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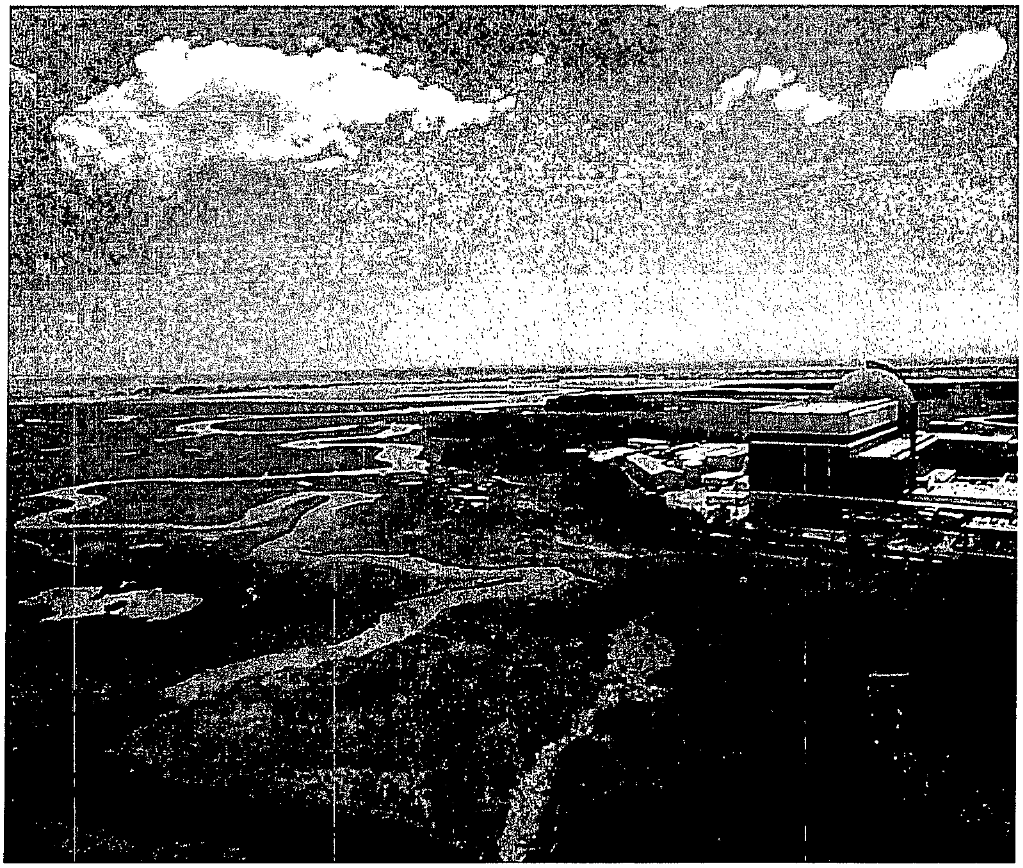
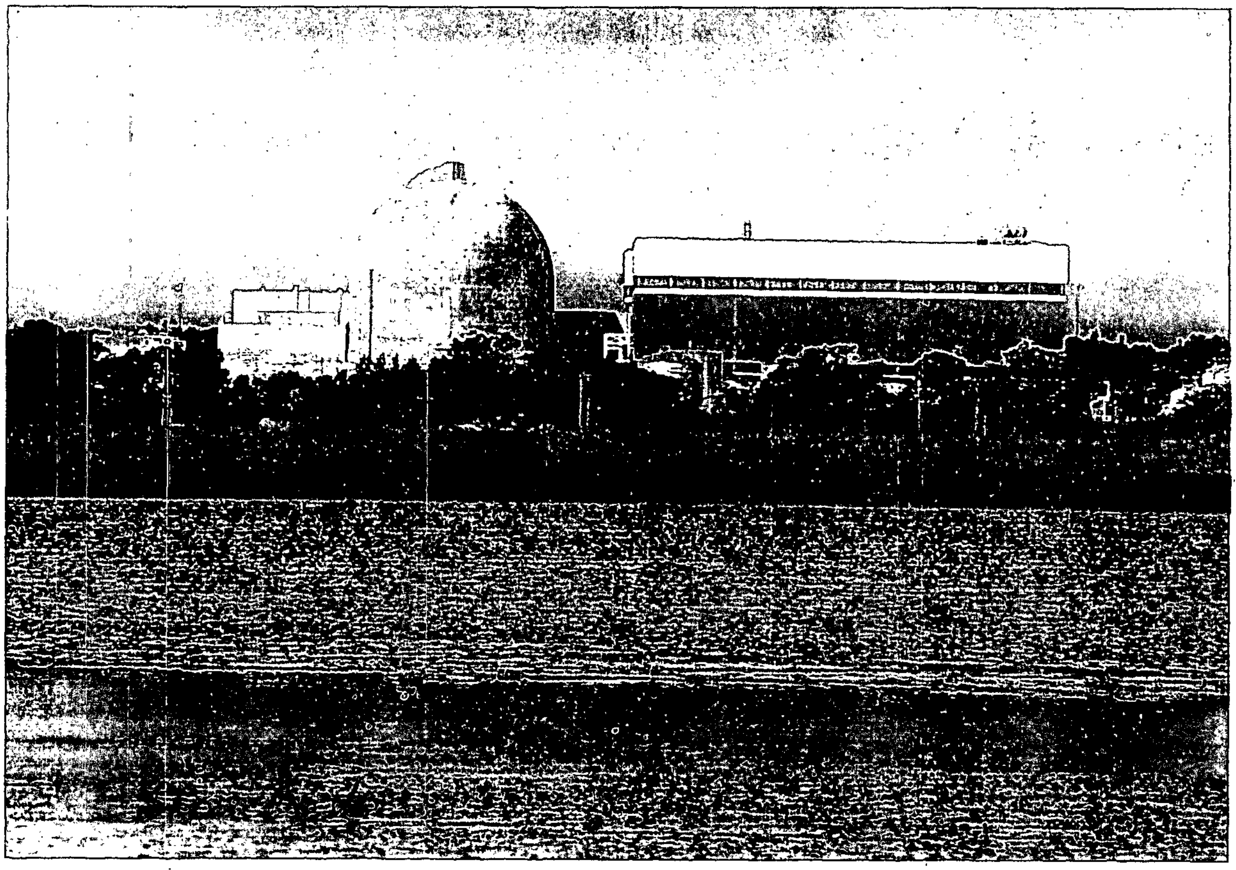


Attachment 2

Vol. 4

Seabrook Station
1996 Environmental Monitoring
in the Hampton - Seabrook Area



A Characterization Of Environmental Conditions

North Atlantic

SEABROOK STATION 1996 ENVIRONMENTAL MONITORING IN THE HAMPTON-SEABROOK AREA
A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS DURING THE OPERATION OF SEABROOK STATION

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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 has 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). Because of the surface to mid-water location of the plume, 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 impact is quantified 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

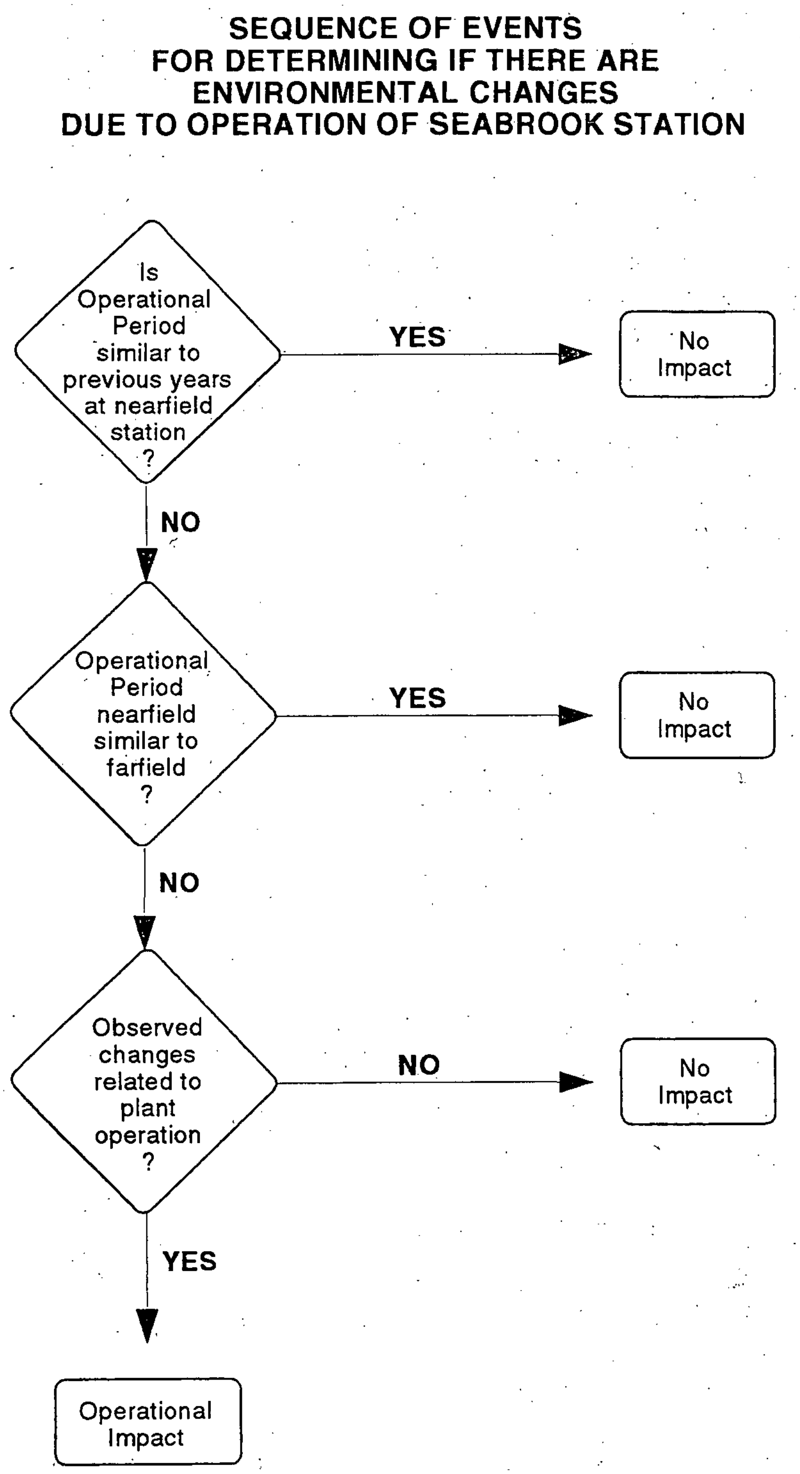

Figure 1-1. Sequence of events for determining if there are environmental changes due to the operation of Seabrook Station. Seabrook Operational Report, 1996.

Table 1-1. Summary of Biological Communities and Taxa Monitored for Each Potential Impact Type. Seabrook Operational Report, 1996.

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	x
		Cancer crab larvae	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

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 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 are 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 not been affected. Analysis of variance (ANOVA) was an important 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 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 potential 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).

A mixed model, randomized block design ANOVA was used with the following 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 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. A significant interaction term indicated a significant difference occurred during the operational period that was restricted to only one of the areas (nearfield or farfield). 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.

A change in the community composition, or abundance of a selected species that did not occur at all stations leads to the following questions:

1. Is there a mechanism for a potential plant impact?

2. What species (in community analyses) are responsible for the observed change?

3. Did the change begin prior to the initiation of plant operation, or is it possibly part of a long-term trend?

4. Is the change possibly caused by an unrelated environmental variable?

5. What is reported in the recent literature or by investigators in the region?

Results of further investigations of significant differences in community composition or a single species' abundance, density or biomass are developed by the section author or principal investigator, then reviewed by a peer with technical expertise in the area of investigation, then reviewed by the Project Manager and Corporate Officer. Following these reviews, the report sections are reviewed by NAESCo, Northeast Utilities Millstone Laboratory, and the Ecological Advisory Committee.

All sources of variation, except Preop-Op, were considered random because they represented a small fraction of all the possible times and locations of sampling (Underwood 1994). Preop-Op was considered a fixed variable because there were only two possible levels (preoperational and operational) and both levels were sampled. The use of both random and fixed variables makes the model a "mixed" effects model, as opposed to a "fixed" model ANOVA where all sources of variation are considered fixed. Further discussion of the differences between the mixed and fixed effects model are found in Appendix A of NAI (1995).

Results from both the mixed and fixed ANOVA models were presented in 1996. The results of the mixed model are presented in the main body of the report because it is considered more appropriate for our study design (Underwood 1994). The results of the fixed model ANOVA are presented in Appendix A of this report for comparison with the mixed model.

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, a consistent sampling regime and the addition of a farfield station provided 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. The plant continued at full operation in 1995 except for short outages in June and November. With the exception of short outages in January and February, the plant operated nearly continuously in 1996. Monthly characteristics of the Circulating Water System operation throughout 1990-1996 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 nutri-

Table 1-2. Monthly Characteristics of Seabrook Operation for the Period 1990 Through 1996. Seabrook Operational Report, 1996.

	Days of Circulating Water System Operations							Average Daily Flow (mgd)						
Month	1990	1991	1992	1993	1994	1995	1996	1990	1991	1992	1993	1994	1995	1996
Jan	31	31	31	31	31	31	31	324	584	585	587	566	576	570
Feb	28	28	29	28	28	28	29	564	580	578	587	589	572	507
Mar	31	31	31	31	31	31	31	563	580	581	580	573	572	573
Apr	30	30	30	30	30	30	30	563	581	576	579	352	573	577
May	31	31	31	31	24	31	31	562	581	581	582	188	625	637
Jun	30	30	30	30	25	30	30	563	578	593	582	171	662	686
Jul	31	31	31	31	31	31	31	582	535	593	578	331	685	689
Aug	31	21	31	31	31	31	31	588	253	583	579	681	687	691
Sep	30	26	29	30	30	30	30	588	257	314	574	696	686	691
Oct	31	31	24	31	31	31	31	590	552	159	574	690	685	678
Nov	30	30	30	30	30	21	30	590	590	566	612	692	287	647
Dec	31	31	31	31	31	31	31	589	591	563	608	628	486	599

ents (total phosphorus, orthophosphate, nitrate, nitrite, and ammonia).

Potential impacts to water quality 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 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 warmer during the operational period, but these differences were consistent at all stations. There were also significant differences among stations that were consistent between the preoperational and operational periods. The discharge station had higher temperatures than the intake station, which in turn was higher than the farfield station. This consistency between periods and among stations indicated that the operation of Seabrook Station has not significantly affected surface or bottom water temperatures in the study area. Mean surface water temperatures decreased in 1996 compared to 1995, ending the increasing trend that began in 1993. Bottom water temperature in 1996 increased compared to 1995.

Seasonal patterns of mean surface and bottom salinity were similar between preoperational and operational periods. There were no significant differences between the preoperational and operational periods or among stations for bottom salinity. Surface salinity decreased significantly between the preoperational and operational periods at both the intake and discharge areas, but there were no changes at the farfield stations, indicating a potential plant effect. The small decreases in mean salinity (0.3 to 0.2 ppt) were statistically significant, but an order of magnitude less than seasonal variations observed over the course of a single year. There is no reasonable mechanism by which the withdrawal of bottom water from the intake area, and its subsequent release as heated effluent into the discharge area, could reduce surface salinity in the intake and discharge areas. The water masses in the intake and discharge areas are essentially identical and the salinity of this water mass cannot be changed by passage through the plant.

Surface and bottom dissolved oxygen concentrations exhibited a seasonal pattern in 1996 that was similar to previous years. There were no significant differences between the preoperational and operational periods, or among stations for bottom dissolved oxygen. Surface dissolved oxygen levels decreased at all stations between the preoperational and operational periods, but the decrease was smaller at the discharge station, indicating a potential plant effect. However, the observed changes are the opposite from those that might be expected from a thermal discharge. A potential plant effect might be indicated by a significantly <u>larger</u> decrease in dissolved oxygen at the discharge station relative to the other stations, as heated effluent reduces the oxygen content of the surrounding waters.

There were no significant differences between the preoperational and operational periods or among stations, for nitrate, nitrite, orthophopsphate, total phosphate, and ammonia.

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, with the exception of surface salinity and dissolved oxygen, were consistent between nearfield and farfield stations, indicating that the chemical and physical environments in the study area are dominated by larger regional trends.

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 was 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; 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 the operational period showed seasonal patterns that were similar to the preoperational years. On average, diatoms (Bacillariophyceae) dominated the phytoplankton assemblage during January through February and June through December during the preoperational and operational periods, while the yellow-green alga *Phaeocystis pouchetti* dominated during March and April. This pattern of seasonal succession in phytoplankton is well documented in other northern temperate waters. The seasonal pattern of succession and abundance was slightly different in 1996, as diatoms were dominant in all months except June and September. The average abundance of phytoplankton in 1996 was higher than the preoperational mean at all stations, but similar to the annual means from 1993-1995. Despite these minor differences in 1996, there were no significant differences in phytoplankton abundance among stations or between the preoperational and operational periods, indicating no effect due to station operation.

During both the preoperational and operational periods, the monthly chlorophyll *a* concentrations exhibited March through May, and October peaks. This pattern was similar in 1996, with the exception that the spring peak occurred earlier in February and March. There were no significant differences in chlorophyll *a* concentrations between the preoperational and operational periods, or among stations. 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 period, and there were no significant differences between stations. During the operational period, both spring and fall peaks were larger than the preoperational period but followed the same general pattern. In 1996, *S. costatum* abundances generally followed historic patterns, except in May when mean abundances were higher than those typically observed.

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 the operational period, PSP was less prevalent, with outbreaks occurring occasionally only in the spring. No PSP was observed in 1996. Throughout the operational study period, there were no outbreaks of PSP 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. A significant Preop X Station interaction term was detected for the copepodites of *Eurytemora* sp. Record high abundances in 1983 contributed to the observed operational period decline that was more pronounced at the farfield station. No significant changes were observed in adult abundances suggesting that the population of *E. herdmani* is unaffected by the operation of Seabrook Station. Abundances of the other microzooplankton selected species were generally similar among stations and between operational periods.

Differences in the bivalve larvae community were detected between the preoperational and operational periods. Typically the early-spring assemblage, characterized by low numbers of *Hiatella* sp., changes to a late-spring assemblage where *Hiatella* sp. predominates along with low numbers of *Mya truncata* and *Mytilus edulis*. In most years of the operational period, a new assemblage characterized the transition between early and late-spring, characterized by moderate numbers of *Hiatella* sp. As this new assemblage occurred at both nearfield and farfield stations, it is unrelated to Seabrook Station. MANOVA results indicated that although significant differences in species abundances occurred during the operational period, they occurred at all stations, indicating an area-wide change. The abundance of the selected species, *Mytilus edulis* was at a record high level in 1996, but no difference was detected between the preoperational and operational periods.

Entrainment collections provide a measure of the actual number of organisms directly affected by Station entrainment. *Anomia squamula* replaced *Mytilus edulis* as the most commonly entrained bivalve larva in 1996. The number of bivalve larvae entrained in 1996 was higher than in any previous year, a result of high abundances of dominants *M. edulis* and *A. squamula*. There was no indication that entrainment within the CWS has affected the balanced indigenous bivalve larvae community in the nearshore waters.

Actual entrainment estimates differed from predicted entrainment estimates developed in the late 1970s (NAI 1977). Entrainment of soft-shell clam (NAI 1977) is much lower than predicted for two reasons. Estimates were based on unusually high larval abundances; actual levels are much lower than predicted. In addition, the cooling water system pumping rates are lower than predicted for one-unit operation. Predictions of larval blue mussel entrainment were within the range of actual annual entrainment.

To better understand community dynamics, the macrozooplankton was divided into two components. A holoplankton and meroplankton component was defined as organisms that spend their entire or a distinct portion of their life in the water column. Demersal plankton, the other component, was defined as organisms that live on or near the bottom, including those suspended by currents (tychoplankton), and benthic organisms that actively migrate into the water column. Preoperationally, the community composition of the holoplankton and meroplankton was variable from February through April. During the operational period, this period of variability shifted to January and February, followed by a consistently recurring community in March and April.

MANOVA detected differences between periods for the holoplankton and meroplankton abundance. These differences were consistent among stations indicating area-wide affects. Of the selected species, significant Preop X Station interaction term was detected for the adult *Calanus finmarchicus*. Abundances decreased at all stations in the operational periods, but the decrease at the control station (P7) was greater. The relative relationship among the three stations was similar in both preoperational and operational periods in terms of rank and changes in magnitude (except 1993). Differences in the abundance of adults had no effect on the copepodite stages of *C. finmarchicus*. Abundances of the other selected species were similar between the preoperational and operational periods.

The demersal zooplankton community composition showed no differences between the preoperational and operational periods. The demersal assemblage varied among stations. The demersal selected species, *Neomysis americana* showed no significant differences between the preoperational and operational periods.

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, with the exception of larval American sand lance, changes in density were consistent between the preoperational and operational periods at all stations, indicating no effect due to the operation of Seabrook Station. Density of larval American sand lance was not significantly different between the preoperational and operational periods at Stations P5 and P7, but increased at Station P7. Examination of the annual time series indicated that the stations generally followed the same trends among years. This consistency among stations suggests that the changes in density are unrelated to plant operation.

Entrainment of eggs in 1996 was the third highest recorded and higher than the 1995 estimate, the only other year with sampling throughout 12 months of the year. The most numerous eggs entrained in 1996 were Atlantic mackerel, hake, and cunner/yellowtail flounder. These three groups of eggs were also among the most numerous in 1995, the only other comparable year. Entrainment of larvae was the highest recorded to date. The most numerous larvae entrained in 1996 were Atlantic seasnail, rock gunnel, silver hake, and hake. Entrainment of silver hake and hake was greatly increased compared to 1995, possibly as result of increased densities of these larvae in the nearshore area.

Actual entrainment of eggs and larvae at Seabrook Station was lower than predictions of entrainment made in the 1970s (NAI 1977), which were based on peak egg and larval densities in the nearfield area and the maximum pumping rate for one unit at Seabrook Station. Egg and larval entrainment densities were much lower than offshore densities, in part a result of the midwater intake location. Actual pumping rates were slightly lower than predicted pumping rates, resulting in lower entrainment than expected.

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, Atlantic mackerel, pollock and blueback herring 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. Atlantic herring and Atlantic mackerel biomass have increased greatly in the Gulf of Maine and Georges Bank.

The geometric mean CPUE of demersal fish at all stations combined increased in 1996 compared to 1995, but remained well below levels in the preoperational period. Dominant demersal fish in the operational period were longhorn sculpin, winter flounder, skates, and hakes. Catches of nearly all species declined from the preoperational to the operational period, particularly for the yellowtail flounder. 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 decreases in rainbow smelt and winter flounder abundance began in the preoperational period and probably are not due to plant operation.

The geometric mean CPUE for estuarine fish caught at all stations increased during 1996, continuing a trend that began in 1992. Average catches were less for the operational period than observed during the preoperational period, a result of diminished catches beginning in 1987. 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 1996 an estimated 26,794 fish, and 31 lobsters were impinged on the travelling screens at Seabrook Station. Rainbow smelt was the most common fish impinged, followed by alewife, grubby, and northern pipefish. The majority of impingement in 1996 occurred in October and November, during strong northeast storms. Impingement in 1996 increased compared to 1995, probably due to increased storm activity. The design of the Seabrook Station offshore intake with a mid-water intake fitted with a velocity cap has apparently 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

Horizontal rock ledge is the predominant benthic habitat in the vicinity of Seabrook Station's intake and discharge. These rocky surfaces support a diverse community of attached macroalgae and macrofauna. Studies were implemented to identify the species inhabiting nearby intertidal and subtidal rock surfaces in nearfield and farfield control areas. Preoperational studies described temporal and spatial patterns in species abundance and identified physical and biological factors influencing observed variability. Operational studies have focused on evaluating any changes in the distribution and abundance in the macrobenthic community and its dominants in light of the operation of Seabrook Station. Possible impacts include temperature-related changes in areas potentially exposed to the buoyant thermal plume, the intertidal and shallow-subtidal stations. Thermal impacts would be unlikely at deeper stations; however, suspended solids and entrained organisms in the discharge plume could potentially increase turbidity and sedimentation, adversely affecting benthic organisms.

<u>Potential thermal Effects</u>

Hydrodynamic modeling and subsequent field verification studies have indicated that intertidal locations showed no temperature increase related to Seabrook Station; shallow subtidal areas showed temperature increases of <1°F (Padmanabhan and Hecker 1991). Intertidal and shallow subtidal community composition was stable throughout the monitoring period. Of the community parameters tested (total biomass, total abundance, number of taxa), only one showed a change between the preoperational and operational periods that differed between nearfield and farfield areas. Number of algal taxa in the intertidal zone decreased between periods, and the decrease was greatest at the farfield station. The decreasing trend at both stations began prior to the initiation of plant operation, suggesting it was unrelated to Seabrook Station.

Of the selected species studied in the intertidal zone, the dominant algae, *Chondrus crispus*, and dominant faunal taxon, Mytilidae, showed no significant change in abundance throughout the study period. Dominant fucoid species *Ascophyllum nodusum* and *Fucus vesiculosis* showed inconsistency among stations between periods. These shifts in abundance began prior to plant startup and were apparently not related to plant operation.

In the shallow subtidal benthic community, no changes have occurred that could be related to the operation of Seabrook Station. Community parameters, including the number of faunal taxa and total abundance, and number of algal taxa and total biomass, as well as results of community analysis, showed no significant changes between periods. No significant changes in abundance of selected dominant faunal species, in the biomass of dominant understory alga *Chondrus crispus*, or in the frequency of dominant kelp species *Laminaria saccharina* occurred during the operational period. Frequency of the subdominant kelp species *Laminaria digitata* showed differing trends among stations and between periods, decreasing at the nearfield station and showing no change at the farfield station. There was no apparent relationship between physical factors or density of its dominant predator, the green sea urchin *Strongylocentrotus droebachiensis*. Additional studies will be undertaken to investigate the decrease in *Laminaria digitata* in the shallow subtidal zone and the potential role of Seabrook Station.

<u>Potential Turbidity Effects</u>

Community structure and abundance/biomass of dominant species in the mid-depth zone have shown few changes during the operation of Seabrook Station. Community parameters including number of algal taxa, number of faunal taxa, total algal biomass, and total faunal density, showed no change between periods. Algal community composition in the mid-depth zone was stable throughout the operational period. The mid-depth macrofauna community during the operational period was similar to the preoperational period with a few exceptions. Collections at two stations (intake station B16 in 1996 and farfield station B31 in 1990 and 1996) had lower numbers of the dominant taxon Mytilidae and higher numbers of subdominant amphipod *Caprella septontrionalis*, creating a unique assemblage. The occurrence at both nearfield and farfield stations suggests that the change is unrelated to Seabrook Station.

Most of the dominant macrofaunal and macroalgal taxa showed no significant change in abundance or biomass during the operational period. The kelp *Laminaria digitata*, a subdominant in the shallow subtidal zone, showed a significant decrease in both frequency and percent cover between periods. The decrease, which began prior to plant operation, intensified during the operational period and was more substantial at the nearfield station, suggesting a potential plant effect. The decrease coincided with increases in densities of its dominant predator, the green sea urchin *(Strongylocentrotus droebachiensis)*, but the relationship was not statistically significant. Additional studies will be done in 1998 to further investigate changes in *Laminaria digitata*.

Macrobenthic deep water communities have remained stable throughout the preoperational and operational periods. The macrobenthic community structure, number of taxa, and total density has shown no change between periods. The macroalgal community also showed no change in community parameters, with one exception. Collections at nearfield station B04 in 1996 contained higher than typical levels of *Phyllophora/Coccotylus* and lower than typical levels of *Ptilota serrata* in comparison to previous years, making it more similar to deep intake station B13.

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 1996 continued the trends observed in 1991 through 1995. Lobster larvae densities during 1996 were higher than during the preoperational period (1988-1989) at all stations. There were no significant differences between preoperational and operational periods, or among the three stations during the 1988-1996 monitoring period. Monthly trends were similar to those observed in previous years. Increases in densities during 1996 were due mainly to increases in Stage IV and Stage I 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.

