximately 300 m upriver from Hampton Beach Marina
S2	0-1 m	sand	Affected by tidal currents; approximately 200 m upstream from the mouth of the Browns River
S3	0-3 m	sand	Affected by tidal currents; located in Seabrook Harbor, approximately 300 m from Hampton Harbor Bridge
GILL NET			
G1	20 m	sand	Seaward of rocky outcropping off Seabrook, approximately 2 km south of the discharge
G2	17 m	sand	Seaward of Inner Sunk Rocks, approximately 250 m southwest of the discharge
G3	17 m	rock, cobble	Offshore from Great Boars Head, approximately 2.5 km north of the discharge
OTTER TRAWL			
T1	20-28 m	sand	Transect begins 0.5 miles southeast of Breaking Rocks Nun, 150-200 m from submerged rock outcroppings, approximately 4 km south of the discharge
T2	15-17 m	sand; drift algae with shell debris	100 m from Inner Sunk Rocks, approximately 1 km south of the discharge; scoured by tidal currents with large quantities of drift algae
T3	22-30 m	sand; littered with shell debris	Located off Great Boars Head, approximately 4 km north of the discharge; just seaward of a cobble area (rocks 15-50 cm in diameter)

practical taxon (usually species), and measured to the nearest 2 cm.

5.2.2.4 Impingement

Fish impinged at Seabrook Station were collected by NAESCO personnel after being washed from the 0.375-in mesh traveling screens within the circulating water pumphouse. Traveling screens were generally washed weekly (R. Sher, NAESCO, pers. comm.) and impinged fish were sluiced into a collection basket. Fish from weekly collections were separated from debris, placed in dated plastic bags, and frozen. On a periodic basis, samples were thawed, identified to species, and counted by NAESCO personnel. Impingement collections were noted as total counts per species by month. In addition, the number of fish impinged per billion gallons of cooling water was calculated.

5.2.3 Analytical Methods

Ichthyoplankton assemblages were investigated using multivariate numerical classification methods to determine whether species composition changed between the preoperational period (July 1990 and earlier) and the operational period (August 1990 and later). The Bray-Curtis similarity index (Clifford and Stephenson 1975) was used with the unweighted pair-group clustering method (Sneath and Sokal 1973). $Log_{10}(x+1)$ transformed sample densities (number per 1000 m^3) of eggs and larvae were analyzed separately. The data sets were reduced by averaging dates within month (transformed data); including only the more abundant taxa; and limiting the analysis to data collected since July 1986, when all three stations of concern (P2, P5, and P7) were sampled. Rare taxa were excluded on the basis of percent-composition (less than 0.1% of the untransformed data) or frequency of occurrence in samples (less than 5%). The resulting dendrograms were evaluated on the basis of whether samples from the operational period were grouped differently by the analysis than were the preoperational samples.

Multivariate analysis of variance (MANOVA; Harris 1985) was used to indicate whether fish egg and larval assemblages had differed significantly ($p \leq 0.05$) between preoperational and operational periods. $Log_{10}(x+1)$ transformed sample densities (number per 1000 m^3) were used. The analysis was restricted to collections from July 1986 through December 1994, the common period of sampling at stations P2, P5, and P7, and the taxa included were the same as those analyzed by numerical classification. The data used were the mean of $\log_{10}(x+1)$ sample densities for individual sampling dates and stations. The model design was a three-way factorial with nested effects. The main effects were period (preoperational and operational), station, and month; interactions among these main effects were included in the model. The nested effect was years within period. Type III sums of squares and tests of hypothesis were used for the analyses and the rationale for their use was the same as that used for analysis of variance, discussed below. The Wilks' lambda statistic (Wilks 1932; Morrison 1976) was used to determine if the taxa assemblages in the preoperational and operational periods were significantly different. For the purpose of power plant impact assessment, sources of variation of primary concern were the period (preoperational or operational) and the period by station interaction.

Of the 76 taxa recorded over the years, 11 were selected for detailed analyses of abundance and distribution and for an assessment of impact by Seabrook Station (Table 5-2). These species were numerically dominant in one or more sampling programs, are important members of the finfish fauna of the Gulf of Maine, and most have recreational or commercial importance. Other species predominant in various sampling programs were noted when they occurred. The selected taxa, listed in Table 5-2 by sampling program, were individually evaluated for temporal and spatial changes in abundance between

TABLE 5-2. SELECTED FINFISHES AND SAMPLING PROGRAMS THAT CONTRIBUTED ABUNDANCE DATA FOR SPECIES-SPECIFIC ANALYSES. SEABROOK OPERATIONAL REPORT, 1994.

SELECTED SPECIES	PREDOMINANT SAMPLING PROGRAMS
Atlantic herring	ichthyoplankton, gill net
Rainbow smelt	otter trawl, beach seine
Atlantic cod	ichthyoplankton, otter trawl
Pollock	ichthyoplankton, gill net
Hakes	ichthyoplankton, otter trawl
Atlantic silverside	beach seine
Cunner	ichthyoplankton
American sand lance	ichthyoplankton
Atlantic mackerel	ichthyoplankton, gill net
Winter flounder	ichthyoplankton, otter trawl, beach seine
Yellowtail flounder	ichthyoplankton, otter trawl

the preoperational and operational periods. Geometric means were compared among the preoperational, operational, and 1994 periods for each station and all stations combined to examine for trends in annual abundance. Geometric means were computed by $\log_{10}(x+1)$ transformation of individual sample abundance indices, which were number per 1000 m^3 for ichthyoplankton, and catch-per-unit-effort (CPUE) for juvenile and adult fish. CPUE was defined as the number per 24-h set for the gill net, number per 10-min tow for the trawl, and number per standard haul for the seine. A transformed mean was calculated for each year and for combined years (e.g., preoperational and operational periods). The coefficients of variation (CV) of the mean of annual means (Sokal and Rohlf 1981) in the logarithmic scale were also computed. The annual and combined geometric means are presented as back-transformed values. Some life stages are seasonal, so the data used to compute the geometric means for some species were restricted to periods of primary occurrence; when trimmed data were used, it is noted in the text, figure, or table.

A mixed model ANOVA developed by Northeast Utilities, based on recent reviews by Underwood (1994) and Stewart-Oaten et al. (1986), was used to test the null hypothesis that spatial and temporal abundances during the preoperational and operational periods were not significantly ($p > 0.05$) different. All effects were considered random, except operational status (Preop-Op). Time and location of sampling were considered random because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). The data collected for the ANOVAs met the criteria of a Before-After/Control-Impact (BACI) sampling design discussed by Stewart-Oaten et. al. (1986), where sampling was conducted prior to and during plant operation and sampling station locations included both potentially impacted and non-impacted sites. The ANOVA was a two-way factorial with nested effects that provided a direct test for the temporal-by-spatial interaction. The main effects were period (Preop-Op) and station (Station); the interaction term (Preop-Op X Station) was also included in the model. Nested temporal effects were years within operational period (Year (Preop-Op)) and months within year (Month (Year)), which were added to reduce the unexplained variance, and thus, increased the sensitivity of the F-test. For both nested terms, variation was partitioned without regard to station (stations combined). An additional term (Station X Year(Preop-Op)) was added to provide the proper mean-square for testing the significance of the Preop-Op X Station term, which may signify a possible plant impact. The final variance not accounted for by the above explicit sources of variation constituted the Error term.

For assessing Seabrook Station effects using the above ANOVA model, the sources of variation of primary concern were the Preop-Op main effect and the Preop-Op X Station interaction. However, a significant Preop-Op term would not imply power plant effect unless the Preop-Op X Station interaction was also significant (Thomas 1977; Green 1979; Stewart-Oaten et al. 1986). Even in the latter case, the interaction would have to be further examined to determine if the significance was the result of differences between potentially impacted and non-impacted stations.

The 1990 sampling year was classified as either preoperational, operational, or was excluded from the analysis for a species, depending on seasonal pattern of occurrence of each species or times of sample collection (Appendix Table 5-4), and is noted as such on the ANOVA tables. For larvae, the data were restricted to the period July 1986 through December 1994, and for selected taxa collected by gill net, trawl, and seine, the data used were from July 1975 through December 1994. For trawl data, the months of August through October were excluded from the ANOVA because of reduced sampling effort at station T2. The data used in the analyses of gill net, trawl, and seine samples were $\log_{10}$(CPUE + 1) transformed for each individual collection. For larvae the transformed mean density of replicate samples was used for data up through 1993 (no replicates were collected in 1994).

5.3 RESULTS AND DISCUSSION

5.3.1 Ichthyoplankton Assemblages

The analyses for the ichthyoplankton program focused on seasonal assemblages of both eggs and larvae, as well as on larvae of individual selected taxa (Table 5-2). Selected taxa are discussed in Section 5.3.3, in relation to juvenile and adult stages collected in other sampling programs. In the assemblage analyses, additional taxa were included to better represent the ichthyoplankton community in the Hampton-Seabrook area.

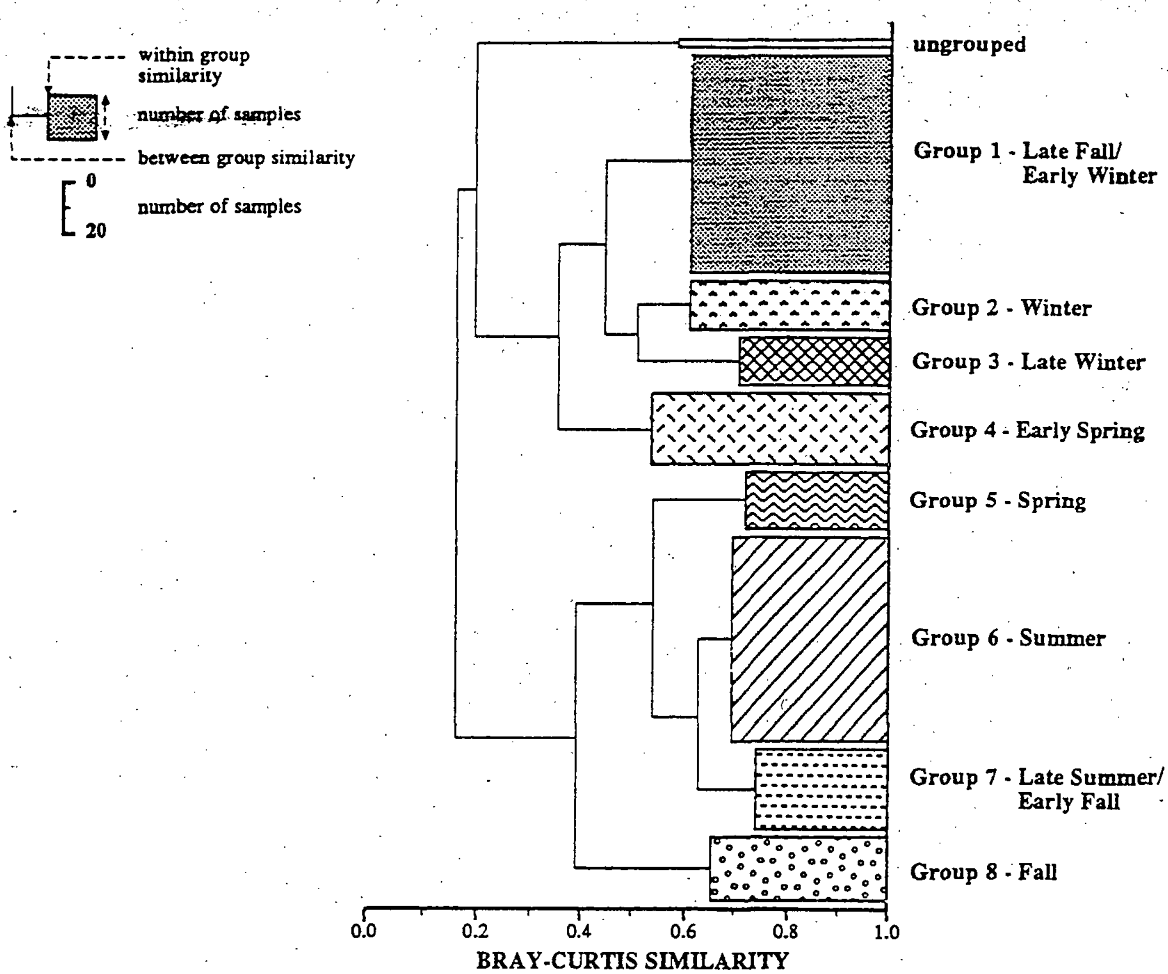
5.3.1.1 Offshore Samples

The seasonal assemblages of ichthyoplankton were examined using multivariate numerical classification (cluster analysis). These analyses were conducted to determine if the operation of Seabrook Station had altered either the seasonal occurrence or the spatial distribution of fish eggs and larvae in the Hampton-Seabrook area. Evaluation of spatial patterns compared the distribution of ichthyoplankton among intake (P2), discharge (P5), and farfield (P7) stations before and after Seabrook Station operation. Typically, ichthyoplankton taxa occur during distinct seasons and periods of frequent occurrence, which are relatively consistent from year to year. The data examined were collected from July 1986 through December 1994, when all three stations (P2, P5, and P7) were sampled. The preoperational period extended through July 1990 and the operational period began in August 1990. Several of the egg taxa were grouped, because during early developmental stages it was difficult to distinguish among some species (e.g. Atlantic cod, haddock, and witch flounder; cunner, yellowtail flounder, and tautog; fourbeard rockling and hakes). Larvae were generally identified to species, except that hake (*Urophycis* sp.) was not identified to species. It is not known whether the hake larvae comprised more than one species (red hake, white hake, and spotted hake have all been collected by the Seabrook otter trawl program as adults).

Eleven egg taxa were analyzed (excluding rare taxa) and the subsequent numerical classification analysis resulted in eight groups (Figure 5-2). A total of 303 monthly "collections" were used for the cluster analysis, with each collection being a monthly average of samples at one station. Only two monthly collections (Station P7, February 1990 and Station P7, February 1992) did not fall within any of the eight groups. The eight groups formed two major categories, which corresponded to annual periods of cold and warm water temperatures. Groups 1-4 were found during periods of cooler water temperatures (November through April) and Groups 5-8 were taken during the warmer period (May through October). There was no difference in these two categories between preoperational and operational periods.

Group 1, termed late fall/early winter, represented the beginning of the cooler water period and consisted primarily of November, December, and January collections. Atlantic cod and pollock were the dominant taxa in this group (Table 5-3). The operational geometric means for both species were lower than the preoperational means. Although eggs of Atlantic cod, haddock, and witch flounder could not usually be identified to species except during their late embryonic stage (Brander and Hurley 1992), Atlantic cod eggs could be identified during this period on the basis of the known spawning seasons of these three species. Egg abundances in Group 2, termed the winter group, were relatively low for the two dominant taxa, Atlantic cod/haddock and American plaice, during both preoperational and operational periods. This winter group consisted primarily of monthly collections from February. Group 3, termed late winter, primarily including March collections, had the same two dominant taxa as the previous group but in somewhat higher densities. Group 4, termed early spring, consisted mostly of April collections. Dominant taxa in the early spring group were American plaice and Atlantic cod/haddock (both in greater abundance than in Group 2 and Group 3 collections), with the addition of fourbeard rockling eggs. Group 4 collections during the operational period had higher American plaice and lower fourbeard rockling densities than during the preoperational period.

Group 5, termed the spring group, was found during the beginning of the warmer water season and consisted of May collections exclusively for all years. The dominant taxa were more diverse than for the four previous groups and included eggs of cunner/yellowtail flounder, fourbeard rockling (most abundant during the preoperational period), American plaice, and Atlantic mackerel (most abundant during the operational period). Group 6 consisted of June, July, and August collections exclusively and was termed the summer grouping. This group appeared less diverse, with only cunner/yellowtail flounder and fourbeard rockling/hake as dominants. These two taxa exhibited fairly similar abundance in the preoperational and the operational periods. Group 7 consisted of late summer/early fall collections, primarily those during September. The taxa comprising this group were fairly diverse, probably due to a general decline in egg abundance during this period. Differences between preoperational and operational periods were greatest for windowpane and silver hake eggs, both being more abundant in the operational period. The season represented by Group 8 was fall and collections occurred primarily in October. Most of the dominant egg taxa in Group 8 were also dominants in Group 7 but the densities were much lower in Group 8. Preoperational and operational period densities in Group 8 were generally similar to each other except that Atlantic cod/haddock were lower in the operational period.



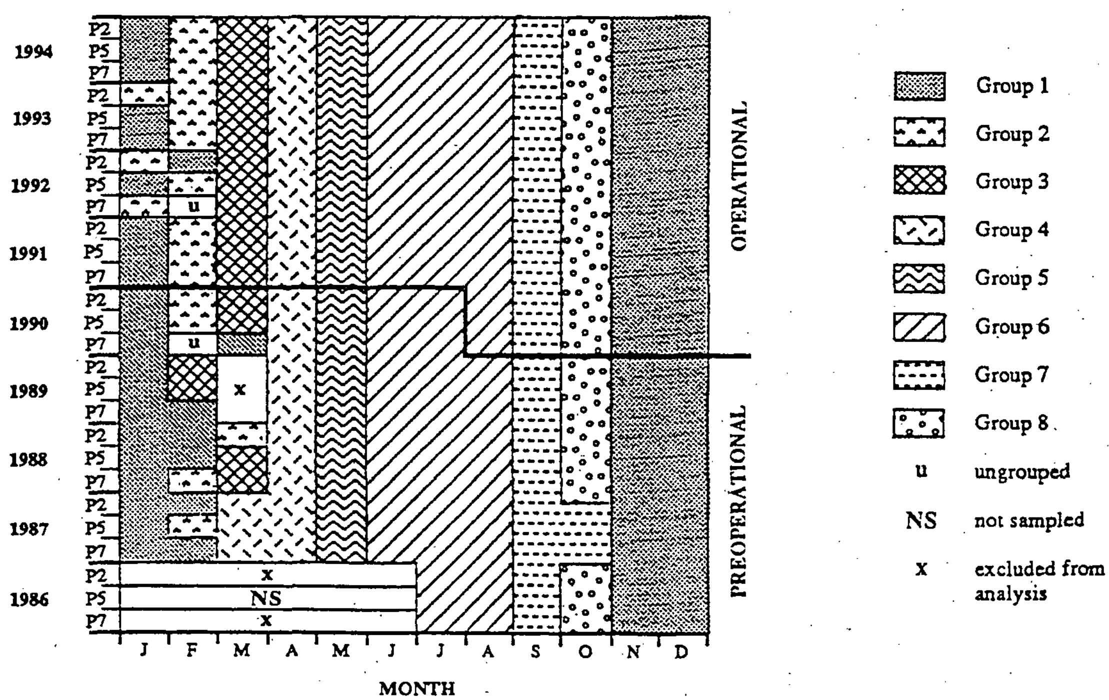


Figure 5-2. Dendrogram and temporal/spatial occurrence pattern of fish egg assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m³) at Seabrook intake (P2), discharge (P5), and farfield (P7) stations, July 1986-December 1994. Seabrook Operational Report, 1994.

TABLE 5-3. FAUNAL CHARACTERIZATION OF GROUPS FORMED BY NUMERICAL CLASSIFICATION OF SAMPLES OF FISH EGGS COLLECTED AT SEABROOK INTAKE (P2), DISCHARGE (P5), AND FARFIELD (P7) STATIONS DURING JULY 1986 THROUGH DECEMBER 1994.[a] SEABROOK OPERATIONAL REPORT, 1994.

		NUMBER OF SAMPLES AND DENSITY (LARVAE/1000 m^3)[d]							
		PREOPERATIONAL PERIOD[e]				OPERATIONAL PERIOD[e]			
GROUP	DOMINANT TAXA[c]	n	LCL	MEAN	UCL	n	LCL	MEAN	UCL
1-Late Fall/Early Winter (0.61/0.44)	Atlantic cod	42	26	39	59	40	16	22	31
	Pollock		3	5	7		1	2	3
2-Winter (0.61/0.52)	Atlantic cod/haddock	5	2	3	4	13	1	2	2
	American plaice		0	1	2		<1	<1	1
3-Late Winter (0.71/0.52)	Atlantic cod/haddock	6	4	7	14	12	3	6	10
	American plaice		2	3	4		3	4	6
4-Early Spring (0.54/0.34)	American plaice	15	22	38	64	12	49	98	197
	Atlantic cod/haddock		7	15	30		12	22	40
	Fourbeard rockling		4	8	16		<1	<1	1
5-Spring (0.72/0.55)	Cunner/yellowtail flounder	12	175	293	488	12	82	198	473
	Fourbeard rockling		77	235	715		4	14	43
	American plaice		54	73	97		35	64	115
	Atlantic mackerel		18	37	77		77	222	635
6-Summer (0.70/0.63)	Cunner/yellowtail flounder	39	2770	5000	9010	39	4090	6440	10100
	Fourbeard rockling/hake		216	399	734		269	362	488
7-Late Summer/Early Fall (0.75/0.63)	Hake	15	89	138	214	15	76	128	217
	Fourbeard rockling/hake		71	133	246		102	176	301
	Windowpane		13	29	64		58	94	151
	Fourbeard rockling		8	20	46		4	8	15
	Silver hake		7	19	47		119	181	275
8-Fall (0.66/0.40)	Atlantic cod/haddock	9	10	20	39	15	2	4	8
	Fourbeard rockling/hake		4	10	25		5	8	14
	Hake		6	10	17		3	4	6
	Silver hake		5	8	12		6	10	19
	Fourbeard rockling		1	4	10		1	2	3

[a]Each "sample" consisted of the average of tows within date and dates within month.
[b](Within group/between group similarity).
[c]Those whose preoperational geometric mean densities together accounted for ≥90% of the sum of the preoperational geometric mean densities of all taxa within the group.
[d]Geometric mean and lower (LCL) and upper (UCL) 95% confidence limits.
[e]Preoperational = July 1986 - July 1990; Operational = August 1990 - December 1994.

The overall results of the cluster analysis is clear. Time of year was the only factor that corresponded with the cluster groups, which were formed by the analysis on the basis of similar species composition and abundance. Every one of the eight groups contained collections from only one season of the year. In contrast, there was a very even distribution of stations and of years within each of the groups. Most significantly, both the assemblages present and their season of occurrence, were consistent between the preoperational and operational periods.

The consistency of assemblages of fish eggs both temporally (among both months and years) and spatially (among stations) suggested that operation of Seabrook Station has not altered the seasonal spawning time nor the distribution of eggs in the Hampton-Seabrook area. The spatial stability was demonstrated by the fact that for 92% of the months analyzed, all three stations were classified into the same group. This spatial similarity was further supported by the results of MANOVA, for which a significant difference was found between the preoperational and operational periods ($p<0.001$), but the interaction was clearly not significant ($p = 0.80$). This indicated that the temporal changes in assemblage abundance occurred concurrently at all three stations, including the farfield station (P7), the control area.

Twenty-two larval taxa were selected for numerical classification analysis, which resulted in seven cluster groups (Figure 5-3). Only one monthly observation (station P2, October 1992) did not cluster within any of the seven groups. Similar to the egg collection data, two major categories were evident, with collections in Groups 1-4 occurring primarily during the cooler water temperature period (generally November through May) and collections in Groups 5-7 during the warmer period (generally June through October). Group 1, termed late fall, included primarily November and December collections (Figure 5-3). Larval Atlantic herring was the most abundant species during this period and there was a decrease in its abundance from the preoperational to the operational period (Table 5-4). Group 2, termed early winter, was more diverse and generally comprised January collections. American sand lance was most dominant, with the remaining predominant taxa (Atlantic herring, gulf snailfish, and pollock) found at lower abundances. There were no apparent differences between preoperational and operational geometric means for any of these taxa. American sand lance larvae again dominated in Group 3, termed late winter/early spring. The period of occurrence for collections of this group was relatively long, generally from February through March and sometimes April. The geometric means were similar between preoperational and operational periods for the two dominant species, American sand lance and rock gunnel. Group 4 occurred during spring and comprised May and sometimes April collections for all years. The Atlantic seasnail and American sand lance were the most abundant larvae in this group and this group was the most diverse of the seven groups. Abundance of Atlantic seasnail larvae decreased from the preoperational to the operational period, but the other species were generally collected in comparable densities before and after Seabrook Station began operation.

Group 5 collections occurred primarily during the late spring and early summer (June and July), representing the first of the warm water groups. The geometric mean for cunner, the most dominant species in this group, declined from the preoperational to the operational period. The annual seasonal patterns of occurrence for Groups 6 and 7 were less consistent than for the other groups. Although Group 6 was not present every year, cunner and fourbeard rockling larvae dominated this group during late summer (August and September). When present, this group annually occurred together at all three stations. In contrast to Group 5, cunner larvae were more abundant during the operational period than during the preoperational period. Group 7 was termed late summer/early fall, and included collections from August through October. Three of the six dominant taxa were also present in the previous group, but they were collected at much lower densities in the Group 7 samples. In general,

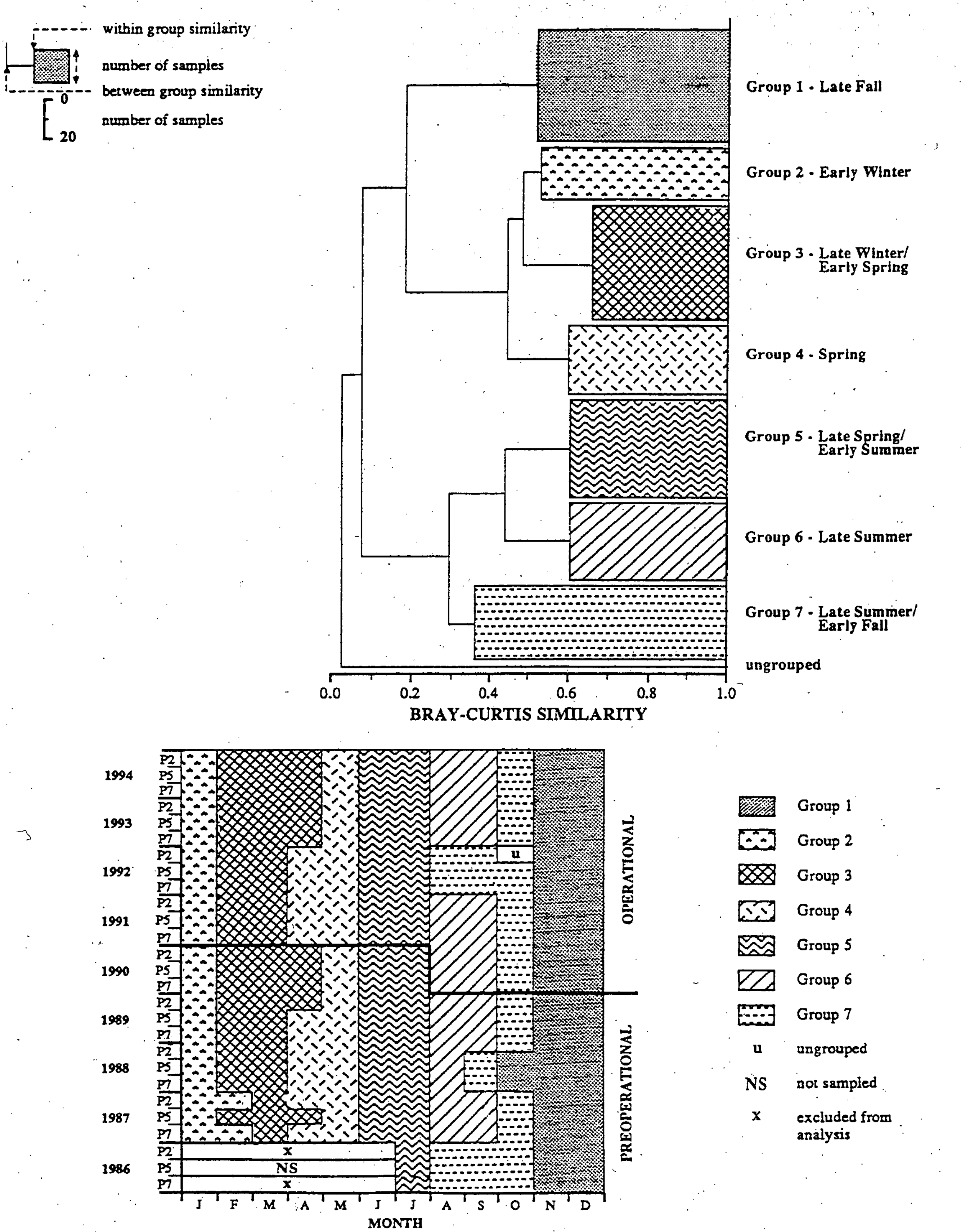


Figure 5-3. Dendrogram and temporal/spatial occurrence pattern of fish larvae assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m³) at Seabrook intake (P2), discharge (P5) and farfield (P7) stations, July 1986-December 1994. Seabrook Operational Report, 1994.

TABLE 5-4. FAUNAL CHARACTERIZATION OF GROUPS FORMED BY NUMERICAL CLASSIFICATION OF SAMPLES OF FISH LARVAE COLLECTED AT SEABROOK INTAKE (P2), DISCHARGE (P5), AND FARFIELD (P7) STATIONS DURING JULY 1986 THROUGH DECEMBER 1994.[a] SEABROOK OPERATIONAL REPORT, 1994.

		NUMBER OF SAMPLES AND DENSITY (LARVAE/1000 m^3)[d]							
		PREOPERATIONAL PERIOD[e]				OPERATIONAL PERIOD[e]			
GROUP	DOMINANT TAXA[c]	n	LCL	MEAN	UCL	n	LCL	MEAN	UCL
1-Late Fall (0.51/0.19)	Atlantic herring	27	24	41	70	30	11	15	21
	Pollock		2	3	4		<1	1	1
2-Early Winter (0.52/0.48)	American sand lance	14	12	24	48	12	17	35	69
	Atlantic herring		2	4	8		1	2	5
	Gulf snailfish		2	4	6		2	4	7
	Pollock		1	3	8		2	3	4
3-Late Winter/Early Spring (0.66/0.48)	American sand lance	27	215	295	404	30	266	332	414
	Rock gunnel		23	34	51		28	45	71
4-Spring (0.60/0.45)	Atlantic seasnail	19	20	39	75	18	12	22	39
	American sand lance		18	30	49		18	29	47
	Winter flounder		2	5	11		1	1	3
	Grubby		3	5	8		4	6	8
	Radiated shanny		2	5	10		1	3	7
	Gulf snailfish		2	4	7		1	1	2
	Rock gunnel		2	3	6		1	2	3
5-Late Spring/Early Summer (0.60/0.44)	Cunner	27	40	94	218	24	10	30	91
	Fourbeard rockling		28	50	88		18	32	56
	Atlantic mackerel		15	27	46		15	32	67
	Radiated shanny		17	26	40		25	36	52
	Winter flounder		8	14	26		8	13	22
6-Late Summer (0.60/0.44	Cunner	15	101	201	399	24	121	308	782
	Fourbeard rockling		28	62	134		24	41	71
	Hake		4	7	12		5	14	33
7-Late Summer/ Early Fall (0.36/0.29)	Fourbeard rockling	18	2	4	6	20	2	4	6
	Atlantic herring		1	4	12		1	1	2
	Cunner		1	2	4		<1	1	1
	Silver hake		<1	1	2		1	2	3
	Windowpane		1	1	2		<1	1	1
	Hake		1	1	1		<1	1	1

[a]Each "sample" consisted of the average of tows within date and dates within month.
[b](Within group/between group similarity).
[c]Those whose preoperational geometric mean densities together accounted for ≥90% of the sum of the preoperational geometric mean densities of all taxa within the group.
[d]Geometric mean and lower (LCL) and upper (UCL) 95% confidence limits.
[e]Preoperational = July 1986 - July 1990; Operational = August 1990 - December 1994.

for the months of August and September, Groups 6 and 7 were mutually exclusive, but there was no apparent pattern that could be related to plant operation.

As was the case with eggs, the cluster groups based on larval species composition and abundance were strongly related to season but were independent of station, year, and preoperational vs. operational status. In 97% of the months analyzed, all three stations were grouped in the same cluster. This high degree of similarity among nearfield (P2 and P5) and farfield (P7) collections was as true during the operational period as it was during the preoperational period. Similarity among stations was also supported by the results of MANOVA, where the preoperational-operational term was significant ($p<0.001$), but the interaction was clearly not significant ($p > 0.99$). These results indicated that the temporal changes in assemblage abundance were consistent at all three stations, including the farfield station (P7), located well outside the zone of thermal influence of Seabrook Station.

5.3.1.2 Entrainment

One of the most direct measures of potential impact of Seabrook Station on the local fish assemblages is the number of eggs and larvae entrained through the condenser cooling water system. During the abbreviated sampling in 1994, 11 egg and 12 larval taxa were collected in entrainment samples (Table 5-5). Total estimates of entrainment were 4.7 million eggs and 31.2 million larvae for the 6.5 months sampled. These numbers are much lower than the 1990-1993 estimates (Table 5-6), primarily because no sampling was conducted at times when dominant taxa would have been abundant (Figure 5-4). This was particularly true for eggs. In 1990-1993 Atlantic mackerel and cunner/yellowtail flounder composed 54-90% of the annual egg entrainment estimates, but in 1994 these two taxa were missing entirely from the total estimate (Table 5-6) because no sampling was conducted from early April through mid-September, which is the time of year they occur in the ichthyoplankton.

Total estimated larval entrainment in 1994 was roughly one-fifth to one-third of estimates for previous years, even though the 1990 estimate included only the months of June through December, and in 1991 and 1992, no entrainment sampling was conducted during a 3- to 4-month period (August or September through November) due to plant outages. The 1994 estimate does not account for any Atlantic seasnail, because no sampling was conducted during their season of occurrence. This species ranked third in 1990, fourth in 1991, second in 1992, and first in 1993 among entrained larvae (Table 5-6). The dominant larval taxon entrained was not consistent from year to year, with cunner predominating in 1990 and rock gunnel in 1991 and 1992. There was no consistent relationship between larval and egg taxa entrained in the same year, due to varying susceptibility of the two developmental stages to entrainment. Among the dominant larval species entrained are several that have demersal or adhesive eggs, which are not susceptible to entrainment, including Atlantic seasnail, grubby, American sand lance, Atlantic herring, rock gunnel, winter flounder, and gulf snailfish. Behavioral characteristics of larvae may also reduce their susceptibility to entrainment. For instance, hake and fourbeard rockling larvae are surface oriented (Hermes 1985) and may not be susceptible to the mid-water intakes. The rapid larval development of Atlantic mackerel may enable them to develop a relatively high swimming speed (Ware and Lambert 1985) and, thus, may be able to avoid entrainment.

Annual Seabrook Station entrainment estimates for the selected taxa were compared to estimates from two other New England power plants, Pilgrim and Millstone Stations, for 1990 through 1994 (Table 5-7). Except for Atlantic seasnail larvae, annual entrainment estimates for Seabrook Station had similar annual estimates or

TABLE 5-5. MONTHLY ESTIMATED NUMBERS OF FISH EGGS AND LARVAE ENTRAINED (x 10^6) BY THE COOLING WATER SYSTEM AT SEABROOK STATION FROM EARLY JANUARY THROUGH EARLY APRIL AND FROM MID-SEPTEMBER THROUGH DECEMBER 1994. SEABROOK OPERATIONAL REPORT, 1994.[a]

TAXON	JAN[b]	FEB	MAR	APR[c]	SEP[d]	OCT	NOV	DEC	TOTAL
EGGS									
Fourbeard rockling/hake	0.0	0.0	0.0	0.0	0.8	0.9	0.0	0.0	1.7
Hake	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.6
Atlantic cod/witch flounder	0.0	0.0	0.2	0.0	0.1	0.0	0.2	0.1	0.5
American plaice	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.4
Silver hake	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4
Atlantic cod/haddock	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.3
Fourbeard rockling	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2
Atlantic cod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Unidentified	0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Windowpane	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Pollock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Lumpfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
TOTAL	0.1	0.1	0.7	0.1	0.9	2.1	0.2	0.5	4.7
LARVAE									
Rock gunnel	0.0	1.8	6.6	2.7	0.0	0.0	0.0	0.0	11.0
American sand lance	0.8	5.0	2.3	0.3	0.0	0.0	0.0	0.0	8.3
Grubby	0.0	0.1	3.6	1.2	0.0	0.0	0.0	0.0	4.9
Gulf snailfish	0.0	0.7	2.8	0.1	0.0	0.0	0.0	0.0	3.5
Moustache sculpin	0.2	0.8	1.3	0.0	0.0	0.0	0.0	0.0	2.2
Unidentified	0.0	0.0	0.4	0.0	0.1	0.0	0.0	0.1	0.6
Longhorn sculpin	0.0	<0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.3
Alligatorfish	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
Atlantic herring	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Shorthorn sculpin	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Cunner	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Windowpane	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	<0.1
Redfish	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
TOTAL	0.9	8.5	17.3	4.2	0.1	0.1	0.0	0.1	31.2

[a]Estimates are unavailable for May-August and portions of January, April, and September due to lack of sampling.
[b]January estimate represents only 3 of 4 weeks due to incomplete sampling
[c]April estimate represents only 1 of 4 weeks due to incomplete sampling.
[d]September estimate represents only 2 of 4 weeks due to incomplete sampling.

TABLE 5-6. ANNUAL ESTIMATED NUMBERS OF FISH EGGS AND LARVAE ENTRAINED ($x10^6$) BY THE COOLING WATER SYSTEM AT SEABROOK STATION FROM JUNE 1990 THROUGH DECEMBER 1994. SEABROOK OPERATIONAL REPORT, 1994.

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]
EGGS					
Atlantic mackerel	518.8	673.1	456.3	112.9	0.0
Cunner/yellowtail flounder	490.4	716.3	198.6	58.4	0.0
Atlantic cod/haddock/witch flounder	29.1	74.5	39.5	50.3	1.0
Fourbeard rockling/hake	114.2	35.1	50.6	32.7	1.7
Windowpane	36.4	19.9	22.5	29.1	0.1
American plaice	2.6	21.0	52.3	19.5	0.4
Lumpfish	0.0	0.0	0.0	9.5	0.1
Fourbeard rockling	7.4	4.3	0.8	1.4	0.2
Unidentified	0.0	2.0	0.0	0.8	0.2
Silver hake	11.4	0.0	0.1	0.4	0.4
Pollock	0.0	1.0	0.4	0.2	0.1
Hake	37.3	2.6	0.0	0.2	0.6
Atlantic menhaden	0.0	0.5	1.4	0.1	0.0
Cusk	0.1	0.5	0.0	0.1	0.0
Tautog	0.0	0.2	0.0	0.0	0.0
Total	1247.7	1551.0	822.6	315.6	4.7
LARVAE					
Atlantic seasnail	11.6	16.0	31.5	64.4	0.0
Grubby	0.0	22.4	18.9	13.8	4.9
American sand lance	0.0	37.3	18.1	12.0	8.3
Atlantic herring	0.7	0.5	4.9	9.6	0.1
Rock gunnel	0.0	51.1	45.3	5.7	11.0
Unidentified	0.7	2.1	1.4	5.6	0.6
Cunner	42.7	<0.1	0.0	4.7	0.1
Winter flounder	3.2	9.0	6.2	2.9	0.0
Gulf snailfish	0.1	2.8	1.9	2.6	3.5
Fourbeard rockling	37.9	0.5	0.1	2.2	0.0
American plaice	0.4	1.0	0.8	0.7	0.0
Longhorn sculpin	0.0	0.6	0.6	0.4	0.3
Moustache sculpin	0.0	0.1	0.3	0.4	2.2
Lumpfish	0.6	0.1	0.1	0.2	0.0
Unidentified snailfish	0.1	0.3	0.0	0.2	0.0
Shorthorn sculpin	0.0	0.2	0.6	0.2	0.1
Radiated shanny	4.8	3.1	1.1	0.2	0.0
Atlantic cod	0.7	1.5	0.4	0.1	0.0
Silver hake	7.7	0.0	0.0	0.1	0.0
Windowpane	3.8	<0.1	0.1	0.1	0.1
Hake	4.8	0.0	0.0	0.1	0.0
Atlantic mackerel	0.2	4.7	0.0	0.0	0.0
Yellowtail flounder	0.1	0.3	0.1	0.0	0.0
Alligatorfish	0.0	0.1	0.2	0.0	0.2
Wrymouth	0.0	0.1	0.0	0.0	0.0
Witch flounder	0.3	0.0	0.0	0.0	0.0
Tautog	0.3	0.0	0.0	0.0	0.0
Pollock	0.2	0.0	0.1	0.0	0.0
Fourspot flounder	0.2	0.0	0.0	0.0	0.0
Rainbow smelt	0.2	0.0	0.1	0.0	0.0
Goosefish	0.1	0.0	0.0	0.0	0.0
Atlantic menhaden	0.1	0.0	0.0	0.0	0.0
Redfish	0.0	0.0	0.4	0.0	<0.1
Haddock	0.0	0.0	0.1	0.0	0.0
Unidentified sculpin	0.0	0.0	0.1	0.0	0.0
Total	121.5	153.8	133.1	126.2	31.2

[a]From NAI (1991). Represents only 7 months.
[b]From NAI (1992). Represents only 8 months.
[c]From NAI (1993). Represents only 9 months.
[d]From NAI and NUS (1994).
[e]Represents only 6.5 months.

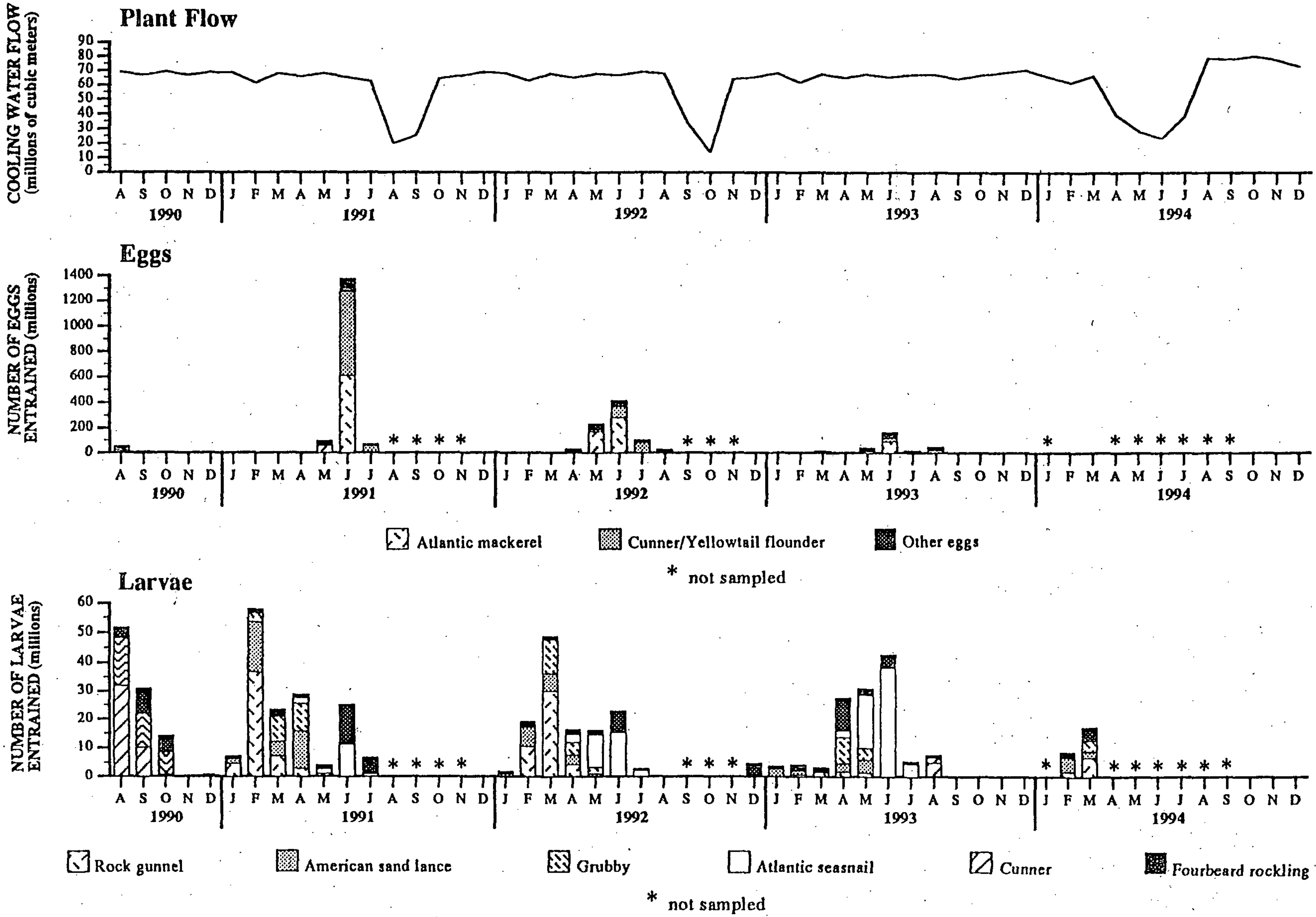


Figure 5-4. Total monthly cooling water system flow and estimated numbers of fish eggs and larvae entrained during the operational period. Seabrook Operational Report, 1994.

TABLE 5-7. COMPARISON OF ENTRAINMENT ESTIMATES (x 10^6) FOR SELECTED TAXA AT SELECTED NEW ENGLAND POWER PLANTS WITH MARINE INTAKES FROM 1990 THROUGH 1994. SEABROOK OPERATIONAL REPORT, 1994.

TAXON	SEABROOK	PILGRIM[a]	MILLSTONE[b]
Cunner/yellowtail flounder/tautog eggs[c]	0[f]-716	860-4122	2,736-5,750
Atlantic mackerel eggs	0[f]-673	337-2066	-
Atlantic herring larvae	<1[f]-10	1-18	-
Cunner larvae	0[f]-43	4-323	-
Grubby larvae[d]	5[f]-22	7-44	34-76
Atlantic seasnail larvae[e]	0[f]-64	2-11	-
Rock gunnel larvae	6-51	7-62	-
American sand lance larvae	8[f]-37	23-459	7-77
Atlantic mackerel larvae	0[f]-5	3-66	-
Winter flounder larvae	0[f]-9	9-21	45-514

[a]MRI (1991, 1992, 1993b, 1994, 1995); Cape Cod Bay.
[b]NUSCO (1994a, 1994b, 1995); eggs-1990-1993, larvae-1990-1994; Long Island Sound.
[c]Seabrook-cunner/yellowtail flounder; Pilgrim-cunner/tautog/yellowtail flounder; Millstone-cunner.
[d]Seabrook and Millstone-grubby; Pilgrim-grubby and other sculpins.
[e]Seabrook-Atlantic seasnail; Pilgrim-Atlantic seasnail and other snailfishes.
[f]Lowst estimate occurred in a year when samples are lacking in some or all of the months when this taxon normally would be entrained (1990's estimate was not included for those taxa usually present before June, when the entrainment sampling program was begun).

were considerably less than at the other two power plants.

5.3.2 Adult Fish Assemblages

5.3.2.1 Pelagic Fishes

The pelagic fish assemblage was sampled using a gill net array at three stations (Figure 5-1). Geometric mean CPUE (catch per 24-hour set) of all fish caught at all three stations combined for 1994 was 2.1, an increase from a mean of 1.8 in 1993, and generally similar to annual means found throughout the 1980s (Figure 5-5). Largest catches were made during the first five full years of sampling (i.e., 1976-80). Catch in 1994 was dominated by the Atlantic mackerel, Atlantic herring, pollock, and blueback herring (Table 5-8).

In general, CPUE at the three gill net stations followed similar trends during the 19-year period of sampling (Figure 5-5), as did the catch of the most numerous species (Table 5-8). Slightly higher catches were made at G3, the northernmost station, particularly during the first few and the most recent years of sampling. Catch during the preoperational period (1976-89) was dominated by Atlantic herring, blueback herring, silver hake, pollock, and Atlantic mackerel (Table 5-8). For the operational period (1991-94), most of the catch was made up of Atlantic herring, pollock, Atlantic mackerel, and spiny dogfish.

The spiny dogfish has become increasingly abundant during the operational period, with a geometric mean CPUE of 0.2, which is approximately seven times the CPUE determined for the preoperational period. Catch in 1994 (0.1) and 1993 (<0.1; NAI and NUS 1994) decreased substantially from the CPUE of 0.4 determined for 1992 (NAI 1993). Spiny dogfish abundance in the region has increased continuously since the 1960s, and, together with skates, now makes up about 75% of the fish biomass on Georges Bank (NFSC 1993). In the Gulf of Maine, the spiny dogfish is primarily found inshore during summer. It is known to prey upon Atlantic herring, Atlantic cod, Atlantic mackerel, and American sand lance, among other species (NFSC 1993). Because female spiny dogfish bear live young that are relatively large and well-developed, no specimens have been entrained at Seabrook Station and only five have been impinged on the traveling screens since 1990. The recent increase in spiny dogfish biomass has taken place concurrently with decreases in groundfish stocks in a large region of the Northwest Atlantic Ocean (NFSC 1993) and, thus, is not related to Seabrook Station operation.

5.3.2.2 Demersal Fishes

A 9.8-m otter trawl was used at three stations (Figure 5-1) to determine the abundance and distribution of demersal fishes. Geometric mean CPUE (catch per 10-minute tow) of all fish caught at all stations combined in 1994 was 12.9, a decrease from the CPUE of 20.6 determined for 1993, and it was the second-lowest CPUE since sampling began in 1976 (Figure 5-6). The trawl CPUE peaked in 1980 (78.6) and 1981 (77.6), primarily due to large catches of yellowtail flounder. In 1994, catch was dominated by longhorn sculpin, winter flounder, yellowtail flounder, skates, hakes, and windowpane (Table 5-9).

Catch of nearly all species declined from the preoperational to the operational period, particularly for the yellowtail flounder (CPUE of 9.3 and 2.0, respectively). Other species with decreased CPUE included the longhorn sculpin (4.1, 3.0), winter flounder (3.5, 3.1), hakes (3.2, 1.3), Atlantic cod (1.8, 0.7), and windowpane (1.3, 0.9). The catch of skates was similar (1.9, 2.0) in both periods. Among commonly captured species, only pollock (0.4, 0.5) and skates (1.9, 2.0) increased in CPUE between the preoperational and operational periods. As noted previously, groundfish stocks have all decreased in the Northwest Atlantic

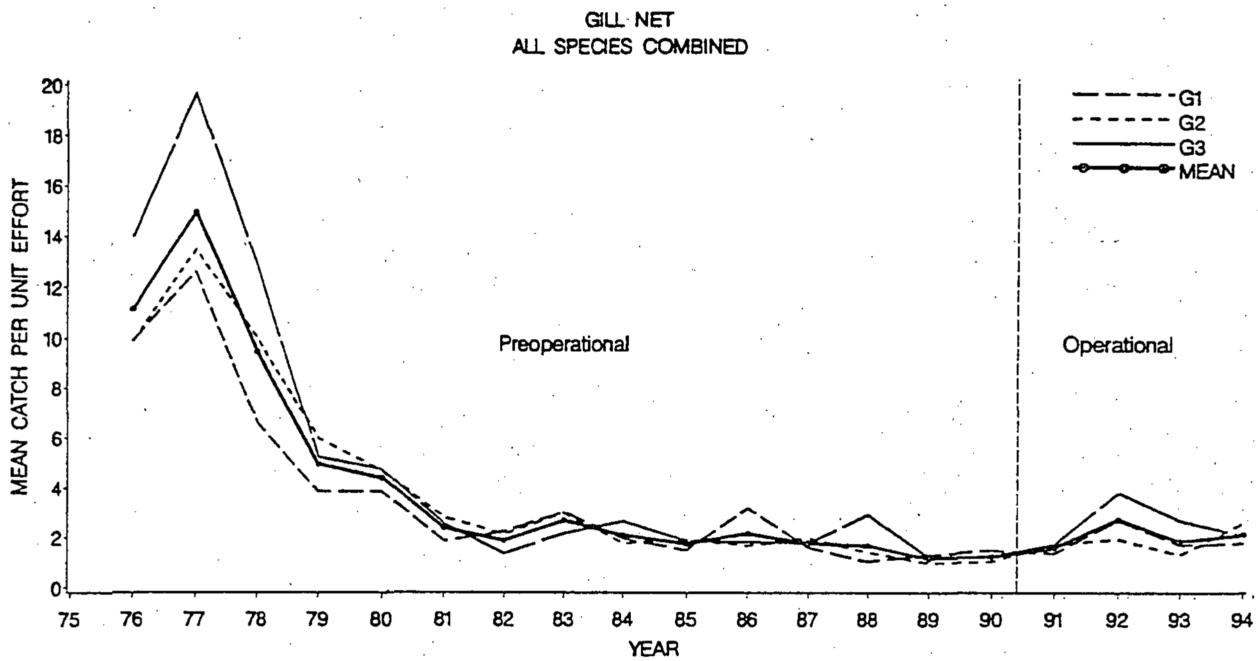


Figure 5–5. Annual geometric mean catch of all species combined per unit effort (number per 24–h set) in gill net samples by station and the mean of all stations, 1976–1994. Seabrook Operational Report, 1994.

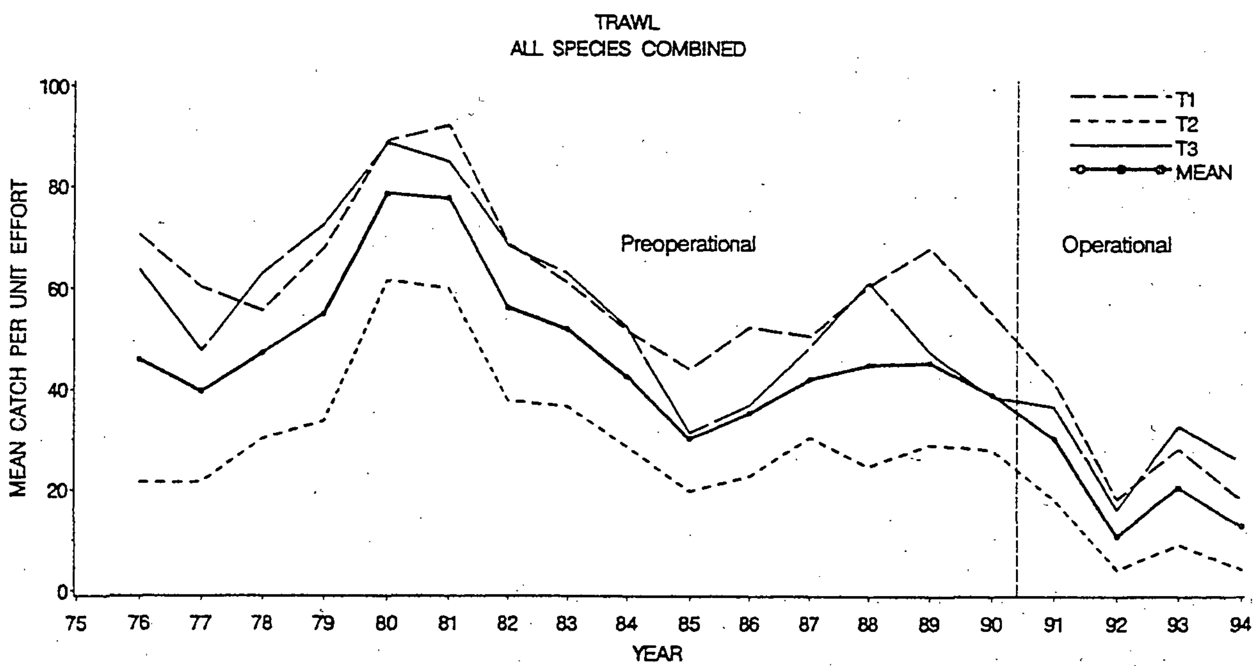


Figure 5–6. Annual geometric mean catch of all species combined per unit effort (number per 10–min tow) in trawl samples by station and the mean of all stations, 1976–1994. Seabrook Operational Report, 1994.

TABLE 5-8. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 24-h SET, SURFACE AND BOTTOM) WITH COEFFICIENT OF VARIATION (CV) BY STATION (G1, G2, AND G3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED BY GILL NET DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1994 MEAN. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	STATION	PREOPERATIONAL PERIOD[a] MEAN	PREOPERATIONAL PERIOD[a] CV	1994[b] MEAN	OPERATIONAL PERIOD[c] MEAN	OPERATIONAL PERIOD[c] CV
Atlantic herring	G1	1.0	18	0.3	0.4	13
	G2	1.1	20	0.2	0.3	23
	G3	1.2	21	0.7	0.5	10
	All Stations	1.1	19	0.4	0.4	9
Atlantic mackerel	G1	0.2	16	0.5	0.3	24
	G2	0.2	15	0.7	0.4	37
	G3	0.3	16	0.4	0.4	14
	All Stations	0.2	15	0.5	0.3	23
Pollock	G1	0.2	17	0.3	0.2	20
	G2	0.3	10	0.5	0.3	16
	G3	0.3	13	0.2	0.2	20
	All Stations	0.3	9	0.3	0.3	14
Spiny dogfish	G1	<0.1	45	0.1	0.1	65
	G2	<0.1	35	0.1	0.1	36
	G3	<0.1	27	0.1	0.2	49
	All Stations	<0.1	30	0.1	0.2	44
Silver hake	G1	0.2	34	0.1	<0.1	68
	G2	0.3	36	0.0	0.1	47
	G3	0.3	32	<0.1	0.1	78
	All Stations	0.3	34	<0.1	0.1	44
Blueback herring	G1	0.2	17	0.1	0.1	26
	G2	0.3	18	0.2	0.1	25
	G3	0.3	24	0.2	0.1	29
	All Stations	0.3	18	0.2	0.1	16
Alewife	G1	0.1	17	0.1	0.1	33
	G2	0.1	14	0.1	0.1	33
	G3	0.1	21	0.0	0.1	51
	All Stations	0.1	14	<0.1	0.1	38
Rainbow smelt	G1	<0.1	26	<0.1	0.1	54
	G2	0.1	21	0.1	0.1	34
	G3	0.1	21	<0.1	0.1	50
	All Stations	0.1	18	0.1	0.1	42
Atlantic cod	G1	0.1	18	<0.1	<0.1	76
	G2	0.1	22	<0.1	<0.1	58
	G3	0.1	13	0.0	0.0	–
	All Stations	0.1	13	<0.1	<0.1	68
Other species	G1	0.4	9	0.2	0.3	17
	G2	0.4	11	0.2	0.3	25
	G3	0.3	12	0.1	0.2	31
	All Stations	0.4	10	0.2	0.3	20

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1994 data.
[c]Operational: 1991-1994 geometric mean of annual means.

TABLE 5-9. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 10-min TOW) WITH COEFFICIENT OF VARIATION (CV) BY STATION (T1, T2, AND T3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED BY OTTER TRAWL DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1994 MEAN. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL PERIOD[a]		1994[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Yellowtail flounder	T1	20.0	3	4.0	4.3	36
	T2	2.7	8	0.1	0.3	20
	T3	10.2	5	1.7	1.8	16
	All stations	9.3	4	1.9	2.0	10
Longhorn sculpin	T1	4.6	7	3.8	3.4	8
	T2	1.1	12	0.3	0.4	9
	T3	8.3	6	7.2	5.9	4
	All stations	4.1	7	3.5	3.0	5
Winter flounder	T1	3.1	6	2.1	3.1	10
	T2	5.9	6	1.8	2.3	12
	T3	2.2	7	3.5	3.2	3
	All stations	3.5	5	2.5	3.1	8
Hakes[d]	T1	4.1	5	0.8	1.5	17
	T2	1.7	7	0.2	0.6	28
	T3	3.5	5	1.0	1.2	18
	All stations	3.2	4	0.8	1.3	17
Atlantic cod	T1	2.0	10	0.3	0.7	52
	T2	0.7	16	<0.1	0.1	40
	T3	3.2	11	1.0	1.3	44
	All stations	1.8	11	0.4	0.7	48
Skates	T1	1.7	15	1.9	2.6	13
	T2	0.6	10	0.3	0.2	20
	T3	3.7	5	3.2	3.0	13
	All stations	1.9	9	1.9	2.0	11
Windowpane	T1	1.9	11	1.3	1.8	10
	T2	0.9	10	0.1	0.5	28
	T3	1.0	13	0.2	0.5	31
	All stations	1.3	10	0.6	0.9	17
Rainbow smelt	T1	1.1	9	0.3	0.4	11
	T2	1.8	9	0.3	0.6	33
	T3	0.8	14	0.2	0.4	28
	All stations	1.1	9	0.2	0.4	24
Ocean pout	T1	0.7	6	0.1	0.1	23
	T2	0.6	8	0.1	0.2	21
	T3	1.4	7	0.1	0.3	21
	All stations	0.8	6	0.1	0.2	20
Silver hake	T1	0.9	16	0.4	0.4	14
	T2	0.2	21	0.0	<0.1	62
	T3	0.8	13	0.6	0.6	14
	All stations	0.7	14	0.4	0.4	14
Pollock	T1	0.3	18	0.4	0.6	28
	T2	0.7	21	1.1	0.7	21
	T3	0.2	20	0.3	0.2	21
	All stations	0.4	18	0.5	0.5	20
Haddock	T1	0.2	34	<0.1	<0.1	58
	T2	<0.1	64	0.0	0.0	—
	T3	0.5	28	<0.1	0.1	50
	All stations	0.2	28	<0.1	<0.1	47
Other species	T1	1.6	6	1.2	1.4	9
	T2	1.6	7	0.3	0.8	29
	T3	1.2	7	0.6	0.7	16
	All stations	1.4	5	0.8	1.0	14

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1993 data.
[c]Operational: 1991-1993; geometric mean of annual means.
[d]May include red hake, white hake, spotted hake, or more than one of these species.

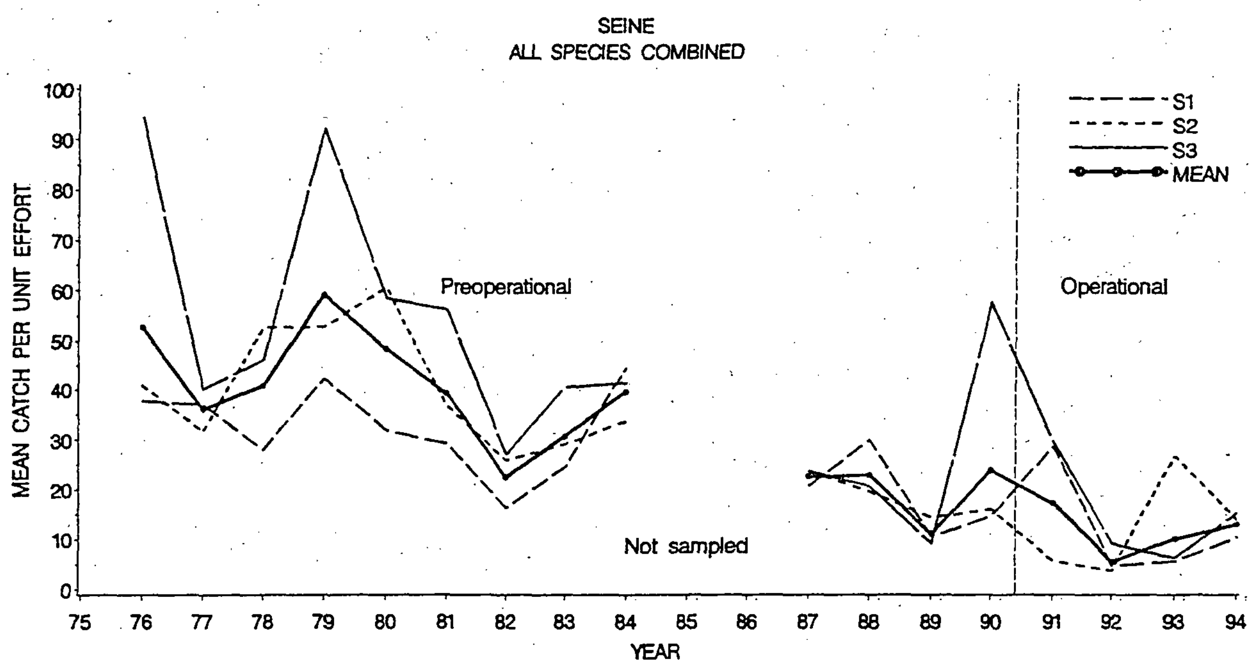


Figure 5-7. Annual geometric mean catch of all species combined per unit effort (number per haul) in seine samples by station and the mean of all stations, 1976-1994. Seabrook Operational Report, 1994.

and skate biomass is currently high in this area (NFSC 1993).

Differences in CPUE and species composition were apparent among the stations. The bottom at nearfield station T2, located in shallow (15-17 m) water off the mouth of Hampton-Seabrook Harbor, was occasionally inundated with drift algae. Stations T1 and T3 are in deeper water (20-28 and 22-30 m, respectively) and have sandy bottoms. CPUE of all species combined was consistently lower at T2 than at T1 and T3, which tended to have similar catches (Figure 5-6). Catch at T2 was dominated by winter flounder, whereas yellowtail flounder (preoperational period) and longhorn sculpin (operational period) were most common at T1 and T3. However, station to station comparisons are limited by the inability to sample by trawl at T2 during many sampling trips, particularly from August through October, when catches tend to be largest. Because largest catches were often made during late summer and early fall, this may have biased interstation comparisons, which used the entire database. Because of this potential bias, data from the August-October period were not used in any of the ANOVA's for selected species collected by trawl sampling (Section 5.3.3). For other months during the past 18 years, a few collections were missed at T2, but overall trawl sampling effort at T2 was 82% of that at T1 or T3.

5.3.2.3 Estuarine Fishes

Sampling for estuarine fishes was conducted at three stations within the estuary of Hampton-Seabrook Harbor (Figure 5-1) using a 30.5-m seine. Geometric mean CPUE (catch per haul) for all fish caught at all stations during 1994 was 13.1, a slight increase in catch from 1993 (CPUE of 10.2; Figure 5-7). Overall, seine catches generally were smaller (5.6-24.1) during 1987-94 than they were during 1976-84, when annual CPUE ranged from 22.7 to 59.1; no seine sampling took place in 1985 or April through June of 1986. The catch of most fishes by seine decreased from the preoperational to the operational period (Table 5-10). The Atlantic silverside has dominated the seine catch in all years sampled. Winter flounder, killifish (mummichog or striped killifish), ninespine stickleback, and rainbow smelt also contributed frequently to the catch.

Catch by station showed considerable variation over the years. Station S3, located near the mouth of the estuary, had peak catches in 1976, 1979, and 1990, but its CPUE has been generally close to the three-station mean since 1991. Station S1, located farthest from the mouth, had relatively low CPUE during the earliest years of sampling, but tended to approximate the overall mean in more recent years. CPUE at S2, located closest to Seabrook Station, had the largest CPUE value in 1993 and was similar to the three station average in 1994. Trends in CPUE were mostly due to the fluctuations in catch of the dominant species, Atlantic silverside. Winter flounder and rainbow smelt were most common at S3, whereas killifish were most abundant at S1, with few taken at S3, likely due to salinity and temperature preferences.

5.3.2.4 Impingement

Seabrook Station operated throughout 1994, with average circulating water flow ranging from 212 to 692 million gallons/day (Table 5-11). During 1994, an estimated 19,221 fish, American lobster, and seals were impinged (Table 5-11). Most (84%) fish were collected in December, followed by November (8%) and October (6%). Impingement in the fall and early winter usually increased due to northeast storms (NAI and NUS 1994). The last quarter of 1994 was no exception, as impingement increased significantly compared to previous months. However, impingement in the last quarter of 1994 was also much higher than the last quarter of previous years. The primary reason for the increase in impingement in the last quarter of 1994 was an increase in the efficiency of sample collection and processing (Drawbridge 1995; pers. comm. to McSweeney USEPA). Impingement samples historically were collected and processed by Seabrook Station personnel. In October of 1994 it became apparent that plant personnel were not adequately removing small fishes from the screenwash debris. Supervisory environmental personnel began collecting and processing impingement samples in October, and the numbers of fish retrieved from screenwash debris increased dramatically. Environmental personnel are continuing to conduct impingement monitoring in 1995. The numbers of fish impinged at Seabrook Station in 1990 through October 1994 were probably underestimated because small fish were not adequately removed from the screenwash debris.

Since 1990, when the station began more or less continuous pumping of seawater, the estimated cumulative impingement totaled 23,009 fish and 73 American lobster (Appendix Table 5-2). More than 75% of all fish recorded since 1990 were collected in December (Appendix Table 5-3). Very few (2%) fish were impinged in June-August. During the 4-yr operational period, Atlantic silverside, hake spp., grubby, pollock, winter flounder, windowpane, and American sand lance made up 78% of the total estimated impingement. Atlantic silverside were the most numerous fish impinged (5,579), and the majority of this impingement occurred in the late fall. This fish is extremely numerous in New England estuaries and is found occasionally in otter trawls and rarely in gill net samples (Appendix Table 5-1). Atlantic silverside leave the estuary in the winter as temperatures drop and overwinter in waters less than 40 m deep (Conover and Murawski 1982). These fish were probably impinged during their winter offshore movement.

With the exception of Atlantic silverside and possibly pollock, the majority of the fishes impinged were demersal. Few pelagic fishes such as Atlantic herring, Atlantic mackerel, alewife, and blueback herring are

TABLE 5-10. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER STANDARD HAUL) WITH COEFFICIENT OF VARIATION (CV) BY STATION (S1, S2, AND S3) AND ALL STATIONS COMBINED FOR ABUNDANT SPECIES COLLECTED BY SEINE DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND THE 1994 MEAN. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL PERIOD[a]		1994[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Atlantic silverside	S1	7.2	7	3.6	3.6	13
	S2	6.8	6	3.1	3.7	14
	S3	6.7	10	3.5	3.9	11
	All stations	6.9	7	3.4	3.7	8
Winter flounder	S1	0.9	11	1.0	0.5	42
	S2	1.0	14	0.1	0.3	59
	S3	3.2	9	0.7	1.0	11
	All stations	1.5	8	0.5	0.6	12
Killifishes	S1	1.1	10	0.5	0.8	45
	S2	1.2	19	0.7	0.2	71
	S3	<0.1	27	<0.1	<0.1	100
	All stations	0.7	13	0.4	0.3	33
Ninespine stickleback	S1	0.7	20	0.3	0.3	36
	S2	0.8	28	<0.1	0.1	24
	S3	0.8	24	0.1	0.2	64
	All stations	0.8	20	0.1	0.2	31
Rainbow smelt	S1	0.1	41	0.4	0.2	52
	S2	0.2	31	0.2	0.3	42
	S3	0.7	21	0.8	0.5	36
	All stations	0.3	16	0.4	0.3	28
American sand lance	S1	0.1	44	0.0	0.2	33
	S2	0.2	48	0.0	0.2	100
	S3	0.1	28	1.5	0.3	82
	All stations	0.1	28	0.4	0.2	28
Pollock	S1	0.1	40	0.0	0.1	58
	S2	0.2	40	0.0	<0.1	100
	S3	0.4	36	0.0	0.1	58
	All stations	0.2	35	0.0	0.1	47
Blueback herring	S1	0.2	29	0.1	0.2	53
	S2	0.1	36	0.0	0.1	100
	S3	0.1	38	0.0	<0.1	100
	All stations	0.1	29	0.0	0.1	51
Atlantic herring	S1	0.1	59	0.0	0.1	67
	S2	0.3	27	0.0	0.1	66
	S3	0.1	24	0.1	0.1	64
	All stations	0.2	19	<0.1	0.1	44
Alewife	S1	0.1	38	0.0	<0.1	61
	S2	0.1	49	0.0	0.0	–
	S3	0.1	31	0.0	<0.1	100
	All stations	0.1	33	0.0	<0.1	36
Other species	S1	0.8	14	0.7	0.3	33
	S2	1.1	8	1.8	0.6	40
	S3	1.5	12	1.2	1.0	21
	All stations	1.1	9	1.2	0.6	25

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1994data.
[c]Operational: 1991-1994 geometric mean of annual means.
[d]May include red hake, white hake, spotted hake, or more than one of these species.

TABLE 5-11. SPECIES COMPOSITION AND TOTAL NUMBER OF FINFISH, AMERICAN LOBSTER AND SEALS IMPINGED AT SEABROOK STATION BY MONTH DURING 1994.[a,b] SEABROOK OPERATIONAL REPORT 1994.

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	PERCENT
Atlantic silverside			3								27	5318	5348	27.82
Hake spp.									2	22	285	2513	2822	14.68
Grubby	2	2	2								60	2612	2678	13.93
Pollock									46	903	408	324	1681	8.75
Winter flounder	6	1	13				1		4		10	1400	1435	7.47
American sand lance												1215	1215	6.32
Windowpane									96	33	127	724	980	5.10
Rainbow smelt	2											543	545	2.84
Herring spp.								1	1		356	156	514	2.67
Rock gunnel									6	95	54	339	494	2.57
Sculpin spp.						2						203	205	1.07
Skate spp.	7		1						11	1	1	169	190	0.99
Northern pipefish	1								3	19	93	72	188	0.98
Lumpfish		3	34	8	6	35		6				90	182	0.95
Seasnail spp.			1						1		52	126	180	0.94
Longhorn sculpin	5	1		2		2	1		1	7	37	49	105	0.55
Sea raven	5		2	2	1	1		3	7	11	24	22	78	0.41
Flounder spp.	2	2	9								2	62	77	0.40
Threespine stickleback			2						1			64	67	0.35
Atlantic cod	1		2			2			2	3	1	47	58	0.30
Wrymouth												55	55	0.29
Cunner	1		1					1	8	11	9	1	32	0.17
American lobster		2							4	8	8	9	31	0.16
Shorthorn sculpin				3	3	3			2		2	1	14	0.07
Blueback herring										13			13	0.07
Seal										3	3		6	0.05
Unidentified									1	5			6	0.03
Killifish spp.												4	4	0.02
Summer flounder									3				3	0.02
Butterfish									1		1	1	3	0.02
Goosefish											2	1	3	0.02
Fourspot flounder									2				2	0.01
Red hake									1				1	0.01
Atlantic tomcod									1				1	0.01
Spiny dogfish										1			1	0.01
White hake									1				1	0.01
Column total:	32	11	70	15	10	45	2	11	205	1134	1563	16123	19218	
CIRCULATING WATER AVERAGE FLOW (MGD)	566	589	573	352	242	212	331	681	695	690	692	628	190077[c]	
RATE (# FISH/MG)	0.002	0.001	0.004	0.001	0.001	0.007	0.000	0.001	0.010	0.053	0.075	0.828	0.102	

[a]Data provided by North Atlantic Energy Service Company.
[b]Impingement data prior to October 1994 was underestimated (see Summary).
[c]Represents the total flow/year in MG

impinged as Seabrook Station, even though the plant draws water from mid-depths.

In addition to the fishes, six seals were impinged in 1994. This is an increase over 1993 when one seal was impinged. Two factors appear to account for the increase in seal impingement. The population of harbor seals in New England is increasing. A recent study showed that the population of harbor seals in southern Maine and New Hampshire (Isle of Shoals to Pemaquid Point) has nearly doubled since 1986 (Kenney and Gilbert 1994). The second factor is time of year. Harbor seals migrate to the warmer waters of Massachusetts, Rhode Island and New York in the fall, returning to northern waters in April (Payne and Selzer 1989 cited in Gilbert 1994). Increased number of seals passing through New Hampshire waters increase the probability of contact with the intake structure.

Seals in general are omnivorous, and are not restricted to consuming fish. Two of the seals impinged in 1994 had fed recently, as evidenced by the presence of fish in their stomach. It is possible that these seals were feeding on fish near the intakes. Large numbers of pollock were impinged in October and November 1994 when the seals were impinged. However, few fish were present in impingement samples in October of 1993 when another seal was impinged. Divers have observed pollock near the intake structures but they appeared to be transitory and did not readily enter the structures.

The number of fish impinged annually at Seabrook Station may be compared to collections or annual estimates made at other large power plants in New England with marine intakes (Table 5-12). From November 1972 through October 1977, nearly 300,000 fish weighing 3,040 kg were collected in 215 24-h samples of impingement at the Maine Yankee Nuclear Generating Station (Evans 1978). The mean number of fish collected each year was approximately 50,000 fish during this period, with an average of 1,395 fish impinged per sampling day. Most fish were collected from November through April, when water temperatures were less than 10°C. Sticklebacks (four species), smooth flounder, alewife, rainbow smelt, Atlantic menhaden, winter flounder, and white perch dominated impingement samples, indicative of this power plant's location within the Sheepscot River estuary. No lobster were impinged at Maine Yankee.

At Pilgrim Nuclear Power Station, sited on Massachusetts Bay, an estimated annual average of 20,029 fish (adjusted for 100% plant operation) was calculated for a 20-yr period (Anderson 1995; Table 5-12). The mean impingement rate was 55 fish per day. During this period, catch was dominated mostly by Atlantic silverside, with rainbow smelt, herrings, and cunner occasionally abundant in samples. In 1994, 97 American lobster were collected, giving an estimated total impingement of 1,152 lobster for 100% station operation, which was a higher estimate than for most other years of Pilgrim Station operation (Anderson 1995).

In 21 years of study, an average of 54,433 fish was impinged annually at the Brayton Point Station (Units 1-3), located on Mount Hope Bay in Massachusetts (MRI 1993a; Table 5-12). Atlantic menhaden, winter flounder, Atlantic silverside, hogchoker, alewife, silver hake, and threespine stickleback were most often impinged. Fish were impinged at an average rate of 118 per day. In a study to determine the effectiveness of angled screens at Brayton Point Unit 4 (LMS 1987), total numbers of fish collected on the screens were 18,095 in 1985 and 1,449 in 1986. These numbers represented fish actually collected and no annual estimates were determined in this study. Bay anchovy made up most (77%) of the catch in 1985; Atlantic silverside, northern pipefish, winter flounder, butterfish, and tautog were also relatively common.

Impingement sampling was conducted at Millstone Nuclear Power Station Unit 2, located on Long Island Sound, from 1976 through 1987 (NUSCO 1988). Annual impingement estimates for fish ranged from

TABLE 5-12. COMPARISON OF FISH IMPINGEMENT ESTIMATES AT SELECTED NEW ENGLAND POWER PLANTS WITH MARINE INTAKES. SEABROOK OPERATIONAL REPORT, 1994.

STATION	SOURCE WATER BODY	RATED CAPACITY (MWe)	NOMINAL COOLING WATER FLOW ($m^3 \cdot sec^{-1}$)	YEARS OF STUDY	MEAN ANNUAL IMPINGEMENT	CV (%)	RANGE FOR ANNUAL ESTIMATES	MEAN NUMBER PER DAY	REFERENCE
Seabrook	Gulf of Maine	1,150	31.5	1990-94	4,618	177	499-19,221	12.7	------
Maine Yankee	Montsweag Bay	855	26.6	1972-77	49,999[a]	34	31,246-73,420[a]	1,395[a]	Evans (1978)
Pilgrim	Massachusetts Bay	670	20.3	1974-94	20,029[b]	115	1,143-87,752[b]	55[b]	Anderson (1995)
Brayton Point 1-3	Mount Hope Bay	1,150	39.0	1972-92	54,433	136	15,957-359,394	118	MRI (1993a)
Brayton Point 4	Mount Hope Bay	460	16.4	1984-85	-	-	1,479-18,095[a]	-	LMS (1987)
Millstone 2	Long Island Sound	870	34.6	1976-87	25,927[c] 65,927[d]	59 214	8,560-60,410[c] 8,560-511,387[d]	71[c] 181[d]	NUSCO (1988)

[a] Collected in sampling only, not a calculated annual estimate.
[b] Estimates adjusted assuming 100% station operation.
[c] Excluding an estimated 480,000 American sand lance taken on July 18, 1984.
[d] Including the sand lance mass impingement episode.

8,560 to 511,387 (Table 5-12). The highest estimate, however, was skewed by a single-day catch of approximately 480,000 American sand lance. Excluding this catch, the largest annual total was 60,410 and the annual mean impingement was 25,927 (71 fish per day). Impingement samples at Millstone Unit 2 were dominated by winter flounder, anchovies, grubby, silversides, and Atlantic tomcod. Annual impingement estimates for American lobster ranged from 261 to 1,167, with an annual mean of 634 (CV = 14%).

Impingement estimates at Seabrook Station were apparently much less (≤ 23%) than those at comparable electrical generating stations in New England. However, as previously discussed, impingement at Seabrook Station was underestimated prior to October 1994. The magnitude of the underestimate is not known, but may become apparent with the collection of the 1995 impingement data. Impingement at a power plant does not reflect absolute fish abundance near the station, but is related to the susceptibility of a species to entrapment, intake design and location, plant operating characteristics, environmental variables (e.g., water temperature, wave height, wind direction and velocity), and time of day (Landry and Strawn 1974; Grimes 1975; Lifton and Storr 1978). The design of Seabrook Station offshore intake with a mid-water entrance and a velocity cap located in a relatively open water body has apparently been successful at reducing the impingement of fish and lobster. Except for pollock and Atlantic silverside, demersal fish are most often impinged. This indicates that some features of the intake, as well as fish behavior and distribution, allow for the entrapment of bottom-dwelling species under certain conditions. The magnitude of impingement at Seabrook Station appears to be affected primarily by storms, particularly northeasters (NAI 1993). A similar phenomenon was noted at Millstone Nuclear Power Station, where large winter flounder impingement episodes were found to be related to a combination of high sustained wind and low water temperatures (NUSCO 1987). Storm events have also increased impingement at other estuarine (Thomas and Miller 1976) and freshwater (Lifton and Storr 1978) power plants.

5.3.3 Selected Species

5.3.3.1 Atlantic Herring

The Atlantic herring ranges in the Northwest Atlantic Ocean from western Greenland to Cape Hatteras (Scott and Scott 1988). Separate spawning aggregations associated with particular geographic areas in the Gulf of Maine have been recognized (Anthony and Boyar 1968; Iles and Sinclair 1982; Sinclair and Iles 1985) and tagging studies have shown high (> 90%) homing fidelity of spawning herring (Wheeler and Winters 1984). However, a lack of evidence exists for biochemical, genetic, and morphometric differentiation among these spawning groups (Kornfield and Bogdanowicz 1987; Safford and Booke 1992), indicating that there is enough gene flow to prevent the evolution of genetically distinct stocks. Atlantic herring spawning grounds are typically located in high energy environments (i.e., tidal or current), with demersal adhesive eggs deposited on marine vegetation or substrata free from silting (Haegele and Schweigert 1985). A major spawning area and source of larvae in the western Gulf of Maine is Jeffreys Ledge (Townsend 1992), although other banks and ledges in this area are also used (Boyar et al. 1971). Other major spawning grounds include Georges Bank and coastal areas of central and eastern Maine and Nova Scotia (Sinclair and Iles 1985).

Currently, the median age and size of maturity for U.S. coastal Atlantic herring is about 3 years and 25 cm (O'Brien et al. 1993); all fish become mature by age-5 (NFSC 1993). Maximum size is about 430 mm and 0.68 kg (Bigelow and Schroeder 1953). Most spawning in the western Gulf of Maine occurs during September and October (Lazzari and Stevenson 1993). Fecundity of fall-spawning Atlantic herring from southwest Nova Scotia ranged from about 50,000 to

222,000 eggs (Messieh 1976). The early life history of Atlantic herring is somewhat unique among other northern temperate fishes in that the larval stage is up to eight months old before metamorphosis to a juvenile phase (Sinclair and Tremblay 1984). Instead of spawning in spring to coincide with increasing water temperature and plankton food resources, fall-spawning herring must deal with extremely low winter temperatures and minimum plankton abundances (Townsend 1992). The 1.0-1.4-mm eggs hatch in about 10-15 days, when larvae are 4-10 mm (Fahay 1983). Hatching and larval growth are highly variable and depend mostly upon prevailing water temperatures. Lough et al. (1982) noted that larvae hatching at 5.7 mm grew to 30.9 mm over a 175-day period. Graham and Townsend (1985) reported mean growth of 0.199 mm/day (range of 0.123-0.270) and a mortality rate of 2% per day (0.7-3.1%) for Gulf of Maine larval Atlantic herring. Larvae hatched early in the season grow faster than those hatched late (Jones 1985). Larval mortality is generally highest in fall, low in winter, and increases again in spring (Graham et al. 1972). Larvae tend to drift or disperse from offshore spawning grounds into coastal bays and estuaries for further development and transformation to the juvenile phase of life. After metamorphosis, juveniles remain in coastal waters during summer. Adults tend to be found in specific summer feeding areas that are located near tidally-induced temperature fronts, where plankton productivity is high, and they overwinter after spawning in areas with slower currents than found elsewhere in the Gulf of Maine (Sinclair and Iles 1985).

Graham (1982) hypothesized that year-class strength was determined by a density-dependent mortality phase in fall and a density-independent phase in winter, both of which may be affected by the time of spawning and larval distribution following hatching and dispersion. Campbell and Graham (1991), however, noted that herring recruitment is a complex interaction among many critical factors, which may differ from year to year. A series of successive cohorts in space and time may help to limit intraspecific competition and mortality (Lambert 1984; Lambert and Ware 1984; Rosenberg and Doyle 1986). An inverse relationship was found between year-class strength and temperature during the late larval and early juvenile phases (Anthony and Fogarty 1985). Survival may be related to the rate at which temperature decreases in winter as well as to the absolute minimum temperatures (Graham et al. 1990). Low temperatures may also indirectly increase starvation and vulnerability to predation. Pedersen (1994) found that survival and larval length was related to changes in food availability. Larvae exposed to varying prey abundance grew less and had lower survival than larvae exposed to a continuously high ration.

Abundance and landings of Atlantic herring have fluctuated considerably over the past 35 years (NFSC 1993). During this period, the fishery in Maine has also changed from predominantly fixed gear to almost all mobile gear in recent years, due to the decreased availability of fish in nearshore areas. The Atlantic herring fishery on Georges Bank peaked at 373,600 metric tons in 1960, but collapsed to 43,500 metric tons in 1976. Recent indications are that the population on Georges Bank is recovering (Stephenson and Kornfield 1990; Smith and Morse 1993). Present biomass may even exceed pre-collapse levels, but without an offshore fishery to provide long-term catch data, present estimates of stock levels, although large, are imprecise (NFSC 1993).

Atlantic herring eggs have not been identified in any ichthyoplankton collections for Seabrook Station studies, probably because they are demersal and adhesive. The larval stage was prevalent and typically occurred during an extended period from October through May. Peak abundance was found during the fall spawning season, from October through December (NAI 1993). Larval densities in 1994 were similar to those found during the operational period (Table 5-13) and in 1993 (NAI and NUS 1994). A large decline occurred during the preoperational period at all three ichthyoplankton stations during the late 1970s

TABLE 5-13. GEOMETRIC MEAN CATCH PER UNIT EFFORT (NUMBER PER 1000 m^3) WITH COEFFICIENT OF VARIATION (CV) BY STATION (P2, P5, AND P7) AND ALL STATIONS COMBINED FOR SELECTED LARVAL SPECIES COLLECTED IN ICHTHYOPLANKTON SAMPLES DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	STATION	PREOPERATIONAL PERIOD[a]		1994[b]	OPERATIONAL PERIOD[c]	
		MEAN	CV	MEAN	MEAN	CV
American sand lance	P2	159.6	14	252.8	133.9	13
(Jan-Apr)	P5	225.4	14	374.4	199.6	9
	P7	106.0	16	266.8	127.4	11
	All stations	162.5	13	293.4	150.5	11
Winter flounder	P2	12.1	19	3.6	6.0	17
(Apr-Jul)	P5	10.5	18	6.4	6.4	10
	P7	8.0	25	7.6	2.5	50
	All stations	10.8	18	5.6	4.6	9
Atlantic cod	P2	2.5	63	0.5	0.8	60
(Apr-Jul)	P5	2.4	80	0.9	0.9	66
	P7	1.0	73	0.7	0.6	25
	All stations	2.3	63	0.7	0.8	50
Yellowtail flounder	P2	3.4	50	0.4	1.5	65
(May-Aug)	P5	5.0	32	0.9	1.9	58
	P7	2.9	44	2.5	1.7	30
	All stations	3.8	39	1.1	1.7	44
Atlantic mackerel	P2	6.9	31	3.3	6.1	54
(May-Aug)	P5	6.8	50	3.3	4.8	51
	P7	5.9	21	4.3	6.3	48
	All stations	6.9	32	3.6	5.7	51
Cunner	P2	48.5	22	110.7	49.3	39
(Jun-Sept)	P5	55.0	29	55.0	38.5	36
	P7	59.0	23	135.3	58.0	37
	All stations	48.8	23	94.9	48.1	37
Hake[d]	P2	3.9	43	12.5	2.2	88
(Jul-Sept)	P5	3.1	50	11.0	2.5	87
	P7	3.9	48	14.1	3.2	97
	All stations	4.0	39	12.5	2.6	88
Atlantic herring	P2	29.0	34	10.0	6.6	35
(Oct-Dec)	P5	28.8	40	11.2	8.7	22
	P7	33.2	22	5.8	8.8	28
	All stations	29.2	32	8.7	8.0	25
Pollock	P2	6.3	50	-[e]	0.8	37
(Nov-Feb)	P5	8.2	52	-	1.0	60
	P7	2.4	50	-	0.7	48
	All stations	6.8	49	-	0.8	46

[a] Preoperational: July 1975-July 1990 (in some years not all three stations were sampled); geometric mean of annual means.
[b] Geometric mean of the 1994 data.
[c] Operational: August 1990-December 1994; geometric mean of annual means.
[d] May include red hake, white hake, spotted hake, or more than one of these species.
[e] Annual geometric mean not computed for pollock in 1994 because January and February 1995 data were not yet available.

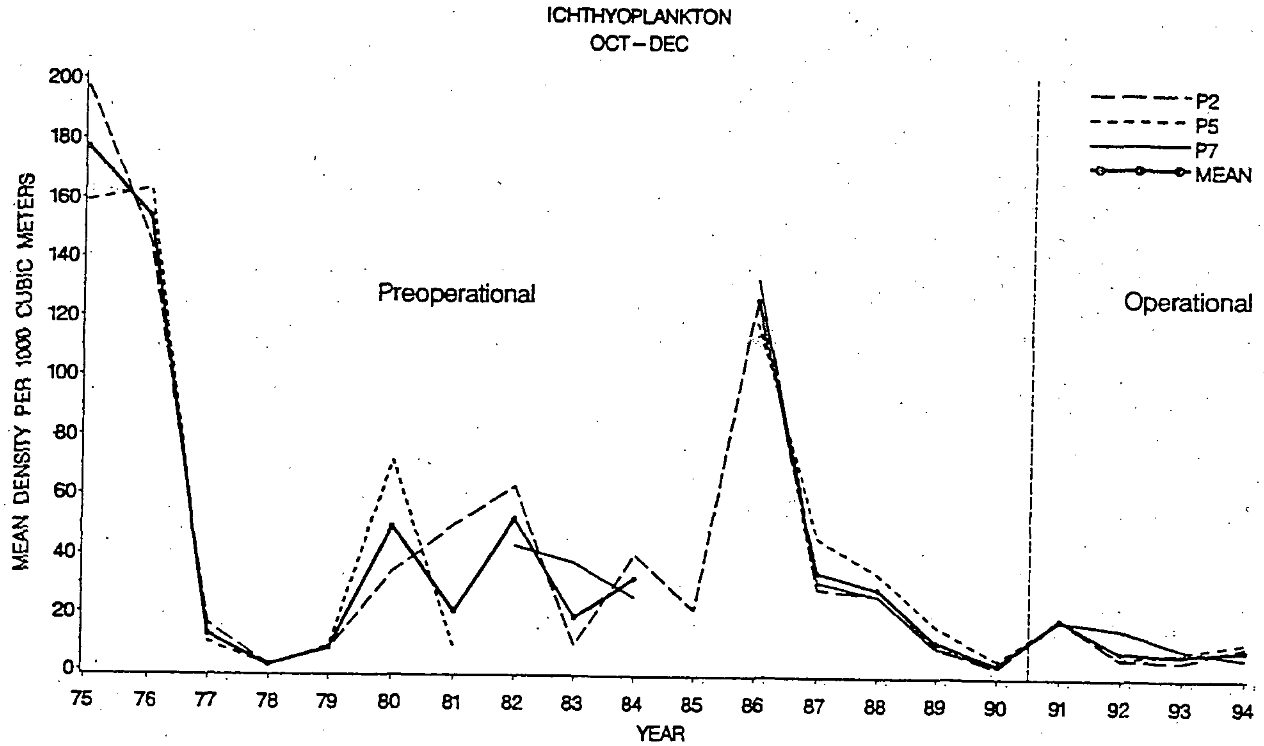
and again during a similar period in the 1980s, prior to the operation of Seabrook Station (Figure 5-8). Since 1989, annual abundance has remained relatively stable. Larval density in the operational period was significantly lower than in the preoperational period (Table 5-14), primarily due to declines in density that began during the preoperational period. During the period when all three stations were sampled (1986-94), similar densities were collected at the three stations. This was substantiated by the ANOVA results, which showed no significant differences detected among stations (Table 5-14).

As pelagic fish, large juvenile and adult Atlantic herring were collected during Seabrook Station studies primarily by gill net. Catches were highest in spring and fall, with few taken during July and August (NAI 1993). Abundance of Atlantic herring has been extremely variable during the entire study period. Annual abundance was highest in 1976 through 1979, and remained at relatively low levels from 1981 through the present (Figure 5-8). The variability among years is reflected in the ANOVA results where there were no significant differences between the preoperational and operational periods, despite the high abundance in the late 1970s (Table 5-14). There were no significant differences among stations and all three stations showed similar trends among years (Table 5-14; Figure 5-8).

Despite their occurrence in the area of the Seabrook Station intake throughout much of the year, apparently no Atlantic herring have been impinged on the traveling screens to date (Appendix Table 5-2). Thus, no direct plant impact to juvenile or adult fish has been observed. Atlantic herring was the ninth-ranked species of entrained larvae in 1994, with an estimated total of 100,000 (Table 5-5); this was the smallest number entrained since the beginning of commercial operation (Table 5-6). Entrainment of Atlantic herring larvae is a relatively small impact given that these larvae are likely drawn from the progeny of large spawning groups in the Gulf of Maine that disperse widely throughout the area over the course of a lengthy larval developmental period. The ANOVA interaction terms for both the ichthyoplankton and gill net programs were not significant, which indicated that the operation of Seabrook Station has not affected the local abundance or distribution of Atlantic herring. Even though the Georges Bank-Gulf of Maine herring biomass has increased in recent years to relatively high levels (NFSC 1993), recovery has not yet occurred in the Hampton-Seabrook area to former levels of abundance. The recovery on Georges Bank appears to be related to the lack of commercial fishing pressure in recent years (NFSC 1993). The stock may have re-established itself from a remnant population of fish that remained on the bank (Stephenson and Kornfield 1990) or by recolonization from other spawning grounds off Southern New England (Smith and Morse 1993).

5.3.3.2 Rainbow Smelt

The anadromous rainbow smelt occurs from Labrador to New Jersey (Scott and Crossman 1973). It serves as forage for fish, birds, and seals and supports minor sport and commercial fisheries in New England and Canada. A small (maximum size of about 35 cm) pelagic schooling species, it is readily available for sampling because it is mostly found in shallow, coastal waters. Adults begin to mature at ages 1 and 2 and live about five years (Murawski and Cole 1978, Lawton et al. 1990). Adults enter estuaries in fall and winter and spawn in spring after ascending brooks or streams to the head of tide. Fecundity ranges from approximately 1000-73,000 eggs per female (Clayton 1976, Lawton et al. 1990). Spawning in the Jones River, MA commenced when water temperature was about 4°C (Lawton et al. 1990). Most of the spawners in this river were age-2 and the abundance of this age-class considerably affected spawning stock size. Based on larval production estimates, minimum egg survivorship in the Jones River was 0.06% in 1980. Eggs range in size from 0.9-1.2 mm, and attach to rocks, gravel, vegetation, or each other (Bigelow and Schroeder 1953).



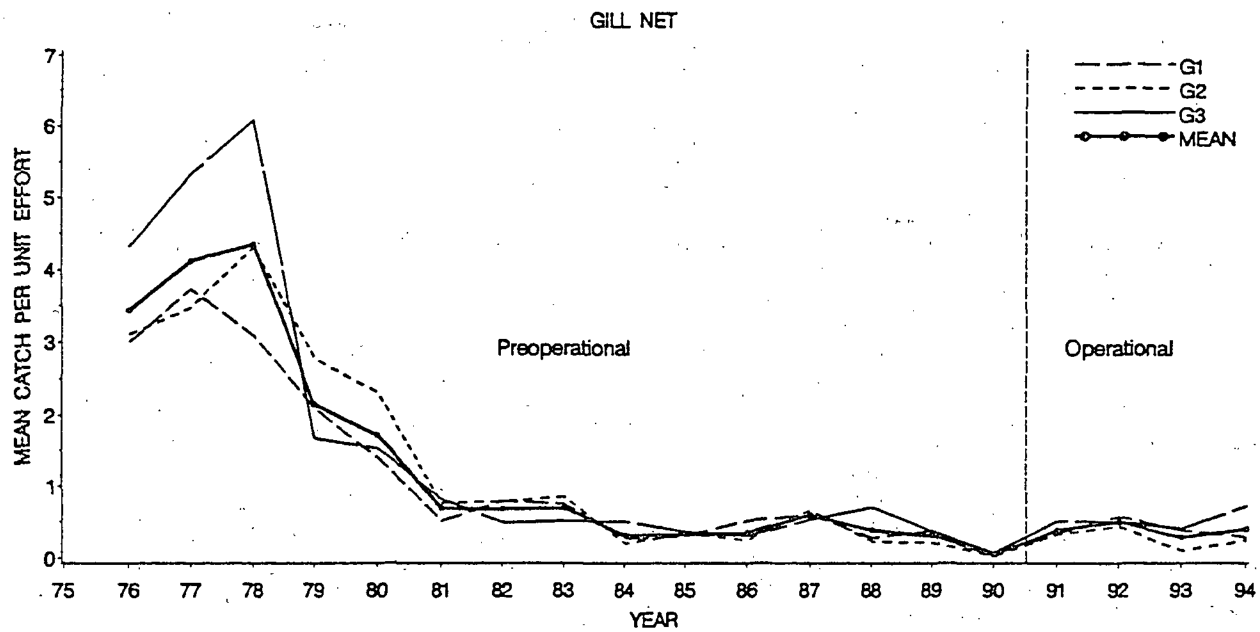


Figure 5-8. Annual geometric mean catch of Atlantic herring per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1994. Seabrook Operational Report, 1994.

TABLE 5-14. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC HERRING DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Oct.-Dec.) (1986-1994)	Preop-Op[a]	1	27.94	7.75*	Op<Preop
	Year (Preop-Op)[b]	7	3.66	1.05 NS	
	Month (Year)[c]	18	3.74	9.11***	
	Station[d]	2	0.35	3.38 NS	
	Preop-Op X Station[e]	2	0.10	0.62 NS	
	Station X Year (Preop-Op)[f]	14	0.17	0.41 NS	
	Error	267	0.41		
Gill Net (Sep.-May) (1976-1994)	Preop-Op[g]	1	4.61	2.88 NS	
	Year (Preop-Op)	17	1.63	4.87 ***	
	Month (Year)	151	0.32	9.26 ***	
	Station	2	0.06	5.01 NS	
	Preop-Op X Station	2	0.02	0.31 NS	
	Station X Year (Preop-Op)	34	0.05	1.45 NS	
	Error	302	0.03		

[a] Preop-Op compares 1990-1994 to 1986-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1990-1994 to 1976-1990, regardless of station.

NS= Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very highly significant ($0.001 \geq p$)

Larvae hatch at about 5 mm in length and grow to about 63 mm by November (Scott and Scott 1988). Larvae hatch at night (24-hour periodicity) independent of water temperature or stream hydrodynamics and are carried down to estuaries, as no larvae are retained on the spawning grounds (Ouellet and Dodson 1985a, b). In the St. Lawrence River, smelt larvae are mostly found in the maximum turbidity zone of that estuary (Laprise and Dodson 1989; Dodson et al. 1989).

Stocks of rainbow smelt are localized to some extent, which would be important for impact assessment. Although adults of three geographical groups of rainbow smelt in estuarine waters of Quebec did not home to specific spawning rivers (Frechet et al. 1983), nor did fish among three different streams of the Parker River, MA estuary (Murawski et al. 1980), other isolating mechanisms apparently limit gene flow. A probable means is the ability of larvae to retain themselves in estuarine areas by using active vertical migration in relation to tides (Ouellet and Dodson 1985a; Laprise and Dodson 1989).

Near Seabrook Station, rainbow smelt were collected by otter trawl mostly from December through April (NAI 1993), which corresponds to the winter-spring spawning run. The annual geometric mean CPUE peaked in 1989 in the late preoperational period, and has steadily declined throughout the operational period (Figure 5-9). Catches were generally highest and most variable at Station T2, off the mouth of Hampton-Seabrook Harbor. Stations generally showed similar trends in CPUE, especially after 1985.

The annual geometric mean CPUE for seine sampling was also highly variable, especially at Station S3 (Figure 5-9). The largest annual seine CPUE values occurred in 1979 and 1990, one year after cyclical peaks were observed in trawl catches. As seine sampling occurs from April through November, these catches may have corresponded to increased numbers of age-1 fish resulting from larger-than-average adult spawning stocks of the previous year. Most rainbow smelt were taken at S3, although catches at all three stations in 1994 showed increases relative to 1991 and 1992. There were no significant differences in seine catches between the preoperational and operational periods (Table 5-15), probably due to the high variability in CPUE during the preoperational period, and the interaction term was not significant.

The results from the ANOVA indicated that trawl catches were significantly greater during the preoperational period in comparison to the operational period (Table 5-15). Given the longer time span of preoperational sampling and the several peaks of abundance that occurred during this period, this was not unexpected. The ANOVA interaction term for trawl catches was significant, indicating a potential power plant impact. CPUE decreased between the preoperational and operational periods at all trawl stations, but the decrease was greater at Station T2 (Figure 5-10). CPUE was generally highest at Station T2 during the preoperational and early operational periods, but by 1992, CPUE at Station T2 was similar to the other two stations (Figure 5-9).