Total CPUE for lobster in 1996 was higher than the preoperational and operational means, and was the highest observed during the entire study period. CPUE declined between the preoperational and operational periods at the farfield station , but increased at the nearfield station, indicating a potential plant effect. The differing trends in CPUE between the two stations may in part be related to a large increase in lobstering activity in the nearfield area, which may be providing a food source for sublegal lobsters. The monthly trend of CPUE in 1996 was similar to that observed during the preoperational period. Legal-sized lobsters in 1996 were 4% and 3% of the total catch at both the nearfield and farfield stations respectively, slightly lower than the preoperational averages of 8% and 7%. 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 1996, 31 lobsters were impinged in the Station's Circulating Water System. A total of 118 lobsters have been impinged since the station began operation in 1990. The current level of impingement does not pose a serious threat to the indigenous population.

Abundances of *Cancer* spp. larvae in 1996 were similar to the preoperational and operational periods at all stations. The average density during the five-year operational period was not significantly different from the preoperational average, and there were no significant differences among stations. The 1996 mean CPUE for Jonah crab was lower than the preoperational and operational periods at both the nearfield and farfield stations. CPUE of Jonah crab was not significantly different between the preoperational and operational periods and there were no significant differences between stations. In 1996, CPUE of rock crab was lower than the preoperational and operational averages at the nearfield station while the opposite occurred at the farfield station. Despite these differences in 1996, there were no significant differences between periods, or between stations for rock crabs. The relationship in rock crab CPUE between stations was consistent between the preoperational and operational periods, indicating no effects due to Seabrook Station. Rock crabs have been less prevalent than Jonah crabs throughout the study area, probably because of their preference for sandy substrate, which is rare in the study area.

<u>Soft-Shell Clam</u>

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 have been 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 1996 were in June and were higher than the preoperational average. There were no significant differences in mean larval abundance between the preoperational and operational periods or among stations.

Mean density of young-of-the-year (YOY) clams (1-25 mm) in 1996 at all flats was relatively high compared to the historical average. Density of yearling clams (26-50 mm) in 1996 decreased slightly compared to 1995 and was within the range of previous years. Density of adult clams (>50 mm) in 1996 was the highest observed in the operational period, and among the highest observed since 1974. There were no significant differences in mean density between the preoperational and operational periods for YOY and yearlings, indicating that the operation of Seabrook Station has not affected the density of these lifestages. Density of adults was significantly greater during the operational period, but this is probably due to the closure of the flats in 1989, and the limited harvesting that has taken place since 1994.

In 1996, the mean density of seed clams (1-12 mm) in Hampton Harbor (nearfield area) was much greater than the preoperational and the operational mean. Densities of seed clams in 1996 in Plum Island Sound (farfield area) were lower than the preoperational and operational means. There were no significant differences in seed clam density between the preoperational and operational periods or between areas. This consistency across periods and stations suggests that settlement has been unaffected by Seabrook Station.

Sarcomatous neoplasia is a lethal form of leukemia in soft-shell clam. Neoplasia was prevalent at Flats 1 and 2 and absent from Flat 4 in 1986 and 1987. By 1996 neoplasia was present at all three flats.

It is difficult to attribute the differing trends in mean YOY, spat, juvenile and adult clam densities to the operation of Seabrook Station. The two possible impacts of station operation include entrainment of larvae (see bivalve larvae summary) and the discharge from the settling basin. Larval density showed no significant differences between periods. In addition, densities of larvae appear unrelated to sets of YOY. Therefore, removal of larvae through entrainment into the cooling water system of the plant has had no apparent effect on YOY clam density. The discharge of the settling basin ceased in April of 1994, and is not likely to have affected clam densities in 1996. The differences in clam density were probably due to a wide variety of physical and biological variables that include recreational harvesting and the presence of neoplasia.

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SUMMARY

Water quality data collected in 1996 were similar to those in previous years, with the exception of surface salinity which was the lowest recorded to date. On average, air temperatures in 1996 were slightly cooler than previous years, but surface and bottom water temperatures were slightly warmer than the preoperational and operational period averages. Both surface and bottom water temperatures were significantly warmer in the operational period. However, this increase occurred at both nearfield and farfield stations, and cannot be attributed to the operation of Seabrook Station. There were no significant differences between the preoperational and operational periods, or among stations, for bottom salinity, bottom dissolved oxygen, and nutrients. Salinity at all three stations was among the lowest recorded to date, paralleling a trend observed at Boothbay Harbor.

There was a significant decrease (0.3 to 0.2 ppt) in mean surface salinity at the intake and discharge stations between the preoperational and operational periods, but there was no decrease at the farfield station, resulting in a significant interaction term. There is no reasonable mechanism by which the withdrawal of bottom water from the intake area, and its subsequent release as heated effluent into the discharge area, can reduce surface salinity at the intake and discharge areas. The water masses in the intake and discharge areas are essentially identical, and the salinity of this water mass cannot be changed by passage through the plant.

Surface dissolved oxygen decreased at all stations between the preoperational and operational periods, but the decrease was less at the discharge station, as indicated by the significant interaction term. A potential plant impact might be indicated by a large decrease, relative to the other stations, at the discharge station as heated effluent would reduce the oxygen holding capacity of the surrounding waters. However, the observed changes are the opposite, where the discharge station has higher dissolved oxygen levels compared to the intake and farfield stations. Therefore, the differing patterns in surface dissolved oxygen between the preoperational and operational periods cannot be attributed to plant operation.

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2.1 INTRODUCTION

Water quality data 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 temperature, through the discharge of a heated effluent from the condensers, and the application of sodium hypochlorite as a biofouling control measure. In addition to the offshore sampling, temperature and salinity were recorded weekly at high and low slack tides in Hampton Harbor to characterize conditions in the vicinity of softshell clam and fish seine study sites.

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 discharged to the ocean through a multiport diffuser system approximately 5,500 feet offshore. All discharges are controlled under the Station's National Pollutant Discharge Elimination System (NPDES) Permit issued by the State of New Hampshire and the Environmental Protection Agency (EPA). This permit specifies that the average monthly 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.

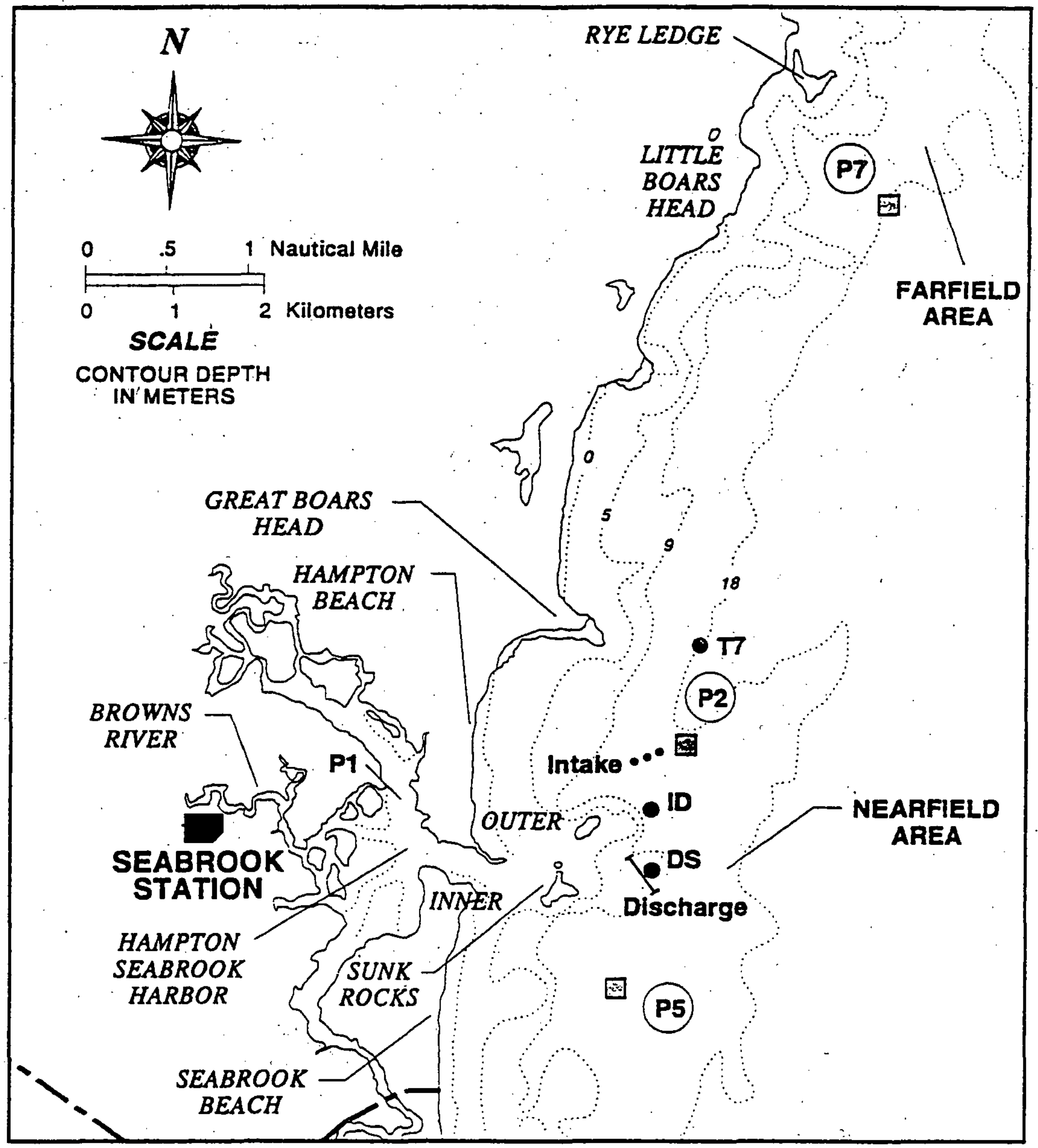
Seabrook Station uses continuous low level chlorination in the circulating and service water systems to control biofouling. Information was gathered through the Chlorine Minimization Program, which assessed the effectiveness of chlorine application in preventing biofouling while using the least amount 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 has 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 has continued to the present; sampling at P5 was interrupted from January 1982 until July



LEGEND

☐ = water quality stations

● = continuous temperature monitoring stations

Figure 2-1. Water quality sampling stations. Seabrook Operational Report, 1996.

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. Beginning in 1995, salinity samples were collected at near-surface (-1 m) and near-bottom (+1 m) depths. Collections were made in wax-sealed glass bottles and analyzed in the lab using a YSI Model 34 S-C-T Meter. During 1996, field temperatures continued to be collected using a YSI Model 33 S-C-T Meter. 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. Continuous temperature data were collected from the discharge (Station DS), and farfield (Station T7) areas at a depth of 0.6 m beginning in August 1990 as part of Seabrook Station's NPDES permit compliance program (Figure 2-1). The monitors were retrieved weekly and the data downloaded to a PC. Water temperatures were continually integrated and recorded over 15-minute intervals. The 15-minute intervals were averaged to produce a daily mean temperature, and the daily mean temperatures were averaged within a month to produce the monthly mean. 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 and in the Hampton-Seabrook estuary. Offshore water quality 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). For both offshore and estuarine stations, seasonal trends were analyzed using monthly arithmetic mean temperatures and salinity, and (for offshore stations) nutrient and dissolved oxygen 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 1996 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 1996 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). Preoperational periods for the different analyses are listed on the appropriate tables and figures; in all cases, the operational period consisted of collections from 1991-1996. 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 for offshore water quality parameters 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-effects ANOVA model was used to test the null hypothesis that spatial and temporal values during the preoperational and operational periods were not significantly ($p>0.05$) 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)), months within year (Month (Year)), and the interaction of station and year within Preop-Op, 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. 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 Offshore Water Quality

2.3.1.1 Physical Environment

Climate

The weather in 1996 was slightly cooler than normal with more precipitation (Boston Globe 1997 and Portland Press Herald 1997). Differences from the long-term monthly means ranged from -5.0 to +5.8°F. Temperatures were below average in March through May, and July through November. Portland also experienced a summer-fall period of below-average temperatures. Both Boston and Portland experienced the year's coldest day in January and the hottest days in July and August.

Precipitation, especially snowfall, was above average in 1996 both in Boston and Portland. After above-average precipitation in January, Boston experienced below-average precipitation during February, March, May, June, August and November. Precipitation was notably above average in both areas during September through November. Both areas received record snowfalls in 1996. In Boston, snowfall in 1996 was twice the historic average.

Temperature

Monthly mean surface water temperatures at the intake area (Station P2) followed a similar seasonal pattern during both the preoperational and operational periods (Figure 2-2). In 1996, monthly mean surface temperatures were coldest in January and February, and warmed by only 1.6°C in March (Figure 2-2). Monthly mean surface temperatures rose rapidly from April through June, deceased slightly in July and reached a peak in September. Following the September peak, mean surface water temperatures decreased rapidly. The single warmest surface temperature measurement in 1996, 20.0°C, occurred on 9 September. The coolest temperature for the year, 0.9°C, was recorded on 5 February, and was the fourth lowest minimum temperature on record for Station P2.

Mean annual surface water temperature in 1996 at the intake station (P2) was 1.4°C higher than the preoperational mean (all years) and 0.7°C higher than the operational mean (Table 2-1). Monthly mean surface water temperatures in 1996 exceeded the preoperational mean in March, May and June, and August through December (Figure 2-2).

Surface temperatures at Stations P2 (intake), P5 (discharge) and P7 (farfield) were similar during 1996 (Figure 2-2), with annual means differing by 0.5°C or less (Table 2-1). Surface temperatures at all stations have shown long term increases, as indicated by the significant Preop-Op difference in the ANOVA results (Table 2-2; Figure 2-3). Temperature differences between stations over all years were significant, with temperatures at P5 the warmest and those at P7 coolest. This relationship was consistent in both the preoperational and operational periods, and therefore the Preop-Op X Station interaction term was not significant (Table 2-2). This consistency also indicates that the operation of Seabrook Station did not affect surface water temperatures at nearfield stations.

As noted for surface temperatures, bottom temperatures at Station P2 in 1996 were generally warmer than preoperational temperatures (Table 2-1; Figure 2-2). Operational monthly mean temperatures were also generally warmer than preoperational temperatures, particularly during the summer and fall. Bottom temperatures in 1996 were similar among the three stations, (Table 2-1; Figure 2-2). Annual mean temperatures for both 1996 and the operational period were warmer at each station compared to the preoperational period. Bottom water temperatures at each station have increased from 1993 to 1995, but decreased in 1996, similar to surface temperatures (Figure 2-3).

ANOVA model results for bottom temperatures were similar to results for surface temperatures. The long-term increase in temperatures since 1987 was reflected by the significantly warmer water temperatures in the operational period. Station differences were significant, and arithmetic means indicate that, over all years, bottom water temperatures at P5 have been warmer than at P2 and P7. This relationship has remained constant between the preoperational and operational periods, as reflected in the non-significant Preop-Op X Station 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 five to six of twelve months, during both operational and preoperational periods. Temperature stratification began to develop at each station by May in 1996, with ΔT values between 4° and 5°C. At Station P2 in 1996, the maximum ΔT occurred in June, with a surface-bottom difference of 6.1°C. A smaller peak occurred again in August, with a difference of

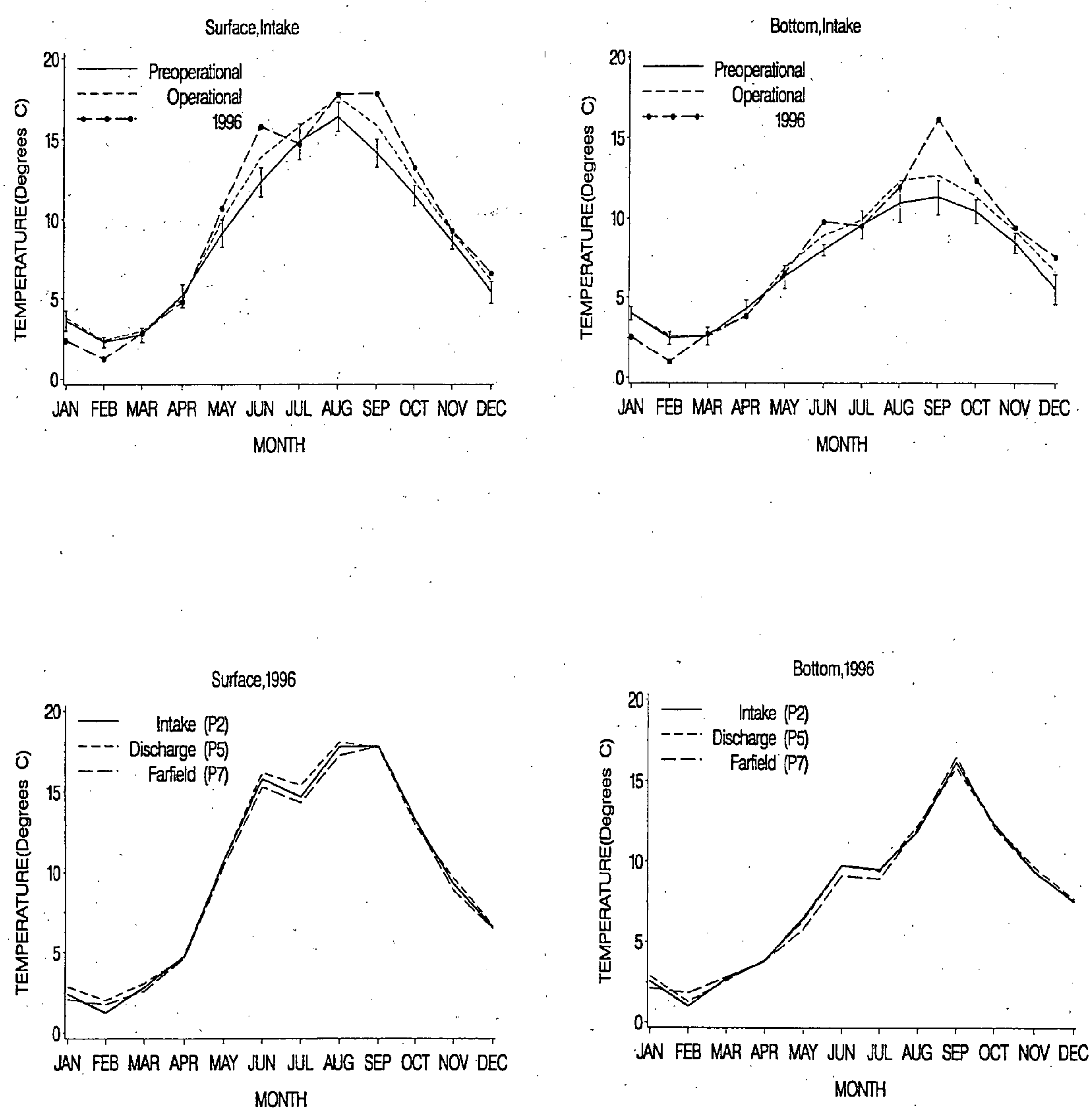


Figure 2-2. Surface and bottom **temperature** (°C) at nearfield Station P2, monthly means and 95% confidence intervals over the preoperational period (1979-1989) and the operational period (1991-1996), and monthly means of surface and bottom temperature at Stations P2, P5, and P7 in 1996. Seabrook Operational Report, 1996.

Table 2-1. Annual Means and Coefficients of Variation (CV,%) and Minima and Maxima for Water Quality Parameters Measured During Plankton Cruises at Stations P2, P5, P7 over Preoperational[a] and Operational (1991-1996) Years, and the Annual Mean, Minimum and Maximum in 1996. Seabrook Operational Report, 1996.

	PREOPERATIONAL								OPERATIONAL				1996		
	ALL YEARS[a]				RECENT YEARS[b]										
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	0.2	19.3	9.0	3.0	0.2	19.0	9.8	7.4	0.0	20.4	10.5	0.9	20.0
P5	9.9	10.7	0.0	19.5	9.1	3.7	0.0	18.4	10.0	6.8	0.1	20.8	10.7	1.0	20.0
P7	8.7	6.3	0.1	19.3	8.8	3.6	0.1	19.3	9.6	7.4	0.2	20.9	10.2	0.6	19.8
Bottom															
P2	7.1	8.8	0.0	17.7	6.6	2.7	0.0	17.7	7.7	8.1	0.1	16.0	8.3	0.5	17.7
P5	7.5	16.9	0.0	17.2	6.7	3.7	0.0	17.2	7.8	7.5	0.0	16.0	8.3	1.0	17.2
P7	6.8	9.3	0.4	18.5	6.4	3.1	0.4	18.5	7.6	8.5	0.2	15.4	8.1	0.9	18.5
SALINITY (ppt)															
Surface															
P2	31.6	1.4	24.7	34.2	31.6	1.2	24.8	34.2	31.3	1.6	26.6	34.2	30.7	28.4	32.0
P5	31.7	0.9	21.4	34.6	31.5	1.1	21.4	34.6	31.3	1.4	23.5	34.0	30.7	27.5	32.6
P7	31.5	1.3	19.6	34.6	31.4	1.0	19.6	33.0	31.3	1.4	26.6	34.4	30.7	28.4	32.2
Bottom															
P2	32.2	0.8	29.0	34.5	32.1	1.0	29.0	34.5	32.0	1.0	28.5	34.2	31.6	29.7	32.9
P5	32.3	0.6	29.8	34.3	32.1	0.7	29.8	34.3	31.9	1.1	25.9	34.1	31.6	30.0	32.9
P7	32.2	0.8	29.2	34.4	32.2	0.8	29.2	34.4	32.0	1.3	26.5	34.7	31.6	30.3	32.5
DISSOLVED OXYGEN (mg/L)															
Surface															
P2	9.7	3.1	6.5	16.0	9.7	1.0	7.0	13.1	9.5	1.3	7.0	12.3	9.5	7.4	11.8
P5	9.6	4.6	7.3	13.1	9.7	1.0	7.4	13.1	9.6	1.3	7.0	12.7	9.5	8.0	12.1
P7	9.7	0.9	6.3	16.2	9.7	1.3	7.3	13.0	9.5	1.3	6.9	12.1	9.4	7.6	12.0
Bottom															
P2	9.2	4.6	6.2	16.1	9.2	4.2	6.2	12.3	9.1	3.0	5.4	12.1	9.0	6.8	11.5
P5	9.0	6.8	6.3	12.3	9.2	4.4	6.3	12.3	9.2	2.1	5.9	12.2	9.1	7.2	11.4
P7	9.1	2.5	4.7	16.0	9.1	4.4	6.0	12.1	9.0	2.7	5.4	12.1	9.0	7.0	11.1

(continued)

Table 2-1. (Continued)

PARAMETER	PREOPERATIONAL								OPERATIONAL				1996		
	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	12.9	27.4	0.5	34.0	14.9	14.7	0.5	34.0	14.9	14.6	1.5	37.5	15.8	1.5	37.5
P5	12.1	22.7	0.5	66.0	14.6	12.2	0.5	42.0	14.5	15.3	2.0	38.0	15.5	2.5	38.0
P7	15.9	10.2	0.5	38.0	15.6	11.4	0.5	38.0	15.6	14.6	1.0	58.0	17.1	1.0	58.0
Total Phosphorus															
P2	25.8	18.8	5.0	95.0	29.2	11.8	5.0	60.0	30.3	24.9	3.0	97.0	28.5	3.0	97.0
P5	27.5	22.6	7.0	82.0	29.7	5.9	10.0	60.0	30.1	24.9	9.5	86.5	30.1	14.0	86.5
P7	29.1	12.2	8.0	70.0	31.0	13.2	10.0	70.0	31.5	25.7	7.0	103.0	31.9	7.0	103.0
Nitrate															
P2	40.0	20.9	5.0	200.0	44.0	24.5	5.0	200.0	44.7	26.9	0.3	274.0	41.5	0.3	274.0
P5	39.8	19.9	5.0	200.0	42.2	26.2	5.0	200.0	39.7	23.4	0.3	192.0	46.4	0.3	192.0
P7	42.1	24.4	5.0	200.0	47.4	22.5	5.0	200.0	44.7	13.9	0.3	282.0	51.2	0.3	282.0
Nitrite															
P2	2.0	30.9	0.5	8.0	2.1	16.2	0.5	7.0	2.3	10.5	0.3	9.0	2.7	0.3	6.0
P5	2.1	26.0	0.5	9.0	2.0	13.6	0.5	9.0	2.1	21.1	0.3	6.5	2.5	0.3	6.5
P7	1.9	32.3	0.5	9.0	2.2	17.5	0.5	9.0	2.6	16.5	0.3	20.5	2.8	0.3	20.5
Ammonia[c]															
P2	6.4	10.7	5.0	20.0	--	--	--	--	10.7	62.8	0.8	57.5	16.4	0.8	57.5
P5	6.1	25.0	5.0	20.0	--	--	--	--	9.8	62.7	0.3	36.5	14.8	0.3	36.5
P7	7.6	18.8	5.0	30.0	--	--	--	--	10.4	59.7	0.8	53.0	15.5	0.8	53.0

[a]Mean of annual means.
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 (1991-1996) Years. Seabrook Operational Report, 1996.

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[i] (ranked in decreasing order)
Surface Temperature	Preop-Op[b,c]	1	48.73	5.70*	Op>Preop
	Year (Preop)[d]	7	8.54	0.10 NS	
	Month (Year)[e]	99	87.47	1531.00***	
	Station[f]	2	3.09	56.33*	P5>P2>P7
	Preop-Op X Station[g]	2	0.05	1.07 NS	
	Station X Year (Preop-Op)[h]	14	0.05	0.89 NS	
	Error	198	0.06		
Bottom Temperature	Preop-Op	1	97.83	12.03*	Op>Preop
	Year (Preop)	7	8.18	0.22 NS	
	Month (Year)	99	36.91	456.15***	
	Station	2	1.39	59.98*	P5>P2>P7
	Preop-Op X Station	2	0.03	0.35 NS	
	Station X Year (Preop-Op)	14	0.07	0.88 NS	
	Error	198	0.08		
Surface Salinity	Preop-Op	1	0.98	0.12 NS	
	Year (Preop-Op)	7	7.65	1.80 NS	
	Month (Year)	99	4.27	55.24***	
	Station	2	0.28	1.02 NS	
	Preop-Op X Station	2	0.26	5.33*	2 Pre 5 Pre 2 Op 7 Op 7 Pre 5 Op
	Station X Year (Preop-OP)	14	0.05	0.63NS	
	Error	198	0.08		
Bottom Salinity	Preop-Op	1	1.81	0.45 NS	
	Year (Preop)	7	4.08	2.68*	
	Month (Year)	99	1.51	35.20***	
	Station	2	0.28	6.74 NS	
	Preop-Op X Station	2	0.04	0.70 NS	
	Station X Year (Preop-Op)	14	0.06	1.41 NS	
	Error	198	0.04		

(continued)

Table 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[i] (ranked in decreasing order)
Surface Dissolved Oxygen	Preop-Op	1	2.84	6.00*	Preop>Op
	Year (Preop)	7	0.44	0.14 NS	
	Month (Year)	99	3.10	184.63***	
	Station	2	0.14	3.14 NS	
	Preop-Op X Station	2	0.04	7.11**	5 Pre 2 Pre 7 Pre 5 Op 2 Op 7 Op
	Station X Year (Preop-Op)	14	0.01	0.35 NS	
	Error	198	0.03		
Bottom Dissolved Oxygen	Preop-Op	1	1.17	0.39 NS	
	Year (Preop)	7	2.96	0.61 NS	
	Month (Year)	99	4.90	188.53***	
	Station	2	0.38	4.75 NS	
	Preop-Op X Station	2	0.08	2.93 NS	
	Station X Year (Preop-Op)	14	0.03	1.01 NS	
	Error	198	5.15		
Orthophosphate	Preop-Op	1	4.71	0.04 NS	
	Year (Preop-Op)	7	128.25	0.59 NS	
	Month (Year)	99	218.11	39.97***	
	Station	2	18.20	non-est.[j]	
	Preop-Op X Station	2	0.04	0.01 NS	
	Station X Year (Preop-Op)	14	3.35	0.61 NS	
	Error	198	5.47		
Total Phosphorus	Preop-Op	1	23.97	0.01 NS	
	Year (Preop-Op)	7	1716.67	4.73**	
	Month (Year)	98	374.89	9.89***	
	Station	2	92.22	6.61 NS	
	Preop-Op X Station	2	14.52	0.56 NS	
	Station X Year (Preop-Op)	14	25.63	0.68 NS	
	Error	196	37.91		

(continued)

Table 2-2 (Continued)

PARAMETER	SOURCE OF VARIATION[a]	DF	MS	F	MULTIPLE COMPARISONS[i] (ranked in decreasing order)
Nitrate	Preop-Op	1	104.02	0.03 NS	
	Year (Preop-Op)	7	3478.10	0.32 NS	
	Month (Year)	99	10692.79	134.20***	
	Station	2	545.50	15.10 NS	
	Preop-Op X Station	2	42.99	0.22 NS	
	Station X Year (Preop-Op)	14	191.10	2.40**	
	Error	198	79.68		
Nitrite	Preop-Op	1	6.67	1.69 NS	
	Year (Preop-Op)	7	4.15	0.52 NS	
	Month (Year)	99	7.82	14.90***	
	Station	2	2.61	5.27 NS	
	Preop-Op X Station	2	0.51	0.71 NS	
	Station X Year (Preop-Op)	14	0.72	1.36 NS	
	Error	198	0.52		
Ammonia	Preop-Op	1	679.04	0.61 NS	
	Year (Preop-Op)	6	1211.77	9.08***	
	Month (Year)	85	140.77	13.49***	
	Station	2	18.19	3.58 NS	
	Preop-Op X Station	2	5.00	1.31 NS	
	Station X Year (Preop-Op)	12	3.16	0.30 NS	
	Error	170	10.43		

[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]Interaction of station and year nested within Preop-Op.
[i]Underlining indicates no significant difference based on a test of H_o: LSMEAN(i)=LSMEAN(j).

Waller-Duncan multiple means comparison test used for significant main effects. LS Means used for significant interaction terms.
[j]Non-estimable due to negative denominator mean square.

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 ($0.001 \geq p$)

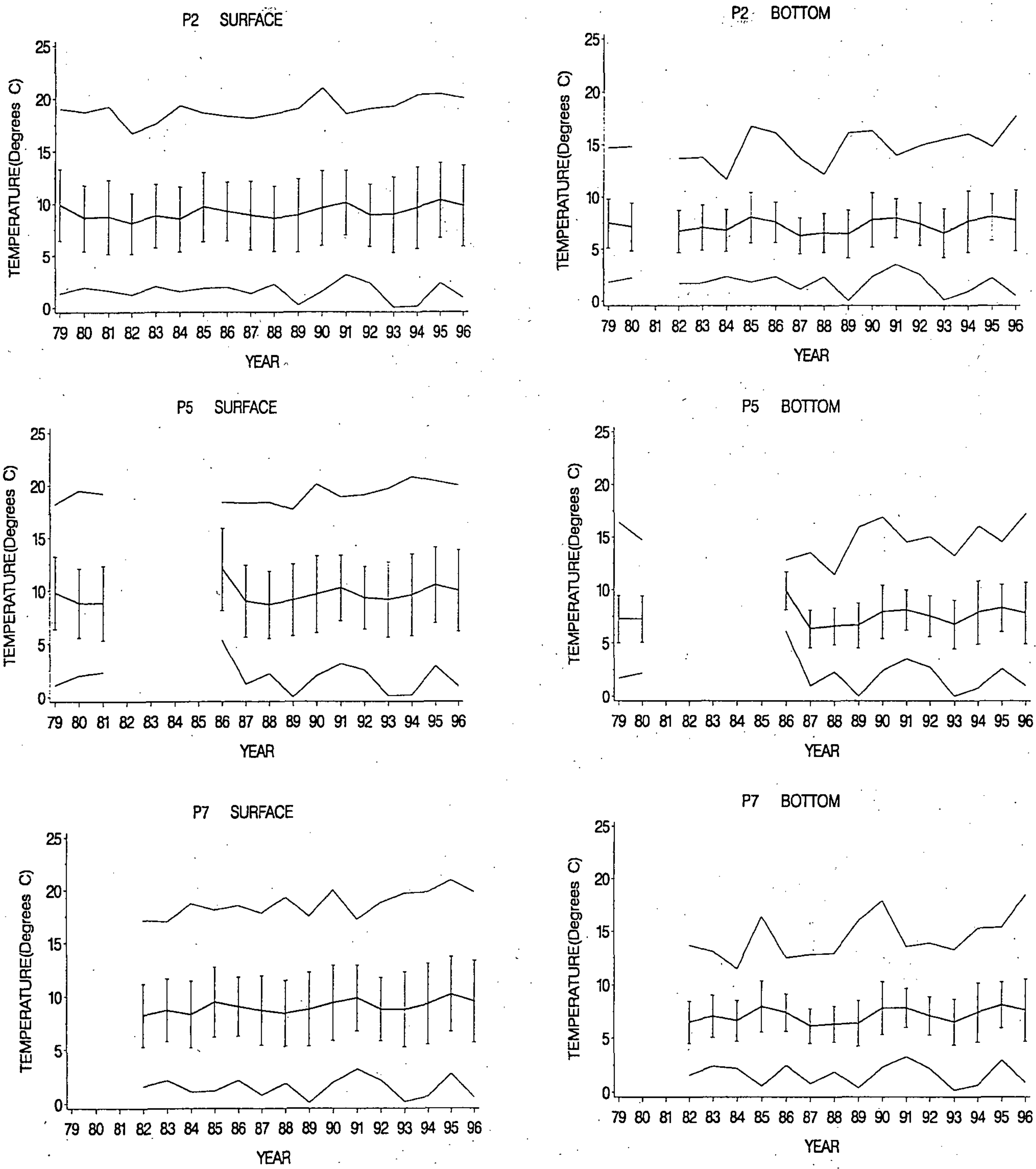


Figure 2-3. Time-series of annual means and 95% confidence intervals and annual minima and maxima of surface and bottom **temperatures** at Stations P2, P5, and P7, 1979-1996. Seabrook Operational Report, 1996.

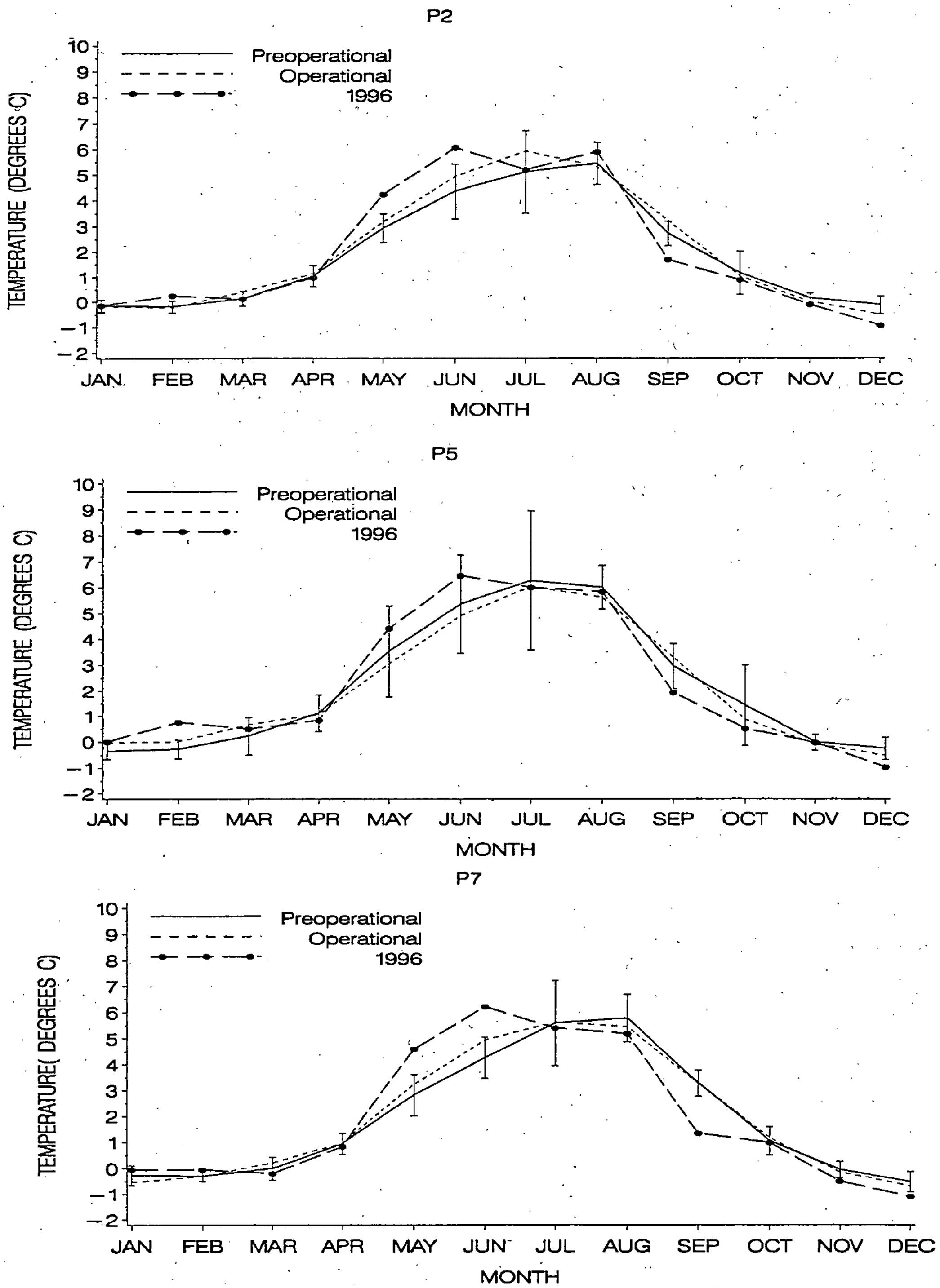


Figure 2-4. Monthly mean difference and 95% confidence intervals between surface and bottom **temperatures** (°C) at Stations P2, P5, and P7 for the preoperational period (1979-1989) and monthly means for the operational period (1991-1996) and 1996. Seabrook Operational Report, 1996.

5.9°C. At Stations P2 and P5, peak stratification occurred in June, with differences of 6.5 and 6.2°C respectively. Temperature differences then began to decline to approximately 1-2°C by September. The water column again became isothermal by late October. Preoperational and operational mean values indicated that the ΔT peak typically occurred in July or August (Figure 2-4), thus the occurrence of maximum ΔT in June at each station in 1996 was unusual, and probably was a reflection of cooler than normal air temperatures in August 1996.

Continuous surface temperatures recorded at Stations DS (discharge) and T7 (farfield) in 1996 showed a similar seasonal pattern to temperatures recorded at the water quality stations, including distinct peaks in August and September (Table 2-3, Figures 2-2, 2-5). The annual mean temperature at DS decreased from 10.4°C in 1995 to 9.9°C in 1996 (Table 2-4). At T7 the annual mean also decreased from 9.7°C to 9.1°C. Monthly temperatures measured in 1996 at both T7 and DS were generally similar to monthly temperatures from previous years (Figure 2-5).

Monthly temperatures at DS were generally 1-2 °C warmer than at T7 during all months except June through August. In June through August, DS was less than 1°C cooler (Table 2-3). These average monthly ΔT values (DS-T7) have shown full compliance with the Station's NPDES permit throughout the operational period.

<u>Salinity</u>

Monthly average surface salinities at P2 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 influenced salinities 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

Table 2-4. Annual Mean Surface Temperatures (°C)[a] and Coefficients of Variation (CV,%) at Stations DS and T7 During Operational Monitoring. Seabrook Operational Report, 1996.

	STATION DS		STATION T7	
YEAR[b]		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
1995	10.4	43.6	9.7	55.4
1996	9.9	48.8	9.1	59.4

[a]mean of monthly means; n=12 in 1991, 1993, 1995 and 1996; n=11 in 1992; n=8 in 1994.
[b]Monitoring conducted by YAEC from 1991-1995.

Table 2-3. **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 1996. Seabrook Operational Report, 1996.**

	1990			1991			1992			1993			1994[d]			1995			1996		
MONTH	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]
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	6.37	4.66	1.72	4.08	2.40	1.68
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	5.41	3.54	1.86	3.21	2.07	1.14
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	4.67	3.23	1.44	4.20	2.69	1.51
APR	--	--	--	6.99	6.37	0.62	5.93	4.26	1.67	5.04	4.44	0.60	--	--	--	6.86	5.33	1.53	6.06	5.00	1.06
MAY	--	--	--	10.43	10.21	0.22	10.52	10.32	0.20	10.74	10.02	0.72	--	--	--	9.56	8.20	1.37	9.57	9.26	0.31
JUN	--	--	--	13.81	13.70	0.11	11.94	11.84	0.10	11.65	10.53	1.12	--	--	--	13.63	15.58	1.94	13.40	13.72	-0.32
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	--	--	--	14.76	15.48	0.73	13.29	13.68	-0.39
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	17.40	17.71	0.31	16.10	17.04	-0.94
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	15.93	15.28	0.64	17.14	16.22	0.92
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	14.27	13.08	1.18	13.24	11.97	1.27
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	9.17	9.11	0.06	10.55	8.90	1.65
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	6.76	5.53	1.23	7.90	6.51	1.39

[a]Commercial operation began in August, 1990.
[b]Data either not collected, or an equipment failure occurred.
[c]ΔT = Surface discharge - surface farfield temperatures (°C)
[d]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.

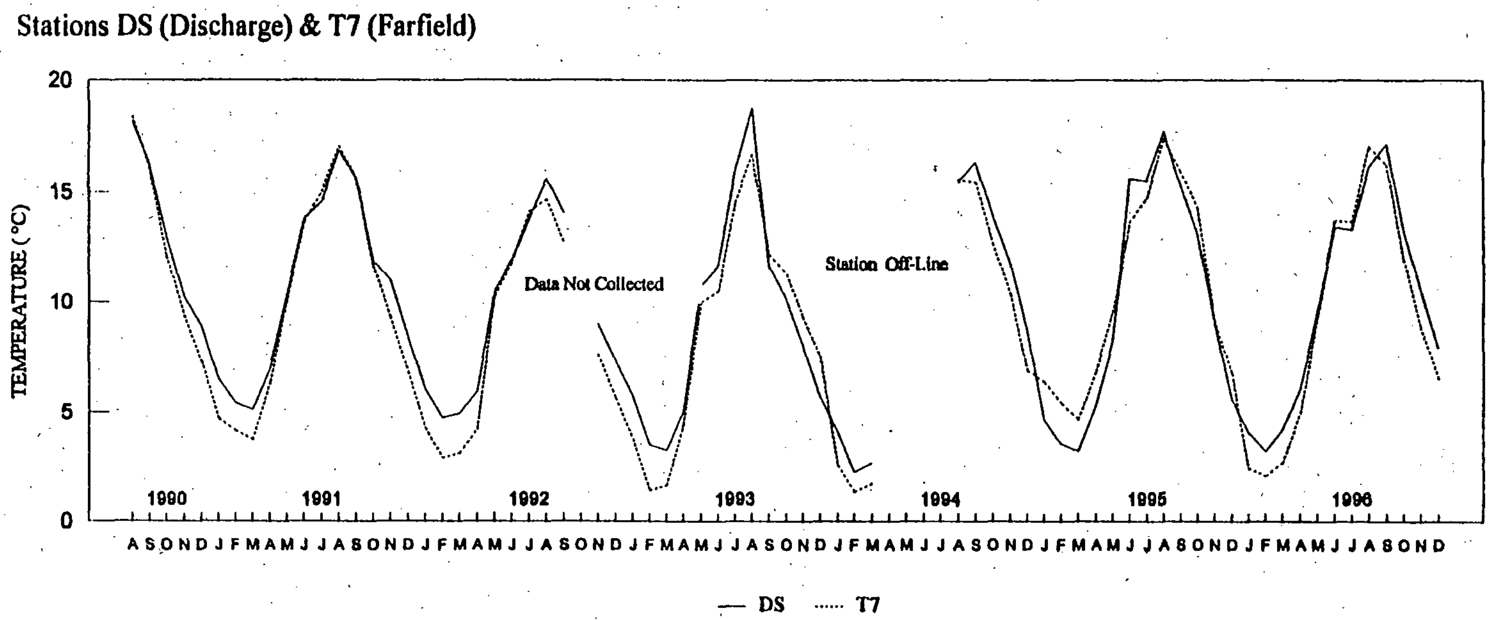


Figure 2-5. Comparison of monthly averaged continuous temperature (°C) data collected at the surface at discharge (DS) and farfield (T7) stations during commercial operation, August 1990-December 1996. Seabrook Operational Report, 1996.

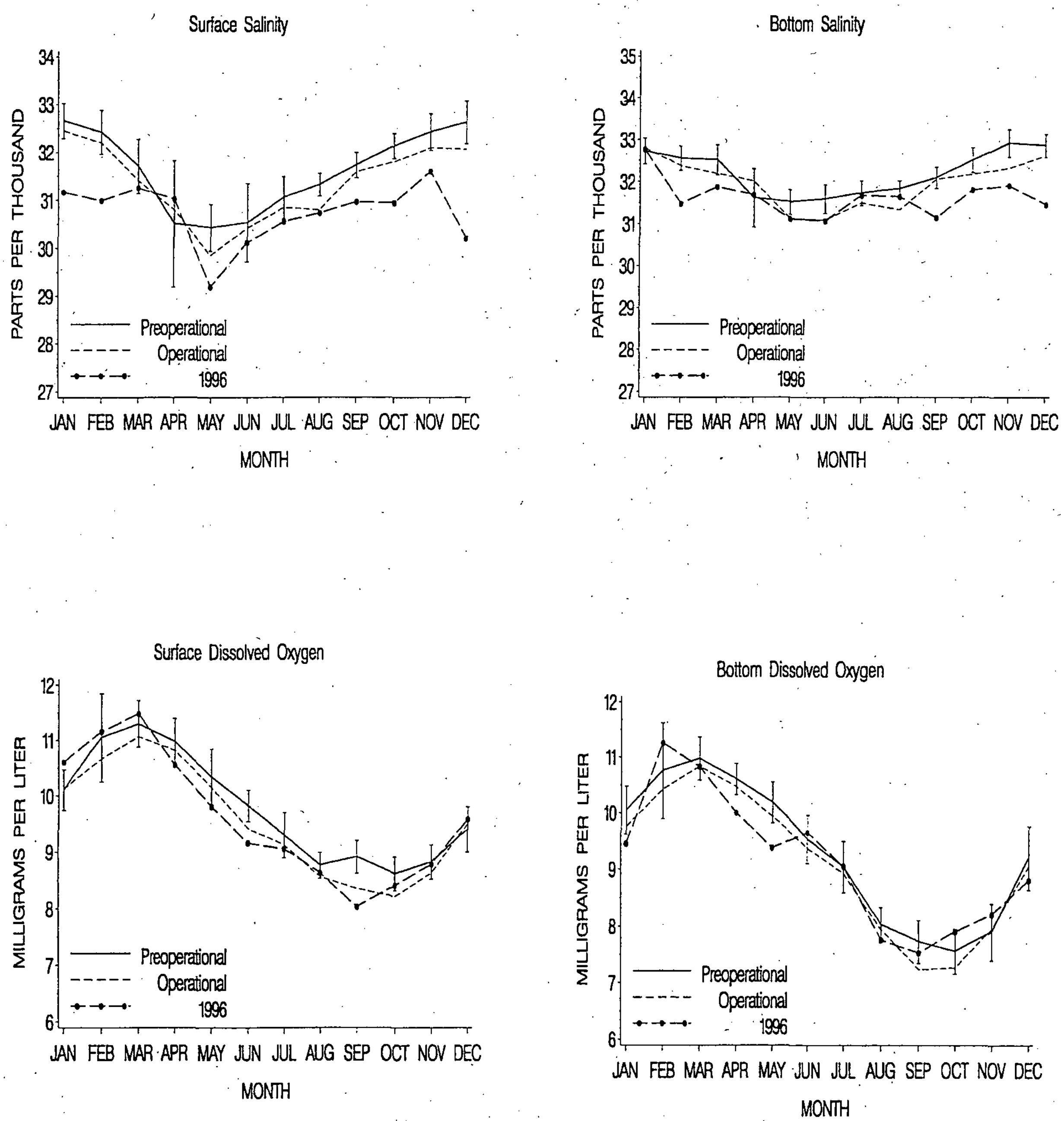


Figure 2-6. Surface and bottom **salinity** (ppt) and **dissolved oxygen** (mg/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1989) and monthly means for the operational period (1991-1996) and 1996. Seabrook Operational Report, 1996.

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 1996 generally exhibited more stable temperature and salinity levels over the year compared to surface waters, i.e., temperature and salinity changed at a faster rate and to a larger degree from month to month in surface waters when compared to bottom waters.

Seasonal patterns of surface and bottom salinity were similar between preoperational and operational periods. Surface salinities measured at Station P2 in 1996 were below preoperational and operational means for every month except April (Figure 2-6). Bottom salinity followed a similar pattern, except monthly variability was less than surface salinity (Figure 2-6).

Long-term annual salinity exhibited a general downward trend during the study period at all stations and depths (Figure 2-7). Surface and bottom annual mean salinities at each station in1996 were among the lowest observed in the time series. A similar trend was observed at the Maine Department of Marine Resources West Boothbay Harbor long-term environmental monitoring station, suggesting a regional trend. 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 29.0 ppt in 1996 (MDMR 1991, 1992, 1993, 1994, 1995, 1996, 1997).

Surface salinity decreased significantly between the preoperational and operational periods at Stations P2 and P5 by 0.3 and 0.2 ppt respectively, but there was no significant change at Station P7, resulting in a significant interaction term (Table 2-2; Figure 2-8). There were no significant differences between the preoperational and operational periods, or among stations for bottom salinity (Table 2-2).

Dissolved Oxygen

Surface and bottom dissolved oxygen concentrations at P2 exhibited a seasonal pattern in 1996 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 from August through October when temperatures reached the annual maximum (Figure 2-2). Surface dissolved oxygen concentrations at Station P2 in 1996 were lower than preoperational monthly means from April through November (Figure 2-6). Bottom dissolved oxygen levels in 1996 were more similar to preoperational levels than surface dissolved oxygen and were below the preoperational means only in January, March, April, and August through September (Figure 2-6). Mean annual dissolved oxygen concentrations in 1996 were similar to the preoperational and operational means, and within the range of values observed in the past (Table 2-1).

Surface dissolved oxygen decreased at all stations between the preoperational and operational period, but the decrease was less at Station P5, resulting in a significant interaction term (Table 2-2; Figure 2-9). The difference in surface dissolved oxygen levels between the preoperational and operational periods at each station ranged from 0.23 mg/l at Station P7 to

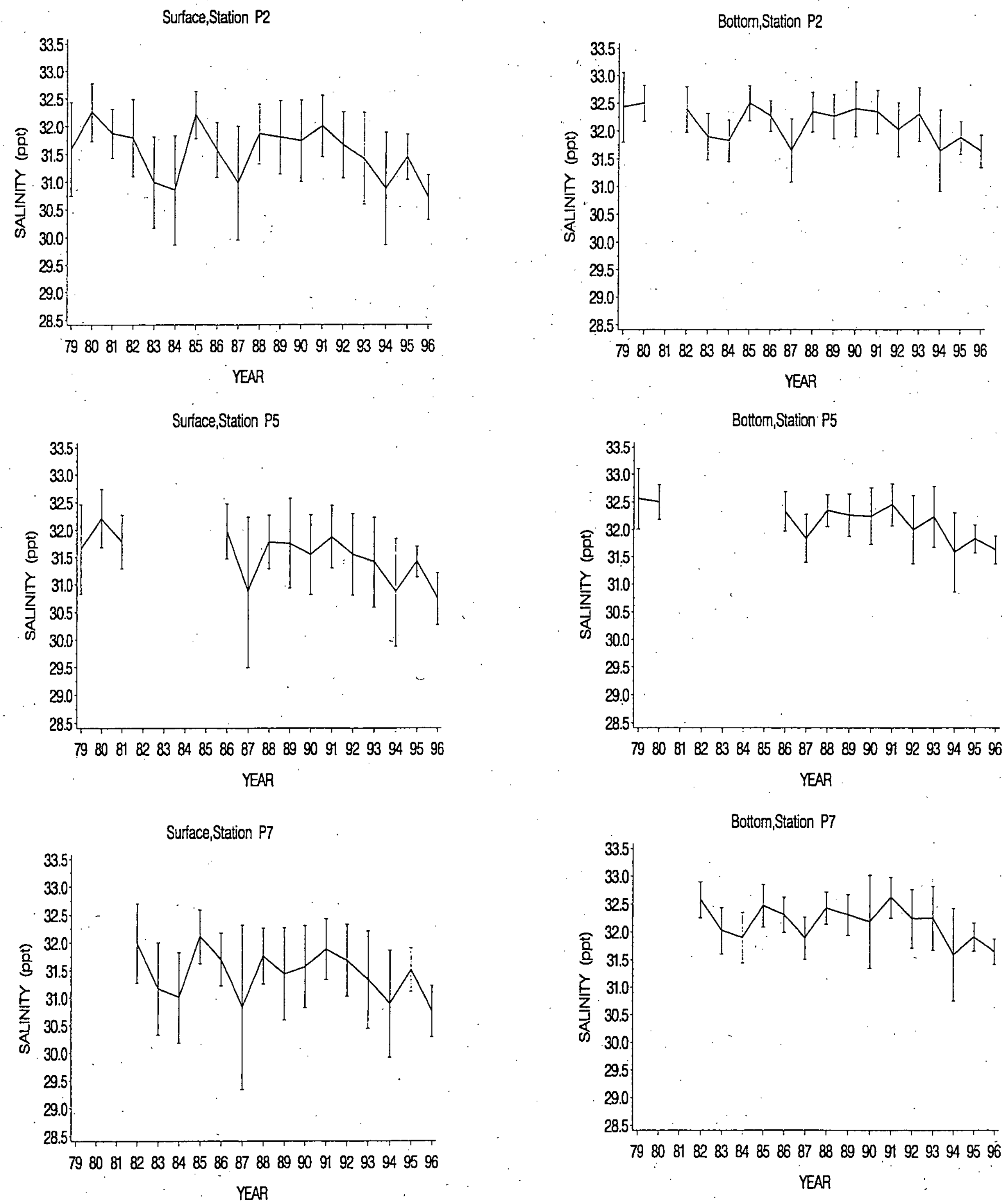


Figure 2-7. Time-series of annual means and 95% confidence intervals of surface and bottom salinity at Stations P2, P5, and P7, 1979-1996. Seabrook Operational Report, 1996.

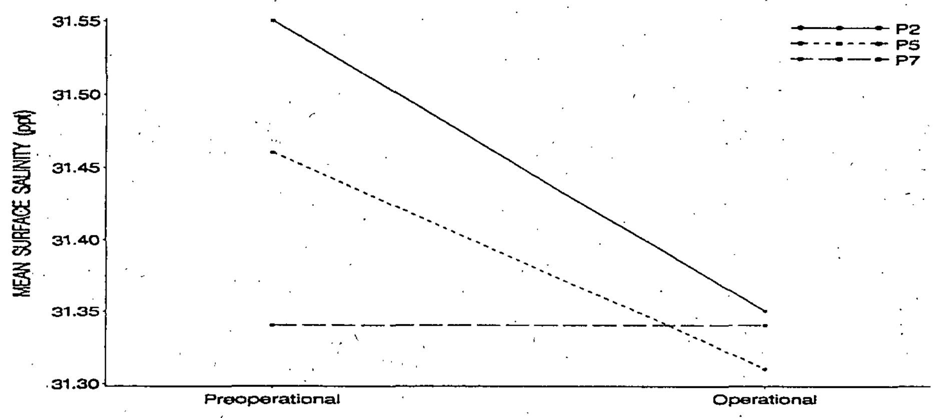


Figure 2-8. A comparison among stations of mean surface salinity (ppt) during the preoperational (1987-1989) and operational periods (1991-1996) for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 2-2). Seabrook Operational Report, 1996.