Because of the behavior and specific life history of the rainbow smelt, no eggs and few larvae (0.03% of all larvae in all offshore samples) have been collected in the ichthyoplankton sampling program. Annual entrainment estimates have been very low, with larvae collected only in 1990 and 1992, accounting for a total entrainment estimate of about 300,000 larvae since the beginning of plant operation in 1990 (Table 5-6). An estimated 704 rainbow smelt were impinged during the last five years (Appendix Table 5-2). Given that so few rainbow smelt have been taken at Seabrook Station and that the abundance in trawl sampling showed similar patterns in annual CPUE at all stations, it is very unlikely that this species is affected by Seabrook Station operation.

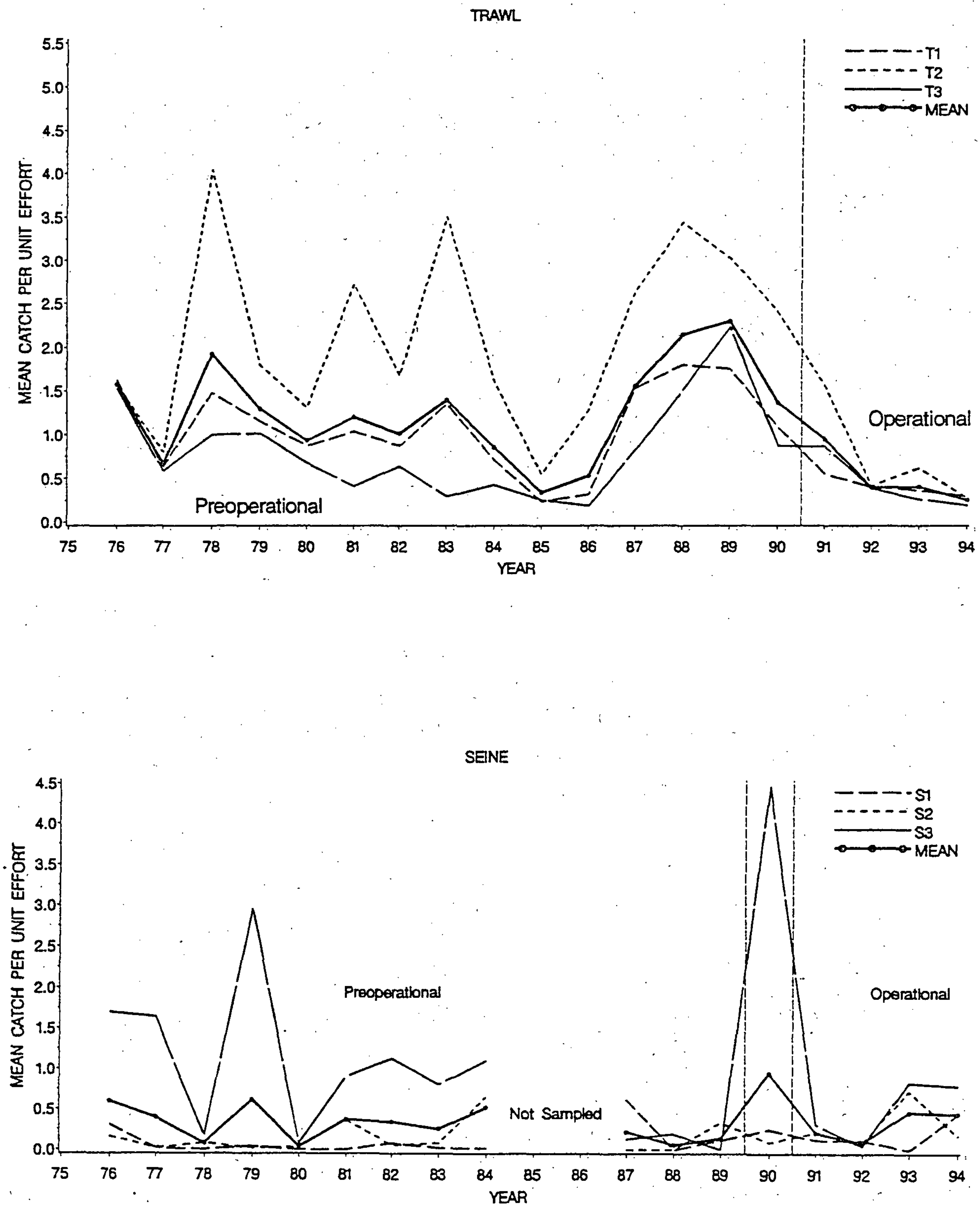


Figure 5–9. Annual geometric mean catch of rainbow smelt per unit effort in trawl (number per 10–min tow) and seine (number per haul) samples by station and the mean of all stations, 1986–1994 (data between two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

TABLE 5-15. RESULTS OF ANALYSIS OF VARIANCE FOR RAINBOW SMELT DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Trawl	Preop-Op[a]	1	5.46	5.82 **	Op<Preop
(Nov-May)	Year (Preop-Op)[b]	17	0.72	1.35 NS	
(1975-1994)	Month (Year)[c]	114	0.55	6.62***	
	Station[d]	2	0.44	1.44 NS	
	Preop-Op X Station[e]	2	0.28	4.65*	2Pre 1Pre 3Pre 1Op 2Op 3Op
	Station X Year (Preop-Op)[f]	34	0.06	0.72 NS	
	Error	227	0.08		
Seine	Preop-Op[g]	1	<0.01	0.02 NS	
(Apr-Nov)	Year (Preop-Op)	15	0.11	0.77 NS	
(1976-1994)	Month (Year)	116	0.10	1.50 **	
	Station	2	0.65	6.75 NS	
	Preop-Op X Station	2	0.10	0.92 NS	
	Station X Year (Preop-Op)	30	0.11	1.60 *	
	Error	232	0.06		

[a] Preop-Op compares 1990-1994 to 1986-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1990-1994 to 1976-1984 and 1986-1989) regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very highly significant ($0.001 \geq p$)

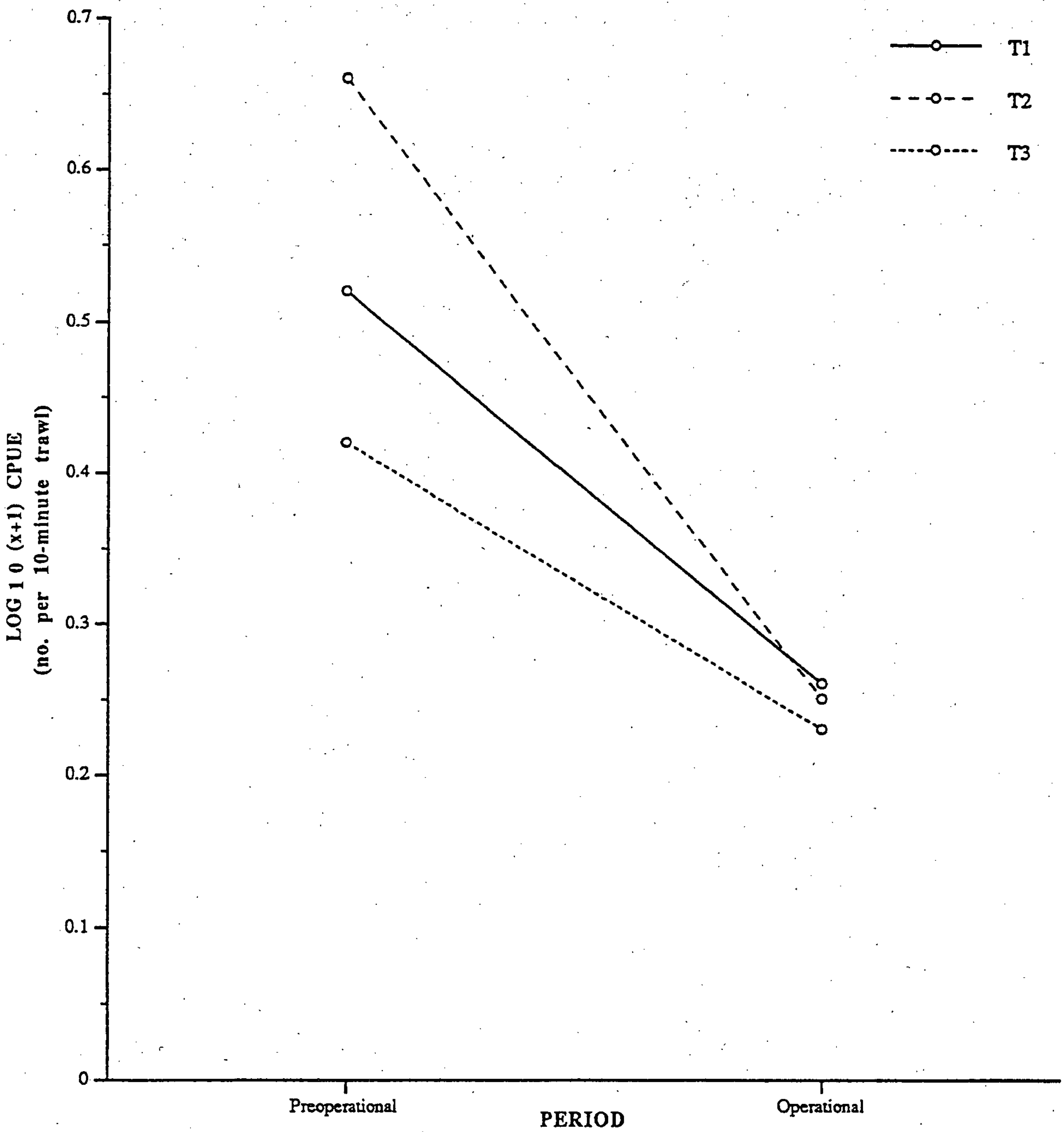


Figure 5-10. A comparison among stations of the mean $\log_{10}$ (x+1) CPUE (number per 10-minute tow) of rainbow smelt caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-23). Seabrook Operational Report, 1994.

5.3.3.3 Atlantic Cod

The Atlantic cod is found in the Northwest Atlantic Ocean from Greenland to Cape Hatteras and is one of the most important commercial and recreational fishes of the United States. The highly predatory, omnivorous cod can commonly achieve a length of 130 cm, a weight of up to 25-35 kg, and can live 20 years or more. However, smaller (50-60 cm, 1.1-2.3 kg, age 2-6) are more typically caught by the fisheries (Bigelow and Schroeder 1953; Scott and Scott 1988; NFSC 1993). The Atlantic cod is a cool-water fish, and is found and spawns at temperatures from about -1 to 10°C; distribution is also influenced by time of year, geographical location, and fish size (Jean 1964; Scott and Scott 1988; Branden and Hurley 1992). Many separate groups spawning at different locations have been noted in the northwest Atlantic, but for management purposes two stocks (Gulf of Maine, and Georges Bank and South) are recognized in U.S. waters (NFSC 1993).

Atlantic cod mature between ages 2 and 4, with age and size of 50% maturity of 2.1-2.3 years and 32-36 cm for Gulf of Maine fish (O'Brien et al. 1993). Fecundity can be quite high, with 0.2 to 12 million shelf (Hutchings et al. 1993). The timing of cod spawning varied among years, and could be accelerated by exposure to warm slope waters or delayed by exposure to cold shelf water (Hutchings and Myers 1994). Older individuals of both sexes initiated and completed spawning later, and spawned for a longer period of time, than younger individuals (Hutchings and Myers 1993). The 1.2-1.6-mm diameter egg is pelagic. Newly-hatched larvae are about 4-5 mm in length and growth over the first nine months averages about 0.21 mm/day (Bolz and Lough 1988). In well-mixed waters the eggs and larvae are distributed throughout the water column (Lough and Potter 1993). However, when lengths reach 6 to 8 mm, larvae develop a diel behavior. During the day, larvae are found predominantly near the bottom and at night from mid-depths to the surface in unstratified waters and at the thermocline in stratified waters (Perry and Nielsen 1988; Lough and Potter 1993). Vertical (Lough and Potter 1993) and horizontal (Suthers and Frank 1989) movements become less extensive with age and larger (> 20 mm) pelagic juveniles occur at greater depths than larvae. By summer, juveniles 40 mm or larger make the transition from a pelagic to a demersal habitat. This transition can occur over a relatively large size range (40-100 mm) over a 1-2 month period and even demersal juveniles may move 3-5 m off the bottom at night (Lough and Potter 1993).

Spatial distribution also changes with age, as cod of ages 1-2, 3, and 4+ in Southern New England and on Georges Bank were reported by Wigley and Serchuk (1992) to be distributed at different depths during spring. Seasonal distribution shifts are likely associated with water temperature. Suthers and Frank (1989) noted that nearshore waters of Nova Scotia contained high densities of young cod and may serve as an important nursery area for fish originating from offshore spawning sites.

The success of cod year-classes in the Northwest Atlantic Ocean exhibit periodicities of 10 to 20 years, and there was little evidence that the annual reproductive output of adult spawners was significantly related to year-class success (Koslow and Silvert 1987). The periodicities observed may correspond to regional physical and biological processes (Koslow 1984). Year-class success tended to be statistically associated with large-scale meteorological patterns. Campana et al. (1989) also did not find evidence that cod year-class strength was related to egg or larval abundance. However, abundance of both pelagic and demersal juveniles did appear to reflect year-class strength. Sources of mortality were not identified, but the mortality between the larval and juvenile stages was inversely correlated to year-class strength. Timing of local physical and biological events were thought to be important for recruitment success. Brander and Hurley (1992) found that cod spawning during spring moved progressively later from southwest to northeast in Nova Scotia waters and matched peak abundance of the copepod *Calanus finmarchicus*. This may be consistent with a "match-mismatch" hypothesis (Cushing 1984) for successful reproduction in that cod spawning is coupled with copepod production, but definitive relationships remain to be demonstrated (Brander and Hurley 1992).

Because of its long history of exploitation, fishing mortality has also played a key role in determining Atlantic cod abundance. Annual sport and commercial landings for the Gulf of Maine averaged about 15,100 metric tons during 1972-82 and 13,100 metric tons for 1983-89, but rose to 18,700 metric tons in 1990 and to a record 20,300 metric tons in 1991 (NFSC 1993). Landings decreased 43% to 11,600 metric tons in 1992, but commercial otter trawl effort remained at near-record high levels. The catch has been dominated by the strong 1987 year-class, which accounted for about 55% of the 1992 landings. Recruitment since 1988 has been average or below average and spawning stock biomass is expected to remain at record low levels. Because of declining stock biomass and continued high rates of fishing, the Gulf of Maine Atlantic cod stock is considered overexploited (NFSC 1993).

Atlantic cod eggs in ichthyoplankton collections were usually grouped as Atlantic cod/haddock because it was difficult to distinguish between these two species; this aggregation also included witch flounder eggs. These taxa have been dominant during the winter and early spring (Table 5-3). Examination of larval data since July 1975 indicated that the percent composition among all larvae collected was 0.49% for Atlantic cod, 0.02% for haddock, and 1.05% for witch flounder. Assuming a relatively similar hatching rate, it would appear that Atlantic cod and witch flounder eggs predominated in this egg group. Atlantic cod eggs have also been dominant in the late fall and early winter (Table 5-3), before the spawning seasons of haddock and witch flounder (Bigelow and Schroeder 1953).

Atlantic cod larvae typically exhibited a bimodal annual occurrence, with one peak from November through February and a second, larger peak from April through July (NAI 1993). To compare abundances among years and stations, only data from April through July were used. There was a decrease in larval densities during the 1970s, but annual abundances have remained relatively stable and very similar at all stations from 1980 to the present (Figure 5-11). This decrease in abundance was evident in the comparison of preoperational and operational geometric means (Table 5-13), but the decline occurred about 10 years before plant operation.

At Seabrook Station, larger Atlantic cod were taken year-round by the trawl sampling program, but consistent with their annual movements, catches were highest in spring and fall and lowest in summer (NAI 1993). Annual geometric mean CPUE was nearly always greater at the two farfield stations (particularly T3) than at the nearfield station T2 (Figure 5-11). This was attributed to differences in habitat between T2 and the other stations (NAI 1993). Overall, cod abundance was relatively stable from 1978-83 and then decreased. An increase in numbers followed until a peak was reached in 1988, perhaps due to the contribution of the strong 1987 year-class. Abundance then declined abruptly to very low levels, particularly in 1992. However, a large increase in abundance occurred in 1993, especially at T3, but abundance at T2 remained depressed. In 1994 abundances decreased sharply at Stations T1 and T3, and remained low at T2. Bottom water temperatures during the operational period increased steadily since 1990 and were significantly higher than during the recent preoperational period at all stations (see Section 2.0 - Water Quality). Bottom water temperatures in 1994 were higher than both the preoperational and operational averages. Water temperature may have affected inshore abundances, especially if the temperature at the nearfield station, even if not raised by station operation, was above the preferred range for Atlantic cod.

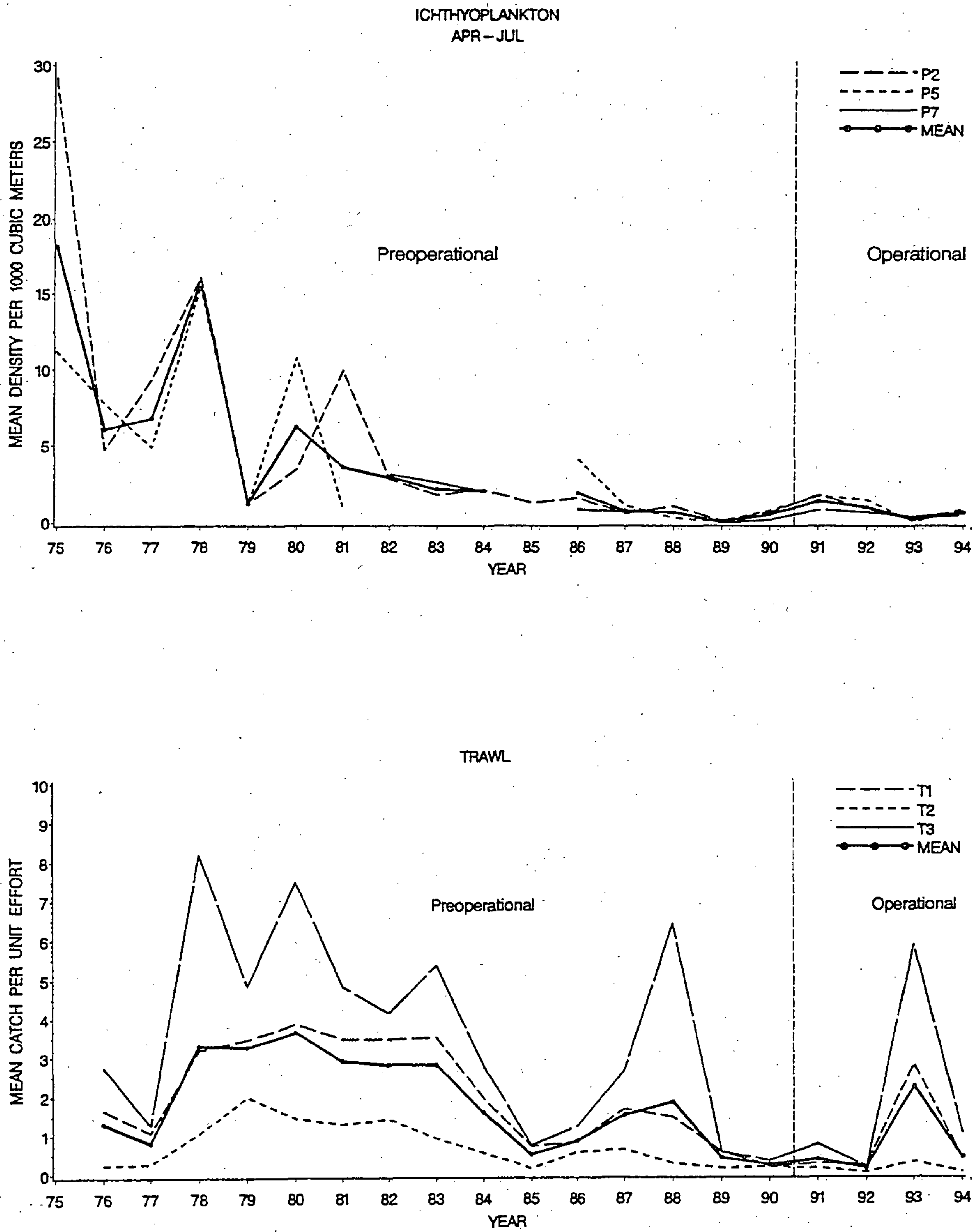


Figure 5–11. Annual geometric mean catch of Atlantic cod per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10–min tow) samples by station and the mean of all stations, 1976–1994. Seabrook Operational Report, 1994.

An ANOVA applied to Atlantic cod trawl data indicated that catch during the operational period was significantly less than during the preoperational period, and there were no significant differences in larval density between periods (Table 5-16). Given the reported decreases in the Gulf of Maine stock and continued low recruitment reported by NFSC (1993), this was not unexpected for the trawl data. The ANOVA interaction terms for both trawl and ichthyoplankton data were not significant, indicating a similar pattern in annual abundance at all stations during both the preoperational and operational periods. An estimated 167 Atlantic cod have been impinged at Seabrook Station since 1990 (Appendix Table 5-2). Egg and, in particular, larval entrainment has been relatively low (Table 5-6), given the high fecundity and source population size of Atlantic cod in the Gulf of Maine. Furthermore, year-class success was apparently related to large region-wide events affecting survival of pelagic and demersal juveniles. Thus, it is very likely that decreases in abundance are due to regional declines in Atlantic cod abundance and to a naturally-occurring increase in temperature. These changes have no relation to the operation of Seabrook Station.

5.3.3.4 Pollock

The pollock is one of the most pelagic of all the gadids and is often found in large schools. It is a cool-water species, preferring water temperatures of 7.2-8.6°C and is not found in waters exceeding 18.3°C (Scott and Scott 1988). Pollock may reach a length of 107 cm and a weight of 32 kg. Found from southwest Greenland to Cape Lookout, NC (Bigelow and Schroeder 1953), it is most abundant on the Scotian Shelf and in the Gulf of Maine (NFSC 1993). Adults move into the southwestern Gulf of Maine in fall or early winter to spawn, which mostly occurs from November through February (Colton et al. 1979). The median age and size of maturity for female pollock is two years and 39.1 cm (O'Brien et al. 1993). Typical of codfishes, the pollock is highly fecund with an average production of 225,000 eggs and with a 10.7-kg female capable of spawning over 4 million eggs (Bigelow and Schroeder 1953). The pelagic egg is 1.04-1.20 mm in diameter (Markle and Frost 1985) and newly-hatched larvae are 3-4 mm in length (Fahay 1983). First-year growth is rapid and young can often be very abundant along Gulf of Maine coastal beaches (MacDonald et al. 1984), rocky subtidal areas (Ojeda and Dearborn 1990), and apparently even use tide pools as a nursery (Moring 1990). Young grow rapidly and by fall can achieve lengths of 215 mm (Ojeda and Dearborn 1990) before they move offshore for the winter.

Combined U.S. and Canadian landings for the Scotian Shelf, Gulf of Maine, and Georges Bank regions increased from a yearly average of about 38,200 metric tons in 1972-76 to 68,500 metric tons by 1986, with U.S. landings alone in 1986 of 24,500 metric tons (NFSC 1993). Recreational landings fluctuated between 100 and 1,300 metric tons. Based on National Marine Fisheries Service trawl surveys, biomass of pollock in the Gulf of Maine and on Georges Bank has decreased sharply during the 1980s from a peak in the late 1970s and has remained relatively low in recent years. During this period, the catch of pollock was dominated by several moderately strong year-classes that occurred every three to four years, including those from 1975, 1979, and 1982. More recently, the 1987 and 1988 year-classes appeared to be above the long-term mean and accounted for about half the landings in 1992. The 1989-91 year-classes, however, are below average in abundance. The pollock stock is considered by NFSC (1993) to be fully exploited.

Pollock eggs and larvae were collected in relatively low density (Tables 5-3 and 5-4). Larval pollock abundance generally peaked during November through February (NAI 1993). There was an evident decline in the geometric mean density between the preoperational and operational periods, with large annual

TABLE 5-16. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC COD DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	0.54	1.11 NS	
(Apr-Jul)	Year (Preop-Op)[b]	6	0.56	1.06 NS	
(1987-1994)	Month (Year)[c]	24	0.58	4.09***	
	Station[d]	2	0.12	6.47 NS	
	Preop-Op X Station[e]	2	0.02	0.19 NS	
	Station X Year (Preop-Op)[f]	12	0.10	0.69 NS	
	Error	318	0.14		
Trawl	Preop-Op[g]	1	5.65	4.69 *	Op<Preop
(Nov-Jul)	Year (Preop-Op)	17	1.19	5.65 ***	
(1975-1994)	Month (Year)	152	0.17	3.17 ***	
	Station	2	3.97	36.71 *	Non. est.
	Preop-Op X Station	2	0.11	1.12 NS	
	Station X Year (Preop-Op)	34	0.10	1.80 **	
	Error	303	0.05		

[a] Preop-Op compares 1991-1994 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1990-1994 to 1975-1990 regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very highly significant ($0.001 \geq p$)

fluctuations occurring during the preoperational period (Table 5-13; Figure 5-12). Except for 1985, annual abundances have been similar at all stations.

Pollock have been collected by gill net near Seabrook Station from spring through fall and were generally absent in winter (NAI 1993). Annual geometric mean CPUE varied considerably from year to year, with no single station producing consistently high or low catches (Figure 5-12). Fluctuations observed may have corresponded to the successive presence of fish from dominant and weak year-classes reported by NFSC (1993). Catch decreased slightly in 1994 compared to 1993, but was higher than in 1992 and 1991.

The ANOVA for gill net catch data and larval density showed no significant differences between preoperational and operational periods (Table 5-17). The interaction terms for both gill net and ichthyoplankton sampling were not significant, suggesting that plant operation has not affected abundance. Relatively few eggs and larvae were entrained (Table 5-6), but pollock ranked second among fishes impinged at Seabrook Station from 1990-94, with estimated total of 2,137 fish (Appendix Table 5-2). Nevertheless, this is a relatively small number for such a widespread and abundant species. It is likely that the catch of juvenile and adult pollock near Seabrook Station reflects natural variability in annual abundance patterns of the Gulf of Maine stock. No changes in abundance or distribution can be attributed to station operation.

5.3.3.5 Hakes

Three species of hake (genus *Urophycis*) are found in the Gulf of Maine: red hake, white hake, and spotted hake. The spotted hake, however, is apparently quite rare in this area (Bigelow and Schroeder 1953; Scott and Scott 1988) and is not important to the fisheries. For these reasons, it will not be discussed below. Both the red and white hakes are common in the Northwestern Atlantic Ocean, particularly on sandy or muddy grounds off Northern New England. They most commonly co-occur in the Gulf of Maine (Musick 1974). Similar in appearance and in many aspects of their biology, other features differ considerably. Some of the most distinguishing characteristics between these two species are in specific geographical distribution and in size attained. The red hake is found in more shallow waters of the inner continental shelf, predominantly in depths of 73 to 126 m (Musick 1974). It occurs in water temperatures of 5 to 12°C, but apparently prefers a range of 8-10°C and avoids waters colder than 4°C. In the Gulf of Maine, red hake are found inshore for spawning, but disperse offshore following spawning. Except for young, most white hake are typically found in deeper (200-1,000 m) water than red hake and are considered to be inhabitants of the outer shelf and continental slope. Temperature preferences (5-11°C), however, are similar to that of the red hake. Current estimates of median size and age of maturity for females are 26.9 cm (1.8 years) for red hake and 35.1 cm (1.4 years) for white hake (O'Brien et al. 1993). Maximum size of the white hake is 135 cm, much larger than the maximum of 50 cm for the red hake (NFSC 1993).

The white hake is highly fecund with a 70-cm female producing 4 million eggs and a 90-cm fish about 15 million (Scott and Scott 1988). Most white hake spawning occurs in spring on the continental slope south of the Scotian Shelf and Georges Bank, and off Southern New England (Fahay and Able 1989; Comyns and Grant 1993). Red hake spawn mostly during summer and fall in mid-shelf areas. Eggs of both species are pelagic and are similar in size (range of 0.63-0.97 mm; Fahay 1983; Markle and Frost 1985). Newly-hatched larvae of both hakes are neustonic (Hermes 1985) and even juveniles remain pelagic for a considerable time, until 25-30 mm for the red hake (Steiner and Olla 1985) and 50-80 mm for the white hake (Markle et al. 1982). Growth of young is rapid and can average about 1 mm/day (Fahay and Able 1989). Larger juveniles of both species tend to be found closer to shore. White hake juveniles recruit

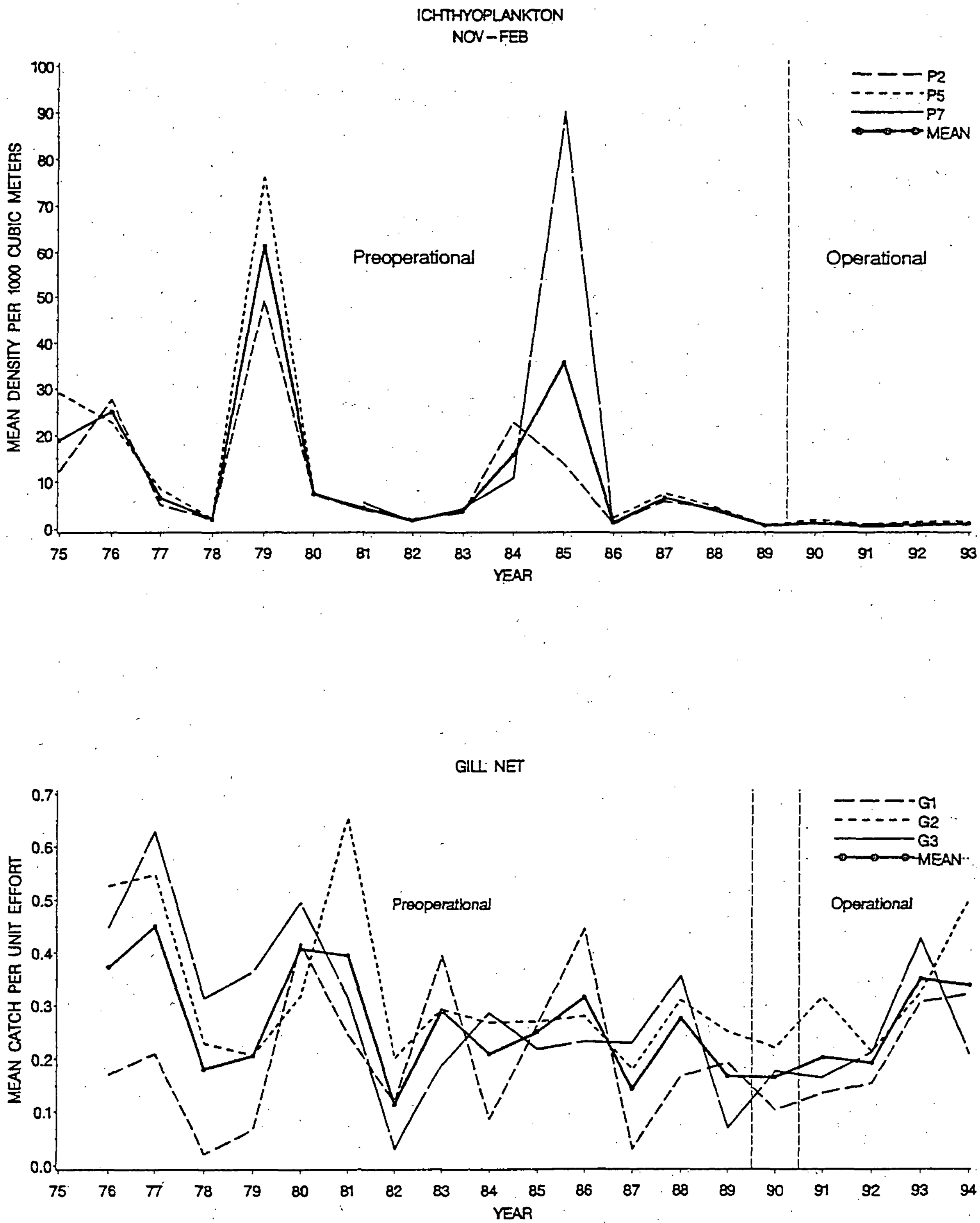


Figure 5-12. Annual geometric mean catch of pollock per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1994 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

TABLE 5-17. RESULTS OF ANALYSIS OF VARIANCE FOR POLLOCK DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	5.45	2.51 NS	
(Nov-Feb)	Year (Preop-Op)[b]	6	2.20	2.62 NS	
(1986-1994)	Month (Year)[c]	24	0.96	5.83 ***	
	Station[d]	2	0.54	25.68 *	P5 P2 P7
	Preop-Op X Station[e]	2	0.02	0.42 NS	
	Station X Year (Preop-Op)[f]	12	0.05	0.30 NS	
	Error	324	0.16		
Gill Net	Preop-Op[g]	1	<0.01	0.02 NS	
(Apr-Dec)	Year (Preop-Op)	16	0.06	0.94 NS	
(1976-1994)	Month (Year)	144	0.05	4.48 ***	
	Station	2	0.08	15.61 NS	
	Preop-Op X Station	2	0.01	0.28 NS	
	Station X Year (Preop-Op)	32	0.02	2.08 **	
	Error	288	0.01		

[a] Preop-Op compares 1990-1993 to 1986-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1991-1994 to 1975-1989 regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

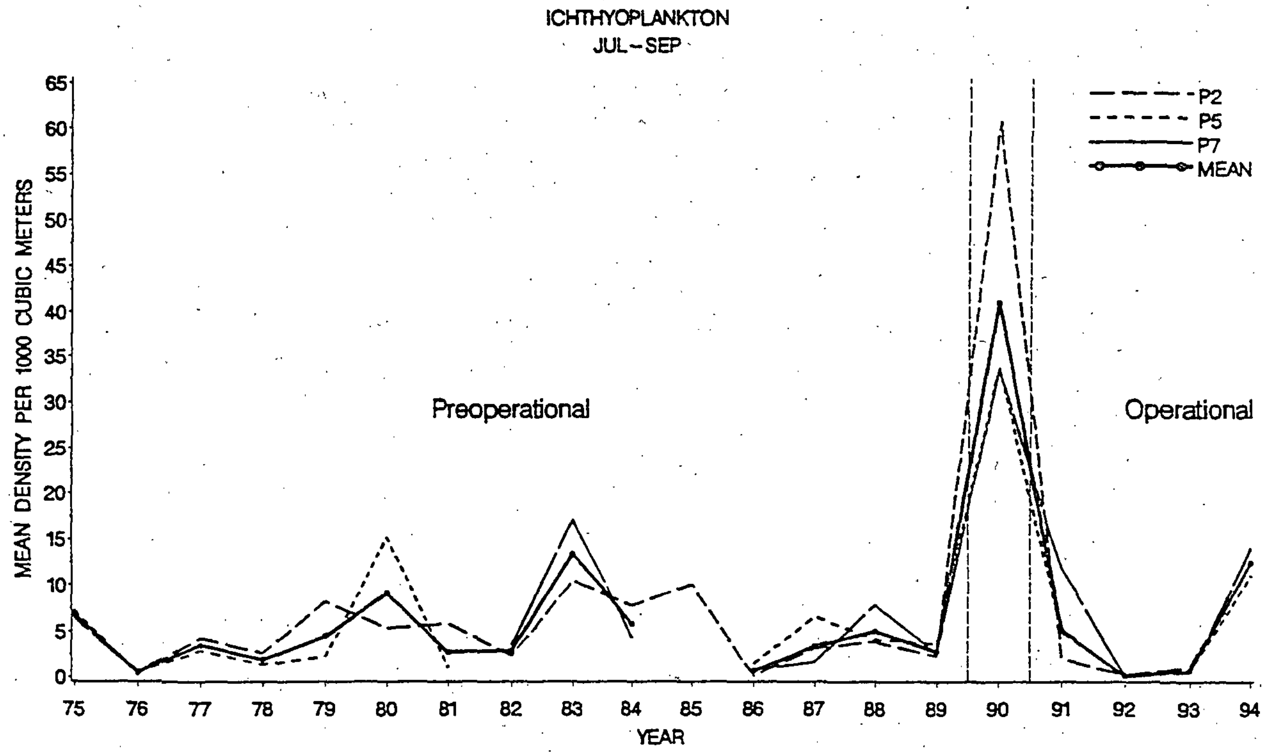
inshore in June and July (Fahay and Able 1989) and red hake from September to December (Steiner et al. 1982). Many young red hake are inquiline and live within the mantle cavity of the sea scallop (*Placopectin magellanicus*) until they outgrow this commensal host (Steiner et al. 1982; Garman 1983; Luczkovitch 1991). Other red hake, however, find shelter under shell or other bottom structures (Steiner et al. 1982).

Based on the depth distribution of the red and white hake, red hake is probably the most common hake in the study area. Commercial fishing landings of red hake in the Gulf of Maine and from the northern Georges Bank are currently very low (< 1,000 metric tons), with an average of only 1,100 metric tons landed over the period of 1977-92 (NFSC 1993). The NMFS trawl survey index showed an increasing trend in abundance from the mid-1970s to a peak in 1990; indices decreased in 1991 and 1992, but remained near the long-term average. Although year-classes produced since 1985 were termed moderate in strength, NFSC (1993) concluded that the red hake is underexploited and could sustain much higher catches. In contrast, although taken primarily in non-directed fisheries, white hake landings in the Gulf of Maine (primarily from the western portion) are currently high, being exceeded only by those for the Atlantic cod (NFSC 1993). Previous landings peaked at 7,500 metric tons in 1984, declined to 5,500 metric tons in 1990, but recently increased to an historic high of 9,600 metric tons in 1992. NMFS trawl survey indices have fluctuated considerably, but indications are that abundance increased in 1991 and 1992. NFSC (1993) concluded that, on the basis of the stability of stock biomass since 1981, the white hake is fully exploited and can sustain annual commercial landings of about 6,500 metric tons. This species may be overharvested if landings (such as those in 1992) begin to continually exceed this level. The recreational landings of both hakes in the Gulf of Maine are insignificant.

Hake eggs collected in ichthyoplankton samples are difficult to distinguish from fourbeard rockling eggs during early development and, therefore, at times were grouped as fourbeard rockling/hake. Hake and fourbeard rockling/hake eggs were the predominant eggs collected during the late summer and early fall (Table 5-3). Hake larvae generally peaked during July through September (NAI 1993). During the preoperational period, catch remained relatively stable; catch was more variable during station operation, with the largest annual mean in 1990. Larval density 1992 and 1993 were among the years of lowest abundance (NAI and NUS 1994). In 1994 larval density increased to the third highest recorded (Figure 5-13). Low abundances in 1991-93 were also apparent in the comparison of preoperational and operational geometric means (Table 5-13).

Hake have been taken year-round in trawl sampling, but peak catches were made from June through October, with a sharp decrease occurring in November (NAI 1993). Generally, catches at the nearfield station T2 were smaller than at T1 or T3 and trends were consistent within the preoperational and operational periods (Figure 5-13). As for the Atlantic cod, the area near T2 may not be a preferred habitat for hake. Geometric mean CPUEs were highest in 1977, 1978, and 1981. Since then, a general decreasing trend has been observed with smaller peaks seen every three to four years. CPUE for 1992, 1993 and 1994 were the three lowest of the time-series.

The ANOVA detected significantly larger preoperational abundances than operational abundances for the trawl, but not for ichthyoplankton collections (Table 5-18). However, the interaction term was not significant, suggesting there were no plant operational effects. Entrainment estimates for hake eggs and larvae during 1994 were the lowest since Seabrook Station began operation, because of a lack of sampling during nearly all of the seasonal period when hake eggs and larvae normally occur. The highest values occurred in 1990, the year when larvae were most abundant (Table 5-6; Figure 5-13). An estimated 2,889 hake have been impinged at Seabrook Station since 1990



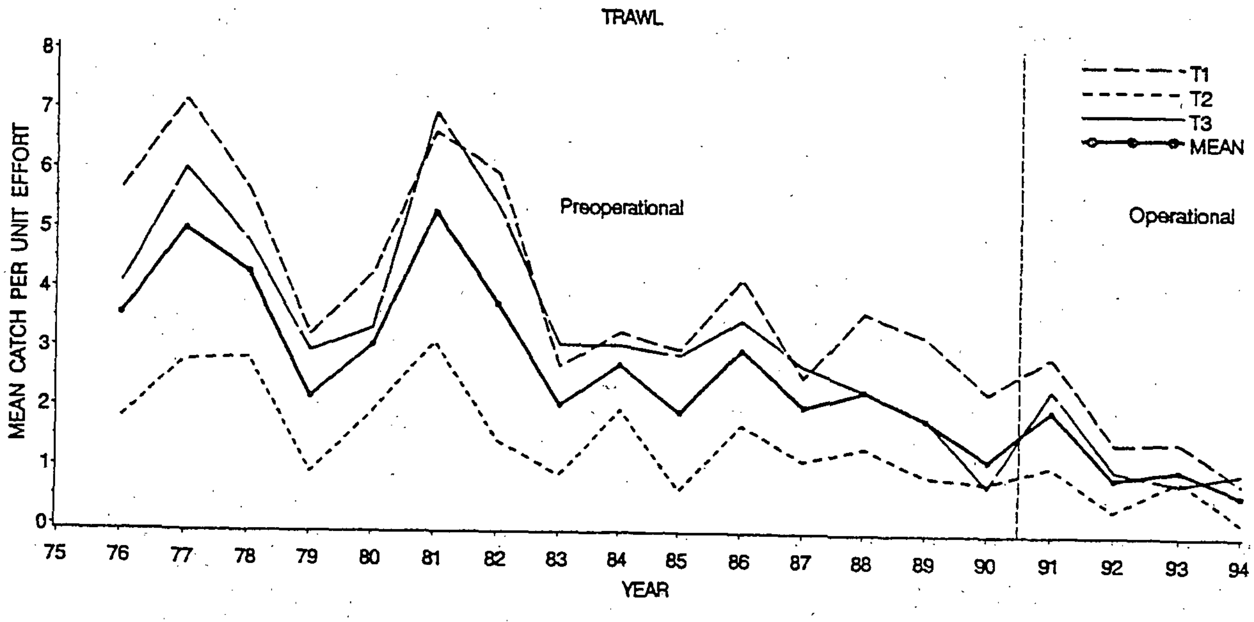


Figure 5-13. Annual geometric mean catch of hakes per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1976-1994 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

TABLE 5-18. RESULTS OF ANALYSIS OF VARIANCE FOR HAKE[a] DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[b]	1	<0.01	<0.01 NS	
(Jul-Sep)	Year (Preop-Op)[c]	6	5.16	2.29 NS	
(1986-1994)	Month (Year)[d]	16	2.37	5.28 ***	
	Station[e]	2	0.33	1.03 NS	
	Preop-Op X Station[f]	2	0.32	0.98 NS	
	Station X Year (Preop-Op)[g]	12	0.33	0.73 NS	
	Error	247	0.45		
Trawl	Preop-Op[h]	1	4.25	10.25**	Op<Preop
(Nov-Jul)	Year (Preop-Op)	17	0.33	0.72 NS	
(1976-1994)	Month (Year)	152	0.48	8.91 ***	
	Station	2	0.83	6.52 NS	
	Preop-Op X Station	2	0.12	3.27 NS	
	Station X Year (Preop-Op)[g]	34	0.04	0.68 NS	
	Error	303	0.05		

[a] May include red hake, white hake, spotted hake, or more than one of these species.
[b] Preop-Op compares 1991-1994 to 1986-1989 regardless of station.
[c] Year nested within preoperational and operational periods regardless of station.
[d] Month nested within Year.
[e] Stations regardless of year or period.
[f] Interaction of the two main effects, Preop-Op and Station.
[g] Interaction of Year and Station nested within Preoperational and Operational period.
[h] Preop-Op compares 1990-1994 to 1976-1990 regardless of station.

* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

(Appendix Table 5-2). The apparent trend in abundance as measured by trawl CPUE at Seabrook Station differs from the trend in indices reported by NFSC (1993) for these species. Since 1976, the NFSC research trawl index for red hake has fluctuated considerably, but with an increasing trend (NFSC 1993). Commercial landings have remained uniformly low throughout this period. White hake have fluctuated without a long-term trend, but recent increases have occurred in both the trawl survey index and in landings. Some unknown factors may be reducing hake abundance in the Hampton-Seabrook area, but it is very unlikely that the operation of Seabrook Station has affected the hakes, as the local decline began in the early 1980s and occurred consistently at all stations. In addition, failing to distinguish among the hake species may have confounded these analyses.

5.3.3.6 Atlantic Silverside

The Atlantic silverside is a small, short-lived schooling fish that is ecologically important as a consumer of zooplankton and as prey for many larger fishes and birds (Bengston et al. 1987). Found in bays, salt marshes, and estuaries from the Gulf of St. Lawrence to northern Florida, the Gulf of Maine is near the northern end of its range (Conover 1992). Most Atlantic silverside complete their life cycle within one year and, typically, few older fish are found in the population. Spawning begins at about 9-12°C, which restricts spawning to May through July in northern areas (Conover and Ross 1982; Jessop 1983; Conover and Kynard 1984). Fecundity within a Massachusetts population ranged from 4,725 to 13,525 eggs per female (Conover 1979). These eggs may be released during at least four separate periods of ripening and spawning. Spawning occurs during daylight, coincides with dates of full and new moons and is apparently synchronized with tides (Conover and Kynard 1984). The adhesive eggs are laid in shallow water on vegetation. Gender of Atlantic silverside is determined largely by water temperature during larval development (Conover and Kynard 1981; Conover and Fleisher 1986). However, this mechanism may not be as important for northern populations because of the temporally reduced spawning season in more northern waters (Conover 1992). Larvae are planktonic, but remain near the spawning areas. Growth of young is fast and mean lengths can exceed 90 mm by November (Conover 1979). As the lower lethal temperature for Atlantic silverside is about 1-2°C (Hoff and Westman 1966; Conover and Murawski 1982), inshore distribution in northern areas is limited in winter. Atlantic silverside undertake an offshore migration in winter to inner continental shelf waters, with most fish caught within 40 km of the shore and at depths less than 50 m (Conover and Murawski 1982). It is during this period that high (up to 99%) overwintering mortality typically occurs, with apparently mostly fish larger than 80 mm able to survive the winter (Conover and Ross 1982; Conover 1992).

Atlantic silverside have been only numerous in the seine sampling program and were taken throughout the August through November sampling season (NAI 1993). Most of these fish were likely young-of-the-year. Geometric mean CPUE was highest from 1976 through 1981, whereupon catch decreased. Since then, CPUE has fluctuated around a lower and more consistent average level to the present (Figure 5-14). Catch at each station tended to follow similar patterns, although it varied somewhat more at S2 than at S1 or S3. No significant differences were found between the preoperational and operational periods, among stations, or for the interaction term (Table 5-19). An estimated 5,579 Atlantic silverside have been impinged since Seabrook Station began operation (about 96% of the total in December 1994; Appendix Table 5-2) and no eggs or larvae were entrained (Table 5-6). The discharge from the Seabrook Station settling basin no longer enters Hampton-Seabrook Harbor and, therefore, marine biota there should no longer be potentially affected by it. As few Atlantic silverside have been harmed by station operation to date and because the decline in seine CPUE occurred before plant start-up,

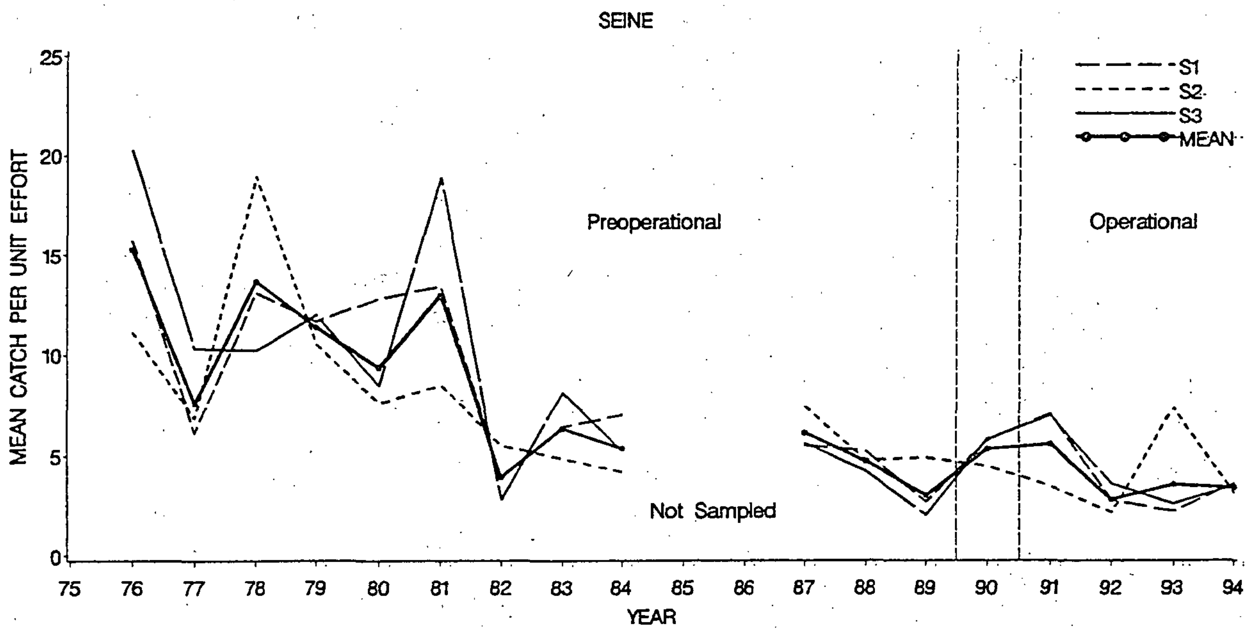


Figure 5–14. Annual geometric mean catch of Atlantic silverside per unit effort in seine (number per haul) samples by station and the mean of all stations, 1976–1994 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

it is reasonable to assume that the continued operation of Seabrook Station will not have any deleterious effect on this species.

5.3.3.7 Cunner

The cunner, found from Newfoundland to Chesapeake Bay (Scott and Scott 1988), is one of the most common fishes in the Gulf of Maine (Bigelow and Schroeder 1953). A small fish residing in inshore waters, few cunner measure over 31 cm, although fish as large as 38 cm are occasionally taken in deeper waters (Johansen 1925; Bigelow and Schroeder 1953). Most cunner are closely associated with structural habitats, such as rocks, tidepools, shellfish beds, pilings, eelgrass, and macroalgae. Cunner exhibit both diel and seasonal behavior in that they remain under cover and become quiescent at night and torpid in winter (Olla et al. 1975, 1979). In fall, when water temperatures fall below about 8°C, cunner move into cover to overwinter (Green and Farwell 1971; Green 1975; Dew 1976; Olla et al. 1979). Although generally remaining within 2 m of territorial shelters, some cunner will move to seasonally transitory habitats (e.g., mussel beds, macroalgae) after emerging from winter shelter when spring water temperatures reach 5 or 6°C (Olla et al. 1975, 1979).

Cunner reach maturity at small (70-90 mm) sizes and at age-1 or 2, depending upon latitude and corresponding length of the growing season (Johansen 1925; Dew 1976; Pottle and Green 1979). Cunner are serial spawners; pairs spawn within male territories, or aggregations of fish spawn together during late afternoon or early evening (Pottle and Green 1979). The reproductive season lasts from May through September, with peak spawning observed by Dew

TABLE 5-19. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC SILVERSIDE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Seine	Preop-Op[a]	1	3.68	4.78 NS	
(Apr-Nov)	Year (Preop-Op)[b]	15	0.89	0.40 NS	
(1976-1994)	Month (Year)[c]	116	2.21	18.01 ***	
	Station[d]	2	0.01	0.12 NS	
	Preop-Op X Station[e]	2	0.02	0.19 NS	
	Station X Year (Preop-Op)[f]	30	0.13	1.05 NS	
	Error	232	0.12		

[a] Preop-Op compares 1991-1994 to 1976-1984 and 1986-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

(1976) during June in Fishers Island Sound. Eggs are pelagic and range from 0.75 to 1.03 mm in diameter (Wheatland 1956); average size of eggs decreases over the season with increasing water temperature (Richards 1959; Williams 1967). Williams et al. (1973) reported that only about 5% of cunner eggs survived to hatching and speculated that predation, particularly by ctenophores, was responsible for the losses. Eggs hatch in 3 d at water temperatures of 12.8-18.3°C (Bigelow and Schroeder 1953). Newly-hatched larvae are 2 to 3 mm in length and settle into preferred habitats when 8 to 9 mm long.

Presently, cunner have no commercial value, although large quantities were apparently landed during the late 1800s and early 1900s (Bigelow and Schroeder 1953). Although the cunner is not primarily sought after, numerous fish are caught by recreational fishermen throughout New England. Because of its restricted inshore habitats and the lack of landings data, no large-area, long-term abundance indices are available for the cunner.

Cunner eggs and larvae were dominant in the ichthyoplankton program (Tables 5-3 and 5-4). Cunner eggs were grouped with yellowtail flounder (cunner/yellowtail flounder). This group also included tautog eggs, although tautog adults were probably not abundant in the Hampton-Seabrook area, which is located near the northern end of their distributional range (Bigelow and Schroeder 1953). Tautog have only accounted for 0.04% of the larvae collected since July 1975. A comparison of cunner and yellowtail flounder larval abundance indicated that most of the eggs in the cunner/yellowtail flounder group were cunner, assuming a relatively similar hatching rate between the two species (Table 5-13). The annual abundance of cunner larvae has greatly fluctuated from year to year, but similar annual densities occurred at all stations since sampling at all three stations began in July 1986, with the exception of 1994 (Figure 5-15). In 1994, density increased at Station P7 (farfield) and P2 (nearfield for intakes), and decreased at P5 (nearfield for discharge). Mean density of cunner larvae in 1994 was greater than both the preoperational and operational mean densities (Table 5-13), and slightly lower than densities observed in 1993 (Figure 5-15). In 1993, larval abundance increased greatly relative to 1992, when abundance was at an all-time low (Figure 5-15). The results of the ANOVA indicated that during the period when all three stations were sampled and cunner larvae were present, there were no significant differences between the preoperational and operational periods (Table 5-20). No members of the cunner/yellowtail flounder egg group were entrained in 1994, primarily due to a plant outage during the summer season of high abundance. Previous to 1994, this group has ranked first or second each year since entrainment sampling was started in June 1990 (Table 5-6). Larval entrainment since 1990 has ranged from 0 to 14.7 million. The large difference between egg and larval entrainment estimates can largely be attributed to the high mortality during the egg stage (Williams et al. 1973). Recent 24-hour diel studies have indicated that most of the egg mortality occurs shortly after spawning (NUSCO 1994a). Also, the lack of sampling in August and September of 1991 and in September of 1992 contributed to the low entrainment estimates for cunner larvae.

Relatively few cunner have been taken by otter trawl, gill net, or seine. Most occurrences were recorded from April through November, which likely corresponds to the period of greatest cunner activity in New Hampshire waters. An estimated 81 cunner were impinged at Seabrook Station during 1990-94, despite the potential of the offshore intake structure to attract cunner (Appendix Table 5-2).

5.3.3.8 American Sand Lance

Both the American sand lance (*Ammodytes americanus*) and the northern sand lance (*A. dubius*) may be taken inshore in the Gulf of Maine (Winters and Dalley 1988; Nizinski et al. 1990). However, the latter species is more common in deeper, offshore

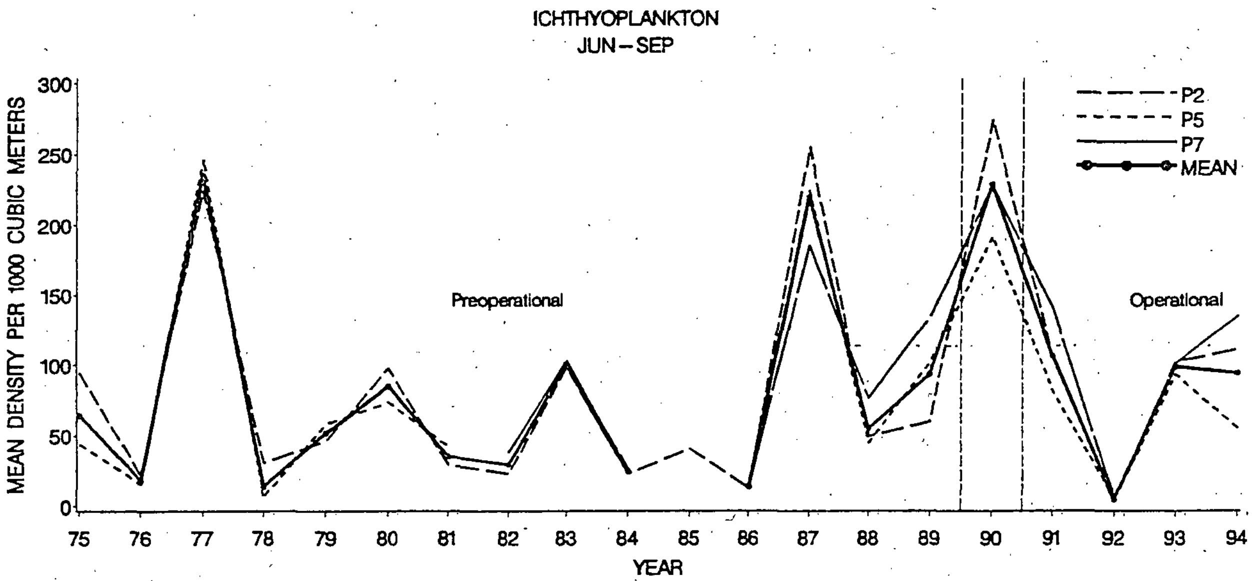


Figure 5-15. Annual geometric mean catch of cunner per unit effort in ichthyoplankton (number per 1000 cubic meters) samples by station and the mean of all stations, 1975-1994 (data between the two vertical dashed lines were excluded from the ANOVA model).
Seabrook Operational Report, 1994.

waters and all sand lance collected in Seabrook Station studies are referred to as the American sand lance. This species is found from Labrador to Chesapeake Bay (Richards 1982; Nizinski et al. 1990) and in the Gulf of Maine is usually found in depths of 6 to 20 m (Meyer et al. 1979). Found in schools ranging from hundreds to tens of thousands, sand lance are an important trophic link between zooplankton and larger fishes, birds, and marine mammals (Reay 1970; Meyer et al. 1979; Overholtz and Nicolas 1979; Payne et al. 1986; Gilman 1994).

Sand lance can live up to nine years, but populations are dominated by the first three age groups (Reay 1970). American sand lance can mature at age-1 at sizes of 90 to 115 mm (Richards 1982). Maximum size commonly observed is about 23-24 cm (Meyer et al. 1979; Richards 1982). An 18-cm female American sand lance is capable of producing 23,000 eggs (Westin et al. 1979). Spawning occurs in inshore waters from November through March with a peak in December and January. Sand lance are well-adapted for winter spawning and embryonic development can occur in temperatures as low as 2°C (Buckley et al. 1984). Eggs are demersal and adhesive, forming clumps, with sizes ranging from 0.67 to 1.03 mm (Williams et al. 1964; Smigielski et al. 1984). Embryonic development is lengthy, resulting in a well-developed larva of about 6 mm in length at hatching. Larvae have ample endogenous energy reserves and can survive long periods without food (Buckley et al. 1984; Monteleone et al. 1986). Larval development is also lengthy, with metamorphosis occurring at sizes of 29-35 mm in 131 days at 4°C and 102 days at 7°C (Smigielski et al. 1984). This long period of development results in larvae being dispersed widely over continental shelf areas (Richards and Kendall 1973), even though most spawning occurs inshore.

TABLE 5-20. RESULTS OF ANALYSIS OF VARIANCE FOR CUNNER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	8.78	0.67 NS	
(Jun-Sep)	Year (Preop-Op)[b]	5	13.14	1.11 NS	
(1987-1994)	Month (Year)[c]	21	12.38	17.55 ***	
	Station[d]	2	0.47	4.17 NS	
	Preop-Op X Station[e]	2	0.11	0.66 NS	
	Station X Year (Preop-Op)[f]	10	0.17	0.24 NS	
	Error	293	0.71		

[a] Preop-Op compares 1991-1994 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational period.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p \geq 0.001$)
*** = Very highly significant ($0.001 \geq p$)

et al. 1987), have become very abundant as sand lance abundance decreased. Another factor noted to affect sand lance reproduction and recruitment is water temperature, as Monteleone et al. (1987) suggested that warm December temperatures were associated with low larval densities.

Larval sand lance abundance in 1994 was higher than the preoperational period average, and similar to densities in the 1970s and early 1980s (Table 5-13; Figure 5-16). Annual geometric means have increased steadily since 1991. The Station X Preop-Op interaction term was significant, indicating a potential impact due to plant operation (Table 5-21). Larval density at Station P7 (farfield) was lower than other stations during the preoperational period, but was similar to the other stations during the operational period (Figure 5-17). American sand lance larvae were a dominant species in entrainment collections during 1991-94 (Table 5-6); their absence in entrainment samples during 1990 can be attributed to the start of sampling in June, which was after their season of occurrence.

Very few American sand lance have been taken by Seabrook Station adult fish sampling programs. A few fish were taken sporadically by otter trawl, mostly during January through March in 1978, 1979, and 1981. Several hundred or more sand lance were occasionally taken by seine, but most catches were small and occurred infrequently. Again, abundance was highest during the late 1970s. An estimated 1,249 fish have been impinged at Seabrook Station since 1990 (Appendix Table 5-2).

5.3.3.9 Atlantic Mackerel

The Atlantic mackerel is a strongly schooling fish found from Labrador to Cape Lookout, NC that prefers a temperature range of 9 to 12°C (Scott and Scott 1988).

American sand lance was the dominant larval taxon collected in the ichthyoplankton program (Tables 5-4 and 5-13). Its eggs have not been collected in ichthyoplankton samples because they are demersal and adhesive. Larvae generally occurred from December through June or July, with peak abundances present during January through April (NAI 1993). Larval abundances in the Hampton-Seabrook area have declined since the early 1980s, but appear to be increasing in the operational period (Figure 5-16). These declines were also apparent in other areas of the Northwest Atlantic Ocean. Larval densities in Long Island Sound over a 32-year period (1951-83) were highest in 1965-66 and 1978-79, with the latter years corresponding with a peak observed throughout the entire range of American sand lance (Monteleone et al. 1987). Similarly, larval sand lance densities were very high in Niantic Bay, CT from 1977 through 1981, with present densities an order of magnitude lower (NUSCO 1994a). Nizinski et al. (1990) also reported a peak in sand lance abundance throughout the Northwest Atlantic in 1981, with numbers declining since then. Sand lance abundance was noted to be inversely correlated with that of Atlantic herring and Atlantic mackerel (Sherman et al. 1981; Nizinski et al. 1990). Sand lance likely increased in abundance, replacing their herring and mackerel competitors, which had been reduced by overfishing in the 1970s (Sherman et al. 1981). In more recent years, Atlantic mackerel, which can prey heavily upon sand lance (Monteleone Maximum size recorded in recent years has been 47 cm and 1.3 kg (NFSC 1993), but most fish average 32-36 cm (Scott and Scott 1988). The median size of maturity for mackerel is about 26 cm, at approximately age-2 (O'Brien et al. 1993). Atlantic mackerel exhibit a distinct pattern of extensive annual movements; fish can migrate in excess of 2,200 km (Parsons and Moores 1974). Atlantic mackerel overwinter offshore along the edge of the continental shelf (Ware and Lambert 1985) and, in spring, move inshore. Temperature is apparently one of the dominant factors influencing the spring distribution and rate of northward migration of Atlantic mackerel (Overholtz et al. 1991). Two separate spawning components of Atlantic mackerel have been recognized (Sette 1950; Berrien

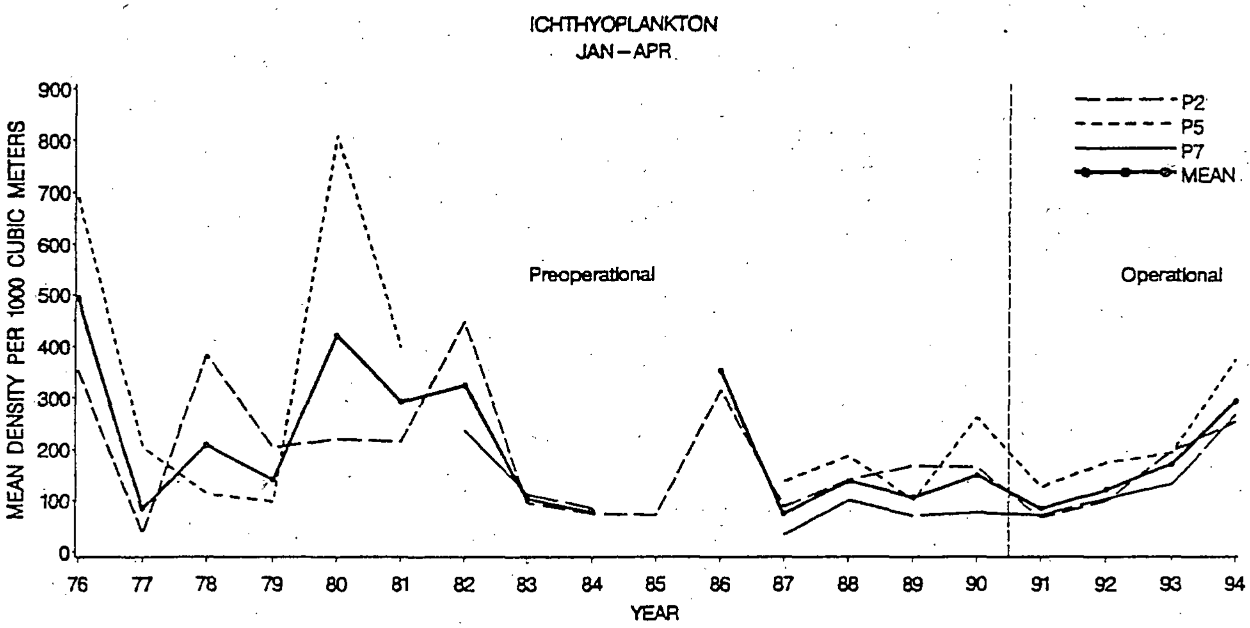


Figure 5–16. Annual geometric mean catch of American sand lance per unit effort in ichthyoplankton (number per 1000 cubic meters) samples by station and the mean of all stations, 1976–1994. Seabrook Operational Report, 1994

1978; Morse 1980). One group spawns progressively northward from mid-April through June in the Mid-Atlantic Bight and the other spawns in the Gulf of St. Lawrence from late May to mid-August; peak spawning occurs at about 13°C (Ware and Lambert 1985). Ware (1977) and Lambert and Ware (1984) suggested that the Atlantic mackerel spawning season is relatively short and coincides with peak copepod biomass. Spawning stock size appears to exert little influence on recruitment, except at very low levels, and environmental factors likely have a major effect on successful reproduction (Anderson 1979). After spawning, the southern contingent moves into coastal areas of the Gulf of Maine and the northern group remains in Canadian waters during summer and fall.

Female Atlantic mackerel are serial spawners and release five to seven successive batches of eggs; fecundity ranges from 285,000 to almost 2 million eggs per female (Morse 1980). The 1.1 to 1.3-mm eggs hatch in 5 to 7 days. Eggs are distributed near the surface, with 85% or more concentrated within the uppermost 15 m (Ware and Lambert 1985; deLafontaine and Gascon 1989; D'Amours and Gregoire 1991). The hatched larvae are 3 mm in length, grow rapidly, and develop a streamlined form early in life that enables relatively high swimming speeds (Ware and Lambert 1985). Larvae are often cannibalistic, preying on smaller individuals from younger cohorts (Peterson and Ausubel 1984; Ware and Lambert 1985). Young from both spawning contingents reach an average size of about 200 mm in late fall, even though their growing seasons differ in length (Sette 1950; Ware and Lambert 1985; D'Amours et al. 1990).

Presently, biomass of the Atlantic mackerel stock is very high (NFSC 1993). Although two spawning contingents exist, the species is managed as a single stock. Mackerel in the Gulf of Maine are primarily landed from May through November by both sport and

TABLE 5-21. RESULTS OF ANALYSIS OF VARIANCE FOR AMERICAN SAND LANCE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jan-Apr) (1987-1994)	Preop-Op[a]	1	1.54	0.69 NS	
	Year (Preop-Op)[b]	6	1.73	0.52 NS	
	Month (Year)[c]	24	3.71	7.08 ***	
	Station[d]	2	2.58	3.82 NS	
	Preop-Op X Station[e]	2	0.68	4.39 *	5 Op 5 Pre 2 Op 2 Pre 7 Op 7 Pre[g]
	Station X Year (Preop-Op)[f]	12	0.15	0.29 NS	
	Error	315	0.52		

[a] Preop-Op compares 1991-1994 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational period.
[g] Underlining indicates no significant difference among least squares means at $p \leq 0.05$.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very highly significant ($0.001 \geq p$)

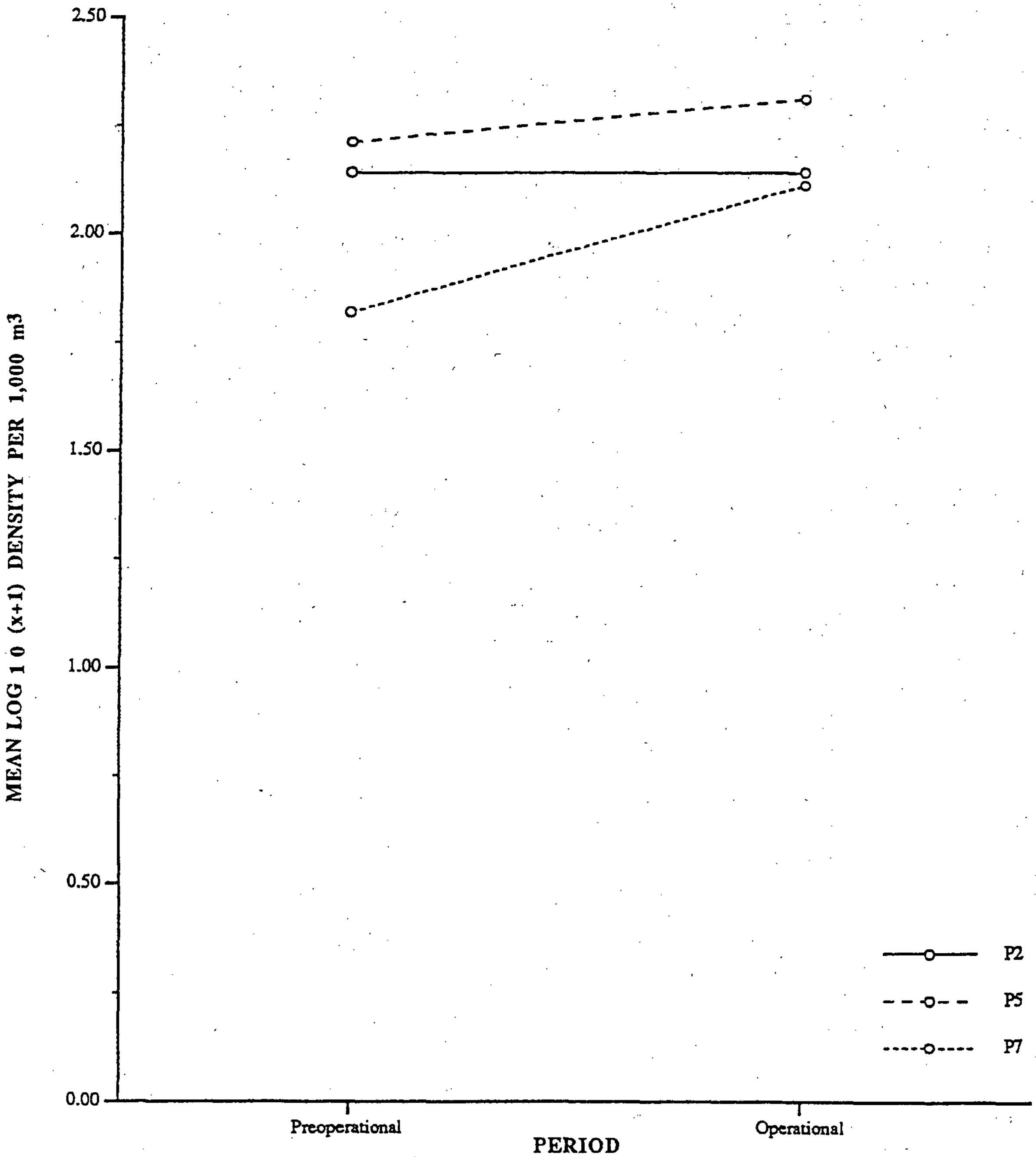


Figure 5-17. A comparison among stations of the mean $\log_{10}$ (x+1) density per 1,000 m^3 of American sand lance larvae during the preoperational (1987-1990) and operational (1991-1994) periods (January-April only) for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-21). Seabrook Operational Report, 1994.

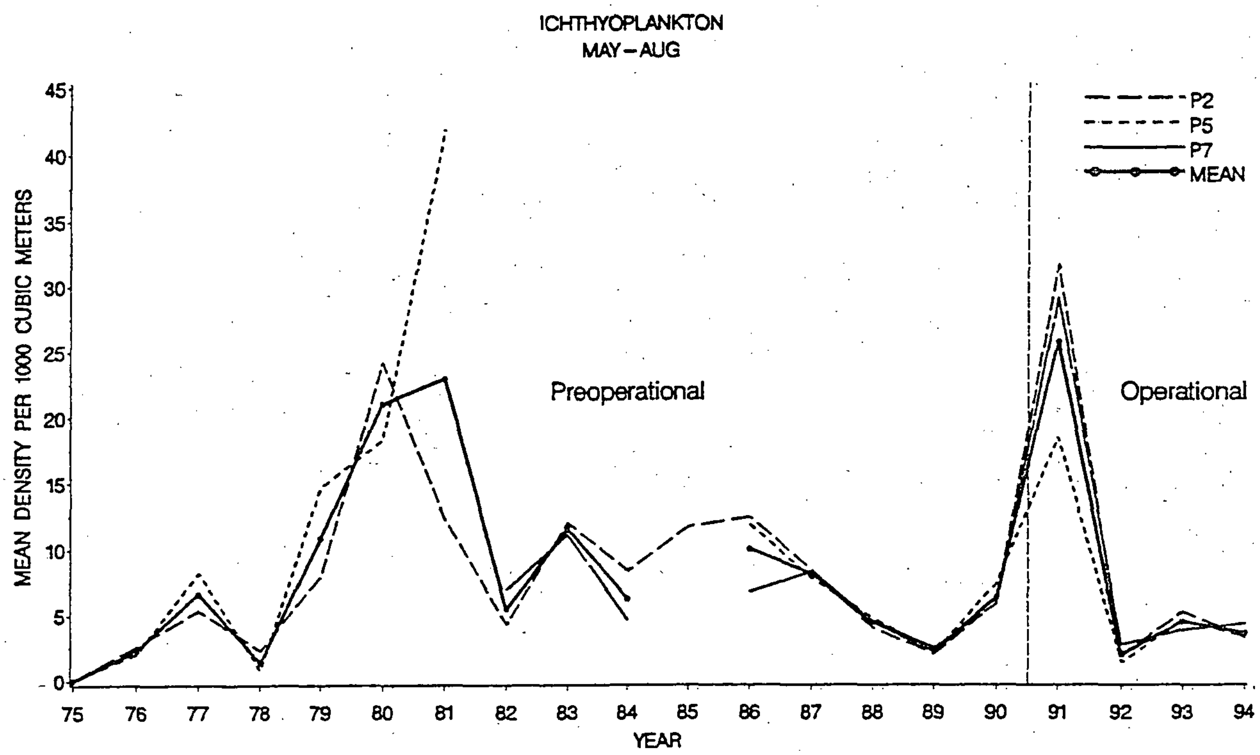
commercial fisheries. Landings from the U.S. (about one-third of the total) and Canada peaked at 400,000 metric tons in 1973 and decreased to about 30,000 metric tons during the late 1970s, as apparently weak year-classes were found from 1975 through 1980. Catches then increased steadily to 82,700 metric tons in 1988, but declined again to 38,300 metric tons in 1992; a very strong year-class was produced in 1982 and relatively good ones in 1984-88. With current spawning stock biomass estimated to exceed 2 million metric tons, catches can be increased substantially without affecting the spawning stock (NFSC 1993).

Atlantic mackerel was the second-most abundant egg taxon collected in the ichthyoplankton program (Table 5-4). The larvae were very abundant in ichthyoplankton collections, but were not dominant in entrainment samples (Tables 5-5 and 5-6). Larvae typically occurred from May through August (NAI 1993) and larval abundance in 1994 was below the preoperational and operational period average (Table 5-13). Annual larval abundances fluctuated, with a peak at station P5 in 1981 (Figure 5-18). Since all three stations were sampled (1986-94), similar densities were found at all stations, except for 1991. The results from the ANOVA indicated no significant difference among stations or between preoperational and operational periods; the interaction term was not significant (Table 5-22).

Atlantic mackerel juveniles and adults were collected by gill net in the Seabrook station area from June through November (NAI 1993). Annual geometric mean CPUE reflected trends noted by NFSC (1993), with peak abundance observed in the mid-1970s that decreased by about two-thirds during the early 1980s (Figure 5-18). Beginning in 1988, an overall increasing trend was found, but geometric means have fluctuated sharply from year to year. Results of the ANOVA showed no difference in catch between the preoperational and operational periods, as mackerel are as abundant now as they were in the 1970s (Table 5-22). There were no significant differences among stations (Table 5-22) and trends in abundance among stations appeared similar within the preoperational and operational periods (Figure 5-18). The interaction term was not significant, indicating that the operation of Seabrook Station did not affect the abundance or distribution of the Atlantic mackerel. Only an estimated 20 larger fish have been impinged at Seabrook Station since 1990 (Appendix Table 5-2). Large numbers of eggs were entrained and mackerel eggs ranked first or second in annual entrainment estimates since 1990 (Table 5-6). However, relatively few (0-4.7 million) larvae were entrained each year. As previously discussed in the entrainment section, this may have been related to the rapid developmental rate of Atlantic mackerel, which results in larger larvae that can avoid the intake. Atlantic mackerel biomass is currently very high and only an insignificant fraction of the egg production of this highly fecund fish is entrained at the plant.

5.3.3.10 Winter Flounder

The winter flounder ranges from Labrador to Georgia (Scott and Scott 1988), but is most common from Nova Scotia to New Jersey (Perlmutter 1947). Maximum size of coastal fish is about 45 cm and 1.4 kg (Bigelow and Schroeder 1953). Populations of winter flounder are composed of reproductively isolated fish that spawn in specific estuaries or coastal embayments (Lobell 1939; Perlmutter 1947; Saila 1961; NUSCO 1994b). North of Cape Cod, movements of winter flounder are generally localized and confined to inshore waters (Howe and Coates 1975). McCracken (1963) reported that winter flounder prefer temperatures of 12-15°C and, except for spawning, will move to remain within that range. However, others (Kennedy and Steele 1971; Van Guelpen and Davis 1979) noted that movements for feeding and to avoid turbulence and ice also affect distribution of northerly populations and Olla et al. (1969) reported observing adult fish in waters as warm as 22.5°C. Young-of-the-year are typically found in



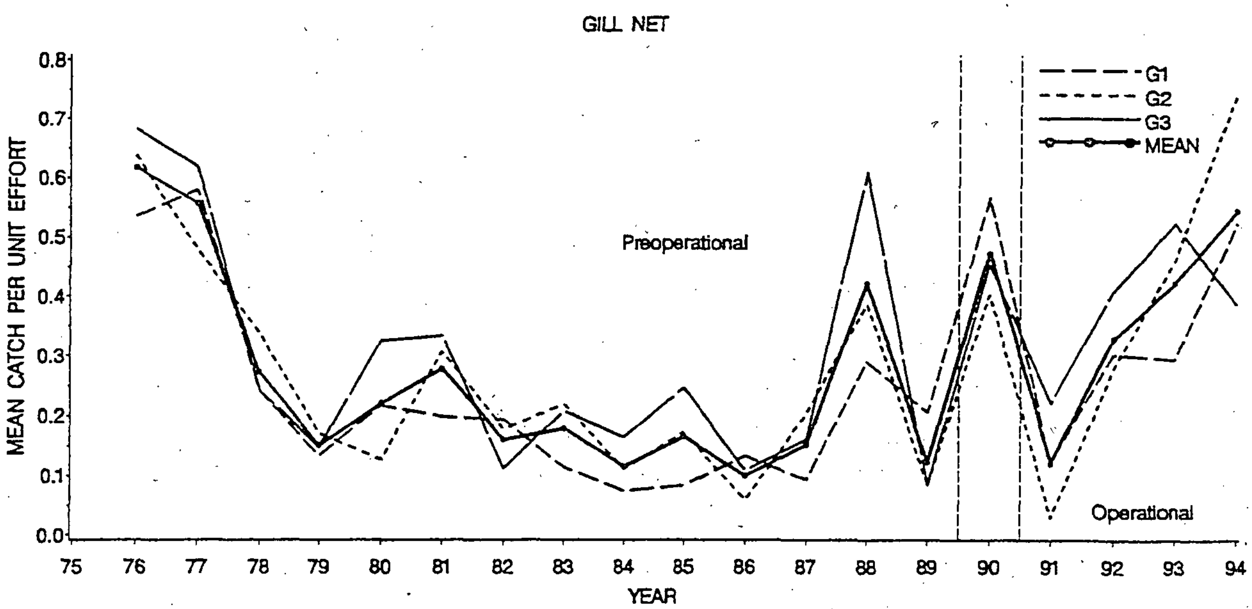


Figure 5-18. Annual geometric mean catch of Atlantic mackerel per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1994 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

TABLE 5-22. RESULTS OF ANALYSIS OF VARIANCE FOR ATLANTIC MACKEREL DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jul-Sep) (1986-1994)	Preop-Op[a]	1	0.01	0.02 NS	
	Year (Preop-Op)[b]	6	5.35	0.66 NS	
	Month (Year)[c]	23	8.94	9.98 ***	
	Station[d]	2	0.11	0.79 NS	
	Preop-Op X Station[e]	2	0.14	2.25 NS	
	Station X Year (Preop-Op)[f]	12	0.05	0.06 NS	
	Error	321	0.90		
Gill Net (Nov-Jul) (1975-1994)	Preop-Op[g]	1	0.31	2.04 NS	
	Year (Preop-Op)	16	0.17	1.68 NS	
	Month (Year)	90	0.10	6.84 ***	
	Station	2	0.04	[h]	
	Preop-Op X Station	2	<0.01	0.07 NS	
	Station X Year (Preop-Op)	32	0.02	1.34 NS	
	Error	180	0.01		

[a] Preop-Op compares 1991-1994 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1991-1994 to 1975-1989.
[h] Non-estimable due to negative denominator mean square.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

shallow estuarine waters and can withstand temperatures of 30 to 32.4°C (Pearcy 1962; Everich and Gonzalez 1977).

Adults enter inshore spawning areas in fall or early winter and spawn in late winter or early spring. Winter flounder in the Gulf of Maine mature at an average age of 3.4 years and at a length of 27.6 cm for males and 29.7 cm for females (O'Brien et al. 1993). Average fecundity is about 500,000 eggs per female (Bigelow and Schroeder 1953), with a maximum as much as 3.3 million for a large fish (Topp 1968). Eggs (0.71-0.96 mm) are adhesive and demersal (Fahay 1983). Winter flounder embryos develop under a relatively wide range of temperature and salinity conditions, with highest viable hatch reported at 3°C over a salinity range of 15 to 35‰ (Rogers 1976). Because winter flounder spawn during periods of low water temperature, larval development is relatively slow and can take up to two months to complete. Larvae flushed out of estuarine nursery areas are believed to have lowered potential for survival and eventual recruitment to adult stocks (Pearcy 1962; Smith et al. 1975; Crawford 1990). Overall mortality of larvae can exceed 99% (Pearcy 1962). Young are common in inshore shallows, where they remain until fall, undertaking little movement away from where they settled (Saucerman and Deegan 1991).

Based on numerous meristic and tagging studies conducted for assessment and management purposes, winter flounder have been divided into three groups: Gulf of Maine, Southern New England and Middle-Atlantic, and Georges Bank (NFSC 1993). Commercial landings of winter flounder from the Gulf of Maine were relatively stable at around 1,000 metric tons per year from 1961 through 1977, but tripled to about 3,000 metric tons in 1982. Recreational landings in some years exceeded those of the commercial fishery (NFSC 1993). Since 1983, a downward trend was observed in landings with a record low of only 900 metric tons taken in 1992. Bottom trawl survey data from the Massachusetts Division of Marine Fisheries spring survey also showed a declining trend since 1983 (NFSC 1993). Lowest values were observed during 1988-92. Continued low landings and trawl catch indices were indications that winter flounder in the Gulf of Maine have been overexploited (NFSC 1993) and the stock likely needs rebuilding before yields can be sustained or increased.

Larval winter flounder were collected in the ichthyoplankton program (Table 5-3), but eggs were absent because they are demersal and adhesive. Larvae typically occurred in the Hampton-Seabrook area during April through July (NAI 1993). Larval winter flounder abundance has declined since the mid-1980s and this was apparent at all three stations. Larger, but not significantly different, annual geometric means were usually found at P2 than at P5 or P7, although in 1994 larval abundance was lowest at Station P2 (Table 5-13, Figure 5-19). Mean larval density in 1994 (all stations combined) was the highest recorded in the operational period and continued a modest positive trend that started after 1991. Despite the apparent decline in larval abundance between the preoperational and operational periods, there were no significant differences in larval abundance between periods, or among stations. The interaction term was not significant, suggesting that the operation of Seabrook Station has not affected the abundance of winter flounder larvae in the Hampton-Seabrook area.

The winter flounder was taken year-round by otter trawl at all stations, but occurred most commonly from May through October (NAI 1993). Geometric mean CPUE peaked in 1980 and 1981, primarily because of high catches made at the nearfield station T2 (Figure 5-19). Winter flounder were considerably more abundant at T2 than at T1 or T3 until 1986, when annual mean CPUE became more similar. CPUE at T3 was generally lowest of all these three stations during the 1970s and 1980s, but catches have become more similar to those at T1 and T2 since 1990. CPUE at T2 was the lowest of the three stations in 1992 through 1994. This decrease may be related, in part, to the inability since 1986 to sample at T2 on many

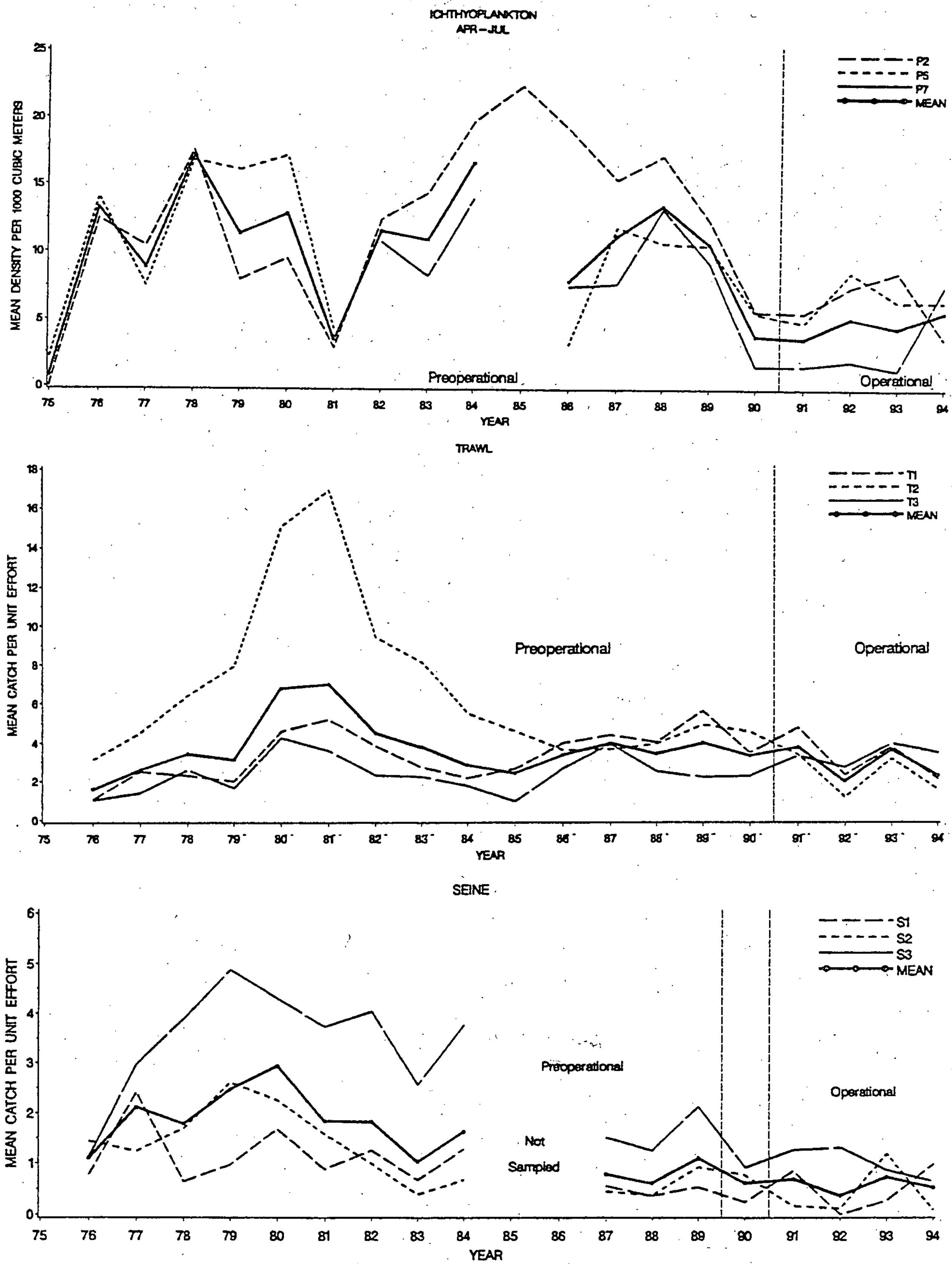


Figure 5–19. Annual geometric mean catch of winter flounder per unit effort in ichthyoplankton (number per 1000 cubic meters), trawl (number per 10–min tow), and seine (number per haul) samples by station and the mean of all stations, 1975–1994 (data between the two vertical dashed lines were excluded from ANOVA model). Seabrook Operational Report, 1994.

scheduled dates during August through October, months in which winter flounder are most abundant, due to the presence of lobster sampling gear in the T2 sampling area. However, decreased abundance was also observed in the other months, used in the ANOVA model.

Geometric mean CPUE for all three stations combined was highest in 1980 and 1981, and then decreased to a preoperational low in 1985 (Figure 5-19). CPUE remained relatively stable from 1985 through 1991. In 1992 and 1994, CPUE was lowest in the time series. The interaction term (Preop-Op X Station) was significant, primarily due to a large decrease in CPUE at Station T2 between the preoperational and operational periods (Figure 5-20). Closer examination of CPUE trends at Station T2 indicates that CPUE began to decrease during the preoperational period (Figure 5-19). To further quantify this decrease, an ANOVA was calculated to investigate the relationship between Year and Station within the preoperational period (Table 5-23). The interaction term for Year and Station was significant which indicates that the stations exhibited differing trends in CPUE within the preoperational period (Table 5-23). Smith et al. (1993) states that differences in trends between control and impact stations in the period prior to plant start-up violate the assumption of non-additivity in a BACI model and may lead to misleading significance. Stewart-Oaten et al. (1986) further suggests that species that exhibit differing trends between control and impact sites prior to plant start-up not be used in a BACI analysis, but due to the commercial and recreational importance of winter flounder, it probably should not be dropped from the analysis. Since the differences in CPUE among stations observed between the preoperational and operational periods were also observed within the preoperational period alone, they probably were not caused by the operation of Seabrook Station.

Smaller winter flounder (juveniles through age-2; NAI 1993) were collected in the Hampton-Seabrook Harbor by seine throughout the April-November sampling period. Annual geometric mean CPUE was consistently higher at station S3, located nearest to the mouth of the estuary, and generally lowest at S1, farthest inland (Figure 5-19). The pattern of annual abundance was somewhat similar to that of the trawl samples in that CPUE peaked in 1980 (one year earlier than for the catch by trawl) and thereafter decreased. Abundance has remained at relatively consistent levels since seine sampling resumed in July 1986. Results of the ANOVA for seine data indicated that abundance during the preoperational period was significantly higher than during the operational period (Table 5-23). This was not surprising, given the relatively high catches made during the 1970s and early 1980s and the current depressed state of winter flounder stocks. The interaction term, however, was not significant suggesting that Seabrook Station has not affected the abundance or distribution of juvenile winter flounder in the Hampton-Seabrook estuary.

Annual entrainment estimates for 1990-94 ranged from 0 to 9.0 million (Table 5-6). These totals, however, are much less than those of other large New England power plants. Annual larval winter flounder entrainment at Pilgrim Nuclear Power Station in Massachusetts ranged from almost 5 to 21 million during 1988-94 (MRI 1995). Similarly, entrainment was much higher at the three-unit Millstone Nuclear Power Station, where annual totals for 1976-94 were from 45 to 514 million larvae (NUSCO 1995). However, only entrainment losses relative to stock size are meaningful in term of impact assessment, and the size of local stock, or stocks, in the Hampton-Seabrook area is unknown.

Since 1990, an estimated 1,919 winter flounder have been impinged at Seabrook Station. This four-year total is considerably less than the number of winter flounder taken each year at several other New England power plants, although the counts at Seabrook Station underestimated the actual impingement prior to October 1994 (Section 5.3.2.4). During 1972-92, annual impingement of winter flounder at Brayton Point Station

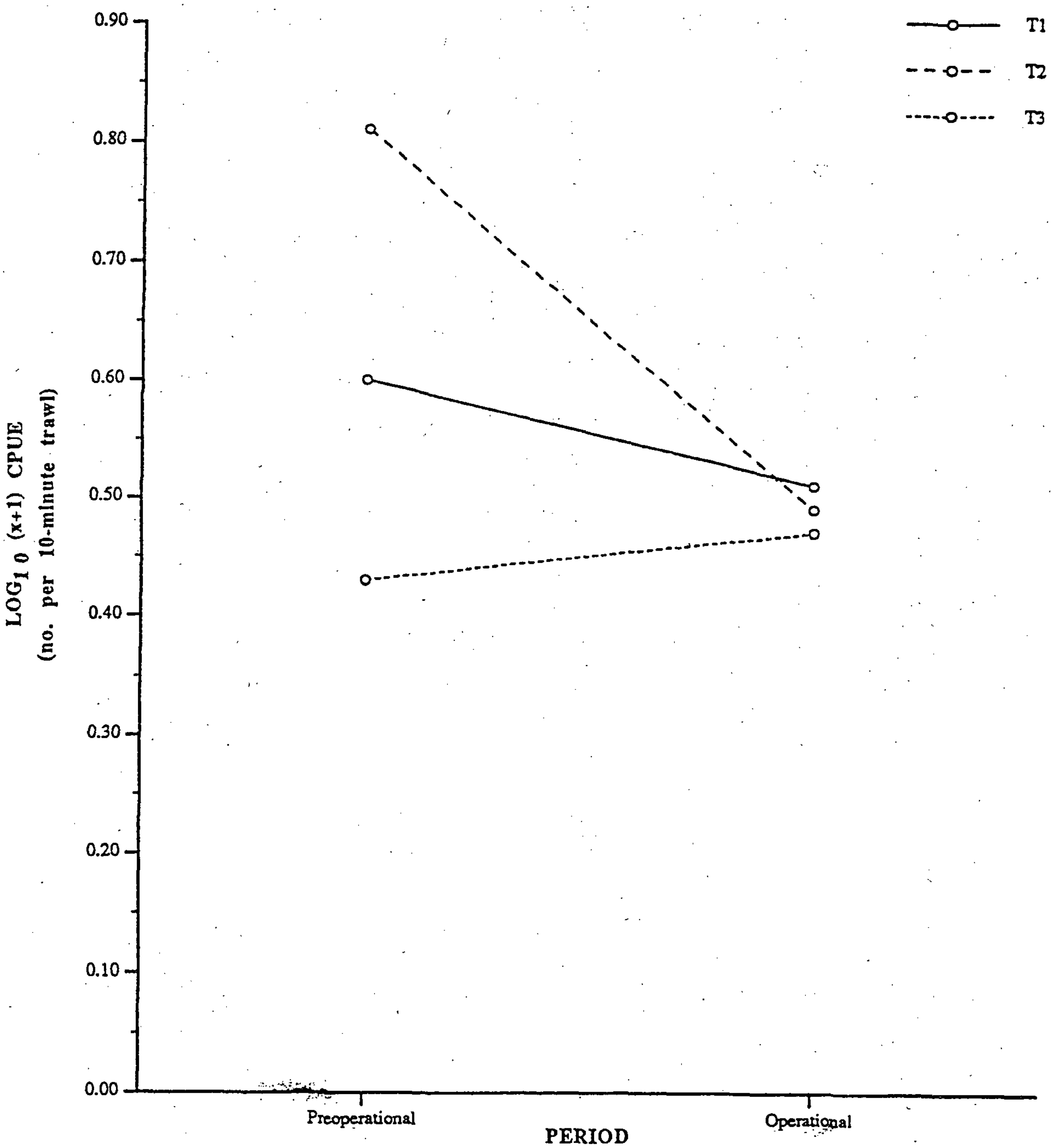


Figure 5-20. A comparison among stations of the mean $\log_{10}$ (x+1) CPUE (number per 10-minute tow) of winter flounder caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-23). Seabrook Operational Report, 1994.

TABLE 5-23. RESULTS OF ANALYSIS OF VARIANCE FOR WINTER FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	1	3.94	4.83 NS	
(Apr-Jul)	Year (Preop-Op)[b]	6	0.93	0.19 NS	
(1987-1994)	Month (Year)[c]	24	4.95	12.80 ***	
	Station[d]	2	2.60	8.73 NS	
	Preop-Op X Station[e]	2	0.30	0.72 NS	
	Station X Year (Preop-Op)[f]	12	0.41	1.06 NS	
	Error	318	0.39		
Trawl	Preop-Op[g]	1	1.30	1.01 NS	
(Nov-Jul)	Year (Preop-Op)	17	0.50	1.90 *	
(1975-1994)	Month (Year)	152	0.16	3.47 ***	
	Station	2	1.42	1.40 NS	
	Preop-Op X Station	2	0.94	6.39 **	2 Pre 1 Pre 1 Op 2 Op 3 Op 3 Pre[h]
	Station X Year (Preop-Op)	34	0.15	3.16 ***	
	Error	303	0.05		
Trawl	Year	14	0.53	2.22 NS	
(Nov-Jul)	Month (Year)	120	0.13	2.58 ***	
(1976-1989	Station	2	4.83	29.73 ***	
Preop only)	Year X Station	28	0.16	3.28 ***	
	Error	239	0.05		
Seine	Preop-Op[i]	1	3.08	7.68 *	Op<Preop
(Apr-Nov)	Year (Preop-Op)	15	0.26	1.64 NS	
(1976-1994)	Month (Year)	116	0.09	1.92 ***	
	Station	2	2.12	7.90 NS	
	Preop-Op X Station	2	0.26	2.19 NS	
	Station X Year (Preop-Op)	30	0.12	2.59 ***	
	Error	232	0.05		

[a] Preop-Op compares 1991-1994 to 1987-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational period.
[g] Preop-Op compares 1990-1994 to 1975-1990.
[h] Underlining signifies no significant differences among least square means at $p \leq 0.05$
[i] Preop-Op compares 1991-1994 to 1976-1984 and 1986-1989.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

in Massachusetts ranged from 859 to 23,452 individuals (mean of 7,925; MRI 1993a). Annual impingement totals from 1976 through 1987 at Millstone Nuclear Power Station Unit 2 in Connecticut were from 624 to 10,077 (annual mean of 3,484; NUSCO 1988).

Abundance of winter flounder throughout the Gulf of Maine has decreased in recent years to historic lows (NFSC 1993), likely due to overfishing. This has been reflected by the reductions in catch of winter flounder in Seabrook Station monitoring studies. The persistently lower abundance at nearfield station T2 since 1991, however, is unexplained. Although perhaps beginning before plant operation, this change bears close monitoring to determine if Seabrook Station has contributed to a distributional change following the 1990 start-up.

5.3.3.11 Yellowtail Flounder

The yellowtail flounder is found from southern Labrador to Chesapeake Bay (Scott and Scott 1988), but its center of abundance is the western Gulf of Maine and Southern New England (Bigelow and Schroeder 1953). It commonly reaches a length of 47 cm and a weight of 1 kg (NFSC 1993). Yellowtail flounder prefer coarser sand and gravel bottom sediments than those preferred by other flounders of the Northwestern Atlantic Ocean (Scott 1982b) and are found mostly in depths of 37 to 91 m (Scott and Scott 1988). Individuals apparently maintain generally similar depths between seasons while tolerating a wide range of temperatures and salinities (Scott 1982a; Murawski and Finn 1988; Perry and Smith 1994). Some limited seasonal movements, however, do occur, with fish moving to shallower waters in spring and into deeper waters during fall and early winter.

Median age of maturity for female yellowtail flounder is age-2, at a size of approximately 26 cm (O'Brien et al. 1993). Fecundity can range from 350,000 to 4.57 million eggs per female (Pitt 1971). Adults spawn in the western Gulf of Maine from March through September (Fahay 1983). Most spawning was observed by Smith et al. (1975) to occur at 4 to 9°C. Eggs (0.8-0.9 mm in diameter) are deposited at or near the bottom, but are pelagic and hatch in five days at temperatures of 10-11.1°C. Larvae are 2 to 3.5 mm in length at hatching (Fahay 1983). Greatest concentrations of pelagic larvae are found in water temperatures of 4.1-9.9°C (Smith et al. 1975). Larvae exhibit pronounced diel vertical movements and are found near the surface at night and at depths of 20 m or so during the day, regardless of thermal gradients (Smith et al. 1978). Ascent and descent occur at sunset and sunrise, respectively, with amplitude of movement increasing with larval size. Larvae metamorphose and become demersal at about 11 to 16 mm in length (Fahay 1983), although fish as large as 20 mm may still ascend to the surface (Smith et al. 1978).