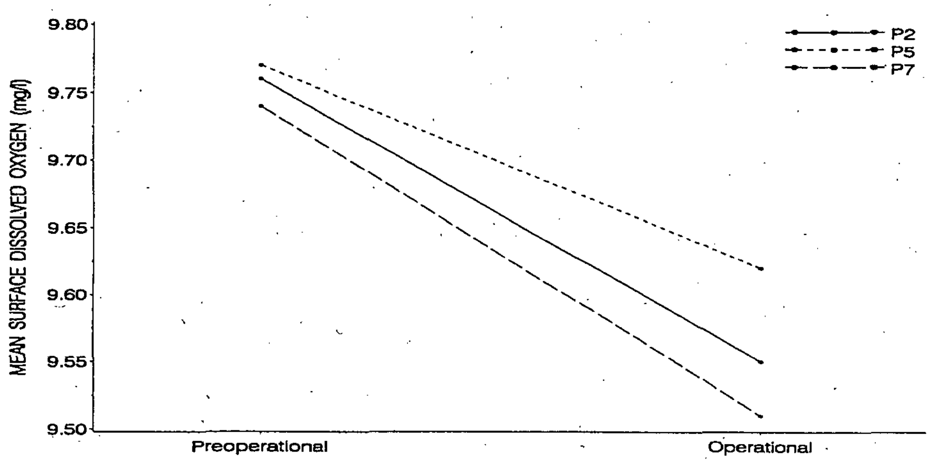


Figure 2-9. A comparison among stations of mean surface dissolved oxygen (mg/l) during the preoperational (1987-1989) and operational periods (1991-1996) for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 2-2). Seabrook Operational Report, 1996.

0.15 mg/l at Station P5. Annual mean surface dissolved oxygen concentrations followed a similar pattern each year for the three stations (Figure 2-10).

There were no significant differences in bottom dissolved oxygen concentrations between the preoperational and operational periods, or among stations (Table 2-2).

2.3.1.2 Nutrients

Phosphorus Species

Monthly mean surface orthophosphate concentrations in 1996 at P2 exceeded the preoperational and operational monthly means in March through July, and September and October, resulting in a seasonal pattern that was similar to earlier years (Figure 2-11). Concentrations were usually lowest from May to September during the preoperational and operational periods, and in 1996. An exception to this pattern occurred in December 1996 when monthly mean orthophosphate concentrations were below the preoperational and operational means (Figure 2-11). A pattern of highest orthophosphate concentrations during late fall through late winter and lowest concentrations during the summer is typical of northern temperate waters in general and is largely associated with the seasonal nutrient requirements of the primary producers (Section 3.0).

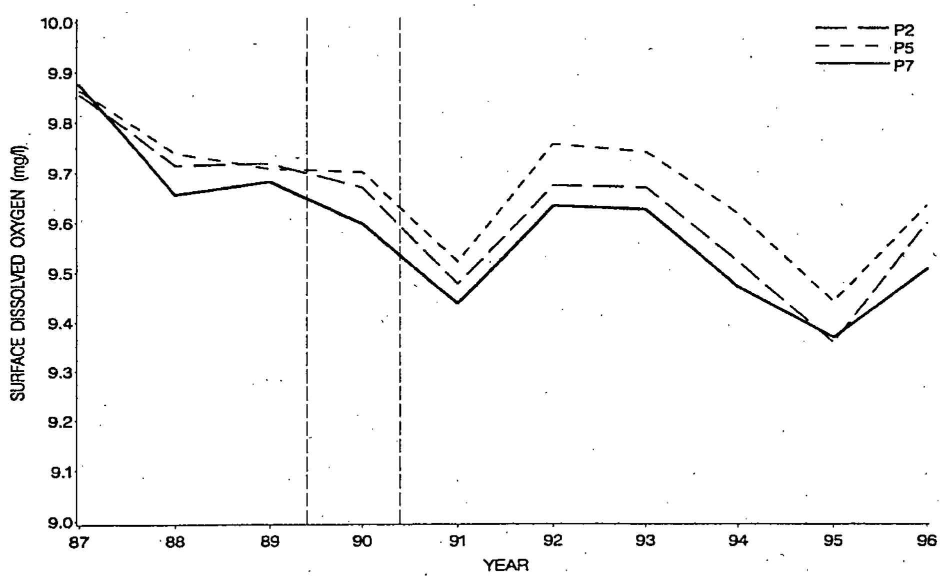
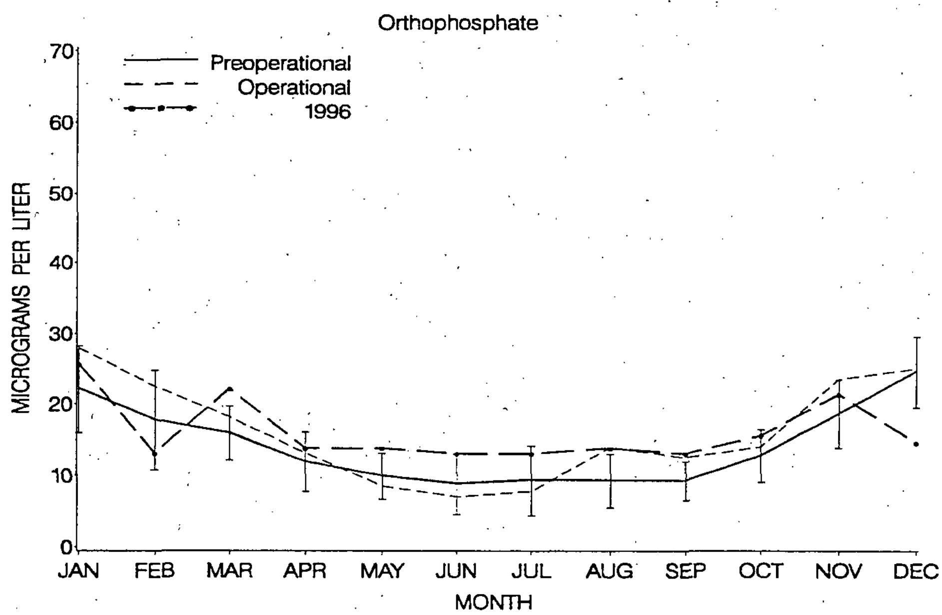


Figure 2-10. Time series of annual mean surface dissolved oxygen (mg/l) 1987-1996 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.



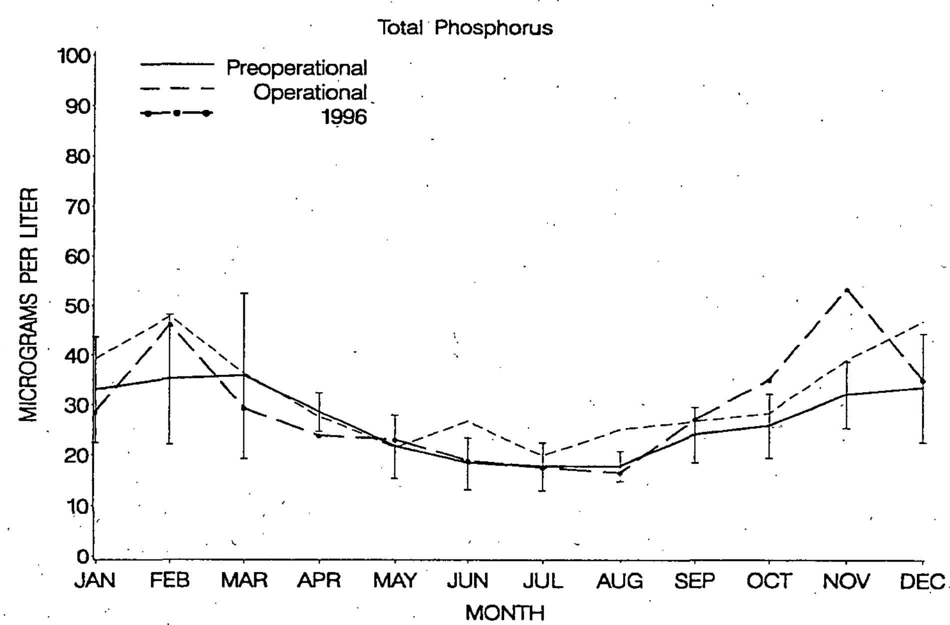


Figure 2-11. Surface **orthophosphate** and **total phosphorus** concentrations (μg P/L) at Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-89), and monthly means for the operational period (1991-1996) and 1996. Seabrook Operational Report, 1996.

Annual mean orthophosphate concentrations in 1996 were higher than the preoperational (all years and recent years) and operational period means (Table 2-1). Differences between stations (both periods combined) were also not significant, nor was the interaction of main effects (Preop-Op X Station term, Table 2-2).

Seasonal patterns in total phosphorus in 1996 generally followed the pattern observed in previous years (Figure 2-11). In contrast to orthophosphate, monthly mean total phosphorus concentrations observed in 1996 exceeded the preoperational and operational monthly means in May, and September through November. Both the operational and 1996 annual mean concentrations were higher than preoperational means (all years) at all three stations (Table 2-1). However, there were no significant differences between operational and preoperational mean concentrations (Table 2-2).

There were no significant differences in mean total phosphorus between stations (Table 2-2). Among station differences were as small as 1.4 μgP/L and 3.3 μgP/L during the operational and preoperational periods respectively. The interaction of the main effects was not significant indicating that the operation of the station did not affect total phosphorus concentrations (Table 2-2).

Nitrogen Species

Nitrate concentrations at P2 exhibited strong seasonality in 1996 typical of patterns observed in previous years (Figure 2-12). Monthly mean concentrations in 1996 were within the 95% confidence limits of the preoperational period during February through April and October through December, and exceeded the upper confidence limits of the preoperational means in January and May through July. In August and September, nitrate concentrations were below detection limits. The annual mean concentration observed in 1996 was higher than during the recent preoperational period (1987-1989) at Stations P5 and P7 (Table 2-1). There were no significant differences between periods, or among stations (Table 2-2). The interaction between main effects was not significant.

Nitrite concentrations at P2 exhibited a similar monthly pattern to nitrate both in the long-term and in 1996 (Figure 2-12). Monthly mean concentrations in 1996 exceeded the preoperational upper 95% confidence limits in several months (February, June, July, October and December). Annual mean nitrite concentrations in 1996 were higher that the recent preoperational mean, and the operational mean at each station (Table 2-1). The operational annual mean concentration of nitrite was not significantly different from the preoperational mean, and there were no differences among stations (Table 2-2). The interaction of Preop-Op X Station was not significant.

As in previous years, ammonia concentrations did not exhibit a strong seasonal trend (Figure 2-12). Monthly mean concentrations in 1996 were higher than the preoperational mean in all months except June, July, September, November and December. Mean concentrations of ammonia in 1996 were higher than during both the preoperational and operational periods at each station (Table 2-1). There were no significant differences between the preoperational and operational periods, or among stations, and the interaction term was not significant (Table 2-2).

2.3.2 Estuarine Water Quality

Monthly averages of surface water salinity and temperature at high and low slack tides in

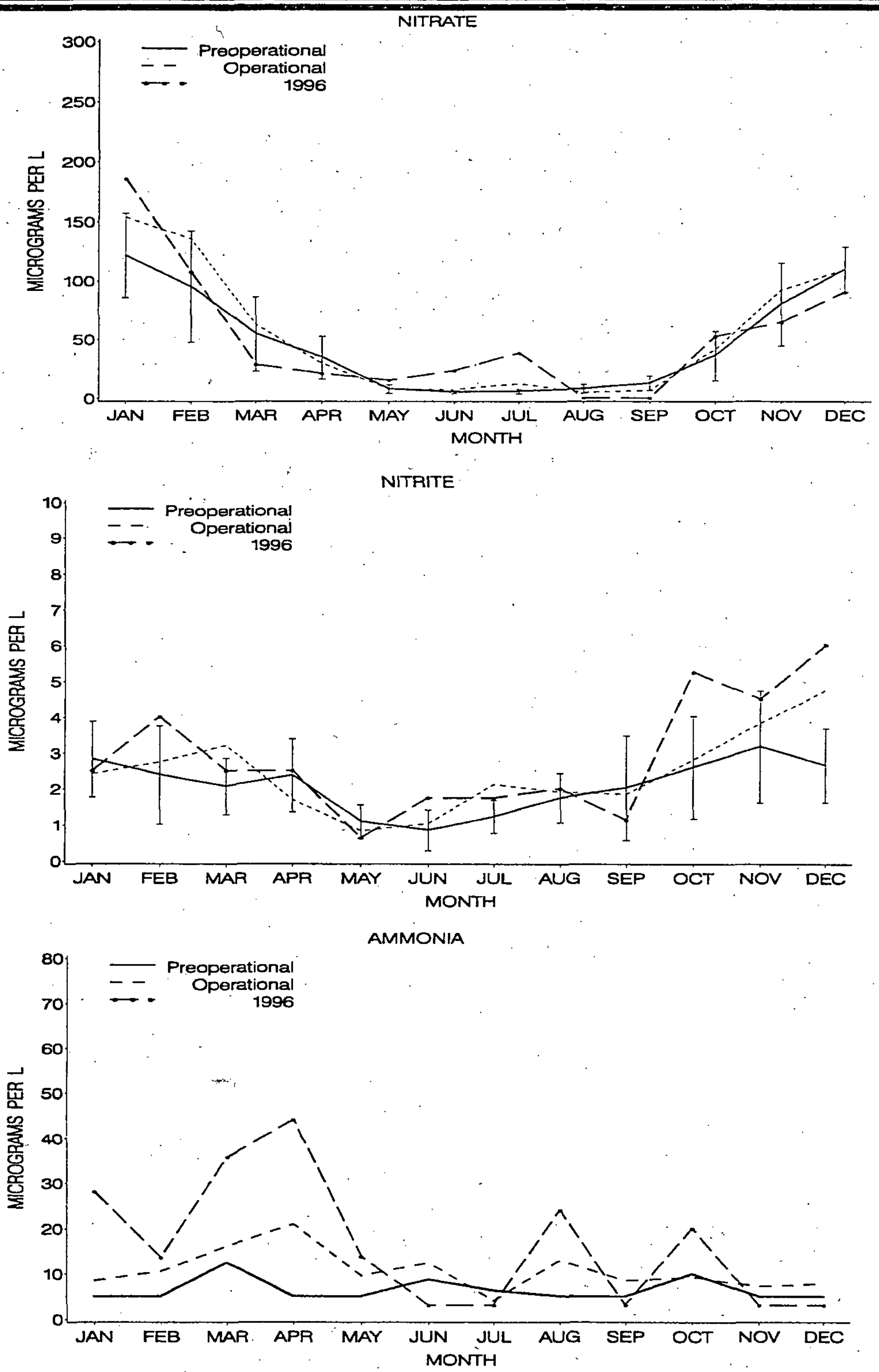


Figure 2-12. Surface nitrate-nitrogen, nitrite-nitrogen and ammonia-nitrogen concentrations (μg N/L) at nearfield Station P2, monthly means and 95% confidence intervals for the preoperational period (1979-1984 and 1987-1989), and monthly means for the operational period (1991-1996) and 1996. Seabrook Operational Report, 1996.

Hampton Harbor were used to examine seasonal and annual patterns in the Hampton-Seabrook estuary.

Temperature

Both low and high tide temperature in 1996 followed the same seasonal patterns observed previously (Figure 2-13). Monthly mean low-tide temperatures were highest in August at 19.2°C and lowest in January at 1.3°C. Across the year, low tide temperatures exceeded the 95% confidence limits of the long-term means during February, September, and December, but the annual mean was similar to the long-term mean (Table 2-5). Annual mean low-tide temperature from 1980-1996 ranged from 9.1 to 11.1°C, averaging 10.1°C.

High-tide temperatures in 1996 were highest in September (17.4°C), deviating slightly from the historical pattern, and were lowest in February (1.6°C). Monthly mean high-tide temperatures in 1996 exceeded the 95% confidence limits of the 16-year monthly means during June, September and December, resulting in an annual mean temperature that was only 0.1°C above the mean (Table 2-5).

Annual mean high-tide temperature was consistently lower than low-tide temperature, ranging from 8.7 to 10.1°C during the study period, and averaging 9.4°C (Table 2-5). Temperature was more variable among months at low tide than high tide in 1996, reflecting a pattern consistent with the long-term average conditions.

Salinity

Salinity in Hampton Harbor at low tide and high tide in 1996 exhibited similar monthly patterns to previous years (Figure 2-14). Salinity at low tide in 1996 was highest in the late summer and early fall. Although the monthly pattern was similar, annual mean low tide salinity in 1996 was the third lowest recorded since 1980 (Table 2-5). Salinity at low tide in 1996 was lower than the historical lower 95% confidence limits in May, July, October, and December.

Salinity at high tide was less variable than low tide salinity (Figure 2-14). Historically, high tide salinity was lowest in March through June, and this pattern was repeated in 1996. High tide salinity was the fifth lowest recorded since 1980 (Table 2-5) and was below the lower 95% confidence limits for the months of February, May, and September through December.

2.4 DISCUSSION

The seasonal cycles of all 1996 water quality parameters were consistent with those of preoperational years. Air temperature can directly affect water temperature and indirectly mediate dissolved oxygen through water temperature, while precipitation can affect salinity. In 1996, air temperature was slightly cooler than average, and precipitation was above average. Despite the slightly cooler air temperatures, surface and bottom monthly mean intake station water temperatures in 1996 were warmer than both the preoperational and operational mean water temperatures, continuing a trend that started in the recent operational years. Surface and bottom water temperatures throughout the operational period were significantly warmer than the preoperational period at all stations (NAI 1996, NAI 1995, NAI and NUS 1994, NAI 1993). Water quality measurements have generally remained similar among the three stations. Small but significant station differences were detected only in surface and bottom temperatures. In each case, however, these differences were consistent

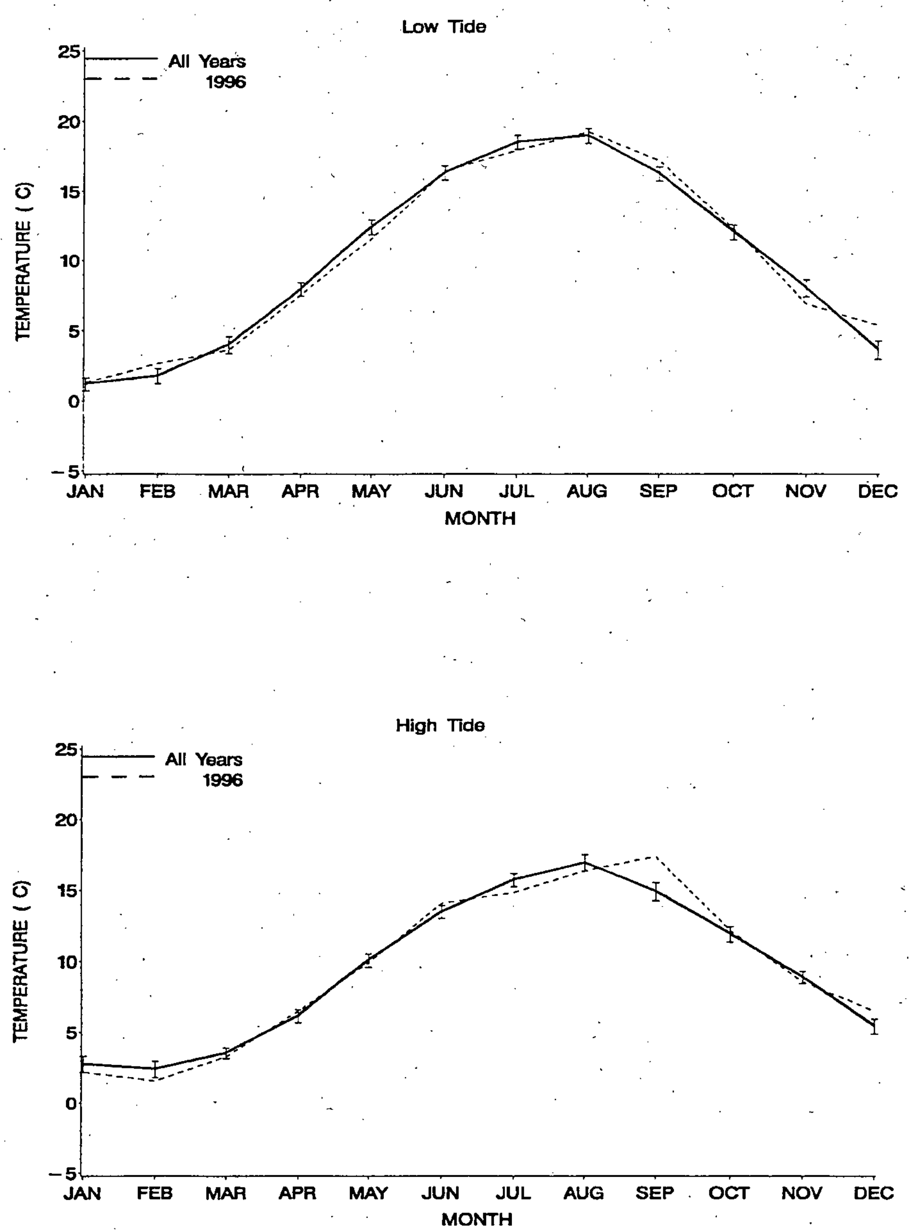
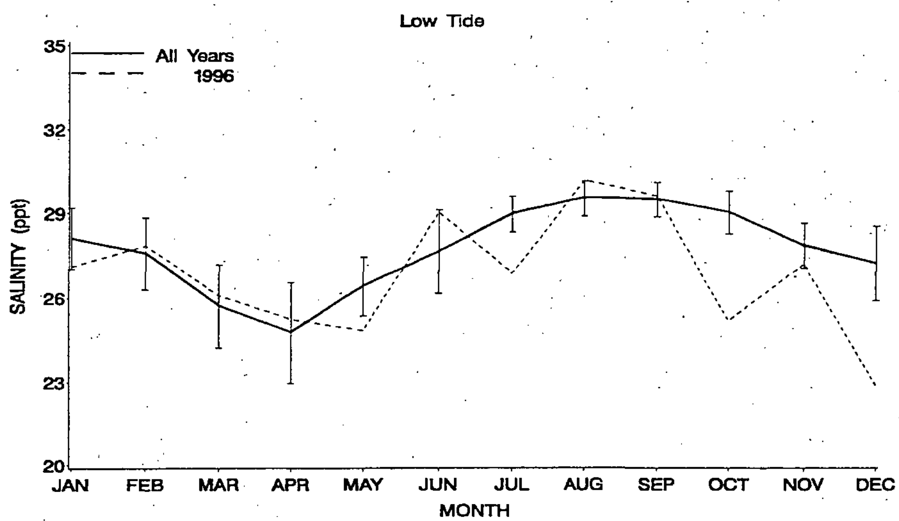


Figure 2-13. Monthly means and 95% confidence limits for temperature measured at low and high tides in Hampton Harbor from May 1979 - December 1996 and monthly means in 1996. Seabrook Operational Report, 1996.

Table 2-5. Annual Mean[a] and 95% CL[b] for Temperature (°C) and Salinity (PPT) Taken at Both High and Low Slack Tide in Hampton Harbor from 1980-1996. Seabrook Operational Report, 1996.

	LOW TIDE		HIGH TIDE	
YEAR	TEMPERATURE	SALINITY	TEMPERATURE	SALINITY
1980	9.6 ± 4.4	29.9 ± 1.4	9.1 ± 3.6	32.0 ± 0.5
1981	10.1 ± 4.4	28.9 ± 1.1	9.3 ± 3.8	31.5 ± 0.4
1982	10.2 ± 4.1	27.3 ± 1.5	9.2 ± 3.5	31.2 ± 0.6
1983	10.4 ± 4.3	25.5 ± 2.4	9.9 ± 3.4	30.1 ± 0.9
1984	10.4 ± 4.1	25.8 ± 2.3	9.4 ± 3.1	30.2 ± 0.9
1985	10.6 ± 4.2	29.1 ± 1.0	10.1 ± 3.3	32.2 ± 0.3
1986	10.0 ± 3.9	27.7 ± 1.3	9.4 ± 3.0	31.5 ± 0.4
1987	10.0 ± 4.3	27.5 ± 2.2	8.9 ± 3.5	30.7 ± 0.9
1988	9.7 ± 3.9	27.8 ± 1.0	9.2 ± 3.3	31.3 ± 0.4
1989	10.2 ± 4.4	28.0 ± 1.2	9.2 ± 3.3	31.4 ± 0.7
1990	10.3 ± 4.3	27.2 ± 1.2	9.7 ± 3.6	31.3 ± 0.6
1991	11.1 ± 4.0	28.0 ± 0.9	9.8 ± 3.1	30.9 ± 0.4
1992	9.1 ± 4.0	27.2 ± 1.6	9.7 ± 2.9	29.4 ± 1.6
1993	9.5 ± 4.4	26.8 ± 1.9	8.7 ± 3.5	29.5 ± 1.1
1994	9.8 ± 4.6	27.8 ± 1.9	9.1 ± 3.7	30.9 ± 0.8
1995	10.2 ± 4.3	28.7 ± 1.4	9.9 ± 3.4	31.5 ± 0.2
1996	10.2 ± 4.1	26.8 ± 1.4	9.4 ± 3.5	30.4 ± 0.5
OVERALL[c]	10.1 ± 0.9	27.6 ± 0.4	9.3 ± 0.7	31.0 ± 0.2

[a] Annual mean=mean of 12 monthly means
[b] Confidence limits expressed as half the confidence interval.
[c] Overall mean=mean of annual means.



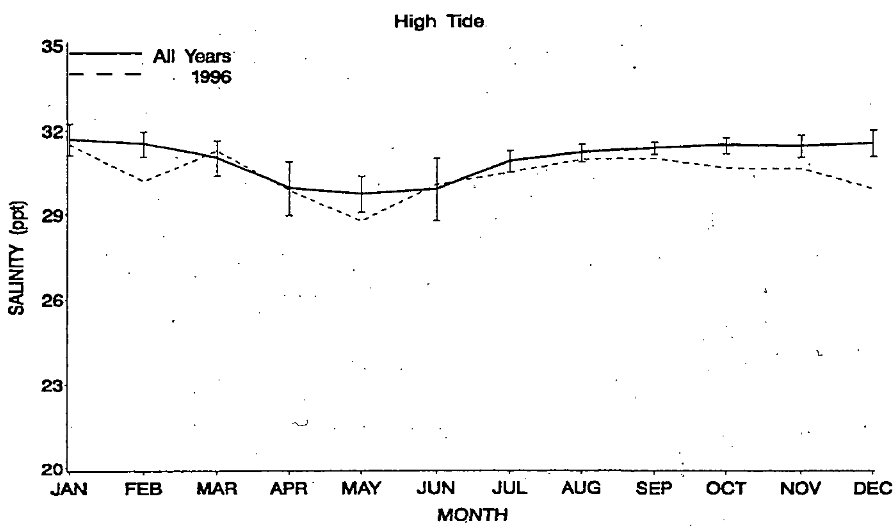


Figure 2-14. Monthly means and 95% confidence limits for **salinity** measured at low and high tides in Hampton Harbor from May 1979 - December 1996 and monthly means in 1996. Seabrook Operational Report, 1996.

between the preoperational and operational periods, and were not due to the operation of Seabrook Station.

Differences between the preoperational and operational periods that were not consistent among stations were detected for surface dissolved oxygen and surface salinity (Table 2-6). Surface dissolved oxygen levels decreased at all stations between the preoperational and operational periods, but the decrease was less at the discharge Station P5, as indicated by the significant interaction term (Tables 2-2, 2-6). There has been a general decreasing trend in mean annual surface dissolved oxygen levels since 1987 although dissolved oxygen levels increased in 1996 (Figure 2-10). The reasons for these decreases are not known, but are probably related to increasing surface water temperatures (Table 2-1). A potential plant impact might be indicated by a significant decrease in dissolved oxygen at Station P5, relative to the other stations, as heated effluent reduces the oxygen content of surrounding waters. However, the observed changes are the opposite, where the discharge station has higher dissolved oxygen levels in the operational period, compared to the intake and farfield stations (Figure 2-9). Therefore, the differing patterns in surface dissolved oxygen levels between the preoperational and operational periods cannot be attributed to plant operation.

The decreases in dissolved oxygen (0.23 to 0.15 mg/l) between the preoperational and operational periods were probably not biologically important because dissolved oxygen was near saturation in both periods. Decreases of this magnitude could be important if dissolved oxygen dropped to levels that affected aquatic life. However, mean annual dissolved oxygen levels were relatively high at all stations during both the preoperational and operational periods (Table 2-2).

Surface salinity decreased significantly between the preoperational and operational periods at both the intake (P2) and discharge (P5) areas, but there were no changes at the farfield area (P7). The small decreases (0.3 to 0.2 ppt) in mean salinity at the discharge and intake areas between the preoperational and operational periods were statistically significant, but an order of magnitude less than that observed over the course of a single year (Figure 2-6). There is no evidence that these small long term changes have affected the balanced indigenous populations in either the intake or discharge areas.

The significant reductions in surface salinity observed were probably influenced by the historically low annual mean surface salinity in 1996 (Figure 2-7). These small changes were observed at the intake and discharge areas but cannot be attributed to the operation of Seabrook Station. There is no reasonable mechanism by which the withdrawal of bottom water from the intake area, and its subsequent release as heated effluent into the discharge area, can reduce surface salinity at the intake and discharge areas. The water masses in the intake and discharge areas are essentially identical, and the salinity of this water mass cannot be changed by passage through the plant.

There were no significant differences in nutrient levels between the preoperational or operational periods or among stations (Table 2-6). Nutrient levels in 1996 were within the ranges of previous years, and there is no evidence that the operation of Seabrook Station has affected nutrient levels in either the discharge or intake areas.

The results of the analyses of water quality parameters highlight the cyclical and variable nature of these parameters. Preoperational and operational patterns for all parameters were consistent (Table 2-6). Overall, no localized effects to water

Table 2-6. Summary of Potential Effects of Seabrook Station on Ambient Water Quality. Seabrook Operational Report, 1996.

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	yes	no P2 Op < Pre P5 Op < Pre P7 Op = Pre
	bottom	yes	yes
Dissolved oxygen	surface	Preop>Op	no P2 Op << Pre P5 Op < Pre P7 Op << Pre
	bottom	yes	yes
Nitrate	surface	yes	yes
Nitrite	surface	yes	yes
Ammonia	surface	yes	yes
Orthophosphate	surface	yes	yes
Total phosphate	surface	yes	yes

[a]based on ANOVA for 1987-1996, when all 3 stations were sampled concurrently
[b]Significant Preop-Op X Station term in ANOVA model

quality that can be attributed to the operation of Seabrook Station were observed.

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3.0 PHYTOPLANKTON

SUMMARY

The phytoplankton community historically has been highly variable in species composition and abundance. This variability has continued during the operational period. Taxa of the class Bacillariophyceae (diatoms) dominated the community numerically throughout most of the preoperational and operational periods and in 1996. In some years, e.g., 1992, the Prymnesiophyceae taxon *Phaeocystis pouchetii* was dominant because of its spring bloom. Such shifts in dominance between diatoms and *P. pouchetii* were also observed in 1981 and 1983 during the preoperational period. Total phytoplankton abundance and abundance of the selected species (the diatom *Skeletonema costatum*) varied from year-to-year during the study period. Community composition during the operational period was generally similar to that observed during the preoperational period. Chlorophyll *a* concentrations were also variable from year-to-year, but were independent of phytoplankton abundances. For example, during 1992 the increase in phytoplankton abundance without a corresponding increase in chlorophyll *a* concentration was likely due to the exceptionally high numbers of *P. pouchetii*, a small-celled form. Any differences in community composition or chlorophyll *a* concentrations observed during the operational periods occurred at both the nearfield and farfield stations.

The ANOVA model comparing nearfield and farfield phytoplankton assemblages showed that total abundance was similar in the preoperational and operational periods. Abundances were also similar between stations. Similar results were observed in the ANOVA model comparing nearfield and farfield abundances of *S. costatum*. Operational abundances were greater than preoperational abundances only for the model comparing P2 and P5; there were no other station differences. For chlorophyll *a* concentrations, there was no significant difference between preoperational (1987-1989) and operational periods or among stations. In all cases, the interaction between time and space (Preop-Op X Station term) was not significant, indicating no impact due to the operation of Seabrook Station.

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3.1 INTRODUCTION

The phytoplankton monitoring program was initiated to identify seasonal, annual, and spatial trends in the phytoplankton community, and 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. The objective of the study was to determine if a significant difference had occurred during the operational period for the following parameters: 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. In previous years ultraplankton taxa were identified and enumerated. Results had limited accuracy because of the small size and colonial habits of these organisms. Therefore enumeration of ultraplankton was eliminated from the program in 1995.

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 from 1978-1984 at Station P2; 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 1996. 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.

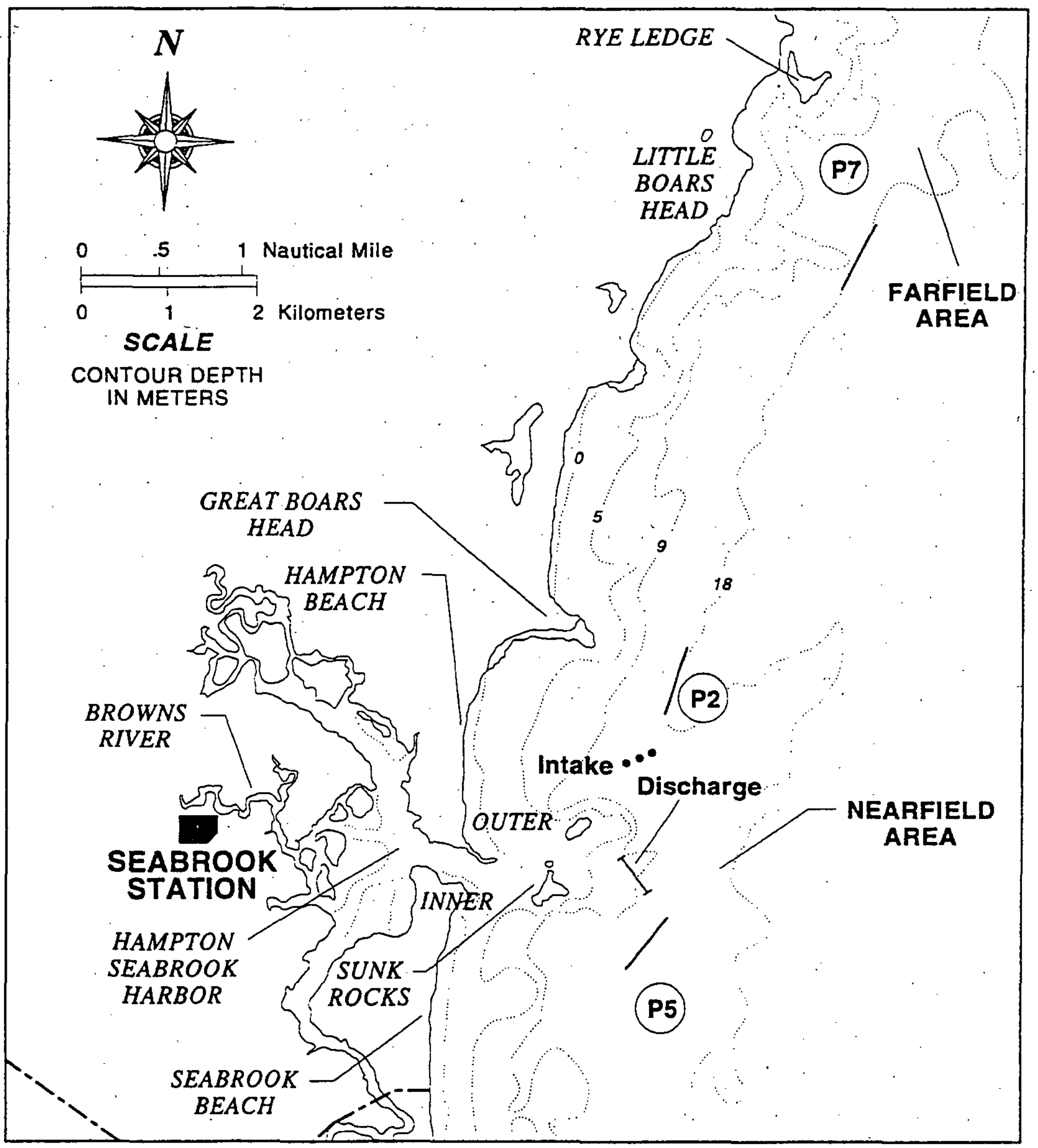
3.2.2 Laboratory Methods

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 *S. 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 taxonomic level, 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 (mg/m^3) were computed.

3.2.3 Analytical Methods

Seasonal abundance patterns of the phytoplankton assemblages during the preoperational and operational periods were compared graphically using



LEGEND

——— = phytoplankton stations

Figure 3-1. Phytoplankton sampling stations. Seabrook Operational Report, 1996.

log (x+1)-transformed monthly mean abundances for the total phytoplankton community and the selected species (*S. 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 spatial 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 effects ANOVA model 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. The mixed effects model was based on reviews of the design by Underwood (1994) and 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. 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 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, increase 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. When the F-value was significant for the interaction term (Preop-Op X Station) or class variable (Station, Preop-Op), the least squares mean procedure (SAS Institute Inc. 1985) was used to evaluate the differences among the means with a t-test at alpha ≤ 0.05. The final variance not accounted for by the above explicit sources of variation constituted the Error term. The preoperational period for each analysis was specified as the period during which at least one nearfield and one farfield station were sampled concurrently (thus maintaining a balanced model design). 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. In all cases the operational period evaluated in this report includes collections from 1991-1996. Finally, weekly mean PSP toxicity levels were arithmetically averaged over the preoperational and operational periods and presented graphically.

Table 3-1. **Summary of Methods Used in Evaluation of the Phytoplankton Community. Seabrook Operational Report, 1996.**

ANALYSIS	TAXA	STATIONS	DATES USED IN ANALYSIS[a]	DATA CHARACTERISTICS	SOURCE OF VARIATION
PHYTOPLANKTON					
Percent Composition	All	P2	1978-1984; 1991-1996	Monthly and annual arithmetic mean abundances	--
		P2,P5,P7	1996	Monthly arithmetic mean abundances	--
Abundance	All	P2,P5,P7	1978-1984; 1991-1996	Monthly log (x+1) and annual geometric mean abundances	--
	Skeletonema costatum	P2	1978-1984; 1991-1996	Monthly log (x+1) and annual geometric mean abundances	--
MANOVA	14 dominants	P2,P5,P7	1996	Monthly log (x+1) mean abundances; species <1% of total abundance not included	Station
ANOVA	All	P2,P7	1982-1984; 1991-1996	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
	Skeletonema costatum	P2,P7	1982-1984; 1991-1996	Monthly log (x+1) mean abundances	Preop-Op, Year, Month, Station
		P2,P5	1979-1981; 1991-1996	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
CHLOROPHYLL *a*					
Concentration	--	P2	1978-1989; 1991-1996	Monthly arithmetic mean concentrations	--
		P2,P5,P7	1978-1984; 1987-1989; 1991-1996	Annual arithmetic mean concentrations	--
ANOVA	--	P2,P5,P7	1987-1989; 1991-1996	Monthly arithmetic mean concentrations	Preop-Op, Year, Month, Station
PSP TOXICITY	--	--	1983-1989; 1991-1996	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: 1991-1996, all stations and parameters

3.3 RESULTS

3.3.1 Total Community

3.3.1.1 Phytoplankton

Seasonal Trends at Station P2

Operational monthly mean phytoplankton abundances at Station P2 were within preoperational 95% confidence limits during all months other than April, when the operational mean exceeded the upper preoperational confidence limit (Figure 3-2). Monthly mean abundances at P2 in 1996 varied about the preoperational means, exceeding upper confidence limits in February, March, and May, and never falling below lower confidence limits. During both the preoperational and the operational periods, two peaks in abundance were evident, one during late spring-early summer and the second during early fall. The precise timing of these peaks shifted among years, as evidenced by the wide confidence intervals in the preoperational period (Figure 3-2).

The most recognizable characteristic of the phytoplankton community offshore of the Hampton-Seabrook estuary is the dominance by

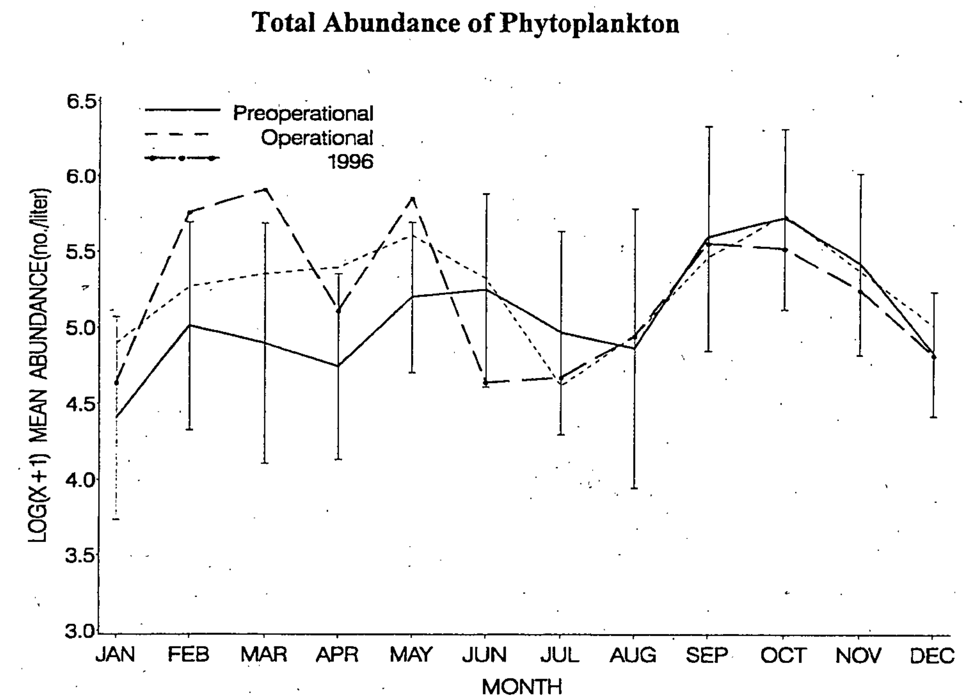


Figure 3-2. Monthly mean log(X+1) total abundance (no./L) of phytoplankton at nearfield Station P2, monthly means and 95% confidence intervals over all preoperational years (1978-1984), and monthly means over operational years (1991-1996) and 1996. Seabrook Operational Report, 1996.

diatoms (Bacillariophyceae) during most of the year. Diatoms accounted for over 60%, and often more than 90%, of the total community during most months in both the preoperational and operational periods and in 1996 (Figure 3-3). The occasional overwhelming dominance by the Prymnesiophyceae taxon *Phaeocystis pouchetii* during the early spring, typically March-May, marked the only periods of dominance by a group other than diatoms. *P. pouchetti* was not abundant during 1996. Dinophyceae (dinoflagellate) taxa were a relatively small component of the phytoplankton community (generally less than 5%) in each month during the preoperational period, and typically accounted for similar small percentages during the operational period, with some exceptions. For example, dinoflagellates accounted for 21% of the individuals in May operational collections, and more than 15% of the total individuals during June, August through October and December in 1996. The Cryptophyceae taxa were small contributors to the overall assemblage during both the preoperational and operational periods, but accounted for 20% of the individuals collected during September and 21% during October 1996. In general, the seasonal pattern of major phytoplankton group abundance observed offshore of Hampton Harbor was typical of northern temperate coastal waters (Cadée and Hegeman 1986, Marshall and Cohen 1983, Peperzak 1993). Specifically, this pattern was characterized by annual dominance by diatoms, which were most abundant in the spring and fall. Abundances of all phytoplankton were relatively low during the summer.

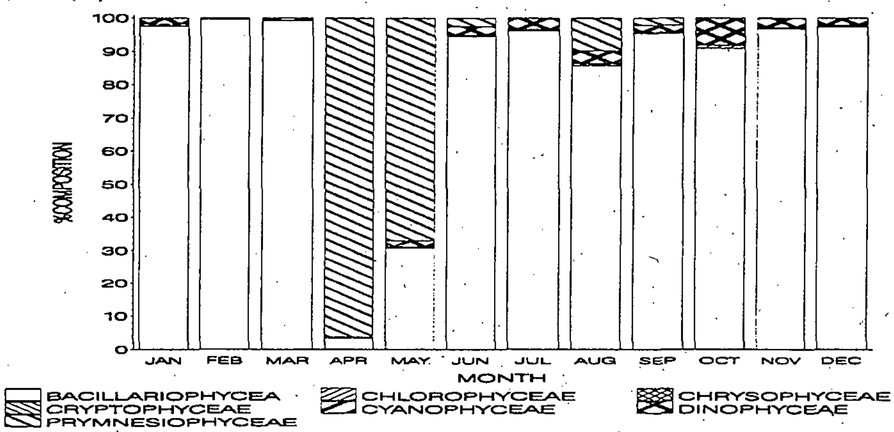
<u>Temporal Trends at Station P2</u>

Phytoplankton abundances at Station P2 shifted markedly from year-to-year throughout the study period (Figure 3-4). On average, total annual community abundances were greater during the operational period compared to the preoperational average (Table 3-2). Annual abundance at P2 during 1996 was also higher than the preoperational period mean, but relatively low compared to operational year 1992 (Figure 3-4).

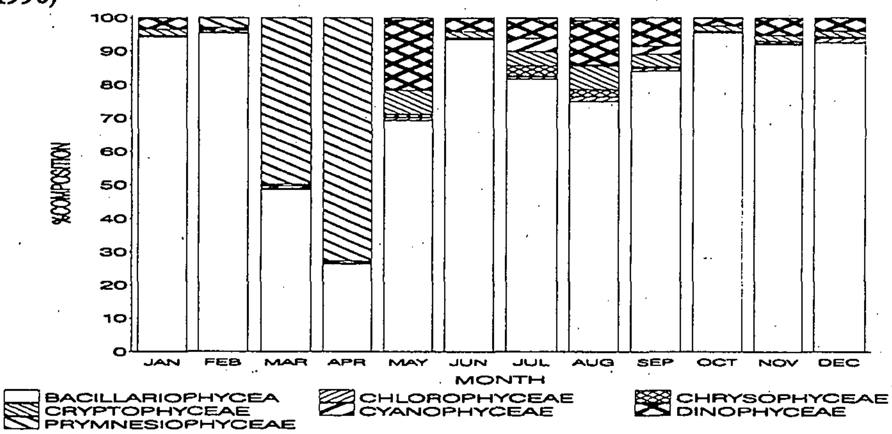
Just as diatoms have been dominant on a seasonal basis, they have also been dominant on an annual basis during most years at Station P2 (Figure 3-4). The most prevalent diatom form has historically been *S. costatum*. The diatoms, including *S. costatum*, accounted for approximately 78% of the preoperational assemblage, 71% of the operational assemblage, and 81% of the assemblage in 1996 (Table 3-3). *S. costatum* alone accounted for 35% of the preoperational assemblage, 25% of the operational assemblage, and 20% of the assemblage in 1996. During some years (1981, 1983 and 1992), *P. pouchetii* was the dominant taxon, while in other years (1982, 1984, 1991, 1993, 1995 and 1996), this species was absent or nearly absent from the assemblage (Figure 3-4).

Phytoplankton community composition is inherently variable from year to year. This is evident in the relative importance of different taxa during each period throughout this study. *S. costatum* was the dominant taxon during nearly every year of this study (Figure 3-4), but the relative abundance of other dominants varied over time (Table 3-3). Second to *S. costatum* (35%) in dominance during the preoperational period was *P. pouchetii* (17%), followed by the diatom *Rhizosolenia delicatula/fragilissima* (14%). Another diatom, *Chaetoceros socialis*, accounted for 9% of the total. Only nine other taxa, individually accounted for 1% or more of the preoperational assemblage. During the operational period, 15

Preoperational (1978-1984)



Operational (1991-1996)



1996

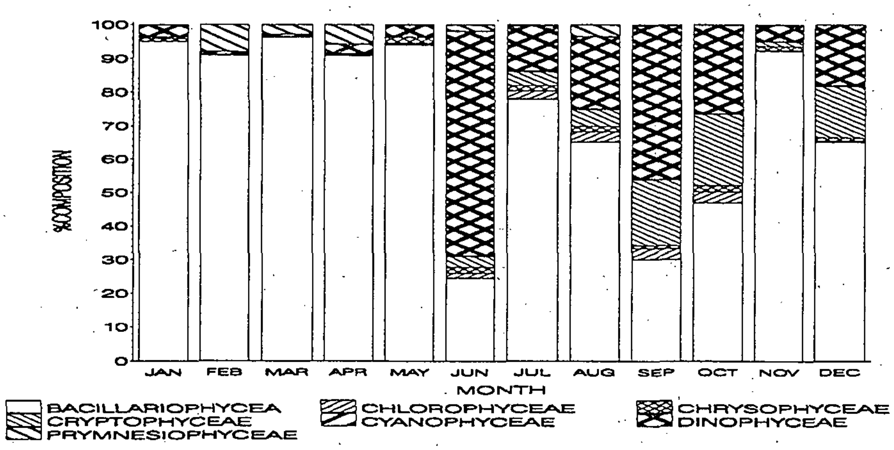


Figure 3-3. Percent composition of major phytoplankton groups at Station P2 over all preoperational (1978-1984) and operational years (1991-1996) and in 1996. Seabrook Operational Report, 1996.

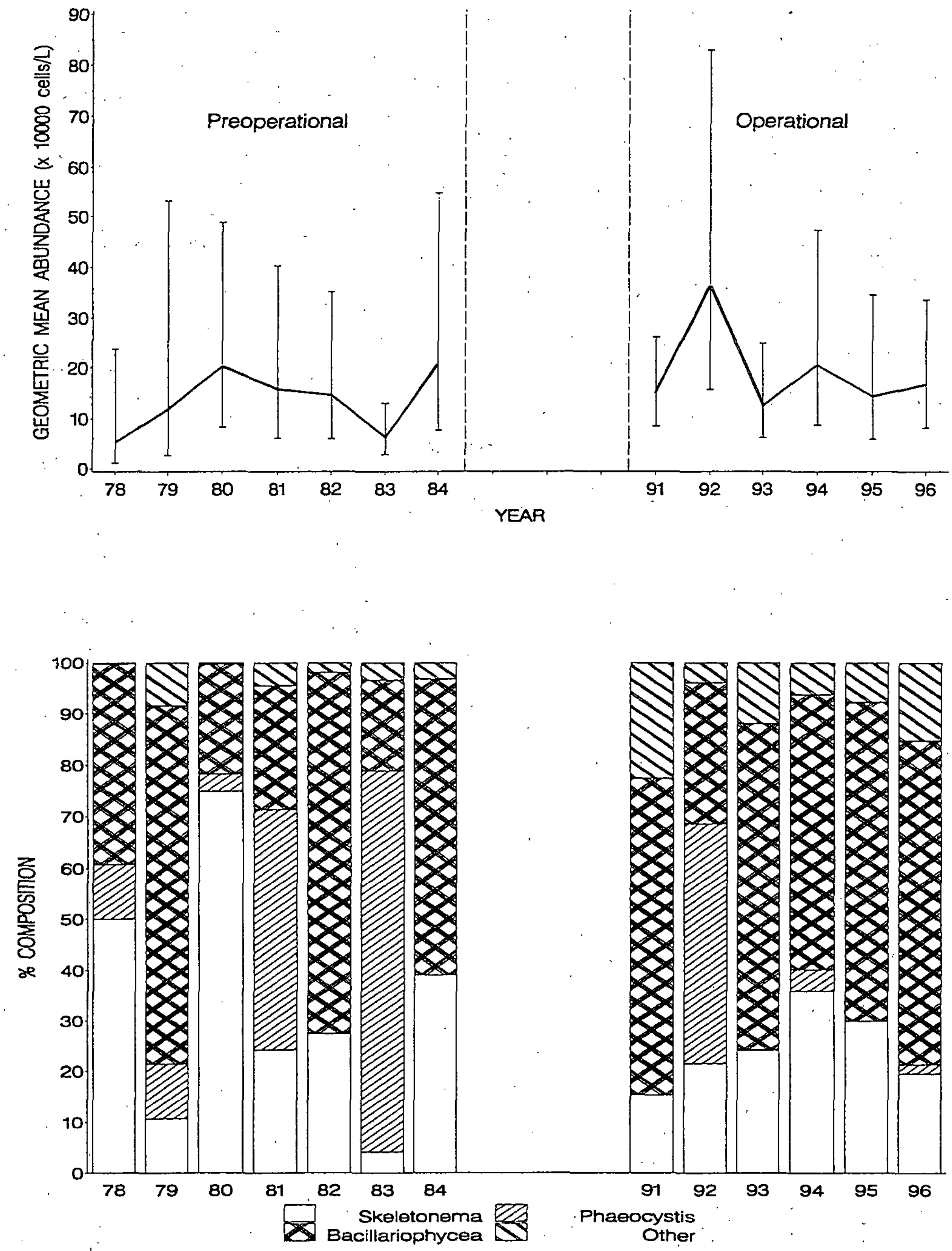


Figure 3-4. Geometric mean abundances (x 10^4 cells/L) and 95% confidence intervals of annual assemblages, and percent composition of four selected phytoplankton groupings at Station P2 during each year of the preoperational and operational periods. Seabrook Operational Report, 1996.

Table 3-2. Geometric Mean Abundance (X 10^4 Cells/L) of Phytoplankton ($\geq 10\mu m$) and *Skeletonema costatum*, and Mean Chlorophyll *a* Concentrations (mg/m^3) and Coefficient of Variation (CV,%) for the Preoperational and Operational (1991-1996) Periods, and 1996 Geometric Means. Seabrook Operational Report, 1996.

	PREOPERATIONAL			OPERATIONAL		1996
STATION	$\bar{x}$[a]	CV[b]	(YEARS)[c]	$\bar{x}$[a]	CV	$\bar{x}$
PHYTOPLANKTON						
P2	11.9	4.9	(78-84)	17.8	3.2	16.6
P5	12.6	4.0	(78-81)	20.2	3.9	17.1
P7	9.9	4.3	(82-84)	16.5	3.0	16.9
CHLOROPHYLL *a*						
P2	0.78	68.1	(87-89)	0.79	75.5	0.64
P5	0.88	70.8	(87-89)	0.81	69.4	0.70
P7	0.75	63.4	(87-89)	0.78	63.0	0.68
SKELETONEMA COSTATUM						
P2	0.2	45.1	(78-84)	0.7	30.5	1.1
P5	0.1	69.0	(78-81)	0.6	32.4	0.9
P7	0.2	32.6	(82-84)	0.5	37.1	1.3

[a]Mean of annual means.
[b]CV = coefficient of variation.
[c]( ) = preoperational years.

taxa individually accounted for 1% or more of the assemblage, led by *S. costatum* (25%), *P. pouchetii* (18%), and *Leptocylindrus minimus* (10%). During the preoperational period, *Leptocylindrus minimus* accounted for only 2% of the assemblage. Similarly, *R. delicatula/ fragilissima*, third most abundant during the preoperational period, accounted for only 3% of the operational assemblage. Fourteen taxa each accounted for 1% or more of the 1996 assemblage. *S. costatum* (20%) was again the most dominant taxon. The diatoms *Chaetoceros* sp. (17%), *Thalassiosira* sp. (15%), and *Nitzschia* sp. (12%) were secondary dominants. Two taxa that have not been typically abundant occurred in relatively high proportions in 1996, unspeciated dinoflagellates (6%) and Cryptomonida (4%).