Three discrete groups of yellowtail flounder are managed in U.S. waters, including Southern New England, Georges Bank, and Cape Cod (NFSC 1993). All of these stocks are considered to be overexploited. Abundance was relatively high in the early 1980s, but subsequently declined due to overfishing. After several years of low abundance, a relatively strong 1987 year-class produced within all three stock areas resulted in an increase in commercial landings in 1990. However, the increase was short-lived as the stocks were rapidly fished down again and current abundance is at very low levels.

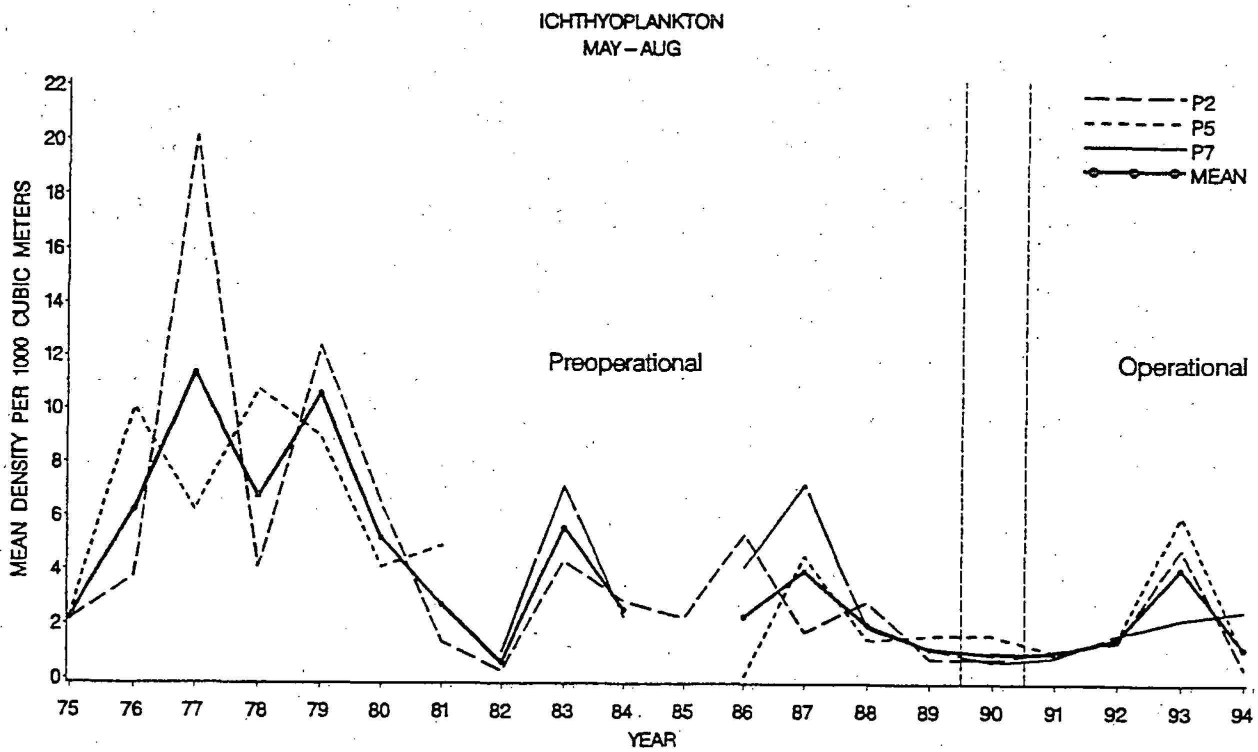
Yellowtail flounder eggs were grouped as cunner/yellowtail flounder because it was difficult to distinguish between these two species; this group would also include tautog eggs, if present. The cunner/yellowtail flounder taxon was the dominant egg collected during both the preoperational and operational periods (Table 5-3). Larvae were less abundant, probably because the egg group consisted primarily of cunner, as previously mentioned (Section 5.3.3.7). Yellowtail flounder were among the commonly occurring larval taxa selected for numerical classification analysis but they were not among the dominant taxa of any of the seasonal groups (Table 5-4). The annual geometric mean of yellowtail flounder larvae decreased from high in 1977 to the lowest in the time series in 1982. Since 1982, larval density has remained relatively low with peaks occurring in 1983, 1987 and 1993 (Figure 5-21). Larval density in 1994 was lower than the preoperational mean and similar to the operational mean (Table 5-13). Results from the ANOVA indicated there was no significant difference detected between the preoperational and operational periods or among stations (Table 5-24). In addition, the interaction term was also not significant, suggesting that the operation of Seabrook Station has not altered the abundance of yellowtail flounder larvae in the Hampton-Seabrook area.

The yellowtail flounder is taken year-round in the Seabrook Station study area and in former years was one of the most abundant fishes taken by otter trawl sampling (Table 5-9). Recently, however, it was most common only from May through October (NAI 1993). To a large degree, annual mean CPUE by otter trawl (Figure 5-21) mirrored that of commercial landings reported by NFSC (1993). Trawl CPUE peaked in the early 1980s and subsequently decreased to a lower, but relatively stable level, until a slight increase was seen in 1989, perhaps due to the relatively strong 1987 year-class. CPUE then steadily decreased to near zero in 1992, rebounded slightly in 1993, and declined again in 1994.

Catches have been consistently (and significantly) highest at farfield station T1 and lowest at nearfield station T2 throughout the 19-year period; CPUE at T3 tended to approximate the overall mean (Tables 5-13, 5-24). This pattern of abundance may reflect habitat preferences of the yellowtail flounder in the Hampton-Seabrook study area. The CPUE during the operational period was significantly smaller than during the preoperational period (Table 5-24). However, this was likely due to the overall decrease in abundance for this species since the early 1980s that resulted from overfishing. The interaction term was not significant, indicating no plant effect. Eleven yellowtail flounder have been impinged at Seabrook Station since 1990 and none were impinged in 1994 (Appendix Table 5-2). Prior to 1994, the cunner/yellowtail flounder group has been consistently ranked first or second among egg taxa entrained at Seabrook Station, with annual totals ranging from 58.4 to 716.3 million (Table 5-6). No entrainment of the cunner/yellowtail flounder group was estimated for 1994 because of lack of sampling due to an extended plant outage and other factors during the period of highest density. It is likely that this group is composed mostly of cunner, as relatively few yellowtail flounder larvae (overall and relative to cunner) have been identified in entrainment samples. The yellowtail flounder has been severely reduced in abundance by overfishing throughout its range, and catch near Seabrook Station reflected this decline. No change in this situation can be expected without a substantial reduction in fishing effort and several years of improved recruitment (NFSC 1993).

5.4 EFFECTS OF SEABROOK STATION OPERATION

The fish community in the Hampton-Seabrook area was sampled to determine if the operation of Seabrook Station has had any discernible effects on fish abundance or distribution. Potential impacts of station operation included the entrainment of fish eggs and larvae and impingement of juvenile and adult fish at the plant intake; entrainment of fish eggs and larvae into and avoidance by larger fish of the offshore discharge thermal plume; and effects of the discharge of the plant settling basin into the Browns River within the Hampton-Seabrook estuary. Monitoring programs were established that used sampling gear appropriate for several specific fish assemblages. Samples were periodically taken at fixed stations in nearfield and farfield areas relative to the station intake and discharge for various periods prior to commencement of Seabrook Station commercial operation in August 1990 and



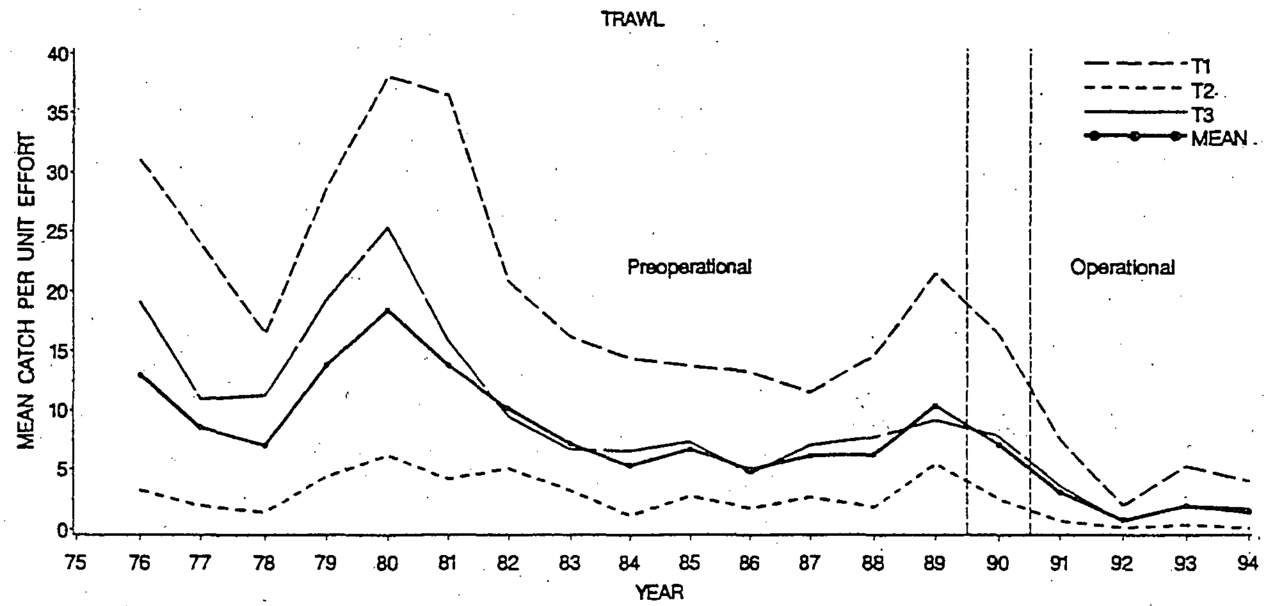


Figure 5-21. Annual geometric mean catch of yellowtail flounder per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1976-1994 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1994.

TABLE 5-24. RESULTS OF ANALYSIS OF VARIANCE FOR YELLOWTAIL FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (May-Aug) (1987-1994)	Preop-Op[a]	1	0.45	0.32 NS	
	Year (Preop-Op)[b]	5	1.71	0.72 NS	
	Month (Year)[c]	21	2.31	7.01 ***	
	Station[d]	2	0.24	2.69 NS	
	Preop-Op X Station[e]	2	0.09	0.23 NS	
	Station X Year (Preop-Op)[f]	10	0.41	1.25 NS	
	Error	290	0.33		
Trawl (Nov-Jul) (1975-1994)	Preop-Op[g]	1	28.71	33.96 ***	Op<Preop
	Year (Preop-Op)	17	0.80	5.37 ***	
	Month (Year)	152	0.09	1.21 NS	
	Station	2	12.60	71.17 *	T1>T3>T2
	Preop-Op X Station	2	0.13	1.29 NS	
	Station X Year (Preop-Op)	34	0.13	1.83 **	
	Error	303	0.07		

[a] Preop-Op compares 1991-1994 to 1987-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Year and Station nested within Preoperational and Operational periods.
[g] Preop-Op compares 1990-1994 to 1975-1990.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very highly significant ($0.001 \geq p$)

sampling has continued to the present. The impacts of impingement and entrainment were directly estimated from samples taken at the station when it operated.

Assessment of impact was based on an ANOVA model, primarily used to examine for differences in abundance of selected fishes between the preoperational and operational periods and for the consistency of any observed differences between these periods among the fixed stations (i.e., the Preop-Op X Station interaction). Data were selected for the ANOVA taking into account the temporal distribution of a species, its occurrence relative to the August 1990 startup, and samples missing as a result of temporary cessation of monitoring or the inability to sample a station at certain times of the year. Possible changes in seasonal ichthyoplankton assemblages were also examined using multivariate analyses. In general, the species selected for analyses are abundant in the Gulf of Maine and are important to the trophic dynamics of this marine ecosystem. Most of these fishes also have commercial and recreational importance for the region. Because fishing can significantly alter the abundance, distribution, and population dynamics of heavily exploited fishes, trends in landings and present status of fishing stocks of these species were also examined to put into perspective any changes seen in the Seabrook area. Finally, comparisons of entrainment and impingement were made between Seabrook Station and those at other large marine power plants in New England to illustrate the relatively benign impact of Seabrook Station as a result of its intake design and placement. As summarized in Table 5-25, a number of differences were found between the preoperational and operational periods for fish assemblages in general, and for many of the selected species. There were few significant differences between the preoperational and operational periods for the ichthyoplankton of any of the selected species. This is not surprising, as the marine larval fish densities are strongly influenced by environmental factors such as water temperature, currents, and availability of food items that varied during the time series (Parsons et al. 1977).

There were significant differences between periods for many demersal fishes (Table 5-25). However, in many instances, the declines began in the early to mid-1980s, well before Seabrook Station began operation. Several of the decreases seen in the Hampton-Seabrook area simply reflect long-term declining trends of overexploited commercial fishes, including the Atlantic cod and yellowtail flounder. Decreases in these and other important New England groundfishes, such as haddock, have resulted in large increases in biomass of skates and spiny dogfish. Increase of the latter was also reflected by increased catches by gill net near Seabrook Station in recent years. The current low population levels for the selected demersal fishes is most likely due to commercial overfishing and not due to the operation of Seabrook Station, because the decline in abundance generally began in the mid-1980s, before the Station went on-line. The abundance trends for demersal fish off the Hampton-Seabrook area are in general agreement with trends observed by the National Marine Fisheries Service in their annual groundfish stock assessment surveys (NFSC 1993). Regional abundance of both red and white hakes is now increasing, but trawl survey indices reported by NFSC (1993) show erratic changes, likely due to varying year-class strength from year to year. A longer time-series of operational data at Seabrook Station may be needed in some cases to discern current abundance trends in the study area.

Few pelagic fishes showed significant differences between the preoperational and operational periods. Pelagic fishes have not been subjected to as much commercial exploitation as demersal fishes. Abundance of Atlantic herring is presently increasing in the Northwest Atlantic Ocean, particularly on Georges Bank. CPUE in the Hampton-Seabrook area has remained essentially stable since the early 1980s, after decreasing from a relatively high peak in the late 1970s. It is unknown why abundance has not increased further in the study area, although it may be related to aspects of Atlantic herring stock structure and recruitment in the Gulf of Maine. Low abundance of Atlantic herring

TABLE 5-25. SUMMARY OF POTENTIAL EFFECTS OF THE OPERATION OF SEABROOK STATION ON THE ICHTHYOPLANKTON ASSEMBLAGES AND SELECTED FISH TAXA. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	SAMPLING PROGRAM	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?[a]	PREOPERATIONAL/ OPERATIONAL DIFFERENCES CONSISTENT AMONG STATIONS?[b]	RECENT ABUNDANCE TREND IN THE GULF OF MAINE[c]	STATUS OF FISHERY[c]
Fish egg assemblages	ichthyoplankton				
seasonal occurrence		Op=Preop	yes		
abundance		variable among taxa	yes		
Fish larvae assemblages	ichthyoplankton				
seasonal occurrence		Op=Preop	yes		
abundance		variable among taxa	yes		
Atlantic herring	ichthyoplankton	Op<Preop	yes	increasing	underexploited
	gill net	Op=Preop	yes		
Rainbow smelt	trawl	Op<Preop	no	unknown	lightly to unexploited
	seine	Op=Preop	yes		
Atlantic cod	ichthyoplankton	Op=Preop	yes	decreasing	overexploited
	trawl	Op<Preop	yes		
Pollock	ichthyoplankton	Op=Preop	yes	stable	fully exploited
	gill net	Op=Preop	yes		
Hakes	ichthyoplankton	Op=Preop	yes	red hake: increasing	underexploited
	trawl	Op<Preop	yes	white hake: increasing	fully exploited
Atlantic silverside	seine	Op=Preop	yes	unknown	unexploited
Cunner	ichthyoplankton	Op=Preop	yes	unknown	unexploited
American sand lance	ichthyoplankton	Op=Preop	no	decreasing in 1980s now stable (?)	unexploited
Atlantic mackerel	ichthyoplankton	Op=Preop	yes	increasing	underexploited
	gill net	Op=Preop	yes		
Winter flounder	ichthyoplankton	Op=Preop	yes	decreasing	overexploited
	trawl	Op=Preop	no		
	seine	Op<Preop	yes		
Yellowtail flounder	ichthyoplankton	Op=Preop	yes	decreasing	overexploited
	trawl	Op<Preop	yes		

[a] Based on results of numerical classification for assemblages and ANOVA for selected taxa.
[b] Based on Preop-Op X Station interaction term from the MANOVA for assemblages and ANOVA for selected taxa.
[c] For commercial species, from NFSC (1993).

in nearshore areas appears to be a coast-wide phenomenon as herring have become less available to the inshore fixed-gear fishery on the coast of Maine (NFSC 1993). For the past three years, abundance of the Atlantic mackerel has increased near Seabrook Station, as it has throughout the northwest Atlantic, but additional years of operational data may be needed to demonstrate a significant change in abundance.

Among the estuarine fish community there were no significant differences in CPUE between the preoperational and operational periods for Atlantic silverside and rainbow smelt. These small, short-lived species appear to exhibit variable and, perhaps, periodic patterns of annual abundance. It is unlikely that the discharge of Seabrook Station would have significantly affected these fishes given their concentration in estuaries distant from the cooling water discharge. However, Atlantic silverside were the most numerous fish impinged in 1994, and over all years combined. Impingement monitoring in future years will continue to document in-plant losses of Atlantic silverside. CPUE for winter flounder in the estuary was significantly greater during the preoperational period than the operational period. This is probably a reflection of the reduction of adult winter flounder due to overfishing, resulting in fewer juveniles in the estuary. The reduction began in the mid-1980s prior to the start of Seabrook Station and cannot be attributed to plant operation. Any hypothesized effects due to the settling basin discharge into the Browns River are no longer applicable, as this discharge was re-routed through the circulating water system in April 1994.

The ANOVA interaction term was significant only for winter flounder and rainbow smelt in the trawl, and larval American sand lance, suggesting further investigation into a potential effect of Seabrook Station operation. Winter flounder abundance at nearfield station (T2) was higher than the farfield stations (T1, T3) during the preoperational period, and lower in the operational period resulting in a significant Preop X Station interaction term. However, abundance at Station T2 began to drop significantly during the preoperational period, indicating that the change in winter flounder abundance between the preoperational and operational periods began prior to the start-up of Seabrook Station. The reasons for this are unknown, but could be related to natural changes in the local environmental or physical conditions. Brylinsky et al. (1994) found that trawl doors made furrows in the substrate that were visible for two to seven months after sampling, although no significant effects were observed on the macrobenthos. Monthly repetitive sampling may have differentially modified the habitat at Station T2, compared to the other two stations, causing a change in winter flounder distribution.

Abundance of rainbow smelt in the trawl decreased between the preoperational and operational periods at all stations, but the decrease was greatest at Station T2, indicating a potential effect due to Seabrook Station. There are no apparent reasons why the plant should be affecting rainbow smelt abundance. Very few eggs and larvae have been entrained at the station because rainbow smelt spawn in the estuary and the eggs and larvae are beyond the influence of the intakes of the plant. The discharge from the settling basin to the Browns River stopped in April 1994. It is unlikely that this discharge affected rainbow smelt abundance because it did not occur for most of 1994. An estimated 704 rainbow smelt have been impinged at Seabrook Station since 1990. This may under-represent the actual total due to the problems with sorting small fish from the screenwash debris. Rainbow smelt appear to be exposed to impingement primarily in December (Appendix Table 5-3). It appears unlikely that such a short exposure to impingement, and apparently small numbers of smelt impinged, could significantly affect abundance in the entire study area.

Rainbow smelt are a small short-lived fish subject to wide variations in population size. In the study area this variability appears to be greatest at Station T2. Dramatic decreases in CPUE at Station T2 occurred in the preoperational period during 1978-1980, and

1983-1985. During these periods, the decrease in CPUE was less at Stations T1 and T3. Large changes in CPUE of rainbow smelt at Station T2 appear to be a natural feature of the population dynamics of this species in the study area, because they had occurred during the preoperational period. Rainbow smelt should be monitored closely in future years to determine if plant operation may be affecting abundance.

Abundance of American sand lance larvae increased at all stations during the operational period. The interaction term was significant because density of sand lance larvae at Station P7 (farfield) was lowest during the preoperational period and was similar to the other two stations during the operational period. It is unlikely that Seabrook Station is affecting the abundance of sand lance larvae, because sand lance larval abundance has been increasing at all stations during the operational period. Larval abundance of American sand lance should be monitored closely in future years.

Compared to other New England marine power plants, Seabrook Station entrains relatively few fish eggs or larvae and apparently impinges very few juvenile and adult fish. The location and design of the offshore intakes have worked as expected in reducing these impacts. In fact, most of the impingement that does occur is not of pelagic fish, but demersal fish that predominantly encounter the intake during storm events. However, impingement to date may not have been fully accounted for. The numbers of fish actually impinged at Seabrook Station in 1990 through October 1994 were probably greater than the impingement counts because small fish were not adequately removed from the screenwash debris. Starting in the last quarter of 1994 the efficiency of the impingement collection process greatly increased, resulting in increased estimates of the numbers of small fishes impinged. More accurate impingement estimates will be made in 1995.

In conclusion, little impact to fishes can be attributed to Seabrook Station operation. Most of the selected species are from very large and highly fecund stocks spawning throughout the Gulf of Maine. Others, such as the rainbow smelt and Atlantic silverside, spawn in estuaries away from the plant intake and have egg or larval life stages that are largely maintained in inshore areas. Atlantic cod, winter flounder, and yellowtail flounder continue to be overexploited by commercial fisheries and their stocks are presently declining. Other fishes, such as Atlantic mackerel, were overfished and now have recovered. Catch of all the selected species in the Hampton-Seabrook area simply reflect long-term, regional trends. Furthermore, the influence of regional environmental factors and interspecific interactions (e.g., American sand lance-Atlantic mackerel) introduces complexities in any evaluation. Because of the apparently small numbers of fish of all life stages directly removed by the plant and the concurrent changes in abundance at both near- and farfield stations in nearly every instance, the operation of Seabrook Station does not appear to have affected the balanced indigenous populations of fish in the Hampton-Seabrook area.

5.5 REFERENCES CITED

Anderson, E.M. 1979. Assessment of the Northwest Atlantic mackerel, *Scomber scombrus*, stock. NOAA Tech. Rep. NMFS SSRF-732. 13 pp.

Anderson, R.D. 1995. Impingement of organisms at Pilgrim Nuclear Power Station (January-December 1994). *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 44. Boston Edison Co., Boston, MA.

Anthony, V.C., and H.C. Boyar. 1968. Comparison of meristic characters of adult Atlantic herring from the Gulf of Maine and adjacent waters. Res. Bull. Int. Comm. Northw. Atl. Fish 5: 91-98.

______, and M. J. Fogarty. 1985. Environmental effects on recruitment, growth, and vulnerability of Atlantic herring (*Clupea harengus harengus*) in the Gulf of Maine region. Can. J. Fish. Aquat. Sci. 42(Suppl. 1): 158-173.

Bengston, D.A., R.C. Barkman, and W.J. Berry. 1987. Relationships between maternal size, egg diameter, time of spawning season, temperature, and length at hatch of Atlantic silverside, *Menidia menidia*. J. Fish. Biol. 31: 697-704.

Berrien, P.L. 1978. Eggs and larvae of *Scomber scombrus* and *Scomber japonicus* in continental shelf waters between Massachusetts and Florida. Fish. Bull., U.S. 76: 95-114.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish. Wildl. Serv. Fish. Bull. 53:1-577.

Bolz, G.R., and R.G. Lough. 1988. Growth through the first six months of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, based on daily otolith increments. Fish. Bull., U.S. 86: 223-235.

Boyar, H.C., R.R. Marak, F.E. Perkins, and R.A. Clifford. 1971. Seasonal distribution of larval herring, *Clupea harengus harengus* Linnaeus, in Georges Bank-Gulf of Maine area, 1962-70. Int. Comm. Northw. Atl. Fish., Res. Doc. 71/100. 11 pp.

Brander, K., and P.C. Hurley. 1992. Distribution of early-stage Atlantic cod (*Gadus morhua*), haddock (*Melangrammus aeglefinus*), and witch flounder (*Glyptocephalus cynoglossus*) eggs on the Scotian Shelf: a reappraisal of evidence on the coupling of cod spawning and plankton production. Can. J. Fish. Aquat. Sci. 49: 238-251.

Brylinsky, M., J. Gibson, and D.C. Gordon Jr. 1994. Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. Can. J. Fish. Aquat. Sci. 51:650-661.

Buckley, L.J., S I. Turner, T.A. Halavik, A.S. Smigielski, S.M. Drew, and G.C. Laurence. 1984. Effects of temperature and food availability on growth, survival, and RNA-DNA ratio of larval sand lance (*Ammodytes americanus*). Mar. Ecol. Prog. Ser. 15: 91-97.

Campana, S.E., K.T. Frank, P.C.F. Hurley, P.A. Koeller, F.H. Page, and P.C. Smith. 1989. Survival and abundance of young Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as indicators of year-class strength. Can. J. Fish. Aquat. Sci. 46(Suppl.1): 171-182.

Campbell, D.E., and J.J. Graham. 1991. Herring recruitment in Maine coastal waters: an ecological model. Can. J. Fish. Aquat. Sci. 48: 448-471.

Clayton, G.R. 1976. Reproduction, first year growth, and distribution of anadromous rainbow smelt, *Osmerus mordax*, in the Parker River-Plum Island Sound estuary, Massachusetts. M.S. Thesis. University of Massachusetts, Amherst, MA. 105 pp.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

Colton, J.B., Jr., W.G. Smith, A.W. Kendall, Jr., P.L. Berrien, and M.P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76: 911-915.

Comyns, B.H., and G.C. Grant. 1993. Identification and distribution of *Urophycis* and *Phycis* (Pisces, Gadidae) larvae and pelagic juveniles in the U.S. Middle Atlantic Bight. Fish. Bull., U.S. 91: 210-223.

Conover, D.O. 1979. Density, growth, production and fecundity of the Atlantic silverside, *Menidia menidia* (Linnaeus), in a central New England estuary. M.S. Thesis. University of Massachusetts, Amherst, MA. 59 pp.

______. 1992. Seasonality and the scheduling of life history at different latitudes. J. Fish Biol. 41: 161-178.

______, and M.H. Fleisher. 1986. Temperature-sensitive period of sex determination in the Atlantic silverside, *Menidia menidia*. Can. J. Fish. Aquat. Sci. 43: 514-520.

______, and B.E. Kynard. 1981. Environmental sex determination: interaction of temperature and genotype in a fish. Science 213: 577-579.

______, and B.E. Kynard. 1984. Field and laboratory observations of spawning periodicity and behavior of a northern population of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). Envir. Biol. Fish. 11: 161-171.

______, and S.A. Murawski. 1982. Offshore winter migration of the Atlantic silverside, *Menidia menidia*. Fish. Bull., U.S. 80: 145-150.

______, and M. R. Ross. 1982. Patterns in seasonal abundance, growth and biomass of the Atlantic silverside, *Menidia menidia,* in a New England estuary. Estuaries 5: 275-286.

Crawford, R.E. 1990. Winter flounder in Rhode Island coastal ponds. Rhode Island Sea Grant, Univ. of Rhode Island, Narragansett, RI. RIU-G-90-001. 24 pp.

Cushing, D.H. 1984. The gadoid outburst in the North Sea. J. Cons. int. Explor. Mer 41: 159-166.

D'Amours, D., and F. Gregoire. 1991. Analytical correction for oversampled Atlantic mackerel *Scomber scombrus* eggs collected with oblique plankton tows. Fish. Bull., U.S. 90: 190-196.

______, J.G. Landry, and T.C. Lambert. 1990. Growth of juvenile (0-group) Atlantic mackerel (*Scomber scombrus*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 47: 2212-2218.

deLafontaine, Y., and D. Gascon. 1989. Ontogenetic variation in the vertical distribution of eggs and larvae of Atlantic mackerel (*Scomber scombrus*). Rapp. P.-v. Reun. int. Explor. Mer 191: 137-145.

Dew, C.B. 1976. A contribution to the life history of the cunner, *Tautogolabrus adsperus*, in Fishers Island Sound, Connecticut. Chesapeake Sci. 17: 101-113.

Dodson, J.J., J.-C. Dauvin, R.G. Ingram, and B. D'Anglejan. 1989. Abundance of larval rainbow smelt (*Osmerus mordax*) in relation to the maximum turbidity zone and associated macroplanktonic fauna of the middle St. Lawrence estuary. Estuaries 12: 66-81.

Evans, S.D. 1978. Impingement studies. Pages 3.1-3.40 *in* Maine Yankee Atomic Power Company. Final report environmental surveillance and studies at the Maine Yankee Nuclear Generating Station 1969-1977.

Everich, D., and J.G. Gonzalez. 1977. Critical thermal maxima of two species of estuarine fish. Mar. Biol. 41: 141-146.

Fahay, M.P. 1983. Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. J. Northw. Atl. Fish. Sci. 4: 1-423.

______, and K.W. Able. 1989. White hake, *Urophycis tenuis*, in the Gulf of Maine: spawning seasonality, habitat use, and growth in young of the year and relationships to the Scotian Shelf population. Can. J. Zool. 67: 1715-1724.

Frechet, A., and J.J. Dodson. 1983. Use of variation in biological characters for the classification of anadromous rainbow smelt (*Osmerus mordax*) groups. Can. J. Fish. Aquat. Sci. 40: 718-727.

Freund, P.J., R.C. Littell, and P.C. Spector. 1986. SAS for linear models: a guide to the ANOVA and GLM procedures. SAS Institute Inc., Cary, NC.

Garman, G.C. 1983. Observations on juvenile red hake associated with sea scallops in Frenchman Bay, Maine. Trans. Am. Fish. Soc. 112: 212-215.

Gilbert, J.R. 1994. Harbor seal distribution in Maine. Prepared for Maine Department of Environmental Protection and Maine Department of Inland Fisheries and Wildlife.

Gilman, S.L. 1994. An energy budget for northern sand lance, *Ammodytes dubius*, on Georges Bank. Fish. Bull., U.S. 92: 647-654.

Graham, J.J. 1982. Production of larval herring, *Clupea harengus*, along the Maine coast, 1964-78. J. Northw. Atl. Fish. Sci. 3: 63-85.

______, S. B. Chenoweth, and C.W. Davis. 1972. Abundance, distribution, movements, and lengths of larval herring along the western coast of the Gulf of Maine. Fish. Bull., U.S. 70: 307-321.

______, D.K. Stevenson, and K.M. Sherman. 1990. Relation between winter temperature and survival of larval Atlantic herring along the Maine coast. Trans. Am. Fish. Soc. 119: 730-740.

______, and D.W. Townsend. 1985. Mortality, growth, and transport of larval Atlantic herring *Clupea harengus* in Maine coastal waters. Trans. Am. Fish. Soc. 114: 490-498.

Green, J.M. 1975. Restricted movements and homing of the cunner, *Tautogolabrus adspersus* (Walbaum) (Pisces: Labridae). Can. J. Zool. 53: 1427-1431.

______, and M. Farwell. 1971. Winter habits of the cunner, *Tautogolabrus adspersus* (Walbaum) in Newfoundland. Can. J. Zool. 49: 1497-1499.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons, New York. 257 pp.

Grimes, C.B. 1975. Entrapment of fishes on intake water screens at a steam electric generating station. Chesapeake Sci. 16: 172-177.

Haegele, C.W., and J.F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42: 39-55.

Harris, R.J. 1985. A primer of multivariate statistics. Academic Press, Orlando. 575 pp.

Hermes, R. 1985. Distribution of neustonic larvae of hakes *Urophycis* spp. and fourbeard rockling *Enchelyopus cimbrius* in the Georges Bank area. Trans. Am. Fish. Soc. 114: 604-608.

Hoff, J.G., and J.R. Westman. 1966. The temperature tolerance of three species of marine fishes. J. Mar. Res. 24: 131-140.

Howe, A.B., and P.G. Coates. 1975. Winter flounder movements, growth and mortality off Massachusetts. Trans. Am. Fish. Soc. 104:13-29.

Hutchings, J.A. and R.A. Myers. 1993. Effect of age on the seasonality of maturation and spawning of Atlantic cod *Gadus morhua*, in the Northwest Atlantic. Can. J. Fish. Aquatic. Sciences 50:2468-2474.

Hutchings, J.A. and R.A. Myers. 1994. Timing of cod reproduction: interannual variability and the influence of temperature. Marine Ecology Progress Series 108:21-31.

Hutchings, J.A., R.A. Myers, and G.R. Lilly. 1993. Geographic variation in the spawning of Atlantic cod *Gadus morhua*, in the Northwest Atlantic. Can. J. Fish. Aquatic. Sciences 50:2457-2467.

Iles, T.D., and M. Sinclair. 1982. Atlantic herring: stock discreteness and abundance. Science 215: 627-633.

Jean, Y. 1964. Seasonal distribution of cod (*Gadus morhua* L.) along the Canadian Atlantic coast in relation to water temperature. J. Fish. Res. Board Can. 21: 429-460.

Jessop, B.M. 1983. Aspects of the life history of the Atlantic silverside (*Menidia menidia*) of the Annapolis River, Nova Scotia. Can. Ms. Rep. Fish. Aquat. Sci. 1694. 41 pp.

Johansen, F. 1925. Natural history of the cunner (*Tautogolabrus adsperus* Walbaum). Contrib. Can. Biol. 2: 423-468.

Jones, C. 1985. Within-season differences in growth of larval Atlantic herring, *Clupea harengus harengus*. Fish. Bull., U.S. 83: 289-298.

Kennedy, J.S., and D.H. Steele. 1971. The winter flounder (*Pseudopleuronectes americanus*) in Long Pond, Conception Bay, Newfoundland. J. Fish. Res. Board Can. 28: 1153-1165.

Kenney, M.K. and J.R. Gilbert. 1994. Increase in harbor and gray seal populations in Maine. Report to National Marine Fisheries Service.

Kornfield, I., and S.M. Bogdanowicz. 1987. Differentiation of mitochondrial DNA in Atlantic herring, *Clupea harengus*. Fish. Bull., U.S. 85: 561-568.

Koslow, J.A. 1984. Recruitment patterns in Northwest Atlantic fish stocks. Can. J. Fish. Aquat. Sci. 41: 1722-1729.

______, and W. Silvert. 1987. Recruitment to northwest Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) stocks: influence of stock size and climate. Can. J. Fish. Aquat. Sci. 44: 26-39.

Lambert, T.C. 1984. Larval cohort succession in herring (*Clupea harengus*) and capelin (*Mallotus villosus*). Can. J. Fish. Aquat. Sci. 41: 1552-1564.

______, and D.M. Ware. 1984. Reproductive strategies of demersal and pelagic spawning fish. Can. J. Fish. Aquat. Sci. 41: 1565-1569.

Landry, A.M., Jr., and K. Strawn. 1974. Number of individuals and injury rates of fishes caught on revolving screens at the P.H. Robinson Generating Station. Pages 263-271 *in* L.D. Jensen, ed. Entrainment and intake screening. Proceedings of the second entrainment and impingement workshop. Rep. No. 15, Edison Electric Institute.

Laprise, R., and J.J. Dodson. 1989. Ontogeny and importance of tidal vertical migrations in the retention of larval smelt *Osmerus mordax* in a well-mixed estuary. Mar. Ecol. Prog. Ser. 55: 101-111.

Lawton, R., P. Brady, C. Sheehan, S. Correia, and M. Borgatti. 1990. Final report on spawning sea-run rainbow smelt (*Osmerus mordax*) in the Jones River and impact assessment of Pilgrim Station on the population, 1979 -1981. Pilgrim Nuclear Power Station Mar. Envir. Monitoring Prog. Rep. Ser. No. 4. 72 pp.

Lazzari, M.A., and D.K. Stevenson. 1993. Influence of residual circulation and vertical distribution on the abundance and horizontal transport of larval Atlantic herring (*Clupea harengus*) in a Maine estuary. Can. J. Fish. Aquat. Sci. 50: 1879-1889.

Lifton, W.S., and J.F. Storr. 1978. The effect of environmental variables on fish impingement. Pages 299-314 *in* L.D. Jensen, ed. Fourth national workshop on entrainment and impingement. EA Communications, Melville, NY.

LMS (Lawler, Matusky & Skelly Engineers). 1987. Brayton Point Station Unit No. 4 angled screen intake biological evaluation program. Vol I. Program summary report 1984-1986. Submitted to New England Power Company, Westborough, MA.

Lobell, M.J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes. Winter flounder (*Pseudopleuronectes americanus*). Suppl. 28th Ann. Rep., N.Y. Cons. Dep., Pt. I:63-96.

Lough, R.G., M. Pennington, G.R. Bolz, and A.A. Rosenberg. 1982. Age and growth of larval Atlantic herring *Clupea harengus* L., in the Gulf of Maine-Georges Bank region based on otolith growth increments. Fish. Bull., U.S. 80: 187-199.

______, and D.C. Potter. 1993. Vertical distribution patterns and diel migrations of larval and juvenile haddock *Melanogrammus aeglefinus* and Atlantic cod *Gadus morhua* on Georges Bank. Fish. Bull. U.S. 91: 281-303.

Luczkovich, J.J. 1991. Seasonal variation in usage of a common shelter resource by juvenile inquiline snailfish (*Liparis inquilinus*) and red hake (*Urophycis chuss*). Copeia 1991: 1104-1109.

MacDonald, J.S., M.J. Dadswell, R.G. Appy, G.D. Melvin, and D.A. Methven. 1984. Fishes, fish assemblages, and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fish. Bull., U.S. 82: 121-139.

Markle, D.F., and L.-A. Frost. 1985. Comparative morphology, seasonality, and a key to planktonic fish eggs from the Nova Scotian shelf. Can. J. Zool. 63: 246-257.

______, D.A. Methven, and L.J. Coates-Markle. 1982. Aspects of spatial and temporal cooccurrence in the life history stages of the sibling hakes, *Urophycis chuss* (Walbaum 1792) and *Urophycis tenuis* (Mitchill 1815) (Pisces: Gadidae). Can. J. Zool. 60: 2057-2078.

McCracken, F.D. 1963. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus* (Walbaum), on the Atlantic coast. J. Fish. Res. Board Can. 20:551-586.

Messieh, S.N. 1976. Fecundity studies on Atlantic herring from the southern Gulf of St. Lawrence and along the Nova Scotia coast. Trans. Am. Fish. Soc. 105: 384-394.

Meyer, T.L., R.A. Cooper, and R.W. Langton. 1979. Relative abundance, behavior, and food habits of the American sand lance, *Ammodytes americanus*, from the Gulf of Maine. Fish. Bull., U.S. 77: 243-253.

Monteleone, D.M., and W.T. Peterson. 1986. Feeding ecology of American sand lance *Ammodytes americanus* larvae from Long Island Sound. Mar. Ecol. Prog. Ser. 30: 133-143.

______. 1987. Interannual fluctuations in the density of sand lance, *Ammodytes americanus*, larvae in Long Island Sound, 1951-1983. Estuaries 10: 246-254.

Moring, J.R. 1990. Seasonal absence of fishes in tidepools of a boreal environment (Maine, USA). Hydrobiologia 194: 163-168.

Morrison, D.F. 1976. Multivariate statistical methods. Second ed. McGraw-Hill Book Co., New York. 415 pp.

Morse, W.W. 1980. Spawning and fecundity of Atlantic mackerel, *Scomber scombrus*, in the Middle Atlantic Bight. Fish. Bull., U.S. 78: 103-107.

MRI (Marine Research, Inc.). 1991. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1990. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 37. Boston Edison Co., Boston, MA.

______. 1992. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1991. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 39. Boston Edison Co., Boston, MA.

______. 1993a. Brayton Point investigations annual report January-December 1992. *In* New England Power Company and Marine Research, Inc. Brayton Point Station annual biological and hydrological report January-December 1992. January 1994.

______. 1993b. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1992. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 41. Boston Edison Co., Boston, MA.

______. 1994. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1993. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 43. Boston Edison Co., Boston, MA.

______. 1995. Ichthyoplankton entrainment monitoring at Pilgrim Nuclear Power Station January-December 1994. Vol. 1 and 2. *In* Marine ecology studies related to operation of Pilgrim Station. Semi-annual rep. no. 44. Boston Edison Co., Boston, MA.

Murawski, S.A., and C.F. Cole. 1978. Population dynamics of anadromous rainbow smelt *Osmerus mordax*, in a Massachusetts river system. Trans. Am. Fish. Soc. 107: 535-542.

______, and C.F. Cole. 1980. Movements of spawning rainbow smelt, *Osmerus mordax*, in a Massachusetts estuary. Estuaries 3: 308-314.

______, and J.T. Finn. 1988. Biological bases for mixed-species fisheries: species co-distribution in relation to environmental and biotic variables. Can. J. Fish. Aquat. Sci. 45: 1720-1735.

Musick, J.A. 1974. Seasonal distribution of sibling hakes, *Urophycis chuss* and *U. tenuis* (Pisces, Gadidae) in New England. Fish Bull., U.S. 72: 481-495.

NAI (Normandeau Associates Inc.). 1991. Seabrook environmental studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

______. 1992. Seabrook environmental studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-1.

______. 1993. Seabrook environmental studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS) 1994. Seabrook Environmental Studies, 1993. A characterization of Environmental Conditions in the Hampton-Seabrook Area during the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

NFSC (Northeast Fisheries Science Center). 1993. Status of fishery resources off the northeastern United States for 1993. NOAA Tech. Mem. NMFS-F/NEC-101. 140 pp.

Nizinski, M.S., B.B. Collette, and B.B. Washington. 1990. Separation of two species of sand lances, *Ammodytes americanus* and *A. dubius*, in the Western North Atlantic. Fish. Bull., U.S. 88: 241-255.

NUSCO (Northeast Utilities Service Company). 1987. Winter flounder studies. *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Summary of studies prior to Unit 3 operation. 151 pp.

______. 1988. Fish ecology studies. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Three-unit operational studies 1986-1987.

______. 1994a. Fish ecology studies. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report 1993.

______. 1994b. Winter flounder studies. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report 1993.

______. 1995. Fish ecology studies. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report 1994.

O'Brien, L., J. Burnett, and R.K. Mayo. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-90. NOAA Tech. Rep. NMFS 113. 66 pp.

Ojeda, F.P., and J.H. Dearborn. 1990. Diversity, abundance, and spatial distribution of fishes and crustaceans in the rocky subtidal zone of the Gulf of Maine. Fish. Bull., U.S. 88: 403-410.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1975. Activity, movements, and feeding behavior of the cunner, *Tautogolabrus adspersus*, and comparison of food habits with young tautog, *Tautoga onitis*, off Long Island, New York. Fish. Bull., U.S. 73: 895-900.

______, A J. Bejda, and A.D. Martin. 1979. Seasonal dispersal and habitat selection of cunner, *Tautogolabrus adspersus*, and young tautog, *Tautoga onitis*, in Fire Island Inlet, Long Island, New York. Fish. Bull., U.S. 77: 255-262.

______, R. Wicklund, and S. Wilk. 1969. Behavior of winter flounder in a natural habitat. Trans. Am. Fish. Soc. 98:717-720.

Ouellet, P., and J.J. Dodson. 1985a. Dispersion and retention of anadromous rainbow smelt *(Osmerus mordax)* larvae in the middle estuary of the St. Lawrence River. Can. J. Fish. Aquat. Sci. 42: 332-341.

______, and J.J. Dodson. 1985b. Tidal exchange of anadromous rainbow smelt (*Osmerus mordax*) larvae between a shallow tributary and the St. Lawrence estuary. Can. J. Fish. Aquat. Sci. 42: 1352-1358.

Overholtz, W.J., and J.R. Nicholas. 1979. Apparent feeding by the fin whale, *Balaenopter physalus* and humpback whale, *Megaptera novaengliae*, on the American sand lance, *Ammodytes americanus*, in the Northwest Atlantic. Fish. Bull., U.S. 77: 285-287.

Overholtz, W.J., R.S. Armstrong, D.G. Mountain and M. Tercerio. 1991. Factors influencing spring distribution, availability, and recreational catch of Atlantic mackerel (*Scomber scombrus*) in the middle Atlantic and southern New England regions. National Oceanographic and Atmospheric Administration Technical Memorandum NMFS-F/NEC-85.

Parsons, L.S., and J.A. Moores. 1974. Long-distance migration of an Atlantic mackerel. J. Fish. Res. Board Can. 31: 1521-1522.

Parsons, T.R., M. Takahashi, and B. Hargrave. 1977. Biological Oceanographic Processes. Pergammon Press, New York. 332 pp.

Payne, P.M., J.R. Nicholas, L. O'Brien, and K.D. Powers. 1986. The distribution of the humpback whale *Megaptera novaeangliae* on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel *Ammodytes americanus*. Fish. Bull., U.S. 84: 687-696.

Payne, P.M. and L.A. Selzer. 1989. The distribution, abundance and selected prey of the harbor seal, *Phora vitulina concolor* in Southern New England. Marine Mammal Science 512:173-192.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder *Pseudopleuronectes americanus* (Walbaum). Bull. Bingham Oceanogr. Coll. 18:1-78.

Pedersen, R.H. 1994. Growth and mortality in young larval herring (*Clupea harengus*); effects of repetitive changes in food availability. Marine Biology 117:547-550.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Coll. 11:1-92.

Perry, I. R., and J. D. Neilson. 1988. Vertical distributions and trophic interactions of age-0 Atlantic cod and haddock in mixed and stratified waters of Georges Bank. Mar. Ecol. Prog. Ser. 49: 199-214.

______, and S.J. Smith. 1994. Identifying habit associations of marine fishes using survey data: an application to the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 51: 589-601.

Peterson, W.T., and S.J. Ausubel. 1984. Diets and selective feeding by larvae of Atlantic mackerel *Scomber scombrus* on zooplankton. Mar. Ecol. Prog. Ser. 17: 65-75.

Pitt, T.K. 1971. Fecundity of the yellowtail flounder (*Limanda ferruginea*) from the Grand Bank, Newfoundland. J. Fish. Res. Board Can. 28: 456-457.

Pottle, R.A., and J.M. Green. 1979. Field observations on the reproductive behaviour of the cunner, *Tautogolabrus adsperus* (Waldbaum), in Newfoundland. Can. J. Zool. 57: 247-256.

Powles, P.M. 1958. Studies of reproduction and feeding of Atlantic cod (*Gadus callarias* L.) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Board Can. 15: 1383-1402.

Reay, P.J. 1970. Synopsis of biological data on North Atlantic sand eels of the genus *Ammodytes*. (*A. tobianus*, *A. dubius*, *A. americanus* and *A. marinus*). FAO Fish. Synop. No. 82. 28 pp.

Richards, S.W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17: 95-124.

______. 1982. Aspects of the biology of *Ammodytes americanus* from the St. Lawrence River to Chesapeake Bay, 1972-75, including a comparison of the Long Island Sound postlarvae with *Ammodytes dubius*. J. Northw. Atl. Fish. Sci. 3: 93-104.

______, and A. W. Kendall. 1973. Distribution of sand lance, *Ammodytes* sp., larvae on the continental shelf from Cape Cod to Cape Hatteras from *RV Dolphin* surveys in 1966. Fish. Bull., U.S. 71: 371-386.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1991. A list of common and scientific names of fishes from the United States and Canada. 5th ed. Am. Fish. Soc. Spec. Pub. No. 20. 183 pp.

Rogers, C.A. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fish. Bull., U.S. 74: 52-58.

Rosenberg, A.A., and R.W. Doyle. 1986. Analysing the effect of age structure on stock-recruitment relationships in herring (*Clupea harengus*). Can. J. Fish. Aquat. Sci. 43: 674-679.

Safford, S.E., and H. Booke. 1992. Lack of biochemical genetic and morphometric evidence for discrete stocks of northwest Atlantic herring *Clupea harengus harengus*. Fish. Bull., U.S. 90: 203-210.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

Saucerman, S.E., and L.A. Deegan. 1991. Lateral and cross-channel movement of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) in Waquoit Bay, Massachusetts. Estuaries 14:440-446.

Scott, J.S. 1982a. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northw. Atl. Fish. Sci. 3: 29-40.

______. 1982b. Selection of bottom type by groundfishes of the Scotian Shelf. Can. J. Fish. Aquat. Sci. 39: 943-947.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board. Can. 184. 966 pp.

______, and M.G. Scott. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219. 731 pp.

Sette, O.E. 1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part II - migrations and habits. U.S. Fish. Wildl. Serv. Fish. Bull. 51: 251-358.

Shaw, R.G., and T. Mitchell-Olds. 1993. ANOVA for unbalanced data: an overview. Ecology 74: 1638-1645.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature (London) 291: 486-489.

Sinclair, M., and T.D. Iles. 1985. Atlantic herring (*Clupea harengus*) distributions in the Gulf of Maine-Scotian Shelf area in relation to oceanographic features. Can. J. Fish. Aquat. Sci. 42:880-887.

______, and M.J. Tremblay. 1984. Timing of spawning of Atlantic herring (*Clupea harengus harengus*) populations and match-mismatch theory. Can. J. Fish. Aquat. Sci. 41: 1055-1065.

Smigielski, A.S., T.A. Halavik, L.J. Buckley, S.M. Drew, and G.C. Laurence. 1984. Spawning, embryo development and growth of the American sand lance *Ammodytes americanus* in the laboratory. Mar. Ecol. Prog. Ser. 14: 287-292.

Smith, E.P., D.R. Orvos, and J. Cairns, Jr. 1993. Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. Can. J. Fish. Aquat. Sci. 50:627-637.

Smith, W. G., and W. W. Morse. 1993. Larval distribution patterns: early signals for the collapse/recovery of Atlantic herring *Clupea harengus* in the Georges Bank area. Fish. Bull., U.S 91: 338-347.

Smith, W.G., J.D. Sibunka, and A. Wells. 1975. Seasonal distributions of larval flatfishes (Pleuronectiformes) on the continental shelf between Cape Cod, Massachusetts and Cape Lookout, North Carolina, 1965-1966. NOAA Tech. Rep. NMFS SSRF-691. 68 pp.

______. 1978. Diel movements of larval yellowtail flounder, *Limanda ferruginea*, determined from discrete depth sampling. Fish. Bull., U.S. 76: 167-177.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. W.H. Freeman Co., San Francisco. 573 pp.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Company, San Francisco. 775 pp.

Steiner, W.W., J.J. Luczkovich, and B.L. Olla. 1982. Activity, shelter usage, growth and recruitment of juvenile red hake *Urophycis chuss*. Mar. Ecol. Prog. Ser. 7: 125-135.

______, and B. Olla. 1985. Behavorial responses of prejuvenile red hake, *Urophycis chuss*, to experimental thermoclines. Envir. Biol. Fish. 14: 167-173.

Stephenson, R.L., and I. Kornfield. 1990. Reappearance of spawning Atlantic herring (*Clupea harengus*

harengus) on Georges Bank: population resurgence not recolonization. Can. J. Fish. Aquat. Sci. 47: 1060-1064.

Stewart-Oaten, A., W.W. Murdoch, and K.E. Parker. 1986. Environmental impact assessment: "psuedo-replication" in time? Ecology 67: 929-940.

Suthers, I.M., and K.T. Frank. 1989. Inter-annual distributions of larval and pelagic juvenile cod (*Gadus morhua*) in southwestern Nova Scotia determined with two different gear types. Can. J. Fish. Aquat. Sci. 46: 591-602.

Thomas, D.L., and G.J. Miller. 1976. Impingement at Oyster Creek Generating Station, Forked River, New Jersey, from September to December 1975. Pages 317-341 *in* L.D. Jensen, ed. Third national workshop on entrainment and impingement. Ecological Analysts, Melville, NY.

Thomas, J.M. 1977. Factors to consider in monitoring programs suggested by statistical analysis of available data. Pages 243-255 *in* W. Van Winkle, ed. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, TN, May 3-6, 1977. Pergamon Press, New York.

Topp, R.W. 1968. An estimate of fecundity of the winter flounder, *Pseudopleuronectes americanus*. J. Fish. Res. Board Can. 25: 1299-1302.

Townsend, D.W. 1992. Ecology of larval herring in relation to the oceanography of the Gulf of Maine. J. Plankton Res. 14: 467-493.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4(1):3-15.

Van Guelpen, L., and C.C. Davis. 1979. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus*, in two contrasting inshore locations in Newfoundland. Trans. Am. Fish. Soc. 108: 26-37.

Ware, D.M. 1977. Spawning time and egg size of Atlantic mackerel, *Scomber scombrus*, in relation to the plankton. J. Fish. Res. Board Can. 34: 2308-2315.

______, and T. C. Lambert. 1985. Early life history of Atlantic mackerel (*Scomber scombrus*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 42: 577-592.

Westin, D.T., K.J. Abernethy, I.E. Meller, and B.A. Rogers. 1979. Some aspects of biology of the American sand lance, *Ammodytes americanus*. Trans. Am. Fish. Soc. 108: 328-331.

Wheatland, S.B. 1956. Oceanography of Long Island Sound. 1952-1954. II. Pelagic fish eggs and larvae. Bull. Bingham Oceanogr. Coll. 15: 234-314.

Wheeler, J.P., and G.H. Winters. 1984. Homing of Atlantic herring in Newfoundland waters as indicated by tagging data. Can. J. Fish. Aquat. Sci. 41: 108-117.

Wigley, S.E., and F.M. Serchuk. 1992. Spatial and temporal distribution of juvenile Atlantic cod *Gadus morhua* in the Georges Bank-Southern New England region. Fish. Bull., U.S. 90: 599-606.

Wilks, S.S. 1932. Certain generalizations in the analysis of variance. Biometrika 24: 471-494.

Williams, G.C. 1967. Identification and seasonal size changes of eggs of the labrid fishes, *Tautogolabrus adspersus* and *Tautoga onitis*, of Long Island Sound. Copeia 1967: 452-453.

__, S.W. Richards, and E.G. Farnworth. 1964. Eggs of *Ammodytes hexapterus* from Long Island, New York. Copeia 1964: 242-243.

______, D.C. Williams, and R.J. Miller. 1973. Mortality rates of planktonic eggs of the cunner, *Tautogolabrus adspersus* (Walbaum), in Long Island Sound. Pages 181-195 *in* A. Pacheco, ed. Proceedings of a workshop on egg, larval and juvenile stages of fish in Atlantic coast estuaries. Nat. Mar. Fish. Serv., Mid. Atl. Coast. Fish. Ctr. Tech. Pub. No. 1.

Winters, G.H., and E.L. Dalley. 1988. Meristic composition of sand lance (*Ammodytes* spp.) in Newfoundland waters with a review of species designations in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 45: 515-529.

APPENDIX TABLE 5-1. FINFISH SPECIES COMPOSITION BY LIFE STAGE AND GEAR, JULY 1975 - DECEMBER 1994. SEABROOK OPERATIONAL REPORT, 1994.

		ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
SCIENTIFIC NAME	COMMON NAME	EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Acipenser oxyrhynchus	Atlantic sturgeon				R[b]	
Alosa aestivalis	blueback herring		–	R	C	C
Alosa mediocris	hickory shad		–		R	
Alosa pseudoharengus	alewife		–	O	O	O
Alosa sapidissima	American shad		–	R	O	O
Alosa sp.	river herring		R	–	–	–
Ammodytes americanus	American sand lance		A	O	R	O
Anarhichas lupus	Atlantic wolffish		R	R		
Anchoa hepsetus	striped anchovy					R
Anguilla rostrata	American eel		C	R		
Apeltes quadracus	fourspine stickleback					R
Archosargus probatocephalus	sheepshead			R		
Aspidophoroides monopterygius	alligatorfish		C	O		
Brevoortia tyrannus	Atlantic menhaden	O	O	R	O	R
Brosme brosme	cusk	O	O			
Caranx hippos	crevalle jack					R
Centropristis striata	black sea bass			R	R	
Conger oceanicus	conger eel		R			
Clupea harengus	Atlantic herring		C	O	A	O
Cryptacanthodes maculatus	wrymouth		O	R		
Cyclopterus lumpus	lumpfish		C	R	R	R
Enchelyopus cimbrius	fourbeard rockling	C	C	O		
Fundulus sp.[c]	killifish					C
Gadus morhua	Atlantic cod	–	C	C	O	R
Gadus/Melanogrammus	Atlantic cod/haddock	C	–	–	–	–
Gasterosteus sp.[d]	stickleback		R	R		C
Glyptocephalus cynoglossus	witch flounder	C	C	O		
Hemitripterus americanus	sea raven		O	C	O	R
Hippoglossoides platessoides	American plaice	C	C	O		
Hippoglossus hippoglossus	Atlantic halibut			R		
Labridae/*Pleuronectes*	cunner/yellowtail flounder[e]	A	–	–	–	–
Liparis atlanticus	Atlantic seasnail	R	C	–	–	–
Liparis coheni	gulf snailfish		C	–	–	–
Liparis sp.[f]	snailfish	R	–	O		
Lophius americanus	goosefish	R	O	O	R	
Lumpenus lumpretaeformis	snakeblenny		O	R		
Lumpenus maculatus	daubed shanny		R	R		
Macrozoarces americanus	ocean pout		O	C	R	
Melanogrammus aeglefinus	haddock	–	O	C	R	
Menidia menidia	Atlantic silverside		R	O	R	A
Menticirrhus saxatilis	northern kingfish				R	
Merluccius bilinearis	silver hake	C	C	C	C	R

(Continued)

APPENDIX TABLE 5-1. (Continued)

SCIENTIFIC NAME	COMMON NAME	ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
		EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Microgadus tomcod	Atlantic tomcod		R	R		O
Morone americana	white perch					R
Morone saxatilis	striped bass				R	R
Mugil cephalus	striped millet					R
Mustelus canis	smooth dogfish				R	
Myoxocephalus aenaeus	grubby		C	O	R	O
Myoxocephalus octodecemspinosus	longhorn sculpin		C	A	O	R
Myoxocephalus scorpius	shorthorn sculpin		C	O	R	R
Odontaspis taurus	sand tiger				R	
Oncorhynchus kisutch	coho salmon				R	R
Oncorhynchus mykiss	rainbow trout					R
Osmerus mordax	rainbow smelt		O	C	O	C
Paralichthys dentatus	summer flounder		R	R		
Paralichthys oblongus	fourspot flounder	O	O	C	R	
Peprilus triacanthus	butterfish	O	O	R	O	R
Petromyzon marinus	sea lamprey				R	
Pholis gunnellus	rock gunnel		C	O	R	R
Pleuronectes americanus	winter flounder		C	C	O	C
Pleuronectes ferrugineus	yellowtail flounder	–	C	A	R	R
Pleuronectes putnami	smooth flounder		R	R		C
Pollachius virens	pollock	C	C	C	C	O
Pomatomus saltatrix	bluefish				O	O
Prionotus carolinus	northern searobin	–	–	C	R	
Prionotus evolans	striped searobin	–	–	R		
Prionotus sp.	searobin	O	R	–	–	–
Pungitius pungitius	ninespine stickleback					C
Raja sp.[g]	skate			C	R	
Salmo trutta	brown trout					O
Salvelinus fontinalis	brook trout					R
Scomber japonicus	chub mackerel				R	
Scomber scombrus	Atlantic mackerel	A	A	R	C	R
Scophthalmus aquosus	windowpane	C	C	C	R	O
Sebastes sp.[h]	redfish		O			
Sphoeroides maculatus	northern puffer			R		R
Squalus acanthias	spiny dogfish			R	C	
Stenotomus chrysops	scup		R	O	R	
Stichaeus punctatus	Arctic shanny		O			
Syngnathus fuscus	northern pipefish		C	O	R	O
Tautoga onitis	tautog	–	C		R	
Tautogolabrus adspersus	cunner	–	A		O	R
Torpedo nobiliana	Atlantic torpedo			R		
Triglops murrayi	moustache sculpin		O	R		

(Continued)

APPENDIX TABLE 5-1. (Continued)

		ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
SCIENTIFIC NAME	COMMON NAME	EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Ulvaria subbifurcata	radiated shanny		C	O		
Urophycis sp.[i]	hake	A	C	A	O	C

Footnotes:

[a] Names are according to Robins et al. (1991). Taxa usually identified to a different level are not included in this list to avoid duplication (e.g., Gadidae, *Enchelyopus/Urophycis*, *Myoxocephalus* sp., *Urophycis chuss*).

[b] Occurrence of each species is indicated by its relative abundance or frequency of occurrence for each life stage or gear type:

A = abundant (≥10% of total catch over all years)
C = common (occurring in ≥10% of samples but <10% of total catch)
O = occasional (occurring in <10% and ≥1% of samples)
R = rare (occurring in <1% of samples)
-- = not usually identified to this taxonomic level at this life stage

[c] Predominantly *Fundulus heteroclitis*, mummichog, but may include a small number of *Fundulus majalis*, striped killifish.

[d] Two species of *Gasterosteus* have been identified from seine samples: *G. aculeatus*, threespine stickleback; and *G. wheatlandi*, blackspotted stickleback (both occurring commonly).

[e] May also include a small number of tautog.

[f] Three species of *Liparis* have been identified from trawl samples: *L. atlanticus*, Atlantic seasnail; *L. coheni*, gulf snailfish; and *L. inquilinus*, inquiline snailfish.

[g] Four species of *Raja* have been identified from trawl samples: *R. radiata*, thorny skate (common); *R. erinacea*, little skate (common); *R. ocellata*, winter skate (occasional); and *R. eglanteria*, clearnose skate (rare).

[h] *Sebastes norvegicus*, golden redfish; *S. mentella*, deepwater redfish; and *S. fasciatus*, Acadian redfish, have been reported to occur in the northwest Atlantic. *Sebastes* in coastal New Hampshire waters are probably *S. fasciatus* (Dr. Bruce B. Collette, U.S. National Museum, pers. comm. April 1982), but larval descriptions are insufficient to allow distinction among the three species.

[i] Three species of *Urophycis* have been identified from trawl samples: *U. chuss*, red hake (common); *U. tenuis*, white hake (common); and *U. regia*, spotted hake (rare).

APPENDIX TABLE 5-2. SPECIES COMPOSITION, ANNUAL TOTALS, AND FIVE-YEAR TOTAL OF FINFISH, AMERICAN LOBSTER AND SEALS IMPINGED AT SEABROOK STATION FROM 1990 THROUGH 1994. SEABROOK OPERATIONAL REPORT, 1994.[a]

SPECIES	1990	1991	1992	1993	1994	TOTAL
Atlantic silverside		8	67	156	5348	5,579
Hakes	16	33	15	3	2822	2,889
Grubby	11	26	54	67	2678	2,836
Pollock	69	124	231	32	1681	2,137
Winter flounder	18	116	209	141	1435	1,919
Windowpane	52	150	96	102	980	1,380
American sand lance	3		28	3	1215	1,249
Rainbow smelt		12	67	80	545	704
Herrings	44	8	22	19	514	607
Rock gunnel	14	11	40	25	494	584
Lumpfish	69	93	29	118	182	491
Longhorn sculpin	67	54	88	37	105	351
Sea raven	38	42	55	98	78	311
Northern pipefish		6	2	83	188	279
Skates			48	35	190	273
Sculpins			1	7	205	213
Snailfishes		3	6	13	180	202
Atlantic cod	18	28	26	37	58	167
Flounders		7		32	77	116
Shorthorn sculpin	4	47	17	28	14	110
Wrymouth	5	15	16	12	55	103
Little skate	6	96				102
Threespine stickleback		3	3	17	67	90
Cunner	21	2	13	13	32	81
American lobster	4	29	8	1	31	73
Tautog	3	9	9	3		24
Searobins	10	12	1	1		24
Silver hake		22				22
Atlantic mackerel	4	13	3			20
Unidentified fish	4	4	5		6	19
Sea lamprey	1	5	3	6		15
Clearnose skate	6	9				15
Blueback herring					13	13
Seal			1	3	6	10
Yellowtail flounder		11				11
Fourspot flounder	2	2	1	1	2	8
Ocean pout	1	2	3			6
Summer flounder		3			3	6
American eel	1	1	3			5
Radiated shanny	4	1				5
Spiny dogfish	1	2	1		1	5
Butterfish			2		3	5
Goosefish	1				3	4
Killifish					4	4
Red hake			1	2	1	4
Smooth flounder	3					3
Rough scad		3				3
Alewife		1		1		2
Cusk		1	1			2
Atlantic wolffish		1				1
White perch	1					1
American plaice				1		1
Conger eel		1				1
Striped anchovy	1					1
Oyster toadfish	1					1
Scup		1				1
Black sea bass		1				1
Northern kingfish		1				1
Atlantic tomcod					1	1
White hake					1	1
ALL SPECIES	503	1,019	1,175	1,177	19,218	23,092

[a]Impingement data prior to October 1994 was underestimated (see summary).

APPENDIX TABLE 5-3. SPECIES COMPOSITION AND CUMULATIVE MONTHLY TOTALS OF FINFISH, AMERICAN LOBSTER AND SEALS IMPINGED AT SEABROOK STATION FROM 1990 THROUGH 1994. SEABROOK OPERATIONAL REPORT, 1994.[a]

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Atlantic silverside	6	5	5	4	2					2	30	5525	5579
Hakes	2	1		8				1	10	38	293	2536	2889
Grubby	18	16	27	7	4	2		1	1	5	66	2689	2836
Pollock	3		4	2	21	117	26		74	957	460	473	2137
Winter flounder	57	25	68	31	6	5	1		25	52	21	1628	1919
Windowpane	19	15	14	44	88	13	2		101	60	159	865	1380
American sand lance	1	1	1	3							1	1242	1249
Rainbow smelt	10	13	2	4	2				1	1	1	670	704
Herrings	1	1	2	9	20	3		7	3	11	372	178	607
Rock gunnel	4	2	5	20	20	3	3	3	10	98	56	360	584
Lumpfish	11	21	81	57	49	121	34	11		2		104	491
Longhorn sculpin	16	4	17	44	21	10	4	5	3	20	80	127	351
Sea raven	7	3	10	38	61	27	6	10	10	30	45	64	311
Northern pipefish	2	2	1	6					3	19	93	153	279
Skates	19	1	5	1		1			11	1	5	229	273
Sculpins				5	2	2						204	213
Snailfishes		1	10	3					1	2	53	132	202
Atlantic cod	2		7	13	16	9	7	3	6	14	9	81	167
Flounders	3	5	22	22							2	62	116
Shorthorn sculpin	6	9	11	17	15	18	1		2	1	9	21	110
Wrymouth	9	1	2		1				2	8	1	79	103
Little skate	21	2	7	6	1				7	40	10	8	102
Threespine stickleback		2	9	8					1			70	90
Cunner	2	2	1	4	19	14	1	5	9	12	11	1	81
American lobster		3				4	1	1	5	13	28	18	73
Tautog				1	8	9	1	1	1	1	1	1	24
Searobins	1		2	5				3	4	8		1	24
Silver hake									2	11	9		22
Atlantic mackerel						6				5	8	1	20
Unidentified fish					4			1	4	5		5	19
Sea lamprey			4	10	1								15
Clearnose skate	1	4		8							1	1	15
Blueback herring										13			13
Seal									3	3	4		10
Yellowtail flounder	4	6	1										11
Fourspot flounder		1		2	2	1			2				8
Ocean pout				3		2						1	6
Summer flounder				3					3				6
American eel						1						4	5
Radiated shanny		1			3						1		5
Spiny dogfish							2		2	1			5
Butterfish									1		1	3	5
Goosefish					1						2	1	4
Killifish												4	4
Red hake						1			2	1			4
Smooth flounder				3									3
Rough scad		2	1										3
Alewife	1									1			2
Cusk	1								1				2
American plaice			1										1
Black sea bass												1	1
Conger eel				1									1
Northern kingfish										1			1
Oyster toadfish												1	1
Scup											1		1
Striped anchovy									1				1
White perch						1							1
Atlantic wolffish						1							1
Atlantic tomcod									1				1
White hake									1				1
ALL SPECIES	227	149	320	392	367	371	89	52	313	1,436	1,833	17,546	23,092

[a]Impingement data prior to October 1994 was underestimated (see summary).

APPENDIX TABLE 5-4. SUBSETTING CRITERIA USED IN ANALYSES OF VARIANCE FOR THE SELECTED FINFISH SPECIES. SEABROOK OPERATION REPORT, 1994.

SPECIES	GEAR	SEASON	PREOPERATIONAL	OPERATIONAL	POOLING	DELETIONS
Atlantic cod	Trawl	Nov-Jul	1975-1990	1990-1994	Nov-Dec with following year	Nov-Dec 1994
Atlantic cod	Ichthyo	Apr-Jul	1987-1990	1991-1994	None	None
Atlantic herring	Gill net	Sep-May	1976-1990	1990-1994	Sep-Dec with following year	Sep-Dec 1994
Atlantic herring	Ichthyo	Oct-Dec	1986-1989	1990-1994	None	None
Atlantic silverside	Seine	Apr-Nov	1976-1984; 1986-1989	1991-1994	None	1990
Atlantic mackerel	Gill net	Jun-Nov	1976-1989	1991-1994	None	1990
Atlantic mackerel	Ichthyo	May-Aug	1987-1990	1991-1994	None	Aug 1990
Atlantic sand lance	Ichthyo	Jan-Apr	1987-1990	1991-1994	None	None
Cunner	Ichthyo	Jun-Sep	1987-1989	1991-1994	None	1990
Hakes	Trawl	Nov-Jul	1976-1990	1990-1994	Nov-Dec with following year	Nov-Dec 1994
Hakes	Ichthyo	Jul-Sep	1986-1989	1991-1994	None	1990
Pollock	Gill net	Apr-Dec	1976-1989	1991-1994	None	1990
Pollock	Ichthyo	Nov-Feb	1986-1989	1990-1993	Jan-Feb with previous year	1994
Rainbow smelt	Trawl	Nov-May	1975-1990	1990-1994	Nov-Dec with following year	Nov-Dec 1994
Rainbow smelt	Seine	Apr-Nov	1976-1984;1986-1989	1991-1994	None	1990
Winter flounder	Trawl	Nov-Jul	1975-1990	1990-1994	Nov-Dec with following year	Nov-Dec 1994
Winter flounder	Seine	Apr-Nov	1976-1984; 1986-1989	1991-1994	None	1990
Winter flounder	Ichthyo	Apr-Jul	1987-1990	1991-1994	None	None
Yellowtail flounder	Trawl	Nov-Jul	1975-1995	1990-1994	Nov-Dec with following year	Nov-Dec 1994
Yellowtail flounder	Ichthyo	May-Aug	1987-1990	1991-1994	None	Aug 1990

TABLE OF CONTENTS

PAGE

SUMMARY

Submerged rock surfaces in the vicinity of Seabrook Station intake and discharge structures support rich and diverse communities of attached algae and animals (macrobenthos). An extensive monitoring program combining destructive and non-destructive techniques was implemented in 1978 to assess the potential population and community level effects of Seabrook Station operation on this habitat. Studies were designed to monitor two types of potential impacts: those associated with exposure to elevated water temperatures from the thermal discharge plume, most likely affecting intertidal and shallow subtidal communities, and those associated with increased turbidity and sedimentation from transport of suspended solids and entrained organisms to deeper water communities near the discharge.

Thermal impacts to macroalgae, such as shifts in abundance or occurrence of typically cold-water or warm-water species (i.e., decreases or increases, respectively), were not evident (all zones combined; destructive samples). Although some typically warm water taxa occurred for the first time during the operational period, some cold water taxa increased in frequency of occurrence, and other warm water taxa decreased in frequency of occurrence, over the same time interval.

Overall, community parameters (biomass, number of taxa, etc.) and analyses of community structure (numerical classification), as measured through destructive sampling, indicated little change in nearfield intertidal or shallow subtidal algal and faunal communities. Of the selected taxa studied in the intertidal zone, percent frequency of occurrence of *Ascophyllum nodosum* increased slightly but significantly in the nearfield area during the operational period, while *Fucus vesiculosis* declined significantly in the same zone. In the shallow subitdal zone, only *Laminaria digitata* densities in the nearfield area declined significantly during the operational period. These trends began in recent preoperational years and their continuation is attributed to natural cycles in environmental or climatic processes rather than to plant operation. Only one intertidal faunal taxon, *Ampithoe rubricata*, exhibited an operational shift in abundance, and this occurred only in the farfield area.

Impacts associated with increased turbidity, such as shifts in community dominance to species tolerant of increases in shading, sedimentation rates, and organic loading were not evident at mid-depth or deep stations in the nearfield area. Analyses of community parameters and overall structure revealed consistency of nearfield and farfield algal and faunal communities in both depth zones over both preoperational and operational periods, reflecting the more stable natural environmental conditions characteristic of deeper benthic habitats. This stability was also exhibited by abundance patterns of selected dominant taxa. None of the mid-depth selected faunal taxa showed significant changes in abundance during the operational period relative to preoperational abundances. Densities of *Laminaria digitata* declined at both nearfield and farfield mid-depth stations during the operational period (a trend that began in late preoperational years). *Laminaria saccharina* densities have also declined, but only in the nearfield area. This decline may be due to the susceptibility of these plants to be removed during major storm events (e.g. Hurricane Bob in 1991). None of the above-mentioned shifts represents a change beyond what would be expected from the inherent natural variability of balanced indigenous communities, and no evidence exists to suggest that thermal or turbidity-related impacts have occurred to local macrobenthic communities since Seabrook Station began operation in 1990.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

6.0 MARINE MACROBENTHOS

6.1 INTRODUCTION

The predominant benthic marine habitat in the vicinity of Seabrook Station intake and discharge structures is rocky substratum, primarily in the form of bedrock ledge and boulders. These rock surfaces support rich and diverse communities of attached plants and animals that are important in coastal ecosystems. In fact, hard-bottom coastal communities are among the most productive regions in the world (Mann 1973). This diversity and productivity is accomplished through modification of the typically two-dimensional substratum by the attached plants and animals to create a multi-tiered community that enhances the number of biological niches.

One of the most productive features of the shore and near-shore biota in the Gulf of Maine is an extensive canopy of brown macroalgae. Rockweeds (fucoids) inhabit intertidal areas (Menge 1976; Topinka et al. 1981; Keser and Larson 1984), while kelp inhabit subtidal areas (Sebens 1986; Witman 1987). Understory layers generally occur beneath these canopies and contain secondary levels of foliose and filamentous algae and upright attached macroinvertebrates over a layer of encrusting algal and faunal species, which occupy much of the remaining primary rock surfaces (Menge 1976; Sebens 1985; Ojeda and Dearborn 1989). Also, many niches created in and around this attached biota are occupied by mobile predator and herbivore species such as fish, snails, sea urchins, starfish, and amphipods (Menge 1979, 1983; Ojeda and Dearborn 1991).

Another important aspect of fucoid and kelp assemblages is the distinct zonation pattern exhibited by the biota, which throughout the North Atlantic is most obvious in the intertidal zone (Stephenson and Stephenson 1949; Lewis 1964; Chapman 1973), but is also present subtidally (Hiscock and Mitchell 1980; Sebens 1985). These patterns of community organization are the result of a variety of interacting physical (e.g., desiccation, water movement, temperature and light) and biological (e.g., herbivory, predation, recruitment, inter- and intraspecific competition for space) mechanisms, which vary over spatial and temporal scales.

Because coastal hard-bottom communities are ecologically important, are well documented as effective integrators of environmental conditions, and are potentially vulnerable to localized anthropogenic impacts, studies of these communities have been and continue to be part of ecological monitoring programs associated with coastal nuclear power plants (Vadas et al. 1976; Wilce et al. 1978; Osman et al. 1981; Schroeter et al. 1993; BECO 1994; NUSCO 1994). Similarly, Seabrook Station marine macrobenthos studies continue to be part of an extensive environmental monitoring program whose primary objective is to determine whether differences that exist among communities at nearfield and farfield sites in the Hampton-Seabrook area can be attributed to power plant construction and operation. Potential impacts on the local macrobenthos from Seabrook Station operation include direct exposure to the thermal discharge plume, most likely at sites in the upper portion of the water column (intertidal and shallow subtidal zones). Thermal impacts are unlikely in deeper areas. However, increased turbidity in discharge water resulting from transport of suspended solids and entrained organisms could increase shading and the rate of sedimentation. To assess these potential impacts, studies were implemented to identify the attached plant and animal species occupying nearby intertidal and subtidal rock surfaces, to describe temporal and spatial patterns of occurrence of these species, and to identify physical and biological factors that affect variability in rocky intertidal and subtidal communities.

6.2 METHODS

6.2.1 Field Methods

Quantitative (destructive) macrofaunal and macroalgal samples were collected three times a year (May, August, November) at six benthic stations (Fig. 6-1); three nearfield-farfield station pairs were established at lower intertidal (approximate mean seal level: B1MLW, B5MLW), shallow subtidal (4-5 m; B17, B35) and mid-depth (9-12 m; B19, B31) zones. Four additional stations were sampled in August only: one mid-depth intake station (B16) and three deep water (18-21 m) stations (nearfield-B13 and B04, and farfield-B34). This sampling program began in 1978 with four nearfield stations (B1, B04, B13, and B19) and one farfield station (B31). Nearfield station B17 was added to the study in 1979, and nearfield station B16 was added in 1980. Subsequently, three farfield stations were added, one in 1980 (B34) and two in 1982 (B35 and B5). Station sampling histories are summarized in Appendix Table 6-1.

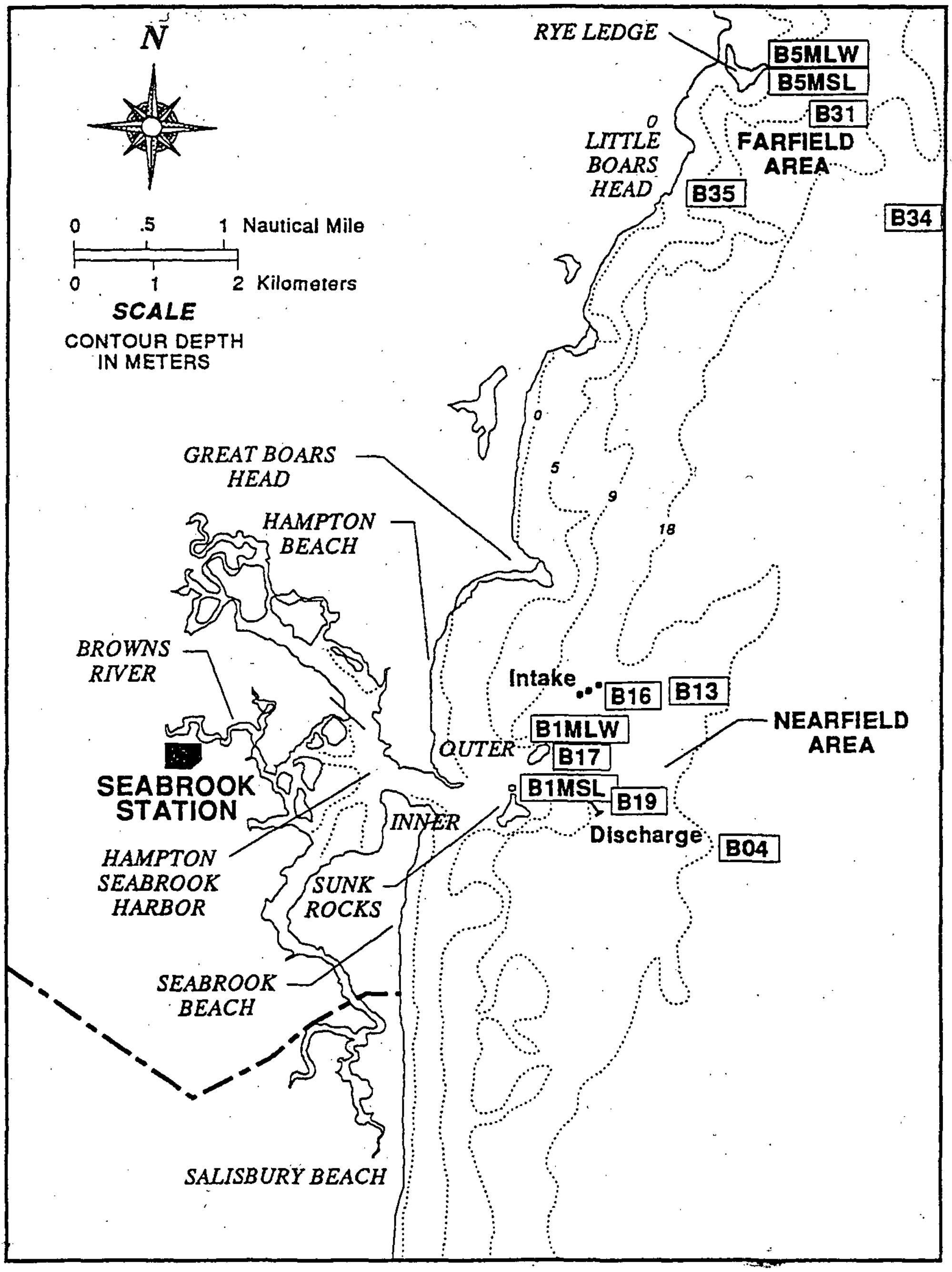
Epifauna and epiflora were removed by scraping from five randomly selected 0.0625 m^2 areas on rock surfaces. Subtidal collections were drawn through a diver-operated airlift into a 0.79 mm mesh bag, placed in a labeled plastic bag, brought to the surface and sent to the laboratory for preservation and processing (NAI 1991a). Intertidal collections followed a similar procedure, excluding the use of an airlift.

A comprehensive record of all visible algal species ("general algae") was made in conjunction with destructive sampling at each sampling station. In addition, observations were recorded from the mean low water and mean sea level areas (including tide pools) in the intertidal zone.

Beginning in 1982, two mid-intertidal stations (approximate mean sea level: B1MSL and B5MSL; Fig. 6-1) were evaluated non-destructively during April, July and December. Observations were made at permanently marked 0.25 m^2 quadrats at three tidal levels: bare rock zone (approximately mean high water or upper intertidal), predominantly fucoid-covered zone (mean sea level or mid-intertidal), and *Chondrus crispus*-covered zone (approximately mean low water or lower intertidal). Percent cover of fucoid algae and percent frequency of occurrence were estimated and recorded for organisms from an established species list of perennial and annual algal species, gastropods (*Acmaea testudinalis*, *Littorina* spp. and *Nucella lapillus*), *Balanus* spp. and Mytilidae. General observations for the entire sampling area were recorded and photographs were taken of each sampling quadrat within each tidal zone. Frequency of occurrence of fucoid algae was also recorded along a 9.5 m transect line (NAI 1991a).

Non-destructive subtidal transects were established in 1978 to monitor larger macroinvertebrates and macroalgae that were not adequately represented in destructive samples. Six randomly placed replicate 1 m x 7 m band-transects were surveyed at nearfield-farfield station pairs in the shallow subtidal (B17, B35) and mid-depth (B19, B31) zones in April, July and October. Percent frequency of occurrence was recorded for dominant "understory" macroalgae (*Chondrus crispus*, *Phyllophora* spp. and *Ptilota serrata*). Counts of *Modiolus modiolus*, *Strongylocentotus droebachiensis* and the kelp species *Laminaria digitata*, *L. saccharina*, *Agarum clathratum* (formerly called *A. cribrosum*), and *Alaria esculenta* were also made.

Information on patterns of recruitment and settlement of sessile benthic organisms was obtained from the bottom panels program. Bluestone panels (60 cm x 60 cm) were placed 0.5 m off the bottom at Stations B19 and B31, beginning in 1982. Stations B04 and B34 were added in 1986. Short-term bottom panels were exposed for four months during three exposure periods: December-April, April-August, and August-December. Long-term bottom panels were exposed for one year, deployed in August and collected in August of the following year.



LEGEND

☐ = benthic samples

Figure 6-1. Marine benthic sampling stations. Seabrook Operational Report, 1994.

6.2.2 Laboratory Methods

All destructive samples were washed over a 1.0 mm sieve. Algal species from each sample were identified to the lowest practicable taxon, dried for 24 hours at 105°C, and weighed. Fauna previously designated as selected species were identified and counted from May and November macrofaunal samples. Selected species were determined from previous studies to be those species that are the most useful as indicators of overall community type in the study area, based on abundance, trophic level, and habitat specificity. All faunal species collected in August were identified to the lowest practicable taxon; non-colonial species were counted and colonial taxa were listed as present. In addition, abundance of spirorbid polychaetes at subtidal Stations B19 and B31 was estimated from five subsamples of the alga *Phyllophora* spp. (which includes *P. pseudoceranoides* and *Coccotylus truncatus*, formerly called *P. truncata*.

Life history information was obtained for nine macrofaunal taxa at paired nearfield-farfield stations where they were most abundant. These taxa (and their station pairs) were *Ampithoe rubricata* (B1MLW/B5MLW), *Jassa marmorata* (B17/B35), *Pontogeneia inermis* (B19/B31), *Cancer irroratus* (B17/B35), *C. borealis* (B17/B35), *Strongylocentrotus droebachiensis* (B19/B31), Asteriidae (B17/B35), *Nucella lapillus* (B1MLW/B5MLW), and Mytilidae (B1MLW/B5MLW, B17/B35, B19/B31).

Individuals of all taxa from one subsample taken at each station in May, August and November were measured to the nearest 0.1 mm and enumerated. For all amphipods collected, sex was determined and the presence of eggs or brood was recorded.

Macroalgae from general collections were identified to the lowest practicable taxon. The complete macroalgal species list was compiled from both general and destructive collections and included crustose coralline algae, collected only in August.

All undisturbed bottom panel faces were first analyzed for *Balanus* spp. (which includes *Semibalanus balanoides*) and Spirorbidae, and then scraped to remove sessile bivalves and solitary chordates for identification and enumeration. Hydrozoa, Bryozoa and any abundant algal species were analyzed only on long-term panels.

6.2.3 Analytical Methods

6.2.3.1 Community

Macroalgal and macrofaunal community analyses included numerical classification and analysis of variance (ANOVA) of community parameters such as number of taxa and total abundance or biomass from August samples (Table 6-1). A mixed model ANOVA developed by Northeast Utilities, based on recent review of the BACI (before-after-control-impact) model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random, except operational status (Preop-Op). Time and location of sampling were considered random factors because both sampling dates and selected locations represented only a fraction of all possible times and locations (Underwood 1994). In addition, the median percent-frequencies of dominant taxa in the intertidal non-destructive program during the operational period were compared to the median and range from the preoperational period. Total number of algal taxa from general collections during 1991-1994 was compared to the median and range from the preoperational period. A comparison of macroalgal and macrofaunal community composition during operational and preoperational periods was carried out using numerical classification methods (Boesch 1977). Bray-Curtis similarity indices were computed for the annual August log-transformed average densities (macrofauna) and square-root transformed average biomass (macroalgae). Macroalgal species with less than 1.2% frequency of occurrence and macrofaunal species with less than 10% frequency

TABLE 6-1. SELECTED BENTHIC TAXA AND PARAMETERS USED IN ANOVA OR WILCOXON'S SUMMED RANKS TEST. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	PARAMETER	STATION	DATA PERIODS USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN ANOVAS[b]
Benthic Macroalgae	*Laminaria saccharina* *Laminaria digitata* *Alaria esculenta* *Agarum clathratum*	B17 B35 B19, B31	1979-1989, 1991-1994 1982-1989, 1991-1994 1978-1989, 1991-1994	Mean number per sample period and station, no transformation. Wilcoxon's summed ranks by station.	Preop-Op[c]
	Chondrus crispus *Phyllophora* spp. *Ptilota serrata*	B17, B19, B31 B35	1981-1989, 1991-1994 1982-1989, 1991-1994	Mean % frequency per year. No transformation. Wilcoxon's summed ranks test.	Preop-Op
	Chondrus crispus	B1MLW, B5MLW B17, B35	1982-1989, 1991-1994 1982-1989, 1991-1994	Biomass per sample period and replicate. Square root transformation, shallow subtidal; no transformation, intertidal.	Preop-Op, Station, Year, Month
	Number of taxa Total biomass	B1MLW, B5MLW B17, B35 B16, B19, B31 B04, B34, B13	1982 - 1994 1982 - 1994 1980 - 1984, 1986 - 1994 1979 - 1984, 1986 - 1994	Amount or number per station, year and replicate; no transformation.	Preop-Op, Station, Year
	Ascophyllum nodosum *Fucus vesiculosus* *Fucus distichus* spp. *edentatus* *Fucus distichus* spp. *distichus* *Fucus* sp.	B1MSL, B5MSL	1983-1989, 1991-1994	Mean % frequency per sample period and year; no transformation. Wilcoxon's summed ranks test by station.	Preop-Op

(Continued)

TABLE 6-1. (CONTINUED)

COMMUNITY	PARAMETER	STATION	DATA PERIODS USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCES OF VARIATION IN ANOVAS[b]
Benthic Macrofauna	*Ampithoe rubricata*[d] *Nucella lapillus* Mytilidae spat	B1MLW, B5MLW	1978-1989, 1991-1994 1982-1989, 1991-1994	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Jassa marmorata[d] Mytilidae spat	B17, B35	1978-1989, 1991-1994 1982-1989, 1991-1994		
	Asteriidae	B17, B35	1981-1989, 1991-1994 1982-1989, 1991-1994		
	Pontogeneia inermis[d] Mytilidae spat *Strongylocentrotus droebachiensis*	B19, B31	1978-1989, 1991-1994		
	Total density Number of Taxa	B1MLW, B5MLW; B17, B35; B16; B19, B31, B04, B34, B13	1982 - 1994 1982 - 1994 1980 - 1984, 1986 - 1994 1979 - 1984, 1986 - 1994	Amount or number per year, station and replicate; no transformation	Preop-Op, Station, Year
	Modiolus modiolus	B19, B31	1980 - 1989, 1991 - 1994	Mean per sample period, Wilcoxon's summed ranks tests, no transformation.	Preop-Op

[a]$Log_{10}(x+1)$ transformation unless otherwise stated.
[b]ANOVAs used except where otherwise noted (e.g., Wilcoxon's tests).
[c]Preop-Op: Preoperational period vs. Operational period.
[d]Life stages determined: juvenile/adult.

of occurrence were excluded from the analysis. In all, 37 algal species and 100 faunal taxa were included in the collections for which similarity indices were computed. The group average method (Boesch 1977) was used to classify the samples into groups or clusters. The actual computations were carried out by the computer program EBORDANA (Bloom 1980).

6.2.3.2 Selected Species

Comparisons between preoperational and operational periods were made by means of ANOVA or Wilcoxon's summed ranks test (Sokal and Rohlf 1969) on data for the selected species listed in Table 6-1. Some species were selected for more detailed analyses due to their ecological or economic importance in the study area. ANOVA was used to test for differences in abundance or biomass between periods at nearfield/farfield station pairs. The adjusted Least Squares Means (LSMEANS, PROC GLM, SAS Institute, Inc. 1985) were used in the t-test to evaluate differences when the Preop-Op X Station interaction term was significant at $\alpha \leq 0.05$. To further facilitate interpretation of these differences, the adjusted LS means for operational and preoperational periods were plotted by station. The Wilcoxon's test was used to test for significant differences in percent-frequency or abundance of selected macroalgal taxa between preoperational and operational periods at each station.

6.3 RESULTS AND DISCUSSION

6.3.1 Marine Macroalgae

6.3.1.1 Horizontal Ledge Communities

Number of Taxa

Assessment of spatial and temporal patterns in number of algal taxa has proven useful as an indicator of impacts associated with several nuclear power plants in New England (Vadas et al. 1976; Wilce et al. 1978; Schneider 1981; NUSCO 1994). To assess algal community diversity at Seabrook study sites, the number of algal taxa was determined in two ways. Numbers of taxa from general collections were used to qualitatively characterize the overall floristic composition at a given study site. The destructive sampling program provided quantitative information on algal diversity (i.e., number of taxa per unit of area), data which are more amenable to statistical analysis. In these facets combined, 139 taxa have been collected during the 17-year study (Appendix Table 6-3).

Number of Taxa: General Collections

Seventy-nine algal taxa were collected during the 1994 sampling year (NAI 1995), which was similar to totals from previous operational and preoperational years (NAI 1992, 1993; NAI and NUS 1994). No new taxa were added in 1994 (Appendix Table 6-3). Red algae (Rhodophyta) composed 56% of the floral assemblage in 1994, brown algae (Phaeophyta) 26%, and green algae (Chlorophyta) 18% (NAI 1995). These proportions were similar to other operational years (NAI 1992, 1993; NAI and NUS 1994), to the overall preoperational period (51% red, 27% brown, 22% green; Appendix Table 6-3), and consistent with other New Hampshire studies (Mathieson and Hehre 1986).

As with previous operational years, numbers of taxa from general collections in 1994 were within the range of annual numbers from preoperational years at most (9 of 12) stations (Fig. 6-2). The total numbers of taxa collected at B1MLW and B34 in 1994 were lower than ranges established during the preoperational period, while the total collected at B35 was higher. The 1994 totals were also comparable to other operational years. In general, fewer taxa were collected during most of the operational years at intertidal, mid-depth subtidal and deep subtidal stations than were collected during the preoperational period. At the same time, more taxa were collected at shallow subtidal stations during

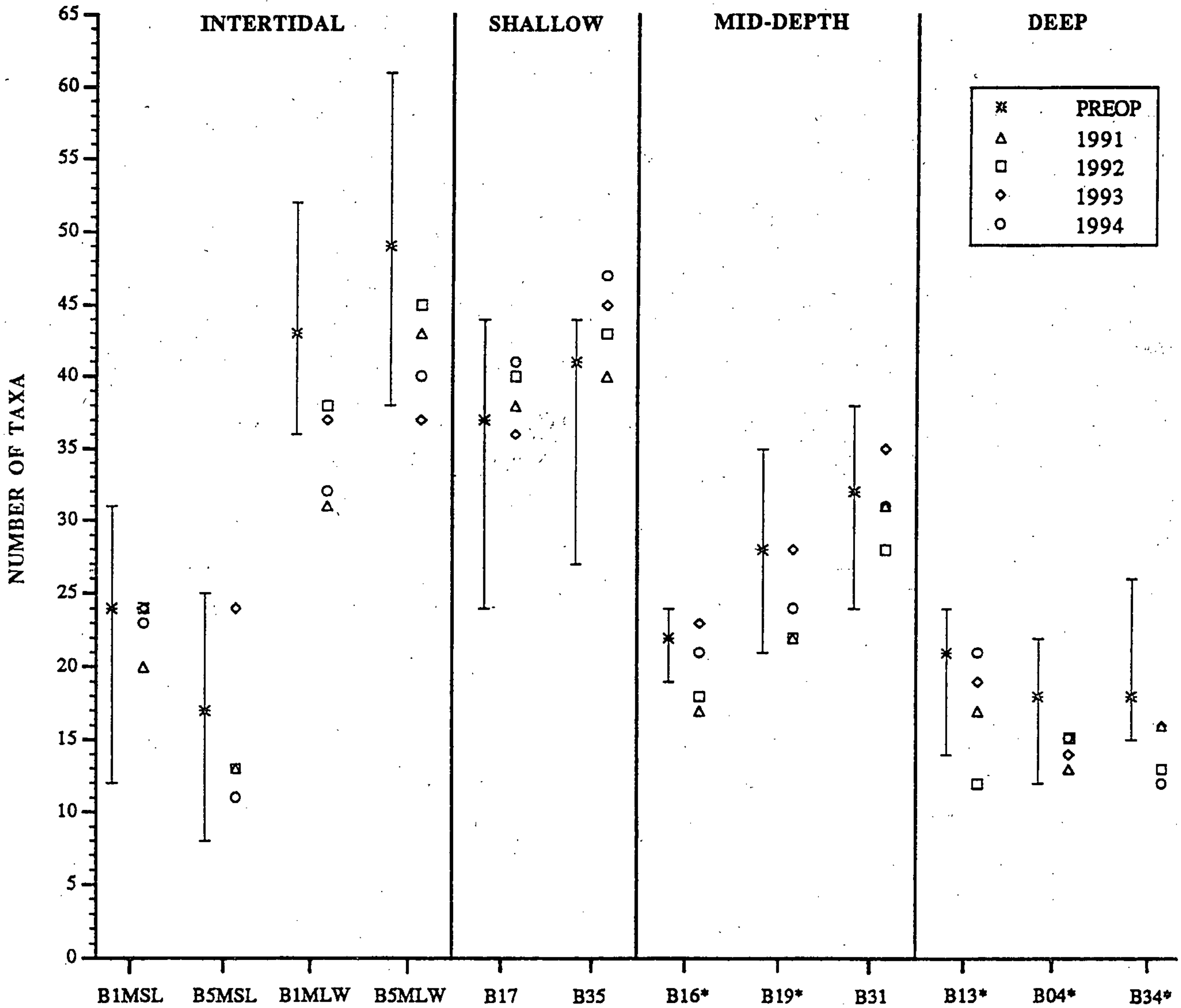


Figure 6-2. Preoperational (through 1989) median and range and 1991-1994 values for total number of unique taxa collected in triannual general algae collections at Stations B1MSL, B1MLW, B17, B19, B31 (1978-1994), B5MSL, B5MLW, B35 (1982-1994), and annual (August only) collections at Stations marked with '*', i.e., B16 (1980-1984; 1986-1994), B13, B04 (1978-1984; 1986-1994) and B34 (1979-1984; 1986-1994). Seabrook Operational Report, 1994.

operational years than were typically collected during preoperational years.

During the preoperational period, the highest numbers of taxa were collected at lower intertidal stations (B1MLW and B5MLW), followed closely by shallow subtidal stations (B17 and B35), mid-depth subtidal stations (B19 and B31) and the nearfield mid-intertidal station (B1MSL; Figure 6-2). The lowest numbers of taxa were collected at the deep subtidal stations (B04, B34 and B13) and the farfield mid-intertidal station (B5MSL). During 1994 specifically, the highest numbers of taxa were collected at the intertidal and shallow subtidal stations, followed by mid-depth subtidal stations and deep subtidal stations. The one exception to this pattern was B5MSL, which had the lowest number of taxa over all stations. This pattern is identical to that observed in the preoperational period. This zonal pattern was consistent with studies conducted elsewhere on the New Hampshire coastline (Mathieson et al. 1981).

Nearfield-farfield differences were apparent in all station pairings in 1994. Farfield stations had a higher number of taxa than nearfield stations in the mid-intertidal zone, shallow subtidal zone, and the mid-depth subtidal zone. Nearfield stations had a higher number of taxa than farfield stations in the remaining zones (lower intertidal and the deep subtidal). In each pairing, differences noted in 1994 were consistent with differences noted in the preoperational period.

Number of Taxa: Quantitative Samples

Numbers of algal taxa based on August quantitative (destructive) samples, in general, followed a pattern similar to that from qualitative (general collections) sampling during both the preoperational and operational periods. The most taxa were typically collected at shallow subtidal and intertidal stations, with fewer taxa at mid-depth stations and lowest numbers at deep stations (Table 6-2). Shallow subtidal and intertidal stations had the highest number of taxa in 1994, as in previous years, although mid-depth stations on average did not differ substantially from deep subtidal stations. There were no preoperational-operational or station differences in any depth zone, nor were any significant interactions between period and station detected in any depth zone (Table 6-3).

Total Biomass

Total algal biomass (g/m^2) exhibited a distinct pattern over depth zones during 1994 and over both preoperational and operational periods that was similar to that described previously for number of taxa (Table 6-2). Biomass in August was consistently highest at shallow subtidal and intertidal stations, and lowest at deep stations. Although the number of taxa collected was similar between mid-depth and deep subtidal stations in 1994, mid-depth biomass in 1994 was greater than deep biomass, as in past years. A significant Preop-Op X Station interaction was detected in the intertidal zone (Table 6-3). Biomass declined significantly at both stations between the preoperational and operational periods, however, the decline was considerably steeper at the nearfield station (B1MLW) compared to the farfield station (B5MLW; Table 6-3, Figure 6-3). Fluctuations in the timing of peak biomass (either prior to or after August) likely accounts for this interaction. When all three months during which biomass was recorded are considered, the Preop-Op X Station interaction is no longer significant (Table 6-3). This is consistent with the results of the ANOVA for *Chondrus crispus* biomass (the overwhelming dominant with respect to biomass in this zone), which uses all three sample periods in the model; this ANOVA will be discussed further in the following section.

TABLE 6-2. ARITHMETIC MEANS AND COEFFICIENTS OF VARIATION (CV,%) FOR NUMBER OF ALGAL TAXA, TOTAL ALGAL BIOMASS, AND *CHONDRUS CRISPUS* BIOMASS AT VARIOUS DEPTHS AND STATIONS DURING 1994 AND DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH ZONE	STATION	PREOPERATIONAL[a] 1978 - 1989 MEAN	CV	REPORT YEAR 1994 MEAN	OPERATIONAL 1990 - 1994 MEAN	CV
Number of taxa[b] (no. per 0.0625 m^2)	Intertidal	B1MLW	11.1	31.8	11.0	9.6	14.0
		B5MLW	18.1	22.6	11.8	13.6	11.3
	Shallow subtidal	B17	11.4	15.2	11.2	11.2	7.2
		B35	15.3	15.0	18.0	14.4	22.9
	Mid-depth	B19	10.2	13.0	7.6	9.2	14.5
		B31	11.1	12.4	10.0	10.8	16.0
		B16	9.0	8.3	8.8	9.4	15.5
	Deep	B04	7.6	10.2	8.4	7.6	9.0
		B13	7.9	8.9	10.4	8.3	17.4
		B34	7.7	7.9	7.2	7.4	5.8
Total biomass[b] (g/m^2)	Intertidal	B1MLW	1300.5	32.7	1157.6	1027.4	25.7
		B5MLW	1198.0	27.4	926.9	1008.3	10.7
	Shallow subtidal	B17	1208.4	12.9	1645.0	1316.1	17.6
		B35	1170.0	21.4	1688.5	1204.7	24.7
	Mid-depth	B19	308.6	25.8	195.0	343.6	30.6
		B31	471.2	27.5	328.0	364.6	16.5
		B16	779.8	28.1	763.5	592.1	22.2
	Deep	B04	99.7	30.1	95.5	93.3	20.5
		B13	96.0	32.1	58.2	81.1	60.2
		B34	71.4	71.3	60.5	40.9	41.7
Chondrus crispus biomass[c] (g/m^2)	Intertidal	B1MLW	908.7	27.6	1011.0	995.1	10.5
		B5MLW	787.8	26.9	792.0	762.5	20.5
	Shallow subtidal	B17	644.1	18.9	811.9	633.8	16.7
		B35	477.3	10.9	700.8	471.1	34.4
	Mid-depth	B19	1.4	135.5	4.9	2.0	99.3
		B31	99.9	40.7	99.8	115.1	54.6

[a]Stations B1MLW, B17, B19, B31: 1978 - 1989; Stations B5MLW B35: 1982 - 1989; Station B16: 1980 - 1989; Station B13, B04: 1978 - 1984, 1986 - 1989; B34: 1979 - 1984, 1986 - 1989. Means of annual means.
[b]August only, therefore operational period = 1990-1994.
[c]Sampled destructively three times annually at intertidal, shallow and mid-depth subtidal only. Rarely collected at deep stations. Operational period for triannual collections = 1991-1994.

TABLE 6-3. ANALYSIS OF VARIANCE RESULTS FOR NUMBER OF TAXA (per 0.0625 m^2) AND TOTAL BIOMASS (g per m^2) OF MACROALGAE COLLECTED IN AUGUST DESTRUCTIVE SAMPLES AT INTERTIDAL, SHALLOW SUBTIDAL, AND DEEP STATIONS DURING PREOPERATIONAL AND OPERATIONAL YEARS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISON[g] (Ranked in decreasing order)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	1	378.73	4.40 NS	
		Station[b]	1	723.75	31.90 NS	
		Year (Preop-Op)[c]	11	76.86	5.65 ***	
		Preop-Op X Station[d]	1	22.61	1.66 NS	
		Station X Year (Preop-Op)[e]	11	13.60	2.02 *	
		Error	100	6.74		
	Shallow Subtidal (B17, B35)	Preop-Op	1	22.96	1.11 NS	
		Station	1	319.69	non-est.[h]	
		Year (Preop-Op)	11	33.99	2.51 NS	
		Preop-Op X Station	1	0.09	<0.01 NS	
		Station X Year (Preop-Op)	11	13.52	2.67 ***	
		Error	100	5.06		
	Mid-depth (B16, B19, B31)	Preop-Op	1	5.82	0.30 NS	
		Station	2	51.10	5.54 NS	
		Year (Preop-Op)	12	15.39	3.05 ***	
		Preop-Op X Station	2	9.13	1.81 NS	
		Station X Year (Preop-Op)	24	5.05	2.82 ***	
		Error	167	1.79		
	Deep (B04, B34, B13)	Preop-Op	1	<0.01	<0.01 NS	
		Station	2	7.24	6.36 NS	
		Year (Preop-Op)	13	5.49	2.86 *	
		Preop-Op X Station	2	1.16	0.61 NS	
		Station X Year (Preop-Op)	26	1.92	1.65 *	
		Error	180	1.16		

(Continued)

TABLE 6-3. (CONTINUED)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
Total Biomass	Intertidal (B1MLW, B5MLW)	Preop-Op	1	3,328,262	2.60 NS	
		Station	1	852,364	1.36 NS	
		Year (Preop-Op)	11	783,334	6.20 ***	
		Preop-Op X Station	1	621,274	4.91 *	B1-Pre B5-Pre B1-Op B5-Op
		Station X Year (Preop-Op)	11	126,337	2.10 *	
		Error	100	60,204		
	Intertidal[i] (B1MLW, B5MLW)	Preop-Op	1	341,446	0.48 NS	
		Station	1	664,315	3.97 NS	
		Month (Year)	24	847,750	14.13 ***	
		Year (Preop-Op)	10	682,608	0.73 NS	
		Preop-Op X Station	1	168,786	0.98 NS	
		Station X Year (Preop-Op)	10	167,439	2.79 **	
		Error	272	59,977		
	Shallow Subtidal (B17, B35)	Preop-Op	1	169,435	0.50 NS	
		Station	1	145,471	3.02 NS	
		Year (Preop-Op)	11	401,940	3.51 *	
		Preop-Op X Station	1	49,118	0.43 NS	
		Station X Year (Preop-Op)	11	114,488	1.44 NS	
		Error	100	79,517		
	Mid-depth (B16, B19, B31)	Preop-Op	1	357,541	1.48 NS	
		Station	2	2,309,951	12.61 NS	
		Year (Preop-Op)	12	139,476	1.77 NS	
		Preop-Op X Station	2	180,904	2.29 NS	
		Station X Year (Preop-Op)	24	78,979	2.11 ***	
		Error	167	37,497		

(Continued)

TABLE 6-3. (CONTINUED)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[e]	MULTIPLE COMPARISON[f] (Ranked in decreasing order)
	Deep	Preop-Op	1	16,556	non-est.[h]	
	(B04, B34, B13)	Station	2	31,286	12.92 NS	
		Year (Preop-Op)	13	4,952	0.65 NS	
		Preop-Op X Station	2	2,571	0.34 NS	
		Station X Year (Preop-Op)	26	7,601	5.45 ***	
		Error	180	1,395		

[a]Compares Preop to Op, regardless of station; years included in each station grouping (Op Years = 1990-1994 for all):
B1MLW, B5MLW: 1982-1994
B17, B35: 1982-1994
B16, B19, B31: 1980-1984, 1986-1994
B04, B34, B13: 1979-1984, 1986-1994
[b]Stations within depth zone.
[c]Year nested within preoperational and operational periods regardless of area.
[d]Interaction of the two main effects, Preop-Op and Station.
[e]Interaction between station and year nested within preoperational and operational periods.
[f]NS = Not significant ($p>0.05$); * = Significant ($0.05 \geq p > 0.01$); ** = Highly significant ($0.01 \geq p > 0.001$); *** = Very Highly Significant ($0.001 \geq p$).
[g]Underlining indicates that t-tests showed no significant differences ($\alpha \leq 0.05$) among the underlined least squares means.
[h]Non-estimatable due to negative mean square denominator.
[i]Includes all months (May, August, November). Month (Year) = month nested within year regardless of station.

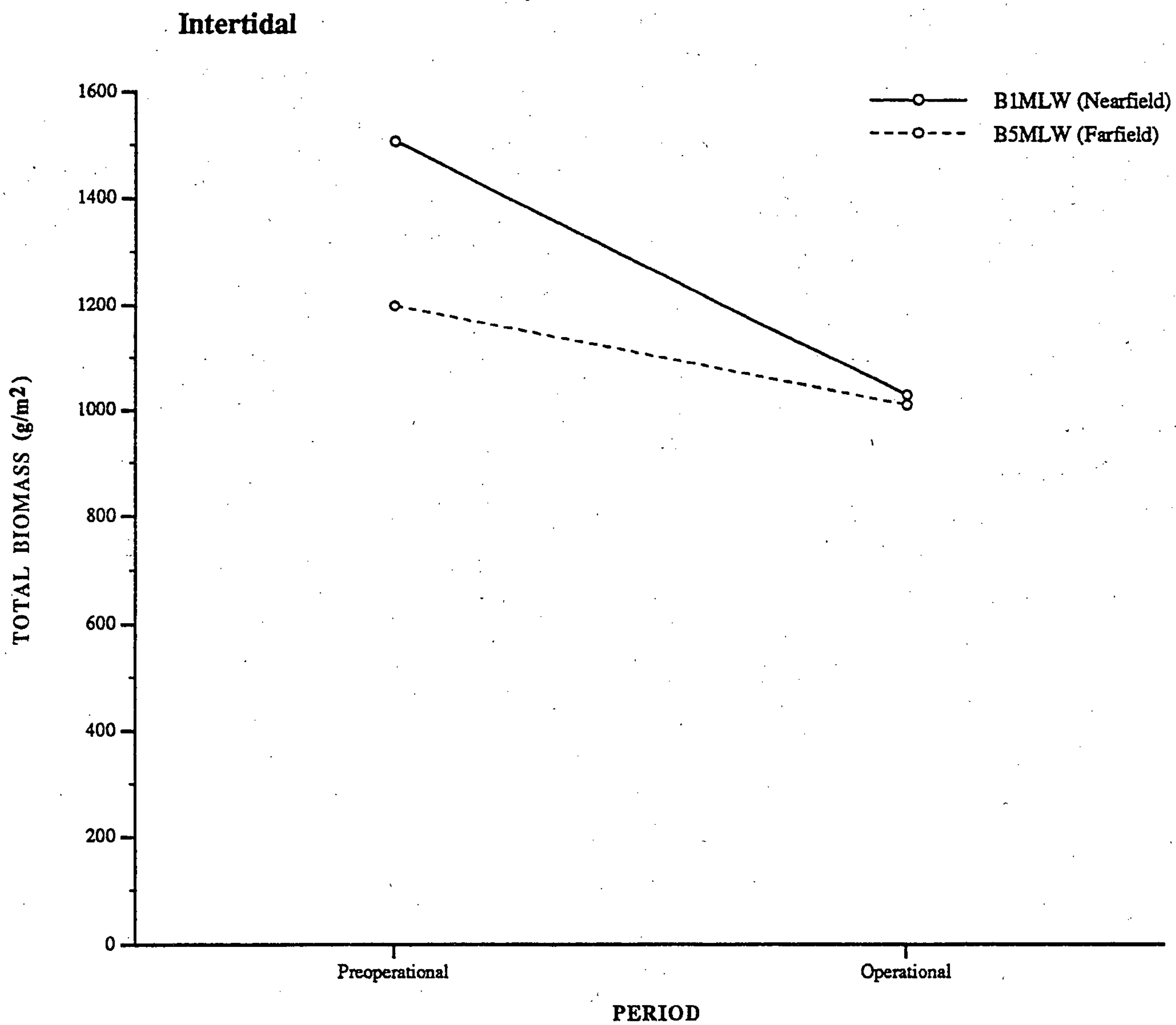


Figure 6-3. Comparisons among stations for mean total **macroalgal** biomass in the intertidal zone during the preoperational (1982-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-3). Seabrook Operational Report, 1994.

Macroalgal Community Analysis

Multivariate community analysis techniques were used in this study to quantify the degree of similarity among all August macroalgal collections made at the macrobenthic sampling stations since 1978. In this case, 155 station/year collections, represented by square-root transformed biomass values of 37 macroalgal taxa, were grouped into clusters according to Bray-Curtis similarity indices. A power plant-induced impact to the macroalgal community could be inferred from the failure of operational years' collections (1990-1994) at a station to be grouped with collections from preoperational years (1989 and earlier) at that station. However, all collections were invariably grouped by station, with all years (preoperational and operational) included (Figure 6-4); each group was distinguished from the others by the abundance of a characteristic macroalgal species assemblage.

The intertidal stations (B1MLW and B5MLW) comprised a discrete entity (Group 1) that was dissimilar to the other groups. This group was characterized by high biomass values for *Chondrus crispus* and *Mastocarpus stellatus* (this was the only group that included *M. stellatus*) and an absence of *Phyllophora* spp. (Table 6-4). Group 1 also included a moderate amount of *Corallina officinalis*. Similarly, Group 2 (the shallow subtidal stations B17 and B35) was characterized by high *C. crispus* and *Phyllophora* spp. abundance, and lesser amounts of *Ceramium nodulosum* (formerly called *C. rubrum)*, *Cystoclonium purpureum*, *C. officinalis*, and *Phycodrys rubens*. The assemblages consisting of the three mid-depth stations (Groups 3, 4 and 5; stations B31, B16 and B19, respectively) were dominated by *Phyllophora* spp. Among the three stations, *Phyllophora* spp. accounted for 48 to 67% of total abundance (ca. 202-405 g/m^2) during preoperational years, and during operational years

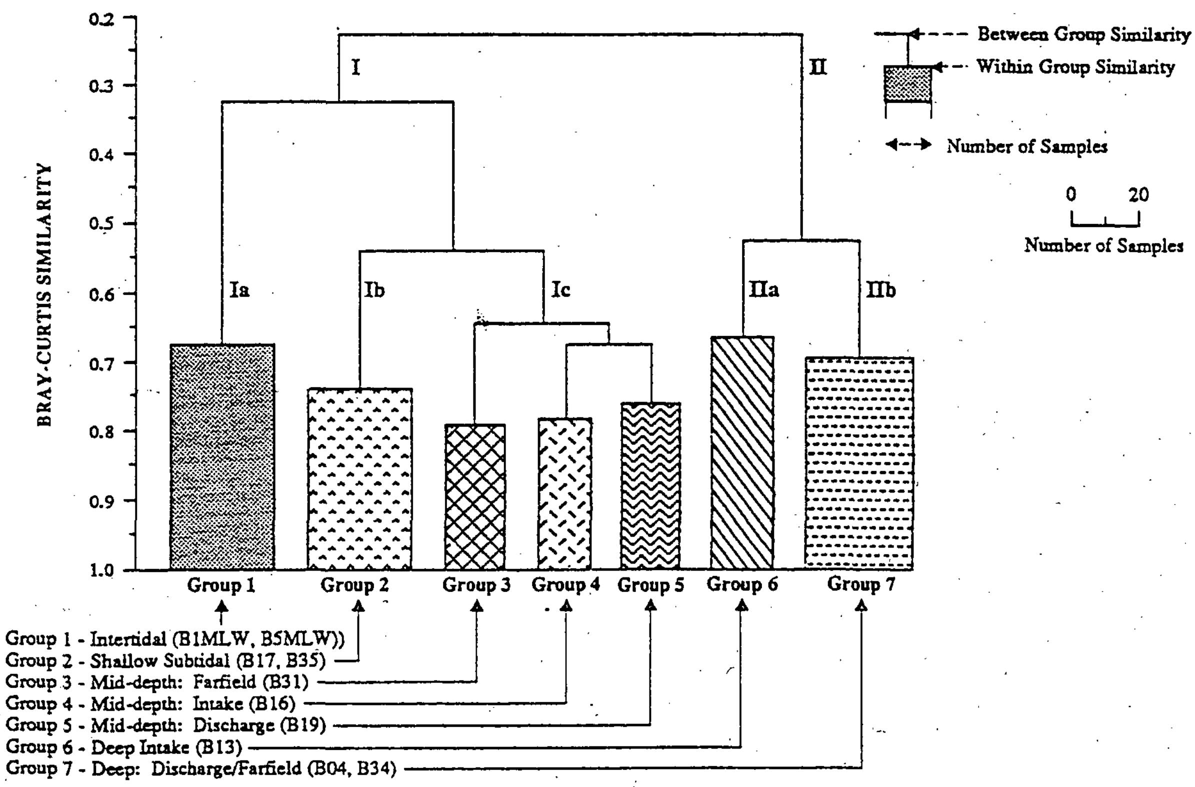


Figure 6-4. Dendrogram and station groups formed by numerical classification of August collections of marine benthic algae, 1978-1994. Seabrook Operational Report, 1994.

TABLE 6-4. SUMMARY OF SPATIAL ASSOCIATIONS IDENTIFIED FROM NUMERICAL CLASSIFICATION (1978 - 1994) OF BENTHIC MACROALGAE SAMPLES COLLECTED IN AUGUST DESTRUCTIVE SAMPLING. SEABROOK OPERATIONAL REPORT, 1994.

						GROUP BIOMASS (g/m²)					
				WITHIN/ BETWEEN		PREOP[b]			OP[c]		
DEPTH ZONE	STATION	MEAN DEPTH (m)	YEARS INCLUDED	GROUP SIMILARITY	DOMINANT TAXA[a]	LCL	MEAN	UCL	LCL	MEAN	UCL
Intertidal	B1MLW	MLW	1978 - 1994	0.68/0.33	*Chondrus crispus*	796.4	986.2	1175.9	568.9	808.1	1047.2
	B5MLW	MLW	1982 - 1994		*Mastocarpus stellatus*	106.6	215.2	323.9	42.4	185.9	329.3
					Corallina officinalis	19.9	51.3	82.5	0.7	19.0	37.3
Shallow Subtidal	B17	4.6	1978 - 1994	0.74/0.55	*Chondrus crispus*	662.6	774.2	885.9	547.4	781.6	1015.9
	B35		1982 - 1994		*Phyllophora* spp.	142.8	204.7	266.6	125.3	232.2	339.2
					Ceramium nodulosum	48.6	69.3	90.0	54.8	84.2	113.6
					Cystoclonium purpureum	15.5	56.6	97.7	35.6	76.7	117.9
					Corallina officinalis	28.3	51.6	74.8	20.9	34.1	47.3
					Phycodrys rubens	11.2	18.8	26.4	18.7	25.1	31.4
Mid-depth Intake	B16	9.4	1980 - 1984; 1986 - 1994	0.79/0.68	*Phyllophora* spp.	304.6	404.5	504.3	211.6	289.9	368.2
					Phycodrys rubens	117.8	188.9	259.9	53.8	134.6	215.3
					Chondrus crispus	26.5	57.0	87.4	0.0	44.5	119.9
					Cystoclonium purpureum	18.0	44.5	71.0	7.3	31.6	55.9
					Ceramium nodulosum	14.3	35.0	55.7	0.0	44.3	98.7
					Callophyllis cristata	23.8	32.5	41.1	11.6	30.7	49.8

(Continued)

TABLE 6-4. (CONTINUED)

DEPTH ZONE	STATION	MEAN DEPTH (m)	YEARS INCLUDED	WITHIN/ BETWEEN GROUP SIMILARITY	DOMINANT TAXA[a]	GROUP BIOMASS (g/m^2)					
						PREOP[b]			OP[c]		
						LCL	MEAN	UCL	LCL	MEAN	UCL
Mid-depth Discharge	B19	12.2	1978 - 1994	0.77/0.68	*Phyllophora* spp.	163.6	201.9	240.1	106.6	196.4	286.2
					Phycodrys rubens	30.9	50.2	60.6	41.7	96.0	150.3
					Corallina officinalis	10.8	15.2	45.8	2.3	6.5	10.7
					Callophyllis cristata	6.8	12.5	71.8	5.9	14.3	22.6
					Ptilota serrata	9.7	16.0	62.3	2.8	9.1	15.4
					Cystoclonium purpureum	1.6	6.0	116.5	3.2	9.9	16.5
Mid-depth Farfield	B31	9.4	1978 - 1994	0.80/0.65	*Phyllophora* spp.	148.5	213.2	277.8	67.7	146.8	225.9
					Corallina officinalis	71.1	97.8	124.5	67.0	89.9	112.7
					Chondrus crispus	72.5	114.8	157.1	9.6	78.5	147.4
					Phycodrys rubens	17.4	22.9	28.4	6.0	26.0	46.1
Deep Intake	B13	18.3	1978 - 1984; 1986 - 1994	0.66/0.53	*Phyllophora* spp.	45.1	68.8	92.6	6.7	62.5	118.3
					Ptilota serrata	7.6	11.5	15.5	0.0	5.5	12.9
					Phycodrys rubens	2.9	5.8	8.8	0.0	4.6	9.4
					Polysiphonia urceolata	0.0	2.9	6.2	0.0	2.6	6.4
					Scagelia pylaisaei	0.0	2.9	5.7	0.0	3.0	6.9
Deep Discharge/ Farfield	B04	18.9 - 21.0	1978 - 1984; 1986 - 1994	0.66/0.53	*Ptilota serrata*	45.7	64.0	82.3	30.3	45.3	60.3
					Phyllophora spp.	5.9	11.0	16.0	2.9	10.5	18.1
	B34		1979 - 1984; 1986 - 1994		*Corallina officinalis*	3.3	6.9	10.4	0.0	1.4	2.8

[a]Dominant taxa compose 2% or more of total abundance in either or both of the periods (Preop, Op).
[b]Preop = preoperational, 1978-1989 period (Stations B1MLW, B17, B19, B31: 1978 - 1989; Stations B5MLW, B35: 1982-1989; Station B16: 1980 - 1984, 1986-1989; Stations B13, B04: 1978-1984, 1986 - 1989; B34: 1979 - 1984, 1986-1989).
[c]Op = 1990-1994

accounted for 43-59% of total abundance (ca. 147-290 g/m^2; Table 6-4). *P. rubens* was among the dominants at each of the three mid-depth stations in both periods. An additional six taxa (*C. crispus*, *C. officinalis*, *C. purpureum*, *C. nodulosum*, *Callophyllis cristata*, and *Ptilota serrata*) were present at one or two of the stations in amounts equal to or exceeding 2.0% of total abundance (Table 6-4).

The deep water groups were segregated from the other stations on the basis of low macroalgal biomass (<200 g/m^2, groups 6 and 7 combined; Table 6-4). The Group 6 assemblage (deep water intake station B13) was dominated by *Phyllophora* spp., with lesser amounts of *Ptilota serrata*, *Phycodrys rubens*, *Polysiphonia urceolata* and *Scagelia pylaisaei* (formerly called *S. corallina*). Group 7, which included the deep water farfield and discharge stations B04 and B34, was dominated by *P. serrata*, with lesser amounts of *Phyllophora* spp. and *Corallina officinalis*.

Total algal biomass for each group except Group 2 (shallow subtidal stations B17 and B35) and Group 5 (mid-depth subtidal discharge station B19) declined during the operational period. The intertidal group (Group 1) had the highest preoperational biomass, but the shallow subtidal stations' biomass exceeded intertidal biomass during the operational period. Total biomass decreased with increasing depth among the groups, as was shown in the individual station mean biomass values (Table 6-2).

The community analysis techniques described above used biomass values from a large number of algal taxa (37 out of a total of 67; all those with an overall frequency of occurrence of at least 1.2%). However, these analyses are influenced most strongly by commonly found species with high total biomass; small, rarely found taxa contribute little to the Bray-Curtis similarity indices. Therefore, a further community analysis was performed, examining rare species (overall frequency of occurrence less than 4%). Of the 33 species that met this criterion in either the preoperational or operational period or both (Table 6-5), eight were found in both preoperational (1989 and earlier) and operational (1990-1994) periods, but have decreased in frequency of occurrence in the operational period. Six species were found in both periods, but have become relatively more frequent since Seabrook Station began operation. Sixteen species were found in preoperational years, but have not yet been collected in the operational period; four species have been identified for the first time since Seabrook Station start-up. None of the 33 rare species was considered a major component of the local macroalgal flora (average biomass was <0.10 g/m^2), nor were the reductions or increases of occurrence during the operational period considered to represent a significant alteration of the established algal community.

Another monitoring study, evaluating the impacts associated with construction and operation of a nuclear power plant on the attached macroalgal flora (NUSCO 1994), documented that incursion of a thermal effluent to nearby rocky shore sites caused an alteration of the algal community at those sites. Specifically, there was an increased frequency of occurrence (i.e., extended growing season) for species requiring or tolerant of warm water, and an absence or reduced frequency of occurrence for species with cold water affinities. If similar trends were observed in the macroalgal community near Seabrook Station, it could be considered evidence of a power plant impact. However, of the three rare species that showed relatively large increases from preoperational to operational periods, (*Bonnemaisonia hamifera*, *Desmarestia viridis*, and *Petalonia fascia* (Table 6-5), the latter two are associated with cold water, and typically found in late winter/early spring (Taylor 1957). *Bonnemaisonia hamiferia* is a small, bushy red algae described by Taylor (1957) as an "exotic," typically found off southern Massachusetts and into Long Island Sound. *B. hamifera* has also been recorded from coastal New Hampshire and from Great Bay by Mathieson and Hehre (1986). None of these taxa are considered nuisance species. *Leathesia difformis*, described as a summer

TABLE 6-5. A COMPARISON OF PERCENT FREQUENCY OF OCCURRENCE OF RARELY FOUND SPECIES (OVERALL FREQUENCY OF OCCURRENCE <4%) IN AUGUST DESTRUCTIVE SAMPLING DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1990-1994) PERIODS, AND OVER ALL YEARS (1978-1994). SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	PREOPERATIONAL	OPERATIONAL	ALL YEARS
Gymnogongrus crenulatus	4.1	3.6	3.9
Bonnemaisonia hamifera	1.4	8.4	3.7
Ectocarpus fasciculatus	4.7	0.4	3.3
Polyides rotundus	3.1	3.2	3.1
Desmarestia viridis	0.6	6.0	2.4
Leathesia difformis	2.9	0.4	2.1
Ulvaria obscura v. Blyttii	1.8	0.4	1.3
Cladophora sericea	1.4	0.8	1.2
Petalonia fascia	0.4	2.8	1.2
Porphyra miniata	1.4	0.8	1.2
Monostroma grevillei	1.6	.	1.0
Ectocarpus siliculosus	1.0	1.2	1.0
Palmaria palmata	1.4	0.4	1.0
Spongomorpha spinescens	1.0	.	0.7
Pilayella littoralis	1.0	.	0.7
Giffordia granulosa	0.8	.	0.5
Sphacelaria cirrosa	0.6	0.4	0.5
Enteromorpha prolifera	0.6	.	0.4
Dumontia contorta	0.6	.	0.4
Ceramium deslongchampii	0.6	.	0.4
Polysiphonia harveyi	0.6	.	0.4
Chordaria flagelliformis	.	0.8	0.3
Scytosiphon lomentaria	0.2	0.4	0.3
Spongonema tomentosum	0.4	.	0.3
Isthmoplea sphaerophora	.	0.8	0.3
Ulvaria oxysperma	0.2	.	0.1
Enteromorpha intestinalis	0.2	.	0.1
Enteromorpha linza	0.2	.	0.1
Bryopsis plumosa	.	0.4	0.1
Plumaria elegans	0.2	.	0.1
Polysiphonia denudata	0.2	.	0.1
Polysiphonia nigra	.	0.4	0.1
Entocladia viridis	0.2	.	0.1

plant, decreased in frequency of occurrence during the operational period. The filamentous brown alga *Ectocarpus fasciculatus*, described by Taylor (1957) as being adapted to warmer waters, also declined in frequency of occurrence during the operational period. Both trends are the converse of the expected response to a thermal incursion. Trends observed in taxa appearing for the first time in the operational period are less conclusive. One form, *Isthmoplea spaerophora*, is a cold water species, ranging from northern Massachusetts to Labrador (Taylor 1957). Two taxa, *Bryopsis plumosa* and *Polysiphonia nigra*, are warm water forms more typical of southern New England and even further south along the Atlantic coast. *Chordaria flagelliformis* is a characteristic species of northern New England, but is adaptable to warmer waters. In general, the macroalgal communities in the vicinity of Seabrook Station are typical of those reported elsewhere in northern New England (e.g., Mathieson et al. 1981; Mathieson and Hehre 1986). No impact on these communities as a result of construction or operation of the power plant has been observed to date.

Kelp and Understory Species (Non-Destructive Monitoring Program)

Extensive canopies of several kelp species commonly occur in coastal subtidal zones (4-18 m) in the northwestern Atlantic, and can account for up to 80% of total algal biomass (Mann 1973). In the Gulf of Maine, *Laminaria* spp. (mostly *L. saccharina* and *L. digitata*) are most common in the shallow subtidal zone (4-8 m), while a mixture of *Agarum clathratum*, *Laminaria* spp. and *Alaria esculenta* are found in deeper zones (Sebens 1986; Witman 1987; Ojeda and Dearborn 1989).

A similar distribution of kelp species was found at Seabrook study sites during the preoperational and operational periods. *Laminaria* spp. were commonly found in both shallow and mid-depth zones during the preoperational period. *L. saccharina* was the dominant kelp species at shallow subtidal stations (B17 and B35), with greater amounts of *L. digitata* occurring at mid-depth stations (B19 and B31). *Agarum clathratum* was a codominant at mid-depth stations (particularly at B19). Moderate amounts of *Alaria esculenta* were also observed in this zone (Table 6-6). In 1994, *L. saccharina* dominated the shallow subtidal as in past years, while *A. clathratum* was the overwhelming dominant at mid-depth stations.

According to the results of Wilcoxon summed ranks tests, the density of *Laminaria digitata* declined significantly between preoperational and operational periods at stations B17, B19 and B31 (Table 6-6). The decrease in operational means at these sites in comparison to preoperational means resulted from a general decline in abundance of *L. digitata* that began prior to power plant start-up (e.g., 1988 at B19, 1983 at B17 and 1980 at B31) and was further exacerbated by Hurricane Bob in 1991, when large scale removal of several kelp species, particularly *L. digitata* at B19, was noted (NAI 1992). *Laminaria saccharina* density also declined during the preoperational period at Stations B17, B19 and B31, although this decrease was significant only at B19 (Table 6-6).

Patterns of occurrence and abundance of some understory species can be influenced by the degree of kelp canopy cover (Johnson and Mann 1988). Common understory species in the Seabrook area, occurring beneath and adjacent to kelp canopies, include the foliose red algae *Chondrus crispus*, *Phyllophora* spp. and *Ptilota serrata*. Mean percent frequencies of occurrence of the three dominant understory algae during 1994 and during preoperational and operational periods are presented in Table 6-6. Patterns of distribution of these species in fixed transects were similar to those observed from biomass collections (Table 6-4). The shallow subtidal zone (B17/B35) was dominated by extensive turfs of the perennial red alga *Chondrus crispus* (ca. 50-75% over preoperational and operational periods), with moderate occurrences of *Phyllophora* spp. (ca. 20-27%). In the mid-depth zone

TABLE 6-6. PREOPERATIONAL AND OPERATIONAL MEANS AND COEFFICIENTS OF VARIATION (CV,%), 1994 MEANS, AND RESULTS OF WILCOXON'S SUMMED RANKS TEST COMPARING DENSITIES OF FOUR KELP SPECIES (#/100 m^2) AND PERCENT FREQUENCY OF OCCURRENCE OF THREE UNDERSTORY SPECIES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS[a]. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL		1994	OPERATIONAL[c]			
TAXON	STATION	MEAN[b]	CV	MEAN	MEAN[b]	CV	n[d]	Z[e]
KELPS (#/100 m^2)								
Laminaria digitata	B17	213.9	51.0	65.8	40.5	42.9	15	-4.97 ***
	B35	155.8	45.5	142.0	134.3	26.3	12	-0.54 NS
	B19	139.9	65.7	3.2	15.7	54.6	16	-4.75 ***
	B31	500.2	31.0	116.6	218.2	32.4	16	-4.79 ***
Laminaria saccharina	B17	415.1	51.8	330.0	334.8	52.1	15	-1.03 NS
	B35	325.7	42.2	451.4	329.0	32.9	12	0.30 NS
	B19	59.1	152.2	4.8	13.3	45.3	16	-2.25 *
	B31	95.5	59.1	70.6	73.0	15.6	16	-1.01 NS
Alaria esculenta	B19	2.4	307.8	0.0	4.8	116.3	16	1.17 NS
	B31	75.2	115.8	46.0	63.5	68.5	16	0.31 NS
Agarum clathratum	B19	786.6	34.6	855.2	694.9	19.4	16	-1.23 NS
	B31	366.4	37.0	885.8	425.5	72.2	16	-0.51 NS
UNDERSTORY (% FREQUENCY)								
Chondrus crispus	B17	71.8	7.7	83.0	74.6	10.8	13	1.31 NS
	B35	54.1	16.8	64.3	62.0	16.3	12	1.44 NS
	B19	4.2	116.0	1.3	5.3	90.4	13	0.63 NS
	B31	21.0	42.2	14.3	22.1	29.4	13	0.85 NS
Phyllophora sp.	B17	20.3	36.7	17.0	21.3	36.7	13	-0.54 NS
	B35	19.9	52.2	23.7	27.2	44.1	12	0.59 NS
	B19	34.0	21.3	21.7	32.9	27.7	13	-1.00 NS
	B31	31.8	25.5	26.7	26.5	26.0	13	-1.47 NS
Ptilota serrata	B17	0.8	126.9	0.0	0.9	138.7	13	-0.18 NS
	B35	0.6	122.5	0.7	0.6	70.1	12	0.26 NS
	B19	35.6	25.5	55.7	41.3	31.1	13	0.23 NS
	B31	13.1	37.8	30.7	14.3	78.1	13	-0.85 NS

[a]All taxa collected on non-destructive subtidal transects in April, July, and October.
[b]Mean of annual means. Preop years for kelps - Stations B19, B31: 1978-1989; Station B17: 1979-1989; Station B35: 1982-1989. For understory species-Stations B17, B19, B31: 1981-1989; Station 35: 1982-1989.
[c]1991-1994.
[d]n=number of years, both periods combined.
[e]Wilcoxon's test: NS = not significant (p>0.05); * = significant (0.05≥p>0.01); ** = highly significant (0.01≥p>0.001); *** = very highly significant (p≤0.001).

(stations B19 and B31), *Phyllophora* spp. and *Ptilota serrata* were dominant. *Phyllophora* spp. was dominant at B31 during the preoperational (32%) and operational periods (27%), although *Ptilota serrata* was dominant in 1994 (31%; Table 6-6). *Ptilota serrata* was dominant at B19 during all periods (36-56%).

Relationships in patterns of occurrence of understory taxa between depth zones and between nearfield-farfield stations have remained remarkably consistent over the study period; operational means were not significantly different from preoperational means for all species, at all stations (Table 6-6). These consistent patterns of occurrence are likely due to the perennial habit of each of these species (Taylor 1957), which allows populations to maintain dominance once established.

Intertidal Communities (Non-Destructive Monitoring Program)

Macroalgal species abundance patterns on intertidal rock surfaces exhibit striking patterns of zonation, which result from factors directly and indirectly related to tidal water movement (Lewis 1964; Chapman 1973; Menge 1976; Lubchenco 1980; Underwood and Denley 1984). To effectively monitor macroalgal species abundance in the intertidal zone and characterize these zonation patterns at each site over time, permanently marked quadrats were established at three tide levels and sampled three times annually at nearfield and farfield sites.

Physical stress (e.g., desiccation, temperature extremes) resulting from long exposure times is an important structuring mechanism on macroalgae in the high intertidal zone (Lewis 1964; Schonbeck and Norton 1978). Other factors related to biological processes, such as grazing pressure (Cubit 1984; Keser and Larson 1984) and recruitment (Underwood and Denley 1984; Gaines and Roughgarden 1985; Menge 1991), can also be seasonally important.

At Seabrook intertidal study sites, much of the high intertidal zone, denoted as Bare Ledge, consists of bare rock with seasonal and perennial populations of fucoids (*Fucus* spp. and *Ascophyllum nodosum*), and seasonally abundant ephemeral green algal turfs (mostly an association of *Urospora penicilliformis* and *Ulothrix flacca*). Fucoids were absent from sampling quadrats at nearfield station B1 in April and July during much of the operational period; however, heavy sets of *Fucus* spp. germlings often occurred after that time, resulting in high frequency of occurrence (median value of 44%) of young fucoids by December (Table 6-7). This annual cycle of fucoid abundances has been observed consistently over the operational period (NAI 1992, 1993; NAI and NUS 1994), and has also been noted during some preoperational years.

In general, fluctuations in fucoid abundances at B1 have been high during the preoperational and operational periods, and likely reflect variability in recruitment and the conditions for new recruit survival characteristic of the high intertidal (Keser and Larson 1984; NUSCO 1992). This variability is apparent in the frequency of occurrence of fucoids in 1994, when they occupied relatively large proportions of the quadrats in April and July (69 and 75%, respectively), but were absent in December. Frequency of occurrence of fucoids in the high intertidal at farfield station B5 has historically (including 1994) been higher than that at B1 (often at levels of 90% or more; Table 6-7), with populations there often persisting year round, as in 1994.

The ephemeral green algal association of *Urospora penicilliformis*/*Ulothrix flacca* exhibited a consistent annual cycle of abundance at both nearfield and farfield stations, occurring only during the April sampling period in most years in both the preoperational and operational periods. These species did not occur in any month in 1994, however, a situation which has occurred in previous years. Conditions for establishment and growth of these species on high intertidal surfaces are most favorable in late winter and early

TABLE 6-7. PERCENT COVER AND PERCENT FREQUENCY OF OCCURRENCE OF DOMINANT PERENNIAL AND ANNUAL MACROALGAL SPECIES AT FIXED INTERTIDAL NON-DESTRUCTIVE SITES DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

ZONE[a] TAXA	DATA TYPE[b] (%)	STATION	PERIOD/ YEAR[c]	APR	JUL	DEC
Bare Ledge						
Fucoid species[d]	Frequency	Nearfield (B1)	Preoperational	6	19	6
			(range)	(0-81)	(0-94)	(0-94)
			Operational	0	0	44
			(range)	(0-69)	(0-75)	(0-81)
			1994	69	75	0
		Farfield (B5)	Preoperational	82	97	100
			(range)	(0-100)	(12-100)	(0-100)
			Operational	94	91	91
			(range)	(94)	(81-100)	(69-100)
			1994	94	100	69
Urospora penicilliformis/ Ulothrix flacca	Frequency	Nearfield (B1)	Preoperational	45	0	0
			(range)	(0-99)	(0)	(0)
			Operational	39	0	0
			(range)	(0-55)	(0)	(0)
			1994	0	0	0
		Farfield (B5)	Preoperational	73	0	0
			(range)	(0-100)	(0)	(0)
			Operational	22	0	0
			(range)	(0-82)	(0)	(0)
			1994	0	0	0
Fucoid Ledge						
Fucoid species	Cover	Nearfield (B1)	Preoperational	93	93	68
			(range)	(25-98)	(60-100)	(25-95)
			Operational	86	89	60
			(range)	(45-95)	(34-98)	(40-60)
			1994	80	100	40
		Farfield (B5)	Preoperational	94	94	93
			(range)	(60-98)	(65-100)	(2-98)
			Operational	71	86	98
			(range)	(71-80)	(80-85)	(85-100)
			1994	71	80	95
Fucoid species	Frequency	Nearfield (B1)	Preoperational	94	88	88
			(range)	(69-100)	(75-100)	(69-94)
			Operational	87	91	72
			(range)	(38-100)	(75-100)	(56-100)
			1994	100	100	56
		Farfield (B5)	Preoperational	85	85	91
			(range)	(62-100)	(69-100)	(31-100)
			Operational	84	82	72
			(range)	(75-94)	(62-100)	(0-88)
			1994	94	62	63

(Continued)

TABLE 6-7. (CONTINUED)

ZONE TAXA	DATA TYPE (%)	STATION	PERIOD/ YEAR	APR	JUL	DEC
Chondrus Zone						
Chondrus crispus	Frequency	Nearfield (B1)	Preoperational	45	34	45
			(range)	(20-53)	(20-38)	(28-53)
			Operational	34	15	38
			(range)	(17-57)	(3-26)	(25-43)
			1994	32	21	38
		Farfield (B5)	Preoperational	45	48	41
			(range)	(0-72)	(41-55)	(39-48)
			Operational	37	46	50
			(range)	(19-58)	(15-65)	(39-59)
			1994	19	31	59
Mastocarpus stellatus	Frequency	Nearfield (B1)	Preoperational	47	66	48
			(range)	(21-69)	(65-71)	(32-67)
			Operational	34	49	41
			(range)	(31-47)	(16-69)	(31-51)
			1994	31	55	51
		Farfield (B5)	Preoperational	47	51	44
			(range)	(0-53)	(41-63)	(43-56)
			Operational	43	39	35
			(range)	(23-49)	(22-63)	(24-46)
			1994	23	22	24
Corallina officinalis	Frequency	Nearfield (B1)	Preoperational	0	0	0
			(range)	(0)	(0)	(0)
			Operational	0	0	0
			(range)	(0)	(0)	(0)
			1994	0	0	0
		Farfield (B5)	Preoperational	30	52	52
			(range)	(15-57)	(33-61)	(31-65)
			Operational	52	59	56
			(range)	(49-66)	(55-68)	(45-69)
			1994	49	58	46

[a]Bare Ledge: approximately mean high water. Fucoid ledge: approximately mean sea level. *Chondrus* Zone: approximately mean low water.
[b]Data Type (%): Frequency - percentage of occurrence based on point contact line sampling.
Cover - percentage of substratum coverage based on fixed quadrats of 0.25 m^2.
[c]Preoperational: 1982-1989 median and range; Operational: 1991-1994 median; 1994: annual mean.
[d]Includes all *Fucus* species and *Ascophyllum nodosum*.

spring. Both physical stress (related to temperature extremes and desiccation) and snail grazing pressure (e.g., by *Littorina littorea* and *L. saxatilis*; Keser and Larson 1984) are least intense during this period (Cubit 1984). Their absence in 1994 may have been due to an unusually warm winter, which may have caused them to bloom earlier and therefore be missed during established sampling periods.

A distinct horizontal band of fuciods delineates the mid-intertidal zone (Fucoid Ledge) at Seabrook study sites. Habitat conditions for these species are ideal in the mid-intertidal, as longer immersion time results in a longer period for zygospore settlement (cf. Underwood and Denley 1984), and reduces physical stress compared to that in the high intertidal; new recruits are able to grow rapidly in this zone and develop physical and chemical defenses against grazing (Geiselman and McConnell 1981; Lubchenco 1983). Fucoids were dominant in mid-intertidal quadrats at both nearfield and farfield stations over the preoperational period and much of the operational period, both in terms of percentage of substatum cover and percent frequency of occurrence (Table 6-7). Percent cover was similar between the nearfield and farfield stations during the preoperational period, except in December when percent cover was lower at the nearfield station. Median percent cover was slightly reduced between the preoperational and operational periods in all months at each station, except in December at the farfield station. Percent frequency of occurrence at nearfield and farfield stations was similar during both the preoperational and operational periods.

The low intertidal or *Chondrus* zone was typically dominated by perennial red algal turfs composed of *Chondrus crispus* and *Mastocarpus stellatus*, which, once established, competitively exclude other algae such as fucoids (Lubchenco 1980). Preoperational median percent frequencies of occurrence of *C. crispus* were similar among the three months and between both stations, ranging from 34-48% (Table 6-7). Operational medians were lower than preoperational medians at both stations in each month, except in December at B5. Operational medians at B5 were higher than those at B1 during each of the three months sampled. Median percent frequency of occurrence of *C. crispus* at nearfield station B1 during each of the three sample periods in 1994 was lower than during the preoperational period, although values were within preoperational ranges and followed a similar seasonal pattern. The operational median for July (15%) was well below the preoperational median (34%). Median percent frequencies of *C. crispus* at farfield station B5 in 1994 were substantially lower than during the preoperational period during April and July, but in December the 1994 median was higher than the preoperational median (Table 6-7).

Percent frequencies of occurrence of *Mastocarpus stellatus* in 1994, and medians for all operational years, were generally slightly lower compared to preoperational medians at Station B1 during each month, particularly in July. The one exception occurred in December 1994, when the percent frequency was higher than the preoperational median. Percent frequencies of *M. stellatus* at Station B5 in 1994 were roughly 50% lower than preoperational medians during all three months, and were the lowest recorded during the operational period. Operational medians were lower than the minimum preoperational values in July and December, but were within the range of preoperational values in April.

The coralline red alga *Corallina officinalis* can be a locally abundant understory species in the low intertidal zone. Percent frequency of occurrence of this species generally exceeded 30% in all seasons at farfield station B5 throughout preoperational and operational years, but was absent from the nearfield (B1) area throughout our studies (Table 6-7).

Additional monitoring of fucoid abundance was carried out in the mid-intertidal zone at B1 and B5 using fixed-line transects located at mean sea level. *Ascophyllum nodosum* was a consistently dominant taxon at both study sites over all years, but particularly in recent years. Mean percent frequencies of occurrence of *A. nodosum* during 1994 and the operational period were comparable at both nearfield and farfield sites, ranging from 36% to 39% (Table 6-8). Mean percent frequency of occurrence at B1 was significantly higher during the operational period than during the preoperational period, whereas the period means at B5 were not significantly different. A concomitant significant decrease in abundance of *Fucus vesiculosus* was observed at B1 between preoperational and operational years, where mean percent frequency levels decreased from 47% to 2%. No significant difference was detected at B5 for this species. *Fucus distichus* subsp. *edentatus* was a persistent component of the rockweed community at both stations, generally at lower abundance levels than the fucoids discussed above, during both periods (i.e., no significant between-period differences were detected). Preoperational-operational differences in abundance were identified at both B1 and B5 for *Fucus distichus* subsp. *distichus*, which did not occur at either study site during preoperational years, but established small populations at both sites during the operational period. These populations persisted through 1994 at B1 (although at less than 1% frequency) and through 1993 at B5 (Table 6-8; NAI and NUS 1994). Significantly higher frequencies of occurrence of juvenile *Fucus* spp. were detected at both stations during the operational period compared to the preoperational period. Juvenile *Fucus* spp. generally occurred infrequently during the preoperational and operational periods, with the exception of 1994 when mean percent frequency of occurrence at B1 was 44% (Table 6-8).

6.3.1.2 Selected Species

Chondrus crispus

Low intertidal and shallow subtidal horizontal rock surfaces in the vicinity of the Seabrook intake and discharge support dense stands of the red alga *Chondrus crispus*. As discussed in the previous section, the tough perennial habit of this species allows extensive populations to continue to dominate suitable rock surfaces to the exclusion of most other species. Similar, nearly monospecific turfs of *C. crispus* are common throughout the North Atlantic (Mathieson and Prince 1973), from New Jersey to southern Labrador (Taylor 1957). Owing to its predominance in the Seabrook area, *C. crispus* was selected for further, more detailed analyses. *C. crispus* biomass (g/m^2) at Seabrook study sites was typically highest at the intertidal sites, at times approaching, and in 1994 exceeding, 1000 g/m^2 (Table 6-2). During 1994, mean biomass at nearfield station B1 was higher than at farfield station B5, as has typically been observed in the past. There were no significant between period or between station differences, and no significant Preop-Op X Station interaction for the intertidal sites (Table 6-9).

Substantial, although somewhat smaller, amounts of *C. crispus* were found at shallow subtidal stations, with biomass levels often exceeding 400 g/m^2. Biomass at nearfield station B17 was higher than at the corresponding farfield station B35 in 1994; this relationship between stations was consistent with what was observed during both preoperational and operational periods (Table 6-2). Consequently, no significant between-period or between station differences, and no significant Preop-Op X Station interaction was detected for *C. crispus* biomass in the shallow subtidal zone (Table 6-9).

6.3.2 Marine Macrofauna

6.3.2.1 Horizontal Ledge Communities

Number of Taxa and Total Density

Many attached and slow-moving invertebrate species comprise the marine macrofaunal community on local intertidal and subtidal rock surfaces. Macrofaunal community parameters similar to those used for

TABLE 6-8. PREOPERATIONAL AND OPERATIONAL MEANS AND COEFFICIENTS OF VARIATION (CV,%), 1994 MEANS, AND RESULTS OF WILCOXON'S SUMMED RANKS TEST COMPARING PERCENT FREQUENCY OF OCCURRENCE OF FUCOID ALGAE AT TWO FIXED TRANSECT (NON-DESTRUCTIVE) SITES IN THE MEAN SEA LEVEL ZONE BETWEEN THE PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL[a]		1994	OPERATIONAL[b]			
TAXON	STATION	MEAN	CV	MEAN	MEAN	CV	n	Z[c]
Ascophyllum nodosum	B1	32.0	18.8	35.7	39.0	7.4	11	1.99 *
	B5	41.2	21.3	34.3	36.3	9.0	11	-1.04 NS
Fucus vesiculosus	B1	47.4	49.4	4.0	2.3	60.9	11	-2.55 *
	B5	27.0	38.9	16.7	15.8	21.0	11	-1.61 NS
Fucus distichus	B1	16.2	67.9	20.3	18.9	20.3	11	1.04 NS
subsp. *edentatus*[d]	B5	3.6	264.6	9.3	6.5	117.4	11	1.42 NS
Fucus distichus	B1	0.0	-	0.7	5.8	147.5	11	2.96 **
subsp. *distichus*	B5	0.0	-	0.0	3.4	88.8	11	2.40 *
Fucus spp.	B1	7.6	148.9	43.7	28.8	41.9	11	1.99 *
(juveniles)	B5	0.6	264.6	11.7	8.7	47.1	11	2.58 *

[a]Mean of annual means, 1983-1989.
[b]1991-1994.
[c]Wilcoxon's test: NS = not significant (p>0.05);
* = significant (0.05≥p>0.01);
** = highly significant (0.01≥p>0.001);
*** = very highly significant (0.001≥p).
[d]Recently revised, and to be included under *F. distichus* subsp. *evanescens*

TABLE 6-9. ANALYSIS OF VARIANCE RESULTS FOR *CHONDRUS CRISPUS* BIOMASS (g/m^2) AT INTERTIDAL AND SHALLOW SUBTIDAL STATION PAIRS FOR THE PREOPERATIONAL (1982 - 1989) AND OPERATIONAL (1991 - 1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

TAXON	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[g]		MULTIPLE COMPARISON OF ADJUSTED MEANS[h] (Ranked in decreasing order)
Chondrus crispus	Intertidal[h] (B1, B5)	Preop-Op[a]	1	101,352	0.26	NS	
		Year (Preop-Op)[b]	10	559,223	0.68	NS	
		Month (Year)[c]	24	692,326	7.39	***	
		Station[d]	1	5,114,901	118.27	NS	
		Preop-Op X Station[e]	1	49,724	0.20	NS	
		Station X Year (Preop-Op)[f]	10	235,936	2.52		
		Error	272	93,640			
	Shallow Subtidal[j] (B17, B35)	Preop-Op	1	12.18	0.13	NS	
		Year (Preop-Op)	10	120.89	0.54	NS	
		Month (Year)	24	234.53	5.57	***	
		Station	1	1,156.68	18,259.00	NS	
		Preop-Op X Station	1	0.86	0.02	NS	
		Station X Year (Preop-Op)	10	35.61	0.85	NS	
		Error	272	42.08			

[a]Preop-Op compares 1982 - 1989 to 1991-1994 regardless of station. The years selected are those during which each station within each pairing were sampled.
[b]Year nested within preoperational and operational periods regardless of station.
[c]Month (May, August, November) nested within year regardless of year, station or period.
[d]Station pairs nested within a depth zone: intertidal = B1MLW, B5MLW; shallow subtidal = B17, B35, regardless of year or period.
[e]Interaction of the two main effects, Preop-Op and Station.
[f]Interaction between station and year nested within preoperational and operational periods.
[g]NS = Not significant ($p>0.05$); * = Significant ($0.05\geq p>0.01$); ** = Highly significant ($0.01\geq p\geq 0.001$); *** = Very highly significant ($0.001\geq p$).
[h]The > or < signs indicate a significant difference between two LS means.
[i]Data untransformed.
[j]Data square-root transformed.

macroalgal monitoring (i.e., number of taxa, total density) have consistently been monitored as part of Seabrook studies since 1978, and have proven useful elsewhere for assessing potential ecological impacts from coastal nuclear power plants (Osman et al. 1981; NUSCO 1992, 1994; BECO 1994). Overall species richness, as determined by the mean number of taxa per 0.0625 m^2 quadrat, generally increased with increasing depth, with lowest numbers of taxa at intertidal stations (B1MLW and B5MLW) and highest numbers at mid-depth (B16, B19, and B31) and deep stations (B04, B13, and B34; Table 6-10). In contrast, total faunal density was highest at the intertidal and shallow subtidal stations, with lowest densities observed at the deep subtidal stations.

A greater number of taxa was collected at nearfield intertidal station B1MLW, when compared to farfield Station B5MLW in 1994 (Table 6-10). Throughout the preoperational and operational periods, however, there has been no significant difference in the mean number of taxa collected at these two stations, nor has a significant difference been detected between preoperational and operational period means for the intertidal stations combined (Table 6-11). Furthermore, no significant Preop-Op X Station interaction was detected for this depth zone. Total faunal density at B1MLW was considerably higher than at B5MLW in 1994, consistent with preoperational years (Table 6-10), and reversing the operational period decline observed at the nearfield station (NAI and NUS 1994). High densities in 1994 substantially increased the operational period mean for B1MLW, resulting in no significant differences between the preoperational and operational periods or between stations, and no significant interaction of these main effects (Table 6-11).

Mean numbers of taxa collected at both shallow subtidal stations (B17 and B35) in 1994 were similar to their respective preoperational and operational period means (Table 6-10). No significant differences were detected between period means or station means for the shallow subtidal group, and there was no significant Preop-Op X Station interaction. Total faunal density was similar at both shallow subtidal stations in 1994 and lower than the preoperational and operational period means for each station (Table 6-10). As with the number of taxa, however, neither station nor period means were significantly different, and there was no significant Preop-Op X Station interaction (Table 6-11).

Similar numbers of taxa were collected at the mid-depth stations (B16, B19, and B31) during the preoperational and operational periods (Table 6-10). Therefore, no significant difference was detected between the means for these periods. A significant station difference over both periods was detected with B31 containing significantly fewer taxa than B16 and B19. The Preop-Op X Station interaction was not significant (Table 6-11). During the preoperational period, mean total density at nearfield Station B16 was 50-60% higher than at nearfield Station B19 and farfield Station B31 (Table 6-10). Similar differences were noted in 1994, when the mean density at B16 was considerably higher (50-70%) than at the other two stations. Over all years (preoperational and operational combined), however, densities among the three stations were not significantly different. Similarly, there were no significant differences between periods nor was there a significant interaction between period and station (Table 6-11).

Preoperational and operational period mean numbers of taxa generally were comparable among the three deep stations (B04, B13 and B34), except for the larger operational period mean at B04. This was due, at least in part, to the great number of taxa collected there in 1994 (Table 6-10). However, no significant differences between period means or among station means were detected, and the Preop-Op X Station interaction term was not significant (Table 6-11). Total faunal densities were similar among the three stations in the preoperational period (Table 6-10). However, the operational period density at intake station B13 was considerably higher than the preoperational and operational period densities at the other two stations. This was in large

TABLE 6-10. PREOPERATIONAL AND OPERATIONAL MEANS (WITH COEFFICIENTS OF VARIATION) AND 1994 MEANS OF THE NUMBER OF TAXA COLLECTED, AND GEOMETRIC MEAN DENSITY FOR NON-COLONIAL MACROFAUNA COLLECTED IN AUGUST AT INTERTIDAL, SHALLOW SUBTIDAL, MID-DEPTH AND DEEP STATIONS. SEABROOK OPERATIONAL REPORT, 1994.

DEPTH ZONE	STATION	PREOPERATIONAL[a]		1994	OPERATIONAL[b]	
		MEAN	CV	MEAN	MEAN	CV
MEAN NO. OF TAXA (per 0.0625 m^2)						
Intertidal	B1MLW	49	18.5	46	39	14.5
	B5MLW	48	16.5	39	42	9.6
Shallow subtidal	B17	58	11.4	61	64	3.9
	B35	55	9.0	55	54	9.1
Mid-depth	B16	70	11.8	80	72	9.9
	B19	68	18.3	69	71	12.5
	B31	51	16.5	61	55	21.7
Deep	B04	63	13.8	102	74	21.7
	B13	54	13.9	64	57	22.5
	B34	64	22.0	83	64	18.5
TOTAL DENSITY (#/m^2)						
Intertidal	B1MLW	122795	5.3	185715	102093	6.4
	B5MLW	68684	5.1	71271	88893	4.1
Shallow subtidal	B17	23373	4.6	21915	28983	3.4
	B35	28372	4.6	16956	33725	6.9
Mid-depth	B16	31590	5.9	38378	18902	7.5
	B19	12785	6.7	12364	15795	6.4
	B31	16240	11.4	19110	15642	4.8
Deep	B04	4936	5.7	26127	6144	9.5
	B13	6073	10.5	68243	17907	9.8
	B34	5523	9.3	23600	6963	8.5

[a]Preoperational period extends through 1989 (Stations B1MLW, B17, B19, B31: 1978-1989; Stations B5MLW, B35: 1982-1989; Station B16: 1980-1984, 1986-1989; Stations B13, B04: 1978-1984, 1986-1989; Station B34: 1979-1984,1986-1989).
[b]Operational period: 1990-1994.

TABLE 6-11. ANALYSIS OF VARIANCE RESULTS FOR NUMBER OF TAXA (per 0.0625 m^2) AND TOTAL DENSITY (per m^2 OF MACROFAUNA COLLECTED IN AUGUST AT INTERTIDAL (1982-1994), SHALLOW (1982-1994), MID-DEPTH (1980-1984; 1986-1994), AN DEEP SUBTIDAL STATIONS (1979-1984; 1986-1994). SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISONS[g] (Ranked in decreasing order)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	1	2626.87	3.62 NS	
		Station[b]	1	4.52	0.02 NS	
		Year (Preop-Op)[c]	11	564.83	8.84 **	
		Preop-Op X Station[d]	1	221.39	3.46 NS	
		Year X Station (Preop-Op)[e]	11	63.91	0.97 NS	
		Error	100	66.01		
	Shallow Subtidal (B17, B35)	Preop-Op	1	260.77	0.55 NS	
		Station	1	1125.70	3.34 NS	
		Year (Preop-Op)	11	220.31	2.83 *	
		Preop-Op X Station	1	333.09	4.28 NS	
		Year X Station (Preop-Op)	11	77.83	0.93 NS	
		Error	100	83.46		
	Mid-depth (B16, B19, B31)	Preop-Op	1	584.33	0.83 NS	
		Station	2	7375.01	192.55 *	B16 B19 B31
		Year (Preop-Op)	12	910.40	3.58 **	
		Preop-Op X Station	2	43.03	0.16 NS	
		Year X Station (Preop-Op)	24	254.20	2.48 **	
		Error	167	102.51		
	Deep (B04, B34, B13)	Preop-Op	1	763.10	0.50 NS	
		Station	2	3043.46	7.50 NS	
		Year (Preop-Op)	13	1392.27	5.00 **	
		Preop-Op X Station	2	402.04	1.44 NS	
		Year X Station (Preop-Op)	26	278.41	2.39 **	
		Error	180	116.33		

(Continued)

TABLE 6-11. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[f]	MULTIPLE COMPARISONS[g] (Ranked indecreasing order)
Total Density	Intertidal (B1MLW, B5MLW)	Preop-Op	1	0.02	0.03 NS	
		Station	1	0.70	2.95 NS	
		Year (Preop-Op)	11	0.57	2.81 NS	
		Preop-Op X Station	1	0.24	1.17 NS	
		Year X Station (Preop-Op)	11	0.20	5.54 **	
		Error	100	0.04		
	Shallow Subtidal (B17, B35)	Preop-Op	1	0.25	0.77 NS	
		Station	1	0.20	32.05 NS	
		Year (Preop-Op)	11	0.41	4.24 *	
		Preop-Op X Station	1	0.01	0.08 NS	
		Year X Station (Preop-Op)	11	0.10	2.04 *	
		Error	100	0.05		
	Mid-depth (B16, B19, B31)	Preop-Op	1	0.12	0.14 NS	
		Station	2	1.01	2.79 NS	
		Year (Preop-Op)	12	0.72	2.93 *	
		Preop-Op X Station	2	0.36	1.46 NS	
		Year X Station (Preop-Op)	24	0.28	3.31 **	
		Error	167	0.07		
	Deep (B04, B34, B13)	Preop-Op	1	2.20	1.46 NS	
		Station	2	1.64	2.62 NS	
		Year (Preop-Op)	13	1.18	4.06 **	
		Preop-Op X Station	2	0.61	2.12 NS	
		Year X Station (Preop-Op)	26	0.29	4.45 **	
		Error	180	0.07		

[a]Preop-Op compares preoperational to operational period regardless of station.
[b]Nearfield = Stations B1MLW, B17, B16, B04, B13; farfield = Stations B5MLW, B35, B31, B34, regardless of year/period.
[c]Year nested within Preoperational and Operational periods regardless of Station.
[d]Interaction of the two main effects, Preop-Op and Station.
[e]Interaction of Station and Year nested within Preoperational and Operational period.
[f]NS = not significant ($p>0.05$); * = significant ($0.05 \geq p > 0.01$); ** = Highly significant ($0.01 \geq p > 0.001$); *** = Very highly significant ($p \leq 0.001$).
[g]Underlining indicates that t-tests showed no significant differences ($\alpha \leq 0.05$) among the underlined least squares means.

part due to an unusually heavy set of barnacles in 1994 (Cirripedia, 31,907/m^3; NAI 1995). ANOVA results indicated no significant differences between preoperational and operational means, among station means, and no significant Preop-Op X Station interaction.

Macrofaunal Community Analysis

The noncolonial macrofauna associated with hard substrata in the vicinity of Seabrook Station comprise a rich and diverse community. Over 400 taxa have been collected in August destructive samples since 1978, some with densities of over 100,000 individuals/m^2. Very few of these animals are "habitat formers" (cf. macroalgal section), and most are motile. Therefore, the faunal species assemblages are not as distinct as those of the algae. However, multivariate macrofaunal community analyses, similar to those performed on macroalgae, facilitate the separation of annual collections at each station into groupings based on Bray-Curtis similarity indices, as well as the determination of within- and between-group relationships. These analyses were applied to log-transformed macrofaunal geometric mean density data for those taxa (94 total) appearing in 50 or more sample replicates over the entire study period. The groupings of the 155 station/year collections are illustrated in Figure 6-5.

As with the macroalgal collections (Figure 6-4), the macrofaunal assemblage at intertidal stations (B1MLW and B5MLW) comprised a distinct entity (Group 1; Figure 6-5), characterized by extremely high densities of mytilid spat (ca. 70,000 individuals/m^2; Table 6-12). These mussels accounted for about 65-70% of the individuals collected at the intertidal sites during the preoperational and operational periods. The isopod *Jaera marina*, gastropods *Lacuna vincta* and *Nucella lapillus*, bivalves *Turtonia minuta* and *Hiatella* sp., oligochaetes, and the amphipod *Gammarus oceanicus* also were commonly found intertidally, but at much lower densities. None of these taxa accounted for more than about 5% of the individuals collected. In addition to the high densities of Mytilidae, and the presence of the primarily intertidal species *Jaera marina*, *Nucella lapillus* and *Turtonia minuta*, this group separated from other groups because of very low densities of strictly subtidal species, such as the gammaridean amphipod *Pontogeneia inermis*, which was much more abundant at subtidal stations.

Collections from the shallow subtidal stations (B17 and B35) made up a second discrete assemblage, Group 2. (Figure 6-5 and Table 6-12). *Lacuna vincta* was the most abundant species at the shallow subtidal stations in terms of number of individuals (ca. 5,000/m^2), and became more abundant in the operational period. This small herbivorous snail is a dominant grazer on the kelp *Laminaria saccharina*, and also feeds on many other attached and drift algae. Since the food resource is quite patchy, the abundance of *L. vincta* also is variable. Mytilidae were dominants at these stations (ca. 4,000-5,000/m^2), but mussel densities were more than an order of magnitude lower than at the intertidal stations. Other species abundant at the shallow subtidal stations (isopods *Idotea phosphorea* and *I. balthica*, gammaridean amphipods *Pontogeneia inermis* and *Jassa marmorata*) exhibited very consistent densities between preoperational and operational periods (Table 6-12).

Group 3 included all collections from mid-depth intake station B16, and nearly all collections from mid-depth discharge station B19, mid-depth farfield station B31, and "recent" (1986, 1987, and 1989-94) collections from deep nearfield station B13 (Table 6-12). As reported earlier, subtidal zonation becomes less distinct with increasing depth, and as the macroalgae (and associated epifauna) become increasingly patchy, assemblages exhibit lower similarity, overlapping among stations and depths. Preoperational and operational period means for the dominant taxa were quite similar, with considerable overlap in the 95% confidence intervals of both periods. Mytilids were dominant in Group 3, but *Lacuna vincta*, which was dominant in Group 2, was present at much lower densities.

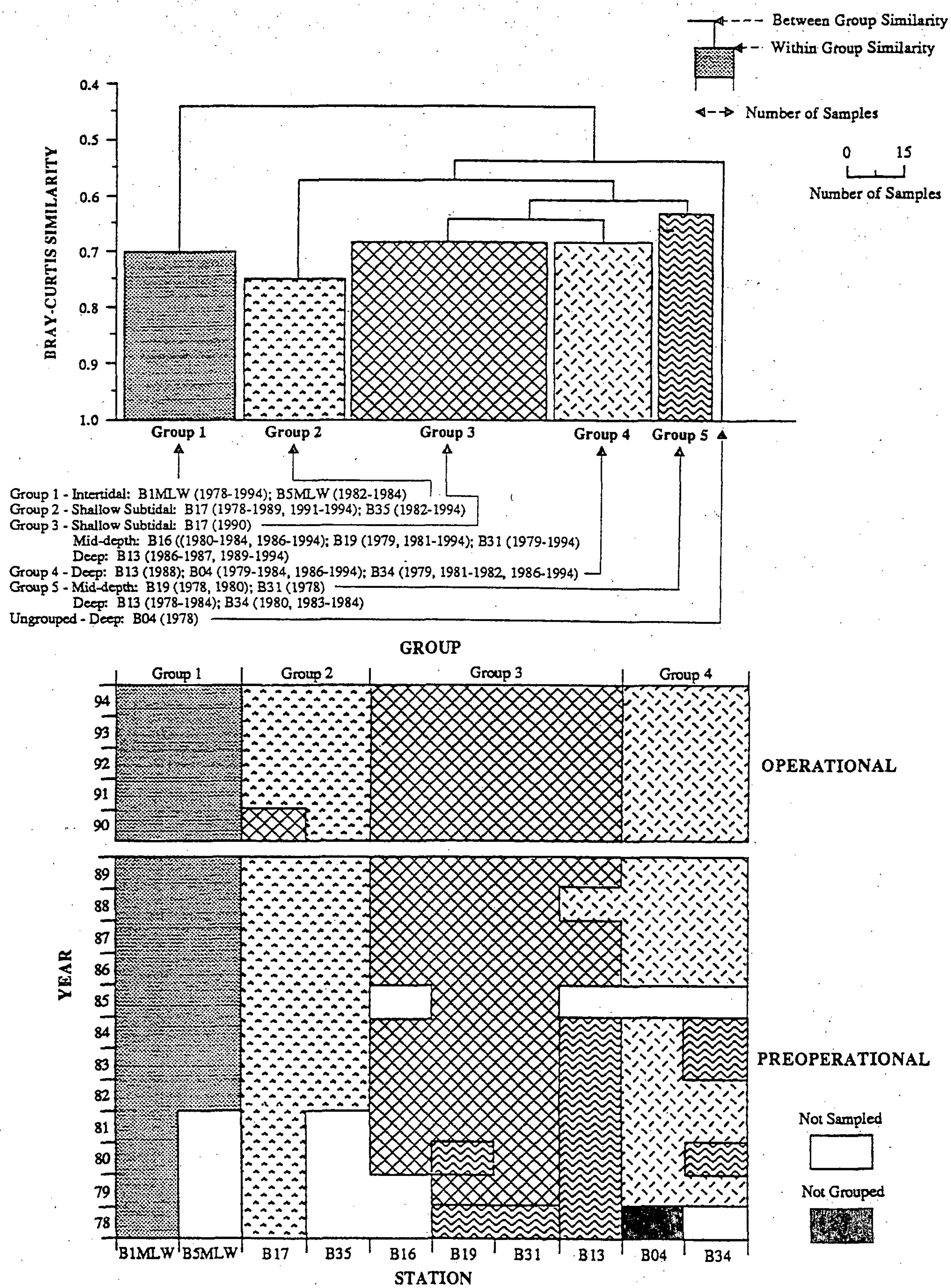


Figure 6-5. Dendrogram and station groups by year formed by numerical classification of August collections of marine macrofauna, 1978-1994. Seabrook Operational Report, 1994.

TABLE 6-12. STATION GROUPS FORMED BY CLUSTER ANALYSIS WITH PREOPERATIONAL AND OPERATIONAL (1990-1994) GEOMETRIC MEAN DENSITY AND 95% CONFIDENCE LIMITS (LOWER, LCL, AND UPPER, UCL) OF DOMINANT MACROFAUNA TAXA (NON-COLONIAL) COLLECTED ANNUALLY IN AUGUST FROM 1978 THROUGH 1994. SEABROOK OPERATIONAL REPORT, 1994.

GROUP NO.	NAME/LOCATION (STATION/YEARS)	SIMILARITY (WITHIN/ BETWEEN GROUP)	DOMINANT TAXA	PREOPERATIONAL			OPERATIONAL		
				LCL	MEAN	UCL	LCL	MEAN	UCL
1	Intertidal	0.70/0.43	Mytilidae	47977	69205	99824	42733	70595	116623
	Nearfield (BIMLW; 1978-94)		*Jaera marina*	2116	3626	6216	712	1177	1946
	Farfield (B5MLW; 1982-94)		*Lacuna vincta*	2035	3209	5060	2964	4620	7202
			Turtonia minuta	1367	2707	5360	795	1709	3675
			Hiatella sp.	1464	2604	4631	338	782	1808
			Oligochaeta	1203	2030	3423	287	923	2958
			Nucella lapillus	925	1501	2432	745	1637	3596
			Gammarus oceanicus	241	564	1319	1004	1962	3833
2	Shallow Subtidal	0.75/0.57	*Lacuna vincta*	3761	5379	7694	6386	9167	13159
	Nearfield (B17; 1978-89, 1991-94)		Mytilidae	2905	4758	7793	1399	4565	14890
	Farfield (B35; 1982-94)		*Idotea phosphorea*	1695	2166	2768	1520	2047	2757
			Pontogeneia inermis	1248	1773	2518	940	1774	3347
			Jassa marmorata	1097	1572	2254	403	1249	3866
			Idotea balthica	508	890	1559	213	508	1212
3	Mid-Depth	0.69/0.65	Mytilidae	3811	6153	9936	2449	4438	8041
	Intake (B16; 1980-84, 1986-94)		*Pontgeneia inermis*	974	1517	2362	541	929	1597
	Discharge (B19; 1979, 1981-94)		*Caprella septemtrionalis*	667	1016	1546	546	1063	2068
	Farfield (B31; 1979-94)		*Anomia* sp.	620	847	1156	718	907	1147
	Nearfield (B13; 1986, 1987, 1989-1993)		*Hiatella* sp.	534	783	1148	327	570	991
	Deep		*Lacuna vincta*	281	416	617	305	563	1039
	Recent Intake (B13; 1986-1987, 1989-1994)		Asteriidae	183	258	365	180	305	517
4	Deep	0.69/0.63	*Pontogeneia inermis*	198	328	542	106	223	471
	Discharge (B04; 1979-84, 1986-94)		Asteriidae	186	259	362	244	321	421
	Farfield (B34; 1979, 1981, 1982, 1986-94)		*Anomia* sp.	158	256	415	321	599	1114
	Intake (B13; 1989)		*Caprella septemtrionalis*	122	196	316	89	181	368
			Musculus niger	141	196	273	67	111	185
			Tonicella rubra	117	151	196	63	87	120
5	Deep	0.63/0.63	*Pontogeneia inermis*	195	369	699	No Data Applicable		
	Historic Intake (B13; 1978-84)		Mytilidae	130	306	719			
	Farfield (B34; 1980, 1983, 1984)		Asteriidae	140	226	363			
	Mid-depth		*Anomia* sp.	97	208	444			
	Nearfield (B19; 1978 and 1980)		*Hiatella* sp.	98	194	380			
			Tonicella rubra	75	125	210			
			Caprella septemtrionalis	62	124	248			

Group 4 contained nearly all collections from deep discharge stations B04 and deep farfield station B34 (Figure 6-5 and Table 6-12). The assemblage was characterized by low mean densities of the dominant taxa (including *Pontogeneia inermis*, Asteriidae, and *Anomia* sp.) in both preoperational and operational periods ($<600/m^2$). Means and 95% confidence intervals were similar for the dominant taxa in both periods.

The last cluster (Group 5) contained collections from deep "historic" intake station B13 (1978-84), deep farfield station B34 (1980, 1983 and 1984), and mid-depth nearfield station B19 (1978 and 1980; Fig. 6-5 and Table 6-12). No collections from the operational period were present in this cluster. These collections were characterized by low mean densities of the dominant taxa ($<400/m^2$), with only relatively small numbers of Mytilidae present. *Pontogenera inermis*, Asteriidae, *Anomia* sp., and *Hiatella* were also among the dominant taxa.

In general, the assemblages from the operational years (1990-1994) at each station were similar enough to be grouped with the majority if not all of those from preoperational years, indicating that no changes to the macrofaunal community have resulted from operation of Seabrook Station.

Intertidal Communities (Non-Destructive Monitoring Program)

Patterns of faunal abundance on local rocky shores exhibit patterns of zonation similar to those discussed previously for intertidal macroalgae (Lewis 1964; Menge 1976; Underwood and Denley 1984). Common intertidal fauna occurring in non-destructive sampling quadrats included barnacles, mussels, snails and limpets. Spatial (among zones, between stations) and temporal (among seasons, between operational periods) abundance patterns of these species for nearfield and farfield sample stations are described below.

Barnacles (especially *Balanus* spp.) commonly occur on high intertidal (Bare Ledge) rock surfaces in the Seabrook area and throughout the North Atlantic (Connell 1961; Menge 1976; Grant 1977; Bertness 1989). Although generally common, intertidal barnacle populations typically exhibit high seasonal and year-to-year variability (Menge 1991; Minchinton and Sheibling 1991; NUSCO 1994); similar temporal variability in barnacle frequency of occurrence has been observed in Seabrook study quadrats (Table 6-13). At both the nearfield and farfield stations, barnacle abundances (based on percent-frequency of occurrence estimates) were lower in April than in July in the operational period, indicating suitable conditions for barnacle settlement and growth during this interval. Because year-to-year variability is so high, between period and within station comparisons are best made by examining ranges of annual frequencies. Taking this approach, operational ranges (both monthly and averages for all seasons), although smaller, fall within preoperational ranges with one exception (B1 in July), indicating overall stability of barnacle populations at both stations. The herbivorous snail, *Littorina saxatilis*, is an important grazer in the high intertidal zone. Abundance of *L. saxatilis* in the high intertidal zone was generally lowest in early spring (April; Table 6-13), providing a temporal refuge for ephemeral algae (see Table 6-7). As with high intertidal barnacles, considerable overlap of preoperational and operational ranges of monthly and all-seasons estimates of *L. saxatilis* abundance were noted for both nearfield and farfield stations.

The dominant faunal taxon in the mid-intertidal (Fucoid) zone has been Mytilidae (primarily the blue mussel *Mytilus edulis*), which dominates certain rocky shores in New England (Lubchenco and Menge 1978; Petraitis 1991) and elsewhere in the North Atlantic (Seed 1976). Mytilidae were most abundant at the nearfield station (B1), with median percent-frequencies (both preoperational and operational) exceeding 40% for all sampling periods (Table 6-13); somewhat lower abundances were observed at this station in 1994. The preoperational and operational seasonal median

TABLE 6-13. MEDIAN PERCENT FREQUENCY OF OCCURRENCE BY SEASON AND OVER ALL SEASONS OF THE DOMINANT FAUNA WITHIN PERMANENT 0.25 m^2 QUADRATS AT THE UPPER (BARE ROCK), MID- (FUCCOID ZONE), AND LOWER (*CHONDRUS ZONE*) INTERTIDAL ZONES AT NEARFIELD (OUTER SUNK ROCKS) AND FARFIELD (RYE LEDGE) STATIONS DURING THE PREOPERATIONAL AND OPERATIONAL (1991-1994) PERIODS, AND MEAN PERCENT FREQUENCY OF OCCURRENCE DURING 1994. SEABROOK OPERATIONAL REPORT, 1994.

ZONE[a] TAXON	STATION	PERIOD/ YEAR[b]	APR	JUL	DEC	ALL SEASONS[c]
Bare Ledge	Nearfield	Preoperational	61	51	9	40
Balanus spp.	(B1)	(range)	(4-100)	(9-88)	(0-88)	(0-100)
		Operational	43	63	61	47
		(range)	(41-51)	(46-98)	(2-81)	(2-98)
		1994	45	46	2	31
	Farfield	Preoperational	89	85	72	82
	(B5)	(range)	(58-100)	(24-100)	(5-100)	(5-100)
		Operational	58	64	31	52
		(range)	(36-95)	(43-67)	(3-54)	(3-95)
		1994	46	43	3	31
Littorina saxatilis	Nearfield	Preoperational	7	57	16	27
	(B1)	(range)	(0-44)	(0-88)	(0-88)	(0-88)
		Operational	44	88	63	66
		(range)	(25-56)	(81-100)	(0-100)	(0-100)
		1994	56	94	50	66
	Farfield	Preoperational	50	66	75	64
	(B5)	(range)	(0-100)	(38-94)	(0-100)	(0-100)
		Operational	28	35	38	28
		(range)	(0-81)	(6-69)	(19-81)	(0-81)
		1994	25	19	25	23
Fucoid Zone	Nearfield	Preoperational	82	76	78	79
Mytilidae	(B1)	(range)	(37-100)	(27-100)	(43-100)	(27-100)
		Operational	56	66	45	45
		(range)	(23-91)	(29-99)	(19-95)	(19-99)
		1994	28	38	37	34
	Farfield	Preoperational	8	1	5	5
	(B5)	(range)	(2-100)	(0-100)	(0-100)	(0-100)
		Operational	7	16	6	10
		(range)	(4-10)	(0-38)	(0-32)	(0-38)
		1994	4	38	32	25
Littorina obtusata	Nearfield	Preoperational	3	10	6	6
	(B1)	(range)	(0-6)	(0-25)	(6-19)	(0-25)
		Operational	6	13	28	9
		(range)	(0-31)	(0-62)	(0-44)	(0-81)
		1994	31	62	81	58
	Farfield	Preoperational	3	16	7	9
	(B5)	(range)	(0-25)	(0-44)	(0-44)	(0-44)
		Operational	9	35	38	28
		(range)	(0-25)	(25-50)	(12-56)	(0-56)
		1994	25	38	38	34

(Continued)

TABLE 6-13. (CONTINUED)

ZONE[a] TAXON	STATION	PERIOD/ YEAR[b]	APR	JUL	DEC	ALL SEASONS[c]
Chondrus Zone	Nearfield	Preoperational	90	89	65	81
Mytilidae	(B1)	(range)	(54-95)	(71-95)	(15-85)	(15-95)
		Operational	72	74	65	70
		(range)	(43-95)	(33-95)	(28-93)	(28-95)
		1994	43	33	28	35
	Farfield	Preoperational	49	63	26	46
	(B5)	(range)	(10-72)	(23-80)	(0-49)	(0-80)
		Operational	22	47	34	34
		(range)	(0-57)	(27-92)	(8-87)	(0-92)
		1994	23	40	19	27
Nucella lapillus	Nearfield	Preoperational	75	100	56	77
	(B1)	(range)	(13-100)	(100)	(31-88)	(13-100)
		Operational	28	100	53	75
		(range)	(19-81)	(94-100)	(19-100)	(19-100)
		1994	31	100	100	77
	Farfield	Preoperational	94	38	69	67
	(B5)	(range)	(75-100)	(13-56)	(56-81)	(13-100)
		Operational	78	72	53	69
		(range)	(37-100)	(37-94)	(19-94)	(19-100)
		1994	62	94	94	83
Littorina littorea	Nearfield	Preoperational	0	0	0	0
	(B1)	(range)	(0)	(0-13)	(0-6)	(0-13)
		Operational	0	13	12	9
		(range)	(0-19)	(0-25)	(0-50)	(0-50)
		1994	0	19	0	6
	Farfield	Preoperational	81	100	88	90
	(B5)	(range)	(75-100)	(94-100)	(44-94)	(44-100)
		Operational	97	100	75	97
		(range)	(81-100)	(100)	(62-94)	(62-100)
		1994	100	100	75	92
Acmaea testudinalis	Nearfield	Preoperational	13	13	13	13
	(B1)	(range)	(6-38)	(0-25)	(6-81)	(0-81)
		Operational	16	12	12	12
		(range)	(0-44)	(6-25)	(0-81)	(0-81)
		1994	44	25	12	27
	Farfield	Preoperational	0	0	0	0
	(B5)	(range)	(0-44)	(0-13)	(0-25)	(0-44)
		Operational	9	9	13	9
		(range)	(6-12)	(0-25)	(0-44)	(0-44)
		1994	6	25	19	17

[a]Bare Ledge station is at upper edge of mean sea level (MSL) zone, approximately mean high water. Fuccoid Zone station is approximately MSL. *Chondrus Zone* station is approximately mean low water.
[b]Preoperational period extends from 1982 - 1989, except for *Chondrus Zone,* where sampling began in April 1985. Operational period extends from 1991 - 1994.
[c]Average of three seasonal medians.

(Continued)

frequencies were all less than 17% at farfield station B5, with considerably higher abundances measured in uly and December 1994. Mussels are typically outcompeted by barnacles at this site (NAI 1993). Operational period ranges generally fell within preoperational period ranges at both stations although operational period medians were lower than preoperational period medians in all sampling periods at nearfield station B1. The herbivorous snail *Littorina obtusata* was a common mid-intertidal resident at both stations throughout the year. Overall, operational frequencies generally have been higher than those during preoperational years, a trend which was apparent at both nearfield and farfield stations (Table 6-13). Frequencies in 1994 were close to or exceeded the maximum values observed during the preoperational period at both stations.

High mussel abundances also were typical of the low intertidal or *Chondrus* zone, with only small differences between nearfield and farfield stations, relative to those in the mid-intertidal (Table 6-13). Frequency of occurrence estimates during 1994 at nearfield station B1 were less than preoperational and operational period medians. At the farfield station (B5), abundances consistent with the operational period were observed in 1994, but these were lower than in preoperational years. As with Station B1 considerable overlap of preoperational and operational ranges was apparent. The carnivorous snail *Nucella lapillus* commonly preys on mussels and barnacles, and can have considerable influence on low intertidal community structure (Connell 1961; Menge 1983, 1991; Petraitis 1991). At Seabrook study sites, *N. lapillus* can be locally abundant, at times reaching frequency of occurrence levels of 100%, particularly in July (Table 6-13). Over the entire study, occurrence of this species has been consistent, both between nearfield and farfield stations and between periods. Of the herbivorous littorine snails occurring in the Gulf of Maine, *Littorina littorea* has the most pronounced effect on intertidal community structure, particularly in the low intertidal zone (Lubchenco 1983; Petraitis 1983). In the Seabrook study area, *L. littorea* was most common at the farfield station (B5), often exceeding 90% frequency of occurrence during both preoperational and operational periods (Table 6-13). Frequencies at the nearfield station (B1) never exceeded 50% during our studies, and many times, *L. littorea* was absent from the study areas. Percent frequencies of *L. littorea* at B1 tended to be lower during the preoperational years (<13%) than during the operational period, when the highest monthly estimates were recorded. Another low intertidal grazer, the limpet *Acmaea testudinalis*, occurred in low to moderate frequencies in most years both at nearfield station B1 and occasionally at farfield station B5 (Table 6-13). Operational period ranges for individual sampling periods were generally similar to preoperational ranges, and within each station, preoperational and operational ranges for all seasons combined were identical (0-81% at B1, 0-44% at B5).

Subtidal Fouling Community (Bottom Panel Monitoring Program)

Recruitment success and annual patterns of settlement for sessile macroinvertebrates were assessed by the bottom panel study using short-term exposure periods (three sequential four-month exposure periods per year). Although the type of substratum, length of exposure period and deployment strategies can all influence the patterns of community colonization (Zobell and Allen 1935; Fuller 1946; Schoener 1974; Osman 1977; Sutherland and Karlson 1977), these factors may be standardized to allow comparisons between nearfield and farfield stations during these different periods of the year (January-April, May-August, and September-December). Four-month exposure periods provide sufficient duration for larval stages to settle, metamorphose, and grow into juveniles or young adults that can be effectively identified. Of the organisms collected on these panels, four taxa (*Balanus, Anomia, Hiatella,* and Mytilidae) have been collected in sufficient frequency and numbers to allow comparisons of long-term trends in densities within and between nearfield

TABLE 6-14. ESTIMATED DENSITY (per 0.25 m^2) AND COEFFICIENT OF VARIATION (CV,%) OF SELECTED SESSILE TAXA ON HARD-SUBSTRATE BOTTOM PANELS EXPOSED FOR FOUR MONTHS AT STATIONS B19 AND B31 SAMPLED TRIANNUALLY (APRIL, AUGUST, DECEMBER) FROM 1981-1994 (EXCEPT 1985). SEABROOK OPERATIONAL REPORT, 1994.

			APRIL		AUGUST		DECEMBER		ALL SEASONS	
TAXA	STATION	PERIOD/YEAR	MEAN	CV[c]	MEAN	CV	MEAN	CV	MEAN	CV
Balanus spp.	Nearfield	Preop[a]	17053	81	6403	78	9	144	7822	110
	(B19)	Op[b]	11179	117	12154	69	763	193	8032	122
		1994	4500	-	22033	-	0	-	8844	-
	Farfield	Preop	40962	55	7917	78	14	121	16298	133
	(B31)	Op	17588	54	12454	51	196	120	10079	96
		1994	11300	-	19233	-	0	-	10178	-
Anomia sp.	Nearfield	Preop	<1	<1	31	219	1232	92	421	167
	(B19)	Op	65	135	68	92	2404	114	846	217
		1994	6	-	34	-	962	-	334	-
	Farfield	Preop	0	0	36	117	993	125	343	164
	(B31)	Op	7	58	106	149	703	88	272	171
		1994	6	-	1	-	1567	-	525	-
Hiatella sp.	Nearfield	Preop	1	200	3966	65	27	115	1331	171
	(B19)	Op	3	106	7203	53	10	114	2405	169
		1994	1	-	12350	-	13	-	4121	-
	Farfield	Preop	<1	<1	11659	91	16	131	3892	173
	(B31)	Op	3	95	14533	67	86	176	4874	180
		1994	1	-	13727	-	1	-	4576	-
Mytilidae	Nearfield	Preop	2	150	367	67	58	98	142	139
	(B19)	Op	78	118	2637	84	45	32	920	187
		1994	44	-	1696	-	26	-	589	-
	Farfield	Preop	8	138	5035	200	36	100	1693	171
	(B31)	Op	19	130	3636	94	56	79	1237	203
		1994	3	-	1091	-	49	-	381	-

[a]Preop: 1981-1984 (*Balanus* and *Anomia*, B19); 1982-1984 (*Balanus* and *Anomia*, B31); 1983-1984 (*Hiatella* and Mytillidae, B19 and B31); Dec. 1986-1989 (all taxa and stations).
[b]Op = 1991-94

and farfield stations for assessing power plant effects (Table 6-14).

Subtidal barnacles in the Seabrook area are represented primarily by two species of *Balanus* (mainly *B. crenatus* and *B. balanus*). Peak settlement usually occurs in early spring, resulting in highest densities in the April exposure period (Table 6-14). However, settlement is protracted and variable from year to year. For example, substantial densities of barnacles were found at both nearfield and farfield stations in August 1994, and in 1993, barnacles recruited to bottom panels during the September-December exposure period (NAI and NUS 1994). Typically, barnacle densities were higher at the farfield station (B31) than at the nearfield station (B19) over both preoperational and operational periods, although this relationship was reversed in August 1994.

Anomia spp. (jingle shells) consistently display peak settlement during the September to December exposure period, a period when water temperatures are rapidly cooling (cf. Fuller 1946). Preoperational densities of these bivalves were similar between the nearfield and farfield stations (Table 6-14). In the operational period, nearfield densities exceeded farfield densities in April and December, while farfield densities exceeded nearfield densities in August. Densities at the farfield station have, on average, remained lower than at the nearfield station during the operational period, with August 1994 an obvious exception. Operational densities at both stations were higher in each month compared to those during the preoperational period, with the exception of December at the farfield station.

Another species of interest is the small crevice-seeking bivalve, *Hiatella*, which historically has settled during the August exposure period at both stations. Settlement has normally been highest at the farfield station in both the preoperational and operational periods, where densities in excess of 10,000 individuals per 0.25 m^2 were commonly reported. Densities at the nearfield station have typically been less than 10,000 per 0.25m^2. In 1994, however, August densities at both stations exceeded 12,000 individuals per 0.25 m^2 (Table 6-14).

Mytilidae (mostly blue mussel, *Mytilus edulis*) are an important component of the local macrofaunal community, and are discussed in more detail in the following section. Recruitment to bottom panels followed a pattern similar to that described for *Hiatella*, i.e., peak recruitment occurred during the August exposure period, with densities typically higher at the farfield station than the nearfield station in both the preoperational and operational periods. At the nearfield station, 1994 densities were consistent with those reported for other operational years, whereas 1994 densities at the farfield station were reduced. A trend for higher densities of mussels on panels during operational years, relative to preoperational years, was observed at the nearfield, but not the farfield station.

6.3.2.2 Selected Benthic Species

Mytilidae

Representatives of the order Mytilidae (mytilids) are common in the North Atlantic, and are typically found attached to intertidal and shallow subtidal rocky substrata, but are occasionally recorded from deeper water (Seed 1976). Important as prey for marine carnivores such as the dogwinkle *Nucella lapillus* in the intertidal zone (Menge 1991; Petraitis 1991), and starfish, lobsters, crabs and fish subtidally (Menge 1979; Witman 1985; Ojeda and Dearborn 1991), mytilid shell surfaces and interstices within mytilid aggregates also provide attachment and habitat areas for many algal and faunal species (Dayton 1971; Seed 1976).

At Seabrook study sites, Mytilidae (primarily the blue mussel *Mytilus edulis*) was, by far, the dominant taxon in terms of density (no./m^2) in the intertidal zone (Stations B1MLW and B5MLW; Table 6-15). Annual mytilid abundances have been variable over the

TABLE 6-15. GEOMETRIC MEAN DENSITIES (NO./M^2) OF SELECTED BENTHIC MACROFAUNA SPECIES WITH COEFFICIENTS OF VARIATION (CV,%) DURING PREOPERATIONAL AND OPERATIONAL PERIODS AND DURING 1994. SEABROOK OPERATIONAL REPORT, 1994.

TAXON	STATION[a]	PREOPERATIONAL[b]		1994	OPERATIONAL[c]	
		MEAN	CV	MEAN	MEAN	CV
Mytilidae	B1MLW	121297	8	71431	83423	10
	B5MLW	72831	7	31923	49702	12
	B17	2580	18	2798	2332	23
	B35	4449	14	2766	6327	22
	B19	1947	23	389	2499	23
	B31	6196	17	5557	5872	9
Nucella lapillus	B1MLW	1970	11	3830	1343	17
	B5MLW	905	10	2467	805	15
Asteriidae						
	B17	590	12	1355	724	11
	B35	184	23	752	161	34
Pontogeneia inermis	B19	604	15	205	541	18
	B31	404	15	265	260	22
Jassa marmorata	B17	1045	14	279	958	17
	B35	1888	15	925	2659	13
Ampithoe rubricata	B1MLW	19	92	15	2	98
	B5MLW	3	125	101	132	12
Strongylocentrotus droebachiensis	B19	66	36	305	100	30
	B31	31	35	132	44	34
Modiolus modiolus[d]	B19	100	14	49	71	23
	B31	89	27	140	86	43

[a]Nearfield = B1MLW, B17, B19; Farfield = B5MLW, B35, B31.
[b]Preoperational = mean of annual means, 1978-1989 (B1MLW, B17, B19, B31) or 1982-1989 (B5MLW, B35).
[c]Operational mean = mean of annual means, 1991-1994, for all stations.
[d]Arithmentic mean of annual means. Preop = 1980-1989, Op = 1991-1994

preoperational period (NAI 1991b), and similar variability has become apparent over the operational period. High year-to-year variability in mytilid recruitment is typical for the Gulf of Maine (Petaitis 1991). For example, 1993 mytilid densities were higher than other operational years (NAI and NUS 1994) and in 1994 they were generally lower. Operational densities have remained lower than preoperational densities at the intertidal stations (B1MLW and B5MLW). There were no significant differences between the preoperational and operational periods, and there was no significant Preop-Op X Station interaction for intertidal mytilid densities (Table 6-16).

Mytilidae also were among the dominant taxa at shallow subtidal stations B17 and B35 (Table 6-12). As in the case of the intertidal stations, dramatic recent year-to-year variability in mytilid density was observed at the shallow subtidal stations. Densities higher than preoperational or operational period means that were observed in 1993 (NAI and NUS 1994) were followed by substantially lower measurements in 1994, especially at the farfield station (B35). There were no significant differences between the preoperational and operational periods or between stations, and no significant Preop-Op X Station interaction (Table 6-16).

Mytilids also were abundant at mid-depth station B19 and B31, relative to other taxa collected at these locations (Table 6-12). Densities have been greater at the farfield station (B31) in both the preoperational and operational periods (Table 6-15). This disparity was particularly obvious in 1994 when relatively small densities were recorded at the nearfield station (B19). However, there were no significant differences between preoperational and operational means or between stations, and no significant Preop-Op X Station interaction (Table 6-16).

The most common mytilid collected at Seabrook study sites, the blue mussel *Mytilus edulis*, can reach shell lengths up to 100 mm (Gosner 1978). However, most mytilids collected during our study ranged from 1 to 25 mm, with the majority collected as newly settled spat measuring 2-3 mm. A summary of mytilid lengths over preoperational and operational years is presented in Table 6-17. Mytilids generally have been largest in the intertidal zone, a trend which has been consistent over both periods. Intertidal mytilids typically have been larger at the farfield station (B5MLW) than at the nearfield station (B1MLW) over both preoperational and operational periods. No difference in size was observed between preoperational and operational periods at either intertidal station.

Mytilids generally were smaller in the subtidal zones than in the intertidal zones. Subtidal operational period means were slightly larger, with exception of mid-depth nearfield station B19 where numbers of very small mytilids collected in 1994 reduced the operational period mean to less than the preoperational mean. Mytilids had settled in May at both Stations B19 and B31, with abundances of over 10,000/m^2. By August, mytilids had nearly disappeared (198/m^2) at B19, and those that remained were smaller than average (NAI 1995). Abundances and lengths at Station B31 were similar to the preoperational and operational means (Table 6-15). The appearance of these very small mytilids at only one station is unexplained, and stands in contrast to the relatively large mytilids measured in 1994 at farfield Station B31. During both the preoperational and operational periods, mytilid lengths were smaller at the nearfield stations (B17 and B19) than at the farfield counterparts (B35 and B31). This was not the case at the shallow subtidal stations in 1994 where measurements at B17 slightly exceeded those at B35.

Nucella lapillus

The only common intertidal macrofaunal predator in the Seabrook area is the dogwinkle, *Nucella lapillus*, preying primarily on mussels and barnacles (Connell 1961; Menge 1976; Petraitis 1991). At Seabrook study sites, *N. lapillus* abundances at nearfield station

TABLE 6-16. ANALYSIS OF VARIANCE RESULTS COMPARING LOG-TRANSFORMED DENSITIES OF SELECTED BENTHIC TAXA COLLECTED IN MAY, AUGUST AND NOVEMBER AT NEAR- AND FARFIELD STATION PAIRS (B1MLW/B5MLW, B17/B35, B19/B31) DURING PREOPERATIONAL (1978 - 1989) AND OPERATIONAL (1991 - 1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	df	MS	F[h]	MULTIPLE COMPARISONS[i] (Ranked in decreasing order)
Mytilidae	Intertidal	Preop-Op[b]	1	1.97	2.27 NS	
(<25 mm)	(B1, B5)	Year (Preop-Op)[c]	10	1.11	0.81 NS	
		Month (Year)[d]	24	1.21	10.51 **	
		Station[e]	1	3.95	non-est.[j]	
		Preop-Op X Station[f]	1	<0.01	<0.01 NS	
		Year X Station (Preop-Op)[g]	10	0.29	2.54 **	
		Error	272	0.11		
	Shallow Subtidal	Preop-Op	1	0.26	0.06 NS	
	(B17, B35)	Year (Preop-Op)	10	4.26	1.62 NS	
		Month (Year)	24	2.23	8.55 **	
		Station	1	8.20	12.73 NS	
		Preop-Op X Station	1	0.65	0.91 NS	
		Year X Station (Preop-Op)	10	0.69	2.65 **	
		Error	264	0.26		
	Mid-Depth	Preop-Op	1	0.15	0.44 NS	
	(B19, B31)	Year (Preop-Op)	14	5.48	1.87 NS	
		Month (Year)	32	1.38	4.56 **	
		Station	1	16.89	111.47 NS	
		Preop-Op X Station	1	0.28	0.14 NS	
		Year X Station (Preop-Op)	14	1.87	6.16 **	
		Error	367	0.30		

(continued)

TABLE 6-16. (Continued)

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	df	MS	F[h]	MULTIPLE COMPARISONS[i] (Ranked in decreasing order)
Nucella lapillus	Intertidal (B1MLW, B5MLW)	Preop-Op	1	0.55	0.44 NS	
		Year (Preop-Op)	10	1.32	1.00 NS	
		Month (Year)	24	1.17	9.33 **	
		Station	1	5.59	35.27 NS	
		Preop-Op X Station	1	0.16	0.54 NS	
		Year X Station (Preop-Op)	10	0.29	2.36 *	
		Error	272	0.13		
Asteriidae	Shallow Subtidal (B17, B35)	Preop-Op	1	0.19	0.06 NS	
		Year (Preop-Op)	10	3.05	1.94 NS	
		Month (Year)	24	0.94	6.68 **	
		Station	1	21.65	77.67 NS	
		Preop-Op X Station	1	0.79	0.97 NS	
		Year X Station (Preop-Op)	10	0.78	5.55 **	
		Error	264	0.14		
Pontogeneia intermis	Mid-Depth (B19, B31)	Preop-Op	1	1.22	1.26 NS	
		Year (Preop-Op)	14	0.91	0.59 NS	
		Month (Year)	32	1.41	6.47 **	
		Station	1	5.42	14.23 NS	
		Preop-Op X Station	1	0.38	1.01 NS	
		Year X Station (Preop-Op)	14	0.37	1.70 NS	
		Error	367	0.22		
Jassa marmorata	Shallow Subtidal (B17, B35)	Preop-Op	1	0.39	0.18 NS	
		Year (Preop-Op)	10	2.24	1.51 NS	
		Month (Year)	24	1.20	4.00 **	
		Station	1	9.78	24.34 NS	
		Preop-Op X Station	1	0.41	0.67 NS	
		Year X Station (Preop-Op)	10	0.60	1.99 *	
		Error	264	0.30		

(continued)

TABLE 6-16. (Continued)

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	df	MS	F[h]	MULTIPLE COMPARISONS[i] (Ranked in decreasing order)
Ampithoe rubricata	Intertidal (B1MLW, B5MLW)	Preop-Op	1	33.88	0.61 NS	
		Year (Preop-Op)	10	7.90	2.60 *	
		Month (Year)	24	1.01	3.23 **	
		Station	1	42.86	0.83 NS	
		Preop-Op X Station	1	50.33	20.18 **	B5-Op <u>B1-Pre B5-Pre B1-Op</u>
		Year X Station (Preop-Op)	10	2.39	7.61 **	
		Error	272	0.31		
Strongylocentrotus droebachiensis	Mid-Depth (B19, B31)	Preop-Op	1	2.30	0.77 NS	
		Year (Preop-Op)	14	3.70	1.66 NS	
		Month (Year)	32	1.78	3.91 **	
		Station	1	10.34	non-est.[i]	
		Preop-Op X Station	1	0.01	0.01 NS	
		Year X Station (Preop-Op)	14	0.93	2.05 *	
		Error	367	0.45		
Modiolus modiolus (adults)	Mid-Depth (B19, B31)	Preop-Op	1	668,582.06	5.13 NS	
		Year (Preop-Op)	12	139,292.27	0.97 NS	
		Month (Year)	28	35,712.22	1.76 **	
		Station	1	43,787.82	0.37 NS	
		Preop-Op X Station	1	119,340.73	0.93 NS	
		Year X Station (Preop-Op)	12	128,303.47	6.34 **	
		Error	945	20,239.83		

[a]$\log_{10}(x+1)$ density, except for *M. modiolus* adults, which were sampled semi-quantitatively and therefore rank densities were used.
[b]Preop-Op compares 1982-1989 to 1991-1994 regardless of station for B1MLW/B5MLW and B17/B35.
Preop-Op compares 1978-1989 to 1991-1994 regardless of station for B19/B31.
Preop-Op compares 1980-1989 to 1991-1994 regardless of station for *M. modiolus*.
[c]Year nested within Preoperational and Operational periods regardless of Station.
[d]Month nested within Year regardless of Station or Period.
[e]Station pairs nested within a depth zone: Intertidal = nearfield (B1MLW), farfield (B5MLW); Shallow subtidal = nearfield (B17), farfield (B35); Mid-depth = nearfield (B19), farfield (B31); regardless of Year, Station or Period.
[f]Interaction of the two main effects, Preop-Op and Station.
[g]Interaction of Station and Year nested within Preoperational and Operational periods.
[h]NS = not significant ($p>0.05$); * = significant ($0.05>p>0.01$); ** = highly significant ($p\leq0.01$).
[i]F-value non-estimable due to a negative denominator mean square.

TABLE 6-17. MEAN LENGTH (mm) AND LOWER (LCL) AND UPPER (UCL) 95% CONFIDENCE LIMITS DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS, AND MEAN LENGTHS DURING 1994 OF SELECTED BENTHIC SPECIES AT NEARFIELD-FARFIELD STATION PAIRS. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL[a]		1994	OPERATIONAL[b]	
TAXON	STATION	MEAN	CV	MEAN	MEAN	CV
Mytilidae[c]	B1MLW	3.1	64.7	2.5	3.1	54.6
	B5MLW	3.3	53.1	2.8	3.3	59.1
	B17	2.3	63.4	2.4	2.5	54.2
	B35	2.5	64.8	2.3	2.6	55.1
	B19	2.4	73.7	1.2	1.9	55.5
	B31	2.8	77.8	4.1	3.1	66.0
Nucella lapillus	B1MLW	6.9	80.5	5.8	6.1	77.5
	B5MLW	6.0	98.5	5.4	5.3	86.2
Asteriidae	B17	5.0	86.0	5.2	5.0	69.7
	B35	6.7	98.5	3.8	5.0	100.3
Pontogeneia inermis	B19	5.1	39.4	5.3	5.3	31.9
	B31	5.3	29.2	5.6	5.4	28.0
Jassa marmorata	B17	4.2	26.6	4.1	4.3	27.4
	B35	3.9	27.2	3.7	3.9	28.7
Ampithoe rubricata	B1MLW	7.0	36.2	9.8	8.6	42.4
	B5MLW	7.8	34.6	7.8	7.2	44.5
Strongylocentrotus droebachiensis	B19	1.9	95.2	3.5	2.6	85.7
	B31	1.9	56.9	4.5	3.6	131.0

[a]Preoperational = mean of annual means, 1982-1989. Annual mean is sum of lengths of all individuals collected in May, August, and November divided by the total number of individuals measured.
[b]Operational = mean of annual means, 1991-1994.
[c]Individuals measuring >25 mm were excluded.