All non-dominant taxa accounted for less than 5% of the preoperational assemblage, 7% of the operational and 6% of the 1996 assemblages (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 spatial relationships during the preoperational period were maintained

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 (1991-1996), and 1996 at Nearfield Station P2. Seabrook Operational Report, 1996.

		PREOPERATIONAL		OPERATIONAL		1996	
CLASS	TAXON	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION	ABUNDANCE[a]	PERCENT COMPOSITION
Dinophyceae	Dinophyceae	0.5	0.7	0.5	0.9	2.2	5.6
	Prorocentrum balthicum	0.0	0.0	0.1	0.2	0.5	1.4
	Prorocentrum micans	0.8	1.1	0.1	0.2	<0.1	<0.1
	Gymnodiniidae[b]	<0.1	<0.1	1.4	2.7	0.5	1.3
	Gymnodinium/Gyrodinium	0.3	0.4	0.3	0.5	0.1	0.3
Cryptophyceae	Cryptomonida	<0.1	<0.1	1.1	2.1	1.5	3.8
Prymnesiophyceae	*Phaeocystis pouchetii*	11.8	17.1	9.6	18.3	0.7	1.8
Bacillariophyceae	Bacillariophyceae	0.8	1.1	0.9	1.6	0.2	0.5
	Asterionella glacialis	<0.1	<0.1	1.0	2.0	0.0	0.0
	Cerataulina bergonii	0.9	1.4	0.1	0.2	0.0	0.0
	Chaetoceros debilis	2.1	3.1	0.4	0.9	0.9	2.4
	Chaetoceros socialis	6.5	9.4	2.1	4.0	1.8	4.4
	Chaetoceros sp.	1.2	1.7	2.5	4.7	6.7	16.9
	Cylindrotheca closterium	<0.1	<0.1	0.8	1.5	0.7	1.7
	Leptocylindrus danicus	0.4	0.6	2.4	4.7	0.1	0.2
	Leptocylindrus minimus	1.0	1.5	5.4	10.4	2.1	5.3
	Nitzschia sp.	3.2	4.6	2.4	4.6	5.0	12.4
	Rhizosolenia	9.9	14.4	1.4	2.8	0.1	0.3
	delicatula/fragilissima	24.3	35.4	13.0	25.0	7.8	19.5
	Skeletonema costatum	1.3	1.9	1.8	3.5	0.9	2.2
	Thalassionema nitzschioides	1.9	2.7	2.7	5.2	6.0	15.1
	Thalassiosira sp.						

[a]Mean abundance over all year(s) in each period and in 1996; taxa accounting for <1% of total abundance in each time period not presented, therefore percent composition as shown does not sum to 100.
[b]Previoiusly called *Oxytoxum* sp.

during the operational period. Preoperational geometric mean abundances at Stations P2 (1978-1984) and P5 (1978-1981; Table 3-2), were similar to each other and higher than abundances at P7 (1982-1984). Mean abundances at each station were higher during the operational period and in 1996 compared to the preoperational period. Analysis of variance comparing nearfield (P2) and farfield (P7) phytoplankton abundances indicated that the apparent increase in abundance during the operational period was not significant (Table 3-4). There were no significant differences among stations, and the interaction term (Preop-Op X Station) was not significant, suggesting that the operation of Seabrook Station has had no effect on phytoplankton abundances.

Species composition was generally similar among the three stations in 1996 (Table 3-5). Four taxa, *S. costatum*, *Nitzschia* sp, *Chaetoceros* sp., and *Thalassiosira* sp. dominated at each station, although their relative abundances varied spatially. Fourteen taxa representing four classes each accounted for 1% or more of the assemblage at at least one of the three stations. All but four of these taxa (*P. pouchetii*, Gymnodiniidae, Dinophyceae, and Cryptomonida) were diatoms. The abundances of these fourteen dominant taxa were not significantly different among the three stations in 1996 ($p = 0.42$, Wilkes' Lambda as computed by MANOVA).

3.3.1.2 Chlorophyll *a* Concentrations

During both the preoperational and operational periods, monthly arithmetic mean total chlorophyll *a* concentrations at P2 exhibited an early spring increase, mid-summer decline, and prominent peak in fall (Figure 3-5). Monthly mean operational chlorophyll *a* concentrations were lower than preoperational mean concentrations (based on all preoperational years) in all months except January, and lower than preoperational lower 95% confidence limits in June, November and December (Figure 3-5). In 1996 the mean concentration at P2 was lower than preoperational means throughout the year and below the preoperational lower 95% limits during June, and October through December.

Arithmetic mean chlorophyll *a* concentrations were similar between the recent preoperational (1987-1989) and operational periods, although slightly lower in 1996 (Table 3-2). The ANOVA model detected no significant differences in chlorophyll *a* concentrations either among the three stations or between the preoperational and operational periods (Table 3-4). Overall, there was no significant interaction between preoperational or operational period and station (Preop-Op X Station term, Table 3-4), indicating that the operation of Seabrook Station has had no effect on chlorophyll *a* concentrations in the study area.

On an annual basis, chlorophyll *a* concentrations and phytoplankton abundances appear not to be always directly related. The differences observed in trends between phytoplankton abundances and chlorophyll *a* concentrations were likely due to differences among dominant 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 *P. pouchettii* on several dates (Figure 3-4). While *P. pouchetii* had a large effect on phytoplankton abundances, it had only a minor effect on chlorophyll *a* concentrations (NAI 1992) since it is a small-celled taxon (Lee 1980). Despite these differences, there is evidence of a relationship between chlorophyl *a* concentrations and phytoplankton

Table 3-4. Results of Analysis of Variance Comparing Abundances Of Total Phytoplankton, *Skeletonema costatum*, and Chlorophyll *a* Concentrations among Stations P2, P5 and P7 During Preoperational and Operational (1991-1996) Periods. Seabrook Operational Report, 1996.

SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS
PHYTOPLANKTON: P2 VS P7 (PREOP = 1982-1984; OP = 1991-1996)[a]				
Preop-Op[b]	1	1.19	1.43 NS	
Year (Preop-Op)[c]	7	0.86	1.38 NS	
Month (Year)[d]	99	0.59	21.14***	
Station	1	0.16	4.62 NS	
Preop-Op X Station[e]	1	0.04	0.60 NS	
Station X Year (Preop-Op)	7	0.06	2.17*	
Error	99	0.03		
CHLOROPHYLL *a*: P2, P5, P7 (PREOP = 1987-1989; OP = 1991-1996)[a]				
Preop-Op[b]	1	<0.01	<0.01 NS	
Year (Preop-Op)[c]	7	1.02	1.33 NS	
Month (Year)[d]	99	0.79	15.00 NS	
Station	2	0.17	2.73 NS	
Preop-Op X Station[e]	2	0.06	1.98 NS	
Station X Year (Preop-Op)	14	0.03	0.60 NS	
Error	198	0.05		
***SKELETONEMA COSTATUM*: P2 VS. P7 (PREOP = 1982-1984; OP = 1991-1996)[a]**				
Preop-Op[b]	1	9.77	3.78 NS	
Year (Preop-Op)[c]	7	2.67	0.92 NS	
Month (Year)[d]	99	2.79	14.59***	
Station	1	0.85	3.99 NS	
Preop-Op X Station[e]	1	0.22	0.71 NS	
Station X Year (Preop-Op)	7	0.31	1.61 NS	
Error	99	0.19		
***SKELETONEMA COSTATUM*: P2 VS. P5 (PREOP = 1979-1981; OP = 1991-1996)[a]**				
Preop-Op[b]	1	12.38	8.36*	Op>Preop
Year (Preop-Op)[c]	7	1.70	0.42 NS	
Month (Year)[d]	98	3.99	14.07***	
Station	1	1.04	17.49 NS	
Preop-Op X Station[e]	1	0.07	.023 NS	
Station X Year (Preop-Op)	7	0.31	1.10 NS	
Error	98	0.28		

[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 period.
[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 ($0.001 \geq p$)

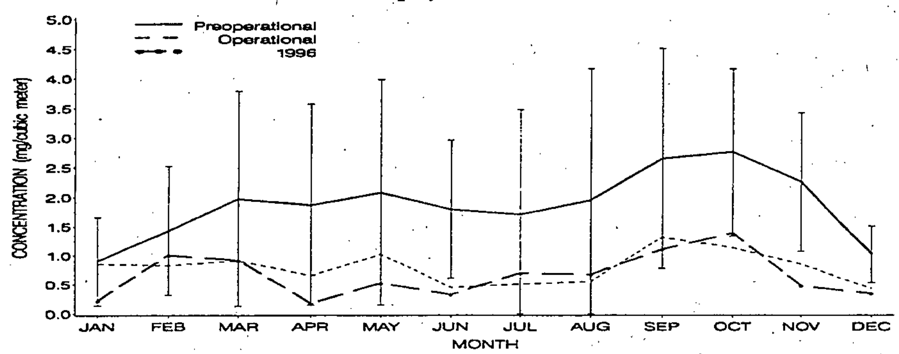
Table 3-5. Phytoplankton (≥10μm) Species Composition by Station in 1996. Seabrook Operational Report, 1996.

CLASS	TAXA	P2	P5	P7
PHYTOPLANKTON[a]				
Cryptophyceae	Cryptomonida	3.8	3.3	3.9
Dinophyceae	Dinophyceae	5.6	5.0	5.7
	Gymnodiniidae[b]	1.3	0.7	0.9
	Prorocentrum balthicum	1.4	0.7	0.7
Bacillariophyceae	*Chaetoceros debilis*	2.4	1.4	1.5
	Chaetoceros socialis	4.4	2.1	5.8
	Chaetoceros sp.	16.9	12.5	14.9
	Cylindrotheca closterium	1.7	1.2	1.3
	Leptocylindrus minimus	5.3	7.6	7.6
	Nitzschia sp.	12.4	27.9	12.5
	Skeletonema costatum	19.5	22.7	27.0
	Thalassionema nitzschioides	2.2	1.5	1.4
	Thalassiosira sp.	15.1	9.2	10.7
Prymnesiophycea	*Phaeocystis pouchetti*	1.8	0.6	1.6

[a]Presents only taxa accounting for ≥1% of total abundance
[b]Previously called *Oxytoxum* sp.

a.

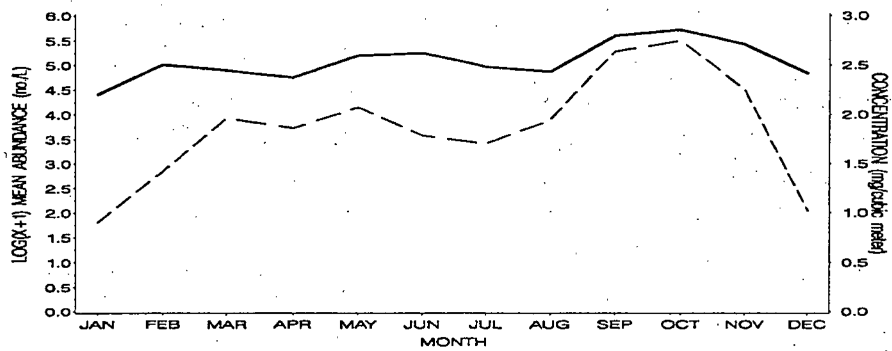
Chlorophyll *a*



b.

Abundance
Chlorophyll *a*

Preoperational Years



Operational Years

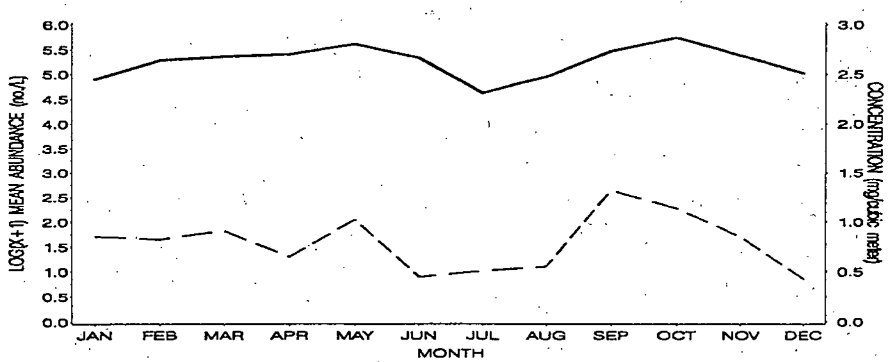


Figure 3-5. (a) Mean monthly chlorophyll *a* concentrations and 95% confidence intervals at Station P2 over preoperational years (1979-1989) and monthly means over operational years (1991-1996) and 1996; (b) mean monthly chlorophyll *a* concentrations and phytoplankton log(x+1) abundances during the preoperational and operational years. Seabrook Operational Report, 1996.

abundances 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

The diatom *S. 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). The operational time series exhibited a similar seasonal pattern, although abundances were generally higher than during the preoperational period. Operational means exceeded preoperational upper 95% confidence limits in April and May (Figure 3-6). In 1996, monthly *S. costatum* abundances followed the same historic seasonal pattern. Monthly means in 1996 exceeded preoperational upper 95% confidence limits from March through May (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 the comparison of P2 and P7 there were no significant differences in abundance between preoperational and operational periods (Table 3-4). There were no significant differences in *S. costatum* abundances between P2 and P7. The interaction between period and station for the P2-P7 model was not significant, suggesting that station operation has not affected *S. costatum* abundances at Stations P2 and P7.

Operational period abundances of *S. costatum* were significantly higher than preoperational abundances at Stations P2 and P5 (Tables 3-2, 3-4). Station differences were not significant in the P2-P5 model, nor was the interaction term (Table 3-4), indicating no effect due to the operation of Seabrook Station.

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 *M. edulis* and periodically above the closure limit then in effect (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 1992, 1993), and during 1993 and 1994 PSP occurrences were recorded only during May and early June (NAI and NUS 1994, NAI 1995; Figure 3-7). PSP was detected on three occasions in late May in 1995, but levels were below closure limits each time. PSP levels were below detection limits during the entire sampling period in 1996 and there were no closures of the Hampton Harbor flats related to PSP in 1996.

3.4 DISCUSSION

3.4.1 Community Interactions

The operation of Seabrook Station has had no demonstrable effect on the phytoplankton community (Table 3-6). Seasonal patterns of total abundance, chlorophyll *a* concentrations, and the occurrence of dominant taxa in the phytoplankton assemblage established in the preoperational period have remained unchanged over the operational period (Figures 3-2, 3-3, 3-4). The phytoplankton assemblage was dominated by diatoms (Bacillariophyceae), both annually and seasonally during both periods. In some years,

Abundance of *Skeletonema costatum*

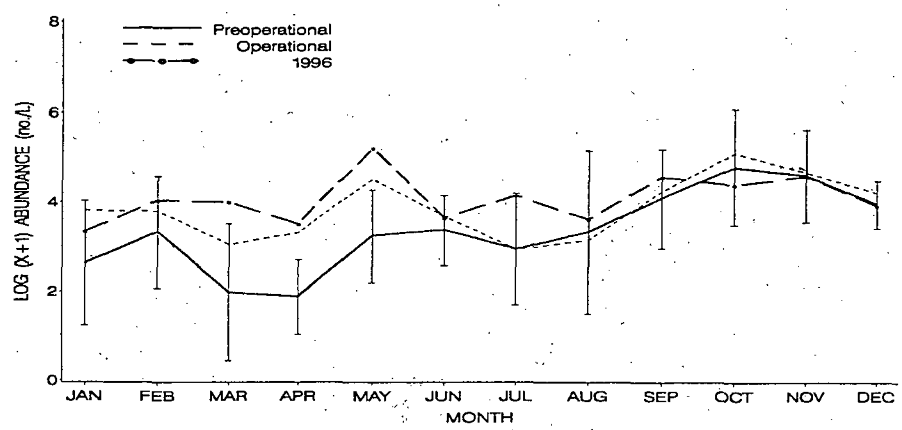


Figure 3-6. Log (x+1) abundance (no./L) of *Skeletonema costatum* at nearfield Station P2; monthly means and 95% confidence intervals over all preoperational years (1978-1984) and monthly means for the operational years (1991-1996) and 1996. Seabrook Operational Report, 1996.

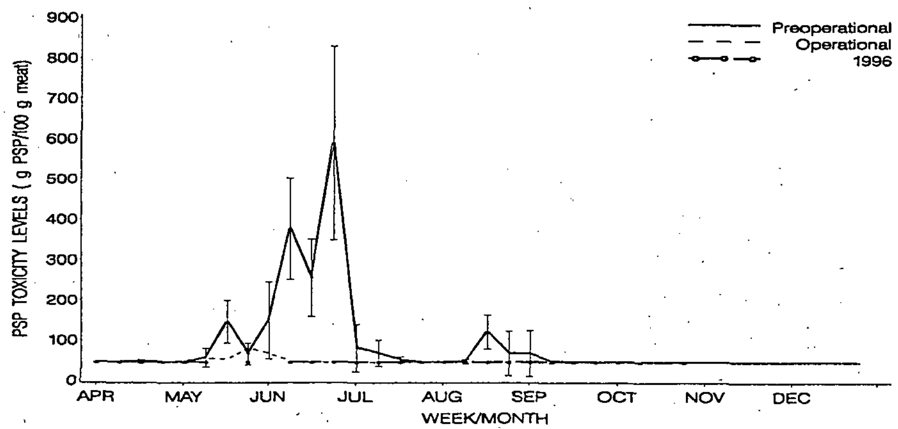


Figure 3-7. Weekly paralytic shellfish poisoning (PSP) toxicity levels in *Mytilus edulis* in Hampton Harbor, mean and 95% confidence intervals over preoperational years (1983-1989) and monthly means during operational years (1991-1996) and in 1996. Data provided by the State of New Hampshire. Seabrook Operational Report, 1996.

Table 3-6. Summary of Potential Effects (Based on ANOVA) of Operation of Seabrook Station on the Phytoplankton Community. Seabrook Operational Report, 1996.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PRE-OPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
Phytoplankton abundance	Op=Preop	yes
Skeletonema costatum	P2 vs. P7, Op=Preop	yes
	P2 vs. P5, Op>Preop	yes
Chlorophyll *a*	Op=Preop	yes

however, *P. pouchetii* accounted for as high a proportion of the total individuals at each station as did total diatoms (Figure 3-4). On average, *P. pouchetii* composed the same proportion of the operational assemblage (18%) as the preoperational assemblage (17%;Table 3-3). The community composition changed little between the preoperational and operational periods (Table 3-3). On a year-to-year basis, however, assemblages differed considerably (Figure 3-4). 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 (*S.costatum)*, or total biomass as estimated by chlorophyll *a* concentrations. The ANOVA model comparing nearfield and farfield phytoplankton assemblages showed that average total abundance remained similar between the preoperational and operational periods and among stations over all years (Table 3-4).

Similar results were observed in the ANOVA models comparing nearfield and farfield abundances of *S. costatum*. Average operational abundances were similar to recent preoperational abundances (1982-1984) for the nearfield-farfield comparison (P2 versus P7). No differences in abundance between stations were apparent between the preoperational and operational periods. The ANOVA comparing the intake (P2) and discharge (P5) stations found that abundance of *S. costatum* was significantly higher in the operational than the preoperational period (1979-1981), although there were no differences between the two stations. There was no significant difference between recent preoperational (1987-1989) and operational chlorophyll *a* concentrations or among all stations (Table 3-2). In all cases, the interaction between Preop-Op and Station (Table 3-4) was not significant, indicating no impact to the phytoplankton community due to the operation of Seabrook Station.

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. Members of the genus *Gonyaulax* have occurred infrequently in Seabrook samples in previous years. Prior to 1995, *Alexandrium* was not differentiated from *Gonyaulax*. *Alexandrium ostenfeldii*, described by Hansen et al. (1992) as weakly toxic, occurred at Station P2 in March, P7 in April and P5 in May of 1996 (NAI 1997).

It is currently thought that *Alexandrium* spp. blooms are transported to this region on coastally-trapped buoyant plumes derived from the Androscoggin and Kennebec Rivers in 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 result of the operation of Seabrook Station.

3.4.2 Effects of Plant Operation

The phytoplankton community exhibited high variability both seasonally and interannually during the entire study period. The highly variable population dynamics of the phytoplankton community were influenced by both physical (e.g., changes in seasonal temperature and irradiance cycles) and chemical (e.g., salinity, nutrients and dissolved oxygen as affected by precipitation and runoff) factors, and by the inherently rapid turnover rate of the phytoplankton community. However, all documented characteristics of the phytoplankton community in the vicinity of Seabrook Station indicate that the community changes that have occurred over time have occurred at all three stations (Table 3-6). Therefore there is no evidence indicating that the operation of Seabrook Station had a demonstrable effect on any aspect of the local phytoplankton community.

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APPENDIX TABLE 3-1. CHECKLIST OF PHYTOPLANKTON TAXA CITED IN THIS REPORT. SEABROOK OPERATIONAL REPORT, 1996.

BACILLARIOPHYCEAE	*Asterionella glacialis* Castracane (syn. *A. japonica* Cleve)
	Cerataulina bergonii H. Péragallo
	Chaetoceros sp.
	Chaetoceros debilis 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	Cryptomonida
DINOPHYCEAE	*Alexandrium* sp.
	Prorocentrum balthicum
	Prorocentrum micans Ehrenberg
	Gymnodiniidae[a]
PRYMNESIOPHYCEAE	*Phaeocystis pouchettii* (Hariot) Lagerheim

[a]previously called *Oxytoxum* sp.

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SUMMARY

Microzooplankton have historically shown a distinct seasonal pattern that relates to the changing abundances of the dominant taxa, *Pseudocalanus* sp., *Oithona* sp., and copepod nauplii. Seasonal patterns during the operational period were generally similar to those observed during the preoperational period. No significant differences in community composition were detected among stations. Record high abundances in one of the three preoperational years (1983) may have contributed to the significant Preop-Op X Station interaction term detected for copepodite *Eurytemora* sp. However, since the anomalous year was in the preoperational period, and mean abundance at each station was similar during all other years, the significant interaction is probably not due to Station operation. Abundances of the other selected species lifestages either remained unchanged or had similar changes at both stations.

The umboned bivalve larval assemblage was defined by varying abundances of the dominants *Hiatella* sp., *Mytilus edulis* and *Anomia squamula*. Community composition changed slightly during the operational period. These changes were restricted to May and reflected varying abundances of *Hiatella* sp. and *M. edulis*. Operational period abundances were higher than preoperational abundances. These changes occurred at both the nearfield stations and Station P7, indicating no effect due to the operation of Seabrook Station. Entrainment sampling in 1996 indicated that unusually large numbers of larvae were entrained in August and September. The total numbers of larvae entrained this year were much higher than all previous years. This was a result of higher than average abundances of *M. edulis* and *A. squamula* larvae in the nearshore waters and relatively high cooling water usage. However, the nearshore community has remained relatively stable over time and there is no evidence that entrainment has resulted in decreased numbers of bivalve larvae in nearshore waters.

For purposes of analysis, the macrozooplankton community was divided into two components: a holoplankton and meroplankton component dominated by the copepods *Calanus finmarchicus*, *Centropages typicus*, *Pseudocalanus* sp., and *Temora longicornis*, and the larval stages of decapods and barnacles; and a demersal plankton component, benthic organisms which venture into the water column, represented by mysids, amphipods and cumaceans and tychoplankton, such as harpacticoids. Seasonally, differences were detected for the holoplankton and meroplankton community component during the operational period. Variation in the winter holoplankton and meroplankton community was observed. The demersal plankton community was similar in both periods. Station differences were also detected for both macrozooplankton components. Changes in community composition that occurred during the operational period were similar among stations, including Station P7, suggesting that factors other than the operation of Seabrook Station were affecting the macrozooplankton communities. Of the four selected species, only the abundances of adult *Calanus finmarchicus* showed a significant Preop-Op X Station interaction. Abundances decreased at all three stations (P2, P5 and P7), but the decrease at Station P7 was greater. However, in terms of rank and, except for 1993, changes in magnitude of annual abundance, the relative relationship among the three stations was similar in both preoperational and operational periods. Therefore, the significant interaction term was probably not due to Seabrook Station operation.

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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, most likely to not be affected by plant operation, was selected as a farfield or control site. Initial monitoring prior to plant operations 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, the annual number of bivalve larvae entrained in the plant's cooling water system was estimated.

4.2 METHODS

4.2.1 Field Methods

4.2.1.1 Microzooplankton

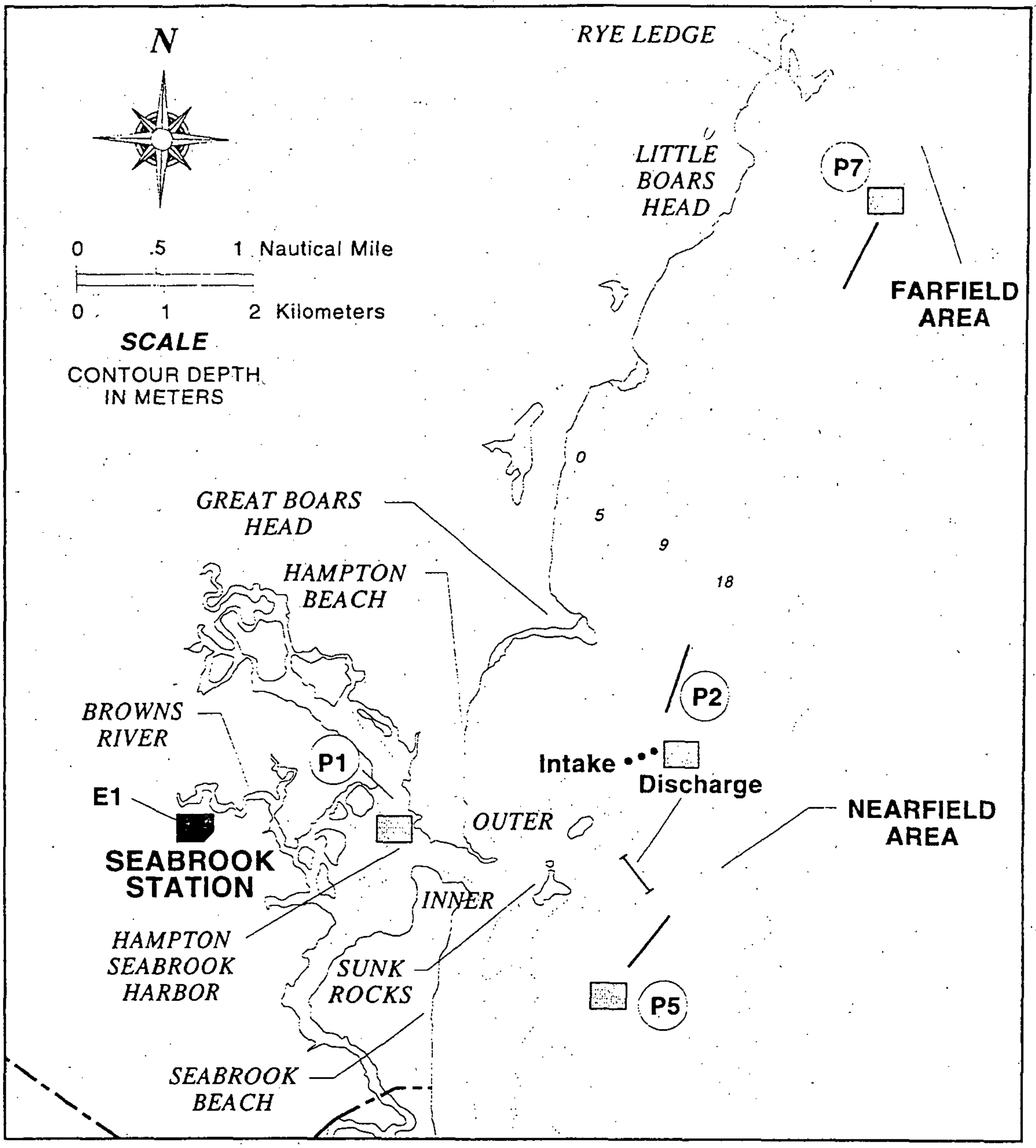
Microzooplankton were collected twice a month from March through November and monthly from December through February at the intake (P2), discharge (P5) and farfield (P7) stations (Figure 4-1). Sampling at all three stations occurred from July through December 1986 and from April 1990 through December 1996. In addition, Station P2 was sampled from January 1978 through December 1984 and Station P7 was sampled from January 1982 through December 1984. Four replicate samples were collected by pump at both one meter below the surface and two meters above the bottom at each station on each sampling date. Discharge from the pump 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 generally averaged 150 liters. 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 the third week in 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, but 1985 samples were not processed. Station P1 was added in July 1986. Samples were collected at Station P5 from July through December 1986 and April 1988 through October 1996. Two simultaneous oblique tows were usually taken at each station. In cases when nets became clogged during oblique tows, vertical tows were taken. Volume filtered generally averaged 9 m^3 for oblique tows and 3 m^3 for vertical tows. 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 Bivalve Larvae Entrainment

Bivalve larvae entrainment sampling was conducted weekly from the third week in April through October by NAESCO personnel within the circulating water pumphouse at Seabrook Station from July 1986 to June 1987 and from June 1990 to October 1996. Three replicates



LEGEND

——— = zooplankton stations

□ = bivalve larvae stations

E1 = Seabrook Entrainment Station

Figure 4-1. Plankton and entrainment sampling stations. Seabrook Operational Report, 1996.

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, 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 collected weekly in 1996 from the third week in April through the fourth week in October.

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. 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 1996 at Stations P2, P5, and P7 (Figure 4-1). Station P2 was also sampled from January 1978 through December 1984, Station P5 from January 1978 through December 1981, and Station P7 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, generally averaged 500 m^3 for 10-minute tows and 200 m^3 for 5-minute tows. 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 microzoo- plankton; the remaining two replicates were archived and stored as "contingency" samples. Samples were 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

All bivalve larvae samples collected at each station were analyzed, no samples were archived as contingency samples. 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. Umboned larvae were identified and enumerated with a dissecting microscope from an established species list. Specimens of other species were enumerated as Bivalvia. Samples collected in 1985 were analyzed for *Mytilus edulis* and *Mya arenaria* only.

4.2.2.3 Macrozooplankton

Prior to 1996, macrozooplankton were analyzed from three of the four tows (randomly selected) at each station. In 1996, only the first replicate was analyzed. 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. Samples with low copepod abundance, which would otherwise require concentration to very small volumes, making efficient subsampling with the Hensen-Stempel pipette difficult, were 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. The selected species *Calanus finmarchicus* was identified to developmental stage, copepodite or adult. 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. 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 inverse of 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 was evaluated by numerical classification and multivariate analysis of variance

(MANOVA) for each component of the zooplankton community. The data set was reduced by eliminating rarely occurring organisms and some general taxa (Table 4-1). Abundance data from each replicate was $\log_{10}(x+1)$ transformed prior to use. Log transformed data reduced the relative contribution of very abundant species in numerical classification and provided data more closely approximating a normal distribution for the MANOVA model.

Temporal and spatial changes in the community structure were evaluated using numerical classification techniques (Boesch 1977). This technique forms groups of stations and 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. Taxa with high abundances largely determine the inter-collection resemblances when using the Bray-Curtis similarity coefficient in numerical classification (Boesch 1977). Specifically, collections would form groups based largely on the abundance of the dominant taxa. 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 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 1996) 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 nearfield 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.

A mixed effects multivariate analysis of variance (MANOVA, Harris 1985) was used to assess the abundances of all members of a community simultaneously for differences between periods (preoperational and operational), and stations P2, P5 and P7 (Table 4-1). The interaction term (Station X Period) was used to determine if there was an impact from plant operation. The random temporal effects, month (weekly for bivalve larvae) and year were nested within period. Probabilities associated with the Wilks' Lambda test statistic (SAS 1985) were used to interpret results.

The analytical methods for the microzooplankton community differed from the methods used for bivalve larvae and macrozooplankton because a complete year with sampling concurrent at all three stations did not occur in the preoperational period. Station P2 was used for temporal analysis in numerical classification because it had the longest preoperational sampling history and was situated near the plant intake. The MANOVA used only 1996 collections to test station differences. Historically, there have been few differences in planktonic species assemblages among the intake, discharge and farfield stations. Continuation of this trend during plant operation would suggest that there were no effects from plant operation on the microzooplankton community. Microzooplankton abundances were aver-

Table 4-1. Summary of Methods Used in Analysis of Zooplankton Communities and Selected Species. Seabrook Operational Report, 1996.

ANALYSIS	TAXON	LIFESTAGE	STATIONS	DATES USED IN ANALYSIS	DATA CHARACTERISTICS[a]	SOURCE OF VARIATION IN (M)ANOVA
MICROZOOPLANKTON						
Numerial classification	36 dominants	--	P2	1978-1984, 7/86-12/86 4/90-12/96	$\overline{x}$ of surface and bottom; species excluded with frequency of occurrence <10%	--
MANOVA	31 dominants	--	P2 P5 P7	1996	$\overline{x}$ 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; 1991-1996	Monthly mean, surface, and bottom	Preop-Op, Station, Year, Month
BIVALVE LARVAE						
Numerical classification	All taxa except Bivalvia	--	P2 P5 P7	1988-1996	Weekly $\overline{x}$, weeks adjusted to a four-week month, half-monthly mean	--
MANOVA	All taxa except Bivalvia	--	P2 P5 P7	1988-1996[c]	Same as above	Preop-Op, Station, Year, Week
ANOVA	Selected species: *Mytilus edulis*	--	P2 P5 P7	1988-1996[c]	Same as above	Preop-Op, Station, Year, Week

(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	Demersal 24 dominants Holo/mero: 50 dominants[d]	--	P2 P5 P7	1986-1996	Monthly $\bar{x}$. Deleted taxa occurring in <10% of 1987-1996 sampling periods, Polychaeta, Hirudinea and Mysidacea	--
MANOVA	Demersal 24 dominants Holo/mero: 50 dominants[d]	--	P2 P5 P7	1987-1996[c]	Same as above	Preop-Op, Station, Year, Month
ANOVA	Selected species:					
	Calanus finmarchicus	C,A[b]	P2 P5 P7	1987-1996[c]	Monthly $\bar{x}$	Preop-Op, Station, Year, Month
	Cancer sp.[e]	L				
	Carcinus maenas[f]	L				
	Crangon septemspinosa	L				
	Neomysis americana	All				

[a]All data log (x+1) transformed at replicate level
[b]C = copepodite; A = adult; N = nauplii; L = larvae
[c]1990 excluded
[d]*Eualus* sp., *Lebbeus* sp. and *Spirontocaris* sp. lumped together as Hippolytidae in 1994.
[e]*Cancer* spp. discussed in Section 8.0
[f]*Carcinus maenas* larvae are essentially absent for 7 of 12 months, therefore a peak period of June-October only was analyzed.

aged over surface and bottom collections for all analyses.

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). The demersl plankton includes benthic species which migrate into the water column on a regular basis (e.g., *Neomysis americana*) and tychoplanktonic species, organisms living on or near the bottom which are suspended by currents (e.g., most Harpacticoids). Because of these behavioral differences, as well as large differences in abundances, macrozooplankton species were categorized into holoplankton and meroplankton species or demersal species prior to statistical analysis. The same types of analyses were performed on each group of species.

For the 1996 analysis, the microzooplankton and macrozooplankton taxa lists were re-evaluated and taxa were selected based on percent frequency of occurrence in all preoperational and operational years combined (Table 4-1). Also some macrozooplankton taxa were reallocated between the two component groups. These factors and the addition of the current years data altered the groupings presented in the numerical classification.

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 1996 geometric means and coefficients of variation (Sokal and Rohlf 1981) were tabulated. Monthly $\log_{10}$ (x+1) means and their 95% confidence limits for the preoperational period were compared graphically to the monthly means for 1996 and the operational period 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 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 date 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). As collections from 1990 occurred during the transition from preoperational to operational periods, they were excluded from the analysis. Some species (e.g. all bivalve larvae, *Carcinus maenas*) were seasonally abundant (peak periods), often rare or absent at other times of the year. Data from only the peak periods were used in analysis of variance and to compute operational, preoperational, and 1996 geometric means for those species.

4.3 RESULTS AND DISCUSSION

4.3.1 Microzooplankton

4.3.1.1 Community

Preoperational Community

The preoperational microzooplankton community at Station P2 as defined by numerical classification showed a recurrent seasonal pattern (Figure 4-2). Four taxa, *Oithona* sp., Copepoda nauplii, *Pseudocalanus/Calanus* nauplii and *Pseudocalanus* sp., dominated collections and determined the seasonal groups (Table 4-2).

Oithona sp. dominated a low abundance group (Group 1), which occurred regularly in January and intermittently from October through April. Copepoda and *Pseudocalanus/Calanus* nauplii, *Pseudocalanus* sp., *Microsetella norvegica,* tintinnids and foraminiferans were also common. Abundances increased in the late winter and spring, distinguishing Group 2. This winter and spring group was dominated by *Oithona* sp., the nauplii of Copepoda and *Pseudocalanus/Calanus*, and *Pseudocalanus* sp. The same four taxa in the same rank order dominated the late spring through fall collections (Group 3). Group 3 was distinguished from Group 2 by higher abundances of the four dominant taxa.

In addition to the three regularly occurring groups, two groups occurred sporadically. In June and July 1980, large abundances of Copepoda and *Pseudocalanus/Calanus* nauplii resulted in the formation of Group 4. *Oithona* sp. and *Pseudocalanus* sp. were also common. Group 5, characterized by variable but low abundances and dominated by *Oithona* sp., occurred sporadically in March. Barnacle (Cirripedia) and polychaete larvae, Copepoda and *Pseudocalanus/Calanus* nauplii, and *Microsetella norvegica* were also common in Group 5.

Operational Period Trends

Numerical classification suggested no large differences between the preoperational and operational periods. The seasonal pattern of the three major groups (Groups 1, 2 and 3) in the operational period was almost identical to the preoperational period. One small difference was that Group 4, which occurred only in 1980, did not recur in the operational period.

Abundances of most taxa in each group were similar between the preoperational and operational periods, with two exceptions. Operational abundances of *Oithona* sp. in Group 3 exceeded preoperational levels. Operational abundances of *Pseudocalanus/Calanus* nauplii were lower in Groups 2 and 3 (Table 4-2).

Spatial Patterns

Differences in abundances of dominant species between Stations P2 and P7 (P5 was not sampled preoperationally for microzooplankton) were not detected during the preoperational period (NAI 1985). Earlier operational comparisons also detected no station differences (NAI 1992, 1993, 1995a, 1996; NAI and NUS 1994). Similarly, in 1996, MANOVA found no differences between Stations P2 and P7 (Wilks' Lambda = 0.24, F = 1.0, p = 0.50). Similarities between nearfield and farfield stations, historically and currently, indicated that Seabrook Station has not affected the microzooplankton community.

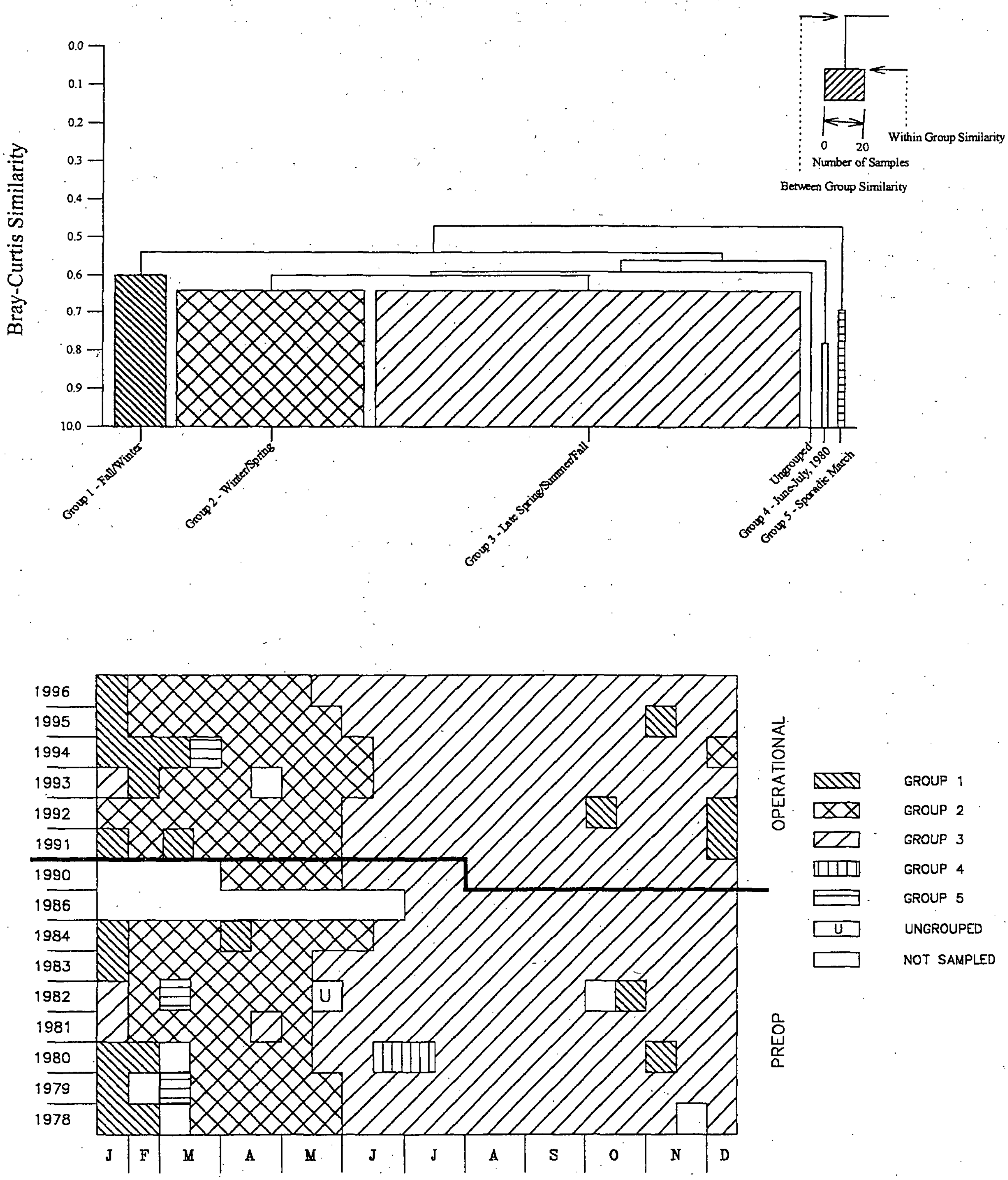


Figure 4-2. Dendrogram and seasonal groups formed by numerical classification of $\log_{10}$ (x+1) transformed microzooplankton abundances (no./m^3) at the intake Station P2, 1978-1984, July-December 1986, April 1990-December 1996. Seabrook Operational Report, 1996.

Table 4-2. Geometric Mean Abundance (No./m^3) of Microzooplankton and the 95% Confidence Limits, Collections for Dominant Taxa Occurring in Seasonal Groups Formed by Numerical Classification of Collections at the Intake Station P2, 1978-84, July-December 1986, April-December 1990, 1991-96. Seabrook Operational Report, 1996.

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL PERIOD				OPERATIONAL PERIOD			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1	*Oithona* sp.	10	85	196	448	12	172	337	656
Fall/Winter	Copepoda nauplii		69	134	260		75	163	354
(0.60/0.54)	*Pseudocalanus* sp.		40	93	215		9	27	81
	Tintinnidae		12	80	494		14	79	428
	Pseudocalanus/Calanus nauplii		25	59	137		7	19	53
	Foraminiferida		10	38	140		20	45	99
	Microsetella norvegica		4	17	67		9	39	153
2	*Oithona* sp.	44	649	960	1420	39	1177	1611	2206
Winter/Spring	Copepoda nauplii		507	716	1011		813	1089	1457
(0.64/0.60)	*Pseudocalanus/Calanus* nauplii		359	518	747		97	171	300
	Pseudocalanus sp.		128	196	301		94	146	229
3	*Oithona* sp.	107	2165	2631	3198	82	3352	4143	5121
Late Spring/	Copepoda nauplii		1225	1589	2062		1739	2211	2811
Summer/Fall	*Pseudocalanus/Calanus* nauplii		808	1009	1259		162	236	342
(0.64/0.60)	*Pseudocalanus* sp.		346	452	591		277	374	506
4	Copepoda nauplii	2	403	9275	213014				
1980 June-July	*Pseudocalanus/Calanus* nauplii		1	9127	3.9×10^7				
(0.78/0.56)	*Oithona* sp.		2374	3553	5317			not represented	
	Pseudocalanus sp.		0	2051	2.1×10^{11}				
5	*Oithona* sp.	2	6	223	7538	1	--	197	--
March (Sporadic)	Cirripedia larvae		0	84	7.8×10^7		--	172	--
(0.69/0.47)	*Pseudocalanus/Calanus* nauplii		0	61	7.4×10^7		--	34	--
	Copepoda nauplii		0	31	1054		--	26	--
	Microsetella norvegica		0	9	718		--	41	--
	Polychaeta larvae		0	13	6.7×10^6		--	39	--

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

4.3.1.2 Selected Species

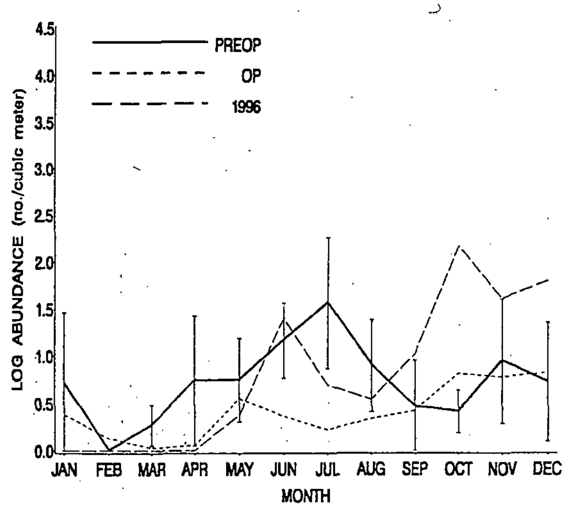
The copepods *Pseudocalanus* sp. and *Oithona* sp. were selected for further analysis in the microzooplankton program because of their numerical dominance. Their abundance and trophic level make them important members of the marine food web throughout the Gulf of Maine and nearby Atlantic Shelf waters (Sherman 1966, Tremblay and Roff 1983, Davis 1984a, 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. Station P5 was not included in the analysis of selected species because only a partial year of preoperational data was collected.

***Eurytemora* sp.**

Both *Eurytemora* sp. copepodites and adult *Eurytemora herdmani* were relatively minor constituents of the microzooplankton community. Abundances were low (Table 4-3) and neither taxon was a dominant in any of the seasonal groups (Table 4-2) formed by numerical classification.

Copepodites In 1996, seasonal abundances of *Eurytemora* sp. copepodites were atypical from both preoperational and previous operational years (Figure 4-3) with an exceptionally large

Eurytemora sp.
Copepodites



Eurytemora herdmani
Adults

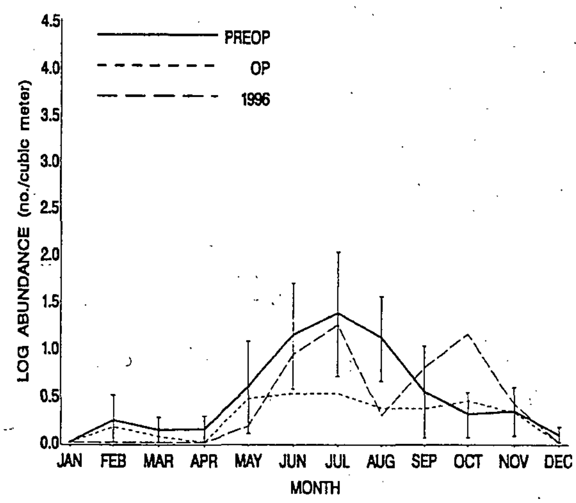


Figure 4-3. Log(x+1) abundance (no./m^3) of *Eurytemora* sp. copepodites and *Eurytemora herdmani* adults at Station P2; monthly means and 95% confidence intervals during the preoperational period (1978-1984), and monthly means during the operational period (1991-1996), and in 1996. Seabrook Operational Report, 1996.

Table 4-3. Geometric Mean Abundance (No./m^3) and the Coefficient of Variation of Selected Microzooplankton Species at Stations P2, P5 and P7 for Preoperational and Operational Periods and 1996. Seabrook Operational Report, 1996.

		PREOPERATIONAL		OPERATIONAL		1996
SPECIES/LIFESTAGE	STATION	MEAN[a]	CV	MEAN[b]	CV	MEAN
Eurytemora sp. copepodites	P2	4	35.1	2	49.1	5
	P5	--	--	1	45.2	3
	P7	4	56.4	1	62.8	5
Eurytemora herdmani adults	P2	2	50.2	1	37.9	2
	P5	--	--	1	32.5	1
	P7	3	51.2	1	33.9	1
Pseudocalanus/Calanus sp. nauplii	P2	593	7.5	141	9.5	81
	P5	--	--	107	6.2	68
	P7	499	11.2	129	5.5	89
Pseudocalanus sp. copepodites	P2	223	8.6	150	7.1	136
	P5	--	--	138	6.0	141
	P7	193	14.0	161	3.4	175
Pseudocalanus sp. adults	P2	23	17.4	14	18.0	9
	P5	--	--	13	18.8	13
	P7	25	16.4	13	18.4	7
Oithona sp. nauplii	P2	465	11.7	596	8.5	1432
	P5	--	--	629	7.3	1336
	P7	403	15.1	541	8.5	1227
Oithona sp. copepodites	P2	490	10.1	724	5.8	1245
	P5	--	--	639	5.9	798
	P7	299	20.1	632	4.5	960
Oithona sp. adults	P2	107	13.4	202	7.6	382
	P5	--	--	177	7.6	250
	P7	98	23.9	179	7.2	303

[a]Preoperational years: P2 = 1978-84, P5 = not sampled, P7 = 1982-84. Mean of annual means.
[b]Operational years = 1991-96; 1990 not sampled during January through March, data not included. Mean of annual means.

fall peak. Winter through summer abundances in 1996 were similar to the preoperational period. The 1996 annual geometric mean was similar to the preoperational mean and higher than the operational mean (Table 4-3).

A potential plant effect was indicated by the significant Preop-Op X Station interaction term (Table 4-4). Abundances declined at both stations P2 and P7, but the decrease at the control site, Station P7, was greater (Figure 4-4). The decrease in abundance at Station P2 resulted from decreased operational summer abundances (Figure 4-3); however, this change in the seasonal cycle occurred at both stations P2 and P7 (NAI 1996), which would indicate no plant effects. High abundances in the three-year preoperational period (1982-1984), especially at Station P7, were primarily due to a peak in 1983 (Figure 4-5). Abundances were similar between stations in 1982 and 1984, and throughout the operational period. Given that the significant interaction term is largely the result of one anomalous year (1983) in the preoperational period, it is unlikely that Seabrook station has been a factor in the differing trends between stations.

<u>Adults</u> The seasonal cycle of adult *Eurytemora herdmani* at Station P2 differed in the operational period, due to the absence of the summer peak (Figure 4-3). This change in the seasonal pattern also occurred at Station P7 (NAI 1996). Abundances in 1996 were atypical. Two peaks occurred, one in July and one in October rather than the June through August peak observed during preoperational years. Geometric mean abundance in 1996 was similar to previous years (Table 4-3).

The ANOVA detected no differences in abundances between stations or between preoperational and operational periods. Adult abundances showed no significant change during the operational period despite significant decreases in abundances of the copepodites at Stations P2 and P7 (Table 4-4).

<u>*Pseudocalanus* sp.</u>

<u>Nauplii</u> The seasonal cycle of *Pseudocalanus/Calanus* nauplii differed between the preoperational and operational periods (Figure 4-6) only in terms of magnitude. Operational abundances were less than preoperational abundances in most months. Abundances in 1996 were also low (Figure 4-6, Table 4-3).

The operational period abundance was significantly lower than the preoperational abundance when tested by ANOVA (Table 4-4), but here were no significant differences between Stations P2 and P7. The decrease in abundance during the operational period occurred at both stations, indicating area-wide changes not related to the operation of Seabrook Station.

<u>Copepodites and Adults</u> The seasonal cycles of both the copepodite and adult *Pseudocalanus* sp. at Station P2 were similar in the preoperational and operational periods (Figure 4-6). January, Febraury and March abundances were substantially lower during 1996 for both copepodites and adults, and lower in September and November for adults only. The 1996 annual means of copepodites were similar to previous years, adults were slightly lower (Table 4-3).

No differences were detected between the preoperational and operational periods or between Stations P2 and P7. No potential plant impacts were detected (Table 4-4).

<u>*Oithona* sp.</u> The seasonal cycles of all three lifestages of *Oithona* sp. were similar in both

Table 4-4. **Results of the Analysis of Variance Comparing Log (X+1) Transformed Abundances (No./m^3) of Selected Microzooplankton Species from Stations P2 and P7 During the Preoperational (1982-84) and Operational (1991-96) Periods. Seabrook Operational Report, 1996.**

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[b]	df	MS	F	MULTIPLE COMPARISONS[b]
Eurytemora sp. copepodite	Preop-Op	1	5.11	1.70 NS	
	Year (Preop-Op)	7	2.69	4.35***	
	Month (Year X Preop-Op)	99	0.86	3.32***	
	Station	1	0.07	0.18 NS	
	Preop-Op X Station	1	0.38	7.87*	P7Pre P2Pre>P2Op P7Op
	Year X Station (Preop-Op)	7	0.05	0.19 NS	
	Error	259	0.26		
Eurytemora herdmani adult	Preop-Op	1	7.86	5.02 NS	
	Year (Preop-Op)	7	1.33	2.41*	
	Month (Year X Preop-Op)	99	0.72	3.62***	
	Station	1	0.22	0.70 NS	
	Preop-Op X Station	1	0.31	5.00 NS	
	Year X Station (Preop-Op)	7	0.06	0.31 NS	
	Error	259	0.20		
Pseudocalanus/Calanus sp. nauplii	Preop-Op	1	25.36	17.40**	Preop>Op
	Year (Preop-Op)	7	1.60	1.23 NS	
	Month (Year X Preop-Op)	99	1.46	6.12***	
	Station	1	0.12	212.40 NS	
	Preop-Op X Station	1	0.01	0.05 NS	
	Year X Station (Preop-Op)	7	0.17	0.72 NS	
	Error	259	0.24		
Pseudocalanus sp. copepodite	Preop-Op	1	1.03	1.41 NS	
	Year (Preop-Op)	7	0.96	0.83 NS	
	Month (Year X Preop-Op)	99	1.19	4.54***	
	Station	1	0.00	0.05 NS	
	Preop-Op X Station	1	0.07	0.21 NS	
	Year X Station (Preop-Op)	7	0.32	1.23 NS	
	Error	259	0.26		
Pseudocalanus sp. adult	Preop-Op	1	5.29	3.00 NS	
	Year (Preop-Op)	7	2.02	1.56 NS	
	Month (Year X Preop-Op)	99	1.35	5.03***	
	Station	1	0.01	7.02 NS	
	Preop-Op X Station	1	0.01	0.05 NS	
	Year X Station (Preop-Op)	7	0.30	1.12 NS	
	Error	259	0.27		

(Continued)

Table 4-4. (Continued)

SPECIES/ LIFESTAGE	SOURCE OF VARIATION[b]	df	MS	F	MULTIPLE COMPARISONS[b]
Oithona sp. nauplii	Preop-Op	1	0.84	0.26 NS	
	Year (Preop-Op)	7	3.18	4.23***	
	Month (Year X Preop-Op)	99	0.95	4.87***	
	Station	1	0.54	17.87 NS	
	Preop-Op X Station	1	0.03	0.68 NS	
	Year X Station (Preop-Op)	7	0.05	0.24 NS	
	Error	259	0.20		
Oithona sp. copepodite	Preop-Op	1	6.28	2.51 NS	
	Year (Preop-Op)	7	2.51	2.41*	
	Month (Year X Preop-Op)	99	1.17	7.32***	
	Station	1	0.80	9.48 NS	
	Preop-Op X Station	1	0.09	0.80 NS	
	Year X Station (Preop-Op)	7	0.11	0.67 NS	
	Error	259	0.16		
Oithona sp. adult	Preop-Op	1	4.47	1.53 NS	
	Year (Preop-Op)	7	2.96	3.00**	
	Month (Year X Preop-Op)	99	1.19	6.04***	
	Station	1	0.45	31.63 NS	
	Preop-Op X Station	1	0.02	0.27 NS	
	Year X Station (Preop-Op)	7	0.06	0.30 NS	
	Error	259	0.20		

NS = Not Significant ($P > 0.05$)
* = Significant ($0.05 \geq P > 0.01$)
** = Highly Significant ($0.01 \geq P > 0.001$)
*** = Very Highly Significant ($P \leq 0.001$)

[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
Station = nearfield vs. farfield stations
Preop-Op X Station = interaction of main effects
Year X Station (Preop-Op) = interaction of station and year nested within preoperational and operational period.