B1MLW were twofold higher than abundances at the farfield station (B5MLW) in the preoperational period and nearly so in the operational period (Table 6-15), although this difference was not significant (Table 6-16). Densities in 1994 exceeded both preoperational and operational period means at both stations. Differences in preoperational and operational periods were not significant and no significant Preop-Op X Station interaction was detected (Table 6-16).

Nucella lapillus shell length measurements from intertidal collections also were made as part of life history studies. *N. lapillus* can reach lengths of up to 51 mm (Abbott 1974), but typically ranged from 3-12 mm during this study (NAI 1993). Mean length was greater at the nearfield station (B1MLW) than at the farfield station (B5MLW) in 1994, a trend observed over preoperational and operational periods (Table 6-17). Operational mean lengths at both stations were below the respective preoperational means.

Asteriidae

Asteriidae (starfish) is another predatory taxon that can occur in the low intertidal zone, but is most abundant in the shallow subtidal zone. Although two genera of starfish occur in the Gulf of Maine, *Asterias* and *Leptasterias* (Gosner 1978), two species of the former, *Asterias forbesii* and *A. vulgaris* are most commonly collected in this study. Predation by *Asterias* spp. on mussels can be locally intense, and this feeding activity is believed to have considerable influence on both intertidal and subtidal community structure (Menge 1979; Sebens 1985). Abundance patterns of Asteriidae in the Seabrook area were examined in detail in the shallow subtidal zone, where they were most abundant. Densities in 1994 exceeded preoperational and operational means at both stations (Table 6-15). No significant differences between the preoperational and operational means or between station means were detected, nor was there a significant Preop-Op X Station interaction (Table 6-16).

The sizes of Asteriidae collected over the study period generally have been consistent, and indicate that the vast majority of individuals collected were juveniles (Table 6-17). Asteriidae collected during the operational period at B35 were smaller than those collected in the preoperational period largely due to the small mean size of starfish collected in 1994; few asteriids measuring >10 mm were collected (NAI 1995), while mean lengths during the two periods were identical at B17.

Pontogeneia inermis

The amphipod *Pontogeneia inermis* is a numerically dominant macrofaunal species in benthic habitats in the Gulf of Maine, where it clings to submerged algae in the intertidal and subtidal zones to depths of more than 10 m, and can also occur in pelagic waters (Bousfield 1973). At Seabrook study sites, *P. inermis* was a dominant taxon at all subtidal stations, but occurred most consistently in the mid-depth zone. Mean densities at B19 have been similar in both the preoperational and operational periods (Table 6-15). During 1994, nearfield mean density was less than either the preoperational or operational means. At the farfield station, the preoperational period mean density was higher than both the 1994 and operational period means. Significant differences were not detected between the preoperational and operational period means or between station means, nor was there a significant Preop-Op X Station interaction (Table 6-16).

Pontogeneia inermis can reach lengths of up to 11 mm (Bousfield 1973); however, at Seabrook mid-depth stations, average lengths were approximately 5 mm (Table 6-17). Mean length at farfield station B31 was slightly larger than at nearfield station B19 in both the preoperational and operational periods and in 1994. Mean length during the operational period was slightly larger than during the preoperational period at both stations.

Jassa marmorata

The tube-building amphipod *Jassa marmorata* is a common member of the local fouling community. Populations of this species can dominate primary space on hard surfaces, often outcompeting encrusting species by forming a mat "complex" composed of numerous tubes made from sediment and detritus (Sebens 1985). Primarily a suspension feeder (Nair and Anger 1979), *J. marmorata* also preys on small crustaceans and ostracods (Bousfield 1973). In the Seabrook study area, *J. marmorata* is most abundant at shallow subtidal stations, where it is among the dominant taxa (Table 6-12). Annual mean densities during 1994 were less than preoperational and operational period means at both stations (Table 6-15). No significant differences between the preoperational and operational period means or between stations were detected, nor was there a significant Preop-Op X Station interaction.

Jassa marmorata can reach a maximum length of up to 9 mm (Bousfield 1973), and growth rate and molting frequency of this species is strongly related to temperature (Franz 1989). Lengths of *J. marmorata* in our study averaged approximately 4 mm, with mean lengths slightly higher at the nearfield station (B17) than at the farfield station (B35) during both periods and during 1994 (Table 6-17). Comparisons of preoperational and operational means revealed few between-period differences at either station.

Ampithoe rubricata

Another amphipod occasionally common to benthic habitats in the Seabrook area is *Ampithoe rubricata*. This species is most abundant in the intertidal zone, building nests among fucoids and in mussel beds (Bousfield 1973). Occurrence and abundance patterns of *A. rubricata* have been unpredictable over the entire study period, with relatively high densities noted in some years, and absence or near-absence observed in other years. For example, *A. rubricata* was the dominant intertidal crustacean in 1982, but was rarely collected during the period 1984-89 (NAI 1991b). Because of this extended period of low abundance, overall preoperational period mean densities for this species were low (Table 6-15). This trend of low abundance has continued through 1990 and all operational years, including 1994, at nearfield station B1MLW. However, a dramatic increase in *A. rubricata* abundance occurred at the farfield station (B5MLW) during operational years, a trend which has continued through 1994. Continued low densities during operational years at B1MLW and continued high densities at B5MLW for that period, when examined with ANOVA, resulted in a significant Preop-Op X Station interaction (Table 6-16, Fig. 6-6).

Ampithoe rubricata reach a maximum size of 20 mm (Bousfield 1973). During our studies, average lengths generally ranged from 7 to 10 mm (Table 6-17), with a variety of size classes observed. During the preoperational period, mean length was larger at the farfield station, with the opposite observed in 1994 and during the operational period. Mean lengths at B1MLW are likely not representative because of the low densities of *A. rubricata* available for measurement.

Strongylocentrotus droebachiensis

The green sea urchin, *Strongylocentrotus droebachiensis*, is well documented as having considerable influence on low intertidal and subtidal community structure (Lubchenco 1980; Witman 1985; Novaczek and McLachlan 1986; Johnson and Mann 1988). Grazing by locally dense aggregates of *S. droebachiensis* in the subtidal zone can preferentially eliminate populations of foliose algae (Breen and Mann 1976; Witman 1985), such as *Laminaria saccharina* and *L. longicruris* (Larson et al. 1980; Mann et al. 1984). What remains after this severe grazing is a barren ground of primarily crustose coralline algae. *S. droebachiensis* is susceptible to disease-induced local extinction, allowing foliose algae to recolonize denuded

Intertidal

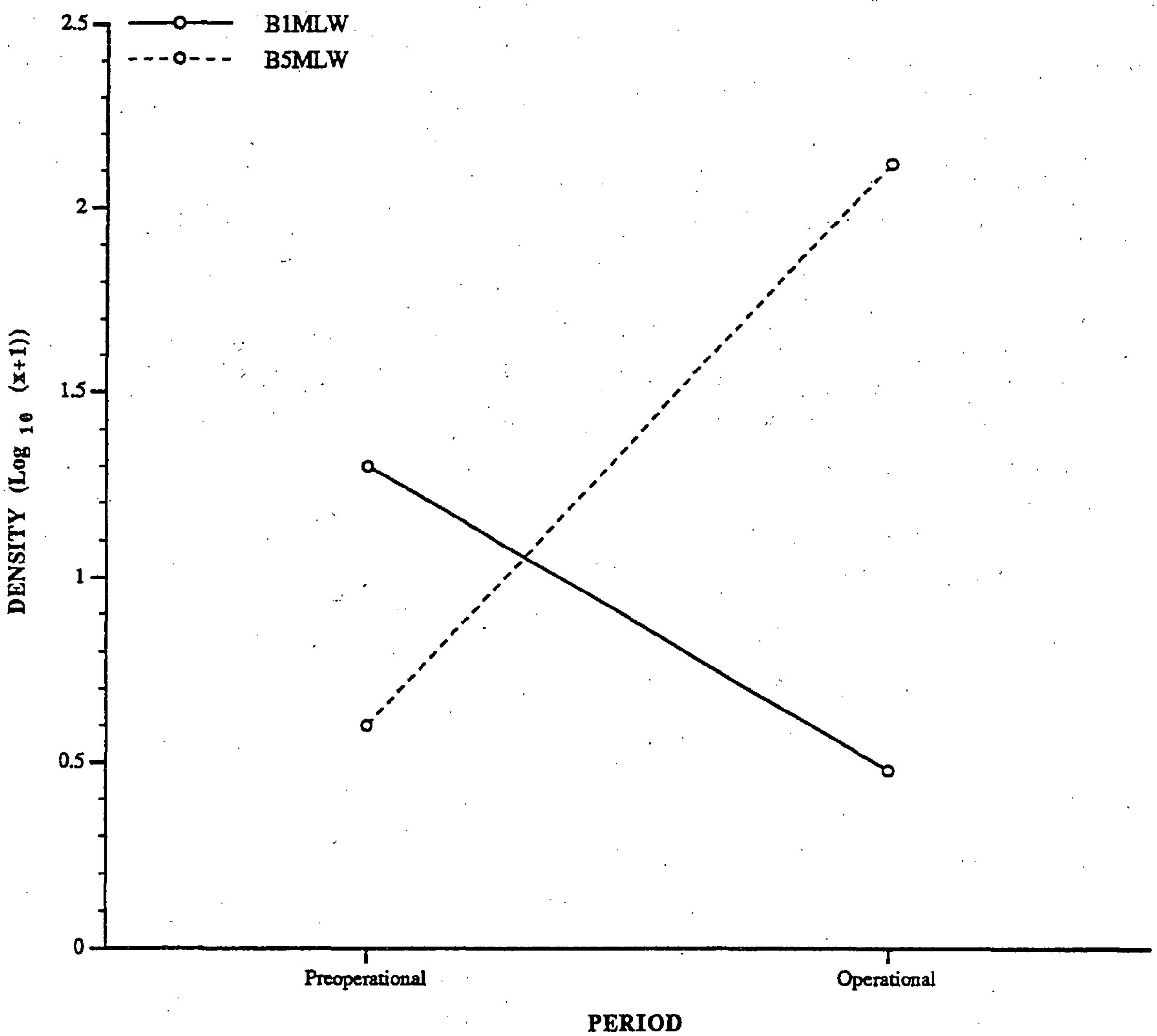


Figure 6-6. Comparisons between intertidal stations of mean density (log (x+1)) of ***Ampithoe rubricata*** during the preoperational (1978-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 6-16). Seabrook Operational Report, 1994.

areas. Sea urchin abundance cycles and subsequent habitat modification have been linked to shifts in local lobster landings (Breen and Mann 1976); however, this relationship is still unclear and remains a source of controversy (Elner and Vadas 1990).

Sea urchins collected in destructive samples were small (Table 6-17), and not considered a dominant factor in structuring communities at any depth zone. Sea urchins were most abundant in the mid-depth zone in the preoperational and operational periods and in 1994 (Table 6-15), with higher densities at the nearfield station compared to the farfield station. Operational period mean densities were similar to preoperational period means at both mid-depth stations, although densities recorded in 1994 were substantially higher than either period mean. No significant between-period or between-station differences were detected and the Preop-Op X Station interaction term was not significant (Table 6-16).

Most sea urchins collected were juveniles, with mean length of approximately 2 mm during the preoperational period at both nearfield and farfield stations (Table 6-17). Mean length was somewhat greater at the farfield station than at the nearfield station during the operational period.

Densities of adult sea urchins also were estimated during subtidal transect sampling, and have been relatively low since sampling began in 1985 (Table 6-18). Annual mean densities during the preoperational period never exceeded $1.3/m^2$, and were typically $<0.5/m^2$. At shallow subtidal station B17, operational and 1994 means were within the range of the preoperational mean. However, higher densities have been recorded at station B35 and both mid-depth stations (B19, B31) during the operational period and, in particular, during 1994. In fact, the highest densities to date were observed in the mid-depth zone in 1994, exceeding 12 urchins/m^2 at the farfield station (B31), and $7/m^2$ at the nearfield station (B19).

TABLE 6-18. MEAN DENSITIES (PER m^2) AND RANGE OF ADULT SEA URCHINS OBSERVED IN SUBTIDAL TRANSECTS DURING PREOPERATIONAL (1985-1989) AND OPERATIONAL (1991-1994) PERIODS, AND DURING 1994. SEABROOK OPERATIONAL REPORT, 1994.

	PREOPERATIONAL		1994	OPERATIONAL	
STATION	MEAN	RANGE	MEAN	MEAN	RANGE
B17	0.20	0.00-1.30	0.31	0.10	0.01-0.31
B35	0.10	0.00-0.50	1.86	0.52	0.00-1.86
B19	0.09	0.02-0.20	7.12	2.31	0.01-7.12
B31	0.04	0.00-0.24	12.31	4.63	0.02-12.31
ALL STATIONS	0.11	0.00-1.30	5.40	1.89	0.00-12.31

Modiolus modiolus

Beds of the northern horse mussel *Modiolus modiolus* are often extensive in subtidal habitats in the Gulf of Maine, providing additional hard substratum for benthic algae (Sebens 1985), and sheltering a diverse group of invertebrates in spaces between individual mussels (Witman 1985; Ojeda and Dearborn 1989). Large sea stars (*Asterias* spp.) actively prey on *M. modiolus*, while another common subtidal predator, the omnivorous sea urchin *Strongylocentrotus droebachiensis*, appears to choose foliose macroalgae over *M. modiolus* (Briscoe and Sebens 1988). Urchin activity may actually enhance *M. modiolus* abundance by grazing kelps off mussels and decreasing the risk of mussel dislodgement (Witman 1987).

Mean densities of *M. modiolus* were similar during the preoperational and operational periods at both mid-depth stations, although a relatively high density occurred at farfield Station B31 in 1994 (Table 6-15). No significant differences between preoperational and operational period means or between station means were detected, nor was Preop-Op X Station interaction term significant (Table 6-16).

6.4 CONCLUSIONS

6.4.1 Introduction

Thermal and hydrodynamic changes in physical conditions, created by operation of the Seabrook Station condenser cooling water system, could potentially affect the local hard-bottom macrobenthic communities in several ways. The most obvious type of impact is temperature-related community alteration, resulting from direct exposure to the discharge thermal plume. This type of impact could produce significant changes to nearby attached communities, depending on the proximity of these habitats to the discharge, and the hydrodynamic characteristics of the thermal plume itself. These changes are most likely to occur in surface and near surface waters, due to the buoyant nature of most thermal plumes. Such impacts are well-documented for intertidal and shallow subtidal communities during monitoring studies for coastal nuclear power plants elsewhere, and include elimination or reduced abundance of cold-water species, and increased abundance of warm-water tolerant and/or opportunistic species, leading to the development of communities distinct from those seen prior to thermal incursion and from those on nearby unaffected coasts (Vadas et al. 1976; Wilce et al. 1976; BECO 1994; NUSCO 1994).

Another less common impact resulting from coastal nuclear power plants is related more to altered water circulation patterns than to thermal incursion. Specifically, the introduction (discharge) of turbid water to an area of historically lower levels of turbidity decreases light penetration and increases sedimentation rates. Sources of this turbidity include suspended inorganic and organic particles from higher energy areas, such as wave-swept shores (Osman et al. 1981; NUSCO 1988; Schroeter et al. 1993) and increased detrital deposition resulting from settlement of entrained organisms. Turbidity impacts would be most pronounced in areas where levels of water movement and physical disturbance are low, such as in deeper water. Turbidity effects detrimental to macrobenthic plants and animals include shading or burial, and an increased community dominance by suspension-feeding organisms and organisms more tolerant of higher sedimentation rates (Hiscock and Mitchell 1980; Schroeter et al. 1993).

Because the type of impact a community is vulnerable to appears to be related to its relative position in the water column (i.e., temperature effects for shallow water sites, turbidity effects at deeper water sites), potential impacts associated with construction and operation of Seabrook Station on communities in each of these depth zones will be examined separately.

6.4.2 Evaluation of Potential Thermal Plume Effects on Intertidal/Shallow Subtidal Benthic Communities

Nearfield sampling sites used for the Seabrook intertidal and shallow subtidal macrobenthos studies were selected because they best represent the shallow water communities that are most susceptible to incursion by the Seabrook Station thermal discharge plume. Hydrodynamic modeling, conducted prior to plant start-up to predict the areal extent of the thermal plume under various meteorological and current regimes, indicated that thermal incursion to these sites would be minimal, with temperature increases of <1°F (Teyssandier et al. 1974). Subsequent field studies, conducted after Seabrook began commercial operation, verified these predictions by measuring no temperature increases at the intertidal sampling site, and increases of <1°F at the shallow subtidal site (Padmanabhan and Hecker 1991).

Few of the many parameters used to evaluate certain aspects of the benthic communities in the intertidal and shallow subtidal zones indicated significant differences between preoperational and operational periods, and analyses of overall community structure showed that nearfield macroalgal and macrofaunal communities have changed little since Seabrook began operation (Table 6-19). Although total August algal biomass declined significantly at both intertidal stations, this decline was larger at the nearfield station (B1MLW, Figure 6-3). This decrease was primarily due to a decrease in August *Chondrus crispus* biomass, which was the dominant species at the nearfield station during both the preoperational and operational periods. It is unlikely that the decrease in *Chondrus crispus* biomass is due to a thermal plume effect. *Chondrus crispus* is found from New Jersey to Newfoundland (Taylor 1957) and is tolerant of a wide range of water temperatures (Mathieson and Prince 1973), nor does the thermal plume appear to raise water temperatures at the nearfield intertidal station (Padmanabhan and Hecker 1991). Furthermore, the decline in total biomass was observed only in August. Over all three sampling periods, preoperational and operational mean biomass values (for total biomass and *C. crispus* biomass only) were not significantly different. Similar changes were not observed in the number of algal or faunal taxa collected or total faunal density in either zone, or in total algal biomass in the shallow subtidal zone.

Numerical classification of macroalgal and macrofaunal biomass and abundance revealed that stations and depth zones had similar assemblages with no evidence of differences between the preoperational or operational periods. This suggests that the important structuring mechanisms creating differences between stations and among years are most likely natural factors that are unrelated to power plant operation. Consistent with this was the examination of rarely occurring algal taxa, which provided no evidence of a proliferation of warm-water species or the appearance of nuisance species, indicating that the thermal plume has had no effect on species composition.

Patterns of abundance and occurrence of individual taxa in the intertidal zone were monitored in several ways. In high, mid and low intertidal quadrats, frequency of occurrence of dominant taxa, including barnacles, snails, mussels, fucoids and *Chondrus crispus*, generally remained consistent over both preoperational and operational periods (Tables 6-7 and 6-13). Some changes during operational years were observed in fucoid abundances at nearfield fixed transect sites (e.g., increased dominance by *Ascophyllum nodosum*, decreased abundance of *Fucus vesiculosus*) However, since *A. nodosum* is reportedly less tolerant of temperature increases than is *F. vesiculosus* (Vadas et al. 1976; NUSCO 1994), this change is most likely a natural successional shift, and not a power plant impact. Increases at both sites have been noted for *F. d. distichus* and *Fucus* sp. juveniles, indicating an area-wide trend.

Destructive sampling allowed more detailed monitoring of abundance patterns of selected dominant

TABLE 6-19. SUMMARY OF EVALUATION OF POTENTIAL THERMAL PLUME EFFECTS ON BENTHIC COMMUNITIES IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	AREA/DEPTH ZONE	PARAMETER[a]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[b]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[c]
Macroalgae	Intertidal	No. of taxa	Yes	Yes
		Total biomass	No	NF: Op<<Preop FF: Op<Preop
		Community structure	Yes	Yes
	Shallow subtidal	No. of taxa	Yes	Yes
		Total biomass	Yes	Yes
		Community structure	Yes	Yes
Macrofauna	Intertidal	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes
	Shallow	No. of taxa	Yes	Yes
	subtidal			Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes

[a]Abundance, no. of taxa, biomass, total density, evaluated using ANOVA; community structure evaluated using numerical classification by year and station.
[b]Operational period = 1990-1994 (August only).
[c]NF = nearfield; FF = farfield.

TABLE 6-20. SUMMARY OF EVALUATION OF POTENTIAL THERMAL PLUME EFFECTS ON REPRESENTATIVE IMPORTANT BENTHIC TAXA IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	AREA/DEPTH ZONE	SELECTED TAXON	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[a]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[b]
Macroalgae	Intertidal	*Chondrus crispus*	Yes	Yes
	Shallow Subtidal	*Chondrus crispus*	Yes	Yes
	Shallow Subtidal	*Laminaria saccharina*	Yes	Yes
	Shallow Subtidal	*Laminaria digitata*	No	NF: Op<Preop FF: Op=Preop
Macrofauna	Intertidal	*Ampithoe rubricata*	No	NF: Op=Preop FF: Op>Preop
	Intertidal	*Nucella lapillus*	Yes	Yes
	Intertidal	Mytilidae	Yes	Yes
	Shallow Subtidal	*Jassa marmorata*	Yes	Yes
	Shallow Subtidal	Asteriidae	Yes	Yes
				Yes
	Shallow Subtidal	Mytilidae	Yes	Yes
				Yes

[a]Conclusions derived from ANOVA or nonparametric analysis for Preoperational versus Operational periods.
[b]NF = nearfield; FF = farfield; note that nonparametric tests do not test for significant station differences or station-period interactions..

intertidal and shallow subtidal taxa. More rigorous statistical tests (i.e., ANOVA and Wilcoxon's summed ranks) were applied to these data to examine differences between preoperational and operational periods and among stations. These analyses indicated that, of the five intertidal/shallow subtidal faunal taxa studied, only one (the amphipod *Ampithoe rubricata*) showed significant changes in the relationship between nearfield and farfield stations during the operational period (Table 6-20). Abundances of *Ampithoe rubricata* in the operational period were not consistent between stations (no shift at the nearfield station, significant increase at the farfield station), relative to the preoperational period. However, examination of annual abundances revealed that these shifts began before power plant start-up. Once dominant at intertidal stations prior to 1986, *A. rubricata* disappeared from both stations until recolonization was observed in 1988 at the farfield station (NAI 1989). Abundances at the farfield station have continued to increase through 1994, but no recolonization has occurred at the nearfield station since 1986. Temporally patchy abundances of *A. rubricata* have been typical of the entire study period, suggesting that highly unpredictable environmental/climatic processes, and not power plant impacts, may have produced local extinction and subsequent recolonization.

Wilcoxon's summed ranks tests indicated that nearfield shallow subtidal populations of *Laminaria digitata* declined during the operational period, although no change was evident in farfield collections. This decline at the nearfield station actually began prior to power plant start-up (1989). A similar decline in *L. digitata* abundance was also observed at both mid-depth stations (Table 6-6), indicating an area-wide shift in abundance likely related to the susceptibility of this species to removal by storms (Kitching 1937), such as Hurricane Bob in 1991, and subsequent natural factors affecting the degree of recolonization. The one selected algal taxon, *Chondrus crispus*, did not exhibit significant temporal or spatial shifts.

6.4.3 Evaluation of Potential Turbidity Effects on the Mid-Depth/Deep Benthic Communities

Nearfield mid-depth and deep study sites represent macrobenthic communities in closest proximity to the Seabrook Station discharge. However, due to their position in the water column (depths 9-21 m) relative to the near surface thermal plume, temperature effects at these sites are unlikely. Higher sedimentation rates resulting from increased levels of suspended particles in discharge waters relative to the surrounding waters could potentially impact nearfield deeper water benthic communities. Higher sedimentation rates (and impacts to nearby macrobenthic communities) associated with a thermal effluent have been documented for a nuclear power plant in California (Osman et al. 1981; Schroeter et al. 1993), with the major source of turbidity being fine inorganic sediments transported from inshore waters where intakes for the plant were located. The organic component of these sediments contributed little to the overall flux of sediments, and no indications of organic enrichment were observed at sites near the discharge. The Seabrook intake is located well offshore and draws in relatively low turbidity water, similar to that near the discharge. Therefore, transport of fine inorganic particles is unlikely and any increase in sedimentation would be the result of settlement of organic material from entrained organisms. However, plankton densities are also lower in deeper offshore waters near the intake structure, compared to those in more productive inshore waters, thereby reducing the likelihood of any organic loading to benthic habitats near the discharge.

All assessments of community parameters and overall community structure indicated no changes to the nearfield mid-depth and deep communities during Seabrook operational years (Table 6-21). Numerical classification characterized overall algal and faunal community structure at mid-depth and deep sites, and revealed high similarity of annual collections within depth zone, and no evidence of separate groupings based on operational and preoperational periods. In other words, no substantive changes in community composi-

TABLE 6-21. SUMMARY OF EVALUATION OF POTENTIAL TURBIDITY EFFECTS ON BENTHIC COMMUNITIES IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	AREA/DEPTH ZONE	PARAMETER[a]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[b]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[c]
Macroalgae	Mid-depth	No. of taxa	Yes	Yes
		Total biomass	Yes	Yes
		Community structure	Yes	Yes
	Deep	No. of taxa	Yes	Yes
		Total biomass	Non est.	Yes
		Community structure	Yes	Yes
Macrofauna	Mid-depth	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes
	Deep	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes

[a]Abundance, no. of taxa, biomass, and total density evaluated using ANOVA; community structure evaluated using numerical classification by year and station.
[b]Operational period = 1990-1994 (August only).
[c]NF = nearfield; FF = farfield.

TABLE 6-22. SUMMARY OF EVALUATION OF POTENTIAL TURBIDITY EFFECTS ON REPRESENTATIVE IMPORTANT BENTHIC TAXA IN THE VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	AREA/DEPTH ZONE	SELECTED TAXON	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?[a]	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[b]
Macroalgae	Mid-depth	*Laminaria digitata*	No	Yes
		Laminaria saccharina	No	Yes
Macrofauna	Mid-depth	*Pontogeneia inermis*	Yes	Yes
		Modiolus modiolus	Yes	Yes
		Mytilidae	Yes	Yes
		Strongylocentrotus droebachensis	Yes	Yes

[a]Conclusions derived from ANOVA or nonparametric analysis for Preoperational versus Operational periods.
[b]NF = nearfield; FF = farfield; note that nonparametric tests do not test for significant station differences or station-period interactions.

tion have occurred at any mid-depth or deep site since Seabrook began commercial operation.

Detailed analyses of selected mid-depth benthic taxa abundance patterns are summarized in Table 6-22. *L. digitata* densities declined significantly at both nearfield and farfield stations, while densities of *L. saccharina* declined only in the nearfield. *L. digitata* began its decline during the preoperational period. Strong storms, Hurricane Bob in 1991 in particular, and increased numbers of the primary grazer, the green sea urchin, particularly in 1994, have further contributed to the decline. The increased numbers of sea urchins may indicate an area-wide movement of this species into the Seabrook area, as has been observed previously at the nearby Isles of Shoals (Witman 1985). None of the selected faunal taxa showed any declines or period-station interactions, indicating that there have been no substantial changes in these populations during Seabrook Station operation.

6.4.4 Overall Effect of Seabrook Operation on the Local Marine Macrobenthos

These extensive monitoring studies have documented that balanced indigenous macrobenthic communities continue to occupy intertidal and subtidal rocky habitats in the vicinity of the Seabrook discharge, with little change beyond that expected from natural variability. While some changes have been detected over the operational period, most were either part of an area-wide trend (occurring at both nearfield and farfield stations), part of an historical trend that began prior to commercial operation of Seabrook, or restricted to a site (intake) where little potential for impact exists. There is no evidence to suggest that thermal impacts or impacts associated with increased organic loading on the local macrobenthos have occurred since the start-up of Seabrook Station in 1990.

6.5 REFERENCES CITED

Abbott, R.T. 1974. American seashells. 2nd ed., Van Nostrand Reinhold, New York.

BECO (Boston Edison Company). 1994. Benthic Algal Monitoring at the Pilgrim Nuclear Power Station. Pages 1-23 *in* Marine ecology studies related to operation of Pilgrim Station. Semi-Ann. Rep. No. 43.

Bertness, M.D. 1989. Intraspecific competition and facilitation in a northern acorn barnacle population. Ecology 70:257-268.

Bloom, S.A. 1980. A package of computer programs for benthic community analyses. Univ. Florida.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Environmental Protection Agency, Ecological Research Report Agency, Ecol. Res. Rep. 114 pp.

Bousfield, E.L. 1973. Shallow water gammaridean Amphipoda of New England. Comstock Pub., Ithaca, NY. 312 pp.

Breen, P.A., and K.H. Mann. 1976. Changing lobster abundance and destruction of kelp beds by sea urchins. Mar. Biol. 34:137-142.

Chapman, A.R.O. 1973. A critique of prevailing attitudes towards to control of seaweed zonation on the sea shore. Bot. Mar. 16:80-82.

Connell, J.H. 1961. Effects of competition, predation by *Thais lapillus*, and other factors on natural populations of the barnacle *Balanus balanoides*. Ecol. Monogr. 31:61-104.

Cubit, J.D. 1984. Herbivory and the seasonal abundance of algae on a high intertidal rocky shore. Ecology 65:1904-1917.

Dayton, P.K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. 41:351-389.

Elner, R.W., and R. L. Vadas. 1990. Inference in ecology: the sea urchin phenomenon in the northwestern Atlantic. Am. Nat. 136:108-125.

Franz, D.R. 1989. Population density and demography of a fouling community amphipod. J. Exp. Mar. Biol. Ecol. 125:117-136.

Fuller, J.L. 1946. Season of attachment and growth of sedentary marine organisms at Lamoine, Maine. Ecology 27:150-158.

Gaines, S., and J. Roughgarden. 1985. Larval settlement rate: a leading determinant of structure in an ecological community of the marine intertidal zone. Proc. Natl. Acad. Sci. USA 82:3707-3711.

Geiselman, J.A., and O.J. McConnell. 1981. Polyphenols in brown algae *Fucus vesiculosus* and *Ascophyllum nodosum*: chemical defenses against the marine herbivorous snail, *Littorina littorea*. J. Chem. Ecol. 7:1115-1133.

Gosner, K.L. 1978. A Field Guide to the Atlantic seashore. Houghton Mifflin Co., Boston. 329 pp.

Grant, W.S. 1977. High intertidal community organization on a rocky intertidal headland in Maine, USA. Mar. Biol. 44:15-25.

Hiscock, K., and R. Mitchell. 1980. The description and classification of sublittoral epibenthic ecosystems. Pages 323-370 *in* J.H. Price, D.E.G. Irvine and W.F. Farnham (eds.) The Shore Environment, Vol. 2: Ecosystems. Academic Press, London and New York. 945 pp.

Johnson, C.R., and K.H. Mann. 1988. Diversity, patterns of adaptation, and stability of Nova Scotian kelp beds. Ecol. Monogr. 58:129-154.

Keser, M., and B.R. Larson. 1984. Colonization and growth dynamics of three species of *Fucus*. Mar. Ecol. Prog. Ser. 15:125-134.

Kitching, J.A. 1937. Studies in sublittoral ecology II. Recolonization at the upper margin of the sublittoral region; with a note on the denudation of *Laminaria* forests by storms. J. Ecol. 25:482-495.

Larson, B.R., R.L. Vadas, and M. Keser. 1980. Feeding and nutrition ecology of the green sea urchin, *Strongylocentrotus droebachiensis* in Maine, U.S.A. Mar. Biol. 59:49-62.

Lewis, J.R. 1964. The Ecology of Rocky Shores. English Univ. Press, London. 323 pp.

Lubchenco, J. 1980. Algal zonation in the New England rocky intertidal community: an experimental analysis. Ecology 61:333-344.

__________. 1983. *Littorina* and *Fucus*: effects of herbivores, substratum heterogeneity, and plant escapes during succession. Ecology 64:1116-1123.

Lubchenco, J., and B.A. Menge. 1978. Community development and persistence in a low rocky intertidal zone. Ecol. Monogr. 48:67-94.

Mann, K.H. 1973. Seaweeds: their productivity and strategy for growth. Science 182:975-981.

Mann, K.H., L.C. Wright, B.E. Welsford, and E. Hatfield. 1984. Responses of the sea urchin *Strongylocentrotus droebachiensis* (O.F. Muller) to waterborne stimuli from potential predators and potential food algae. J. Exp. Mar. Biol. Ecol. 79:233-244.

Mathieson, A.C., E.J. Hehre, and N.B. Reynolds. 1981. Investigations of New England marine algae. II: The species composition, distribution and zonation of seaweeds in the Great Bay estuary system and the adjacent open coast of New Hampshire. Bot. Mar. 24:533-545.

Mathieson, A.C., and E.J. Hehre. 1986. A synopsis of New Hampshire seaweeds. Rhodora 88:1-139.

Mathieson, A.C., and J.S. Prince. 1973. Ecology of *Chondrus crispus* Stackhouse. Pages 53-79 *in* M.J. Harvey and J. MacLachlan (eds.) *Chondrus crispus*. Nova Scotian Inst. Sci., Halifax.

Menge, B.A. 1976. Organization of the New England rocky intertidal community: role of predation, competition, and environmental heterogeneity. Ecol. Monogr. 46:355-393.

__________. 1979. Coexistence between the seastars *Asterias vulgaris* and *A. forbesii* in a heterogeneous environment: a non-equilibrium explanation. Oecologia 41:245-272.

__________. 1983. Components of predation intensity in the low zone of the New England rocky intertidal region. Oecologia 58:141-155.

__________. 1991. Relative importance of recruitment and other causes of variation in rocky intertidal community structure. J. Exp. Mar. Biol. Ecol. 146:69-100.

Minchinton, T.E., and R.E. Scheibling. 1991. The influence of larval supply and settlement on the population structure of barnacles. Ecology 72:1867-1879.

NAI (Normandeau Associates, Inc.). 1989. Seabrook Environmental Studies. 1988. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1988. A preoperational study for Seabrook Station. Tech. Rep. XX-II.

__________. 1991a. Seabrook Environmental Studies. 1990 Data Report. Tech. Rep. XXII-I.

__________. 1991b. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

__________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1

__________. 1994. Seabrook Environmental Studies. 1993 Data. Unpublished Data Tables.

__________. 1995. Seabrook Environmental Studies. 1994 Data. Unpublished Data Tables.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area During the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corp.

Nair, K.K.C., and K. Anger. 1979. Experimental studies on the life cycle of *Jassa falcata* (Crustacea, Amphipoda). Helgo. Wiss. Meeres. 37:444-452.

Novaczek, I., and J. McLachlan. 1986. Recolonization by algae of the sublittoral habitat of Halifax County, Nova Scotia, following the demise of sea urchins. Bot. Mar. 29:69-73.

NUSCO (Northeast Utilities Service Company). 1992. Rocky Intertidal Studies. Pages 237-292 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Ann. Rep., 1991.

__________. 1994. Rocky Intertidal Studies. Pages 51-79 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Ann. Rep., 1993.

Ojeda, F.P., and J.H. Dearborn. 1989. Community structure of macroinvertebrates inhabiting the rocky subtidal zone in the Gulf of Maine: seasonal and bathymetric distribution. Mar. Ecol. Prog. Ser. 57:147-161.

__________. 1991. Feeding ecology of benthic mobile predators: experimental analyses of their influence in rocky subtidal communities of the Gulf of Maine. J. Exp. Mar. Biol. Ecol. 149:13-44.

Osman, R.W. 1977. The establishment and development of a marine epifaunal community. Ecol. Monogr. 47:37-63.

Osman, R.W., R.W. Day, J.A. Haugsness, J. Deacon, and C. Mann. 1981. The effects of the San Onofre Nuclear Generating Station on sessile invertebrate communities inhabiting hard substrata (including experimental panels). Hard Benthos Project, Marine Science Institute, University of California, Santa Barbara. Final Rep., 223 pp.

Padmanabhan, M., and G.E. Hecker. 1991. Comparative evaluation of hydraulic model and field thermal plume data, Seabrook Nuclear Power Station. Alden Research Laboratory, Inc. 12 pp.

Petraitis, P.S. 1983. Grazing patterns of the periwinkle and their effect on sessile intertidal organism. Ecology 64:522-533.

Petraitis, P.S. 1991. Recruitment of the mussel *Mytilus edulis* L. on sheltered and exposed shores in Maine, USA. J. Exp. Mar. Biol. Ecol. 147:65-80

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 edition. SAS Inst., Inc., Cary, N.C. 956 pp.

Schneider, C.W. 1981. The effect of elevated temperature and reactor shutdown on the benthic marine flora of the Millstone thermal quarry, Connecticut. J. Therm. Biol. 6:1-6.

Schoener, A. 1974. Experimental zoogeography: colonization of marine mini-islands. Am. Nat. 108:715-738.

Schonbeck, M.W., and T.A. Norton. 1978. Factors controlling the upper limits of fucoid algae on the shore. J. Exp. Mar. Biol. Ecol. 31:303-313.

Schroeter, S.C., J.D. Dixon, J Kastendiek, and R.O. Smith. 1993. Detecting the ecological effects of environmental impacts: a case study of kelp forest invertebrates. Ecol. Appl. 3:331-350.

Sebens, K.P. 1985. The ecology of the rocky subtidal zone. Am. Sci. 73:548-557.

__________. 1986 Community ecology of vertical walls in the Gulf of Maine. USA: small scale processes and alternative community states. Pages 346-371 *in* P.G. Moore and R. Seed (eds.). The Ecology of Rocky Coasts. Columbia Univ. Press, New York.

Seed, R. 1976. Ecology. Pages 13-65 *in* B.L. Bayne (ed.), Marine Mussels: Their Ecology and Physiology. Cambridge Univ. Press, Cambridge.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. 775 pp.

Stephenson, T.A., and A. Stephenson. 1949. The universal features of zonation between tidemarks on rocky coasts. J. Ecol. 38:289-305.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental Impact Assessment: "pseudoreplication in time?" Ecology 67:929-940.

Sutherland, J.P., and R.H. Karlson. 1977. Development of stability of the fouling community at Beaufort, North Carolina. Ecol. Monogr. 47:425-446.

Taylor, W.R. 1957. Marine algae of the northeastern coast of North America. University of Michigan Press, Ann Arbor. 509 pp.

Teyssandier, R.G., W.W. Durgin, and G.E. Hecker. 1974. Hydrothermal studies of diffuser discharge in the coastal environment: Seabrook Station. Alden Research Laboratory Rep. No. 86-124.

Topinka, J., L. Tucker, and W. Korjeff. 1981. The distribution of fucoid macroalgal biomass along the central coast of Maine. Bot. Mar. 24:311-319.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4(1):3-15.

Underwood, A.J., and E.J. Denley. 1984. Paradigms, explanations and generalizations in models for the structure of intertidal communities of rocky shores. Pages 151-180 *in* D.R. Strong, Jr., D. Simberloff, L.G. Abele and A.B. Thistle (eds.), Ecological Communities: Conceptual Issues and the Evidence. Princeton Univ. Press, Princeton N.J.

Vadas, R.L., M. Keser, and P.C. Rusanowski. 1976. Influence of thermal loading on the ecology of intertidal algae. Pages 202-251 *in* G.W. Ecsh and R.W. MacFarlane (eds.) Thermal Ecology II. ERDA Symp. Ser., Augusta GA.

Wilce, R.T., J. Foertch, W. Grocki, J. Kilar, H. Levine, and J. Wilce. 1978. Flora: Marine Algal Studies. Pages 307-656 *in* Benthic Studies in the Vicinity of Pilgrim Nuclear Power Station, 1969-1977. Sum. Rep. Boston Edison Co.

Witman, J.D. 1985. Refuges, biological disturbance, and rocky subtidal community structure in New England. Ecol. Monogr. 55:421-445.

__________. 1987. Subtidal coexistence: storms, grazing, mutualism, and the zonation of kelps and mussels. Ecol. Monogr. 55:421-445.

Zobell, C.E., and E.C. Allen. 1935. The significance of marine bacteria in fouling of submerged surfaces. J. Bacter. 29:239-251.

APPENDIX TABLE 6-1. MARINE MACROBENTHOS SAMPLING HISTORY. SEABROOK OPERATIONAL REPORT, 1994.

STATIONS		SAMPLING METHOD	MONTHS	YEARS
FARFIELD STATIONS				
Intertidal:	B5MLW	Destructive	May, August, November	1982-1994
	B5MSL	Non-destructive	April, July, November	1983-1994
Subtidal:	B35 (shallow)	Destructive	May, August, November	1982-1994
		Non-destructive	April, July, October	1978-1994
	B31 (mid-depth)	Destructive	May, August, November	1978-1994
		Non-destructive	April July, October	1978-1994
		Panel Studies	Short Term, Long Term[a]	1982-1994
	B34 (deep)	Destructive	August	1979-1994
		Panel Studies	Short Term, Long Term[a]	1986-1994
NEARFIELD STATIONS				
Intertidal:	B1MLW	Destructive	May, August, November	1982-1994
	B1MSL	Non-destructive	April, July, November	1983-1994
Subtidal:	B17 (shallow)	Destructive	May, August, November	1978-1994
		Non-destructive	April, July, October	1979-1994
	B16 (mid-depth)	Destructive	August	1980-1984, 1986-1994
	B19 (mid-depth)	Destructive	May, August, November	1978-1994
		Non-destructive	April, July, October	1978-1994
	B04 (deep)	Panel Studies	Short Term, Long Term	1982-1994
		Destructive	August	1978-1994
	B13 (deep)	Panel Studies	Short Term, Long Term	1986-1994
		Destructive	August	1978-1994

[A]Short-term panel studies: three exposure periods - December to April, April to August, August to December.
Long-term panel studies: one-year exposure, August to August.

APPENDIX TABLE 6-2. NOMENCLATURAL AUTHORITIES FOR MACROFAUNAL TAXA CITED IN THE MARINE MACROBENTHOS SECTION. SEABROOK OPERATIONAL REPORT, 1994.

Mollusca
- Polyplacophora
  - *Tonicella rubra* (Linnaeus 1767)
- Gastropoda
  - *Lacuna vincta* (Montagu 1803)
  - *Littorina littorea* (Linnaeus 1758)
  - *Littorina obtusata* (Linnaeus 1758)
  - *Littorina saxatilis* (Olivi 1792)
  - *Nucella lapillus* (Linnaeus 1758)
- Bivalvia
  - Mytilidae
  - *Musculus niger* (J.E. Gray 1824)
  - *Modiolus modiolus* (Linnaeus 1758)
  - *Anomia* sp.
  - *Turtonia minuta* (Fabricius 1780)
  - *Hiatella* sp.

Annelida
- Polychaeta
  - *Thelepus cincinnatus* (Fabricius 1780)
- Oligochaeta

Arthropoda
- Pantopoda
  - *Achelia spinosa* (Stimpson 1853)
- Crustacea
  - *Balanus* sp.
  - *Balanus crenatus* Bruguiere 1789
  - *Idotea balthica* (Pallas 1772)
  - *Idotea phosphorea* Harger 1873
  - *Jaera marina* (Fabricius 1780)
  - *Ampithoe rubricata* (Montagu 1808)
  - *Gammarus oceanicus* Segerstråle 1947
  - *Jassa marmorata* (Holme 1903)
  - *Pontogeneia inermis* Krøyer 1842
  - *Caprella* sp.
  - *Caprella septentrionalis* Krøyer 1838

Echinodermata
- Echiniodea
  - *Strongylocentrotus droebachiensis* (Müller 1776)
- Stelleriodea
  - Asteridae

APPENDIX TABLE 6-3. THE OCCURRENCE OF MACROALGAE FROM GENERAL COLLECTIONS AND DESTRUCTIVE SAMPLING AT ALL SUBTIDAL AND INTERTIDAL DESTRUCTIVE STATIONS, 1978-1994. SEABROOK OPERATIONAL REPORT, 1994.

CHLOROPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
BLIDINGIA MINIMA (Naeg. ex Kuetz.) Kylin	X		X	X	X	X	X	X	X								
BRYOPSIS PLUMOSA (Hudson) Agardh							X								X	X	
CHAETOMORPHA BRACHYGONA Harvey	X				X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA LINUM (O.F. Muell.) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA MELAGONIUM (F. Weber et Mohr) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHAETOMORPHA PICQUOTIANA Mont. ex Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
CHAETOMORPHA SP.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CLADOPHORA REFRACTA (Roth) Kuetz.														X		X	X
CLADOPHORA SERICEA (Hudson) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CODIOLUM PETROCELIDIS Kuckuck	X	X															
ENTEROMORPHA COMPRESSA (L.) Grev.													X				
ENTEROMORPHA INTESTINALIS (L.) Link		X		X	X	X		X					X				
ENTEROMORPHA LINZA (L.) J. Agardh	X	X		X	X	X	X	X									X
ENTEROMORPHA PROLIFERA (O.F. Muell.) J. Agardh		X	X		X	X	X	X		X		X					
ENTEROMORPHA SP.				X			X		X	X	X						
MONOSTROMA FUSCUM (Postels et Rupr.)					X	X	X	X	X								
MONOSTROMA GREVILLEI (Thuret) Wittr.	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X
MONOSTROMA PULCHRUM Farlow	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
MONOSTROMA SP.																X	X
PSEUDENDOCLONIUM SUBMARINUA Wille					X												
RHIZOCLONIUM TORTUOSUM (Dillwyn) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SPONGOMORPHA ARCTA (Dillwyn) Kuetz.	X	X		X	X	X	X		X			X		X	X		
SPONGOMORPHA SP.	X																
SPONGOMORPHA SPINESCENS Kuetz.	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
ULOTHRIX FLACCA (Dillwyn) Thuret				X							X						
ULOTHRIX SP.																X	
ULVA LACTUCA L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ULVARIA OBSCURA V. BLYTTII (Aresch.) Bliding	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
ULVARIA OXYSPERMA (Kuetz.) Bliding	X	X	X		X					X							
UROSPORA PENICILLIFORMIS (Roth) Aresch.						X	X			X				X		X	
UROSPORA WORMSKJOLDII (Mert.) Rosenv.						X											

(continued)

APPENDIX TABLE 6-3. (CONTINUED)

PHAEOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGARUM CLATHRATUM Dumort.[1]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ALARIA ESCULENTA (L.) Grenville	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ASCOPHYLLUM NODOSUM (L.) LeJolis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHORDARIA FLAGELLIFORMIS (Muell.) Agardh	X	X	X	X	X	X				X	X	X		X	X	X	X
DESMARESTIA ACULEATA (L.) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DESMARESTIA VIRIDIS (Muell.) Lamouroux	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
ECTOCARPUS FASCICULATUS Harvey					X	X	X	X	X	X	X			X	X	X	X
ECTOCARPUS SILICULOSUS (Dillwyn) Lyngbye	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X
ECTOCARPUS SP.												X	X				
ELACHISTA FUCICOLA (Velley) Aresch.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS DISTICHUS SSP. DISTICHUS[2]	X	X	X				X					X	X	X	X	X	X
FUCUS DISTICHUS SSP. EDENTATUS (Bach. Pyl.) Powell[3]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS DISTICHUS SSP. EVANESCENS Agardh			X		X	X	X	X	X	X		X	X	X		X	
FUCUS SP.	X	X		X		X			X	X	X	X	X	X	X	X	X
FUCUS VESICULOSUS L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FUCUS VESICULOSUS V. SPIRALIS L.						X							X				
GIFFORDIA GRANULOSA (Sm.) Hamel						X	X										
ISTHMOPLEA SPHAEROPHORA (Carm. ex Harv.) Kjell.												X	X				X
LAMINARIA DIGITATA (Hudson) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LAMINARIA SACCHARINA (L.) Lamouroux	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LAMINARIA SP.			X		X		X		X		X						
LAMINARIOCOLAX TOMENTOSOIDES (Farlow) Kylin															X		
LEATHESIA DIFFORMIS (L.) Aresch.	X	X		X	X	X	X	X	X		X	X	X	X			X
PETALONIA FASCIA (Muell.) O. Kuntze	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
PETALONIA ZOSTERIFOLIA (Reinke) O. Kuntze									X								
PETRODERMA MACULIFORME (Wollny) Kuck.							X										
PHAEOPHYCEAE					X												
PILAYELLA LITTORALIS Kjellman	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
PSEUDOLITHODERMA EXTENSUM (P. Crou. et H. Crou.) S. Lund										X							
SACCORHIZA DERMATODEA (Bach. Pyl.) J. Agardh	X			X													
SCYTOSIPHON LOMENTARIA (Lyngbye) Link	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
SORAPION KJELLMANNI (Wille) Rosenv.								X									
SPHACELARIA CIRROSA (Roth) Agardh		X		X	X	X	X	X	X		X		X				X
SPHACELARIA PLUMOSA Lyngbye							X	X		X		X					
SPHACELARIA RADICANS (Dillwyn) Agardh						X	X	X									
SPONGONEMA TOMENTOSUM Kuetzing			X	X		X	X	X	X	X		X	X	X	X	X	X

(continued)

APPENDIX TABLE 6-3. (CONTINUED)

RHODOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
ACROCHAETIUM FLEXUOSUM					X	X	X										
ACROCHAETIUM SP.	X	X		X													
AHNFELTIA PLICATA (Hudson) Fries	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ANTITHAMNIONELLA FLOCCOSA (Muell.) Whitt.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AUDOUINELLA DAVIESII (Dillwyn) Woelk.														X			X
AUDOUINELLA MEMBRANACEA (Magnus) Papenf.															X	X	
AUDOUINELLA PURPUREA (Lightf.) Woelk.							X		X	X		X					
AUDOUINELLA SP.												X					X
BANGIA ATROPURPUREA (Roth) Agardh						X	X									X	
BONNEMAISONIA HAMIFERA Hariot	X	X			X				X	X	X	X	X	X	X	X	X
CALLITHAMNION SP.			X														
CALLITHAMNION TETRAGONUM (With.) S.F. Gray		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CALLOPHYLLIS CRISTATA (Agardh) Kuetz.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CERAMIUM DESLONGCHAMPII Chauvin					X	X											
CERAMIUM NODULOSUM (Lightf.) Ducluzeau[4]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CERATOCOLAX HARTZII Rosenv.	X	X	X	X	X	X	X	X	X								
CHONDRIA BAILEYANA (Mont.) Harvey	X																
CHONDRUS CRISPUS Stackhouse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CHOREOCOLAX POLYSIPHONIAE Reinsch					X	X	X		X	X	X	X	X		X		X
CLATHROMORPHUM CIRCUMSCRIPTUM (Stroemf.) Foslie	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
CLATHROMORPHUM COMPACTUM (Kjellm.) Foslie				X								X			X		X
COCCOTYLUS TRUNCATUS (Pallas) M.J.Wynne et Heine[5]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
COLACONEMA SECUNDATA	X	X	X														
CORALLINA OFFICINALIS L.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CYSTOCLONIUM PURPUREUM (Hudson) Batters	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DERMATOLITHON PUSTULATUM (Lamour.) Foslie	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DEVALERAEA RAMENTACEUM (L.) Guiry						X	X	X		X		X					
DUMONTIA CONTORTA (S. Gmelin) Rupr.				X		X	X	X	X	X	X	X	X	X	X	X	X
ERYTHROTRICHIA CARNEA (Dillwyn) Agardh	X	X			X	X											
FIMBRIFOLIUM DICHOTOMUM (Lepechin) G. Hansen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FOSLIELLA FARINOSA (Lamour.) Howe	X																
FOSLIELLA LEJOLISII	X	X	X	X	X	X	X	X	X	X		X					
GIGARTINALES					X												
GLOIOSIPHONIA CAPILLARIS (Hudson) Carmich. ex Berk.						X	X										
GYMNOGONGRUS CRENULATUS (Turner) J. Agardh	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X
HILDENBRANDIA RUBRA (Sommerf.) Mengh			X			X	X		X	X	X						
LEPTOPHYTUM FOECUNDUM (Kjellman) Adey	X	X		X	X	X	X		X	X		X	X	X	X		X

(continued)

APPENDIX TABLE 6-3. (CONTINUED)

RHODOPHYTA

SPECIES	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
LEPTOPHYTUM LAEVE (Stroemf.) Adey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LEPTOPHYTUM SP.														X			
LITHOPHYLLUM CORALLINAE (Crouan frat.) Heydr.	X					X											
LITHOTHAMNION GLACIALE Kjellman	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MASTOCARPUS STELLATUS (Stack.) Guiry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MEMBRANOPTERA ALATA (Hudson) Stackhouse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PALMARIA PALMATA (L.) O. Kuntze	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PEYSSONNELIA ROSENVINGII Schmitz	X	X	X	X	X	X	X	X	X	X	X	X			X		X
PHYCODRYS RUBENS (L.) Batters	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA PSEUDOCERANOIDES (S. Gnelin) Newr.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA SP.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PHYLLOPHORA TRAILLII Holmes ex Batters								X	X								
PHYMATOLITHON LAEVIGATUM (Foslie) Foslie			X		X	X	X	X	X	X	X	X	X	X	X	X	X
PHYMATOLITHON LENORMANDII (Aresch.) Adey	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
PHYMATOLITHON RUGULOSUM Adey		X		X	X		X	X				X	X	X	X	X	X
PLUMARIA ELEGANS (Bonhem.) Schmitz			X		X	X	X	X	X	X		X					
POLYIDES ROTUNDUS (Hudson) Greville	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA DENUDATA (Dillwyn) Grev. ex Harvey										X							
POLYSIPHONIA FLEXICAULIS (Harvey) F. Collins	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA HARVEYI J. Bailey						X	X	X	X	X	X	X		X			
POLYSIPHONIA LANOSA (L.) Tandy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA NIGRA (Hudson) Batters			X		X	X	X		X		X			X		X	X
POLYSIPHONIA NIGRESCENS (Hudson) Grev.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POLYSIPHONIA SP.			X														
POLYSIPHONIA URCEOLATA (Lightf. ex Dillwyn) Grev.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORPHYRA LEUCOSTICTA Thuret	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORPHYRA LINEARIS Greville														X			X
PORPHYRA MINIATA (Agardh) Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
PORPHYRA SP.												X	X	X	X	X	X
PORPHYRA UMBILICALIS (L.) J. Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PTILOTA SERRATA Kuetzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RHODOMELA CONFERVOIDES (Hudson) Silva	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RHODOPHYSEMA ELEGANS (P. Cruan et H. Cruan) P. Dixon		X			X		X	X		X	X						
SCAGELIA PYLAISAEI (Mont.) Wynne[6]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TURNERELLA PENNYI (Harvey) Schmitz		X		X													

[1] Formerly called *Agarum cribrosum* (Mert.) Bory.
[2] Name in question.
[3] Recently revised, and to be included under *F. distichus* ssp. *evanescens*
[4] Formerly called *Ceramium rubrum* (Hudson) Agardh.
[5] Formerly called *Phyllophora truncata* (Pallas) A. Zin.
[6] Formerly called *Scagelia corallina* (Rupr.) Hansen.

Stations B1MLW, B1MSL (general collection only), B17, B19, B31 sampled in 1974-1994; B5MLW, B5MSL (general collection only), B35 sampled in 1982-1994; B16 sampled in 1980-1984 and 1986-1994; B13, B04 sampled 1978-1984 and 1986-1994; B34 sampled 1979-1984 and 1986-1994.

Stations B04, B13, B16 sampled in August only.

TABLE OF CONTENTS

PAGE

SUMMARY

The fouling community settling and developing on surface panels has shown predictable seasonal patterns throughout the study. Trends observed during the operational period were similar to previous years. Most measures of community structure (biomass, abundance, number of taxa), and abundances and frequencies of individual taxa indicate fouling community settlement (on panels exposed for one month) and development (on panels exposed for increasing time periods, 1-12 months) showed no significant differences between preoperational and operational periods. Some parameters measured on the year-end fouling community (panels exposed for one year) indicated changes during the operational period that were not consistent between nearfield and farfield areas. This observation is complicated by the weather-related loss of panels at the nearfield station in 1992, reducing the number of observations during the operational period.

LIST OF FIGURES

LIST OF TABLES

7.0 SURFACE PANELS

7.1 INTRODUCTION

The surface fouling panels program was designed to study both settlement patterns and community development in the discharge plume area and the corresponding farfield area. The program is based on the hypothesis that the local fouling community is not adversely influenced due by exposure to the thermal plume. Short-term panels, submerged for one month, provided information on the temporal sequence of settlement activity, while monthly sequential panels, collected after one to twelve months exposure and quarterly sequential panels collected after three, six, nine and 12 months, provided information on species growth and patterns of community development.

7.2 METHODS

7.2.1 Field Methods

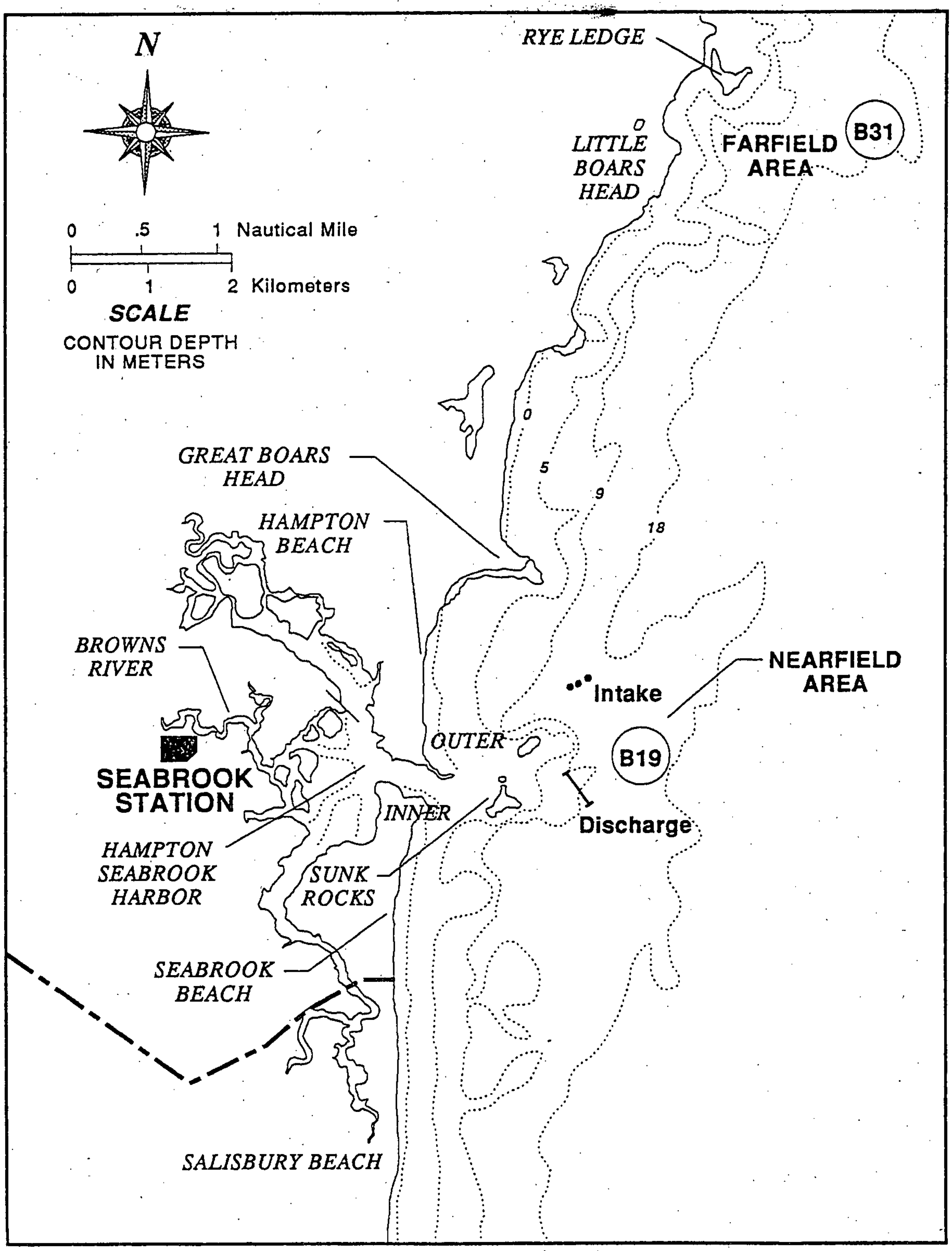
Fouling panels (10.2 cm x 10.2 cm roughened plexiglass plates, bolted to pine blocks of equal size) were collected monthly from January through December at two mid-depth stations (nearfield B19, depth 12.2 m and farfield B31, depth 9.4 m, Figure 7-1). The designation mid-depth was based on the surface to bottom depth in relation to more shallow stations sampled for other programs in this study (i.e., benthos, macroalgae). Panel depths below the water surface ranged from 3 to 6 m depending on the tidal stage. Collections were made at Stations B19 and B31 from 1978 to 1984 and from July 1986 through 1994. Historically, collections were also made at Station B04 from 1978 to 1984 and 1986-1993, and at Station B34 from 1982-1984 and 1986-1993. Information on these stations is presented in NAI and NUS (1994).

Three different exposure strategies were employed at each station: short-term (ST) panels, exposed for one month; monthly sequential (MS) panels, exposed for increasing time periods from 1-12 months and quarterly sequential (QS) panels exposed three, six, nine and 12 months. Two replicate short-term panels and one monthly sequential panel were collected monthly at each of the stations. In addition to the one MS panel, two QS panels were collected in March, June, September and December for a total of three panels. In December, an additional MS panel was collected at each station.

7.2.2 Laboratory Methods

In the laboratory, each panel was dismantled and the panel face photographed. Fouling material was scraped off the wood block and panel support apparatus and rinsed over a 0.25 mm mesh sieve prior to storage or processing. Wood blocks from all MS and QS panels were dried, split, and examined for the presence of wood-boring organisms.

All noncolonial species collected monthly on both ST replicates and one December MS replicate were identified and enumerated. When high abundances of Mytilidae, *Hiatella* sp. and *Anomia* sp. occurred, organisms were enumerated from subsamples generated using a Folsom plankton splitter (NAI 1990). Colonial animals, diatoms and macroalgae on ST panels were quantified by determining the percent frequency of occurrence on the panel face (Mueller-Dombois and Ellenberg 1974; Rastetter and Cooke 1979; NAI 1990). Colonial animals, diatoms, and macroalgal species were recorded as "P" (present, but not quantified) when found in the sample, but not directly on the panel face. For MS and QS panels, the percent frequency of occurrence of selected dominant animals (colonial and noncolonial), and diatom and macroalgal species was estimated using the procedure cited above. Counts were estimated for noncolonial species and an abundance class was recorded. Abundance classes, assigned 1 through 5, consist of ranges of numbers of individuals (1-10, 11-100, ..., >10,000, respectively). Colonial and noncolonial



LEGEND

○ = surface panels

Figure 7-1. Surface panel sampling stations. Seabrook Operational Report, 1994.

dominants, diatoms, and macroalgae were recorded as "P" (present, but not quantified) when found in the sample, but not directly on the panel face. These laboratory methods for MS panels were initiated in 1987.

Random samples of ≥200 Mytilidae and ≥100 *Jassa marmorata* Holmes 1903 individuals found on MS and QS panels and in the residue were measured and recorded in 0.1 mm increments (NAI 1990). All *J. marmorata* and Mytilidae individuals less than 1.0 mm were recorded as <1.0 mm and estimated at 0.5 mm in calculations of mean lengths.

Dry-weight biomass from one of each pair of ST replicates and all MS and QS panels was determined after taxonomic processing by drying all faunal and floral material to a constant weight at 105°C.

7.2.3 Analytical Methods

Analysis of Variance

Recruitment on ST panels, measured on a monthly basis by the number of all taxa, the abundance of noncolonial organisms, and total biomass, indicated the potential for fouling community development. Monthly biomass levels on MS and quarterly biomass levels on QS panels give an indication of community development. Multiway analyses of variance (variables Preop-Op, Year, Station and Month) were used to compare fouling community settlement patterns (as exemplified by species richness, abundance, biomass and selected dominant species on short-term panels) as well as community development (biomass, dominant species on MS and QS panels) between preoperational (1978-1984 and 1986-1989 for short-term panels and MS biomass, 1987-1989 for other MS variables) and operational (1991-1994) years at paired nearfield (B19) and farfield (B31) Stations (the two preoperational periods, 1978-1984 and 1987-1989, were treated as one period and were not statistically compared). A mixed model ANOVA developed by Northeast Utilities, based on recent reviews of the Before-After/Control-Impact (BACI) model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random except operational status (Preop-Op). Sampling time and location were considered random because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). Preoperational periods for each analysis are listed on the appropriate figures and tables. Log (x+1) transformed monthly mean values were used in the ANOVAs for short-term noncolonial total abundance and all selected species abundances (*Jassa marmorata* and Mytilidae), or frequencies of occurrence (*Tubularia* sp.). Non-transformed monthly means were used in the multiway analyses of variance for short-term and monthly sequential biomass and short-term number of taxa. A significant difference in the interaction (Preop-Op X Station) was investigated by comparing the least square means with a paired *t*-test (SAS 1985).

t Test

Community development was also assessed by examining biomass, species richness, and abundance on surface panels exposed for one year. A comparison was made between preoperational (generally 1982-1984 and 1986-1989, which was treated as one period (no statistical comparisons were made between the two periods) and operational (1991-1994) periods at each station using paired *t* tests (SAS 1985). Selected dominant species (Mytilidae and *Jassa marmorata*) lengths from MS and QS panels were also compared using paired *t* tests to determine if average annual lengths varied between the nearfield and farfield station pair in 1994.

7.3 RESULTS

7.3.1 Short-Term Panels

Short-term panels provided information on the seasonal cycles of settlement activity. Seasonal cycles in number of taxa in 1994 and during the operational period were similar to the preoperational trend (Figure 7-2). The number of taxa typically increased during May and June and remained high through September at both B19 and B31. Monthly numbers of taxa during the operational period and 1994 were similar to the preoperational average at both stations with the exception of June and August when 1994 and operational taxa numbers were above the 95% confidence intervals (Figure 7-2). Annual mean numbers of taxa at B19 and B31 were also similar and consistent with both preoperational and operational periods (Table 7-1). Based on ANOVA, there were no significant differences between the preoperational and operational periods or between stations (Table 7-2). The interaction term (Preop-Op X Station) was not significant.

Seasonal patterns of faunal abundance for non-colonial species at mid-depth Stations B19 and B31 during the operational years were similar to those during preoperational years. Historically, abundances remained low from January to May, increased in June and July, then declined from August to December (Figure 7-2). Mean abundances at both stations during 1994 were greater than the preoperational and operational period means, primarily due to the elevated abundances during June, October and November, which were outside the preoperational 95% confidence intervals (Table 7-1, Figure 7-2). There were no significant differences between the preoperational and operational periods, or between stations, and the interaction term (Preop-Op X Station) was also not significant (Table 7-2).

Seasonal settling patterns for the entire fouling community (motile fauna, colonial organisms, macroalgae) were best demonstrated by changes in biomass. The 1994 seasonal trend for biomass at Station B19 followed a pattern similar to the preoperational and operational periods (Table 7-2). Biomass remained low through August in 1994, peaked in September and declined steadily from October through December (Figure 7-2).

At farfield Station B31, the operational period biomass levels remained low throughout the year with two minor peaks, May and November, when biomass levels were above the 95% confidence levels established during the preoperational period. During 1994 at Station B31, biomass levels remained low through July, increased steadily to a pronounced peak in November (nearly 5g/panel), then dropped to low levels in December, consistent with operational and preoperational periods (Figure 7-2). However, on an annual basis, 1994 biomass means at both stations were similar to preoperational and operational means (Table 7-1). ANOVA results indicated there were no significant differences for the main effects (Preop-Op and Station), and the interaction of the main effects (Preop-Op X Station) was not significant (Table 7-2).

Several dominant taxa on short-term panels were monitored to determine their seasonal settlement patterns. Historically, Mytilidae (mainly *Mytilus edulis* Linné 1758 spat) was the most abundant noncolonial taxon. Seasonally, the recruitment pattern for Mytilidae during 1994 at Stations B19 and B31 closely followed the operational and preoperational seasonal trends (Figure 7-3). Low to moderate settlement occurred from January to May. Settlement increased in June and remained high until late fall, following the pattern of larval availability (Section 4.0). In 1994, the June-September period of increased abundance was bimodal at both Stations B19 and B31, with the first peak occurring in July (B19) or June (B31) and the second peak occurring in October at both stations. The 1994 monthly abundances at both stations were higher than the operational and preoperational averages during June, October and November. Annual mean abundances at Stations B19 and B34 in 1994 were higher than their

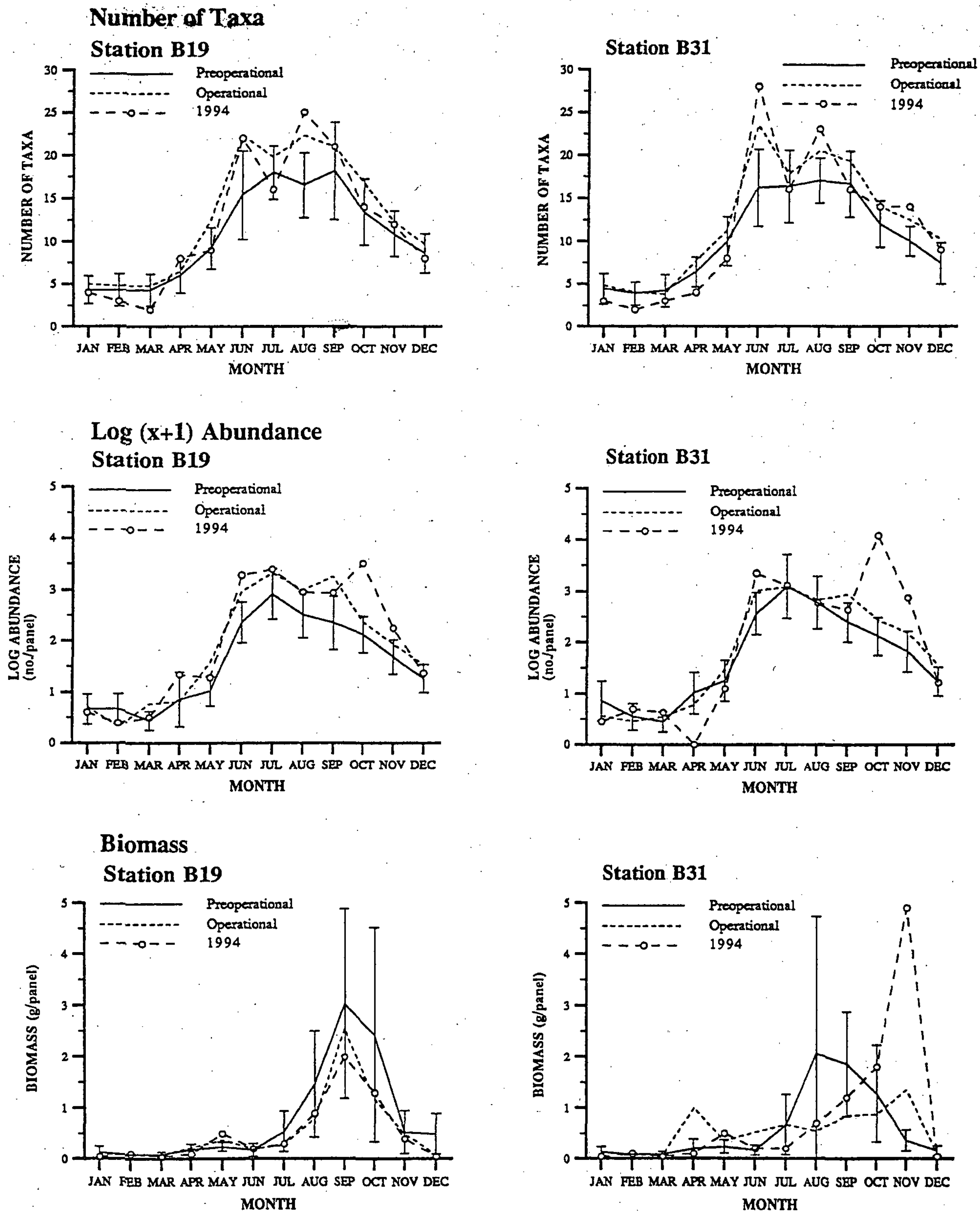


Figure 7-2. Monthly **faunal number of taxa** (on two replicate panels), **abundance**, and **biomass on short-term panels** at the nearfield/farfield station pair B19 and B31. The operational period (1991-1994) and 1994 compared to the means and 95% confidence limits during the preoperational period (1978-1984 and July 1986-December 1989). Seabrook Operational Report, 1994.

TABLE 7-1. MEANS (PER PANEL) AND COEFFICIENT OF VARIATION (%) FOR SELECTED PARAMETERS AND SPECIES ABUNDANCES AT STATIONS B19 AND B31 DURING THE PREOPERATIONAL[b] AND OPERATIONAL PERIODS (1991-1994), AND 1994 MEANS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER/ TAXON	PANEL[a] TYPE	STATION	PREOPERATIONAL[b] MEAN[c]	PREOPERATIONAL[b] CV	1994 MEAN[c]	OPERATIONAL MEAN[c]	OPERATIONAL CV
Total no. of taxa	ST	B19	11.3	30.4	12.0	13.2	14.0
		B31	10.8	25.2	11.7	12.4	5.5
Total noncolonial abundance	ST	B19	42.3	20.5	94.5	74.8	13.3
		B31	53.9	20.5	80.3	65.7	16.2
Total biomass (g)	ST	B19	0.8	40.8	0.5	0.5	56.2
		B31	0.6	67.5	0.8	0.5	57.2
Mytilidae	ST	B19	30.4	22.6	58.9	41.8	21.6
		B31	39.6	21.1	61.2	37.0	27.2
Jassa marmorata	ST	B19	3.0	29.0	2.1	2.1	7.9
		B31	3.9	30.4	4.2	3.2	36.8
Tubularia spp.	ST	B19	1.9	51.2	2.1	1.9	14.6
		B31	1.1	73.6	0.3	0.7	105.7
Biomass (g)	MS	B19	207.8	106.6	127.7	201.1	56.1
		B31	236.8	90.0	139.8	203.9	37.6
Biomass (g)	QS	B19	--	--	151.4	--	--
		B31	--	--	157.0	--	--
Total number of taxa	QS	B19	--	--	22	--	--
		B31	--	--	16	--	--
Laminaria sp.	QS	B19	--	--	0	--	--
		B31	--	--	0	--	--

[a]ST = short term MS = monthly sequential QS = quarterly sequential
[b]Preoperational = 1978-1984; Jul 1986-Dec 1989
[c]Geometric mean for total abundance, and Mytilidae and *J. marmorata* abundance
Percent frequency of occurrence for *Tubularia* sp. Preop. and Op. means are means of annual means.

TABLE 7-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING MONTHLY TOTAL NUMBER OF TAXA, NONCOLONIAL FAUNAL ABUNDANCE, TOTAL BIOMASS, AND SELECTED SPECIES ABUNDANCE OR PERCENT FREQUENCY ON SHORT TERM PANELS AT MID-DEPTH STATION PAIR (B19 AND B31) DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	STATIONS	SOURCE OF VARIATION	df	MS	F[g]
Number of taxa	B19, B31	Preop-Op[a]	1	216.66	1.68 NS
		Year (Preop-Op)[b]	13	137.83	1.61 NS
		Month (Year)[c]	155	80.74	13.53***
		Station[d]	1	26.43	51.92 NS
		Preop-Op X Station[e]	1	1.15	0.10 NS
		Year (Preop-Op) X Station[f]	13	11.04	1.85*
		Error	155	5.97	
Noncolonial faunal abundance	B19, B31	Preop-Op	1	1.69	0.74 NS
		Year (Preop-Op)	13	1.97	0.92 NS
		Month (Year)	155	2.12	24.44***
		Station	1	0.08	0.18 NS
		Preop-Op X Station	1	0.41	4.26 NS
		Year (Preop-Op) X Station	13	0.10	1.12 NS
		Error	155	0.09	
Biomass	B19, B31	Preop-Op	1	3.44	5.79 NS
		Year (Preop-Op)	11	1.74	0.62 NS
		Month (Year)	135	2.33	2.71***
		Station	1	1.09	6.88 NS
		Preop-Op X Station	1	0.21	0.16 NS
		Year (Preop-Op) X Station	11	1.34	1.56 NS
		Error	135	0.86	
Mytilidae	B19, B31	Preop-Op	1	0.15	0.06 NS
		Year (Preop-Op)	13	2.27	0.83 NS
		Month (Year)	155	2.71	25.46***
		Station	1	0.09	0.19 NS
		Preop-Op X Station	1	0.48	3.91 NS
		Year (Preop-Op) X Station	13	0.12	1.14 NS
		Error	155	0.11	

(continued)

TABLE 7-2. (Continued)

PARAMETER	STATIONS	SOURCE OF VARIATION	df	MS	F[g]
Jassa marmorata	B19, B31	Preop-Op	1	0.63	1.63 NS
		Year (Preop-Op)	13	0.58	0.71 NS
		Month (Year)	155	0.69	8.48***
		Station	1	0.81	79.44 NS
		Preop-Op X Station	1	0.02	0.11 NS
		Year (Preop-Op) X Station	13	0.21	2.58**
		Error	155	0.08	
Tubularia sp.	B19, B31	Preop-Op	1	0.17	0.25 NS
		Year (Preop-Op)	13	0.85	0.99 NS
		Month (Year)	155	0.70	5.19***
		Station	1	2.41	22.19 NS
		Preop-Op X Station	1	0.12	0.41 NS
		Year (Preop-Op) X Station	13	0.30	2.20*
		Error	155	0.13	

[a]Preop-Op = 1991-1994 v. previous years (1978-84; July 1986-December 1989) regardless of station
[b]Year nested within preoperational and operational periods regardless of station
[c]Month nested within year regardless of station
[d]Station regardless of year or period
[e]Interaction between main effects Station and Preop-Op
[f]Interaction of station and year nested within preoperational and operational periods
[g]NS = Not significant (p≥0.05)
* = Significant (0.05≥p>0.01)
** = Highly significant (.01≥p>0.001)
*** = Very highly significant (0.001≥p)

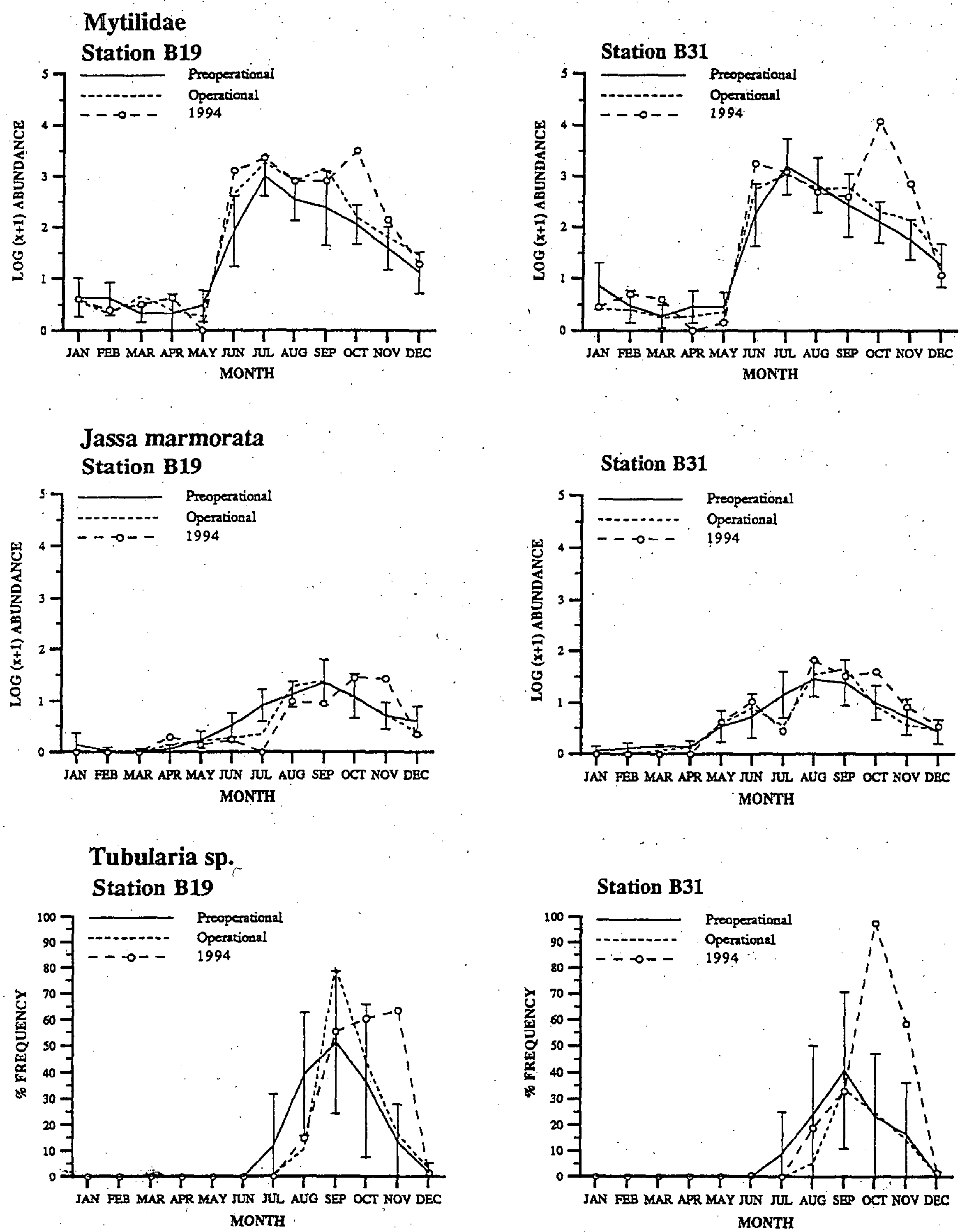


Figure 7-3. Log abundance (no. per panel) of Mytilidae, and *Jassa marmorata* and monthly mean percent frequency of ***Tubularia*** **sp.** on **short-term panels** at nearfield Stations Stations B19 and B31. The operational period (1991-1994) and compared to the mean abundance or percent frequency and 95% confidence limits during the preoperational period (1982-1984 and July 1986-December 1989). Seabrook Operational Report, 1994.

respective preoperational and operational averages (Table 7-1). Based on ANOVA, there were no significant differences between the preoperational and the operational periods, between stations, and the interaction term for these two main effects was not significant.

The amphipod *Jassa marmorata* (Holmes 1903, formerly known as *J. falcata* and revised by Conlan (1990)) is a common fouling organism (Barnard 1957). This species lacks a larval stage, so recruitment occurs through dispersal of juveniles or adults through the water column (Bousfield 1973). In 1994, and throughout the study period, *J. marmorata* abundances at B19 and B31 were low throughout the year with a small late-summer increase (Figure 7-3). Annual mean abundances in 1994 were comparable to the preoperational and operational means (Table 7-1). Based on ANOVA, there were no significant differences between the preoperational and operational periods or between stations (Table 7-2). Similarly, the interaction term was not significant (Table 7-2).

Hydroids of the genus *Tubularia* sp. are dense summer colonizers. They are important as habitat formers and provide a substrate (Field 1982) and food source (Clark 1975) for epifaunal taxa. In previous years, *Tubularia* sp. reached peak cover between July and September (NAI 1992). During 1994 the peak percent cover occurred in November at Station B19 and in October at B31, one to two months later than the preoperational peaks (Figure 7-3). Although the 1994 peak frequencies at both stations were high relative to preoperational and operational peaks, annual means were similar to (B19) or below preoperational and operational means (Table 7-1). There were no significant differences for the main effects (Preop-Op and Station), and the interaction of the main effects (Preop-Op X Station), was not significant (Table 7-2).

7.3.2 Monthly Sequential Panels

Monthly sequential panels provide information on cumulative growth and successional patterns of development within the fouling community. Seasonal patterns of community development were assessed by examining monthly biomass levels. At stations B19 and B31 during the operational and preoperational periods, seasonal biomass patterns on monthly sequential panels remained low from January to June, increasing from July to a peak in late fall/winter (Figure 7-4). During 1994, the summer increase began in June, peaked in August then declined through December at both stations to levels below the preoperational and operational means. On an annual basis, the 1994 mean biomass at both stations was lower than either preoperational or operational means (Table 7-1). Historically there has been high yearly variability in this measurement as is indicated by the high coefficient of variation (CV) at each station during the preoperational period (Table 7-1), resulting in a significant difference among years (Table 7-3). There were no significant differences between the preoperational and operational periods, between stations, and no significant interaction of these main effects.

Seasonal patterns of abundance of the community dominants in 1994 were similar to those observed during the preoperational period in most cases. Mytilidae spat settled heavily on panels in June at both stations (Figure 7-4). Percent frequency of occurrence during 1994 reached a peak in August followed by a general decline through December at both stations. During the operational period Mytilidae monthly percent frequencies of occurrence showed high seasonal variability and were similar to monthly means during the preoperational period.

Mytilidae spat measurements from monthly sequential panels in 1994 were compared to determine if mean lengths differed between the nearfield-farfield station pair. Mytilidae annual mean lengths averaged 1.7 at Station 19 and 2.2 mm at Station 31 in 1994

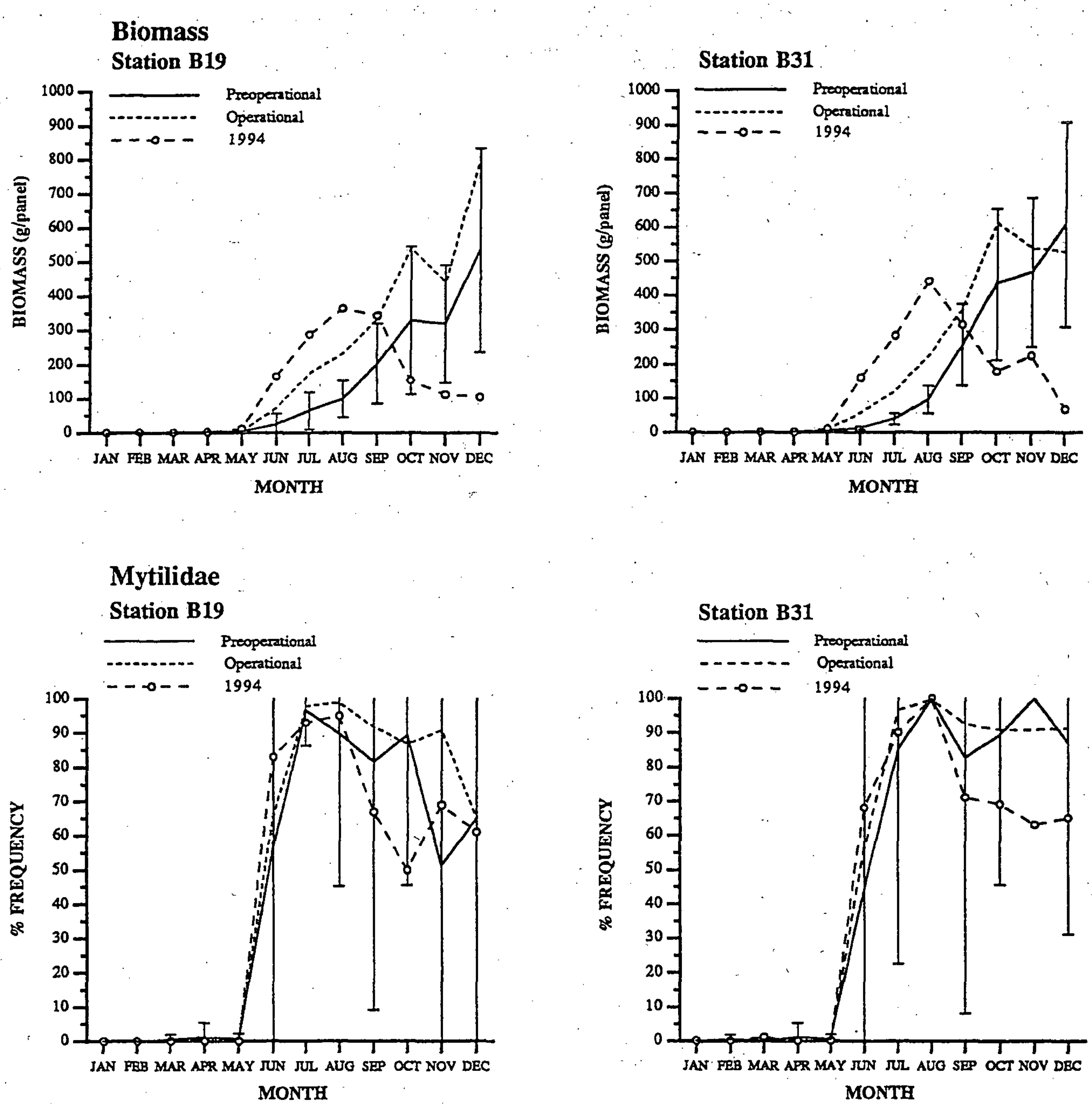


Figure 7-4. Mean **biomass** (g/panel) and **Mytilidae** spat (percent frequency of occurrence) during the operational period (1991-1994) and in 1994 compared to mean and 95% confidence limits during the preoperational period (Stations B19 and B31 from 1978-1984 and July-December 1986-1989 for biomass and 1987-1989 for Mytilidae) on **monthly sequential** panels. Seabrook Operational Report, 1994.

TABLE 7-3. ANOVA RESULTS COMPARING MONTHLY SEQUENTIAL PANEL BIOMASS AT THE MID-DEPTH (B19, B31) STATION PAIR DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

STATIONS	SOURCE OF VARIATION	df	MS	F[g]
Mid-depth B19, B31	Preop-Op[a]	1	1,672.30	0.01 NS
	Year (Preop-Op)[b]	13	294,681.80	2.06*
	Station[c]	1	8,130.21	0.48 NS
	Month (Year)[d]	145	133,139.93	12.44***
	Preop-Op X Station[e]	1	17,361.34	0.89 NS
	Station X Year (Preop-Op)[f]	13	20,818.86	1.95*
	Error	145	10,703.21	

[a]Preop-Op = 1991-1994 v. previous years (1978-84; July 1986-December 1989)
[b]Year nested within preoperational and operational periods regardless of station
[c]Station regardless of year or period
[d]Month nested within year regardless of station
[e]Interaction between main effects
[f]Interaction between station and year nested within the preoperational and operational periods
[g]NS= Not significant (.05>p)
 * = Significant (.01<p≤.05)
 ** = Highly significant (.001<p≤.01)
 *** = Very highly significant (p≤.001)

(Table 7-4), and were not statistically different based on a paired *t*-test ($t=-0.65$, $p>0.5$).

Jassa marmorata percent frequency at Station B19 during the preoperational period was quite variable seasonally. This trend has continued throughout the operational period and was especially noticeable in 1994 (Figure 7-5). However, in general, frequency of occurrence has been low from January to June followed by an increase through the end of the year. The farfield Station B31 has been seasonally less variable during the preoperational period, with frequencies low from January to June, peaking in August followed by a decline through December. The operational period was similar to the preoperational period, although monthly frequencies in 1994 were quite variable from June to December. The average length of *Jassa marmorata* individuals colonizing monthly sequential panels was 3.0mm in 1994 at both stations (Table 7-4).

A *t* test indicated that there were no significant length differences at the nearfield-farfield station pair B19 and B31 ($t=-0.11$ $p>0.9$).

In 1994, *Balanus* sp. (including *Balanus* spp. and *Semibalanus balanoides* L.) first appeared at nearfield Stations B19 and B31 in April, similar to previous years (Figure 7-5). Monthly percent frequency in 1994 remained high at both stations through late spring and summer season, June-September at B19 and May-August at B31, in contrast to the preoperational means. With few exceptions, the operational monthly means at both stations were greater than the preoperational means, but within the established 95% confidence intervals.

During the preoperational period *Tubularia* sp. generally first occurred in April at both stations, with the seasonal pattern of occurrence quite variable from

TABLE 7-4. NEARFIELD/FARFIELD COMPARISON OF ANNUAL MEAN AND STANDARD ERROR OF *JASSA MARMORATA* AND MYTILIDAE SPAT LENGTHS (mm) FROM MONTHLY SEQUENTIAL PANELS COLLECTED IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

		MYTILIDAE SPAT		*JASSA MARMORATA*	
STATION		MEAN LENGTH (mm)	STANDARD ERROR	MEAN LENGTH (mm)	STANDARD ERROR
Mid-depth	B19	1.7	0.44	3.0	0.30
	B31	2.2	0.70	3.0	0.35

year to year as evidenced by the wide 95 % confidence intervals (Figure 7-5). In 1994, at both the nearfield and farfield station, *Tubularia* sp. first appeared in October. However, at B19 frequencies were higher than the established 95% confidence intervals during November and December. At Station B31 *Tubularia* sp. occurred only in October. During the operational period *Tubularia* sp. has occurred later in the year, July at B19 and August at B31, than during preoperational years.

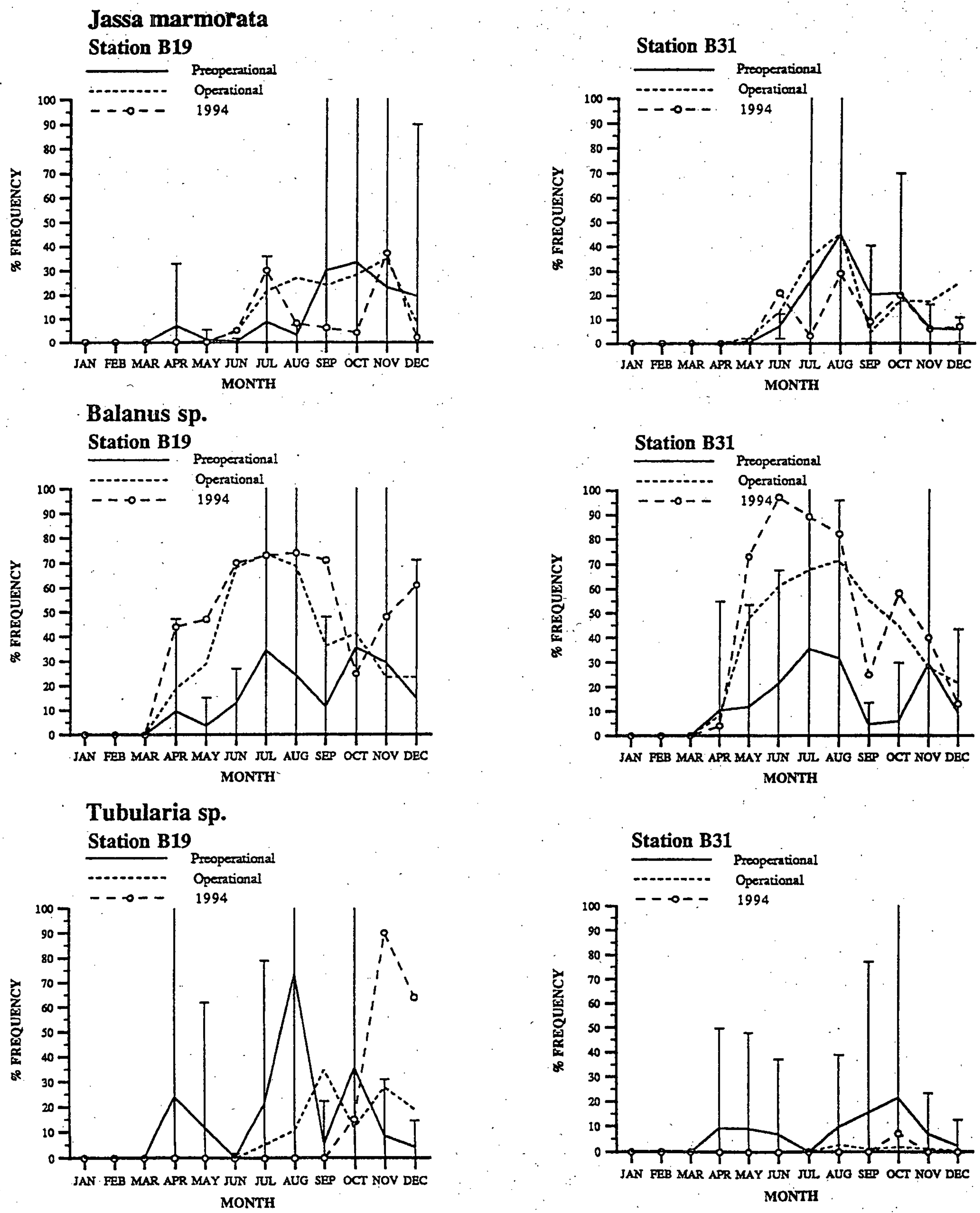


Figure 7-5. Monthly mean percent frequency of occurrence on **monthly sequential panels** for ***Jassa marmorata*, *Balanus*** sp., and ***Tubularia*** sp. at Stations B19 and B31 during the operational period (1991-1994) and in 1994, compared to mean and 95% confidence limits during the preoperational period (1987-1989). Seabrook Operational Report, 1994.

7.3.3 Quarterly Sequential Panels

Quarterly sequential (QS) panels provide additional information on growth and successional patterns of development within the fouling community, and through panel replication, allow assessment of within-station variability. Comparisons can be made with the preoperational period by using the monthly preoperational mean from the MS panel program for those months sampled in the QS program (Figure 7-7). Quarterly biomass levels were used to assess patterns of community development. During 1994 biomass levels were first measurable in June, increased to a peak in September, then declined in December at both Stations B19 and B31 (Figure 7-6). This seasonal trend paralleled those observed in ST panels (Figure 7-2) and MS panels. These programs showed an unusual fall decline in 1994 in comparison to the preoperational period, which showed peak biomass in December (Figures 7-4, 7-6). The annual average biomass in 1994 was similar to that observed for MS panels (Table 7-1). The nearfield and farfield biomass values were similar, also paralleling trends on the MS panels. Within-station variability was high, particularly during peak periods.

The number of taxa on QS panels in 1994 averaged 22 at Stations B19 and 16 and B31 (Table 7-1). The numbers of taxa on QS panels were higher than those on ST panels, a reflection of increased exposure time.

No *Laminaria* sp. were collected on QS panels in 1994 (Table 7-1), consistent with trends observed in the 12-month MS or long-term panels (Section 7.3.4).

Seasonal patterns of abundance of dominant animals on QS panels were examined in 1994. Mytilidae were not present during March but were present during the last three quarters, with percent frequencies between 60% and 85% at both stations (Figure 7-6). Seasonal patterns in 1994 were similar to those observed during the preoperational period. In 1994, *Jassa marmorata* frequency of occurrence was low throughout the year (less than 20%), first appearing in June at both stations and reaching a high in December at Station B19 and September at Station B31. Frequencies in 1994 were lower than the preoperational average at Station B19 but consistent with the previous years (Figure 7-7) at Station B31. In 1994, *Balanus* sp. first appeared in June with approximately 90% frequency of occurrence at both stations followed by a decline through the last quarter (Figure 7-7). Percent frequencies in 1994 were higher than those observed during the preoperational period. *Tubularia* sp. was absent from panels at Station B31, and was rare at Station B19, reaching a peak of only 30% in December (Figure 7-7). Quarterly trends observed during the preoperational period showed average percent frequencies were less than 20%. However, the quarterly sampling regime misses the months where the preoperational average has been highest (Figure 7-5). When present, all selected dominant taxa showed high within-station variability in frequency of occurrence.

Mytilidae spat and *Jassa marmorata* measurements from QS panels in 1994 were compared to determine if mean lengths differed between the nearfield/farfield station pair. Mytilidae annual mean lengths averaged 1.8 mm at Station B19 and 2.8 mm at Station B31 (Table 7-5). This difference was not significant ($t=-0.55$, $p>0.61$). Average lengths of *J. marmorata* individuals colonizing QS panels averaged 2.6 mm at Station B31 and 2.7 mm at Station B19. There was no significant difference in length between the two stations ($t=0.24$, $p>0.82$).

7.3.4 One Year Panels

Community development was also assessed by examining biomass, species richness and abundance on surface panels exposed for one year. Year-end biomass in 1994 was substantially lower than the preoperational mean at both stations. The values were similar to levels observed in 1990, which were the lowest observed to date (NAI 1991). Both stations showed a similar decrease. Mean year-end biomass

7.3.3 Quarterly Sequential Panels

Quarterly sequential (QS) panels provide additional information on growth and successional patterns of development within the fouling community, and through panel replication, allow assessment of within-station variability. Comparisons can be made with the preoperational period by using the monthly preoperational mean from the MS panel program for those months sampled in the QS program (Figure 7-7). Quarterly biomass levels were used to assess patterns of community development. During 1994 biomass levels were first measurable in June, increased to a peak in September, then declined in December at both Stations B19 and B31 (Figure 7-6). This seasonal trend paralleled those observed in ST panels (Figure 7-2) and MS panels. These programs showed an unusual fall decline in 1994 in comparison to the preoperational period, which showed peak biomass in December (Figures 7-4, 7-6). The annual average biomass in 1994 was similar to that observed for MS panels (Table 7-1). The nearfield and farfield biomass values were similar, also paralleling trends on the MS panels. Within-station variability was high, particularly during peak periods.

The number of taxa on QS panels in 1994 averaged 22 at Stations B19 and 16 and B31 (Table 7-1). The numbers of taxa on QS panels were higher than those on ST panels, a reflection of increased exposure time.

No *Laminaria* sp. were collected on QS panels in 1994 (Table 7-1), consistent with trends observed in the 12-month MS or long-term panels (Section 7.3.4).

Seasonal patterns of abundance of dominant animals on QS panels were examined in 1994. Mytilidae were not present during March but were present during the last three quarters, with percent frequencies between 60% and 85% at both stations (Figure 7-6). Seasonal patterns in 1994 were similar to those observed during the preoperational period. In 1994, *Jassa marmorata* frequency of occurrence was low throughout the year (less than 20%), first appearing in June at both stations and reaching a high in December at Station B19 and September at Station B31. Frequencies in 1994 were lower than the preoperational average at Station B19 but consistent with the previous years at Station B31 (Figure 7-7). In 1994, *Balanus* sp. first appeared in June with approximately 90% frequency of occurrence at both stations followed by a decline through the last quarter (Figure 7-7). Percent frequencies in 1994 were higher than those observed during the preoperational period. *Tubularia* sp. was absent from panels at Station B31, and was rare at Station B19, reaching a peak of only 30% in December (Figure 7-7). Quarterly trends observed during the preoperational period showed average percent frequencies were less than 20%. However, the quarterly sampling regime misses the months where the preoperational average has been highest (Figure 7-5). When present, all selected dominant taxa showed high within-station variability in frequency of occurrence.

Mytilidae spat and *Jassa marmorata* measurements from QS panels in 1994 were compared to determine if mean lengths differed between the nearfield/farfield station pair. Mytilidae annual mean lengths averaged 1.8 mm at Station B19 and 2.8 mm at Station B31 (Table 7-5). This difference was not significant ($t=-0.55$, $p>0.61$). Average lengths of *J. marmorata* individuals colonizing QS panels averaged 2.6 mm at Station B31 and 2.7 mm at Station B19. There was no significant difference in length between the two stations ($t=0.24$, $p>0.82$).

7.3.4 One Year Panels

Community development was also assessed by examining biomass, species richness and abundance on surface panels exposed for one year. Year-end biomass in 1994 was substantially lower than the preoperational mean at both stations. The values were similar to levels observed in 1990, which were the lowest observed to date (NAI 1991). Both stations showed a similar decrease. Mean year-end biomass

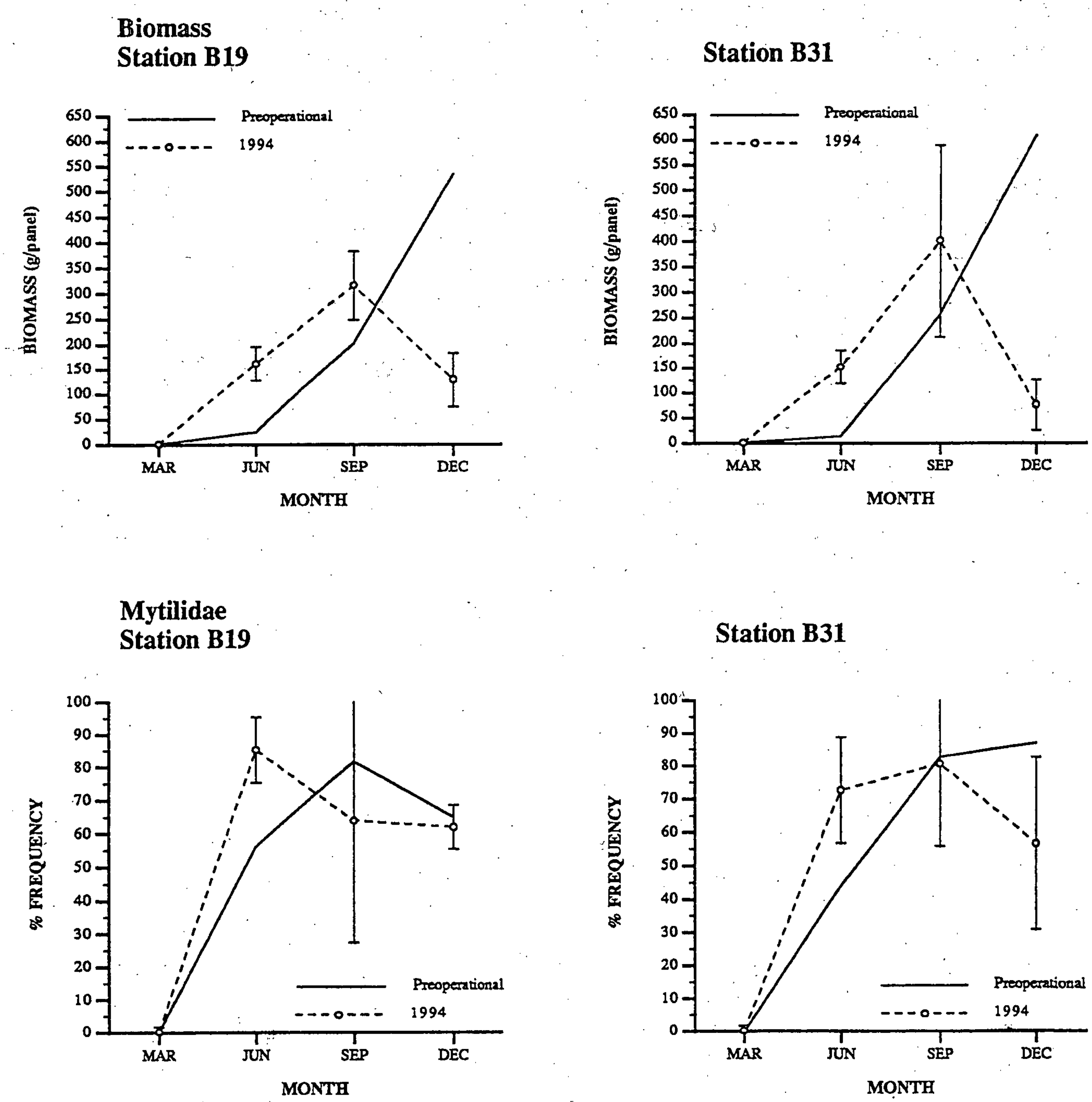


Figure 7-6. Mean biomass (g/panel) and Mytilidae spat (percent frequency of occurence) and 95% confidence limits (n=3) during 1994 from Stations B19 and B31 on **Quarterly Sequential** panels compared to the monthly preoperational means (1987-1989). Seabrook Operational Report, 1994.

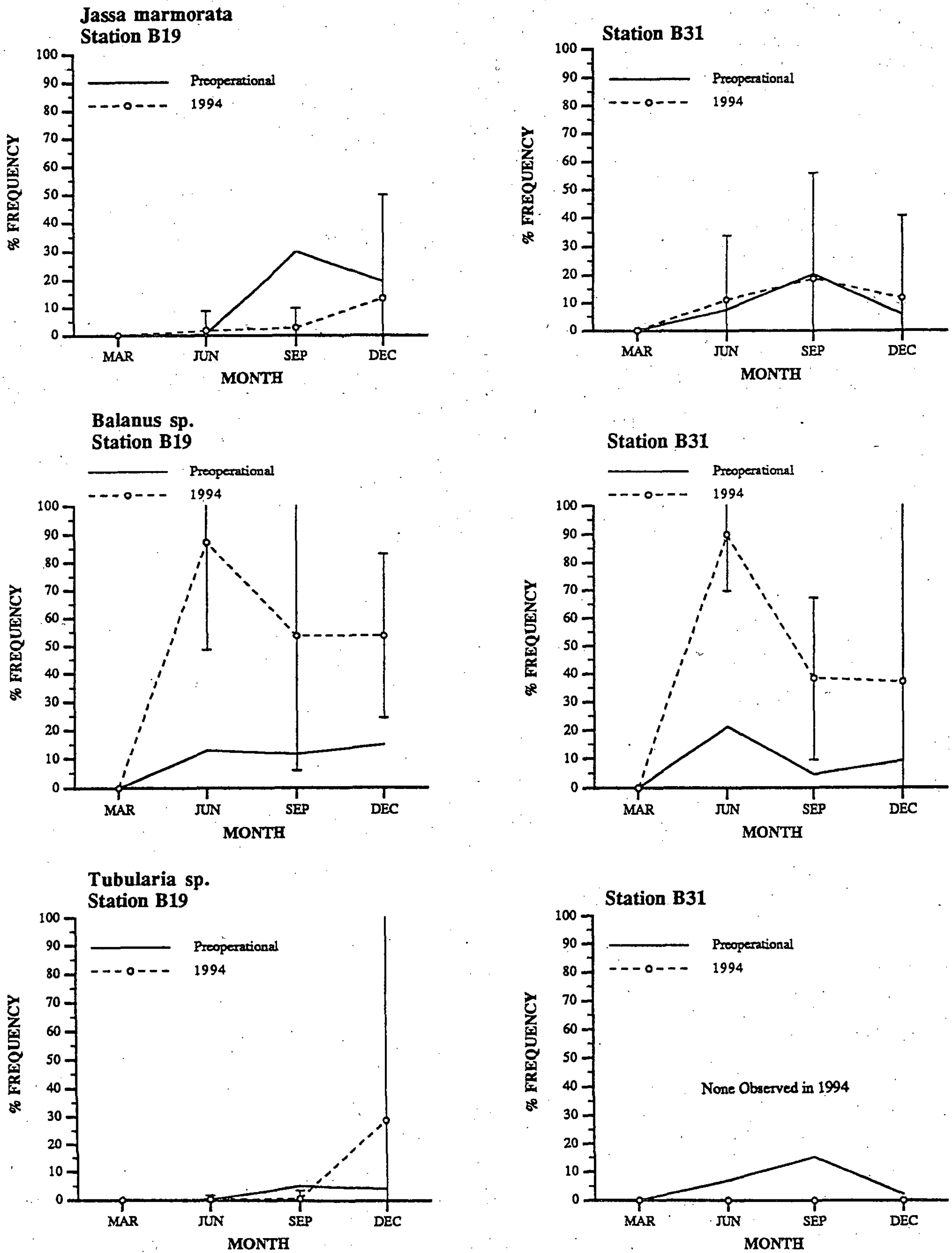


Figure 7-7. Mean percent frequency of occurence and 95% confidence limits (n=3) on **Quarterly Sequential** panels for *Jassa marmorata*, *Balanus* sp. and *Tubularia* sp. at Stations B19 and B31 during 1994 compared to the monthly preoperational means (1987-1989). Seabrook Operational Report, 1994.

TABLE 7-5. NEARFIELD/FARFIELD COMPARISON OF ANNUAL MEAN AND STANDARD ERROR OF MYTILIDAE SPAT AND *JASSA MARMORATA* LENGTHS (mm) FROM QUARTERLY SEQUENTIAL PANELS COLLECTED IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

	MYTILIDAE SPAT		*JASSA MARMORATA*	
STATION	MEAN LENGTH (mm)	STANDARD ERROR	MEAN LENGTH (mm)	STANDARD ERROR
B19	1.8	0.97	2.7	0.31
B31	2.8	1.60	2.6	0.35

during the operational period was not significantly different from the preoperational mean at both Stations B19 and B31 (Table 7-6).

The number of noncolonial taxa in 1994 was higher than the preoperational mean at Station B19 and lower than the preoperational mean at B31 (Table 7-6). The operational mean was significantly greater than the preoperational mean at Station B19, while there were no significant differences between the preoperational and operational means at Station B31. Numbers of noncolonial taxa at both stations were substantially lower than those in 1993 (NAI and NUS 1994), and lower than the averages for the operational period (Table 7-6).

Non-colonial abundance in 1994 was less than both the preoperational and operational mean abundance (Table 7-6). However, there were no significant differences between the preoperational and operational means at either station. Noncolonial abundance at the farfield station was substantially higher than at the nearfield station during the operational period, consistent with the trend observed during the preoperational period.

Laminaria sp. blade counts on one-year panels have been low during most years of this study. At nearfield Station B19, *Laminaria* sp. did not occur during 3 of the 7 preoperational years (NAI 1991, 1992, 1993) and has not occurred during any operational year. *Laminaria* sp. did occur during each preoperational year at farfield Station B31. During 1994, *Laminaria* sp. did not occur at either of the mid-depth stations (Table 7-6). Differences between operational and preoperational means were significant only at the farfield Station B31.

7.4 DISCUSSION

The surface panels program was established to document the temporal and spatial patterns in the recruitment and development of the fouling community and to monitor the effects of Seabrook Station's operation on the community. The characteristics of Seabrook Station's thermal plume have been estimated from hydrothermal modeling studies (Teyssandier et al. 1974) and confirmed in recent field studies (Padmanabhan and Heckler 1991). Results from field studies generally confirmed initial model results, indicating that the discharge plume area was relatively small under the conditions tested. For example, the isotherm of a surface temperature increase of 3°F (1.7°C) covered a relatively small 32-acre area in the vicinity of the discharge area. Water temperatures were elevated at most by 1-2°F (under the conditions tested) in the approximate area where panels are deployed.

TABLE 7-6. DRY WEIGHT BIOMASS, NONCOLONIAL NUMBER OF TAXA, ABUNDANCE, AND *LAMINARIA* SP. COUNTS ON SURFACE FOULING PANELS SUBMERGED FOR ONE YEAR AT STATIONS B19 AND B31. MEAN AND STANDARD DEVIATION FOR THE PREOPERATIONAL PERIOD (1982-1984 AND 1986-1989) AND MEAN FOR 1994, AND THE OPERATIONAL PERIOD (1991-1994). SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL		OPERATIONAL	
	STATION	MEAN	S.D.	1994	MEAN
BIOMASS (g/panel)	B19	661.5	476.88	103.4	798.3 NS
	B31	708.9	523.86	67.6	523.1 NS
NUMBER OF NON-COLONIAL TAXA (No./panel)	B19	21.3	4.42	27.0	31.3 *
	B31	25.9	4.60	15.0	31.3 NS
NONCOLONIAL ABUNDANCE (No./panel)	B19	13,905.1	7,046.48	10,074.0	29,078.7 NS
	B31	21,967.6	18,398.27	11,188.0	59,612.0 NS
LAMINARIA SP.** (No./panel)	B19	24.3	36.91	0.0	0.0 NS
	B31	39.3	29.24	0.0	5.8 *

*.01<p≤.05 when preoperational and operational means tested for equality with a single sample *t* test (SAS 1985)
**not determined to species due to juvenile condition of most plants

The community settling and developing on surface panels has shown predictable seasonal patterns throughout the study, as evidenced by both measures of community structure (biomass, abundance, and number of taxa) and abundance or percent frequency of occurrence of dominant taxa. During 1994, abundance and biomass varied seasonally on both ST and MS panels, and nearfield and farfield stations showed similar trends. Fall MS biomass in 1994 showed an unusual decrease at both stations. In most cases the operational means closely followed the historical patterns established during the preoperational period (Table 7-7), indicating that settlement and development of the local fouling community remains unaffected by the operation of Seabrook Station.

The year-end values for parameters measured for surface panels exposed for twelve months provide information on long-term successional development of the fouling community and reflect cumulative effects of biological processes such as recruitment, growth, and competition. One parameter showed a difference during the operational period that was not consistent between the nearfield-farfield station pair (Table 7-7). This assessment is complicated by the weather-related loss of the nearfield mid-depth panel in 1992. The mean number of non-colonial taxa was significantly higher at Station B19 (nearfield) during the operational period. Although the number of taxa was higher at the farfield station, this difference was not significant. A similar trend was observed in 1993 (NAI and NUS 1994), where significant differences were noted at both stations. This parameter will be monitored closely in the future. The algal species *Laminaria* sp. did not appear in 1994 at any station, which appears to be a continuation of a declining trend that began during the preoperational years (NAI 1991, 1992, NAI 1993, NAI and NUS 1994). However, the differences in abundance of *Laminaria* during the operational period were significant only at the mid-depth farfield Station B31. There is no indication that this effect is due to Seabrook Station operation, since the decline occurred at both nearfield and farfield stations and began prior to the operation of Seabrook Station.

The quarterly sequential panel program was initiated in 1994 to better assess patterns of settlement and development by providing information on within-station variability. Given the varying exposure period (3, 6, 9 and 12 months), the program parallels that of the community development (1-12 month's exposure, MS) program. The methodology used is similar to the MS program, relying on percent frequencies for dominant taxa. Quarterly biomass values were similar to those observed in the MS program in 1994, which was an atypical year. The 1994 monthly MS and QS biomass levels showed an unusual fall decrease at both stations, likely a result of weather-related die-off. Selected species Mytilidae, *Balanus* sp. and *Jassa marmorata* collected in the QS program showed similar seasonal patterns and frequencies to the MS program, as would be expected. *Tubularia* sp. typically has an August peak that is not detected by the QS program. QS panel analyses demonstrate within-station variability was high for all parameters, a factor which should be taken into account in interpretation of MS and ST results.

Overall, there is no conclusive evidence of an impact to the local fouling community from the operation of Seabrook Station.

TABLE 7-7. SUMMARY OF EVALUATION OF DISCHARGE PLUME EFFECTS ON THE FOULING COMMUNITY IN VICINITY OF SEABROOK STATION. SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY	DEPTH ZONE	PARAMETER[a]	OPERATIONAL PERIOD SIMILAR TO PREVIOUS YEARS?	NEARFIELD-FARFIELD DIFFERENCES CONSISTENT WITH PREVIOUS YEARS?[b]
Fouling community: Settlement[c]	Mid-depth	Abundance	yes	yes
		No. of taxa	yes	yes
		Biomass	yes	yes
Fouling community: Development-MS[c]	Mid-depth	Biomass	yes	yes
Fouling community: Development-year end[c]	Mid-depth	Abundance	yes	yes
		No. of taxa	no	NF:OP>Preop FF:OP=Preop
		Biomass	yes	yes
Fouling community: Settlement[c]	Mid-depth	Mytilidae	yes	yes yes
	Mid-depth	<u>Jassa marmorata</u>	yes	yes
	Mid-depth	<u>Tubularia</u> sp.	yes	yes

[a]Abundance, number of taxa, biomass, total density, and frequency of occurrence evaluated using ANOVA, or *t* test
[b]NF = nearfield FF = farfield
[c]Settlement = short term panels; Development = MS panels; MS = Monthly sequential; year end = one year exposure

7.5 REFERENCES CITED

Barnard, J. Laurens. 1957. Amphipod crustaceans as fouling organisms in Los Angeles-Long Beach Harbors, with reference to the influence of seawater turbidity. California Department of Fish and Game. Contribution No. 212. Allan Hancock Foundation.

Bousfield, E.L. 1973. Shallow-Water Gammaridean Amphipoda of New England. Comstock Pub. Ithaca, NY. 312 pp.

Clark, K.B. 1975. Nudibranch life cycles in the northwest Atlantic and their relationship to the ecology of fouling communities. Helgo. Wiss. Meere. 27-28-69.

Conlan, Kathleen E. 1990. Revision of the crustacean amphipod; genus *Jassa* Leach (Corophioidea: Ischyroceridae. Can. J. Zool. 68:2031-2075.

Field, B. 1982. Structural analysis of fouling community development in the Damariscotta River estuary, Maine. J. Exp. Biol. Ecol. 57:25-33.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, NY. 547 pp.

Normandeau Associates Inc. 1988. Seabrook Environmental Studies. 1987. A characterization of baseline conditions in the Hampton-Seabrook area. 1975-1987. A preoperational study for Seabrook Station. Tech. Rep. XIX-II.

__________. 1990. Seabrook Environmental Studies. 1989 Data Report. Tech. Rep. XXI-I.

__________. 1991. Seabrook Environmental Studies, 1990. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXII-II.

__________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during operation of Seabrook Station. Tech. Rep. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-I.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area During the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

Padmanabhan, M., and G.E. Hecker. 1991. Comparative evaluation of hydraulic model and field thermal plume data. Seabrook Nuclear Power Station. Alden Res. Lab., Inc. 12 p.

Rastetter, E.B. and W.J. Cooke. 1979. Response of marine fouling communities to sewage abatement in Kaneohe Bay, Oahu, Hawaii. Mar. Biol. 53:271-280.

SAS Institute, Inc. 1985. User's Guide: Statistics, Version 5 Edition. SAS Inst. Inc. Cary, NC 956 pp.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. xxi + 776 pp.

Stewart-Oaten,A., W.M. Murdoch and K.R. Parker. 1986. Environmental impact assessment: "Pseudoreplication in time?. Ecology. 67:920-940.

Sutherland, John P., and Ronald H. Karlson. 1977. Development and stability of the fouling community at Beaufort, North Carolina. Ecol. Monog. 47:425-446.

Teyssandier, R.G., W.W. Durgin, and G.E. Hecker. 1974. Hydrothermal studies of diffuser discharge in the coastal environment: Seabrook Station. Alden Res. Lab. Rep. No. 86-24.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect enviromnental disturbances. Ecological Applications. 4(1):3-15.

TABLE OF CONTENTS

SUMMARY

Epibenthic crustacea in the study area include the American lobster and rock and Jonah crabs, important invertebrate predators in the region. Lobster larvae have historically been relatively rare in the study area, averaging less than 1 per 1000 square meters. The larvae, predominantly Stage IV, typically had peak abundances in July and August. Larval abundance during the operational period was significantly greater than during the preoperational period at all three stations. Adult lobster catches (all sizes) were typically highest from August through November. A similar seasonal cycle was observed during the operational period, but catches showed a significant decline that was most pronounced at the farfield station. The decrease is thought to be related to increased fishing pressure. Catches of legal sized lobsters remained unchanged during the operational period. There was no evidence of an effect from Seabrook Station operation.

Cancer crab larvae were most abundant in the study area from June through September. Average densities during the operational period were not significantly different from the preoperational period at all three stations. There were no significant differences in adult Jonah crab catches between the preoperational and operational periods, or between stations. Adult rock crabs were less abundant than their congener, likely due to preference for sandy substrate, which is less common in the study area than hard substrate. No differences in rock crab catch were observed during the operational period in comparison to the preoperational period or between stations. There was no evidence of an effect of Seabrook Station on local Jonah or rock crab populations.

LIST OF FIGURES

LIST OF TABLES

8.0 EPIBENTHIC CRUSTACEA

8.1 INTRODUCTION

The objective of the epibenthic crustacea monitoring program was to determine the monthly, spatial, and annual trends in larval density and catch per unit effort for the juvenile and adult stages of American lobster (*Homarus americanus* Milne-Edwards 1837), Jonah crab (*Cancer borealis* Stimpson 1859), and rock crab (*Cancer irroratus* Say 1817). Analyses were done to determine if the discharge from Seabrook Station had any measurable effect on these species. The planktonic larval stages of *Cancer* species may potentially be affected by entrainment within the cooling system of the plant where mechanical damage or temperature increase may cause death or stress. Lobster larvae may be entrained in the buoyant discharge plume, which may affect survival, successful molting, and settlement to the bottom. The benthic (bottom dwelling) stages of these crustaceans may be impinged at the intake or be subject to possible discharge effects such as increased turbidity.

8.2 METHODS

8.2.1 Field Methods

Lobster Larvae (Neuston)

To monitor the distribution of American lobster larvae, neuston samples were collected once a week, during the day, from May through October along horseshoe-shaped tows approximately 1/2 mile (800 m) long on a side. These tows were centered at the intake (P2), discharge (P5), and farfield (P7) stations (Figure 8-1). Collections began in 1978 at Station P2, in 1982 at Station P7, and in 1988 at Station P5. Collections were made with a 1-mm mesh net (1 m deep x 2 m wide x 4.5 m long) fitted with a General Oceanics® flowmeter and a 40-lb depressor. Thirty minute surface tows were taken with the bottom of the net mouth approximately 0.5 m below the surface. The area sampled averaged about 3732 m^2 (generally ranging from 2874 to 4300 m^2).

Cancer spp. Larvae (Macrozooplankton)

Cancer spp. larvae (*C. borealis* and *C. irroratus*) and other macrozooplankton were sampled four times per month from January through December. On each date, four replicate (two paired-sequential) oblique tows were made at night with 1-m diameter, 0.505-mm mesh nets at the intake (P2), discharge (P5), and farfield (P7) stations (Figure 8-1). Collections began in 1978 at Station P2 and in 1982 at Station P7. Collections at Station P5 occurred from 1978-1981, July-December 1986, and from 1987 to the present. No collections were made in 1985 at any station. The nets with depressors were set off the stern and towed for 10 minutes while varying the boat speed, causing the net to sink to approximately 2 m off the bottom and to rise to the surface at least twice during the tow. If nets became clogged due to plankton blooms, tows were shortened to 6 minutes. The volume filtered was determined with a General Oceanics® digital flowmeter. Upon retrieval, each net was thoroughly washed down with filtered seawater and the contents preserved in 5-10% borax-buffered formalin.

Juveniles and Adults (Lobster Traps)

American lobster, Jonah crab and rock crab were collected at the nearfield discharge station (L1) and a farfield station located off Rye Ledge (L7) (Figure 8-1). Collections began at Station L1 in 1975 and at Station L7 in 1982. Fifteen 25.4 mm (1 in) mesh experimental lobster traps without escape vents were retrieved at two-day intervals, approximately three times per week from June through November. Lobster carapace lengths were recorded in the field in the following 12.7 mm (1/2 in) size classes:

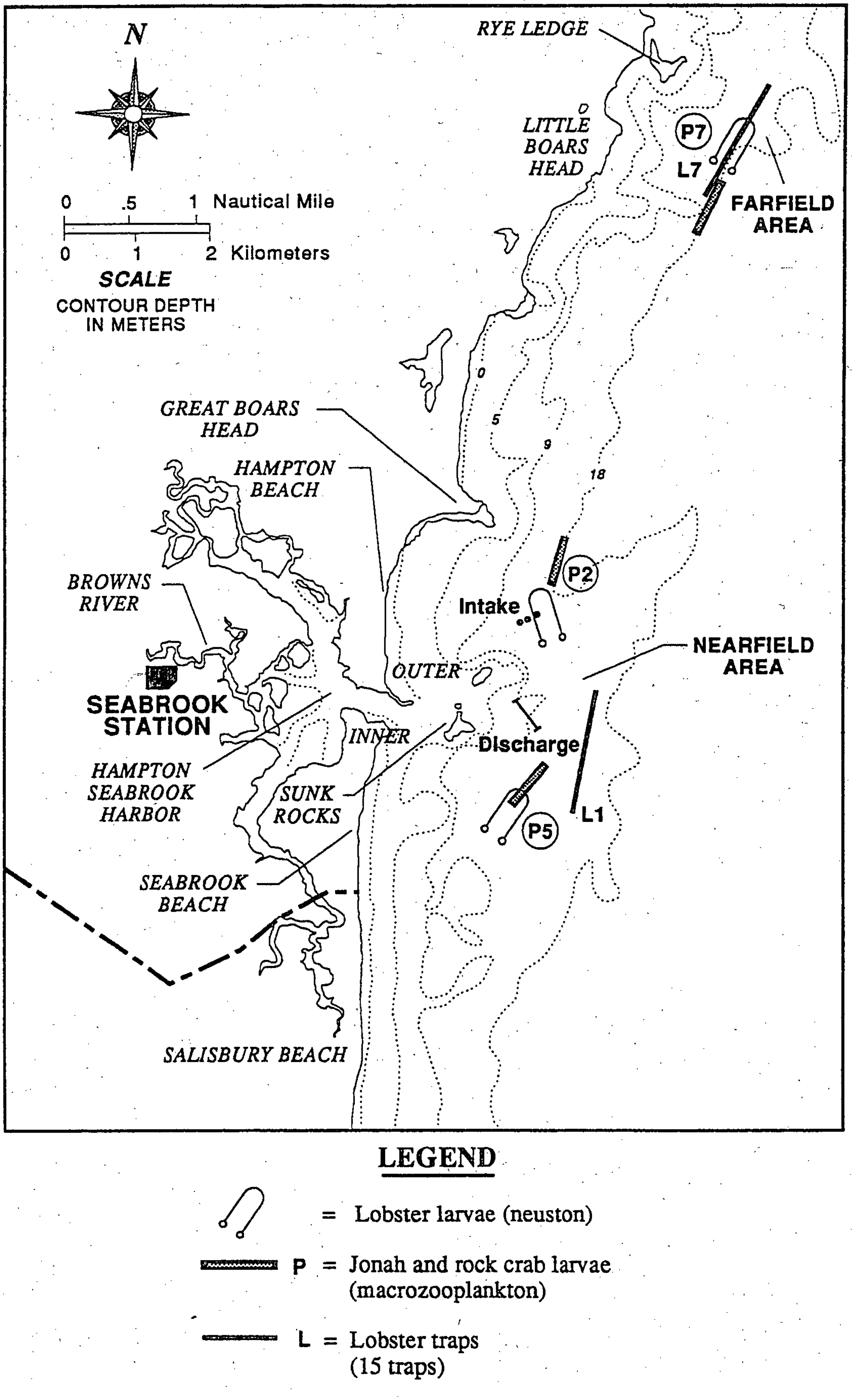


Figure 8-1. Epibenthic crustacea (American lobster, Jonah and rock crabs) sampling stations. Seabrook Operational Report, 1994.

Size Class (mm)	Range (inches)
<54	<2-1/8
54-67	2-1/8 to 2-5/8
68-79	>2-5/8 to 3-1/8
80-92	>3-1/8 to 3-5/8
93-105	>3-5/8 to 4-1/8
>105	>4-1/8

Lobsters in the 80-92 mm (>3-1/8 to 3-5/8 in) class were classified in two groups separating the legal and sublegal lobsters based on the current State of New Hampshire regulations. Beginning in 1990, lobsters measuring greater than 83 mm (3-1/4 in) were classified as legal. The total numbers of males, females, and egg-bearing females were also recorded.

Impingement Collections

See Section 5.2.2.4 for a description of impingement collection procedures.

8.2.2 Laboratory Methods

In the laboratory, lobster larvae (neuston) samples were rinsed through a 1-mm mesh sieve, and sorted. The live lobster larvae (Stages I-IV) were enumerated and released into Hampton Harbor. Those samples that were not processed the day of collection were preserved in 6% formalin (NAI 1991).

Cancer spp. larvae from macrozooplankton samples were analyzed from three of the four tows (randomly selected) at each station for two of the four sampling periods each month (usually the first and third weeks). In the laboratory, each sample was split with a Folsom plankton splitter into fractions that provided counts of at least 30 individual *Cancer* spp. larvae. A maximum of 100 ml of settled plankton, generally 1/4 of the original sample volume, was analyzed. *Cancer* spp. larvae were identified to developmental stage and enumerated (NAI 1991).

In the laboratory, juvenile and adult *Cancer* spp. were identified, enumerated and sexed, and the carapace width was measured to the nearest millimeter. In addition, the number of egg-bearing females was recorded.

8.2.3 Analytical Methods

An analysis of variance (SAS 1985) was used on log (x +1) transformed densities of lobster and *Cancer* spp. larvae to determine differences between the average abundances for the operational (1991-1994) and recent preoperational (1988-1989, when all three stations were sampled concurrently) periods at the nearfield, intake, and farfield stations. Monthly geometric means were calculated for lobster larvae and for *Cancer* spp. larvae. The untransformed monthly arithmetic mean CPUE (no. per 15 traps) was used for juvenile and adult lobsters and crabs for the preoperational (1982-1989) and operational (1991-1994) periods.

A mixed model ANOVA developed by Northeast Utilities, based on recent reviews of the BACI model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random, except operational status (Preop-Op). Time and location of sampling of sampling were considered random factors because both sampling dates and selected locations represented only a fraction of the possible times and locations (Underwood 1994). When the F-value was significant for the interaction term (Preop-Op X Station), or class variable (Station, Preop-Op), the least squares means procedure (SAS 1985) was used to evaluate differences among least squares means with a t-test at alpha ≤ 0.05.

8.3 RESULTS

8.3.1 American Lobster

Lobster Larvae

Annual mean densities in 1994 continued the trends observed in 1991 through 1993 (NAI 1992, 1993; NAI and NUS 1994). Lobster larvae densities during 1994 were higher than preoperational (1988-1989) densities at each station, and lower than the operational (1990-1994) densities at Stations P2 and P5 (Table 8-1). Average larval densities during the four-year operational period were significantly higher than the average densities during the preoperational period (Table 8-2). There were no significant differences among the three stations during the 1988-1994 study period. The interaction term (Preop-Op X Station) was not significant, indicating increases between the preoperational and operational periods were consistent among stations.

Monthly trends in 1994 were similar to previous years (Figure 8-2). In 1994, high densities of lobster larvae occurred at the nearfield station in June, July and August, while low densities occurred in May, September and October. The timing of peak lobster larvae abundance during the preoperational period was consistent with other studies in New England, indicating that peak abundances occur sometime from June through August (Fogarty and Lawton 1983; NUSCO 1995). Other studies relate first appearance of lobster larvae with a surface temperature of 12.5°C (Harding et al. 1983), which typically occurs in June or July in the study area (Section 2.0).

The increases in density in 1994 and the operational period, compared to the preoperational period, were due mainly to increases in Stage IV larvae, historically the most numerous of the four larval stages (Figure 8-2). Stage I larvae were the second-most abundant, in 1994 and during the preoperational and operational period. Stage II and Stage III larvae have historically been least abundant. Stage I lobster predominated in the majority of other studies, mainly from southern New England, as reviewed by Fogarty and Lawton (1983). Stage IV lobsters, however, were most numerous in some years in Cape Cod and Buzzards Bay, and Long Island Sound (Fogarty and Lawton 1983), as well as in collections from the coast of southwestern Nova Scotia to New Hampshire (Harding et al. 1983). These Stage IV larvae, including those in the study area, are hypothesized to originate, at least in part, offshore in the warm waters of the southwestern Gulf of Maine and Georges Bank (Harding et al. 1983, Harding and Trites 1988).

Total Catch: Legal- and Sublegal-Sized

The 1994 total catch per unit effort (CPUE) for lobster was lower than the average CPUE during both the preoperational (1982-89) and operational periods (1991-94) at both the nearfield (L1) and farfield (L7) stations (Table 8-1). Both stations showed a decline in the average catch between the preoperational and operational periods; however, continuing a trend observed in 1993 (NAI and NUS 1994), the operational period decline was greater at the farfield station when compared to the nearfield station, resulting in a significant Preop-Op X Station interaction term (Table 8-2, Figure 8-3).

In 1994, the monthly trend in total CPUE was similar to that observed during the preoperational period (Figure 8-2). The monthly total catch peaked in September and October, and was below the operational and preoperational averages for all months (Figure 8-2). The monthly pattern during the operational period (1991-94) was similar to the preoperational period, but monthly operational averages were usually below preoperational averages (Figure 8-2). Monthly variations in lobster catch were due in part to regional temperature changes. Warmer temperatures tend to increase the activity level of adults, in turn enhancing the likelihood of being caught (McLeese and Wilder

TABLE 8-1. GEOMETRIC MEAN ABUNDANCE (LARVAE: LOBSTER = NO./1000 m^2; *CANCER* SPP. = NO./1000 m^3) OR ARITHMETIC MEAN CATCH PER UNIT EFFORT (NO./15 TRAPS) AND THE COEFFICIENT OF VARIATION (CV,%) OF EPIBENTHIC CRUSTACEA AT NEARFIELD (P2, P5, L1) AND FARFIELD (P7, L7) STATIONS DURING THE PREOPERATIONAL AND OPERATIONAL PERIODS AND IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL[a]		1994[b]	OPERATIONAL[c]	
SPECIES (period sampled)	STATION	MEAN	CV	MEAN	MEAN	CV
Lobster larvae (May-Oct)	P2	0.4	22.7	0.7	0.9	24.5
	P5	0.4	33.3	0.5	0.8	27.7
	P7	0.6	28.0	1.5	1.2	22.6
Lobster, total (Jun-Nov)	L1	70.7	20.4	52.4	56.7	13.8
	L7	87.2	16.9	52.4	56.7	7.3
Lobster, legal (Jun-Nov)	L1	6.0	29.6	2.7	2.4	13.5
	L7	6.0	37.2	1.4	1.9	26.3
Lobster, female (Jun-Nov)	L1	39.0	19.4	29.8	31.0	15.5
	L7	47.2	17.0	30.1	30.9	9.7
Lobster, egg-bearing (Jun-Nov)	L1	0.6	17.1	0.3	0.5	28.1
	L7	0.6	31.8	0.5	0.8	28.6
Cancer spp. larvae (May-Sep)[d]	P2	9,532.4	5.2	4,174.1	13,154.7	9.6
	P5	5,063.9	5.6	3,502.6	9,634.3	8.1
	P7	8,426.2	5.7	6,509.5	13,484.4	7.3
Jonah crab, total (Jun-Nov)	L1	12.3	52.7	11.4	13.3	19.9
	L7	9.4	31.4	2.1	6.0	54.9
Jonah crab, female (Jun-Nov)	L1	9.5	50.6	8.8	9.5	15.5
	L7	6.7	30.1	1.1	3.8	66.3
Rock crab, total (Jun-Nov)	L1	2.4	78.9	1.1	3.4	75.0
	L7	1.5	133.5	1.7	3.0	48.7
Rock crab, female (Jun-Nov)	L1	0.5	119.4	0.0	0.7	128.9
	L7	0.3	148.7	0.2	0.7	130.8

[a]Preoperational: Lobster larvae from Sta. P2-1978-89; Sta. P5-1988-1989; Sta. P7-1982-89; *Cancer* spp. larvae from Sta. P2-1978-84, 1986-89; Sta. P5-1982-84 + Jul-Dec 1986 + 1987-89; Sta. P7 1982-84 + 1987-89; all others 1982-89.

[b]1994 mean; mean of the total number of samples collected during the period sampled.

[c]Operational: 1991-94, mean of annual means.

[d]Sampled year-round but abundance computed for peak period (May - September).

TABLE 8-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING DENSITIES OF LOBSTER AND *CANCER* SPP. LARVAE COLLECTED AT INTAKE, NEARFIELD, AND FARFIELD STATIONS, AND CATCHES OF TOTAL AND LEGAL-SIZED LOBSTERS, JONAH CRAB, AND ROCK CRAB AT THE NEARFIELD AND FARFIELD STATIONS. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	SOURCE OF VARIATION[a]	df	MS	F[b]	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Lobster larvae (May-Oct)	Preop-Op	1	1.92	8.64 *	Op>Preop
	Station	2	0.04	0.45 NS	
	Year (Preop-Op)	4	0.18	0.56 NS	
	Week (Year)	112	0.33	7.45 **	
	Preop-Op X Station	2	0.09	2.18 NS	
	Station X Year(Preop-Op)	8	0.04	0.96 NS	
	Error	260	0.04		
Lobster (total catch) (Jun-Nov)	Preop-Op	1	132,110.13	4.12 NS	
	Station	1	24,962.66	1.10 NS	
	Year (Preop-Op)	10	16,430.19	0.57 NS	
	Month (Year)	59	26,026.61	34.02 ***	
	Preop-Op X Station	1	21,742.02	5.31 *	7 Pre 1 Pre 7 Op 1 Op
	Station X Year(Preop-Op)	10	4,317.00	5.64 ***	
	Error	1451	764.95		
Lobster (legal size) (Jun-Nov)	Preop-Op	1	4,448.17	12.71 *	Op<Preop
	Station	1	16.49	0.48 NS	
	Year (Preop-Op)	10	366.45	2.84 *	
	Month (Year)	59	112.41	12.77 **	
	Preop-Op X Station	1	33.77	1.75 NS	
	Station X Year(Preop-Op)	10	19.91	2.08 *	
	Error	1451	9.58		
Cancer spp. larvae (May-Sep)	Preop-Op	1	1.63	0.79 NS	
	Station	2	0.61	3.13 NS	
	Year (Preop-Op)	5	1.98	0.29 NS	
	Month (Year)	28	7.67	9.68 ***	
	Preop-Op X Station	2	0.19	0.14 NS	
	Station X Year (Preop-Op)	10	0.11	1.80 NS	
	Error	158	0.79		

(continued)

TABLE 8-2. (Continued)

SPECIES	SOURCE OF VARIATION[a]	df	MS	F[b]	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Jonah Crab (Jun-Nov)	Preop-Op	1	352.98	0.15 NS	
	Station	1	8,136.83	5.32 NS	
	Year (Preop-Op)	10	1,810.61	0.96 NS	
	Month (Year)	59	1,224.94	16.25 **	
	Preop-Op X Station	1	1,495.22	1.95 NS	
	Station X Year(Preop-Op)	10	806.30	10.70 **	
	Error	1429	75.37		
Rock Crab (Jun-Nov)	Preop-Op	1	256.89	0.86 NS	
	Station	1	144.94	6.23 NS	
	Year (Preop-Op)	10	376.13	2.24 *	
	Month (Year)	59	107.96	6.29 **	
	Preop-Op X Station	1	25.16	0.32 NS	
	Station X Year(Preop-Op)	10	82.33	4.80 **	
	Error	1428	17.17		

[a]Preop-Op = Preoperational period (Lobster and *Cancer* spp. larvae, all stations: 1988, 1989; Adult lobster and crabs: 1982-1989); Operational period: 1991-94 regardless of station or month.
Station = Station differences (Lobster and *Cancer* spp. larvae: P2, P5, P7; all others: Discharge (L1) and Rye Ledge (L7)) regardless of year, month or period.
Year (Preop-Op) = Year nested within preoperational and operational periods regardless of year, month or station.
Week (Preop-Op X Year) or Month (Preop-Op X Year) = Week or month nested within interaction of Preop-Op and Year.
Preop-Op X Station = Interaction of main effects.
Station X Year(Preop-Op) = Interaction of station and year nested within preoperational and operational period.
[b]NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very Highly Significant ($0.001\geq p$)
[c]Underlining signifies no significant differences ($\alpha\leq0.05$) among least squares means with a paired t-test.

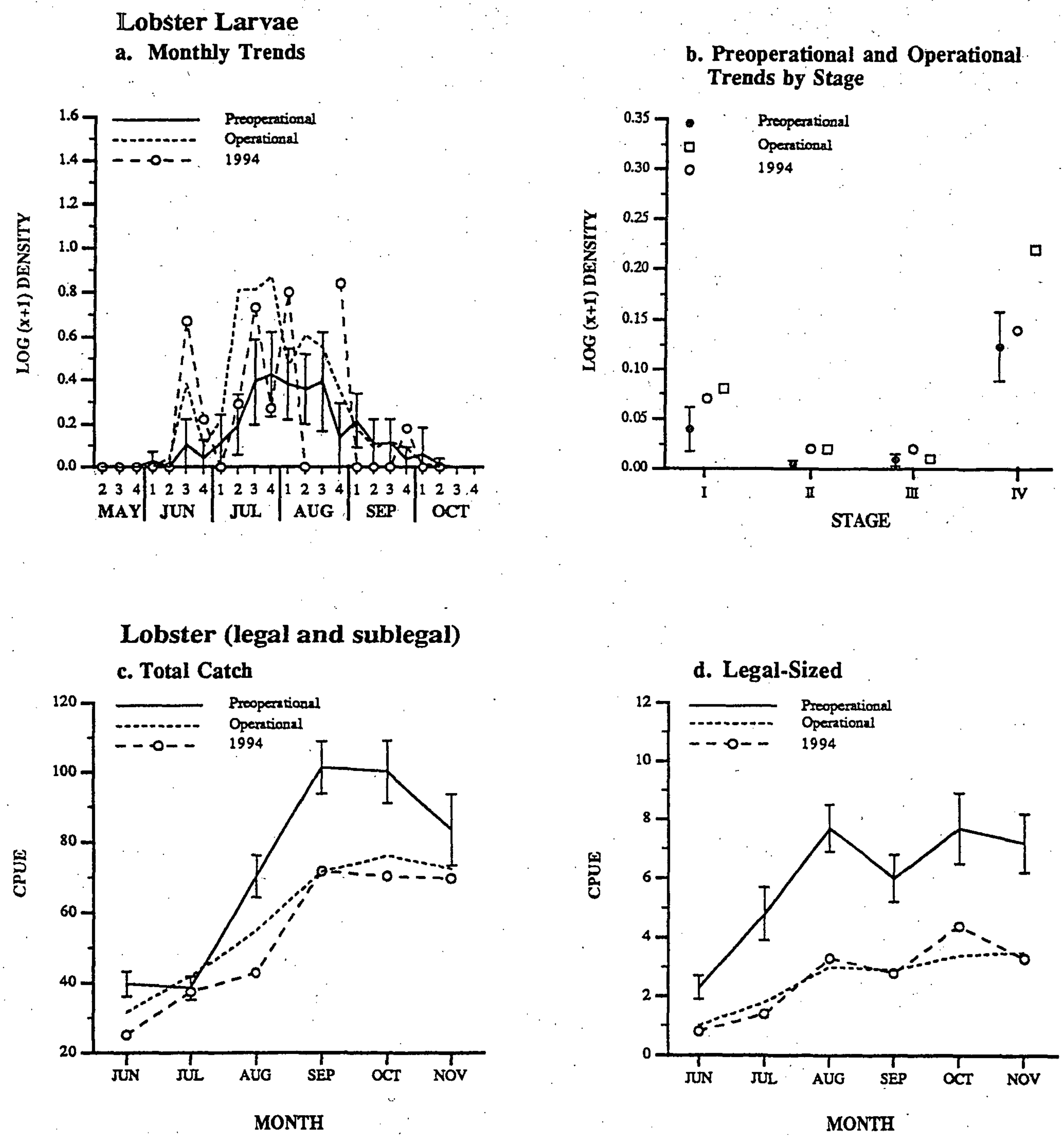


Figure 8-2. Preoperational mean and 95% confidence limits and 1994 and operational means of **a.** weekly density (no./1000m^2) of **lobster larvae** at Station P2, **b. lobster larvae** density by lifestage at P2, **c.** monthly CPUE (15 traps) of **total** (legal and sublegal) **lobster** at Station L1, and **d.** monthly CPUE (15 traps) of **legal-sized lobster** at Station L1. Seabrook Operational Report, 1994.

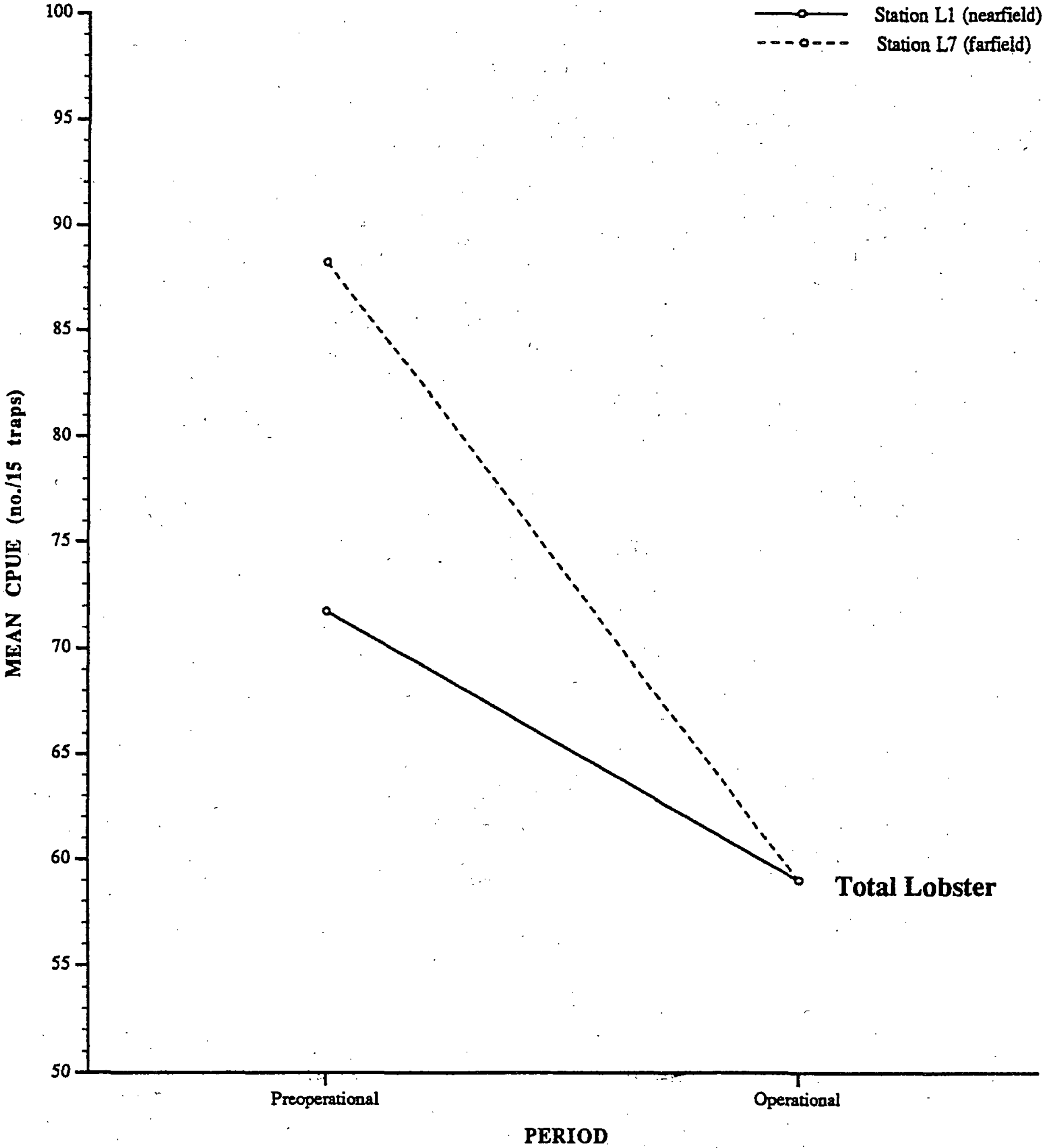


Figure 8-3. A comparison of the mean catch per unit effort (no. per 15 traps) for **total lobster** by station during the preoperational (1982-1984 + 1986-1989) and operational (1991-1994) periods when the interaction term (Preop-Op X Station) of the ANOVA model was significant (Table 8-2). Seabrook Operational Report, 1994.

1958, Dow 1969). In addition, temperature may affect seasonal lobster migrations (Campbell 1986). In New Hampshire, adult lobsters are thought to move inshore in spring and summer and offshore in fall and winter (NHFG 1992).

Legal-sized Lobster

During 1994, legal-sized lobsters were 5% of the average total catch at the nearfield station and 3% at the farfield station, slightly lower than the preoperational averages of 8% and 7%, respectively (Table 8-1). During the four-year operational period, the average annual catch at both stations was significantly lower than the preoperational average (Tables 8-1, 8-2). There was no significant difference in CPUE between the nearfield and farfield stations, and the decrease between the preoperational and operational periods was consistent between stations resulting in no significant interaction term. The monthly pattern of legal-sized lobster catches in 1994 showed an October peak, similar to monthly patterns observed during the preoperational period (Figure 8-2).

Catches of legal-sized lobsters were affected by fisheries regulations and environmental factors such as water temperature. The legal-size limit for lobsters was increased in 1984, 1989, and in 1990, and is currently defined as a carapace length of 83 mm (3-1/4 in). Each increase in the legal size proportionally reduced the catch of legal-sized lobsters (Figure 8-4).

Size Class and Sex Distribution

The majority of lobsters collected at the nearfield station in 1994 were in the 68-79 mm (2-5/8 - 3-1/8 in) carapace length size class, as was true in previous years beginning in 1980 (Figure 8-4). Lobsters measuring 80-92 mm (2-6/8 - 3-1/8 in) ranked second in abundance in 1994, as opposed to most years when the 54-67 mm (1-1/8 - 2-5/8) size class was second in abundance. Catches (CPUE) during 1994 in the 80-92 mm size class, which includes both legal-sized and sublegal-sized lobsters, were the highest since 1991, and may be due to an increased standing stock of legal sized lobsters resulting from the recent increases in the legal size limit.

In 1994, female lobster catch CPUE averaged 29.8 at the nearfield station, 57% of the total lobsters collected (Table 8-1). During the preoperational period, the proportion of females was 55% at the nearfield station. The proportion was similar at the farfield Rye Ledge Station, both in 1994 (57%) and during the preoperational period (54%). NHFG studies found that females were 52% of the total legal-sized population in the New Hampshire coastal area (Grout et al. 1989).

Egg-bearing female lobsters represented a small component of the lobster population. In 1994, they averaged 0.3 CPUE at the nearfield station, representing 0.6% of the total catch. Catches of egg-bearing females at Rye Ledge were slightly higher and averaged 0.5 CPUE, 1.0% of the total catch (Table 8-1). During the preoperational period, egg-bearing females composed 0.8% of the total catch at the nearfield station, and 0.7% at the farfield station. NHFG studies (Grout et al. 1989) found that 0.4% of 911 lobsters examined during lobster surveys of New Hampshire coastal waters from 1983-1985 were egg-bearing.

Impingement

In 1994, 31 lobster were impinged in the plant's cooling water system. One lobster was impinged in 1993, six lobsters were impinged in 1992, 29 were impinged in 1991 and four in 1990 (NAI 1993). Of the 29 impinged in 1991, 19 were found in November following a severe northeastern storm.

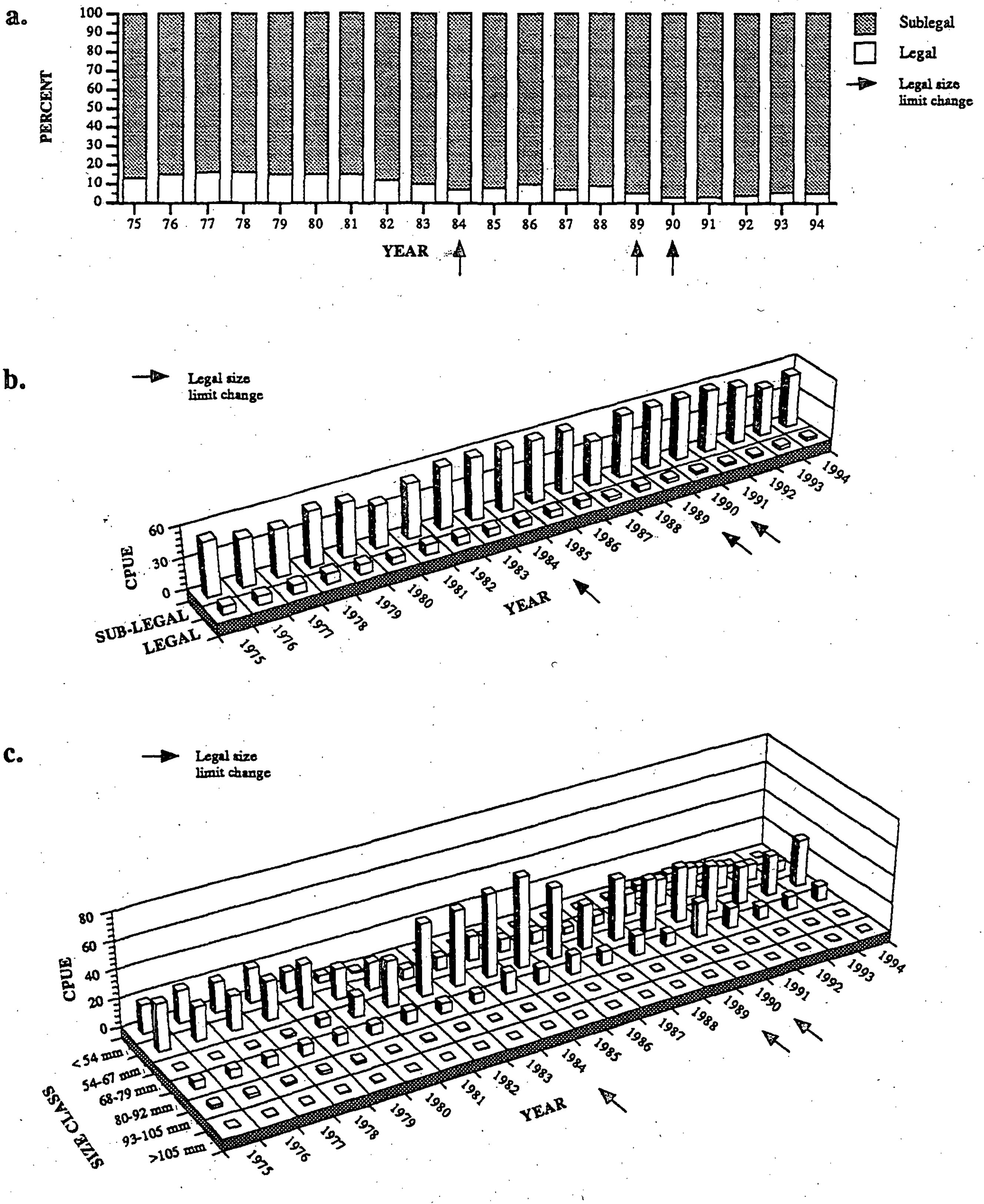


Figure 8-4. **a.** Percentage and **b.** catch (per 15 trap effort) of **legal-sized** and **sublegal-sized lobster** at Station L1 and **c.** size-class distribution at Station L1 from 1975-1994. Seabrook Operational Report, 1994.

8.3.2 Jonah and Rock Crabs

Larvae

Cancer spp. (*Cancer borealis* and *Cancer irroratus*) larvae had lower peak period abundances in 1994 than during the preoperational period at all three stations (Table 8-1). During the four-year operational period, the average density was higher than the preoperational average at each station, both the increase was not significant (Tables 8-1, 8-2). Since the increase occurred at both the nearfield and farfield stations, it reflects an area-wide increase and is not due to plant operation. The seasonal trend of occurrence at nearfield Station P2 in 1994 and for the average operational period was similar to preoperational years. Densities were low from January through April, peaked from May or June through September, then decreased from October through December (Figure 8-5).

Total Catch: Juveniles and Adults

The 1994 mean CPUE for Jonah crab (*Cancer borealis*) at both nearfield and farfield stations were lower than both the preoperational and operational averages (Table 8-1). Highest catches in 1994 at the nearfield station occurred in September and were above preoperational monthly means for September and October (Figure 8-5).

There were no significant differences in mean CPUE of Jonah crab between the preoperational and operational periods (Table 8-2). Similarly there were no significant differences in mean CPUE between the nearfield and farfield stations. Trends in CPUE between the preoperational and operational periods were similar at both the nearfield and farfield stations, and the interaction term was not significant.

Trends in female Jonah crab CPUE paralleled those of total catch. Female crab catches in 1994 were 77% and 52% of the total catches at the nearfield and farfield stations, respectively. During the preoperational period the proportion has varied from year to year, and averaged 77% and 72% at the near- and farfield stations, respectively (Table 8-1). Rock crab catches were less abundant than Jonah crab in the study area (Table 8-1), probably a result of this species' preference for sandy habitat rather than the cobble-rock that predominates in the study area (Jefferies 1966) as well as intra-specific competition (Richards et al. 1983).

In 1994, rock crab (*Cancer irroratus*) CPUE at the nearfield and farfield stations decreased from the high catches observed in 1992 and 1993 (NAI 1993; NAI and NUS 1994) and were below the preoperational averages (Table 8-1). In 1994 CPUE of rock crab peaked in August, similar to the preoperational period (Figure 8-5). During the operational period average CPUE was highest in June, and generally declined in subsequent months. There were no significant differences in CPUE between the preoperational and operational periods, or between the nearfield and farfield stations (Table 8-2). The differences between the preoperational and operational periods were consistent at both stations, thus the interaction term was not significant.

Female rock crab CPUE decreased in 1994 to levels that were lower than operational and preoperational means at both stations. No female rock crabs were caught at the nearfield station in 1994. Female rock crabs composed approximately 20% of the average total catch at each station during the preoperational period. The proportion increased slightly to 21-23% at each station during the operational period (Table 8-1).

8.4 DISCUSSION

8.4.1 American Lobster

Newly-hatched larvae require a sea water temperature above 10°C (50°F) to survive (Mariano 1993). Larvae

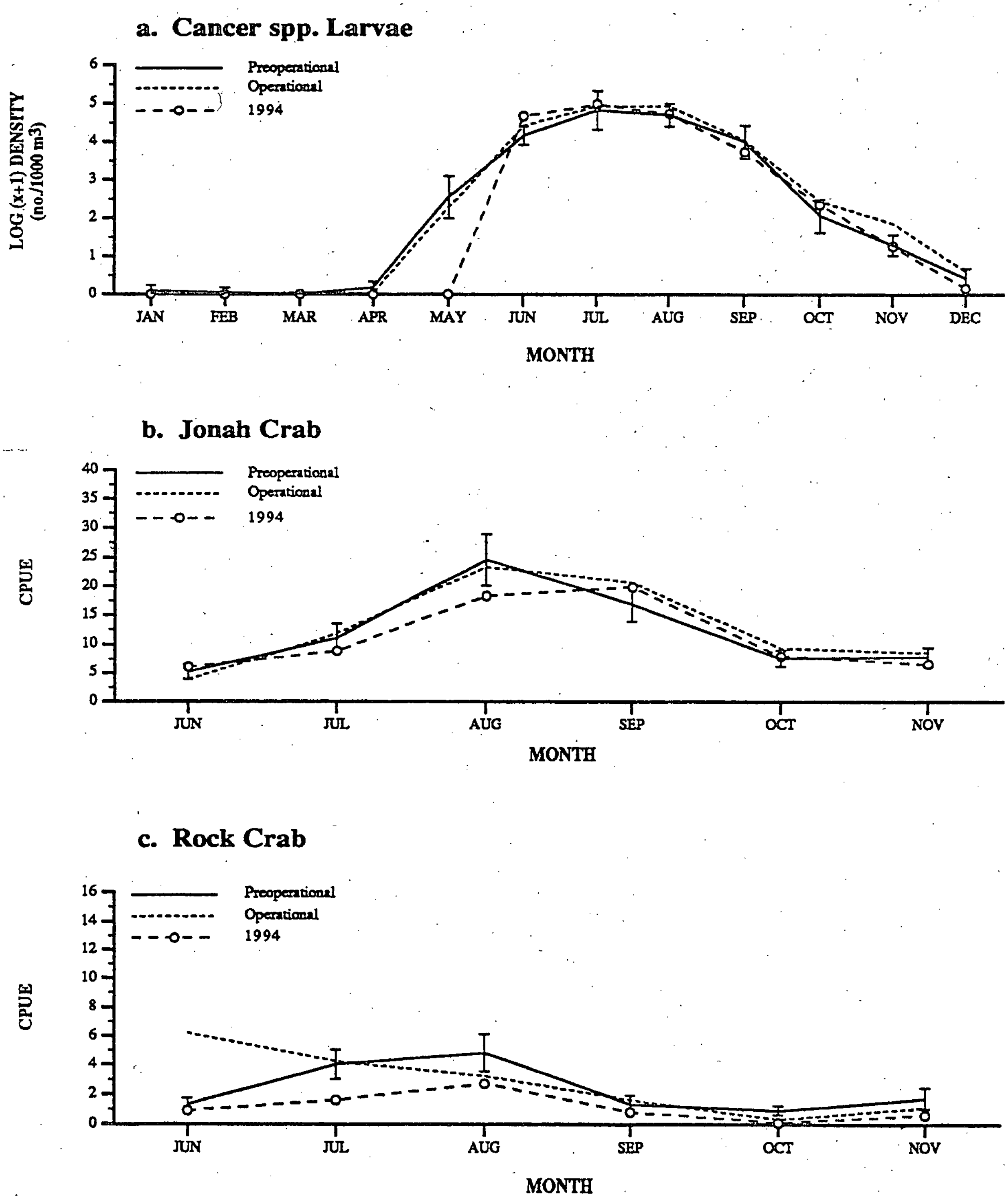


Figure 8-5. Monthly means and 95% confidence intervals of log (x+1) density (no./1000 m³) of **a.** ***Cancer*** **spp.** larvae at Station P2, and monthly mean catch per unit effort (15 traps) of **b. Jonah** and **c. Rock crabs** at Station L1 during the preoperational period (1978-1984 + 1986-1989: larvae, 1975-1984 + 1986-1989: adults) and monthly means during the operational period (1991-1994) and in 1994. Seabrook Operational Report, 1994.

spend roughly one month in the water column, molting three times before they settle to the bottom. The frequency of molting and growth rate may increase with temperature (Mariano 1993).

Lobster larvae have traditionally been thought of as strictly neustonic, although recent research suggests that they migrate vertically in waters above the thermocline (Harding et al. 1987, Boudreau et al. 1991). Lobster larvae could be exposed to the discharge plume, which may influence larval survival, molting and successful bottom settlement of Stage IV lobster. Juvenile lobsters in the study area are recruited from Stage IV larvae (the stage prior to benthic settlement), some of which are believed to originate offshore from waters of the southwest Gulf of Maine and Georges Bank (Harding et al. 1983). Although the level of juvenile recruitment has been correlated with abundances of Stage IV larvae (Harding et al. 1982, Harding et al. 1983), others have failed to demonstrate this relationship (Fogarty and Idoine 1986). Recent research indicates that successful benthic recruitment of larval lobsters is affected more by the availability of suitable habitat for the early benthic phase lobsters than by larval abundance (Wahle and Steneck 1991).

Lobster larvae have historically been relatively rare in the study area, averaging less than 1 per 1000 m^2. Average lobster larvae density during the operational period was significantly higher than the preoperational average and between period trends in density among stations were consistent (Table 8-3). Thus, the operation of Seabrook Station did not appear to affect lobster larvae densities. Densities of both Stage I and Stage IV larvae increased during the operational period. These density increases, particularly for Stage I larvae,

TABLE 8-3. SUMMARY OF POTENTIAL PLANT EFFECTS ON ABUNDANCE OF EPIBENTHIC CRUSTACEA. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER MEASURED	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD[a]	DIFFERENCES BETWEEN PREOPERATIONAL AND OPERATIONAL PERIODS CONSISTENT AMONG STATIONS[b]
Lobster: Larvae	Op>Preop	Yes
Lobster: Total Catch	Yes	nearfield: Op<Preop farfield: Op<Preop greatest decline at farfield
Lobster: Legal-Sized Catch	Op<Preop	Yes
Cancer spp.: Larvae	Yes	Yes
Jonah Crab: Total Catch	Yes	Yes
Rock Crab: Total Catch	Yes	Yes

[a]based on Preop-Op term of ANOVA model (Table 8-2)
[b]based on the interaction term (Preop-Op X Station) of the ANOVA model and multiple comparison test at $\alpha \leq 0.05$ (Table 8-2)

may be related to the increase in the percentage of egg-bearing females in the operational period (Table 8-1, Figure 8-2). Distribution of Stage I larvae has been linked to brood stock distribution in Jaddore Harbor, Nova Scotia (Dibacco and Pringle 1992). Regional fishing regulations have increased protection of the lobster population over the past decade, prohibiting harvest of egg-bearing females and V-notched females (marked while egg-bearing). Also the minimum legal size has been increased three times during the study period (1975-94). Even so, most females that are legal-sized (minimum carapace width of 83 mm) have not attained sexual maturity (90-100 mm in the Gulf of Maine, NH Fish and Game 1974, Mariano 1993). Despite this fact, these regulations may have contributed to the slight increase in the proportion of egg-bearing females during the operational period and resulted in increased numbers of larvae, especially Stage I.

Bottom dwelling juvenile and adult lobsters would most likely be susceptible to the potential effects of plant operation due to changes in their food sources that might result from the effects of increased detritus and turbidity around the discharge area. Temperature can also affect lobster activity, likelihood of capture, and migratory behavior (Dow 1969, Campbell 1986). However, changes in bottom temperature resulting from Seabrook Station are unlikely because of the design of the discharge diffuser and the buoyancy of the discharge plume.

Average total lobster CPUE at the farfield station decreased more than CPUE at the nearfield station between the preoperational and operational periods resulting in a significant interaction term (Table 8-3, Figure 8-3). This differing trend in CPUE between stations was also observed in 1993 (NAI and NUS 1994). Decreases in lobster landings have been correlated with temperature decreases in the current year and after a six-year lag period (Fogarty 1988; Campbell et al. 1991). However, bottom water temperatures during the operational period were significantly higher than bottom water temperatures in the preoperational period (Section 2.0). Thus, the decrease in CPUE of lobsters cannot be totally explained by a decrease in bottom water temperatures. The decrease is probably not due to the operation of Seabrook Station because the decline occurred at both stations; furthermore, the greatest decline was at the farfield station. In addition a regional decline was also observed (NOAA 1993).

The area-wide decline in total lobster CPUE observed in this study coincides with a regional decline. NOAA (1993) changed the status of the entire inshore/offshore population of lobster throughout its range, Gulf of Maine (71% of landings) through the mid-Atlantic, from "fully exploited" (NOAA 1992) to "over-exploited." Intense commercial fishing may in part account for the significant decline in total lobster catch at both stations during the operational period. In 1992, the NOAA Autumn Survey Index (kg per trawl tow) decreased, as did the commercial landings. In response to the recent increases in legal-size limits, fishermen have increased the number of pots fished inshore, as well as the areas fished (NOAA 1993). Inshore landings decreased by 13% between 1991 and 1992 (NOAA 1993), in spite of increased effort. NHFG (1993) also reported an overall decrease in the abundance of lobster sampled with lobster traps between 1992 and 1993 along the New Hampshire coast within three miles of shore. In 1994, NHFG (1995) reported a slight increase in lobster CPUE along coastal New Hampshire.

In Maine, newly recruited legal-sized lobsters are almost completely harvested within a year (Fogarty 1988). Historically, in this study, percentages of legal-sized lobsters have decreased with each increase in the legal-size limit, as would be expected. Hence, operational catches of legal-sized lobsters were lower than preoperational catches, with similar decreases at nearfield and farfield stations (Table 8-3). Proportions of female lobsters in 1994 were also consistent with previous years. The proportion of egg-bearing lobsters decreased slightly (Table 8-1).

Impingement of lobsters in the cooling water system was not expected because of the off-bottom intake location. A total of 71 lobsters were impinged during the operational period (1990-94); nearly 27% (19) were sub-legal sized lobsters impinged after a severe northeaster in November, 1991. This level of impingement does not pose a threat to the local lobster population.

8.4.2 Jonah and Rock Crabs

Cancer spp. larvae abundance was not significantly different between the preoperational and operational periods at each of the three stations (Table 8-1). Annual abundances were higher in 1991 through 1993 than in 1994 (NAI 1992, 1993; NAI and NUS 1994). The changes indicate an area-wide trend that is unrelated to plant operation.

Jonah and rock crabs are taken incidentally in lobster traps and could be subject to the same potential for impact as lobsters. There were no significant differences in CPUE between the preoperational and operational periods, or between stations for Jonah and rock crabs (Table 8-3), and no indication of impact due to the operation of Seabrook Station (Table 8-3).

8.5 REFERENCES CITED

Addison, J. and M. Fogarty. 1993. Juvenile lobster habitat limitation: what can landings tell us. The Lobster Bull. 6(2):2.

Boudreau, B., Y. Simard and E. Bourget. 1991. Behavioral responses of the planktonic stages of the American lobster *Homarus americanus* to thermal gradients, and ecological implications. Mar. Ecol. Prog. Ser. 76:13-23.

Campbell, A., O.J. Noakes and R.W. Elmer. 1991. Temperature and Lobster, *Homarus americanus*, yield relationships. Can. J. Fish. Aquat. Sci. 48:2073-2082.

Dibacco, C. and J.D. Pringle. 1992. Larval lobster (*Homarus americanus*, H. Milne Edwards, 1837) distribution in a protected Scotian Shelf bay. J. Shell. Res. II(1):81-84.

Dow, R. 1969. Cyclic and geographic trends in seawater temperature and abundance of American lobster. Science 164:1060-1063.

Fogarty, M.J. 1988. Time series models of the Maine lobster fishery: the effect of temperature. Can. J. Fish. Aquat. Sci. 45:1145-1153.

Fogarty, M.J., and J.S. Idoine. 1986. Recruitment dynamics in an American lobster (*Homarus americanus*) population. Can. J. Fish. Aquat. Sci. 43:2368-2376.

Fogarty, M.J., and R. Lawton. 1983. An overview of larval American lobster *Homarus americanus*, sampling programs in New England during 1974-70. pp 9-14. In. M.J. Fogarty (ed.) Distribution and Relative Abundance of American Lobster, *Homarus americanus*, Larvae: New England Investigations During 1974-79, NOAA Tech. Rep. NMFS SSRF-775.

Grout, D.E., D.C. McInnes and S.G. Perry. 1989. Impact evaluation of the increase in minimum carapace length on the New Hampshire lobster fishery. N.H. Fish and Game Dept.

Harding, G.C., K.F. Drinkwater, and W.P. Vass. 1983. Factors influencing the size of American lobster (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. Can. J. Fish. Aquat. Sci. 40:168-184.

Harding, G.C., J.D. Pringle, W.P. Vass, S. Pearre, and S. Smith. 1987. Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. Mar. Ecol. Prog. Ser. 41:29-41.

Harding, G.C., and R.W. Trites. 1988. Dispersal of *Homarus americanus* larvae in the Gulf of Maine from Brown's Bank. Can. J. Fish. Aquat. Sci. 45:416-425.

Harding, G.C., W.P. Vass, and K.F. Drinkwater. 1982. Aspects of larval American lobster (*Homarus americanus*) ecology in St. Georges Bay, Nova Scotia. Can. J. Fish. Aquat. Sci. 39:1117-1129.

Jefferies, H.P. 1966. Partitioning of the estuarine environment by two species of *Cancer*. Ecology 47(3):477-481.

McLeese, D., and D.G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Bd. Can. 15:1345-1354.

Mariano, M. 1993. American lobster. NH Fish and Game and NOAA Agreement #M9270R0188-01. 4p.

New Hampshire Fish and Game Department (NHFG). 1974. Investigation of American Lobsters (*Homarus americanus*) in New Hampshire Coastal Waters. 34 pp.

__________. 1992. Monitoring of the American lobster resource and fishery in New Hampshire - 1991. Performance Rep. submitted to the Nat. Mar. Fish. Serv. Management Div. under contract no. NA16FI-0353-02. 28 pp.

__________. 1993. Monitoring of the American lobster resource and fishery in New Hampshire - 1992. Performance report submitted to the Nat. Mar. Fish. Serv. Management Div. under contract no. NA16FI-0353-02. 35 pp.

__________. 1995. Monitoring of the American lobster resource and fishery in New Hampshire - 1994. Performance report submitted to the Nat. Mar. Fish. Serv. Management Div. under contract no. NA16FI-0353-03. 35 pp.

NOAA. 1992. Status of the fishery resources of the northeastern United States for 1992. NOAA Tech. Memo. NMFS-F/NEC-95. 133 p.

__________. 1993. Status of the fishery resources of the northeastern United States for 1993. NOAA Tech. Memo NMFS-F/NEC-101. 140 pp.

Normandeau Associates (NAI). 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Rep. XXII-I.

__________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-I.

__________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Enviornmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area During the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

NUSCO (Northeast Utilities Service Co.). 1995. Lobster studies. Pages 123-147 in Monitoring the Marine Environment of Long Island sound at

Millstone Nuclear Power Station, Waterford, CT. Annual Report 1994.

Richards, R.A., J.S. Cobb, and M.J. Fogarty. 1983. Effects of behavioral interactions on the catchability of American lobster, *Homarus americanus*, and two species of Cancer crab. Fish. Biol. 81(1):51-60.

SAS Institute, Inc. 1985. User's Guide: Statistics, Version 5 edition. SAS Inst., Inc. Cary, N.C. 956 pp.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "Pseudo-replication in time?" Ecology. 67:929-940.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4(1):3-15.

Wahle, R.A. and R.S. Steneck. 1991. Recruitment habitats and nursery ground of the American lobster *Homarus americanus*: a demographic bottleneck? Mar. Ecol. Prog. Series. 69:231-243.

TABLE OF CONTENTS

SUMMARY

Since 1978, the species composition and abundance of dominant taxa of the benthic macrofaunal communities in the Hampton-Seabrook estuary have been characterized to identify spatial and temporal patterns in community structure and to assess whether observed changes could be attributed to construction and operation of the Seabrook Station. The discharge of effluent from the plant's sewage treatment plant and settling basin into the Browns River had the potential to be a measurable impact on estuarine benthic communities. The sewage treatment plant effluent discharged into the settling basin, which collected rainwater from the plant site as well. The combined flows from these two facilities subsequently discharged to the Browns River. In April 1994, the sewage treatment plant and settling basin effluents were diverted offshore via the cooling water discharge tunnel. As in other temperate estuaries, spatial and temporal patterns of abundance, numbers of species and dominant taxa in intertidal and subtidal communities were largely controlled by the physical environment, and the most numerous species were those that tolerated fluctuating water temperature and salinity and changing sedimentary conditions. Macrofaunal species composition in Browns River nearby the outfall during 1994 was similar to that in Mill Creek, a control site located away from the influence of the settling basin discharge. The dominant taxa collected at both sites included the polychaetes *Streblospio benedicti, Capitella capitata,* and *Hediste diversicolor* and oligochaetes; all these organisms are classified as opportunists and have also predominated in previous study years. In general, total density, mean number of taxa and density of dominant taxa during 1994 were within the ranges reported since 1978 in the Seabrook study area, suggesting that the absence of the settling basin effluent has not adversely impacted the indigenous benthic community. The total macrofaunal density at the intertidal station in the Browns River in 1994 was the highest recorded during the study period and densities of both *Streblospio benedicti* and *Hediste diversicolor* increased relative to 1993. Densities of *H. diversicolor* and *S. benedicti* in 1994 were within the range of previous years. Results of ANOVA tests did not show 1994 to be significantly different from previous years at any station for any variable. In May 1995, monitoring of the estuarine benthos in the Browns River and Hampton Harbor was discontinued. The discontinuance of this program had been previously authorized by the EPA and the State of New Hampshire in May 1993, following a year of monitoring after discharges to the Browns River were terminated. This section is the final "Estuarine Studies Report" to be provided as part of the Seabrook Station Environmental Studies Program.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

9.0 ESTUARINE STUDIES

9.1 INTRODUCTION

Environmental studies conducted in the Hampton-Seabrook estuary since 1978 have included monitoring of physical parameters (temperature and salinity), fish populations, benthic macrofauna, and juvenile and adult soft-shelled clams (*Mya arenaria*). Long-term data are needed to distinguish impacts of human activities on marine environments from the inherent variability of estuarine systems (Holland 1985; Nichols 1985; Holland et al. 1987; Warwick 1988; Rees and Eleftheriou 1989). Impact assessments, in general, are often difficult because of our lack of understanding of how physical and biological factors control the structure and function of benthic communities (Diaz and Schaffner 1990). To aid in our understanding, a time series of data have been collected since 1978 at sites potentially affected by Seabrook Station (nearfield), and at sites in the estuary beyond power plant influence (farfield).

The discharge of effluent from the power plant's sewage treatment plant and settling basin into the Browns River had the potential to be a measurable impact on the estuarine benthic communities in the Hampton-Seabrook estuary. The sewage treatment plant effluent discharged into the settling basin, which collected rainwater from the plant site as well. The combined flows from these two facilities subsequently discharged to the Browns River. During the construction of the Seabrook intake and discharge tunnels (1979-1983), the outfall became more saline due to dewatering of the tunnels, and volume of the discharge increased greatly. The effluent also contained higher than average levels of organic material, nutrients (nitrate, nitrite, and phosphate) and suspended solids, which consisted mainly of granite rock flour from tunnel drilling (NAI 1980a, 1981). Bioassays using undiluted effluent from the settling basin indicated that such effluent adversely affected sand shrimp (*Crangon septemspinosa*), but not soft-shelled clams (*Mya arenaria*; NAI 1979, 1980b). Once the tunnels were completed in 1983, the volume of water discharged from the settling basin diminished and has had no saline component. In April 1994 the discharge was diverted to the open ocean via the cooling water discharge tunnel.

The objectives of the estuarine benthos studies are to characterize the abundance and species composition of macrofaunal communities in the Hampton Harbor estuary, to identify spatial and temporal patterns in community structure and abundance, and to assess whether observed changes are related to the construction and operation of Seabrook Station. One of the main environmental issues in the Hampton-Seabrook estuary related to plant operation was whether the offshore intake and discharge could impact the adult soft-shell clam population in Hampton Harbor. The specific impact from entrainment of *Mya* larvae is discussed in the 1994 Seabrook Operational Report. Estuarine monitoring efforts in 1994 were primarily directed to identify potential effects from the removal of settling basin discharge.

9.2 METHODS

9.2.1 FIELD AND LABORATORY

Surface temperature (^{O}C) and salinity (ppt) were measured weekly during slack water at high and low tide at the Browns River Station (BR) from May 1979 through May 1995 and Hampton Harbor Station from May 1979 through December 1994 (HH; Figure 9-1). Precipitation was recorded continuously at the Seabrook Station meteorological tower from 1980-1994 (excluding 1984-1986).

Benthic macrofaunal sampling stations were located at Browns River (nearfield), just downstream from the settling basin outfall and Mill Creek (farfield), a tidal creek located southeast of the outfall (Figure 9-1). Macrofaunal samples have been collected in subtidal (Browns River Station 3, Mill Creek Station 9) and

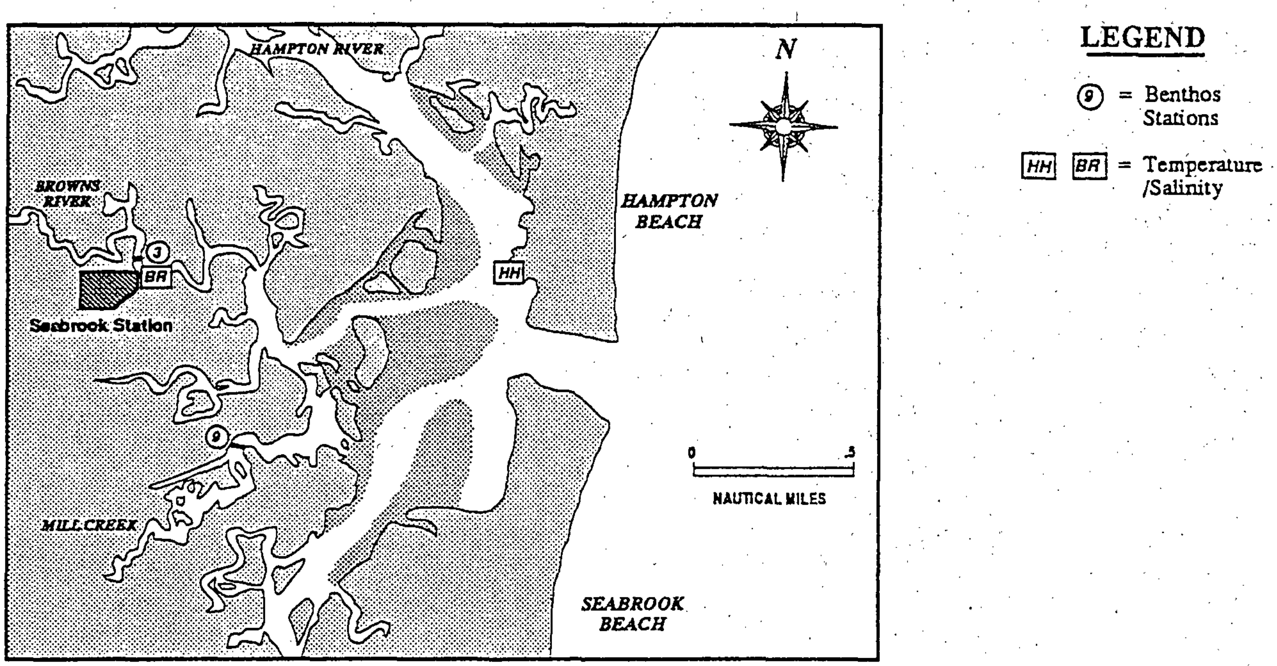


Figure 9-1. Hampton-Seabrook estuary temperature/salinity and benthos sampling stations. Seabrook Operational Report, 1994.

intertidal areas at mean low water (Browns River Station 3MLW, Mill Creek 9MLW) in May, August, and November since 1978 (excluding 1985, when sampling was suspended). SCUBA divers collected five samples (25 cm^2 x 10.2 cm deep) using an airlift system fitted with a 0.79 mm mesh bag. In the laboratory, all samples were washed through a 1.0 mm mesh sieve, preserved in 6% buffered formalin and sorted under dissecting microscopes. All non-colonial organisms were identified to the lowest possible taxon and counted (NAI 1990).

9.2.2 ANALYTICAL METHODS

Weekly measurements of surface water salinity and temperature were averaged by month, and patterns of monthly and annual means were examined. Annual mean densities (No./m^2) of the total number of individuals and of dominant macrofaunal taxa were computed by averaging the $\log_{10}(x+1)$ transformed seasonal densities. The number of taxa in each season was computed by pooling all five samples collected by the divers; the three seasonal values (May, August, November) were averaged to calculate the annual mean. A one-way ANOVA was used to test for differences among years in total macrofaunal density, number of taxa, and density of individual dominant taxa. Significant differences ($\alpha \leq 0.05$) between years were evaluated using the Waller-Duncan k-ratio t-test (SAS Institute Inc. 1988).

9.3 RESULTS AND DISCUSSION

9.3.1 PHYSICAL ENVIRONMENT

Salinity, Temperature, and Precipitation

Monthly averages of surface water salinity and temperature at high and low slack tides in Browns River and Hampton Harbor were used to examine seasonal and annual patterns of these parameters in the Hampton-Seabrook estuary. Monthly and annual patterns of precipitation were investigated using rainfall data collected at the Seabrook Station meteorological tower. The mean monthly salinity at low tide in Browns River during 1994 ranged from 7.7 ppt in March to 29.6 ppt in July. During the first five months of 1995, salinity was similar to 1994, except for February when salinity was higher. The patterns observed in 1994 and 1995 were similar to long-term averages, where monthly salinities were consistently lowest in spring and highest in summer (Figure 9-2, Appendix Table 9-2). In Browns River, the long-term average salinity was lowest in April and November. Mean monthly precipitation at Seabrook Station during 1994 was highest in September (6.4 inches) and March (6.1 inches) (Figure 9-2). Concurrently, the monthly salinity values in March were below average in both Browns River and Hampton Harbor. However, in September the salinity values were average or above average at both stations, in spite of the high precipitation. In October 1994, when precipitation was well below average, salinity values were above average in both Browns River and Hampton Harbor. Total annual precipitation during 1994 was 42.2 inches, which was within the range of annual precipitation values reported since 1980 (28.7 to 46.3 in).

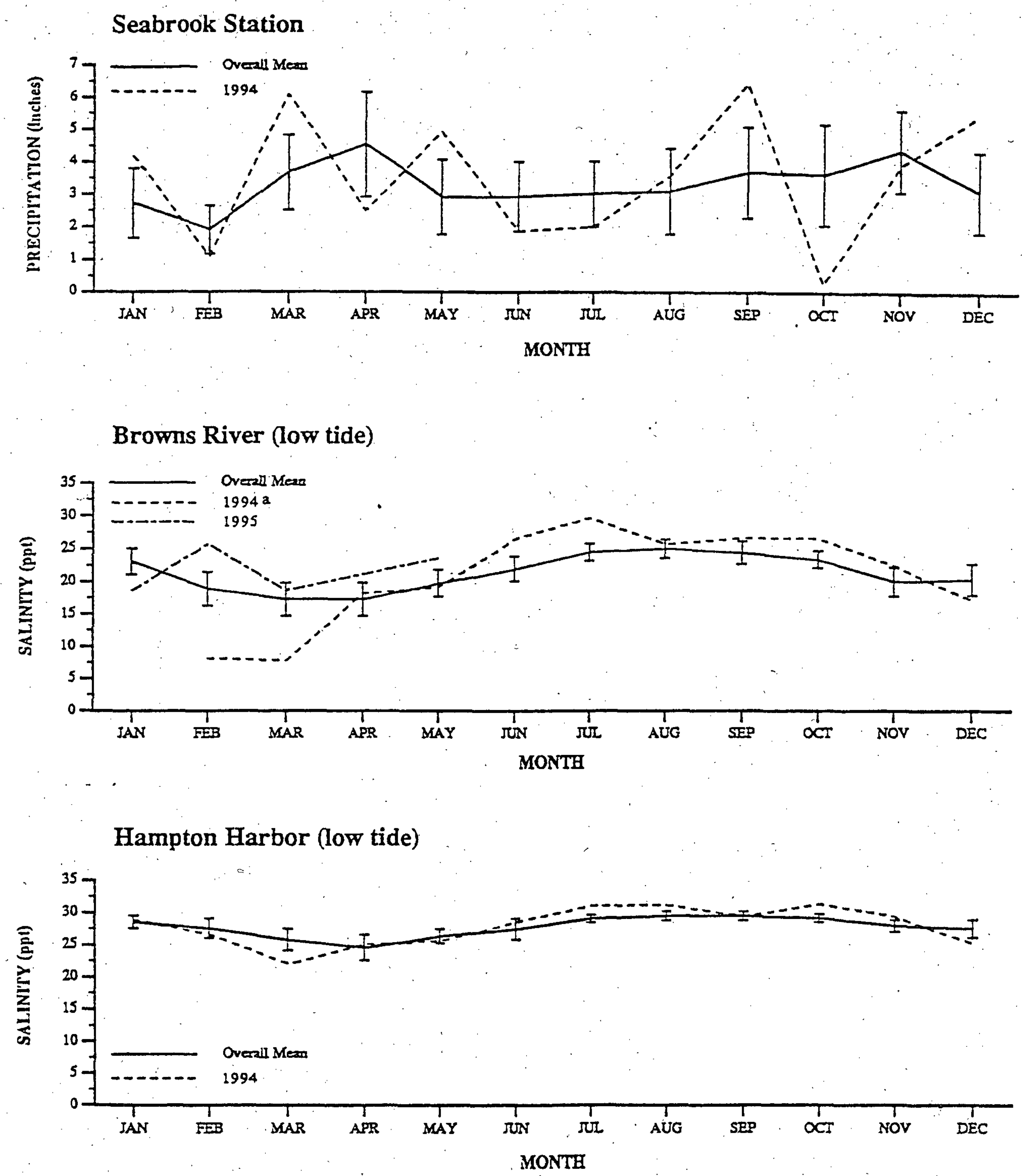
Salinities at both Browns River and Hampton Harbor were consistently lower at low tide than at high tide. During 1994, the mean salinities were 20.6 ppt and 27.8 ppt during low tide, and 28.7 ppt and 30.9 ppt during high tide at Browns River and Hampton Harbor, respectively (Table 9-1). At each site in 1994, the annual average salinities during both tidal stages were within the ranges of values reported since 1980. Relatively high salinities observed from 1980-1982 were attributed to a combination of dry years and dewatering of the intake and discharge tunnels during Seabrook Station construction, whereas the relatively high values in 1993 (particularly at low tide) were attributed to the unusually dry summer. The 1994 annual mean low tide salinity in Browns River and the low and high tide salinities in Hampton Harbor were within the 95% CL of the mean for the 15-year time series.

Mean monthly temperatures at Browns River at low tide during 1994 were not recorded from January through March, but reached 24.3°C in July. During the first five months of 1995, water temperature at low tide at Browns River ranged from 2.8°C in February to 10.0 °C in May. The temperature at Hampton Harbor in 1994 ranged from 0.6°C in January to 20.1°C in August (Figure 9-3). In contrast to salinity, water temperatures were higher at low tide compared to high tide. Annual mean temperatures during 1994 were 9.8°C during low tide, and 9.1°C during high tide at Hampton Harbor (Table 9-1). At both sites during 1994 and 1995, the pattern of monthly mean water temperatures at high and low tides were similar to the historical monthly means, but a few individual months were outside of the 95% confidence limits.

When the two sites were compared, the ranges of water temperatures and salinities were consistently larger at Browns River than at Hampton Harbor during low tide. Over all years, water temperature averaged 11.4°C during low tide at Browns River, and 10.0°C at Hampton Harbor (Table 9-1). Conversely, the overall salinity at Browns River during low tide (21.3 ppt) was considerably lower than at Hampton Harbor (27.6 ppt; Table 9-1). Both patterns resulted from the relative position of the sampling stations in the estuary, i.e., Browns River is located farther up the estuary, and more influenced by freshwater runoff, while Hampton Harbor is nearer the mouth of the estuary, and more influenced by mixing with water from Gulf of Maine.

9.3.2 MACROFAUNA

The general macrobenthic community structure at both nearfield (Browns River 3 and 3MLW) and farfield (Mill Creek 9 and 9MLW) stations in the vicinity of Seabrook Station were typical for East Coast estuarine



[a] Monthly means are usually an average of weekly measurements however, in February and May 1994 one out of four weeks was sampled, in March 1994 two out of five weeks were sampled (Appendix Table 14-4 in NAI 1994.)

Figure 9-2. Monthly means and 95% confidence limits for **precipitation** measured at Seabrook Station from 1980-1994 (excluding 1984-1986) and **surface salinity** measured at low tide in Browns River and Hampton Harbor from May 1979-December 1994 and monthly means in 1994 and 1995 (Browns River only). Seabrook Operational Report, 1994.

TABLE 9-1. ANNUAL MEAN WITH 95% CONFIDENCE INTERVAL FOR SALINITY (ppt) AND TEMPERATURE (°C) TAKEN AT BOTH HIGH AND LOW SLACK TIDE IN BROWNS RIVER AND HAMPTON HARBOR DURING 1980-1994. SEABROOK OPERATIONAL REPORT, 1994.

	SALINITY (ppt)			
	BROWNS RIVER		HAMPTON HARBOR	
	LOW TIDE	HIGH TIDE	LOW TIDE	HIGH TIDE
1980	25.1 ± 1.9	31.0 ± 1.6	29.9 ± 1.4	32.0 ± 0.5
1981	25.5 ± 1.6	30.0 ± 1.7	28.9 ± 1.1	31.5 ± 0.4
1982	22.8 ± 1.8	30.0 ± 1.2	27.3 ± 1.5	31.2 ± 0.6
1983	19.4 ± 3.6	28.0 ± 1.9	25.5 ± 2.4	30.1 ± 0.9
1984	18.1 ± 3.3	28.4 ± 1.8	25.8 ± 2.3	30.2 ± 0.9
1985	21.7 ± 2.1	30.6 ± 0.7	29.1 ± 1.0	32.2 ± 0.3
1986	20.4 ± 3.1	30.2 ± 0.9	27.7 ± 1.3	31.5 ± 0.4
1987[a]	20.6 ± 2.6	28.9 ± 1.8	27.5 ± 2.2	30.7 ± 0.9
1988	20.5 ± 2.2	29.8 ± 0.7	27.8 ± 1.0	31.3 ± 0.4
1989	20.2 ± 2.5	30.0 ± 0.7	28.0 ± 1.2	31.4 ± 0.7
1990[a]	19.5 ± 2.7	29.6 ± 1.4	27.2 ± 1.2	31.3 ± 0.6
1991	19.4 ± 1.9	29.6 ± 1.3	28.0 ± 0.9	30.9 ± 0.4
1992	21.9 ± 1.5	29.6 ± 0.8	27.2 ± 1.6	29.4 ± 1.6
1993	23.6 ± 2.1	29.7 ± 1.1	27.0 ± 1.8	29.6 ± 1.1
1994	20.6 ± 5.0[c]	28.7 ± 3.5	27.8 ± 1.9	30.9 ± 0.8
ALL[b]	21.3 ± 0.7	29.6 ± 0.4	27.6 ± 0.4	31.0 ± 0.2

	TEMPERATURE			
	BROWNS RIVER		HAMPTON HARBOR	
	LOW TIDE	HIGH TIDE	LOW TIDE	HIGH TIDE
1980	10.9 ± 5.2	9.6 ± 4.4	9.6 ± 4.4	9.1 ± 3.6
1981	10.6 ± 4.4	10.3 ± 4.6	10.1 ± 4.4	9.3 ± 3.8
1982	10.7 ± 4.5	9.9 ± 4.2	10.2 ± 4.1	9.2 ± 3.5
1983	11.9 ± 5.0	11.0 ± 4.2	10.4 ± 4.3	9.9 ± 3.4
1984	11.9 ± 5.1	10.6 ± 3.9	10.4 ± 4.1	9.4 ± 3.1
1985	11.3 ± 5.0	10.1 ± 4.4	10.6 ± 4.2	10.1 ± 3.3
1986	10.3 ± 4.8	9.6 ± 4.0	10.0 ± 3.9	9.4 ± 3.0
1987[a]	11.5 ± 5.1	9.6 ± 4.1	10.0 ± 4.3	8.9 ± 3.5
1988	10.6 ± 5.1	10.3 ± 4.0	9.7 ± 3.9	9.2 ± 3.3
1989	11.5 ± 5.4	10.1 ± 3.9	10.2 ± 4.4	9.2 ± 3.3
1990[a]	12.6 ± 5.3	10.9 ± 4.5	10.3 ± 4.3	9.7 ± 3.6
1991	12.4 ± 5.0	11.7 ± 4.1	11.1 ± 4.0	9.8 ± 3.1
1992	11.7 ± 5.2	11.1 ± 3.7	9.1 ± 4.0	8.6 ± 2.9
1993	12.1 ± 5.9	10.4 ± 3.8	9.5 ± 4.4	8.7 ± 3.5
1994	NC[d]	NC[d]	9.8 ± 4.6	9.1 ± 3.7
ALL[b]	11.4 ± 1.2[c]	10.4 ± 1.0[c]	10.0 ± 0.9	9.3 ± 0.8

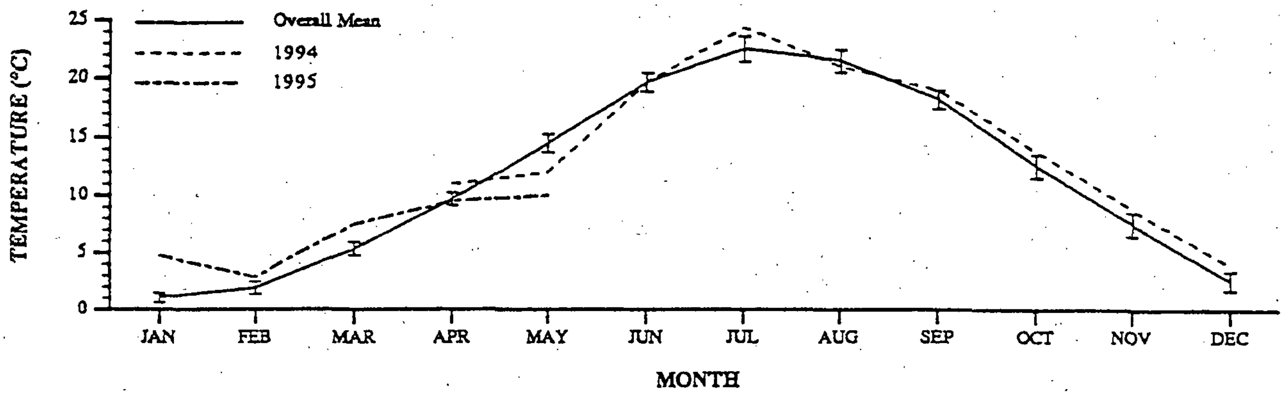
[a]Annual mean is the mean of monthly means, except for Browns River in 1987 and 1990 when Jan and Feb monthly means were estimated by using the overall years mean for Jan and Feb from 1980-1990.

[b]All years mean is the mean of monthly means.

[c]No data from January, 1994.

[d]Annual means not reported when two or more months of data are absent.

Browns River (low tide)



Hampton Harbor (low tide)

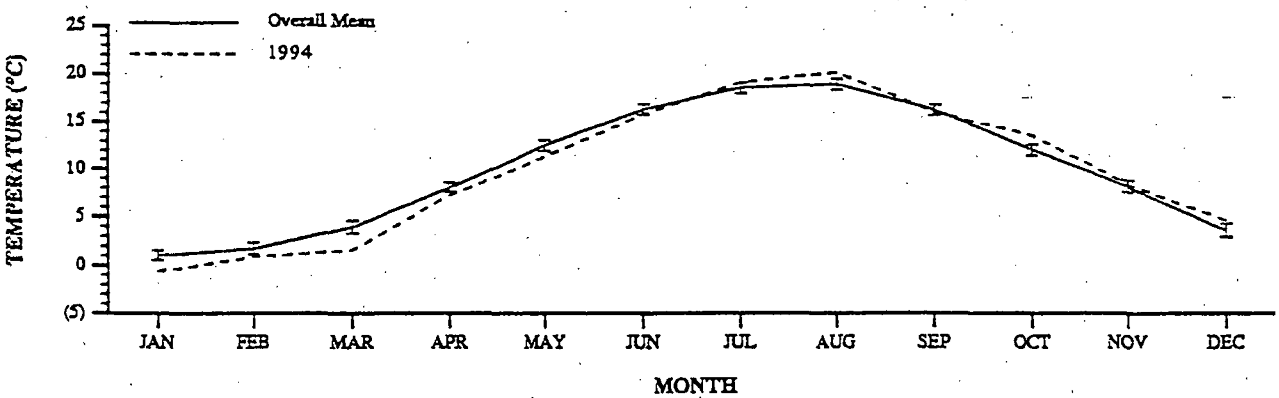


Figure 9-3. Monthly means and 95% confidence limits for **temperature** measured at low tide in Browns River and Hampton Harbor from May 1979-December 1994 and monthly means in 1994 and 1995 (Browns River only). Seabrook Operational Report, 1994.

areas with fine-grained sediments (Watling 1975; McCall 1977; Whitlatch 1977; Santos and Simon 1980; Whitlatch and Zajac 1985). Sediments at subtidal stations were generally fine sand with organic carbon ranging from 1.0 to 2.7%; at intertidal stations the sediments usually varied between fine sand and silt with organic carbon ranging from 1.6 to 5.9% (NAI 1985). Wide temporal and spatial fluctuations were observed in the total density of macrofauna inhabiting the soft-bottom habitats of the Hampton-Seabrook estuary. Species abundance and dominance in the estuary are generally controlled by the physical environment, and the most numerous species are those that tolerate fluctuating water temperature and salinity and a changing sedimentary environment (Flint 1985; Diaz and Schaffner 1990).

Total mean macrofaunal density averaged 4,961 individuals/m^2 at all sites combined during 1994, and was within the range of densities reported since 1978 (995-8,424/m^2; Table 9-2). More organisms were collected during 1994 at the intertidal stations (nearfield: 8,452/m^2; farfield: 5,281/m^2) than were collected at subtidal stations (nearfield: 4,931/m^2; farfield: 2,760/m^2,Table 9-2). At the nearfield Browns River intertidal station, total density was the highest ever recorded (8,452/m^2), continuing the trend of above average abundances that began in 1991 (Table 9-2). The 1982 density at the Browns River intertidal station was similar (8,022/m^2) to that observed in 1994.

Significant differences in mean density among years were observed only at the nearfield Browns River subtidal and intertidal stations, and the farfield Mill Creek intertidal station (Table 9-3). Mean density in 1994 at the nearfield stations and the farfield intertidal station was above average and similar to years with higher-than-average density.

Mean number of taxa collected at subtidal sites during 1994 was higher at the nearfield station (n=40) than at the farfield (n=24); mean number of taxa collected at the corresponding intertidal sites (3MLW and 9MLW) averaged 30 and 33, respectively (Table 9-2). Mean numbers of taxa at all sites during 1994 were within the range for the 16-year time series (Table 9-2). Results of ANOVAs indicated significant variation in the annual mean number of taxa collected at all sites except nearfield subtidal (Table 9-3). Number of taxa was among the highest observed at the intertidal stations and similar to years with intermediate and low numbers of taxa at the farfield subtidal station. Annual values for mean number of taxa followed a pattern similar to that observed for total density. Mean numbers of taxa were highest during 1980-1982, when salinity and settling basin discharge were also highest.

Streblospio benedicti, a small deposit-feeding polychaete, is widespread on the western and eastern coasts of North America and in Europe. Characterized as an opportunist (Grassle and Grassle 1974), *S. benedicti* is able to rapidly colonize perturbed estuarine environments, and high abundance of this species has also been suggested as an indicator of organic enrichment (Wass 1967). This polychaete was the most abundant species in the Hampton-Seabrook estuary and accounted for 7% of the total faunal density at subtidal and 16% at intertidal stations over the 16-year study period. During 1994, densities of *S. benedicti* were substantially higher at the nearfield Browns River stations (135/m^2 and 2,235/m^2 at subtidal and intertidal areas, respectively) than at the farfield Mill Creek stations (12/m^2 and 43/m^2, respectively; Table 9-2). High abundance of *S. benedicti* at the nearfield intertidal station in 1994, a trend that began in 1991, contributed to the higher than average total density. *S. benedicti* density at each station during 1994 was within the range for the time series at all stations except the farfield subtidal station, where the density (12/m^2) was the lowest recorded (Table 9-2). Despite this historic low, density of *S. benedicti* in 1994 was not significantly different from other years with low density (Table 9-3). Because of the high population fluctuations of *S. benedicti*, particularly at farfield intertidal (e.g., 3,215/m^2 in 1983 to 11/m^2 in 1987), significant annual

TABLE 9-2. MEAN NUMBER OF TAXA AND GEOMETRIC MEAN DENSITY (No./m²) FOR EACH YEAR AND OVER ALL YEARS WITH 95% CONFIDENCE LIMITS FROM ESTUARINE STATIONS AT BROWNS RIVER SUBTIDAL (3) AND INTERTIDAL (3MLW) AND MILL CREEK SUBTIDAL (9) AND INTERTIDAL (9MLW) SAMPLED FROM 1978 THROUGH 1994 (EXCLUDING 1985). SEABROOK OPERATIONAL REPORT, 1994.

																		ALL YEARS[c]		
	STA.	1978	1979	1980	1981	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	1994	MEAN[d]	UCL[d]	LCL[d]
Total Density[a]	3	3170	4616	4978	5360	9331	2635	1244	1182	1198	3472	2583	1707	1889	2253	3955	4931	2873	3573	2309
	9	3619	2209	14,767	11,277	4335	4533	620	2819	726	4764	1878	2488	5373	2178	2641	2760	3736	4182	2258
	3MLW	4260	6136	5695	6833	8022	2723	2187	5632	1727	3936	6940	1778	6834	4842	4774	8425	4522	5517	3706
	9MLW	3120	4512	6947	12,189	11,383	11,151	5131	4203	653	6115	7525	3845	3572	4997	5461	5281	5076	6704	3843
	ALL	3514	4099	7344	8424	7796	4364	1715	2980	995	4467	3990	2321	3967	3301	4062	4961	3773	4291	3317
Mean No. of Taxa[b]	3	35	41	38	42	47	32	27	38	33	38	38	35	32	34	38	40	37	39	35
	9	26	34	47	44	34	36	21	36	21	27	25	31	30	31	26	24	31	34	28
	3MLW	28	37	31	38	35	28	18	32	23	31	31	28	25	26[b]	24	30	29	31	27
	9MLW	28	35	35	41	36	33	21	36	16	29	29	36	25	33	27	33	31	33	29
	ALL	29	37	38	41	38	32	22	35	23	31	31	33	28	31	29	32	32	33	31
Streblospio benedicti	3	367	123	193	525	1064	552	239	99	66	550	181	56	462	160	293	135	232	329	163
	9	106	26	2396	525	81	538	16	161	49	744	167	400	1612	296	76	12	170	320	90
	3MLW	439	505	1010	928	3584	525	535	1421	316	1306	3227	259	3301	1635	1977	2235	1058	1487	753
	9MLW	566	434	466	2700	2354	3215	1560	1299	11	744	399	1023	604	231	27	43	450	829	244
	ALL	314	163	684	912	925	842	242	415	58	794	445	278	1105	366	187	113	370	482	284
Oligochaeta	3	242	270	204	651	2189	556	225	95	133	768	301	156	233	421	392	361	325	445	237
	9	16	100	2910	969	1058	1603	162	528	131	272	233	260	525	293	140	114	297	463	191
	3MLW	87	186	318	320	350	292	382	968	215	322	409	48	197	428	334	546	279	395	197
	9MLW	574	810	1067	861	565	2877	572	742	161	351	2888	362	610	2024	1680	1407	830	1242	555
	ALL	119	253	671	646	823	931	298	437	157	382	537	163	348	572	419	422	387	470	318
Capitella capitata	3	11	63	123	473	889	216	66	73	57	105	72	16	33	153	268	140	96	152	61
	9	238	29	2453	277	291	376	28	808	113	1530	262	259	479	220	1042	780	321	495	207
	3MLW	17	29	138	244	540	208	124	197	26	46	27	24	10	57	62	62	64	95	44
	9MLW	279	45	125	320	276	800	303	234	19	1068	173	466	143	181	208	197	210	320	138
	ALL	60	40	269	318	443	341	91	228	42	299	98	84	71	137	245	191	143	179	114
Hediste diversicolor	3	83	172	158	352	452	45	50	52	43	128	52	38	64	50	342	118	97	132	71
	9	21	29	41	205	41	7	7	43	2	33	29	8	45	35	82	76	28	42	18
	3MLW	800	1343	1169	1613	975	220	296	987	150	523	1235	199	1906	1105	1120	1934	756	1083	527
	9MLW	170	164	101	241	135	57	513	184	6	29	93	18	30	25	89	29	70	106	46
	ALL	125	183	167	410	223	45	89	143	18	90	115	33	115	84	230	151	110	141	85

(Continued)

TABLE 9-2. (Continued)

	STA.	1978	1979	1980	1981	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	1994	ALL YEARS[c] MEAN[d]	UCL[d]	LCL[d]
Mya arenaria	3	69	158	92	181	132	75	31	21	30	12	35	64	7	17	49	25	43	63	30
	9	265	427	299	246	148	168	157	34	53	83	69	208	48	32	82	17	103	152	70
	3MLW	106	224	26	179	117	103	22	13	27	12	73	25	22	31	91	51	48	71	72
	9MLW	100	328	62	400	141	70	86	13	73	39	425	266	102	107	309	398	126	184	87
	ALL	118	265	82	237	134	98	55	19	42	26	93	98	30	37	103	55	72	88	59
Spio setosa	3	38	39	65	155	159	120	113	151	171	244	447	334	376	267	254	594	169	230	125
	9	50	59	287	346	170	16	3	75	6	315	236	110	158	66	42	150	74	128	43
	3MLW	7	9	8	6	4	8	2	46	25	46	24	26	8	2	5	2	9	15	5
	9MLW	54	59	43	78	48	30	8	65	2	32	41	117	46	5	3	18	26	45	15
	ALL	30	33	51	72	51	26	10	76	16	104	102	103	70	22	21	45	42	56	32
Tharyx acutus	3	330	221	835	1	2	3	12	9	1	101	7	6	24	10	103	88	22	44	11
	9	10	40	46	292	136	35	7	10	3	16	4	46	75	27	34	8	21	40	11
	3MLW	106	174	607	3	23	52	44	255	87	244	80	28	4	9	90	39	53	90	31
	9MLW	8	298	48	43	1634	278	325	307	1	21	3	8	8	22	6	30	37	75	18
	ALL	42	147	183	17	64	37	34	53	5	54	10	9	16	15	38	30	31	42	22

[a] Yearly mean density = mean of three seasonal means (where seasonal mean = mean of five replicates).
[b] Yearly mean number of taxa = mean of three seasonal totals (where seasonal total = total number in all five 1/16 m^2 replicates combined). In August 1992 at Station 3MLW, the total number of replicates was four, not five.
[c] Mean of all years = mean of 48 seasonal means (3 seasons x 16 years).
[d] Upper and lower 95% confidence limits.

TABLE 9-3. RESULTS OF ONE-WAY ANALYSIS OF VARIANCE AMONG YEARS FOR MEAN NUMBER OF TAXA (per 5/16 m^2) AND LOG10 (x+1) TRANSFORMED DENSITY (No./m^2) OF THE MOST ABUNDANT ESTUARINE SPECIES OF MACROFAUNA AND TOTAL DENSITY (ALL SPECIES) COLLECTED AT FOUR ESTUARINE STATIONS FROM 1978 THROUGH 1994 (EXCLUDING 1985). SEABROOK OPERATIONAL REPORT, 1994.

PARMETER[a]	STATION	F[b]	MULTIPLE COMPARISONS[c] - SUBTIDAL STATIONS
Mean Density (All spp.)	3	3.54***	82,81,80,94,79,93,88; 78,83,89,92,91,90,84,87,86
	9	2.89 NS	
Mean Number of Taxa	3	1.51 NS	
	9	4.13***	80,81,83,86; 82,79,90,92,91,88,78,93,89,94>90,92,91,88,78,93,89,94,87,84
Streblospio benedicti	3	1.79 NS	
	9	2.04*	80,91,88,83,81,90,92,89,86,78,82,93,87>88,83,81,90,92,89,86,78,82,93,87,79,84,94
Oligochaeta	3	1.88 NS	
	9	4.02**	80,83,82,81,86,91>86,91,92,88,90,89,84,93,87,94,79>79,78
Capitella capitata	3	2.14*	82,81,93,83,92,94,80,88,86,89,84,79,87>92,94,80,88,86,89,84,79,87,91,90,78
	9	3.92***	80,88,93,86,94,91,83>91,83,82,81,89,90,78,92,87>87,79,84
Hediste diversicolor	3	2.82**	82,81,93,79,80,88,94>79,80,88,94,78,91,86,89,92,84,83,87,90
	9	2.52**	81,93,94,91,86,82,80,92,88,79,89,78>79,89,78,90,84,83,87
Mya arenaria	3	1.95 NS	
	9	1.79 NS	
Spio setosa	3	2.79**	94,89,91,90,92,93,88,87,82,81,86,83>87,82,81,86,83,84,80,79,78
	9	2.03*	81,88,80,89,82,91,94,90,86,92,79,78,93,83>90,86,92,79,78,93,83,87,84
Tharyx acutus	3	5.09***	80,78,79,93,88,94; 91,84,92,86,89,90,83,82>84,92,86,89,90,83,82,87,81
	9	0.99 NS	

(continued)

TABLE 9-3. (Continued)

PARMETER[a]	STATION	F[b]	MULTIPLE COMPARISONS[c] - INTERTIDAL STATIONS
Mean Density (All spp.)	3MLW	2.62*	94,82,89,91,81,79,80,86,92,93,78,88; 92,93,78,88,83,84,90,87
	9MLW	2.04*	81-83,89,80,88,93,94,84,92,79,86,90,91,78; 90,91,78,87
Mean Number of Taxa	3MLW	2.99**	81,79,82,86,89,80,88,94,78; 83,90,92,91,93,87,84
	9MLW	2.66**	81,90,82,86,80,79,92,94,83,88,89,78>89,78,93,91,84,87
Streblospio benedicti	3MLW	2.24*	82,91,89,94,93,92,86,88,80,81,84,83,79>93,92,86,88,80,81,84,83,79,78,87,90
	9MLW	3.03**	83,81,82,84,86,90,88,91,78,80,79,89,92>92,94,93,87
Oligochaeta	3MLW	1.02 NS	
	9MLW	0.97 NS	
Capitella capitata	3MLW	3.96***	82,81,83,86,80,84; 94,93,92,88,79,89,87,90,78>92,88,79,89,87,90,78,91
	9MLW	1.57 NS	
Hediste diversicolor	3MLW	1.63 NS	
	9MLW	3.17**	84,81,86,78,79,82,80,89,93>82,80,89,93,83,91,94,88,92,90>91,94,88,92,90,87
Mya arenaria	3MLW	1.68 NS	
	9MLW	2.49*	89,81,94,79,93,90,82,92,91,78,84,87,83,80>92,91,78,84,87,83,80,88,86
Spio setosa	3MLW	1.20 NS	
	9MLW	1.32 NS	
Tharyx acutus	3MLW	3.08***	80,86,88,79,78,93,87,89,83->83,84,94,90,82,92,91,81
	9MLW	3.37***	82,84,86,79,83>80,81,94,92,88,90,78,91,93,89>81,94,92,88,90,78,91,93,89,87

[a] Degrees of freedom for the model (years) = 15; Degrees of freedom for the error = 32;
[b] NS = Not significant (p>0.05); * = Significant (0.05≥p>0.01); ** = Highly significant (0.01p≥0.001); *** = Very highly significant (p≤0.001);
[c] Multiple comparison test is Waller-Duncan k-ratio t test with alpha = 0.05. Groups and years are in order of decreasing abundance. Groups that contain years that overlap with less abundance groups are separated by (>). Groups that contain years that are all significantly greater than less abundant groups are separated by (;).

differences were observed at both nearfield and farfield intertidal sites, and at the farfield subtidal site. By contrast, annual variation in *S. benedicti* abundance was not significant at the nearfield subtidal site (Table 9-3).

Oligochaetes are small deposit feeding annelids that can be very abundant in organically enriched shallow-water marine habitats, feeding on microbes that colonize organic detritus (Soulsby et al. 1982; Hull 1987). As the amount of detrital material varies both spatially and temporally, oligochaete abundance can exhibit rapid and large fluctuations (Giere 1975; Price and Hylleberg 1982). Oligochaetes were the second most abundant taxon collected, comprising on average 11% of the total number of individuals collected at both intertidal and subtidal stations. Densities of oligochaetes during 1994 at nearfield Browns River subtidal ($361/m^2$) and intertidal ($546/m^2$) sites were within the range of previous study years (Table 9-2). At the farfield subtidal site, however, oligochaete density during 1994 was $114/m^2$, within the range of previous years but considerably lower than the 1,407 individuals/m^2 collected intertidally (9MLW). Significant annual differences in oligochaete density were observed only at the Mill Creek farfield site over the 16-year study period, with 1978 and 1979 having significantly lower densities that the other years (Table 9-3). Density of oligochaetes in 1994 at the farfield subtidal station was not significantly different from other years of intermediate density (Table 9-3). No significant annual differences in oligochaete densities then observed at either nearfield site, or at the intertidal farfield site.

The polychaete genus *Capitella* occurs worldwide (Hartman 1969; Wade 1972) and, as an opportunist, is a good indicator of a wide variety of environmental stresses (Wass 1967). *C. capitata*, a sedentary tube-dwelling deposit-feeding polychaete, is commonly found in oxygen-depleted estuaries and harbors where sedimentation rates are high (Reish 1967). *C. capitata* was also present in high numbers at Seabrook estuarine study sites. During 1994, *C. capitata* densities at the farfield and nearfield subtidal sites were 140 and $780/m^2$, respectively, within the range of the 16-year time series (Table 9-2). Differences among annual densities of *C. capitata* were significant at all stations except the farfield Mill Creek intertidal site (9MLW; Table 9-3). Density of *C. capitata* in 1994 at the nearfield Browns River subtidal and intertidal stations, and the farfield (Mill Creek) subtidal station was ranked with the years of highest abundance.

The clam worm *Hediste* (formerly *Nereis) diversicolor* inhabits near-shore marine sediments from the North Atlantic and North Sea to the Mediterranean (Gosner 1971). This relatively large polychaete has often been identified as an "indicator of organic pollution" because of its high abundance in nutrient rich areas (Hull 1987). *H. diversicolor* is a common member of the macrofaunal community in Hampton-Seabrook estuary, with densities during these studies averaging over $100/m^2$. During 1994, mean densities of *H. diversicolor* at the nearfield Browns River subtidal and intertidal sites were 118 and $1{,}934/m^2$, respectively, and were considerably higher than the densities at the farfield Mill Creek sites ($76/m^2$ and $29/m^2$; Table 9-2). With the exception of the nearfield intertidal station, the 1994 densities of *H. diversicolor* at all stations were within the range of previous study years (Table 9-2). The 1994 density was the highest recorded at the nearfield Browns River intertidal site contributing to a high total density. Densities of *H. diversicolor* have been higher than average since 1991 at this station. Significant differences among years occurred at all stations except nearfield intertidal (3MLW), where *H. diversicolor* was consistently most abundant (ANOVA results; Table 9-3). In 1994, densities of *H. diversicolor* at the nearfield and farfield subtidal stations were among the years of highest density. At the farfield intertidal station, density in 1994 was among the years of intermediate density.

The soft-shelled clam *Mya arenaria* is harvested in great numbers from mud flats in New England (Abbott 1974). In Hampton Harbor, *M. arenaria* has important recreational value since flats were reopened to shellfishing in 1994. The predominant life stage of *M. arenaria* collected in estuarine samples were young-of-the-year (spat <5 mm) and juvenile clams (<12 mm). Mean clam densities during 1994 at the nearfield subtidal ($25/m^2$) and intertidal sites ($51/m^2$) and at farfield subtidal site ($17/m^2$) were lower than the farfield intertidal site ($398/m^2$). Annual densities of *M. arenaria* were significantly different at only the farfield intertidal station (Table 9-3). Densities in 1994 at this station were among the years of highest density.

The tube-dwelling polychaete *Spio setosa* is most common in sandy, shelly subtidal areas where it feeds on suspended particles (Dauer et al. 1981). In the Hampton-Seabrook estuary, *S. setosa* was more common in subtidal collections, particularly at the nearfield Browns River station, and uncommon in intertidal collections. During 1994, density of *S. setosa* at the nearfield subtidal station was the highest recorded, while densities at the other stations were intermediate (Table 9-2). No significant differences in *S. setosa* density occurred among years at either of the intertidal stations; however, densities at both subtidal stations exhibited significant annual variability, with 1994 ranking among the years with highest abundance (Table 9-3).

The polychaete *Tharyx acutus* (formerly *Caulleriella* sp. B), was occasionally abundant in the Hampton-Seabrook estuary, and has exhibited wide density fluctuations from one year to the next since 1980 at both nearfield and farfield sites (Table 9-2). Densities of *T. acutus* during 1994 were higher at the nearfield station ($88/m^2$ subtidal and $39/m^2$ intertidal) than at the farfield ($8/m^2$ subtidal and $30/m^2$ intertidal; Table 9-2). Densities in 1994 were within the range of previous years at all four stations, and variation among years was significant at all stations except for the farfield subtidal station, where the density was among the highest observed (Table 9-3).

9.4 CONCLUSIONS

9.4.1 PHYSICAL ENVIRONMENT

Physical factors such as temperature and salinity are important factors in controlling the structure of soft-bottom communities in the Hampton-Seabrook estuary. The predictable seasonal cycles of temperature and salinity provide valuable information for interpreting changes in macrofaunal abundance and community composition. Maximum temperatures usually occurred in July or August, with minimum temperatures in January or February. Monthly temperatures in Browns River from April through December 1994 and January through May 1995 fluctuated around the monthly overall average. Salinity levels had a less distinct seasonal cycle than did temperatures, but were usually lowest in spring coincident with increased runoff, and highest in summer due to decreased precipitation. Monthly salinities in Browns River were well above the upper 95% CL in June, July and October 1994, when rainfall was below average. During a three year period from 1980 to 1982, salinities in Browns River were among the highest observed in this study (especially at low tide), and coincided with low precipitation and highest discharge volume from the Seabrook Station settling basin. During this period, construction of intake and discharge tunnels, and tunnel dewatering caused the salinity of the settling basin's discharge water to be relatively high. Since the decrease of discharge volumes in 1983, salinity levels in Browns River have also decreased and remained at levels typical of estuarine environments. The diversion of settling pond effluent from Browns River to the offshore discharge tunnel in April 1994 has not caused a measurable increase in salinity for Browns River. Above-average salinity in Browns River occurred only in June, July and October 1994, coincident with below-average precipitation at Seabrook Station. A similar trend was observed at the farfield station in Hampton Harbor, which indicates the salinity increase was not a localized effect due to diversion of the settling basin effluent from Browns River to the open ocean via the cooling water discharge tunnel. With the exception of February, the 1995 salinity values from Browns River was similar to the overall monthly means.

9.4.2 MACROFAUNA

The benthic macrofaunal community in the Hampton-Seabrook estuary was representative of other communities reported throughout New England. Species composition in nearfield Browns River (Stations 3 and 3MLW) and farfield Mill Creek (Stations 9 and 9MLW) was similar to that described in other estuaries along the Atlantic Coast (Watling 1975; McCall 1977; Whitlatch 1977; Santos and Simon 1980; Whitlatch and Zajac 1985). As in most other temperate areas, spatial and temporal patterns of abundance, numbers of species, and dominant taxa comprising intertidal and subtidal communities were largely determined by physical characteristics and sediment type (Rhoads et al. 1978; Flint 1985). The annelid worms such as *Streblospio benedicti, Capitella capitata, Hediste diversicolor*, and oligochaetes have predominated in the macrofaunal collections from 1978 through 1994. These organisms have been classified as opportunists and are characterized by rapid development, several reproductions per year, and high recruitment and mortality (Grassle and Grassle 1974; McCall 1977; Rhoads et al. 1978). As a result of these life history strategies and the natural variability in physical and chemical properties of this estuary, significant annual variation was observed in total macrofaunal density, mean number of taxa, and density of most of the dominant organisms. Changes such as these are typical of those in marine benthic communities following disturbance (Kaplan et al. 1974; Sanders et al. 1980; Swartz et al. 1980; Nichols 1985; NUSCO 1987, 1993; Berge 1990).

The number of taxa collected and macrofaunal densities were high from 1980 to 1982, most likely due to a combination of low precipitation and high discharge rates from the settling basin. Also during this period, the discharge contained higher than average levels of nutrients, organic matter and suspended solids (NAI 1980a, 1981). The increased volume of discharge water during 1980-1982 may have disturbed the established faunal community in Browns River, which was rapidly colonized by opportunist species such as *S. benedicti, C. capitata, H. diversicolor*, and oligochaetes. However, since changes in total density and density of dominants occurred simultaneously at Browns River and Mill Creek, they were probably related to area-wide changes in natural abiotic (precipitation, temperature, salinity) and/or biotic (predation, competition) factors. Nevertheless, decreases in settling basin discharge volume and, as a result salinity were followed by lower total density and the lowest number of taxa in 1984. Macrofaunal density increased by 1986 and then decreased again in 1987. These rapid changes were apparently related to high precipitation and low salinity consistent with observations reported in NAI (1988, 1992). The macrofaunal community recovered within one to two years, and since then, total density and number of taxa have been less variable (NAI 1993). Since 1990, macrofaunal densities at all four stations have generally increased from year to year.

The estuarine benthic community in 1994 generally resembled that observed in previous years (Table 9-4). Number of taxa, total density, and abundance of dominants were within the range of previous years, with a few exceptions. Total density at the nearfield Browns River intertidal station in 1994 was the highest observed to date, caused by high numbers of polychaetes *Streblospio benedicti*, and *Hediste diversicolor*. Higher than average abundances of these species have been observed since 1991, and appeared unrelated to the cessation of Browns River discharge.

The results of the estuarine benthos study show no measurable effects related to the settling basin discharge, during or after construction of Seabrook Station. Similarly, no effects of the operation of

TABLE 9-4. SUMMARY OF EVALUATION OF EFFECTS OF SEABROOK STATION OPERATION ON BENTHIC MACROFAUNA OF BROWNS RIVER (STATIONS A3, 3ML) AND HAMPTON-SEABROOK ESTUARY (STATIONS, 9, 9ML). SEABROOK OPERATIONAL REPORT, 1994.

COMMUNITY/ SPECIES	WAS 1994 SIMILAR TO PREVIOUS YEARS?[a]
Number of taxa	Yes
Total density	Yes
Streblospio benedicti	Yes
Oligochaeta	Yes
Capitella capitata	Yes
Hediste diversicolor	Yes
Mya arenaria	Yes
Tharyx acutus	Yes
Spio setosa	Yes

[a] Results based on ANOVA done by station for Stations 3, 3ML, 9 and 9ML (see Table 3).

Seabrook Station have been observed in the estuarine macrofauna community. Cessation of the Browns River discharge in April 1994 has had no adverse effect on the resident macrofaunal community.

9.5 REFERENCES CITED

Abbott, R.T. 1974. American Seashells. The marine Mollusca of the Atlantic and Pacific Coasts of North America. Van Nostrand Reinhold Co., New York. 663 pp.

Berge, J.A. 1990. Macrofaunal recolonization of subtidal sediments. Experimental studies on defaunated sediment contaminated with crude oil in two Norwegian fjords with unequal eutrophication status. I. Community responses. Mar. Ecol. Prog. Ser. 66:103-115.

Dauer, D.M., C.A. Maybury, and R.M. Ewing. 1981. Feeding behavior and general ecology of several spionid polychaetes from the Chesapeake Bay. J. Exp. Mar. Biol. Ecol. 54:21-38.

Diaz, R.J., and L.S. Schaffner. 1990. The functional role of estuarine benthos. Pages 25-56 *in* Contribution 1595. College of William and Mary, Virginia Inst. of Mar. Sci.

Flint, R.W. 1985. Long-term estuarine variability and associated biological response. Estuaries 8:158-169.

Giere, O. 1975. Population structure, food relations and ecological role of marine oligochaetes, with special reference to meiobenthic species. Mar. Biol. 31:139-156.

Gosner, K.L. 1971. Guide to Identification of Marine and Estuarine Invertebrates. Wiley-Interscience. John Wiley and Sons, Inc., New York. 693 pp.

Grassle, J.F., and J.P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. J. Mar. Res. 32:253-284.

Hartman, O. 1969. Atlas of the Sedentariate Polychaetous Annelids from California. Los Angeles, Allan Hancock Fnd., Univ. S. Cal. 812 pp.

Holland, A.F. 1985. Long-term variation of macrobenthos in a mesohaline region of Chesapeake Bay. Estuaries 8:93-113.

Holland, A.F., A.T. Shaughnessy, and M.H. Hiegel. 1987. Long-term variation in mesohaline Chesapeake Bay macrobenthos: spatial and temporal patterns. Estuaries 10:227-245.

Hull, S.C. 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. and Shelf Sci. 25:519-532.

Kaplan, E.H., J.R. Welker, and M.G. Kraus. 1974. Some effects of dredging on populations of macrobenthic organisms. Fish. Bull., U.S. 72:445-480.

McCall, P.L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. 35:221-266.

NAI (Normandeau Associates, Inc.). 1979. Effects of the settling basin effluent on survival of selected marine invertebrates: *in situ* bioassay. Prepared for Public Service Company of New Hampshire. 8 pp.

_________. 1980a. A report to the Public Service Company of New Hampshire concerning nutrient and phytoplankton concentrations in the Seabrook Station sewage lagoons. 5 pp.

_________. 1980b. Effects of Seabrook station's settling basin effluent on survival of selected marine invertebrates. Tech. Rep. XI-4 Seabrook Ecological Studies, 1979.

_________. 1981. Seabrook Environmental Studies. 1979 Seabrook benthic report. Tech. Rep. XI-5.

_________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook area, 1975-1984. Tech. Rep. XVI-II.

_________. 1988. Seabrook Environmental Studies. 1987 data report. Tech. Rep. XIX-I.

_________. 1990. Seabrook Environmental Studies, 1989 data report. Tech. Rep. XXI-I.

_________. 1992. Seabrook Environmental Studies, 1991. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIII-1.

_________. 1993. Seabrook Environmental Studies, 1992. A characterization of environmental conditions in the Hampton-Seabrook area during the operation of Seabrook Station. Tech. Rep. XXIV-1.

_________. 1995. Seabrook Environmental Studies. 1994 Data Report. Tech. Rep. XXVI-1.

Nichols, F.H. 1985. Abundance fluctuations among benthic invertebrates in two Pacific estuaries. Estuaries 8:136-144.

NUSCO (Northeast Utilities Service Company). 1987. Benthic Infauna. Pages 1-51 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Summary of studies prior to Unit 3 operation. Annual Report 1986.

_________. 1993. Benthic Infauna. Pages 115-150 *in* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1992.

Price, L.H., and J. Hylleberg. 1982. Algal-faunal interactions in a mat of *Ulva fenestrata* in False Bay, Washington. Ophelia 21:75-88.

Rees, H.L., and A. Eleftheriou. 1989. North Sea benthos: a review of field investigations into the biological effects of man's activities. J. Cons. int. Explor. Mer 45:284-305.

Reish, D.J. 1967. Relationship of the polychaetous annelid *Capitella capitata* (Fabricius) to waste discharges of biological origin. Pages 195-200 *in* C.M. Tarzwell, ed. Biological problems in water pollution. U.S. Health Service.

Rhoads, D., P.L. McCall, and T.Y. Yingst. 1978. Disturbance and production in the estuarine seafloor. Amer. Sci. 66:577-586.

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge "Florida" off West Falmouth, Massachusetts. J. Mar. Res. 38:265-380.

Santos, S.L., and J.L. Simon. 1980. Response of soft-bottom benthos to annual catastrophic disturbance in a South Florida estuary. Mar. Ecol. Prog. Ser. 3:347-356.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, N.C. 1028 pp.

Soulsby, P.G., D. Lowthion, and M. Houston. 1982. Effects of macroalgal mats on the ecology of intertidal mudflats. Mar. Poll. Bull. 13:162-166.

Swartz, R.C., W.A. DeBen, F.A. Cole, and L.C. Bentsen. 1980. Recovery of the macrobenthos at a dredge site in Yaquina Bay, Oregon. Pages 391-408 *in* R.A. Baker, ed. Contaminants and Sediments, Vol. 2. Ann Arbor Science Publisher, Inc., Ann Arbor, Mich.

Wade, B.A. 1972. A description of a highly diverse soft-bottom community in Kingston Harbor, Jamaica. Mar. Biol. 13:57-69

Warwick, R.M. 1988. Effects on community structure of a pollutant gradient-introduction. Mar. Ecol. Prog. Ser. 46:149.

Wass, M.L. 1967. Biological and physiological basis of indicator organisms and communities II. Indicators of pollution. Pages 271-283 *in* T.A. Olsen, and E.J. Burgers, eds. Pollution and Marine Ecology. Interscience Publ., New York.

Watling, L. 1975. Analysis of structural variations in a shallow estuarine deposit-feeding community. J. Exp. Mar. Bio. Ecol. 19:275-313.

Whitlatch, R.B. 1977. Seasonal changes in the community structure of the macrobenthos inhabiting the intertidal sand and mudflats of Barnstable Harbor, MA. Biol. Bull. 152:275-294.

Whitlatch, R.B., and R.N. Zajac. 1985. Biotic interactions among estuarine infaunal opportunistic species. Mar. Ecol. Prog. Ser. 21:299-311.

APPENDIX TABLE 9-1. NOMENCLATURAL AUTHORITIES FOR TAXA CITED IN THE ESTUARINE BENTHOS SECTION. SEABROOK OPERATIONAL REPORT, 1994.

Oligochaeta

Polychaeta
Capitella capitata (Fabricius 1780)
Hediste diversicolor (Müller 1776)
Spio setosa (Verrill 1875)
Streblospio benedicti (Webster 1879)
Tharyx acutus (Webster and Benedict 1887)

Mollusca
Mya arenaria Linnaeus 1758

APPENDIX TABLE 9-2. WATER QUALITY DATA FOR BROWNS RIVER, JANUARY THROUGH MAY 1995. SEABROOK OPERATIONAL REPORT 1994.

	TEMPERATURE (°C)		SALINITY (ppt)	
MONTH	LOW TIDE	HIGH TIDE	LOW TIDE	HIGH TIDE
January	4.7	6.2	18.6	29.0
February	2.8	4.3	25.7	31.1
March	7.5	6.5	18.6	26.4
April	9.5	10.5	21.1	29.9
May	10.0	12.0	23.6	30.6

TABLE OF CONTENTS

SUMMARY

Since Hampton-Seabrook estuary contains the majority of New Hampshire's stock of the recreationally important soft-shell clam, an extensive program has been undertaken to characterize the population of all life stages. Larvae have typically been abundant in June and July, with a second, larger peak in late August and September. Larval densities during the operational period showed a seasonal cycle that was similar to previous years, but mean abundances were lower than the preoperational average at both nearfield and farfield stations. Adult soft-shell clam densities have been highly variable during the preoperational period, a result of varying recruitment success, variable predation levels, and the presence of disease. The closure of Hampton Harbor to recreational clamming in 1989, a result of coliform contamination, has eliminated a substantial source of mortality. Clamming resumed at Flats 1 and 3 in October of 1994, which reintroduced a significant source of mortality. Mean density in 1994 of young-of-the-year clams on all three flats was less than the preoperational mean and equal to the operational mean density. Juvenile mean density in 1994 was less than the preoperational mean and greater than the operational mean. Spat and adult mean densities in 1994 were greater than the operational and preoperational mean densities. There were no significant differences in densities of young-of-the-year, spat, and juveniles between the preoperational and operational periods. However, the Preop-Op X Area term was significant for adults, which indicated differing trends between the preoperational and operational periods among flats. Adult clam densities increased significantly at Flat 4, and decreased significantly at Flat 2, between the preoperational and operational periods.

LIST OF FIGURES

LIST OF TABLES

PAGE

10.0 SOFT-SHELL CLAM (*MYA ARENARIA*)

10.1 INTRODUCTION

The objectives of the soft-shell clam (*Mya arenaria* Linnaeus 1758) monitoring programs are to determine the spatial and temporal patterns of abundance of various life stages of soft-shell clams in the vicinity of Hampton Harbor, NH. Planktonic larval stages may be subject to impacts from Seabrook Station due to entrainment through the offshore intake structure into the circulating water system. Benthic stages (after settlement to the bottom) in the Hampton-Seabrook estuary may be subject to impacts from the station's settling pond discharge, which ended in April 1994. Other factors that may affect the clam density, such as predation, disease, and recrational clamming have been considered. Nearfield/farfield comparisons of seed clam densities (1-12 mm) are made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich MA.

10.2 METHODS

10.2.1 Bivalve Larvae

The spatial and temporal distributions of 12 species of umboned bivalve larvae, including *Mya arenaria,* were monitored using a 0.5-m diameter, 0.076-mm mesh net. Samples were collected weekly from mid-April through October at Hampton Harbor (P1), intake (P2), discharge (P5) and farfield (P7) stations (Figure 10-1). Sampling began at Station P2 in July 1976, Station P7 in July 1982, and at Station P1 in July 1986. Collections were made at Station P5 from July-December 1986 and April 1988 to the present. Two simultaneous two-minute oblique tows were taken at each station. Upon recovery, net contents were preserved with 1-2% borax-buffered formalin (with sugar added to enhance color preservation) and refrigerated. In the laboratory, samples were split when the total umboned bivalve larvae count exceeded 300 specimens and two subsample fractions were enumerated from each sample. A more detailed description of methods can be found in NAI (1991).

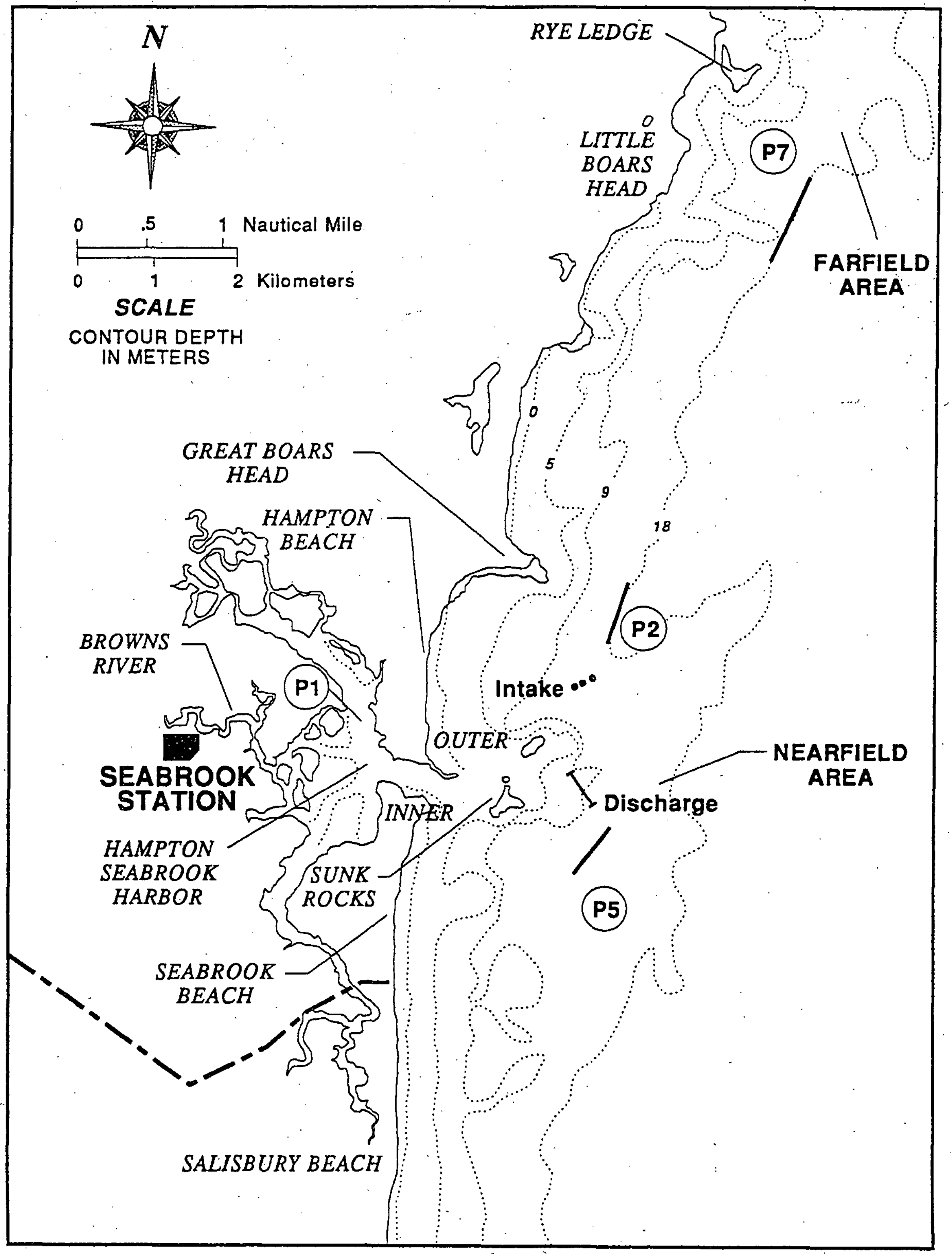
10.2.2 Hampton Harbor Population Survey

The five largest flats in the Hampton-Seabrook estuary (Figure 10-2) were surveyed in the late fall from 1974-1994 to obtain information on clams measuring at least 1 mm. Sampling sites within each flat were chosen randomly. The number of stations sampled on each flat was proportional to the variance in density observed at that flat historically. Flats 3 and 5 were not sampled for clams greater than 25 mm in length, since the density has historically been extremely low.

A sample for 1-25 mm clams consisted of three 10.2-cm diameter x 10.2-cm deep cores (4-in diameter x 4-in deep) taken within a 30-cm x 61-cm quadrat (1-ft x 2-ft). Samples were sieved with a 1-mm mesh sieve, and clams were enumerated, measured, and released. A sample for clams >25 mm consisted of one quadrat dug to a depth of 45 cm (1.5-ft) with a clam fork. Large clams were removed from the sediment in the field, enumerated, measured, and released.

10.2.3 Nearfield/Farfield Study

To compare seed clam densities (1-12 mm), surveys were conducted in the fall at 10 sites in both Hampton Harbor (Flats 2 and 4) and Plum Island Sound beginning in 1976. Three cores were taken per station and processed using the same methods employed in the Hampton Harbor survey described above. An additional 1-cm deep x 35-mm diameter core was taken for analysis of newly-set soft-shell clam spat (<1.0 mm). Sampling sites were fixed at locations where the abundance of clams has been high historically.



LEGEND

—— = Bivalve Larvae Stations P1, P2, P5, P7

Figure 10-1. Bivalve larvae (including *Mya arenaria*) sampling stations. Seabrook Operational Report, 1994.

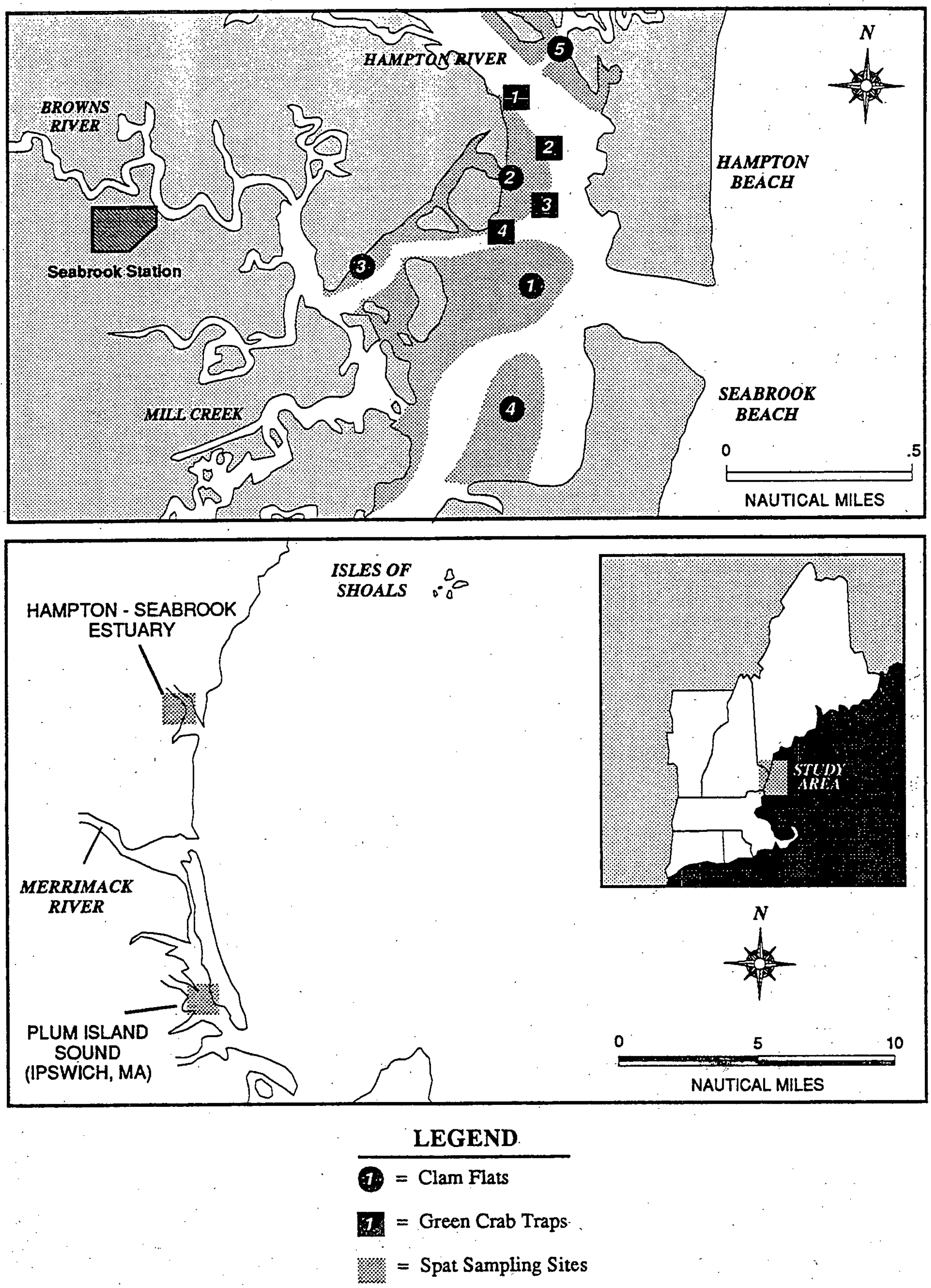


Figure 10-2. Hampton-Seabrook estuary and Plum Island Sound soft-shell clam *(Mya arenaria)* and green crab *(Carcinus maenas)* sampling areas. Seabrook Operational Report, 1994.

10.2.4 Green Crab *(Carcinus maenas)*

Beginning in 1983, green crabs (*Carcinus maenas* Linnaeus 1758) were collected at four estuarine locations on the perimeter of Flat 2 in Hampton Harbor (Figure 10-2). The traps were set twice a month for 24 hours year-round except for February and March, when historically no crabs have been found. Two 13-mm mesh, baited crab traps were set at each station so that they were awash at mean low tide (NAI 1991).

10.2.5 Analytical Methods

Annual geometric mean density was computed based on the number of samples taken during any given year (n = number of samples). Preoperational and operational geometric mean densities were based on the annual means (n = number of years sampled), to avoid variation caused by an uneven number of samples per year. Means were plotted graphically and examined for trends.

An analysis of variance (ANOVA) was used on log (x+1) transformed density (n=number of samples) to determine differences for the following main effects: spatial (among stations or areas/flats), temporal (among weeks (larvae only) and years), and periodic (between preoperational and operational periods) variation. In addition, the interaction between station or area and period was investigated. If the interaction term (Preop-Op X Area) was found significant ($\alpha \leq 0.05$), the least squares means procedure (SAS 1985) was used to evaluate differences among means, and significant interactions were presented graphically. A mixed model ANOVA developed by Northeast Utilities, based on recent reviews of the BACI model by Underwood (1994) and Stewart-Oaten et al. (1986), was used with all effects considered random, except operational status (Preop-Op). Time and location of sampling of sampling were considered random factors because both sampling dates and selected locations represented only a fraction of all the possible times and locations (Underwood 1994). ANOVA used weekly means of log (x+1) density for larvae collected from 1988-1994, when all three stations were sampled concurrently. The ANOVA model used log (x+1) densities from the total number of samples taken for benthic stages sampled from 1974-1994 in the Hampton Harbor survey, and from 1987-94 for the nearfield/farfield survey.

10.3 RESULTS

10.3.1 Larvae

Mya arenaria larvae occurred most weeks from late May through October during preoperational years at nearfield Station P2 (Figure 10-3). Maximum densities were typically recorded in late summer or early fall, and a secondary peak usually occurred in early summer. Peak abundances in 1994 occurred in late June and late September and were approximately an order of magnitude larger than the preoperational average. The late September 1994 peak in larval clam abundance was the highest recorded in the operational period, although higher abundances were observed during the preoperational period. Annual mean density of larvae in 1994 was higher than the operational mean at Stations P2 and P7, and lower than the preoperational and operational means at Station P5. The overall operational mean larval abundance at all three stations was not significantly different than the preoperational mean (Tables 10-1, 10-2). Larval densities were not significantly different among stations, regardless of plant operational status. Trends in larval abundance between stations remained consistent during both the preoperational and operational periods and were not affected by the operation of Seabrook Station.

Sexual maturity in *Mya arenaria* is primarily a function of size rather than age, with clams larger than 20 mm in shell length capable of spawning (Coe and Turner 1938). Clams north of Cape Cod usually began to spawn once per year when the water temperature reached 4-6°C. Factors which affect spawning in

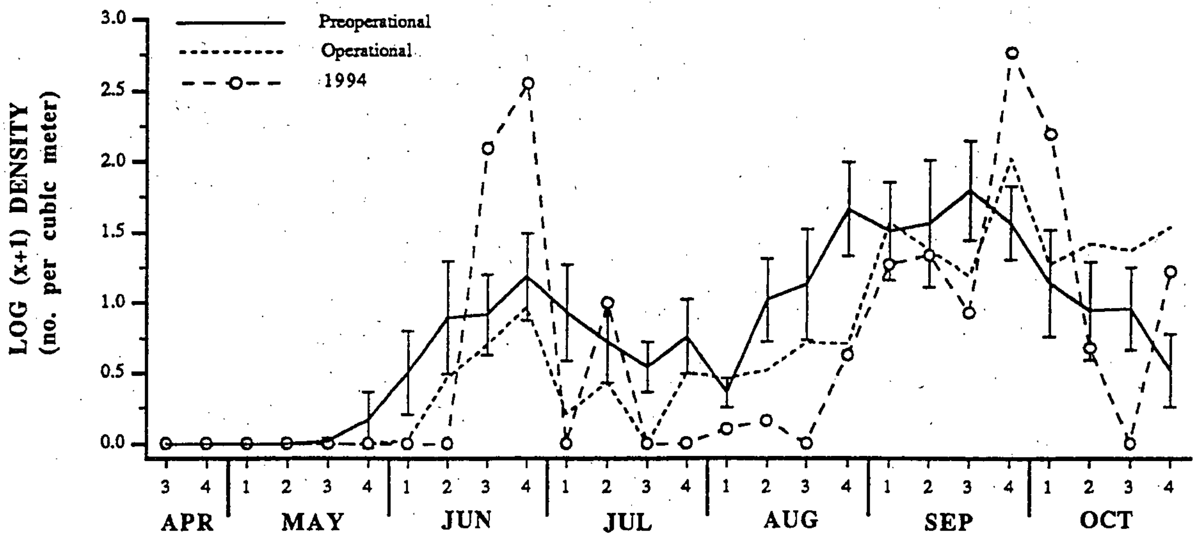


Figure 10-3. Weekly mean and 95% confidence interval of log (x+1) density (no. per cubic meter) of *Mya arenaria* larvae at Station P2, during the preoperational (1978-1989) and operational (1991-1994) periods and in 1994. Seabrook Operational Report, 1994.

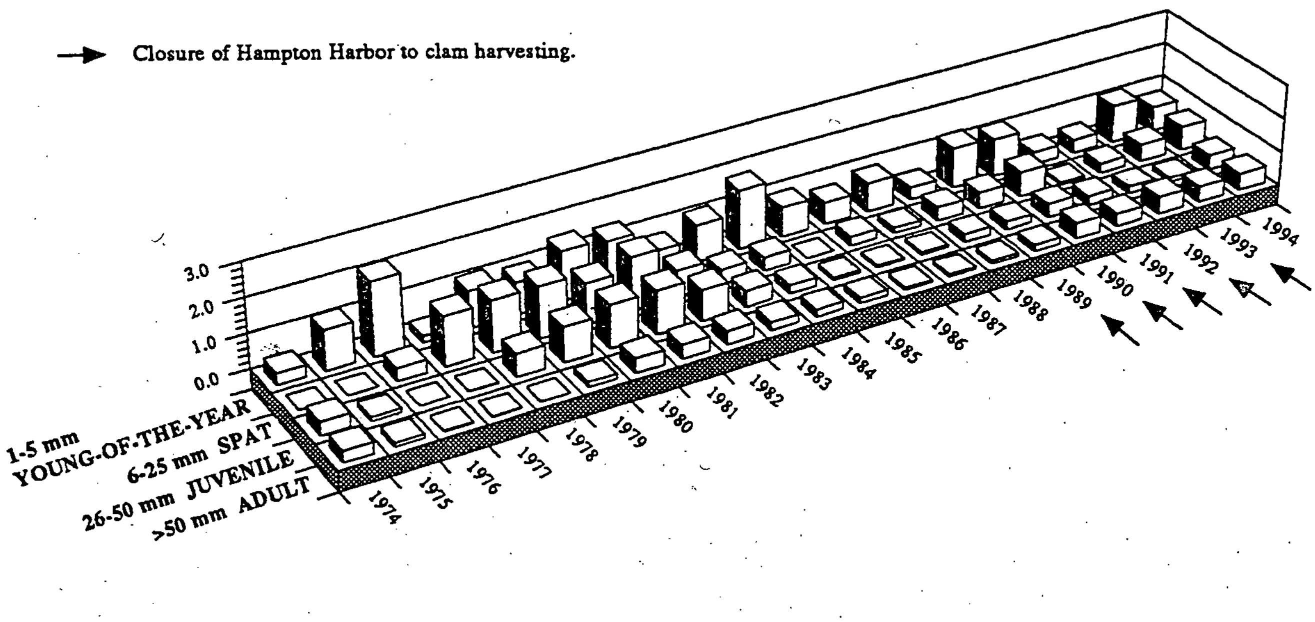


Figure 10-4. Annual mean log (x+1) density (number per square foot) of **young-of-the-year** (1-5 mm), **spat** (6-25 mm), **juvenile** (26-50 mm), and **adult** (>50 mm) ***Mya arenaria*** at Hampton-Seabrook Harbor Flat 4 from 1974-1994. Seabrook Operational Report, 1994.

TABLE 10-1. GEOMETRIC MEAN DENSITY (NUMBER OF LARVAE PER CUBIC METER; NUMBER OF JUVENILES/ADULTS PER SQUARE FOOT) AND THE COEFFICIENT OF VARIATION (CV) OF *MYA ARENARIA* COLLECTED DURING PREOPERATIONAL AND OPERATIONAL YEARS AND IN 1994. SEABROOK OPERATIONAL REPORT, 1994.

		PREOPERATIONAL[a]		1994	OPERATIONAL[a]	
LIFESTAGE	AREA	MEAN[b]	CV	MEAN[b]	MEAN[b]	CV
Larvae	P2	5.5	17.7	3.8	3.6	4.6
	P5	5.0	12.0	2.6	3.2	27.2
	P7	5.7	13.0	6.6	4.1	21.5
1-5 mm young-of-the-year	HH-1	3.5	48.5	5.1	3.9	45.0
	HH-2	8.6	58.8	3.3	4.8	41.9
	HH-4	10.5	43.8	4.4	4.6	49.1
	All	6.4	49.0	4.3	4.3	42.4
6-25 mm spat	HH-1	1.7	127.8	5.5	1.4	88.6
	HH-2	0.7	153.5	1.4	0.5	73.6
	HH-4	3.4	89.7	4.1	1.9	60.6
	All	1.8	108.5	3.4	1.2	74.1
26-50 mm juveniles	HH-1	1.6	108.6	0.6	0.4	42.2
	HH-2	0.4	115.6	1.0	0.2	145.2
	HH-4	1.7	100.4	1.8	1.0	45.2
	All	1.2	97.4	0.9	0.4	57.3
>50 mm adults	HH-1	0.6	76.6	0.6	0.6	16.5
	HH-2	0.4	96.5	0.3	0.2	44.1
	HH-4	0.5	78.2	2.2	1.9	11.5
	All	0.5	76.5	0.7	0.6	17.3
1-12 mm seed clams	Hampton Harbor	5.7	70.8	6.6	6.1	73.2
	Plum Is. Sound	17.1	68.5	7.3	8.9	80.0

[a]Larvae PREOP = 1988, 1989; OP = 1991-94. Hampton Harbor (HH) PREOP = 1974-1989; OP = 1990-1994.
Hampton Harbor-Plum Is. PREOP = 1987-1989; OP = 1990-1994

[b]PREOP and OP means = mean of annual means. 1994 mean = mean of the number of samples.

TABLE 10-2. RESULTS OF ANALYSIS OF VARIANCE COMPARING *MYA ARENARIA* LARVAL, SPAT, JUVENILE AND ADULT DENSITIES DURING PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

MYA ARENARIA LIFESTAGE	STATION/FLAT	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS[j] (in decreasing order)
larvae[a]	NEARFIELD (P2, P5)	Preop-Op[c,d]	1	3.15	17.67 NS	
	FARFIELD (P7)	Year (Preop-Op)[e]	4	0.55	0.33 NS	
		Week (Preop-Op X Year)[f]	146	1.52	6.93***	
		Station[g]	2	0.27	Non-est.[k]	
		Preop-Op X Station[h]	2	0.01	0.02 NS	
		Year (Preop-Op) X Area[i]	8	0.38	1.71 NS	
		Error	289	0.22		
	HAMPTON HARBOR					
1-5 mm[b] young-of-the-year	1, 2, 4	Preop-Op	1	8.22	0.60 NS	
		Year (Preop-Op)	19	10.36	9.35***	
		Area	2	8.21	2.21 NS	
		Preop-Op X Area	2	3.64	3.07 NS	
		Year (Preop-Op) X Area	38	1.14	2.60***	
		Error	1622	0.44		
6-25 mm[b] spat	1, 2, 4	Preop-Op	1	2.49	0.24 NS	
		Year (Preop-Op)	19	10.07	9.78***	
		Area	2	11.26	23.44 NS	
		Preop-Op X Area	2	0.53	0.47 NS	
		Year (Preop-Op) X Area	38	1.06	4.65***	
		Error	1622	0.23		
26 -50 mm[b] juvenile	1, 2, 4	Preop-Op	1	11.94	1.09 NS	
		Year (Preop-Op)	19	9.39	7.42***	
		Area	2	11.81	4.78 NS	
		Preop-Op X Area	2	2.43	1.76 NS	
		Year (Preop-Op) X Area	38	1.33	9.77***	
		Error	2853	0.14		
>50 mm[b] adult, legal	1, 2, 4	Preop-Op	1	2.51	0.40 NS	
		Year (Preop-Op)	19	1.55	10.68***	
		Area	2	6.36	1.22 NS	
		Preop-Op X Area	2	4.95	31.94***	4 Op 1 Op 1 Pre 4 Pre 2 Pre 2 Op
		Year (Preop-Op) X Area	38	0.15	2.63***	
		Error	2853	0.06		
	NEARFIELD/FARFIELD					
1-12 mm[b]	Hampton Harbor	Preop-Op	1	0.52	2.44 NS	
	Plum Island Sound	Year (Preop-Op)	6	0.86	0.61 NS	
		Area	1	3.02	4.03 NS	
		Preop-Op X Area	1	0.77	0.54 NS	
		Year (Preop-Op) X Area	6	1.42	3.00**	
		Error	144	0.47		

[a]Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1988, 89 and op = 1991-94.
[b]For Hampton Harbor Survey preop = 1974-89 and op = 1990-94. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-94.
[c]Commercial operation began in August, 1990, therefore the operational period includes 1990 for spat, juveniles, and adults, but not for larvae.
[d]Operational versus preoperational period regardless of area.
[e]Year nested within preoperational and operational periods, regardless of area.
[f]Week nested within year regardless of area.
[g]Station or flat, regardless of year or period.
[h]Interaction of main effects.
[i]Interaction of year and area nested within preoperational and operational periods.
[j]Underlining signifies no significant differences among least square means at alpha ≤ 0.05.
[k]F-value non-estimable due to a negative denominator mean square.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

addition to temperature include adult condition and food availability (Newell and Hidu 1986). Larval abundance is dependent upon the number of adults spawning, the location of spawning sites, larval behavior, coastal currents, water column stratification and other environmental conditions. Length of life spent in the larval state is approximately 12 days at 20°C, but lasts up to 21 days under cooler conditions (Turner 1949). Planktonic larvae settle to the bottom after this period to become young-of-the-year (seed clams).

Gonadal studies demonstrate that the onset of spawning in Hampton Harbor and Plum Island Sound (late May-June) usually followed the appearance of larvae in offshore tows (early-mid May) (NAI 1985). Therefore, the spring and early summer larvae population may in part originate in areas farther south. Historically, the late-summer peaks generally were coincident with northward-flowing currents. Recruitment of larvae of non-local origin is likely due to current patterns in the Gulf of Maine, which may move water masses and their entrained larvae significant distances before larval settlement (NAI 1979).

10.3.2 Hampton Harbor Survey

Young-of-the-year (1-5 mm). This size class contains recently settled clams that have not yet survived a winter. In 1994, mean density of 1-5 mm clams at Flat 1 was higher than the preoperational and operational averages (Table 10-1). At Flats 2 and 4, mean density in 1994 was lower than the preoperational and operational averages (Table 10-1). Historically, 1-5 mm clam density has been highly variable, and 1994 was within the range of previous years (Figure 10-4 and NAI 1990). There were no significant differences in mean 1-5 mm clam density between the preoperational and operational periods and all three areas showed similar trends between the preoperational and operational periods (Table 10-2).

Spat (6-25 mm) and Juveniles (26-50 mm). Trends in the 6-25 mm size class indicate the survival success of young-of-the-year (1-5 mm spat) that have over-wintered, and may also include some fast-growing young-of-the-year. During 1994, recruitment into the 6-25 mm size class increased over 1993 (NAI and NUS 1994) and was greater than the preoperational and operational means at all three flats (Table 10-1). The mean density of 6-25 mm clams during the operational period was not significantly different from the preoperational period, and all three flats showed similar trends between the preoperational and operational periods (Table 10-2).

Juvenile (26-50 mm) mean densities at all flats in 1994 increased compared to 1993 (NAI and NUS 1994) and were higher than the operational mean density (Table 10-1). However, mean density at Flat 1 was lower than the preoperational mean density, and mean densities at Flats 2 and 4 were higher than the preoperational mean. There were no significant differences in mean density of juvenile clams between the operational and preoperational periods and all three flats showed similar trends between the preoperational and operational periods (Table 10-2).

Adults (>50 mm). Clams measuring more than 50 mm are at least 4 years of age (Ayer 1968) and considered adults in this study. In 1994, mean densities of adults were slightly lower than 1993 at Flat 1 and higher at Flats 2 and 4 (NAI and NUS 1994). Mean densities in 1994 were equal to or higher than the operational mean at all flats, and higher than the preoperational period mean densities at Flat 4 (Table 10-1). The Preop-Op X Area term was significant, which indicated differing trends between the preoperational and operational periods among flats (Table 10-2; Figure 10-5). Adult clam densities increased significantly at Flat 4, and decreased significantly at Flat 2, between the preoperational and operational periods. There was no significant difference in adult clam densities at Flat 1 between the preoperational and operational periods.

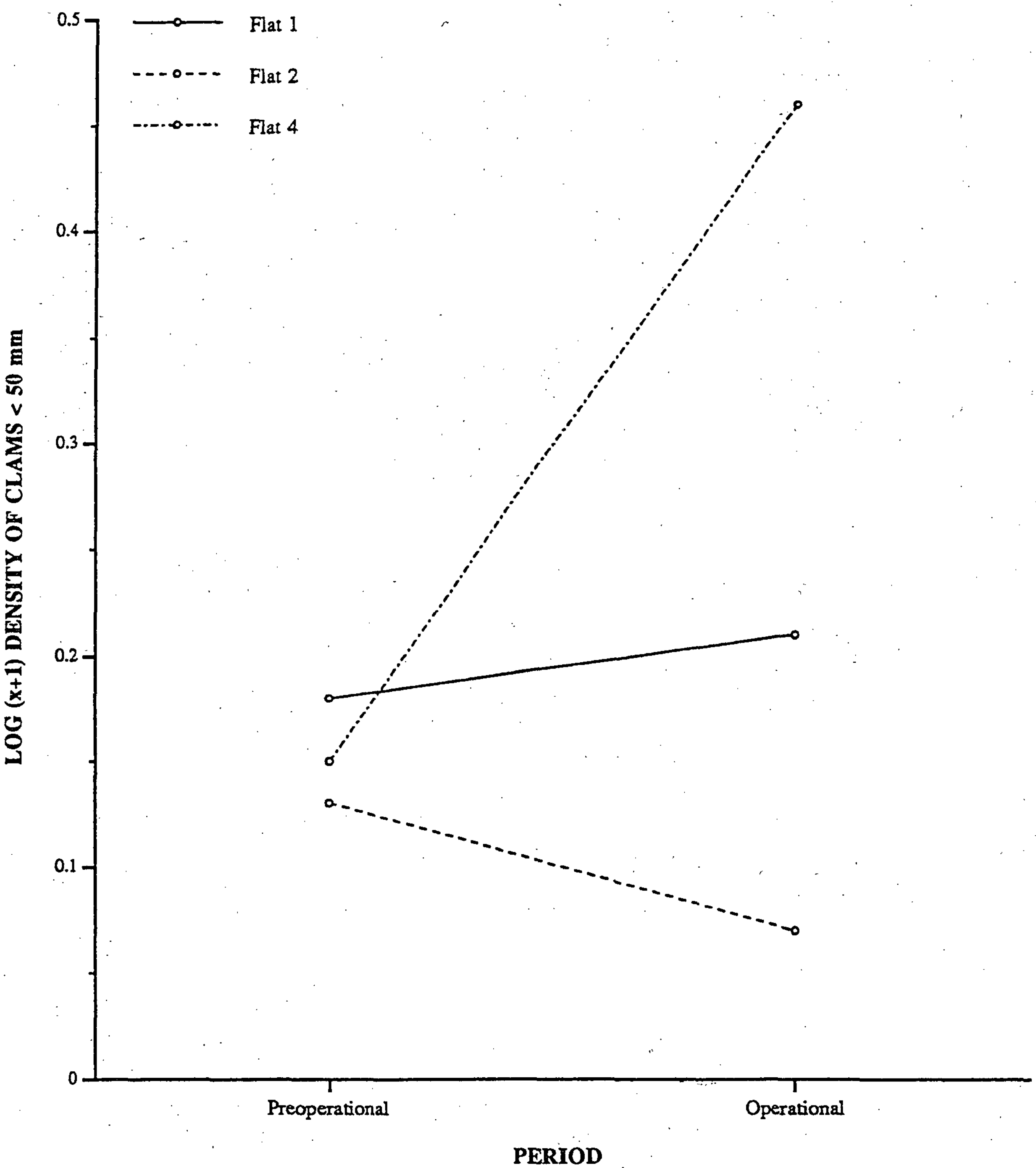


Figure 10-5. A comparison of the mean log (x+1) density of clams <50 mm (number per square foot) among flats during the preoperational (1974-1989) and operational (1990-1994) periods when the interaction term (Preop-op X Area) of the ANOVA model is significant (Table 10-2). Seabrook Operational Report, 1994.

10.3.3 Nearfield/Farfield Study

In 1994, the mean density of seed clams in Hampton Harbor (nearfield area) was lower than the record set of 1993 (NAI and NUS 1994). Densities of seed clams in 1994 in Plum Island Sound (farfield area) were lower than the preoperational mean density and similar to the operational mean (Table 10-1). The mean density of seed clams during the operational period was not significantly different from the preoperational period, and the nearfield and farfield areas showed similar trends between the preoperational and operational periods (Table 10-2).

10.3.4 Effects of Predation and Perturbation

Clams in Hampton Harbor have historically been subjected to predation from two major sources: green crab (*Carcinus maenas*), which consume clams up to about 50 mm in length (Ropes 1969), and humans who dig adult *Mya* and also cause mortality to smaller clams following flat disturbance. Sea gulls are also predators, as they are commonly observed picking over clam digger excavations for edible invertebrates.

Clams are a major source of food for green crab, particularly in the fall (Ropes 1969). Maximum green crab abundance usually occurred in the late fall (Figure 10-6). Mean monthly densities during the 1991-1994 operational period were lower than preoperational densities except during January and December.

Welch (1969) and Dow (1972) found that green crab abundance increased markedly following relatively warm winters. Data from Hampton Harbor from the past 15 years for the most part corroborate their findings (Figure 10-6) although there are exceptions. During the winters (January-March) when the minimum temperature was relatively high (1983-1989), green crab abundance in the following fall was also high (Figure 10-6). In 1992, the minimum temperature was low, but the fall green crab abundance was at its highest level to date. In 1993, when the minimum winter temperature was low, green crab abundance declined from the previous year. Minimum water temperature in Hampton Harbor during 1994 was again low (-1.6° C) and green crab abundance in the fall was among the lowest recorded since 1979. It is likely that many factors, both physical and biological are involved in controlling the green crab population size. Green crabs were not found in New England before the early 1900s (Gosner 1983), and the local population has generally increased since the late 1970s (Figure 10-6).

Recreational clam digging on the Hampton Harbor flats was a significant source of mortality for adult clams (>50 mm) and smaller clams through April 1989. Hampton Harbor flats were closed to clam digging from April 1989 through September 1994 by the New Hampshire Department of Health and Human Services due to coliform contamination. The number of clams greater than 50 mm in length on Flat 4 greatly increased from 1989 to 1990 (Figure 10-4) and remained relatively high from 1991 through 1994. With the Hampton Harbor flats closed, the harvesting pressure on the adult clam population was removed, and the estimated number of bushels per acre in 1992 was the highest during the study period (Figure 10-7). However, in 1993, the estimated bushels per acre declined slightly. The decrease may be due to illegal harvesting, but the extent to which this occurs is unknown (Bruce Smith, NHFG, Durham, NH; Pers. Comm. April 1994). In 1994 the estimated standing crop of adult clams on Flats 1, 2 and 4 increased slightly to 113 bushels per acre. Standing crop decreased 6% at Flat 1 in 1994 compared to 1993, and increased 26% and 18% at Flats 2 and 4 respectively (NAI 1994 and NUS; NAI 1995).

In 1994, Flats 1 and 3 were opened to harvesting (Flats 2 and 4 remained closed) of all size classes of clams on Fridays and Saturdays from September through May when less than 0.1 inch of cumulative rainfall was recorded during the previous 5 days. The days

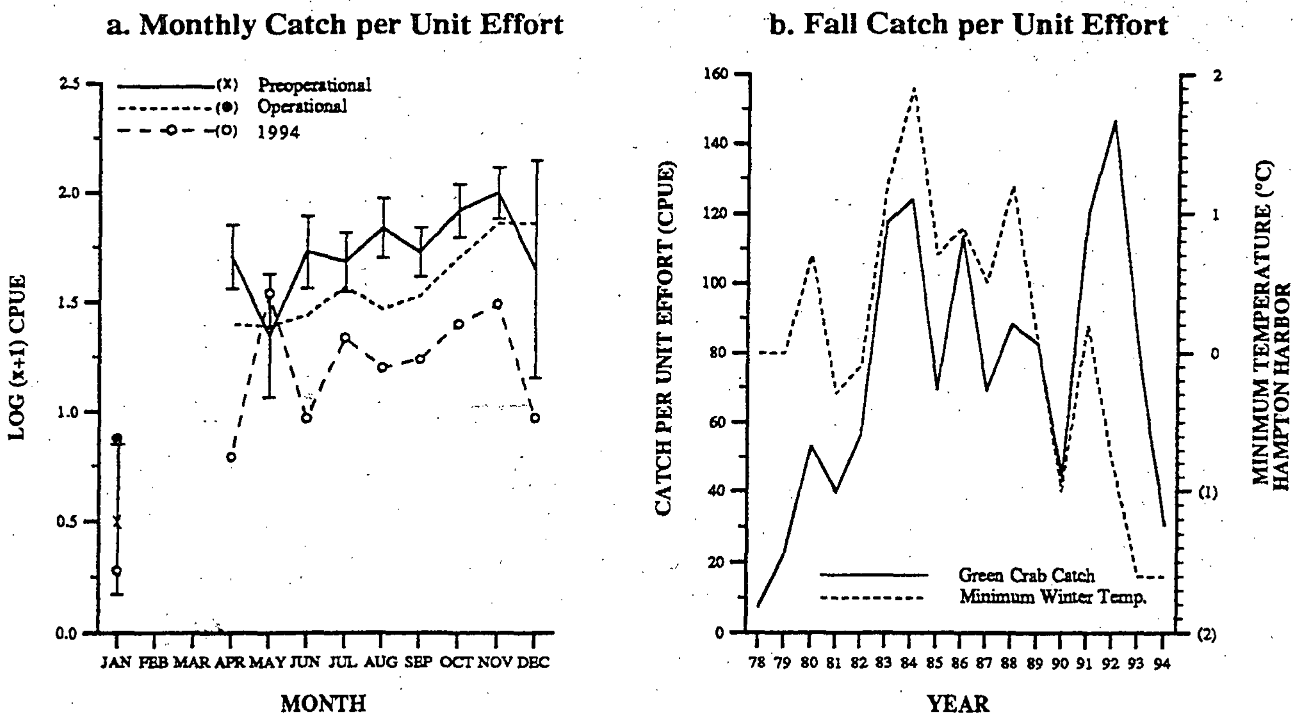


Figure 10-6. **a.** Mean monthly catch per unit effort log (x+1) and 95% confidence intervals of **green crabs** (*Carcinus maenas*) collected during preoperational years (1983-1989) and operational years (1991-1994) and **b.** Mean fall (October-December) catch per unit effort of **green crabs** in Hampton-Seabrook Harbor and its relationship to minimum winter temperature from 1978-1994. Seabrook Operational Report, 1994.

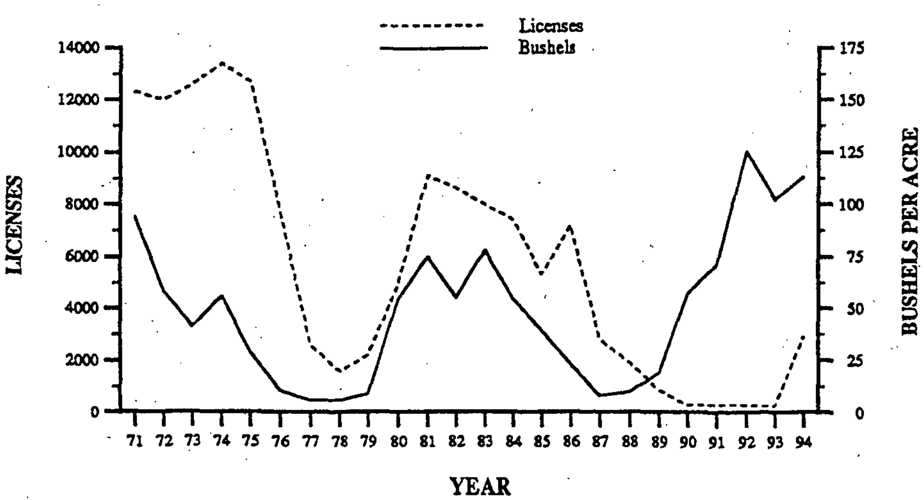


Figure 10-7. Number of **clam licenses** issued and the estimated bushels per acre of adult (>50 mm) clams in Hampton-Seabrook estuary, 1971-1994. Seabrook Operational Report, 1994.

meeting these criteria were 7, 8, 14, 15, 21, 22, and 28 October. The annual clam flat survey took place on November 1 through 3 after 7 days of recreational harvesting. Most of the recreational harvesting took place on Flat 1 where approximately 1,000 clammers were present on each of the Saturdays when the flats were open. Most clammers reached the 10 quart limit, especially on the first weekend (Nash 1994). No accurate estimates of the number of clams harvested are available, but it appears that large numbers of clams were removed. Despite the heavy harvest of clams, the effects of harvesting are not readily apparent in the 1994 clam survey data (Figure 10-8). The mean densities in Flat 1 of most lifestages of clams in 1994 were similar to, or greater than the operational mean densities (Table 10-1). The total estimated standing crop of adult clams at Flats 1, 2 and 4 combined in November of 1994 increased slightly from the 1993 estimate to 113 bushels/acre, despite the opening of Flat 1 to harvesting (Figure 10-7). Flat 4, which was not open to clamming, made the largest contribution to the increase in adult clam density in Hampton Harbor. Density of adult clams in Flat 4 increased to 2.2 clams/square foot in 1994 (Table 10-1) from 1.8 clams/square foot in 1993 (NAI and NUS 1994). Density of clams on Flat 1 decreased slightly to 0.6 clams/square foot (Table 10-1) from 0.7 clams/square foot in 1993 (NAI and NUS 1994) and density on Flat 2 increased to 0.3 clams/square foot (Table 10-1) from 0.2 clams/square foot (NAI and NUS 1994).

10.3.5 Effect of Disease

Sarcomatous neoplasia, a lethal form of leukemia in *Mya arenaria*, was identified in a limited number of individuals taken from Hampton Harbor *Mya* populations (Hillman 1986, 1987). Although the infection has been observed in relatively pristine waters, the rate of infection may also be enhanced by pollution-mediated deterioration of the environment (Reinisch et al. 1984). The infection rate in some *Mya* populations may reach 100 percent with 100 percent mortality of infected clams (Farley et al. 1986). The incidence of sarcomatous neoplasms in the Hampton Harbor *Mya* population was observed in October 1986 and February 1987 (Hillman 1986, 1987). Neoplastic infections were more prevalent in February, reaching 6% at Flat 1 and 27% at Flat 2. Infections were absent from Flat 4. Assuming 100 percent mortality of infected clams (Farley et al. 1986), Flats 1 and 2 may have suffered substantial disease-related reductions in clam production. In 1987, clam flat surveys indicated that juvenile and adult densities fell by over 50% at Flat 1 and Flat 2, while Flat 4 remained unchanged from the previous year. In November 1989, fifteen large (>40 mm) clams were taken from Flat 2, and 80% had neoplastic cells (verified by D.J. Brousseau, Ph.D.; Fairfield University; Fairfield, CT). At Flat 4 during the 1990-1993 operational period, adults >50 mm have more than tripled their preoperational abundance in comparison to other flats, which showed no increase (Table 10-1). The absence of neoplasia may have contributed to these spatial differences.

10.4 DISCUSSION

Since the Hampton-Seabrook estuary contains the majority of New Hampshire's stock of the recreationally-important soft-shell clam, an extensive sampling program was undertaken to characterize the variability in the population for all lifestages.

Recruitment and survival of the soft-shell clam population in Hampton Harbor is affected by a variety of factors, including physical and biological factors, that must be considered in impact assessment. Recruitment from larvae to young-of-the-year is not well understood, but is apparently unrelated to the abundance levels of larval stages (NAI 1982). Successful young-of-the-year sets have occurred throughout the preoperational period as well as during 1990 and 1993 (Figure 10-4, NAI 1994). Young-of-the-year densities in 1994 were above the preoperational (1974-1989) average only at Flat 1. Young-of-the-year densities for the operational period (1990-1994) were similar to the preoperational average at all flats (Table 10-3). In the nearfield/farfield comparison study of 1-12 mm clams, average densities during the preoperational and operational periods were not significantly different (Table 10-3).

Survival of the young-of-the-year set depends on a number of factors including the level of predation and disease. The preoperational period includes the extremes of a "boom and bust" cycle of spat, and juveniles in part dictated by a classic predator-prey relationship, at least for the smaller size classes. The preoperational densities are elevated by the high densities that began in the mid-1970s and ended in the early 1980s, similar to trends noted in Maine and Massachusetts (Crago 1993). In 1991 and 1992, densities of spat and juvenile clams were lower than the preoperational years, coinciding with a period of high green crab abundance. Densities of spat in 1993 and juveniles and spat in 1994 increased, which coincided with a period of low green crab abundance. The reasons for the recent increases in spat and juvenile densities in 1993 and 1994 are complex, but probably include decreases in the abundance of its major predator, green crab *Carcinus maenus*, a good set of young-of-the-year in 1993, and the cumulative effect of the stoppage of clamming beginning in 1989.

Another factor in the evaluation of long-term trends is human predation by clam diggers. Each digging (with a 4-tined clam fork) causes a total reduction of 80% of the harvestable adults and 50% of the smaller size classes (Medcof and MacPhail 1964). The number of clam licenses sold dropped sharply beginning in 1977, coinciding with the reduced numbers of adults available to harvest (estimated bushels per acre). The decrease in clamming resulted in an increase in the numbers of adult clams throughout Hampton Harbor (Figures 10-7, 10-8). In 1989, the clam flats were closed due to coliform contamination, and the estimated standing crop generally increased through 1994. Closure of the flats likely increased survival, particularly of the size classes greater than 25 mm. Flat 4 historically has been heavily used by recreational clammers (NAI 1988), but was not open to clamming in 1994. The most notable change in the clam population structure during the operational period was a sharp increase of adult clams in Hampton Harbor, primarily at Flat 4. The operational mean density of clams increased sharply (3.6 times) over the preoperational period of Flat 4, but was the same or slightly lower at Flats 1 and 2. Flat 4 was also the only area where historically no evidence of the lethal disease neoplasia was detected.

Overall densities of adult clams in 1994 increased compared to 1993 over all flats, and were similar to both preoperational and operational densities at Flats 1 and 2. Flat 1 was opened to harvesting in October of 1994, and was quantitatively surveyed on November 1-3 after 7 days of harvesting. The effects of harvesting were not apparent in the survey, as densities of adult clams in 1994 were similar to 1993 densities, and densities of juvenile clams, which were also subject to harvesting, increased in 1994 compared to 1993. However, the smallest increase in juvenile clam densities occurred at Flat 1, which was opened to harvesting. This apparent paradox may be partially resolved by comparing the purpose and methods by which the survey was taken with the purpose and methods used by clammers to harvest the resource. Molluscs are usually highly clumped, often exhibiting a negative binomial distribution with a large number of areas with no clams, and a few areas with high numbers of clams (Saila and Gaucher 1966). The clam survey is designed to estimate the number of clams in an entire flat, not just in areas of the flat that may be good habitat. To accomplish this, samples were randomly allocated to all parts of the clam flat, including areas that may not be good clam habitat. As an example, 42% of the samples in the 1994 survey contained no clams. In contrast, clammers want to maximize their catch of clams. They will actively seek out only those areas where larger numbers of clams are present. Therefore, the removal of a large number

TABLE 10-3. SUMMARY OF EVALUATION OF EFFECTS OF OPERATION OF SEABROOK STATION ON SOFT-SHELL CLAM. SEABROOK OPERATIONAL REPORT, 1994.

STUDY	LIFESTAGE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD[a]	SPATIAL DIFFERENCES CONSISTENT BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS[b]
NEARFIELD (P2,P5)/ FARFIELD (P7)	Larvae	Yes	Yes
HAMPTON HARBOR	Young-of-year (1-5mm)	Yes	Yes
	Spat (6-25mm)	Yes	Yes
	Juvenile (26-50mm)	Yes	Yes
	Adult (>50mm)	Yes	Flat 1 Op=Preop Flat 2 Op<Preop Flat 4 Op>Preop
HAMPTON HARBOR/ PLUM ISLAND SOUND	Young-of-year (1-12mm)	Yes	Yes

[a]Operational period for larvae = 1991-94; 1->50 m size classes = 1990-94; preoperational period for larvae = 1988, 1989; preoperational period for nearfield farfield = 1987-89; preoperational period for Hampton Harbor = 1974-89; results based on Op-Preop term of ANOVA model, when Preop-Op x Area is not significant.

[b]Results based on interaction term (Preop-Op X Area) of ANOVA model and LS means multiple comparisons at alpha ≤ 0.05.

—▶ Closure of Hampton Harbor to clam harvesting.

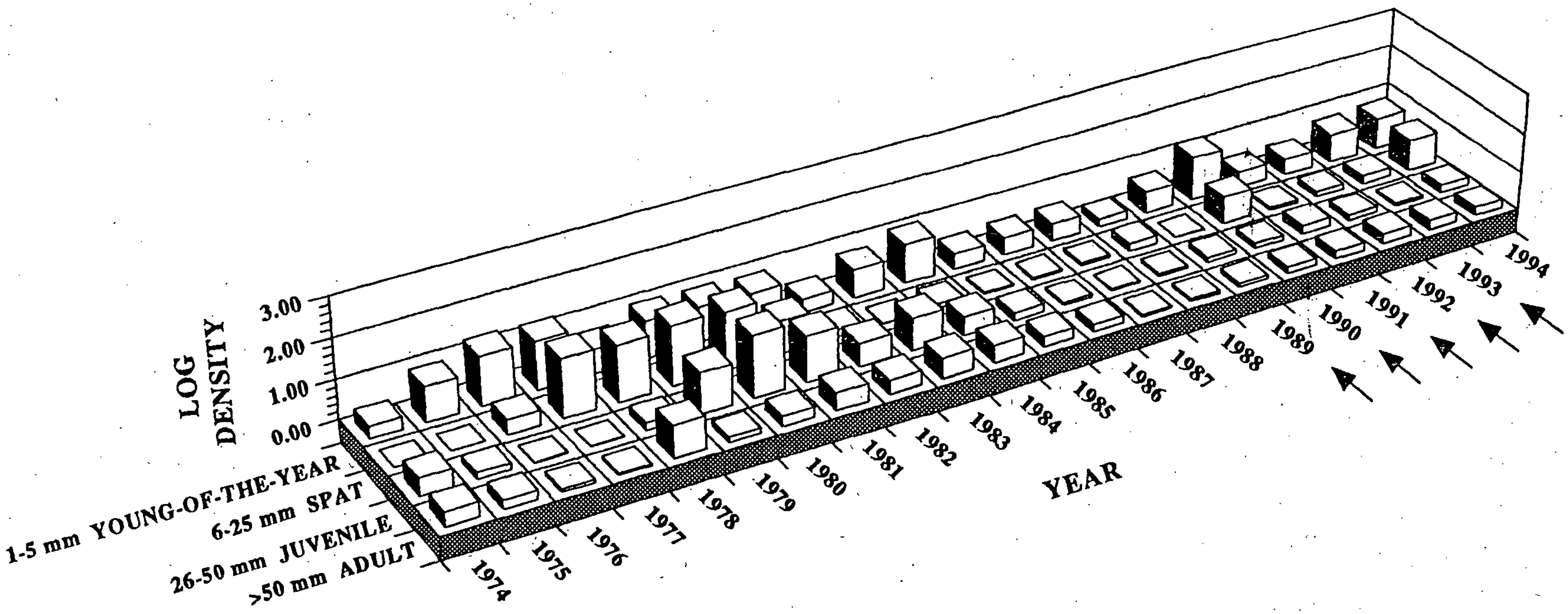


Figure 10-8. Annual mean log (x+1) density (number per square foot) of **young-of-the-year** (1-5 mm), **spat** (6-25 mm), **juvenile** (26-50 mm), and **adult** (>50 mm) ***Mya arenaria*** at Hampton Harbor Flat 1 from 1974-1994. Seabrook Operational Report, 1994.

of clams from a portion of the flat may have gone undetected in the survey. Alternatively, clam populations in 1994 prior to the start of harvesting may have been at record levels, and the population was reduced to historic levels by harvesting prior to the survey. Without a survey before the opening of the clam flats, it is impossible to evaluate this alternative.

A factor likely to affect growth and survival of juvenile and adult clams was the presence of sarcomatous neoplasia, a lethal form of blood cancer in the soft-shell clam. During 1986 and 1987, the incidence of neoplasia in Hampton Harbor was restricted to Flats 1 and 2 (Hillman 1986, 1987). Significant increases in adult clam densities in the 1990-1994 operational period in comparison to previous years occurred primarily at Flat 4, where neoplasia was apparently absent. Neoplasia is suggested as a cause for declining catches throughout New England (Crago 1993).

Mya arenaria population changes during the operational period are indicated by visual inspection of graphs and by the interaction term of the ANOVA model. Differences between the preoperational and operational means were consistent at nearfield and farfield areas for larvae and seed clams, 1-12 mm in length (Table 10-3). This indicates the operation of Seabrook Station has not affected larvae or seed clam densities. Intensive fall surveys within the nearfield area (Hampton Harbor) found the differences between preoperational and operational means were not consistent among the three flats. The differences are due to a variety of physical and biological variables that occur within the nearfield area. The most notable change to occur (a significant increase in the number of adults at Flat 4 during the operational period) was probably due to the closure of flats to clam harvesting, and the absence of neoplasia.

The key to monitoring the effects of plant operation (1990-1994) on the soft-shell clam population is understanding its long-term cycle and the multitude of factors that affect it. Average seed clam (1-12 mm) density during the operational period in Hampton Harbor followed the same trend as that of a neighboring estuary, indicating that Seabrook Station was not affecting larval settlement (Table 10-3). In Hampton Harbor, average spat densities from 1990-1994 at each flat were lower than the preoperational average. However, the 15-year preoperational period includes extremely successful periods of clam recruitment and survival, when densities of its major predator were low, as well as periods of very low clam density, leading to a significant difference in density among years. Given the high variability among years, and the complexity of factors affecting clam recruitment, there is no indication that Seabrook Station has had a positive or negative effect on the Hampton Harbor population.

10.5 REFERENCES CITED

Ayer, W.C. 1968. Soft-shell clam population study in Hampton-Seabrook Harbor, New Hampshire. New Hampshire Fish and Game Dept. 39 pp.

Coe, W.R. and H.J. Turner. 1938. Development of the gonads and gametes of the soft shell clam *Mya arenaria*. J. Morph. 62:91-111.

Crago, T.I. 1993. Getting to why. Understanding leukemia in soft shell clams. Nor'easter 5(1):20-23.

Dow, R. 1972. Fluctuations in Gulf of Maine sea temperature and specific molluscan abundance. J. Cons. Int. Explor. Mer. 34(3):532-534.

Farley, C.A., S.A. Otto, and C.L. Reinisch. 1986. New occurrence of epizootic sarcoma in Chesapeake Bay soft shell clams, *Mya arenaria*. Fish. Bull., U.S. 84(4):851-857.

Gosner, K.L. 1978. A Field Guide to the Atlantic Seashore. Houghton Mifflin Company, Boston. 329 pp.

Hillman, R.E. 1986. Summary report on determination of neoplasia in soft-shell clams, *Mya arenaria*, near the Seabrook Nuclear Plant. Battelle study no. N-0954-9901 to YAEC. 6 pp.

Nash, C. 1994. Thousands Turn Out for Clam Harvest. Tidelines, Fall/Winter 1994. New Hampshire Office of State Planning.

__________. 1987. Final report on determination of neoplasia in soft-shell clams *Mya arenaria* near the Seabrook Nuclear Plant. Battelle study no. N-0954-9901 to YAEC. 7 pp.

Newell, C.R., and H. Hidu. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) -- softshell clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.53). U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

Normandeau Associates, Inc. 1979. Soft-shell clam, *Mya arenaria*, study. Tech. Rept. X-3.

__________. 1982. Seabrook Environmental Studies, 1981. Soft-shell clam, *Mya arenaria* study. Tech. Rept. XIII-II.

__________. 1985. Seabrook Environmental Studies, 1984. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1984. Tech. Rept. XVI-II.

__________. 1988. Seabrook Environmental Studies, 1987 Data Report. Tech. Rept. XIX-1.

__________. 1990. Seabrook Environmental Studies, 1989. A characterization of baseline conditions in the Hampton-Seabrook Area, 1975-1989. Tech. Rept. XXI-II.

__________. 1991. Seabrook Environmental Studies. 1990 Data Report. Tech. Rept. XXII-1.

__________. 1995. Seabrook Environmental Studies. 1994 Data Report. Tech. Rept. XXVI-1.

Normandeau Associates (NAI) and Northeast Utilities Corporate and Environmental Affairs (NUS). 1994. Seabrook Environmental Studies, 1993. A Characterization of Environmental Conditions in the Hampton-Seabrook Area During the Operation of Seabrook Station. Prepared for North Atlantic Energy Service Corporation.

Medcof, J.C. and J.S. MacPhail. 1964. Fishing efficiency of clam hacks and mortalities incidental to fishing. Proc. Natl. Shellfish. Assoc. 55:53-72.

Ropes, J.W. 1969. The feeding habits of the green crab *Carcinus maenas* (L.) U.S. Fish Wildl. Serv. Fish. Bull. 67:183-203.

Reinisch, C.L., A.M. Charles, and A.M. Stone. 1984. Epizootic neoplasia in soft-shell clams collected from New Bedford Harbor. Hazardous Waste 1:73-81.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics Version.5 edition. SAS Inst., Inc., Cary, N.C. 956 pp.

Saila, S.B. and T.A. Gaucher. 1966. Estimation of the sampling distribution and numerical abundance of some mollusks in a Rhode Island salt pond. Proc. of the National Shellfisheries Assoc. 56:73-79.

Stewart-Oaten, A., W.M. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "Pseudoreplication in time?" Ecology. 67:929-940.

Turner, H.J., Jr. 1949. The soft-shell clam industry of the east coast of the United States. App. I. Report on investigations of the propagation of the soft-shell clam, *Mya arenaria*. WHOI collected reprints 1948, Contrib. No. 462, pp. 11-42.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4(1):3-15.

Welch, W.R. 1969. Changes in abundance of the green crab, *Carcinus maenas* (L.) in relation to recent temperature changes. U.S. Fish Wild. Serv. Fish. Bull. 67:337-345.

TABLE OF CONTENTS

LIST OF FIGURES

PAGE

PAGE

PAGE

LIST OF TABLES

PAGE

APPENDIX A. COMPARISON OF FIXED AND MIXED ANOVA MODELS

1.0 INTRODUCTION

Analysis of variance (ANOVA) is a statistical method used in the Seabrook Environmental Studies Monitoring Program to determine whether the operation of Seabrook Station has had any adverse effects on the local marine balanced indigenous populations. The ANOVA model used in the Seabrook Station monitoring program was based on Green's (1979) Before-After, Control-Impact (BACI) principles. In the BACI model, samples are taken both before and after the putative effect, and in both control and impact areas. In the Seabrook monitoring program, the Before and After terms are represented data collected during the preoperational and operational time periods, and the Control and Impact terms are represented by data collected in nearfield and farfield areas. The advantage of the BACI model is that potential impacts are indicated by the significance of the interaction term of time (Before-After) and location (Control-Impact).

The specific ANOVA model used was a randomized block design developed by Dr. Roger Green of the University of Waterloo, Ontario, with the following terms as sources of variation: Preop-Op, Station, Preop-Op X Station, Year(Preop-Op), Time(Year), (e.g. week or month) and Error. The term Preop-Op had two levels: preoperational and operational. This term compares data collected during the preoperational to operational periods regardless of other sources of variation such as Station. A significant Preop-Op term does not indicate a plant impact, but rather an area wide trend at both the nearfield and farfield areas, where the farfield area is presumably beyond the influence of the plant. The Station term contains levels for each sampling station. This term compares data collected from the sampling stations throughout the study period, both preoperational and operational periods. A significant Station term indicates a difference between the nearfield and farfield areas; by itself it does not suggest a plant effect because the data span both the preoperational and operational periods.

The Preop-Op X Station term (interaction term) was the most important term in the analysis, as it alone could indicate potential plant impact. The interaction term would be significant if the relationship between stations for a given parameter, such as species density or number of taxa, changed significantly between the preoperational and operational periods. The remaining terms, Year(Preop-Op) and Month(Year), were nested terms that explained some of the temporal variation in the data and improved the fit of the model. The error term included all the variation not explained by the model.

The ANOVA developed by Green was a "fixed" effects model, meaning each term in the model was considered fixed. In a fixed effects model, the F-statistic for each term is calculated as the ratio between the Mean Square (MS) for the term and the Mean Square Error (MSE) of the model.

In 1993, after 2½ years of plant operation, NAI initiated an independent review of the ANOVA model by Dr. Jay Geaghan of Louisiana State University. He recommended that all "time" variables such as Year, Month, Week be considered random effects. The rationale for this approach is explained below. This change necessitated the addition of the term Station X Year(Preop) to provide the proper denominator mean square for calculation of the F-statistic for the interaction term. The inclusion of both fixed and random factors in the ANOVA makes the model a "mixed" effects model.

Northeast Utilities Company (NUSCO), in 1994, conducted another review of the fixed ANOVA model and came to essentially the same conclusions as Geaghan (Lorda and Miller 1994). NUSCO recommended that both the "time" variables and Station be considered random variables because they represent all possible times of sampling and locations of sampling. Preop-Op should be considered fixed because there are only two possible levels, preoperational and operational, and both are represented. The use of both random and fixed variables makes the model a "mixed" effects model. NUSCO also recommended the inclusion of the Station X Year(Preop) term in the model for the same reason that Geaghan presented.

In 1994, North Atlantic Energy Service Corporation (NAESCO) made a recommendation to the Seabrook Ecological Advisory Committee (SEAC) to revise the fixed effects model, based on the independent evaluations of the fixed effects ANOVA model, and the advice of its consultants, NAI and NUSCO. The SEAC is a group of five regional university professors who advise NAESCO about Environmental Studies Program matters. The SEAC concurred with this recommendation. NAESCO subsequently recommended this change to the Technical Advisory Committee (regulatory agencies) at its annual program review in December 1994.

There are few differences between the two models. Principally, the mixed effects model assumes that sampling time (Year, Month or Week) and Station variables are random, while the fixed effects model assumes that these variables are fixed. The treatment of these variables as random is well established in the statistical literature. Underwood (1994) states that "Locations represent a random factor in the sampling design" and cites Snedecor and Cochran (1967), Winer (1971) and Underwood (1981). Winer (1971) used a variable called the sampling fraction, defined as the ratio between the number of areas or dates sampled and all possible sampling dates or areas, to decide if a factor should be treated as random. If this sampling fraction is small, meaning that only a few of the total possible areas or times were sampled, then the variable should be considered random. A variable is considered fixed if all possible times or areas were sampled. Fixed variables are more common in laboratory experimental work where a variable such as temperature can be strictly controlled, and all temperatures within a range can be investigated. Random variables typify environmental sampling where an investigator may have little control over the variable being investigated, and is using relatively small samples to describe a larger area or time period.

If time and location of sampling are considered random, then the second modification, inclusion of the term Station X Year(Preop-Op), is necessary. The Station X Year(Preop) term provides the proper denominator mean square for testing the significance of the interaction term (Preop-Op X Station). SAS, the statistical package used in this case, provides this calculation automatically when time and location of sampling are declared to be random variables.

The mixed effects model is the more appropriate model if we wish to draw inferences beyond the exact location and time of sampling. If time and location of sampling are declared fixed, then the ANOVA model can only be used to draw inferences for the exact location and time of sampling. Since the purpose of the monitoring study is to characterize the entire nearfield and farfield areas for extended periods of time, the mixed effects model is clearly the appropriate statistical tool to use. Only inferences drawn from the results of the mixed effects analysis can determine if the operation of Seabrook Station is affecting balanced indigenous populations in the nearfield area.

The following is a comparison of the fixed effects model (used in prior Operational Reports) and the mixed effects model used in the 1994 Operational Report. A total of 98 ANOVAs were rerun treating time and location of sampling as fixed variables. The comparison between the mixed model and the fixed model is tabulated for each section in the report. Only Preop-Op, Station, and the interaction term (Preop-Op X Station) are presented in the tabulation because these are the most important terms. In general, for most communities, the fixed effects model indicated more significant differences than the mixed effects model, although occasionally the mixed model detected significance that the fixed model did not. The additional significant interaction terms may suggest that either additional potential impacts have occurred, or significant differences are indicated (statistically) where none has actually occurred. This situation is known as Type II error, when the model suggests potential impacts from plant operation where none have occurred. The parameters for each significant interaction term were evaluated to determine whether a change to the balanced indigenous population had occurred. The annual time series provided an historical context for comparison of the significant preoperational-operational differences, which enabled us to determine their biological significance.

2.0 WATER QUALITY

A total of 11 water quality parameters were analyzed with ANOVA. The fixed effects (old) model detected more significant differences in the average parameter levels between the preoperational and operational period, and among stations than the mixed effects (new) mixed model (Table A-1). However, the fixed effects model did not detect any significant differences for the Preop-Op X Station interaction terms. The mixed effects model detected a significant difference in the interaction term for surface dissolved oxygen and this is discussed in Section 2.3.1.

3.0 PHYTOPLANKTON

The fixed effects (old) model and mixed effects (new) model were in generalagreement for ANOVA results for the phytoplankton community characteristics and selected species abundance (Table A-2). For each of the five parameters, the fixed effects model detected one significant difference (either between the preoperational and operational periods or among stations) whereas the mixed effects model detected none; however, neither model detected any significant differences for the interaction term.

4.0 ZOOPLANKTON

Abundances of eight microzooplankton, one bivalve larvae, five meroplankton and one tychoplankton taxa were analyzed with ANOVA (Tables A-3, A-4, A-5). For nearly every microzooplankton, and macrozooplankton taxon, the fixed effects model detected an additional significant difference between the preoperational and operational periods, or among stations, than the mixed effects model. Neither model detected any significant differences for the important interaction term for microzooplankton taxa or *Mytilus edulis* (Tables A-3, A-4). In the macrozooplankton, the mixed effects model detected a significant interaction for *Calanus finmarchicus* that the fixed effects model did not detect (Table A-5). This interaction is discussed in Section 4.3.3.2.

5.0 FINFISH

Abundances of 20 larval and adult finfish were analyzed with ANOVA. As with previous communities, the fixed effects (old) model detected more significant differences in abundances between preoperational and operational periods and among stations than the mixed effects (new) model (Tables A-6 through A-16). Each model detected significant Preop-Op X Station interactions for three species. Of these, two, rainbow smelt and winter flounder in trawls, had similar results using each model (Table A-7, A-15). The interaction term was significant for American sand lance larvae density in the mixed effects model, but not in the fixed effects model (Table A-13). This interaction term is discussed in Section 5.3.3.

The fixed effects model detected a significant interaction term for winter flounder in the estuary that was not significant in the mixed effects model (Table

TABLE A-1. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR WATER QUALITY CHARACTERISTICS AMONG STATIONS P2, P5, AND P7 DURING RECENT PREOPERATIONAL YEARS (1987-1989) AND OPERATIONAL (1991-1994) YEARS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	SOURCE OF VARIATION[a]	F FOR MIXED MODEL (NEW)	F FOR FIXED MODEL (OLD)
Surface Temperature	Preop-Op[b,c]	3.47 NS	383.44***
	Station[d]	45.01*	45.17***
	Preop-Op X Station[e]	0.91 NS	1.02 NS
Bottom Temperature	Preop-Op	7.66*	714.55***
	Station	21.72*	17.41***
	Preop-Op X Station	1.08 NS	0.82 NS
Surface Salinity	Preop-Op	<0.01 NS	<0.01 NS
	Station	1.89 NS	5.72**
	Preop-Op X Station	2.86 NS	0.62 NS
Bottom Salinity	Preop-Op	0.03 NS	2.10 NS
	Station	9.47 NS	5.72**
	Preop-Op X Station	0.40 NS	0.62 NS
Surface Dissolved Oxygen	Preop-Op	4.05 NS	95.51***
	Station	2.84 NS	6.66**
	Preop-Op X Station	8.72**	2.44 NS
Bottom Dissolved Oxygen	Preop-Op	0.18 NS	29.62***
	Station	4.27 NS	10.81***
	Preop-Op X Station	1.92 NS	2.57 NS
Orthophosphate	Preop-Op	0.76 NS	23.68***
	Station	39.86*	72.75***
	Preop-Op X Station	0.08 NS	0.10 NS
Total Phosphorus	Preop-Op	1.73 NS	22.82***
	Station	1.82 NS	1.92 NS
	Preop-Op X Station	0.87 NS	1.08 NS

(continued)

TABLE A-1. (Continued)

PARAMETER	SOURCE OF VARIATION[a]	F FOR MIXED MODEL (NEW)	F FOR FIXED MODEL (OLD)
Nitrate	Preop-Op	0.49 NS	36.78***
	Station	34.62*	9.97***
	Preop-Op X Station	0.19 NS	0.30 NS
Nitrite	Preop-Op	0.83 NS	7.94**
	Station	4.83 NS	4.65**
	Preop-Op X Station	0.48 NS	1.01 NS
Ammonia	Preop-Op	<0.01 NS	0.17 NS
	Station	4.88 NS	6.39***
	Preop-Op X Station	0.93 NS	2.88 NS

[a]Based on averaged monthly collections for all parameters
[b]Preoperational years: 1987-1989 at each station for all parameters except ammonia, which was April 1988 through December 1989
[c]Preoperational versus operational period, regardless of station
[d]Station P2 versus P5 versus P7, regardless of year
[e]Interaction between main effects

NS = not significant ($p \geq 0.05$)
* = significant ($0.05 \geq p > 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)

TABLE A-2. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ABUNDANCES OF TOTAL PHYTOPLANKTON, ULTRAPLANKTON AND *SKELETONEMA COSTATUM*, AND CHLOROPHYLL *a* CONCENTRATIONS AMONG STATIONS P2, P5 AND P7 DURING PREOPERATIONAL AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
PHYTOPLANKTON: P2 VS P7 (PREOP = 1982-1984; OP = 1991-1994)[a]		
Preop-Op[b]	1.15 NS	49.66***
Station	4.67 NS	3.43 NS
Preop-Op X Station[c]	0.37 NS	1.00 NS
CHLOROPHYLL *a*: P2, P5, P7 (PREOP = 1987-1989; OP = 1991-1994)		
Preop-Op	<0.01 NS	<0.01 NS
Station	3.74 NS	3.13 NS
Preop-Op X Station	1.17 NS	0.82 NS
***SKELETONEMA COSTATUM*: P2 VS. P7 (PREOP = 1982-1984; OP = 1991-1994)**		
Preop-Op	4.53 NS	49.66***
Station	3.60 NS	3.43 NS
Preop-Op X Station	0.69 NS	1.00 NS
***SKELETONEMA COSTATUM*: P2 VS. P5 (PREOP = 1979-1981; OP = 1991-1994)**		
Preop-Op	9.54 NS	37.24***
Station	14.65 NS	2.70 NS
Preop-Op X Station	0.14 NS	0.20 NS
ULTRAPLANKTON: P2, P5, P7 (Operational period only, 1991-1994)		
Year	0.67 NS	8.02***
Station	0.92 NS	1.68 NS
Year X Station	1.82 NS	1.82 NS

[a]ANOVA based on mean of twice-monthly collections Mar-Nov and monthly collections Dec-Feb; only years when collections at these stations were concurrent are included; analyses include only years when all 12 months were sampled.
[b]Preoperational versus operational period regardless of station.
[c]Interaction between main effects.

NS = not significant ($p \geq 0.05$)
* = significant ($0.05 > p \geq 0.01$)
** = highly significant ($0.01 \geq p > 0.001$)
*** = very highly significant ($0.001 \geq p$)

TABLE A-3. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR (X+1) TRANSFORMED DENSITY (No./m^3) OF SELECTED MICROZOOPLANKTON SPECIES AMONG PREOPERATIONAL YEARS (1982-84) AND OPERATIONAL YEARS (1991-94) AND NEARFIELD (STATION P2) VS. FARFIELD (STATION P7) AREAS. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES/LIFESTAGE	SOURCE OF VARIATION[a]	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Eurytemora sp. copepodite	Preop-Op	3.05 NS	31.09***
	Area	0.36 NS	0.47 NS
	Preop-Op X Area	4.39 NS	1.13 NS
Eurytemora herdmani adult	Preop-Op	3.89 NS	36.79***
	Area	1.80 NS	1.59 NS
	Preop-Op X Area	3.22 NS	0.86 NS
Pseudocalanus/Calanus sp. nauplii	Preop-Op	9.95*	68.17***
	Area	3.14 NS	1.08 NS
	Preop-Op X Area	0.53 NS	0.35 NS
Pseudocalanus sp. copepodite	Preop-Op	0.47 NS	1.93 NS
	Area	7.71 NS	0.43 NS
	Preop-Op X Area	0.80 NS	0.06 NS
Pseudocalanus sp. adult	Preop-Op	1.07 NS	5.96*
	Area	1.18 NS	<0.01 NS
	Preop-Op X Area	0.02 NS	0.01 NS
Oithons sp. nauplii	Preop-Op	<0.01 NS	0.03 NS
	Area	327.81 NS	4.70*
	Preop-Op X Area	0.07 NS	0.30 NS
Oithona sp. copepodite	Preop-Op	1.71 NS	30.18***
	Area	16.22 NS	4.70*
	Preop-Op X Area	0.38 NS	0.30 NS
Oithona sp. adult	Preop-Op	0.65 NS	11.33***
	Area	1055.00 NS	2.44 NS
	Preop-Op X Area	0.02 NS	<0.01 NS

[a]Preop-Op = preoperational period vs. operational period, regardless of area
Area = nearfield vs. farfield stations
Preop-Op X Area = interaction of main effects

NS = Not Significant (P> 0.05)
* = Significant (0.05 ≥ P >0.01)
** = Highly Significant (0.01 ≥ P > 0.001)
*** = Very Highly Significant (P ≤ 0.001)

TABLE A-4. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) WEEKLY ABUNDANCES OF *MYTILUS EDULIS* DURING PREOPERATIONAL (1988-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

SOURCE OF VARIATION[a]	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Preop-Op	0.03 NS	4.69 NS
Station	3.21 NS	2.25 NS
Preop-Op X Station	0.97 NS	0.72 NS

[a]Preop-Op = preoperational period vs. operational period, regardless of area
Station = nearfield vs. farfield stations
Preop-Op X Area = interaction of main effects

NS = Not Significant ($p > 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly Significant ($0.01 \geq p > 0.001$)
*** = Very Highly Significant ($p \leq 0.001$)

TABLE A-5. COMPARISONS OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ABUNDANCES OF SELECTED MACROZOOPLANKTON SPECIES FROM STATIONS P2, P5, AND P7 DURING PREOPERATIONAL (1987-1989) AND OPERATIONAL (1991-1994) PERIODS.
SEABROOK OPERATIONAL REPORT, 1994.

SPECIES[a]	SOURCE[b]	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Calanus finmarchicus	Preop-Op[c]	1.46NS	4.09*
copepodites	Station[d]	15.31NS	5.13**
(January-December)	Preop-Op X Station[e]	1.82NS	0.34 NS
Calanus finmarchicus	Preop-Op	0.02NS	0.11 NS
adults	Station	10.19NS	3.82*
(January-December)	Preop-Op X Station	6.15*	0.38 NS
Carcinus maenas	Preop-Op	0.01NS	4.86**
larvae	Station	2.83NS	0.51 NS
(June-September)	Preop-Op X Station	0.31NS	0.19 NS
Crangon	Preop-Op	0.32NS	2.14 NS
septemspinosa	Station	28.66*	18.08***
zoeae and post larvae	Preop-Op X Station	0.60NS	0.66 NS
(January-December)			
Neomysis americana	Preop-Op	0.05NS	0.60 NS
all lifestages	Station	18433.00NS	59.97***
(January-December)	Preop-Op X Station	0.01NS	0.01 NS

[a]Based on twice monthly sampling periods.
[b]Commercial operation began in August 1990; 1990 data left out of analysis to keep a balanced design in the ANOVA procedure.
[c]Preoperational (1987-1989) versus operational (1991-1994) periods, regardless of station; 1987-1989 reflects the period of time that all three stations were sampled coincidentally.
[d]Station P2 vs. station P5 vs. station P7, regardless of year.
[e]Interaction between main effects.

NS = Not significant ($p > 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

TABLE A-6. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ATLANTIC HERRING DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	7.75*	70.09***
(Oct-Dec)	Station[b]	3.38 NS	0.90 NS
(1986-1994)	Preop-Op X Station[c]	0.62 NS	0.79 NS
Gill Net	Preop-Op[d]	2.88 NS	128.06***
(Sep-May)	Station	5.01 NS	1.53 NS
(1976-1994)	Preop-Op X Station	0.31 NS	0.43 NS

[a] Preop-Op compares 1990-1994 to 1986-1989 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1976-1990, regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

TABLE A-7. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR RAINBOW SMELT DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)	MULTIPLE COMPARISONS OF ADJUSTED MEANS[e]
Trawl	Preop-Op[a]	5.82**	67.64***	
(Nov-May)	Station[b]	1.44 NS	4.29***	
(1975-1994)	Preop-Op X Station[c]	4.65*	3.43*	2Pre 1Pre 3Pre 1Op 2Op 3Op
Seine	Preop-Op[d]	0.02 NS	0.02 NS	
(Apr-Nov)	Station	6.75 NS	8.38 NS	
(1976-1994)	Preop-Op X Station	0.92 NS	1.45 NS	

[a] Preop-Op compares 1990-1994 to 1986-1990 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1976-1984 and 1986-1989, regardless of station.
[e] Underlining indicates that t-tests showed no significant differences ($\alpha \leq 0.05$) among the underlined least square means.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

TABLE A-8. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ATLANTIC COD DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	1.11 NS	3.82 NS
(Apr-Jul)	Station[b]	6.47 NS	0.93 NS
(1987-1994)	Preop-Op X Station[c]	0.19 NS	0.14 NS
Trawl	Preop-Op[d]	4.69*	98.49***
(Nov-Jul)	Station	36.71*	61.62***
(1975-1994)	Preop-Op X Station	1.12 NS	1.85 NS

[a] Preop-Op compares 1991-1994 to 1987-1990 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1975-1990, regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

TABLE A-9. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR POLLOCK DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	2.51 NS	34.00***
(Nov-Feb)	Station[b]	25.68*	3.41*
(1986-1994)	Preop-Op X Station[c]	0.42 NS	0.13 NS
Gill Net	Preop-Op[d]	0.02 NS	0.08 NS
(Apr-Dec)	Station	15.61 NS	5.67***
(1976-1994)	Preop-Op X Station	0.28 NS	0.52 NS

[a] Preop-Op compares 1990-1993 to 1986-1990 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1975-1989, regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very highly significant ($0.001\geq p$)

TABLE A-10. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR HAKE[a] DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[b]	<0.01 NS	0.01 NS
(Jul-Sep)	Station[c]	1.03 NS	0.75 NS
(1986-1994)	Preop-Op X Station[d]	0.98 NS	0.71 NS
Trawl	Preop-Op[e]	10.25**	82.25***
(Nov-Jul)	Station	6.52 NS	14.17***
(1976-1994)	Preop-Op X Station	3.27 NS	2.34 NS

[a] Hake = red, white, and spotted hakes.
[b] Preop-Op compares 1991-1994 to 1986-1989, regardless of station.
[c] Stations regardless of year or period.
[d] Interaction of the two main effects, Preop-Op and Station.
[e] Preop-Op compares 1990-1994 to 1976-1990, regardless of station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very highly significant ($0.001\geq p$)

TABLE A-11. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ATLANTIC SILVERSIDE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Seine	Preop-Op[a]	4.78 NS	0.02 NS
(Apr-Nov)	Station[b]	0.12 NS	8.38**
(1976-1994)	Preop-Op X Station[c]	0.19 NS	1.45 NS

[a] Preop-Op compares 1991-1994 to 1976-1984 and 1986-1989, regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant (p>0.05)
* = Significant (0.05≥p>0.01)
** = Highly significant (0.01≥p>0.001)
*** = Very highly significant (0.001≥p)

TABLE A-12. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR CUNNER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	0.67 NS	12.72**
(Jun-Sep)	Station[b]	4.17 NS	0.66 NS
(1987-1994)	Preop-Op X Station[c]	0.66 NS	0.16 NS

[a] Preop-Op compares 1991-1994 to 1987-1989, regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very highly significant ($0.001\geq p$)

TABLE A-13. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR AMERICAN SAND LANCE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	0.69 NS	3.02 NS
(Jan-Apr)	Station[b]	3.82 NS	5.19 NS
(1987-1994)	Preop-Op X Station[c]	4.39*	1.33 NS

[a] Preop-Op compares 1991-1994 to 1987-1990, regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very highly significant ($0.001\geq p$)

TABLE A-14. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR ATLANTIC MACKEREL DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	0.02 NS	0.11 NS
(Nov-Feb)	Station[b]	0.79 NS	0.13 NS
(1986-1994)	Preop-Op X Station[c]	2.25 NS	0.09 NS
Gill Net	Preop-Op[d]	2.04 NS	20.95***
(Apr-Dec)	Station	non-est.[e]	2.47 NS
(1976-1994)	Preop-Op X Station	0.07 NS	0.09 NS

[a] Preop-Op compares 1991-1994 to 1987-1989 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1991-1994 to 1975-1989, regardless of station.
[e] Non-estimable due to negative denominator mean square.

NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very highly significant ($0.001\geq p$)

TABLE A-15. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR WINTER FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)	MULTIPLE COMPARISONS OF ADJUSTED MEANS[f]
Ichthyoplankton (Apr-Jul) (1987-1994)	Preop-Op[a]	4.83 NS	10.17*	
	Station[b]	8.73 NS	6.90*	
	Preop-Op X Station[c]	0.72 NS	0.76 NS	
Trawl (Nov-Jul) (1975-1994)	Preop-Op[d]	1.01 NS	23.03***	
	Station	1.40	20.09***	
	Preop-Op X Station	6.39**	16.54***	
Seine (Apr-Nov (1976-1994)	Preop-Op[e]	7.68*	57.85***	
	Station	7.90 NS	32.23***	
	Preop-Op X Station	2.19 NS	4.23*	S3Pre S2Pre S3Op S1Pre S1Op S2Op

[a] Preop-Op compares 1991-1994 to 1987-1990 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1975-1990.
[e] Preop-Op compared 1991-1994 to 1976-1984 and 1986-1989.
[f] Underlining signifies no significant differences among least square means at $p \leq 0.05$.

NS = Not significant ($p > 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

TABLE A-16. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR YELLOWTAIL FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1994.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)
Ichthyoplankton	Preop-Op[a]	0.32 NS	1.34 NS
(May-Aug)	Station[b]	2.69 NS	0.73 NS
(1987-1994)	Preop-Op X Station[c]	0.23 NS	0.31 NS
Trawl	Preop-Op[d]	33.96***	361.24***
(Nov-Jul)	Station	71.17*	142.00***
(1975-1994)	Preop-Op X Station	1.29 NS	2.15 NS

[a] Preop-Op compares 1991-1994 to 1987-1989 regardless of station.
[b] Stations regardless of year or period.
[c] Interaction of the two main effects, Preop-Op and Station.
[d] Preop-Op compares 1990-1994 to 1975-1990.

NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

A-15). Winter flounder CPUE in the seine decreased at all stations between the preoperational and operational periods, but the decrease was greatest at Station S3 (Figure A-1). CPUE at Station S3 was generally much higher than Stations S1 and S2 during the preoperational period, especially for the period 1978 through 1984 (See Figure 5-19). However beginning in 1987 and continuing into the operational period, CPUE at Station S3 decreased and became more similar to that at the other two stations. In 1993 and 1994, CPUE at Station S3 ranked second, the first time this has occurred since 1976. The significant difference in CPUE is probably not due to Seabrook Station because the decrease at Station S3 began prior to plant start-up.

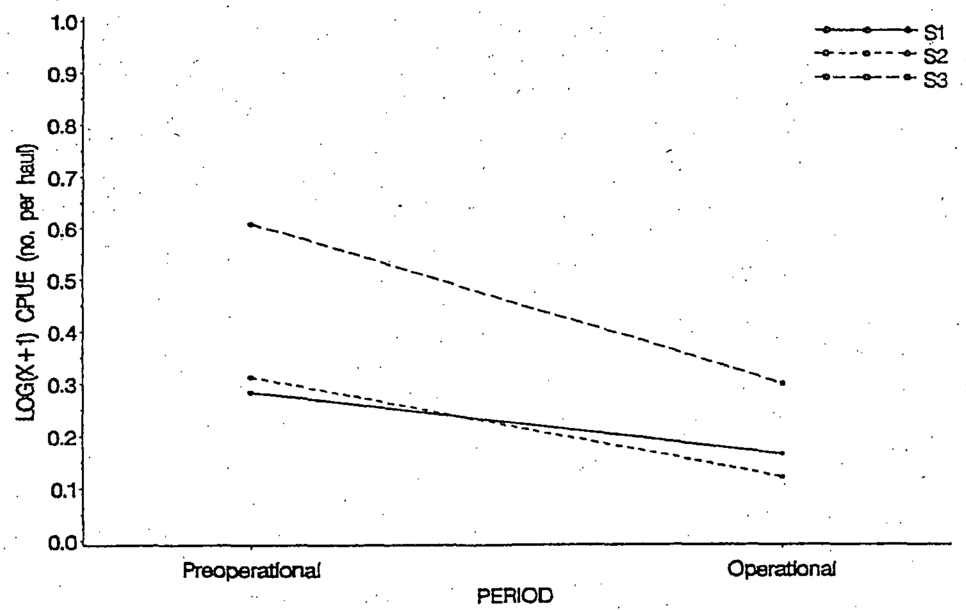


Figure A-1. Comparisons among stations of the mean $\log_{10}(X+1)$ CPUE (number per haul) of winter flounder caught by seine during the preoperational (April - November 1976-1984; 1986-1989) and operational periods (April 1990 - November 1994) for the significant interaction term (Preop X Station) of the ANOVA model (Table A-15). Seabrook Operational Report, 1994.

6.0 MACROBENTHOS

Analysis of variance was performed for ten parameters generated from macroalgae collections from the destructive monitoring program. There were no significant Preop-Op or Station terms for any of the ANOVAs using the new mixed effects model. Using the mixed effects model, one Preop-Op X Station interaction term was significant while three interactions using the fixed effects model were significant (Tables A-17, A-18). The interaction term for total intertidal biomass, significant under both models, was discussed in Section 6.3.1.

ANOVA results from the fixed model indicate that the relationship between the average number of taxa at the nearfield intake station (B16) and the farfield station (B31) did not change significantly between the preoperational and operational periods. At discharge station B19, however, the mean number of taxa declined

TABLE A-17. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR NUMBER OF TAXA (per 0.0625 m^2) AND TOTAL BIOMASS (g per m^2) OF MACROALGAE COLLECTED IN AUGUST DESTRUCTIVE SAMPLES AT INTERTIDAL, SHALLOW SUBTIDAL, AND DEEP STATIONS DURING PREOPERATIONAL AND OPERATIONAL YEARS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	4.40 NS	51.05***	
		Station[b]	31.90 NS	95.84***	
		Preop-Op X Station[c]	1.66 NS	2.97 NS	
	Shallow Subtidal (B17, B35)	Preop-Op	1.11 NS	3.89 NS	
		Station	non-est.[f]	53.85***	
		Preop-Op X Station	<0.01 NS	0.01 NS	
	Mid-depth (B16, B19, B31)	Preop-Op	0.30 NS	2.65 NS	
		Station	5.54 NS	22.57***	
		Preop-Op X Station	1.81 NS	4.16*	B31Pre B31Op B19Pre B16Op B19Op B16Pre
	Deep (B04, B34, B13)	Preop-Op	<0.01 NS	0.01 NS	
		Station	6.36 NS	5.80*	
		Preop-Op X Station	0.61 NS	0.92 NS	
Total Biomass	Intertidal (B1MLW, B5MLW)	Preop-Op	2.60 NS	49.86***	
		Station	1.36 NS	11.64***	
		Preop-Op X Station	4.91*	9.03**	B1Pre B5Pre B1Op B5Op
	Intertidal (B1MLW, B5MLW)	Preop-Op	0.48 NS		
		Station	3.97 NS		
		Preop-Op X Station	0.98 NS		
	Shallow Subtidal (B17, B35)	Preop-Op	0.50 NS	2.04 NS	
		Station	3.02 NS	1.56***	
		Preop-Op X Station	0.43 NS	0.76 NS	

(continued)

TABLE A-17. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Total Biomass (Cont.)	Mid-depth (B16, B19, B31)	Preop-Op	1.48 NS	8.30**	
		Station	12.61 NS	51.97***	
		Preop-Op X Station	2.29 NS	4.23*	B16Pre B16Op B31Pre B31Op B19Op B19Pre
	Deep (B04, B34, B13)	Preop-Op	non-est.[f]	7.60**	
		Station	12.92 NS	14.30***	
		Preop-Op X Station	0.34 NS	1.18 NS	

[a]Compares Preop to Op, regardless of station; years included in each station grouping (Op Years = 1990-1994 for all):
B1MLW, B5MLW: 1982-1994
B17, B35: 1982-1994
B16, B19, B31: 1980-1984, 1986-1994
B04, B34, B13: 1979-1984, 1986-1994
[b]Stations within depth zone.
[c]Interaction of the two main effects, Preop-Op and Station.
[d]NS = Not significant ($p>0.05$); * = Significant ($0.05\geq p>0.01$); ** = Highly significant ($0.01\geq p>0.001$); *** = Very Highly Significant ($0.001\geq p$).
[e]Underlining indicates that t-tests showed no significant differences ($\alpha\leq0.05$) among the underlined least squares means.
[f]Non-estimatable due to negative mean square denominator.

TABLE A-18. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR *CHONDRUS CRISPUS* BIOMASS (g/m^2) AT INTERTIDAL AND SHALLOW SUBTIDAL STATION PAIRS FOR THE PREOPERATIONAL (1982 - 1989) AND OPERATIONAL (1991 - 1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

TAXON	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)
Chondrus crispus	Intertidal[e] (B1, B5)	Preop-Op[a]	0.26 NS	1.03 NS
		Station[b]	118.27 NS	52.10***
		Preop-Op X Station[c]	0.20 NS	0.65 NS
	Shallow Subtidal[f] (B17, B35)	Preop-Op	0.13 NS	0.01 NS
		Station	18,259.00 NS	34.22***
		Preop-Op X Station	0.02 NS	0.01 NS

[a]Preop-Op compares 1982 - 1989 to 1991-1994 regardless of station. The years selected are those during which each station within each pairing were sampled.
[b]Station pairs nested within a depth zone: intertidal = B1MLW, B5MLW; shallow subtidal = B17, B35, regardless of year or period.
[c]Interaction of the two main effects, Preop-Op and Station.
[d]NS = Not significant ($p>0.05$); * = Significant ($0.05\geq p>0.01$); ** = Highly significant ($0.01\geq p\geq 0.001$); *** = Very highly significant ($0.001\geq p$).
[e]Data untransformed.
[f]Data square-root transformed.

significantly between the preoperational and operational periods (Figure A-2). The mean number of species collected at B19 increased between 1989 and 1993 (Figure A-3). The fixed effects ANOVA model run from 1980 through 1993 showed no significant Preop-Op X Station interaction for the mean number of taxafrom 1980 through 1993 (NAI and NUSCO 1994). The mean number of taxa at Station B19, as well as B16 and B31 dropped sharply in 1994 (the lowest to date) contributing to the significant Preop-Op X Station interaction. A similar steep drop in number of taxa was observed at Station B19 between 1987 (when mean number of taxa was at its highest value for this station) and 1989. The fact that a similar trend was observed during the preoperational period, plus the fact that both nearfield and farfield stations showed similar decreases in 1994 suggests that the cyclical pattern observed at B19 during the operational period is due to natural, local factors rather than the operation of Seabrook Station.

Mean biomass in the mid-depth zone decreased significantly at the intake and farfield stations (B16 and B31, respectively) between the preoperational and operational periods, but remained unchanged at the discharge station (B19) (Table A-17, Figure A-4). Biomass at Station B16 has been highly variable over time (Figure A-5). Biomass declined between 1989 and 1992, but then increased in 1993 and 1994. Biomass at B31 has also been variable, and at times has shown an opposite trend from levels at Station B16. Biomass levels at Station B19 have been less variable than at the other two stations; biomass at this station has decreased since 1991, but there was no significant difference between preoperational and operational periods. As biomass at the discharge station, the nearfield station most likely to experience operational impacts on the benthos, has shown no statistically significant change during the operational period, there is likely no impact related to Seabrook Station.

For both parameters (annual mean number of taxa, annual mean biomass) in the mid-depth zone, variability is clearly evident in the preoperational period at all stations. The parameters that showed a significant difference at only one of the nearfield stations (B19, number of taxa; B16 total biomass) had annual means during the operational period that were within the range of previous years, suggesting natural fluctuations unrelated to Seabrook Station. This conclusion is supported by the numerical classification results, which indicate that community structure has thus far remained unchanged through the Operational period (Table 6-4).

Eighteen ANOVA models were run for parameters assessed in the marine macrofauna sampling program. There was only one significant Preop-Op X Station interaction indicated by the mixed effects (new) model. The fixed effects (old) model indicated significant differences for five of the Preop-Op X Station interaction terms (Tables A-19, A-20).

Number of taxa in the shallow subtidal zone had a significant Preop-Op X Station interaction term with the fixed effects model that was not significant when the mixed effects model was used. Average number of taxa was higher during the operational period at the nearfield station B17 (Table 6-10, Figure A-6) in comparison to the average for the preoperational period. Average number of taxa at the farfield station B35 showed no significant difference between the preoperational and operational periods. Examination of annual means for the entire study period (Figure A-7) showed high year-to-year variability, with nearfield numbers of taxa generally similar to those at the farfield station from 1982 through 1988. Beginning in 1989, and generally continuing through 1994, the average number of taxa at the nearfield station was elevated in comparison to the farfield station. The significant increase in number of taxa at the nearfield station is not biologically important for two reasons: the trend of elevated abundances at the nearfield station began prior to plant operation, and numbers of taxa at both stations during the operational period are within the range observed during the preoperational period.

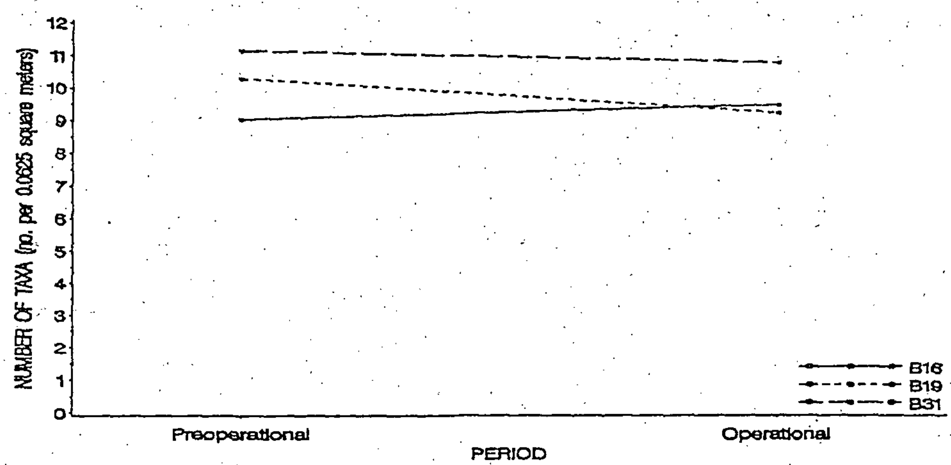


Figure A-2. Comparisons among stations for number of macroalgal taxa (per 0.0625 m^2) in the mid-depth zone during the preoperational (1980-1984; 1986-1989) and operational (1990-1994) periods for the significant interaction term (Preop X Station) of the ANOVA model (Table A-17). Seabrook Operational Report, 1994.

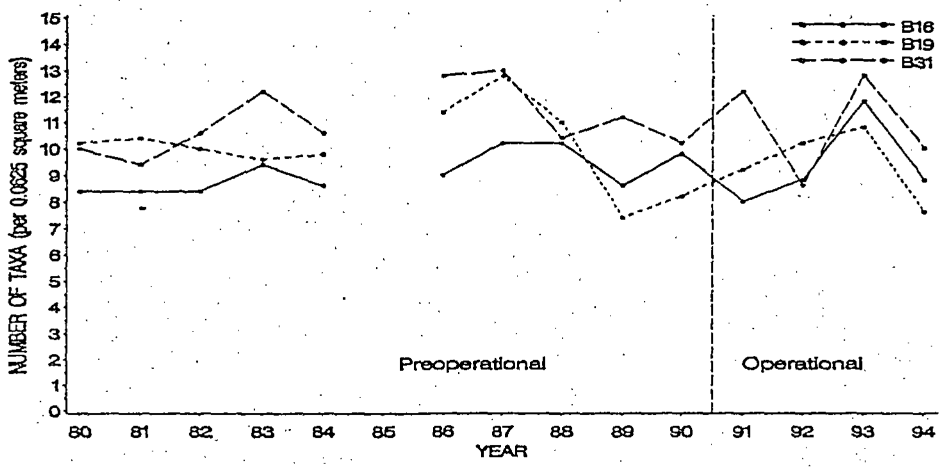


Figure A-3. Annual mean number of macroalgal taxa (per 0.0625 m^2) at mid-depth stations 1980-1994. Seabrook Operational Report, 1994.

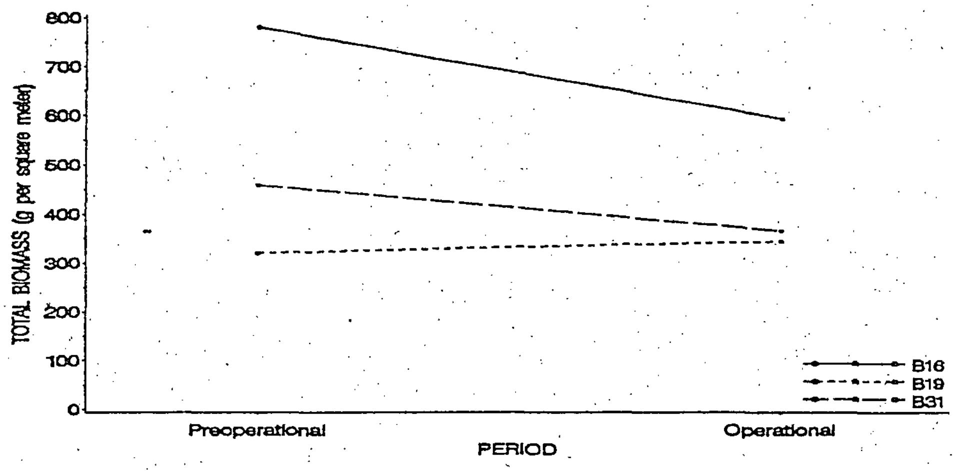


Figure A-4. Comparisons among stations for the mean total macroalgal biomass (g per m^2) in the mid-depth zone during the preoperational (1980-1984; 1986-1989) and operational (1990-1994) periods for the sigificant interaction term (Preop-Op X Station) of the ANOVA model (Table A-17). Seabrook Operational Report, 1994.

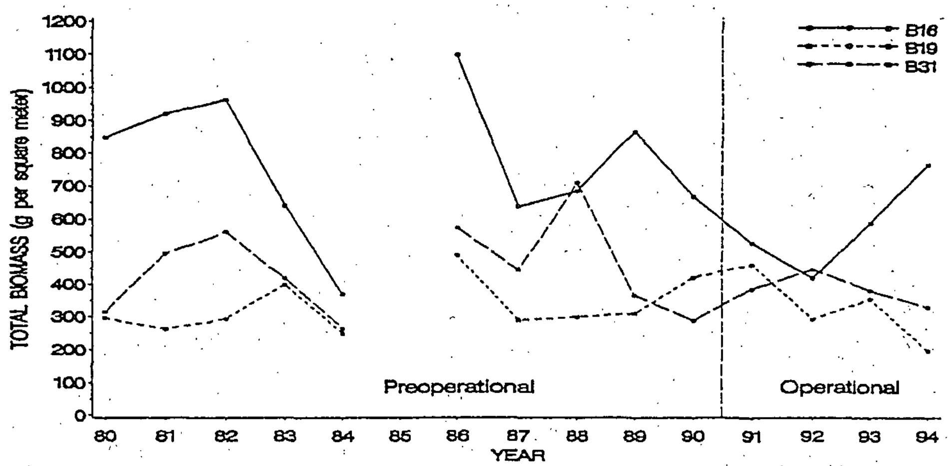


Figure A-5. Annual mean biomass (g per m^2) of macroalgae in the mid-depth zone 1980-1994. Seabrook Operational Report, 1994.

TABLE A-19. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR NUMBER OF TAXA (per 0.0625 m^2) AND TOTAL DENSITY (per m^2) OF MACROFAUNA COLLECTED IN AUGUST AT INTERTIDAL, SHALLOW, MID-DEPTH, AND DEEP SUBTIDAL STATIONS 1978-1994. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F^d FOR MIXED MODEL (new)	F^d FOR FIXED MODEL (old)	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	3.62 NS	39.92***	
		Station[b]	0.02 NS	0.07***	
		Preop-Op X Station[c]	3.46 NS	3.62 NS	
	Shallow Subtidal (B17, B35)	Preop-Op	0.55 NS	3.15 NS	
		Station	3.34 NS	13.34**	
		Preop-Op X Station	4.28 NS	4.47*	B17Op B17Pre B35Pre B35Op
	Mid-depth (B16, B19, B31)	Preop-Op	0.83 NS	2.16 NS	
		Station	192.55 NS	61.97***	
		Preop-Op X Station	0.16 NS	1.01 NS	
	Deep (B04, B34, B13)	Preop-Op	0.50 NS	1.63 NS	
		Station	7.50 NS	22.18***	
		Preop-Op X Station	1.44 NS	2.62 NS	
Total Density	Intertidal (B1MLW, B5MLW)	Preop-Op	0.03 NS	0.29 NS	
		Station	2.95 NS	13.38**	
		Preop-Op X Station	1.17 NS	4.94*	B1Pre B1Op B5Op B5Pre
	Shallow Subtidal (B17, B35)	Preop-Op	0.77 NS	4.74*	
		Station	32.05 NS	3.72 NS	
		Preop-Op X Station	0.08 NS	0.12 NS	
	Mid-depth (B16, B19, B31)	Preop-Op	0.14 NS	6.99**	
		Station	2.79 NS	7.35**	
		Preop-Op X Station	1.46 NS	2.61 NS	

(continued)

TABLE A-19. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
	Deep	Preop-Op	1.46 NS	23.50***	
	(B04, B34, B13)	Station	2.62 NS	12.60***	
		Preop-Op X Station	2.12 NS	6.57***	B13Op B34Op B13Pre B4Op B34Pre B4Pre

[a]Preop-Op compares 1982 - 1989 to 1990 - 1994 regardless of station.
[b]Nearfield = Stations B1MLW, B17, B16, B04, B13; farfield = Stations B5MLW, B35, B31, B34, regardless of year/period.
[c]Interaction of the two main effects, Preop-Op and Station.
[d]NS = not significant ($p>0.05$); * = significant ($0.05\geq p>0.01$); ** = Highly significant ($0.01\geq p>0.001$); *** = Very highly significant ($p\leq 0.001$).
[e]Underlining indicates that t-tests showed no significant differences ($\alpha\leq 0.05$) among the underlined least squares means.

TABLE A-20. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR LOG-TRANSFORMED DENSITIES OF SELECTED BENTHIC TAXA COLLECTED IN MAY, AUGUST AND NOVEMBER AT NEAR- AND FARFIELD STATION PAIRS (B1MLW/B5MLW, B17/B35, B19/B31) DURING PREOPERATIONAL (1978 - 1989) AND OPERATIONAL (1991 - 1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	F[e] FOR MIXED MODEL (new)	F[e] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[f] (RANKED IN DECREASING ORDER)
Mytilidae (<25 mm)	Intertidal (B1, B5)	Preop-Op[a]	2.27 NS	16.28***	
		Station[b]	non-est.[g]	33.15***	
		Preop-Op X Station[c]	<0.01 NS	0.03 NS	
	Shallow Subtidal (B17, B35)	Preop-Op	0.06 NS	0.93 NS	
		Station	12.73 NS	29.32***	
		Preop-Op X Station	0.91 NS	2.76 NS	
	Mid-depth (B19, B31)	Preop-Op	0.04 NS	0.44 NS	
		Station	111.47 NS	46.31***	
		Preop-Op X Station	0.14 NS	1.14 NS	
Nucella lapillus	Intertidal (B1MLW, B5MLW)	Preop-Op	0.44 NS	4.19*	
		Station	35.27 NS	38.23***	
		Preop-Op X Station	0.54 NS	0.76 NS	
Asteriidae	Shallow Subtidal (B17, B35)	Preop-Op	0.06 NS	1.14 NS	
		Station	77.67 NS	132.95***	
		Preop-Op X Station	0.97 NS	5.14*	<u>B17Op B17Pre</u> <u>B35Pre B35Op</u>
Pontogeneia inermis	Mid-Depth (B19, B31)	Preop-Op	1.26 NS	5.41*	
		Station	14.23 NS	25.30***	
		Preop-Op X Station	1.01 NS	1.43 NS	
Jassa marmorata	Shallow Subtidal (B17, B35)	Preop-Op	0.18 NS	1.26 NS	
		Station	24.34 NS	29.17***	
		Preop-Op X Station	0.67 NS	2.03 NS	

(continued)

TABLE A-20. (Continued)

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	F[e] FOR MIXED MODEL (new)	F[e] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[f] (RANKED IN DECREASING ORDER)
Ampithoe rubricata	Intertidal (B1MLW, B5MLW)	Preop-Op	0.61 NS	87.47***	
		Station	0.83 NS	134.15***	
		Preop-Op X Station	20.18**	120.01***	B5Op B1Pre B5Pre B1Op
Strongylocentrotus droebachiensis	Mid-Depth (B19, B31)	Preop-Op	0.77 NS	4.94*	
		Station	non-est.[g]	23.05***	
		Preop-Op X Station	0.01 NS	0.01 NS	
Modiolus modiolus (adults)	Mid-Depth (B19, B31)	Preop-Op	5.13 NS	31.69***	
		Station	0.37 NS	2.18 NS	
		Preop-Op X Station	0.93 NS	5.82*	

[a]Log_{10} (x+1) density, except for *M. modiolus* adults, which were sampled semi-quantitatively and therefore rank densities were used.
[b]Preop-Op compares 1978-1989 to 1990-1994 regardless of station.
[c]Station pairs nested within a depth zone: Intertidal = nearfield (B1MLW), farfield (B5MLW); Shallow subtidal = nearfield (B17), farfield (B35); Mid-depth = nearfield (B19), farfield (B31); regardless of Year, Station or Period.
[d]Interaction of the two main effects, Preop-Op and Station.
[e]NS = not significant (p>0.05); * = significant (0.05≥p>0.01); ** = highly significant (0.01≥p>0.001); *** = very highly significant (p≤0001).
[f]Underlining indicates that t-tests showed no significant differences (α≤0.05) among the underlined least squares means.
[g]F-value non-estimable due to a negative denominator mean square.

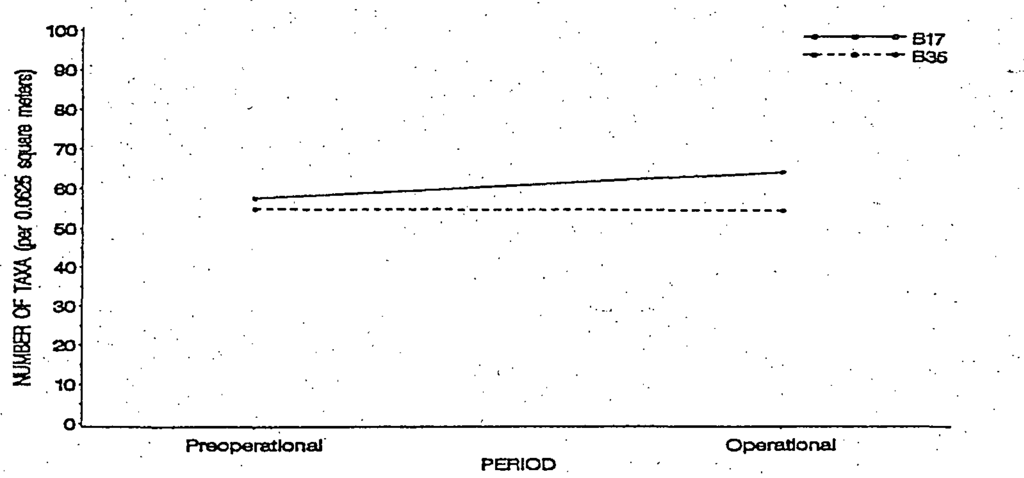


Figure A-6. Comparisons between shallow subtidal stations of mean number of taxa (per 0.0625m^2) during the preoperational (1978-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table A-19). Seabrook Operational Report, 1994.

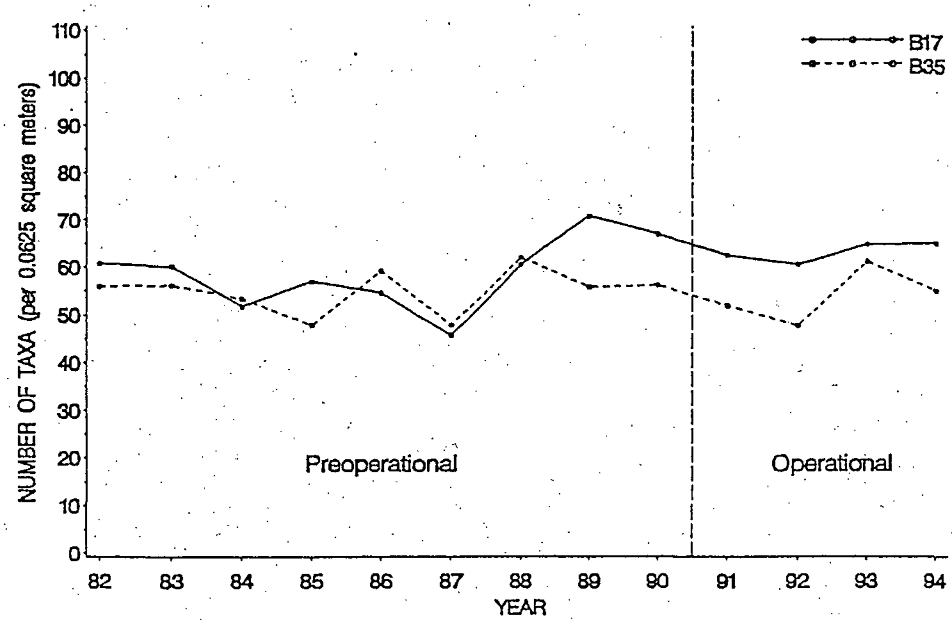


Figure A-7. Annual mean number of macrofaunal species (per 0.0625 m^2) at shallow subtidal stations, 1982-1994. Seabrook Operational Report, 1994.

Total density in the intertidal zone had a significant Preop-Op X Station interaction term with the fixed effects model that was not significant when the mixed effects model was employed (Table A-19). Average density at each station showed no significant difference between the preoperational and operational periods. However, average density at the nearfield station during the preoperational period was significantly higher than at the farfield station (Table 6-10, Figure A-8). During the operational period there was no significant difference in average abundance between the two stations. Examination of annual means for the entire study period (Figure A-9) showed high year-to-year variability, with nearfield abundances higher than those at the farfield station in some years. The lower average density during the operational period at the nearfield station was largely due to low density in 1991, which was the lowest recorded to date. Density at the farfield station showed a similar decrease. In 1992-1994, densities at both stations increased to levels similar to those observed preoperationally. In two of the four operational years, the nearfield station had higher densities than the farfield station, continuing the preoperational trend. The differing trends in density in the intertidal zone are not biologically important for two reasons: when average density at each station is examined individually, there is no significant difference between the preoperational and operational periods. Furthermore, the annual mean densities during the operational period do not show a consistent trend at the nearfield station that could be related to plant operation. Average densities at both stations show high variability that, with the exception of 1991 at the nearfield station, are within the range of previous years.

Total density in the deep subtidal zone had a significant Preop-Op X Station interaction term with the fixed effects model that was not significant when the mixed effects model was employed (Table A-19). Average density at the nearfield intake station B13 more than doubled during the operational period in comparison to the preoperational period. Average densities at the nearfield deep discharge and farfield stations increased during the operational period, but these differences were not significant (Table A-19, Figure A-10). Examination of annual means for the entire study period (Figure A-11) showed high year-to-year variability. Annual densities at Station 13 have been elevated in comparison to the other stations during the preoperational period (1988, 1989) as well as during the operational period (1992-1994). Typically, these increased densities were the result of large sets of barnacles, usually *Balanus crenatus*. In 1993, an unusual set of *Hiatella* sp. contributed to the increased densities. Community analysis revealed that community composition during the years when densities were elevated was more similar to the mid-depth stations than deep stations. The differing trends in density in the deep zone are not biologically important because the average density at the nearfield discharge station has been elevated in the past as well as during the operational period, due to increased numbers of newly settled barnacles, generally *Balanus crenatus*, along with the mollusc *Hiatella* sp. It is unknown whether small scale spatial variability in the substrate or differences in the timing of settlement have caused these differences. However, these variations in community composition have been observed throughout the study period. Therefore, these differences appear to be unrelated to the operation of Seabrook Station.

The density of Asteriidae in the shallow subtidal zone had a significant Preop-Op X Station interaction term with the fixed effects model that was not significant when the mixed effects model was employed (Table A-20). Average density was significantly higher during the operational period at the nearfield station B17 (Table 6-10, Figure A-12) in comparison to the average for the preoperational period. Average asteriid density at the farfield station B35 showed no significant difference between the preoperational and operational periods, although densities showed a similar trend to the nearfield station. Examination of annual means for the entire study period (Figure A-13) showed highest year-to-year variability at the farfield station, with nearfield densities consistently higher than those at the

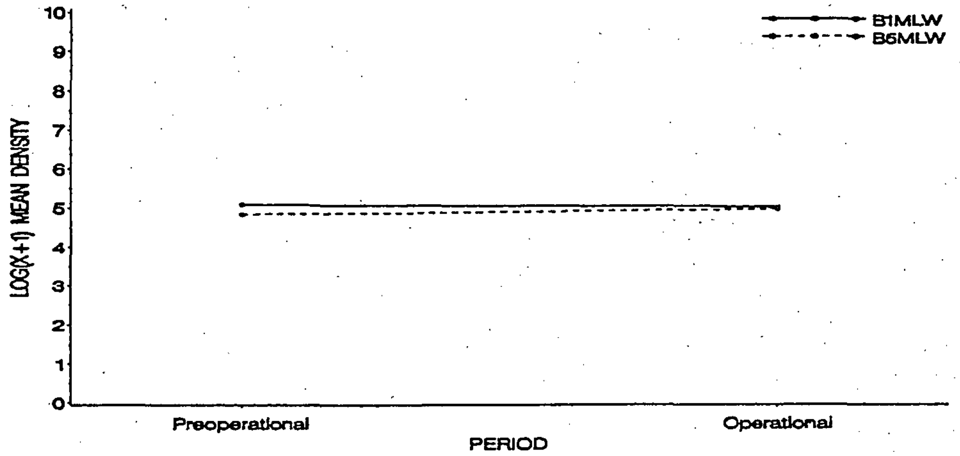


Figure A-8. Comparisons between intertidal stations of mean density ($\log_{10}(X+1)$) of macrofauna during the preoperational (1978-1989) and operational (1990-1994) periods for the significant term (Preop X Station) of the ANOVA model (Table A-19). Seabrook Operational Report, 1994.

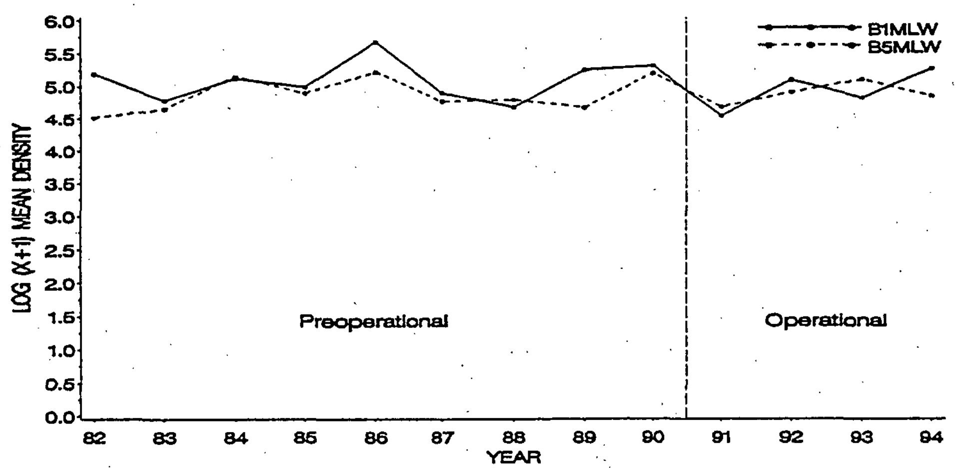


Figure A-9. Annual mean density ($\log_{10}(X+1)$) of macrofaunal species at intertidal stations, 1982-1994. Seabrook Operational Report, 1994.

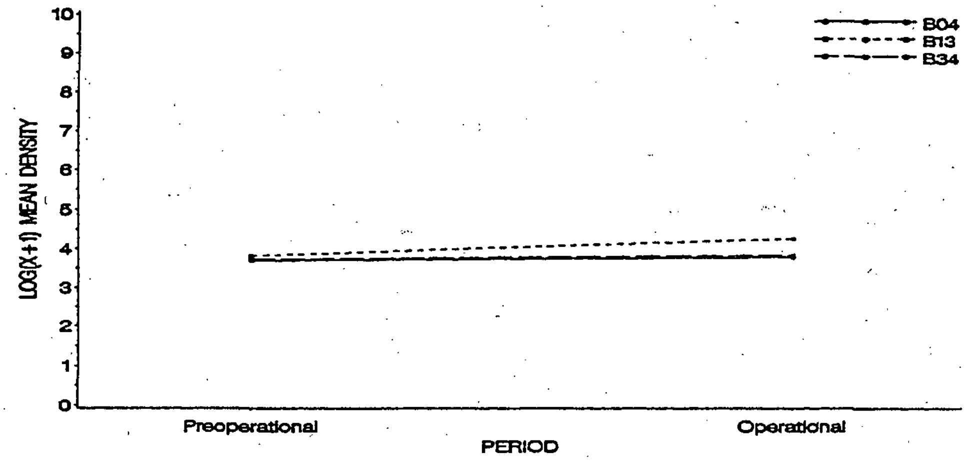


Figure A-10. Comparisons among deep subtidal stations of mean density ($\log_{10}(X+1)$) of macrofauna during the preoperational (1978-1989) and operational (1990-1994) periods for the significant term (Preop X Station) of the ANOVA model (Table A-19). Seabrook Operational Report, 1994.

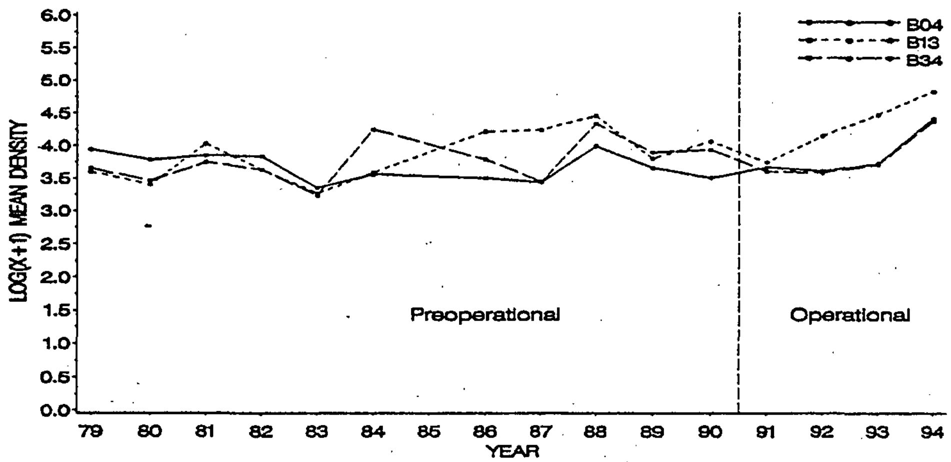


Figure A-11. Annual mean density ($\log_{10}(X+1)$) of macrofaunal species at deep subtidal stations, 1979-1984. Seabrook Operational Report, 1994.

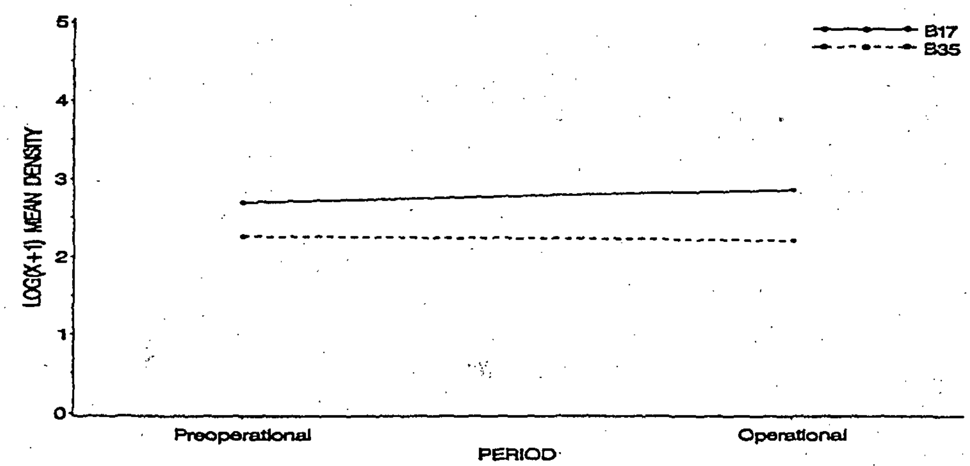


Figure A-12. Comparisons between shallow subtidal stations of mean density ($\log_{10}(X+1)$) of *Asteriidae* during the preoperational (1978-1989) and operational (1990-1994) periods for the significant interaction term (Preo-Op X Station) of the ANOVA model (Table A-20). Seabrook Operational Report, 1994.

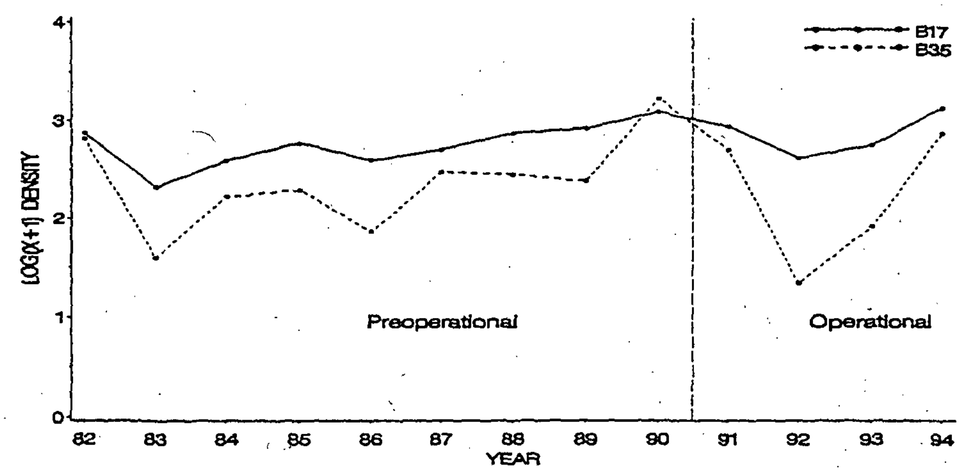


Figure A-13. Annual mean density ($\log_{10}(X+1)$) of *Asteriidae* at shallow subtidal stations, 1982-1994. Seabrook Operational Report, 1994.

farfield station. Densities at Station 35 reached the lowest level to date in 1992, followed by a dramatic increase in 1993 and 1994. While densities at Station 17 showed a similar trend, the differences were much less dramatic. The significant increase in Asteriidae density at the nearfield station is not biologically important for two reasons: annual densities at the nearfield station were generally within the range of previous years, and year-to-year variations at the nearfield station were generally paralleled by those at the farfield station.

The density of *Modiolus modiolus* in the mid-depth subtidal zone had a significant Preop-Op X Station interaction term with the fixed effects model that was not significant when the mixed effects model was employed (Table A-20). Average density was significantly lower during the operational period at the nearfield station B19 (Table 6-10, Figure A-14) in comparison to the average for the preoperational period. Similarly, average *M. modiolus* density at the farfield station B31 showed a small but significant decrease during the operational period. The significant interaction reflects the fact that during the preoperational period, there was no significant difference in average density between the two stations, while average densities at the farfield station were significantly higher than those at the nearfield station during the operational period. This was largely the result of a dramatic increase in average density in 1994 at the farfield station coupled with a decline at the nearfield station. Prior to 1994, the Preop X Station interaction term was not significant (NAI and NUS 1994). Examination of annual means for the entire study period (Figure A-15) showed high year-to-year variability with no consistent relationship between the two stations. The significant decrease at the nearfield station is not judged biologically important as it is only an average of 3 mussels per m^2, or approximately 3% of the total.

Average abundances of one other species, *Ampithoe rubricata*, had a significant Preop X Station interaction term for the fixed effects model. This interaction term was also significant for the mixed effects model, and is discussed in Section 6.3.2.2.

7.0 SURFACE PANELS

Seven ANOVA models were run for parameters collected in the surface panels program. The fixed effects (old) model detected significant differences for two of the Preop-Op X Station interaction terms (Tables A-21, A-22). There were no significant differences detected for the interaction of Preop-Op X Station when the mixed effects (new) model was used.

Total noncolonial abundance and Mytilidae were the two parameters that had significant Preop-Op X Station interaction terms with the fixed effects model that were not significant when the mixed effects model was employed. These two parameters are related, since Mytilidae is the most abundant taxon contributing to total abundance. For both parameters, average abundances showed a significant increase during the operational period in comparison to the preoperational period at Station B19, while there were no significant differences in abundances between the two periods at Station B31 (Figures A-16, A-17). Examination of annual means for the entire study period for both parameters showed high year-to-year variability, with nearfield abundances paralleling those at the farfield station. The trends in annual mean noncolonial abundances were reflected by those of Mytilidae (Figures A-18, A-19). During the preoperational period, in most years, the annual abundances at Station B31 were higher than those at B19. Beginning in 1992, annual noncolonial abundances as well as those of Mytilidae were almost identical between the two stations, but continued to show the high variability observed during the operational period.

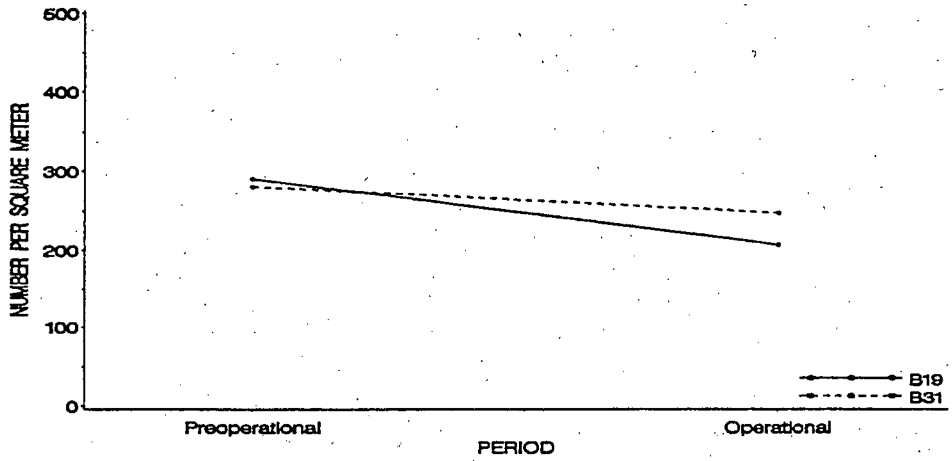


Figure A-14. Comparisons between mid-depth stations of mean density (number per m^2) of *Modiolus modiolus* during the preoperational (1978-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op x Station) of the ANOVA model (Table A-20). Seabrook Operational Report, 1994.

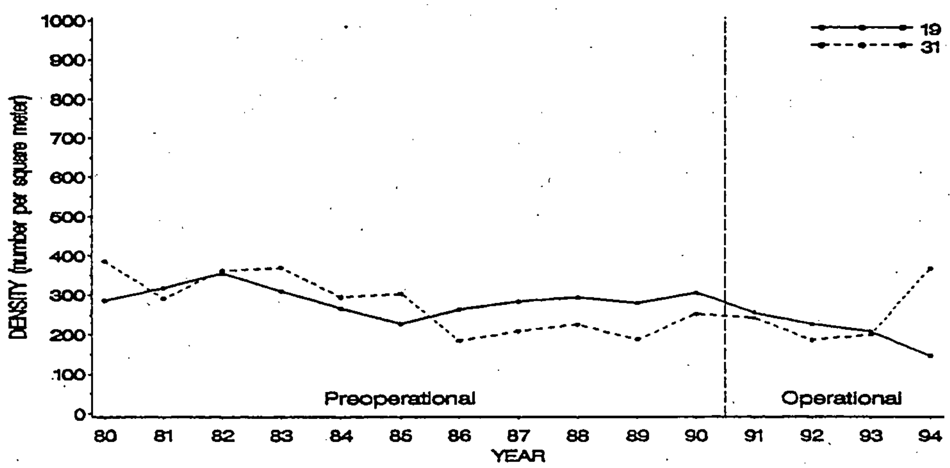


Figure A-15. Annual mean density (number per m^2) of *Modiolus modiolus*, 1980-1994. Seabrook Operational Report, 1994.

TABLE A-21. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR MONTHLY TOTAL NUMBER OF TAXA, NONCOLONIAL FAUNAL ABUNDANCE, TOTAL BIOMASS, AND SELECTED SPECIES ABUNDANCE OR PERCENT FREQUENCY ON SHORT TERM PANELS AT MID-DEPTH STATION PAIR (B19 AND B31) DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

PARAMETER	STATIONS	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Number of Taxa	B19, B31	Preop-Op[a]	1.68 NS	34.34***	
		Station[b]	51.92 NS	3.64 NS	
		Preop-Op X Station[c]	0.10 NS	0.28 NS	
Noncolonial faunal abundance	B19, B31	Preop-Op	0.74 NS	19.52***	
		Station	0.18 NS	0.63 NS	
		Preop-Op X Station	4.26 NS	4.95*	B19Op B31Op B31Pre B19Pre
Biomass	B19, B31	Preop-Op	5.79 NS	3.83 NS	
		Station	6.88 NS	1.20 NS	
		Preop-Op X Station	0.16 NS	0.26 NS	
Mytilidae	B19, B31	Preop-Op	0.06 NS	1.45 NS	
		Station	0.19 NS	0.62 NS	
		Preop-Op X Station	3.91 NS	4.50*	B19Op B31Pre B31Op B19Pre
Jassa marmorata	B19, B31	Preop-Op	1.63 NS	6.86**	
		Station	79.44 NS	8.56**	
		Preop-Op X Station	0.11 NS	0.44 NS	
Tubularia sp.	B19, B31	Preop-Op	0.25 NS	1.15 NS	
		Station	22.19 NS	15.02**	
		Preop-Op X Station	0.41 NS	1.17 NS	

[a]Preop-Op = 1991-1994 v. previous years (1978-84; July 1986-December 1989) regardless of station
[b]Station regardless of year or period
[c]Interaction between main effects Station and Preop-Op
[d]NS = Not significant ($p \geq 0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly significant ($.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)
[e]Underlining indicates that t-tests showed no significant differences ($\alpha \leq 0.05$) among the underlined least squares means.

TABLE A-22. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR MONTHLY SEQUENTIAL PANEL BIOMASS AT THE MID-DEPTH (B19, B31) STATION PAIR DURING PREOPERATIONAL (1978-1989) AND OPERATIONAL (1991-1994) PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

STATIONS	SOURCE OF VARIATION	F[d] FOR MIXED MODEL (new)	F[d] FOR FIXED MODEL (old)
Mid-depth B19, B31	Preop-Op[a]	0.01 NS	<0.01 NS
	Station[b]	0.48 NS	0.74 NS
	Preop-Op X Station[C]	0.89 NS	0.13 NS

[a]Preop-Op = 1991-1994 v. previous years (1978-84; July 1986-December 1989)
[b]Station regardless of year or period
[c]Interaction between main effects
[d]NS= Not significant (.05>p)
* = Significant (.01<p≤.05)
** = Highly significant (.001<p≤.01)
*** = Very highly significant (p≤.001)

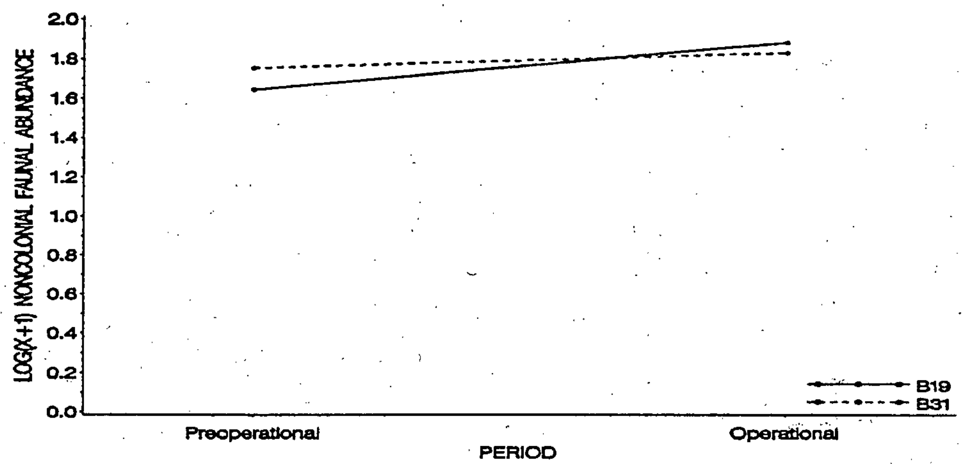


Figure A-16. Comparisons between stations of the mean $\log_{10}(X+1)$ noncolonial faunal abundance on short term panels during the preoperational (1978-1984; July 1986 - December 1989) and operational (1991-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table A-21). Seabrook Operational Report, 1994.

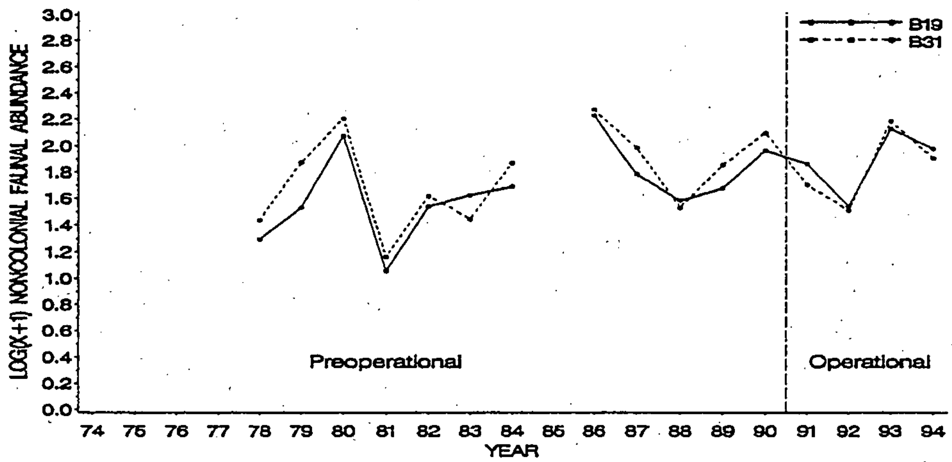


Figure A-17. Annual $\log_{10}(X+1)$ mean noncolonial faunal abundance at Stations B19 and B31 on short term panels for the period 1978-1984 and July 1986-1994. Seabrook Operational Report, 1994.

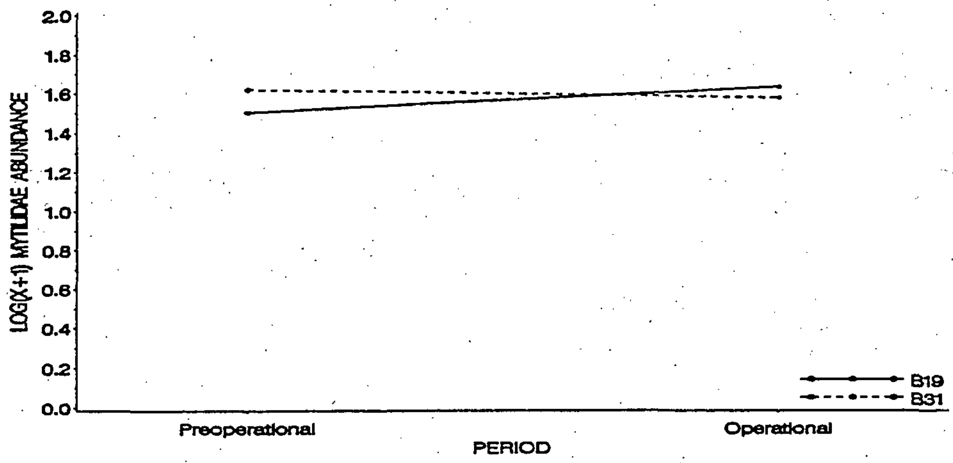


Figure A-18. Comparisons between stations of the mean $\log_{10}(X+1)$ *Mytilidae* abundance on short term panels during the preoperational (1978-1984; July 1986-December 1989) and operational (1991-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table A-22). Seabrook Operational Report, 1994.

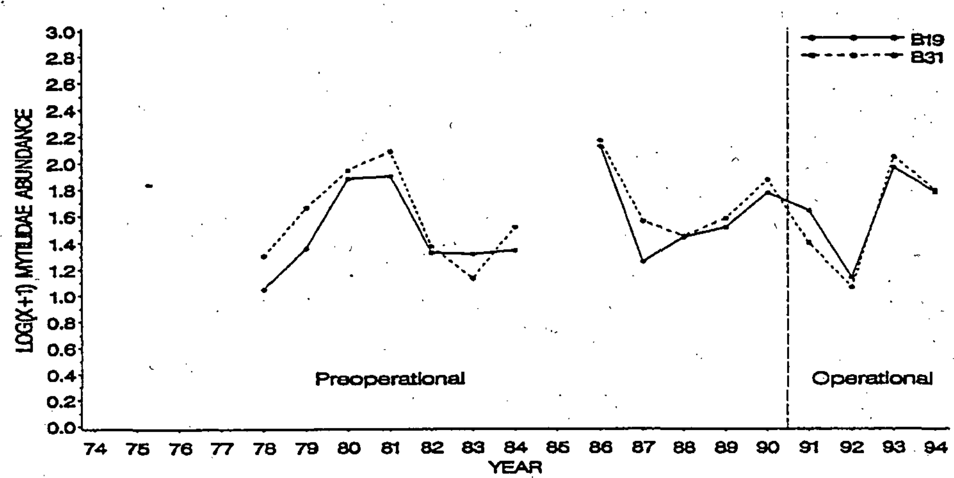


Figure A-19. $\log_{10}(X+1)$ abundance of *Mytilidae* at Stations B19 and B31 on short term panels for the period 1978-1984 and July 1986-1994. Seabrook Operational Report, 1994.

The biological importance of the increase in both average total abundance and abundance of Mytilidae at Station B19 during the operational period must be put in the context of the annual trends. Annual mean abundances at both stations have shown high variability throughout the study period. Annual averages at the nearfield station during the operational period were within the range of previous years. There was no evidence that total abundances or abundances of Mytilidae were elevated at the nearfield station during the operational period in a way that was inconsistent with previous years, given the historical variability.

8.0 EPIBENTHIC CRUSTACEA

Analysis of variance was performed for six species and lifestages. The fixed effects (old) model detected more significant differences between the preoperational and operational periods and among stations than the mixed effects (new) model (Table A-23). Most importantly, the fixed effects model detected significant interaction terms for total lobster catch, legal lobster catch, and Jonah crab catch. The mixed effects model also detected a significant interaction for total lobster catch and this is discussed in Section 8.3.1.

According to the results of the fixed effects model, during the operational period there was a significantly greater decrease in CPUE at Station L7 compared to Station L1 (Table A-23). Mean monthly CPUE during the operational period was 2.4 lobsters per 15 traps at Station L1, and 1.9 lobsters per 15 traps at Station L7, resulting in a difference between the two stations of 0.5 lobsters (Figure A-20). During the preoperational period CPUE at both stations averaged 6.0. A mean difference between stations of 0.5 lobsters (23%) per 15 traps may have been statistically significant according to the fixed effects model, but probably had no biological significance. Legal-sized lobster CPUE has declined steadily at both stations since 1982 (Figure A-21). Increases in the legal size limit in 1984, 1989 and 1990 have contributed to this decline, but probably affected both stations equally. In 1993 and 1994 in the operational period, CPUE at the farfield station decreased to the lowest in the time series, while CPUE remained steady but low at the nearfield station.

Jonah crab catches decreased significantly between the preoperational and operational periods at Station L7, but there were no significant differences at Station L1 (Table A-23; Figure A-22). For the period 1982 through 1985, Jonah crab catches were generally similar at both stations (Figure A-23). However beginning in 1988, and continuing into the operational period, catches of Jonah crab at Station L7 paralleled L1, but were much lower. The decline is probably not due to the operation of Seabrook Station because it began before the station became operational.

9.0 SOFT-SHELL CLAM (*MYA ARENARIA)*

Analysis of variance was used to assess the potential plant effects on six lifestages of the soft-shell clam. The fixed effects (old) model detected significant differences between the preoperational and operational periods, among flats, and the interaction of these main effects for 1-5 mm, 6-25 mm, 26-50 mm and > 50 mm clams in Hampton Harbor (Table A-23). The mixed effects (new) model only detected a significant interaction of the main effects for clams >50 mm, and this interaction is discussed in Section 10.3.2. Neither model detected a significant interaction term for *Mya* larvae, nor for the nearfield/farfield study.

According to the fixed effects model, average density of the 1-5 mm size class decreased significantly between the preoperational and operational periods at Flats 2 and 4, but not at Flat 1 (Figure A-24). This size class may undergo an approximate three year periodicity in abundance with peaks occurring in 1976, 1980-81, 1984, 1987, 1990 and 1993 (Figure A-25). The highest densities of 1-5 mm clams occurred in 1976 and 1980-1981 and have generally declined at all flats since the early 1980s (Figure A-25). Average annual densities

TABLE A-23. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR DENSITIES OF LOBSTER AND *CANCER* SPP. LARVAE COLLECTED AT INTAKE, NEARFIELD, AND FARFIELD STATIONS, AND CATCHES OF TOTAL AND LEGAL-SIZED LOBSTERS, JONAH CRAB, AND ROCK CRAB AT THE NEARFIELD AND FARFIELD STATIONS. SEABROOK OPERATIONAL REPORT, 1994.

SPECIES	SOURCE OF VARIATION[a]	F[b] FOR MIXED MODEL (new)	F[b] FOR FIXED MODEL (old)	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Lobster larvae (May-Oct)	Preop-Op	8.64 *	43.53***	
	Station	0.45 NS	0.67 NS	
	Preop-Op X Station	2.18 NS	2.06 NS	
Lobster (total catch) (Jun-Nov)	Preop-Op	4.12 NS	167.44***	
	Station	1.10 NS	30.03***	
	Preop-Op X Station	5.31 *	25.22***	7 Pre 1 Pre 7 Op 1 Op
Lobster (legal size) (Jun-Nov)	Preop-Op	12.71 *	461.14***	
	Station	0.48 NS	3.29 NS	
	Preop-Op X Station	1.75 NS	4.76*	L7Pre L1Pre L1Op L7Op
Cancer spp. larvae (May-Sep)	Preop-Op	0.79 NS	2.17 NS	
	Station	3.13 NS	0.83 NS	
	Preop-Op X Station	0.14 NS	0.25 NS	
Jonah Crab (Jun-Nov)	Preop-Op	0.15 NS	4.46*	
	Station	5.32 NS	116.15***	
	Preop-Op X Station	1.95 NS	20.64***	L1Op L1Pre L7Pre L7Op
Rock Crab (Jun-Nov)	Preop-Op	0.86 NS	14.44**	
	Station	6.23 NS	6.78*	
	Preop-Op X Station	0.32 NS	2.11 NS	

[a]Preop-Op = Preoperational period (Lobster and *Cancer* spp. larvae, all stations: 1988, 1989; Adult lobster and crabs: 1982-1989); Operational period: 1991-94 regardless of station or month. Station = Station differences (Lobster and *Cancer* spp. larvae: P2, P5, P7; all others: Discharge (L1) and Rye Ledge (L7)) regardless of year, month or period. Preop-Op X Station = Interaction of main effects.

[b]NS = Not significant ($p>0.05$)
* = Significant ($0.05\geq p>0.01$)
** = Highly significant ($0.01\geq p>0.001$)
*** = Very Highly Significant ($0.001\geq p$)
[c]Underlining signifies no significant differences ($\alpha\leq0.05$) among least squares means with a paired t-test.

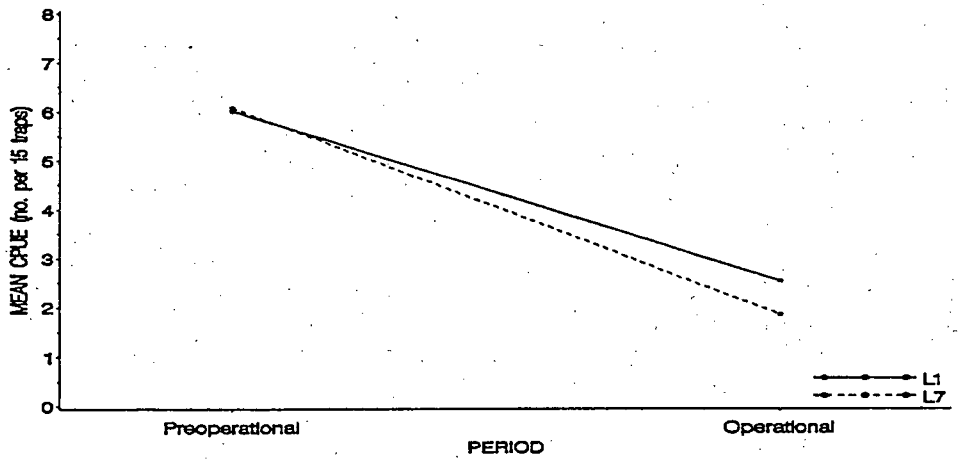


Figure A-20. Comparisons between stations of the mean catch per unit effort (no. per 15 traps) for legal-sized lobster during the preoperational (1982-1984; 1986-1989) and operational (1991-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table A-23). Seabrook Operational Report, 1994.

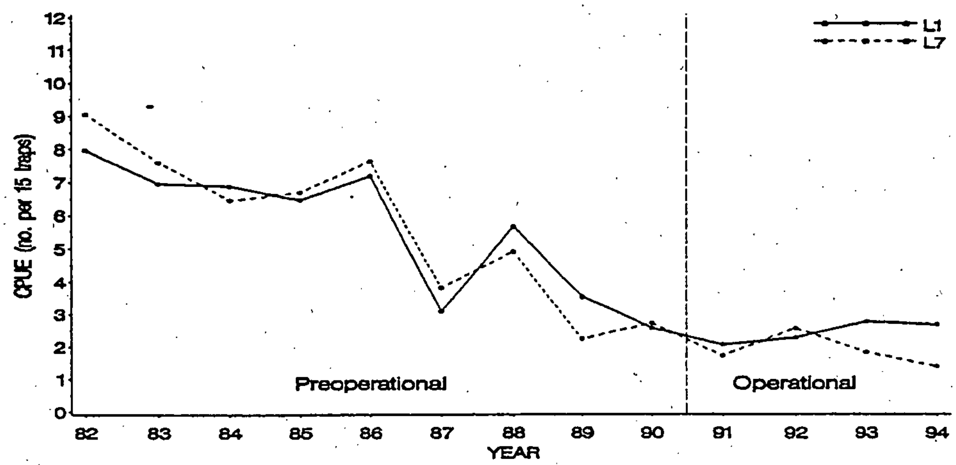


Figure A-21. Annual mean CPUE (no. per 15 traps) for legal-sized lobster, 1982-1994. Seabrook Operational Report, 1994.

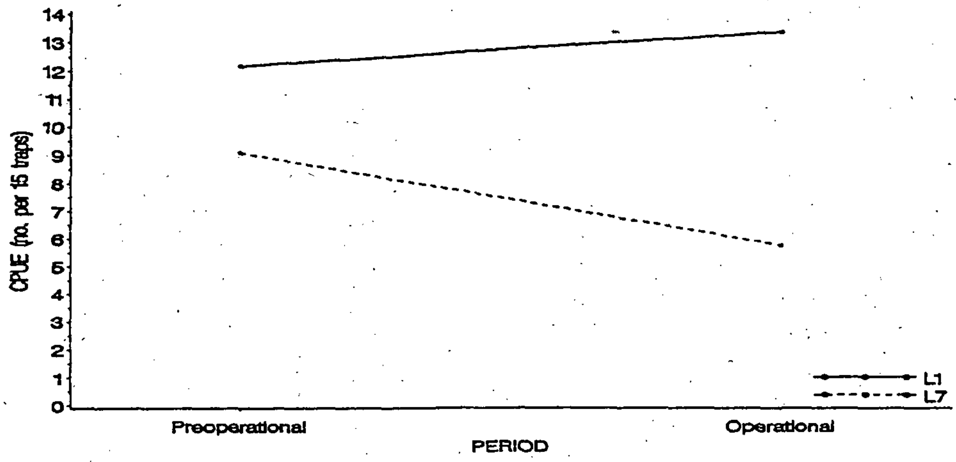


Figure A-22. Comparisons between stations of mean catch per unit effort (no. per 15 traps) for Jonah crab during the preoperational(1982-1989) and operational (1991-1994) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table A-23). Seabrook Operational Report, 1994.

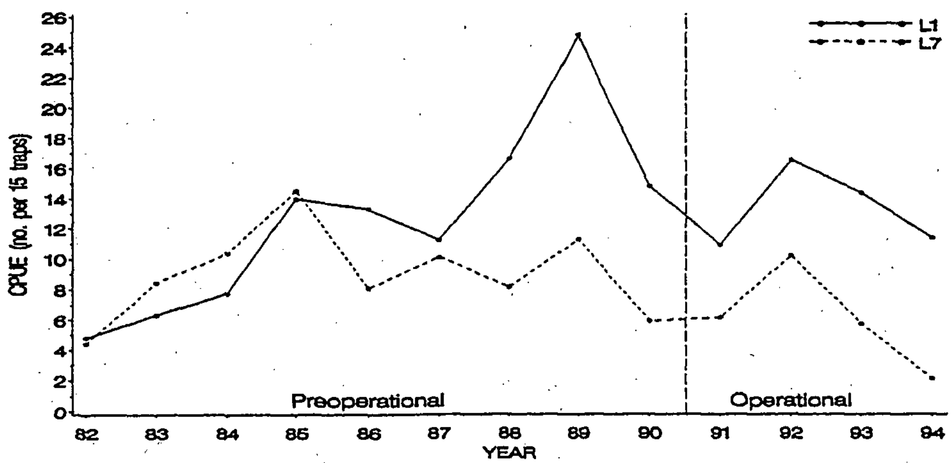


Figure A-23. Annual mean CPUE (no. per 15 traps) for Jonah crab, 1982-1994. Seabrook Operational Report, 1994.

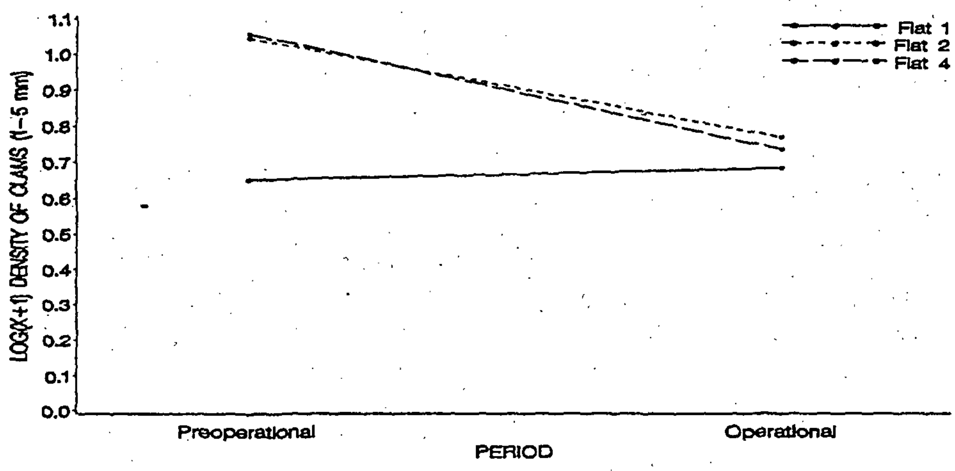


Figure A-24. Comparisons among flats of the mean $\log_{10}(X+1)$ density of clams 1-5 mm (number per square foot) during the preoperational (1974-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Area) of the ANOVA model (Table A-24). Seabrook Operational Report, 1994.

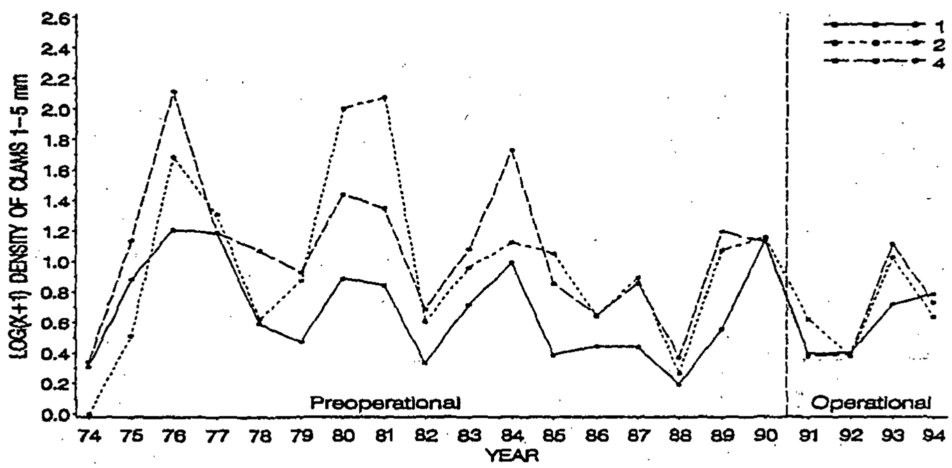


Figure A-25. Annual mean $\log_{10}(X+1)$ density (number per square foot) of clams 1-5 mm, 1974-1994. Seabrook Operational Report, 1994.

in the operational period were within the range of preoperational years suggesting that there was no effect due to the operation of Seabrook Station.

Average density of the 6-25 mm size class decreased significantly between the preoperational and operational periods only at Flat 4 (Figure A-26), Since Seabrook Station became operational in 1990, density of 6-25 mm clams has increased at all flats (Figure A-27). The significant decrease in average density between the preoperational and operational periods is caused by the exceptionally high densities that occurred in the preoperational period between 1976 and 1981, a factor that is unrelated to Seabrook Station's operation.

Average density of the 26-50 mm size class decreased significantly at Flats 1 and 2 between the preoperational and operational periods, while there was no significant difference at Flat 4 (Figure A-28). Densities of 26-50 mm clams were highest in 1979 through 1983, and generally declined until 1994, when densities at all three flats increased (Figure A-29). The significant decline at Flats 1 and 2 reflects the exceptionally high densities observed in 1979 through 1983. Average annual densities during the operational period were within the range of previous years and showed no trend that could be related to Seabrook Station.

The observed trends in clam density in Hampton Harbor show no clear pattern among size classes and flats. With the exception of clams >50 mm at Flats 4 (see Section 10.3.2), average clam density either decreased between the preoperational and operational periods or showed no significant differences.

The ANOVA results for juvenile and adult clam densities reflect highly variable densities during the 20 years study period, where the preoperational averages were elevated by several years of exceptionally high density. The differing trends among size classes and flats in Hampton Harbor seem to indicate that factors that may operate on smaller geographic scale such as disease, harvesting and natural variations in settlement, may be the primary causes of the observed differences in clam densities.

The operation of Seabrook Station has the potential to affect soft-shell clam densities either through entrainment of larvae, or through cumulative impacts on spat and adults in the estuary (Section 1.0, Table 1-1). Seabrook Station is not affecting larval densities as shown by the non-significant interaction term for both the mixed and fixed effects models (Table A-24). Furthermore, if larval entrainment resulted in reduced recruitment in Hampton-Seabrook estuary, it would be apparent in an area-wide decrease. Clam density for most size classes was highest in the late 1970s and early 1980s. The decline from these peaks began in the mid 1980s and continued into the operational period. This decline cannot be attributed to plant operation because it began prior to plant start up.

10.0 DISCUSSION

The purpose of this study was to evaluate the use of two types of Before-After/Control-Impact (BACI) ANOVA or statistical models for the Seabrook Environmental Studies monitoring program. The objective of the monitoring program is to determine if there has been any adverse impact to the balanced indigenous population in the vicinity of Seabrook Station as a result of the Station's operation. The models were evaluated in two ways:

- appropriateness, given the study's hypothesis, sampling design and characteristics of the data collected

- effectiveness in detecting biologically meaningful changes related to Station operation

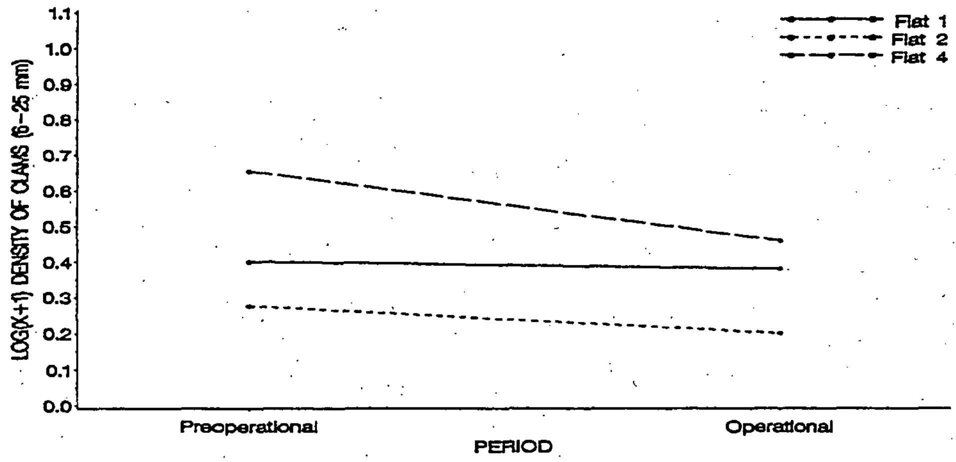


Figure A-26. Comparisons among flats of the mean $\log_{10}(X+1)$ density of clams 6-25 mm (number per square foot) during the preoperational (1974-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Area) of the ANOVA model (Table A-24). Seabrook Operational Report, 1994.

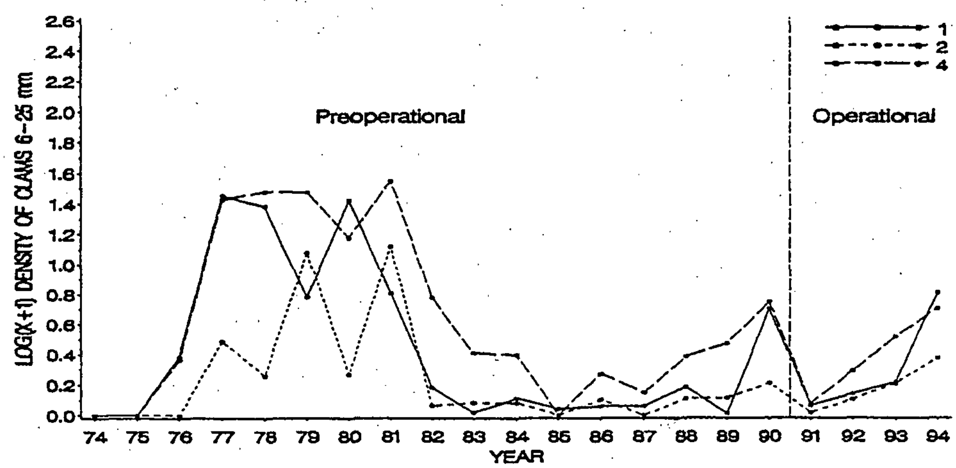


Figure A-27. Annual mean $\log_{10}(X+1)$ density (number per square foot) of clams 6-25 mm, 1974-1994. Seabrook Operational Report, 1994.

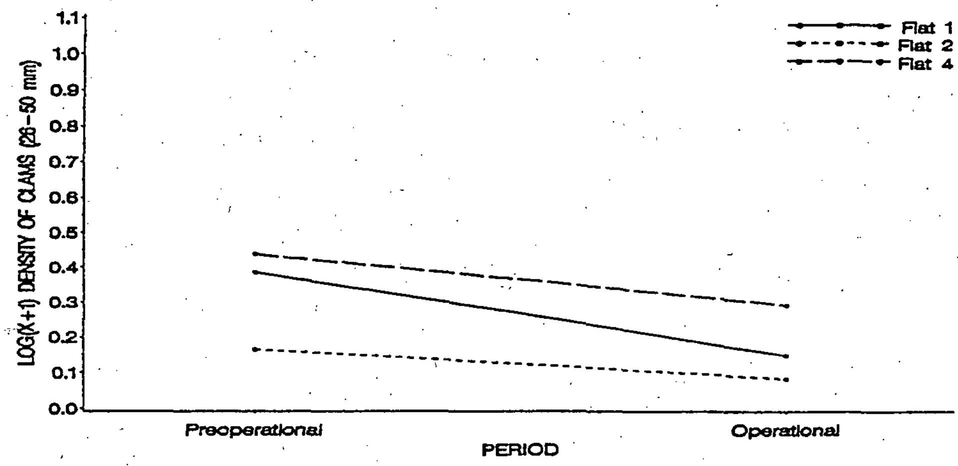


Figure A-28. Comparisons among flats of the mean $\log_{10}(X+1)$ density of clams 26-50 mm (number per square foot) during the preoperational (1974-1989) and operational (1990-1994) periods for the significant interaction term (Preop-Op X Area) of the ANOVA model (Table A-24). Seabrook Operational Report, 1994.

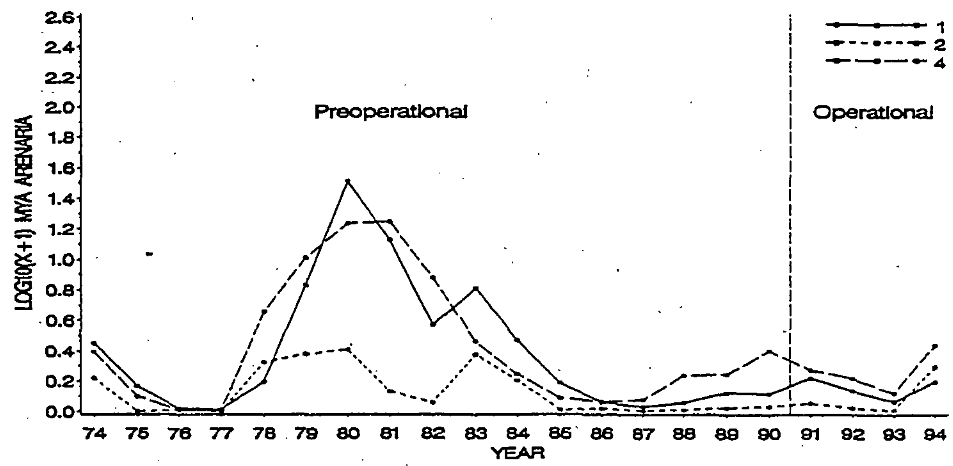


Figure A-29. Annual mean $\log_{10}(X+1)$ density (number per square foot) of clams 26-50 mm, 1974-1994. Seabrook Operational Report, 1994.

TABLE A-24. COMPARISON OF ANOVA RESULTS BETWEEN THE NEW MIXED MODEL AND THE OLD FIXED MODEL FOR *MYA ARENARIA* LARVAL, SPAT, JUVENILE AND ADULT DENSITIES DURING PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1994.

MYA ARENARIA LIFESTAGE	STATION/FLAT	SOURCE OF VARIATION	F FOR MIXED MODEL (new)	F FOR FIXED MODEL (old)	MULTIPLE COMPARISONS[h] (in decreasing order)
larvae[a]	NEARFIELD (P2, P5)	Preop-Op[c,d]	17.67 NS	14.01**	
	FARFIELD (P7)	Station[e]	non-est[g]	1.13 NS	
		Preop-Op X Station[f]	0.02 NS	0.03 NS	
	HAMPTON HARBOR				
1-5 mm[b] young-of-the-year	1, 2, 4	Preop-Op	0.60 NS	23.60***	
		Area	2.21 NS	23.17***	
		Preop-Op X Area	3.07 NS	10.09***	4Pre 2Pre 2Op 4Op 1Op 1Pre
6-25 mm[b] spat	1, 2, 4	Preop-Op	0.24 NS	11.28**	
		Area	23.44 NS	39.04***	
		Preop-Op X Area	0.47 NS	3.44*	4Pre 4Op 1Pre 1Op 2Pre 2Op
26 -50 mm[b] juvenile	1, 2, 4	Preop-Op	1.09 NS	79.67***	
		Area	4.78 NS	62.60***	
		Preop-Op X Area	1.76 NS	8.95***	4Pre 1Pre 4Op 2Pre 1Op 2Op
>50 mm[b] adult, legal	1, 2, 4	Preop-Op	0.40 NS	41.53***	
		Area	1.22 NS	117.68***	
		Preop-Op X Area	31.94***	85.64***	4 Op 1 Op 1 Pre 4 Pre 2 Pre 2 Op
	NEARFIELD/FARFIELD				
1-12 mm[b]	Hampton Harbor	Preop-Op	2.44 NS	1.01 NS	
	Plum Island Sound	Area	4.03 NS	6.11*	
		Preop-Op X Area	0.54 NS	1.51 NS	

[a]Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1988, 89 and op = 1991-94.
[b]For Hampton Harbor Survey preop = 1974-89 and op = 1990-94. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-94.
[c]Commercial operation began in August, 1990, therefore the operational period includes 1990 for spat, juveniles, and adults, but not for larvae.
[d]Operational versus preoperational period regardless of area.
[e]Station or flat, regardless of year or period.
[f]Interaction of main effects.
[g]F-value non-estimable due to a negative denominator mean square.
[h]Underlining signifies no significant differences among least square means at alpha ≤ 0.05.

NS = Not significant (p>0.05)
* = Significant (0.05≥p>0.01)
** = Highly significant (0.01≥p>0.001)
*** = Very highly significant (0.001≥p)

Appropriateness

A statistical method should be chosen prior to analysis based on the assumptions of the analysis, the study hypothesis, the sampling design, and data characteristics. The statistical model used in the 1990 through 1993 Seabrook Operational Reports was termed a "fixed effects" model because all variables were classified as fixed. The selection of the mixed model for the 1994 Seabrook Operational Report was based on independent reviews of the previously used fixed effects model and recent biostatistical literature (Underwood 1994). This was done to stay current with and utilize the most appropriate techniques in evaluating the monitoring results. The reviews suggested that the data collected in the Seabrook Monitoring Program more closely met the assumptions of a mixed effects model than the previously used fixed effects model. The mixed effects model treats station location and time periods as random variables, representative of more than the specific times and places where samples were collected. This "mixed" model allows the results to be extrapolated over the time periods and areas that the samples represent. Therefore, the mixed effects model is the more appropriate model to use to determine potential impacts from the operation of Seabrook Station. In the fixed effects model variables related to time and space were considered fixed points, and conclusions can be made only with regard to specific times and locations.

Effectiveness

ANOVA is a statistical tool used to help interpret biological trends. The BACI model was specifically designed to detect potential environmental impacts by segregating one term, the Preop X Station (preoperational-operational period, nearfield by farfield station) interaction term. A statistically significant interaction term can mean one of two things:

1. A potential impact has occurred

2. An impact has actually not occurred, a situation called the Type II error.

The Type II error is difficult to measure (Sokal and Rohlf 1981). The fixed effects model, which was used historically, identified 20 significant interaction terms of the 98 models tested; the mixed model identified 8 (Table A-25). Each significant interaction term was evaluated in terms of the natural variability and long term trends of the parameter tested. In no instance did the trends related to the significant interaction terms appear to be biologically meaningful. In almost all cases, trends during the operational period at the nearfield station were within the range of previous years; furthermore, trends at the nearfield station generally paralleled those at the farfield stations. In many cases, trends occurring during the operational period were part of a long term cycle that began prior to plant operation. These results indicate that use of the fixed effects model resulted in additional significant interaction terms that, upon investigation, did not indicate an adverse effect from Seabrook Station; this indicated a potentially higher Type II error with the model. This result is consistent with the use of a fixed effects model where conclusions can only be made about specific times and places. In no case did a significant difference from either the fixed effects or the mixed effects model point to a deleterious effect on the local biological community as a direct result of plant operations.

TABLE A-25. NUMBER OF SIGNIFICANT INTERACTION TERMS (PREOP-OP X STATION) INDICATED BY THE MIXED EFFECTS (NEW) MODEL AND THE FIXED EFFECTS (OLD) MODEL.
SEABROOK OPERATIONAL REPORT, 1994.

REPORT SECTION	NUMBER OF SIGNIFICANT INTERACTION TERMS (mixed effects model)	NUMBER OF SIGNIFICANT INTERACTION TERMS (fixed effects model)
2.0 Water Quality	1	0
3.0 Phytoplankton	0	0
4.0 Zooplankton		
Microzooplankton	0	0
Bivalve Larvae	0	0
Macrozooplankton	1	0
5.0 Finfish	3	3
6.0 Macrobenthos		
Macroalgae	0	2
Macrofauna	1	6
7.0 Surface Panels	0	2
8.0 Epibenthic Crustaceans	1	3
10.0 *Mya arenaria*	1	4
TOTAL	8	20

11.0 LITERATURE CITED

Green, R.H. 1979. Sampling Design and Statistical Methods. John Wiles & Sons, New York. 257 pp.

Lorda, E. and D. Miller. 1994. Extended ANOVA model proposed for assessing potential Seabrook Station impacts using the current data base generated under the BACI experimental design. Northeast Utilities Services Company. Prepared for North Atlantic Energy Services Company.

Snedecor G.W. and W.G. Cochran. 1967. Statistical methods. Sixth edition. University of Iowa Press, Ames, Iowa.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry, 2nd edition. W.H. Freeman and Company, San Francisco. 859 pp.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications, 4(1):3-15.

________. 1981. Techniques of analysis of variance in experimental marine biology and ecology. Annual Review of Oceanography and Marine Biology 19:513-605.

Winer, B.J. 1971. Statistical principles in experimental design. Second edition. McGraw-Hill, New York. 907 pp.