[b]Waller-Duncan multiple means comparison test used for significant main effects. LS Means used for significant interaction terms.

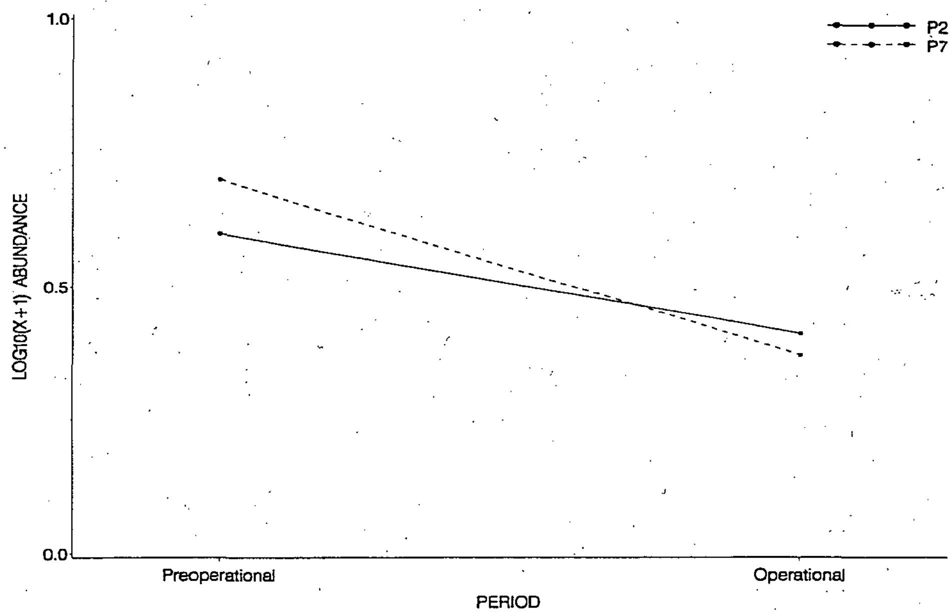


Figure 4-4. A comparison between stations of the mean log(x+1) abundance (no./m^3) of *Eurytemora* sp. copepodites during the preoperational (1982-1984) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model. Seabrook Operational Report, 1996.

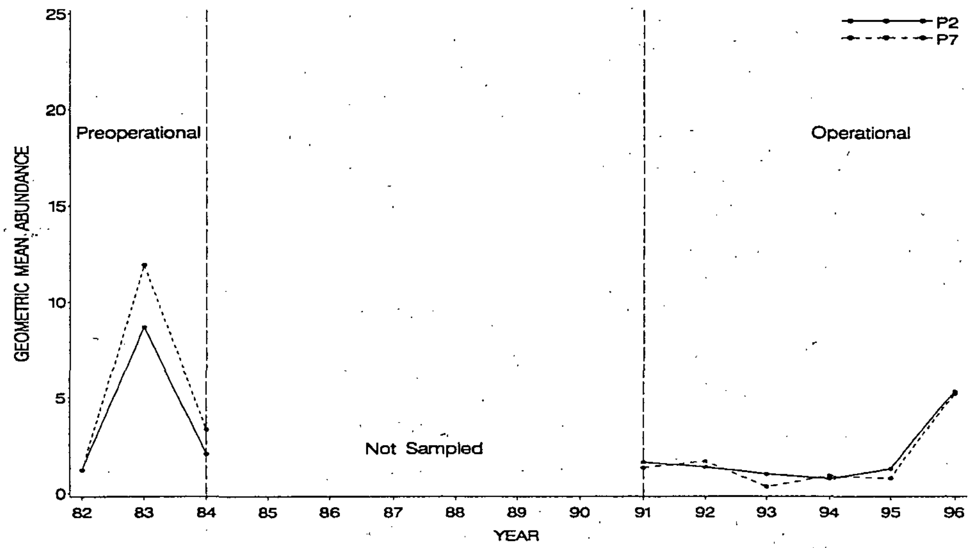


Figure 4-5. Annual geometric mean abundances (no./m^3) of *Eurytemora* sp. copepodite by station during the preoperational (1978-1984) and operational (1991-1996) period. Seabrook Operational Report, 1996.

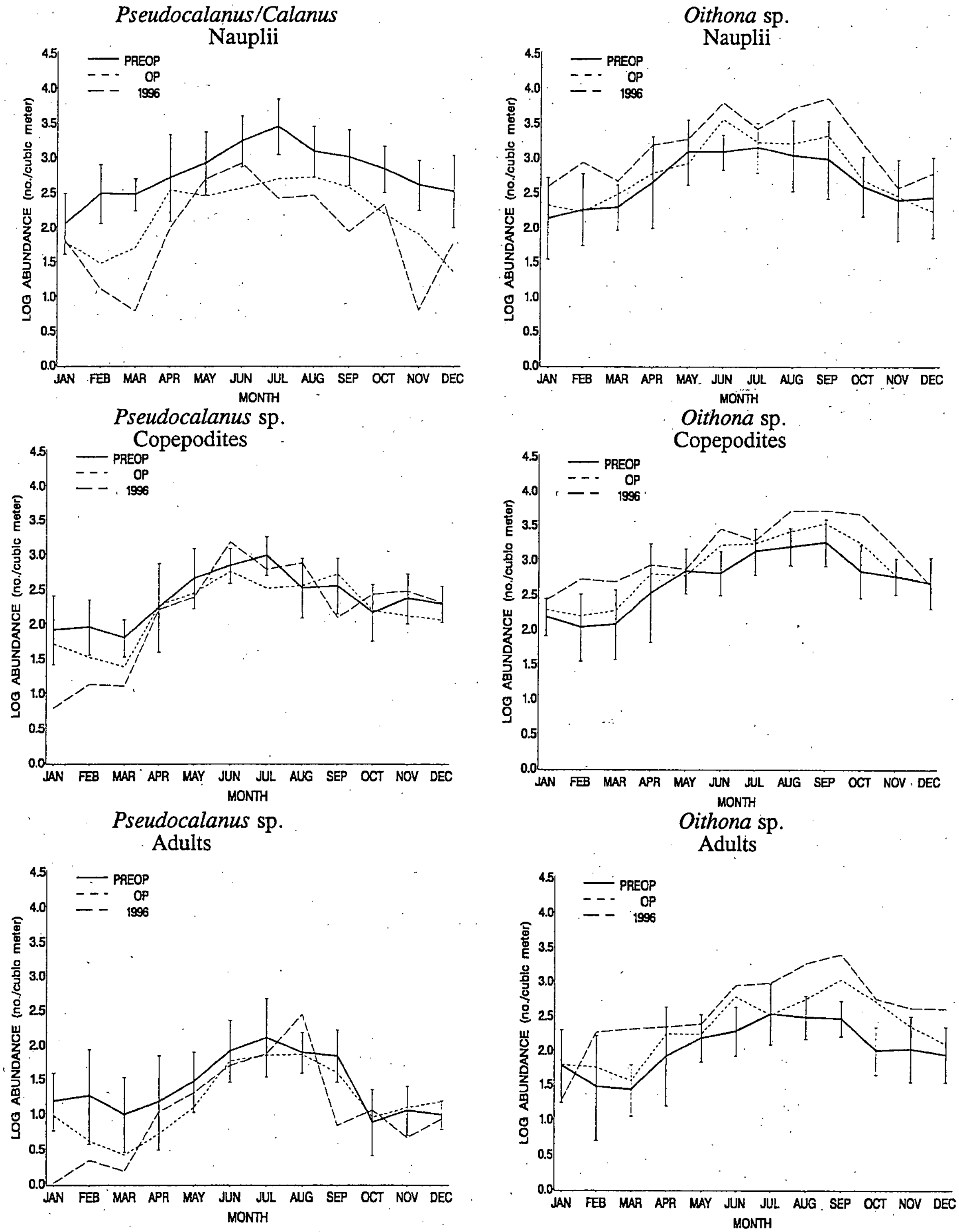


Figure 4-6. Log(x+1) abundance (no./m^3) of *Pseudocalanus/Calanus* and *Oithona* sp. nauplii, and *Pseudocalanus* sp. and *Oithona* sp. copepodites and adults at Station P2; monthly means and 95% confidence intervals during the preoperational period (1978-1984), and monthly means during the operational period (1991-1996), and in 1996. Seabrook Operational Report, 1996.

preoperational and operational periods, although adult *Oithona* sp. were more abundant during the operational period in June, September and October (Figure 4-6). Monthly means of all lifestages were typically higher in 1996 than in previous years. Annual geometric means of each lifestage in 1996 were high in relation to the preoperational and operational means (Table 4-3).

No significant differences were detected for any of the lifestages of *Oithona* sp. Abundances were similar at both stations and in both preoperational and operational periods. No effects from plant operation were detected (Table 4-4).

4.3.2 Bivalve Larvae

4.3.2.1 Community

Preoperational Community

During the preoperational period, *Hiatella* sp. dominated collections in April and May (Groups 1 and 2), although abundances were generally low (Figure 4-7, Table 4-5). By late May, abundances of *Hiatella* sp. had increased and *Mya truncata* and *Mytilus edulis* had become important components of the bivalve larvae assemblage (Group 4). Peak abundances of bivalve larvae occurred in late spring (Group 5) with both *M. edulis* and *Hiatella* sp. reaching their annual peak abundances at this time. Also in Group 5, *Anomia squamula*, the summer and fall dominant, began to appear in moderate numbers. Moderate (Group 6) and low (Group 7) abundances of *A. squamula, M. edulis* and *Modiolus modiolus* occurred in an irregular pattern during the summer and early fall. *Hiatella* sp., the spring dominant, did not occur as a dominant during the summer and early fall. Less common taxa (*Mya arenaria*, Solenidae, and *Spisula solidissima*) were important components of the community during periods of low abundance in summer (Group 7). In early August 1988, a group dominated by *M. modiolus* and *A. squamula* occurred (Group 8).

Bivalve larvae community distribution over the study area during the preoperational period was homogeneous. The same community was seen at all three stations on 91% of the biweekly periods.

Operational Period Trends

Differences in community structure during the operational period were suggested by numerical classification. More than half of the May collections from 1991 to 1996 were allied with Group 3, which was unique to the operational period (Table 4-5, Figure 4-7). This group was characterized by abundances of *Hiatella* sp. that were higher than Group 2, but within the range observed in Group 4. It was distinguished from Group 4 by the reduced abundances of *Mya truncata* and *Mytilus edulis*. Group 4, which characterized late May and early June collections during the preoperational period, occurred in three of the six operational years. The *Modiolus modiolus* dominated community (Group 8), which occurred only in early August 1988, did not recur in the operational period. Compared to all other years, preoperational and operational, 1996 was an unusual year in the early occurrence of Group 5 in late May and the absence of the low abundance (Group 7) summer community.

Differences between the preoperational and operational periods were also detected by MANOVA (Wilks' Lambda = 0.35, F = 64.36, p = 0.0001). Abundances of some dominant taxa were higher in the operational period in the spring. Operational period abundances of *Hiatella* sp. were higher in Groups 2 and 5. The abundance of *Anomia squamula* was higher in

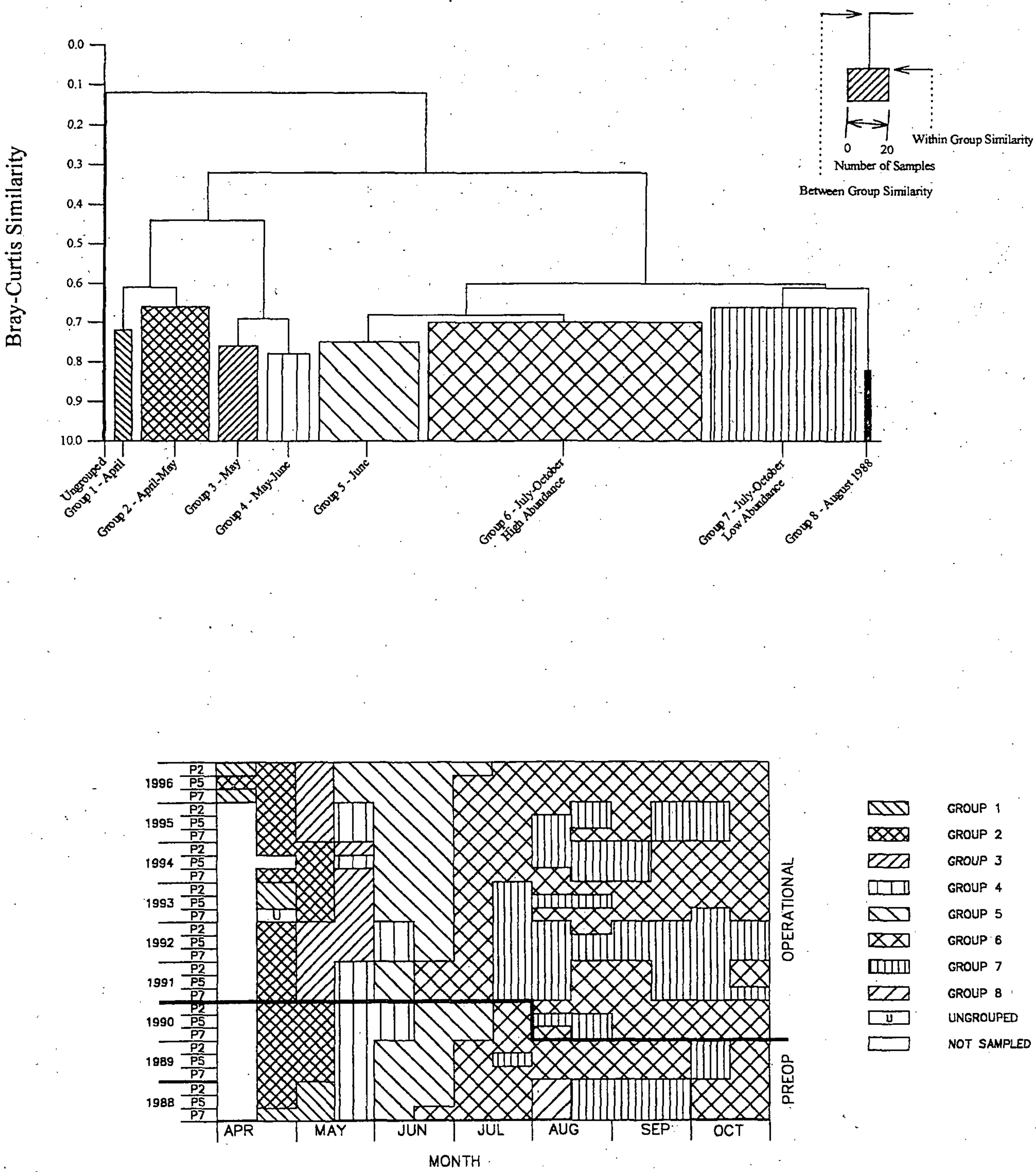


Figure 4-7. Dendrogram and seasonal groups formed by numerical classification of $\log_{10}$ (x+1) transformed bivalve larvae abundances (half-monthly means; no./m^3) at the intake (P2), discharge (P5) and farfield (P7) stations, April-October, 1988-1996, Seabrook Operational Report, 1996.

Table 4-5. Geometric Mean Abundance (No./m³) and the 95% Confidence Limits of Dominant Taxa Occurring in Seasonal Groups Formed by Numerical Classification of Bivalve Larvae Collections at the Intake (P2), Discharge (P5) and Farfield (P7) Stations, 1988-1996. Seabrook Operational Report, 1996.

GROUP NO./ NAME SIMILARITY[a]	DOMINANT TAXA[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N[d]	LCL	MEAN	UCL	N[d]	LCL	MEAN	UCL
1 April (0.72/0.47)	*Hiatella* sp.	4	12	16	22	4	7	10	14
	Solinidae		0	1	4		0	0	0
2 April-May (0.66/0.61)	*Hiatella* sp.	14	37	51	69	21	84	172	349
3 May (0.76/0.69)	*Hiatella* sp.	--	--	--	--	20	453	684	1031
4 May-June (0.78/0.69)	*Hiatella* sp.	12	834	1417	2406	10	620	952	1462
	Mya truncata		75	126	213		19	42	95
	Mytilus edulis		20	69	233		27	68	167
5 June (0.75/0.68)	*Mytilus edulis*	17	5490	9179	15347	34	10133	16293	26198
	Hiatella sp.		1237	2125	3648		4457	6119	8399
	Anomia squamula		82	243	717		751	1446	2783
6 July-October (0.70/0.68)	*Anomia squamula*	36	642	1134	2002	104	1083	1494	2061
	Mytilus edulis		461	925	1853		1161	1518	1984
	Modiolus modiolus		265	410	633		98	146	218
7 July-October (0.66/0.61)	*Anomia squamula*	13	46	103	229	60	168	219	285
	Mytilus edulis		29	42	62		62	90	131
	Modiolus modiolus		10	22	49		4	5	7
	Mya arenaria		9	16	27		4	6	8
	Solenidae		4	13	33		3	4	6
	Spisula solidissima		8	12	17		8	11	14
8 August 1988 (0.82-0.61)	*Modiolus modiolus*	3	19	59	180	--	--	--	--
	Anomia squamula		12	48	185				
	Mytilus edulis		2	11	53				

[a] (within-group similarity/between-group similarity)
[b] those taxa contributing ≥5% of total group abundance in either preoperational or operational period collections
[c] preoperational = April 1988-July 1990; operational = August 1990-October 1996
[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)

Group 5. Summer abundances of *Modiolus modiolus* were lower.

Spatial Patterns

Numerical classification detected few station differences during the preoperational period. Similarly, few differences were seen during the operational period; the bivalve larvae community was similar at all stations in 84% of the biweekly periods and the differences were not specific to any one station (Figure 4-7). No differences among stations were detected by MANOVA (Wilks' Lambda = 0.93, F = 1.32, p = 0.15).

The changes which occurred in the operational period occurred at all stations, including the control site, Station P7. Since potential plant impacts should be localized at either Stations P2 or P5, the area-wide changes detected during the operational period indicated that other factors were influencing the bivalve larvae community. No effects due to plant operation were detected by MANOVA (Preop-Op X Station: Wilks' Lambda = 0.92, F = 0.42, p = 0.10).

4.3.2.2 Selected Species

Mya arenaria

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. This species is discussed in detail in Section 10.0.

Mytilus edulis

Mytilus edulis, the blue mussel, has been the most abundant species encountered in bivalve larvae investigations and is the dominant species in the surrounding shallow-water hard-substrate benthic community (Section 7.0).

The weekly abundances of *Mytilus edulis* larvae followed a similar seasonal pattern in both preoperational and operational periods. However, operational period abundances were frequently slightly higher (Figure 4-8). Abundances generally increased rapidly in mid-spring to a seasonal high in late June. Abundances then gradually declined through summer and early fall. Weekly abundances in 1996 were typically higher than in the preoperational period and numbers were unusually high in mid-May. The early appearance of *M. edulis* larvae in May 1996 may have been influenced by the early warming of the nearshore waters (Section 2.3.1.1). Nelson (1928) cited 10-12°C as the temperature above which *M. edulis* will spawn. The high abundance of phytoplankton (Section 3.3.1.1) may also have contributed, as metabolites from phytoplankton have been shown to induce spawning in *Mytilus edulis* (Starr et al. 1990).

Annual geometric mean abundances in 1996 were an order of magnitude higher than the preoperational and operational means (Table 4-6). Means in 1996 were the highest values recorded since sampling began in 1978 and were comparable to the Station P2 abundance of 1786 larvae/m^3 in 1981 (NAI 1982; Stations P5 and P7 were not sampled in 1981).

The effect of temperature, food supply and other factors on abundance is complicated in field studies by dispersion from the parent populations. Higher temperatures increase the rate at which larvae develop allowing more individuals to reach the umbonate stage earlier (straight hinge stages are not counted in the Seabrook study) resulting in an earlier increase in abundance. Gametogene-

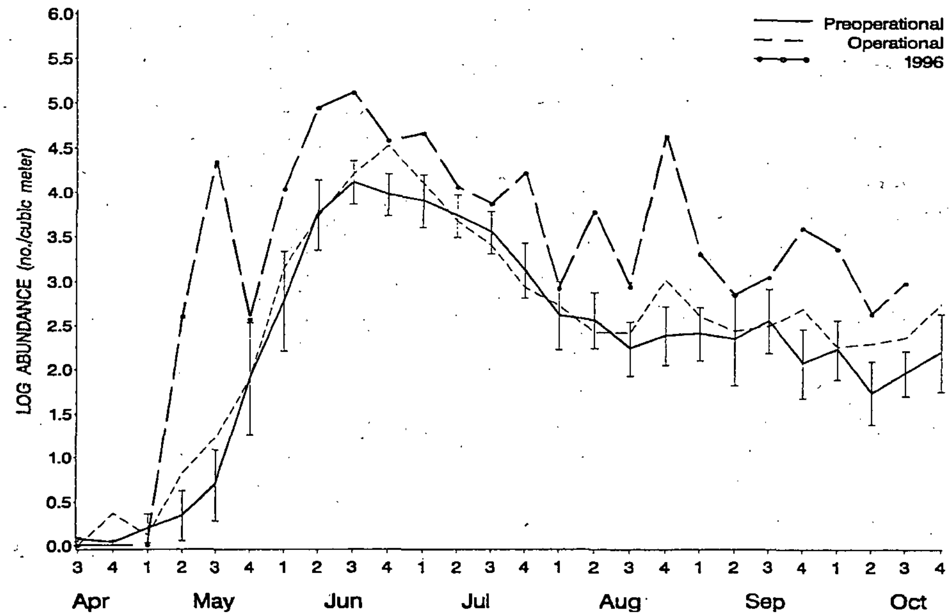


Figure 4-8. Log(x+1) abundance (no./m^3) of *Mytilus edulis* larvae at Station P2; weekly means and 95% confidence intervals during the preoperational period (1978-1989), and weekly means during the operational period (1991-1996), and in 1996. Seabrook Operational Report, 1996.

Table 4-6. Geometric Mean Abundance (No./m^3) and the Coefficient of Variation for *Mytilus edulis* Larvae at Stations P2, P5 and P7 During the Preoperational and Operational Periods and 1996. Seabrook Operational Report 1996.

		Preoperational		Operational		1996
Station	Year	Mean[a]	CV	Mean[a]	CV	Mean
P2	1978-1989[b]	208	21.2	319	22.9	1873
P5	1988-1989	132	23.4	286	20.7	1482
P7	1982-1984, 1987-1989	208	13.8	335	21.7	1754

[a]mean of annual means
[b]1986 excluded

sis is dependent on nutrient reserves accumulated during periods when food is abundant, following the spawning period (Gabbot 1976). High phytoplankton abundance in June 1995 (NAI 1996), and possibly also February and March 1996 (Section 3.3.1.1), may have increased production locally. High abundance in the study area could be due to recruitment from other nearby areas.

Despite the higher operational period means, no significant differences were detected between the preoperational and operational periods (Table 4-7). No station differences were detected and no effects were attributed to plant operation.

4.3.2.3 Entrainment

The species composition and abundance of bivalve larvae passing through the cooling water system of Seabrook Station were measured to estimate the direct loss of larvae to entrainment. Entrainment losses are related to the volume of cooling water circulating and larval abundance because these determine the number of larvae exposed to lethal temperatures and physical shock.

Table 4-7. Results of Analysis of Variance Comparing Log (X+1) Transformed Abundances (No./m^3) of *Mytilus edulis* Larvae from Stations P2, P5 and P7 During the Preoperational (1988-1989) and Operational (1991-1996) Periods. Seabrook Operational Report, 1996.

SPECIES	SOURCE OF VARIATION[a]	df	MS	F	MULTIPLE COMPARISONS
Mytilus edulis	Preop-Op	1	9.14	0.38 NS	
	Year (Preop-Op)	6	23.48	4.35***	
	Week (Year X Preop-Op)	193	5.49	39.42***	
	Station	2	0.37	3.01 NS	
	Preop-Op X Station	2	0.11	1.71 NS	
	Station X Year (Preop-Op)	12	0.07	0.49 NS	
	Error	383	0.14		

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
Week (Year X Preop-Op)=week nested within year
Station = Station P2 vs. Station P5 vs. Station P7, regardless of 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.

Although Seabrook Station operated its circulating water system at varying levels since 1985, no power or heated discharge were produced until August of 1990. No entrainment samples were collected during several scheduled plant shutdowns during the operational period: early August through November 1991; September and October 1993; and January through April and October through December in 1994 (no entrainment samples were collected in 1994).

The total number of bivalve larvae entrained in 1996 ($52,547.4 \times 10^9$; Table 4-8) was almost twice the previous high of $27,326.5 \times 10^9$, which occurred in 1995 (NAI 1996). The high number of bivalve larvae entrained in 1996 may be due to the relatively large amount of larvae available offshore, as reflected in the high *Anomia squamula* (Section 4.3.2.1) and *Mytilus edulis* densities in 1996 (Table 4-6). *A. squamula* was the most common bivalve entrained (44.8%) followed by *M. edulis* (34.1%) and *Modiolus modiolus* (9.8%; Table 4-8). Proportions of larvae entrained in 1996 generally reflected the proportions present in the natural environment. *M. edulis* entrainment was highest in June through August, reflecting the peak of abundance observed nearshore (Figure 4-8). *A. squamula* was dominant from July through October, the same period in which entrainment estimates were highest (Table 4-7).

Monthly entrainment of all taxa was less in 1991 and 1992 (as indicated by the reduced duration of the high abundance Group 5 and increased duration of the low abundance Group 7, Figure 4-7, Table 4-5) in comparison to other years and was highest in 1996 (Figure 4-9). Three taxa, *Mytilus edulis*, *Anomia squamula* and *Hiatella* sp., accounted for more than 85% of the bivalve larvae entrained each year (Figure 4-9). *M. edulis* was the most entrained species in all years except 1996 when *A. squamula* ranked first. Although total entrainment has increased over time, there has been no apparent effect on the offshore bivalve larvae community (Section 4.3.2.1).

Actual entrainment levels have been lower than predicted prior to operation. Approximately 41 x 10^9 *Mya arenaria* (soft-shell clam) larvae were predicted to be entrained at one unit of Seabrook Station in one year (NAI 1977). This estimate, based on field sampling conducted in 1976, included a 113 day season of larval abundance, a pumping rate of 2.33 x 10^6 m^3/day (one unit operating at 100% capacity) and an estimated density of 158 larvae/m^3. Actual entrainment totals, which ranged from 0.2 x 10^9 in 1992 to 33.2 x 10^9 in 1996, were lower than predicted due to reduced cooling water system pumping rates, and lower than predicted larval clam densities. The actual average pumping rate of 1.97 x 10^6 m^3/day during the April-through-October bivalve entrainment season was approximately 15% lower than the predicted pumping rate due to outages (see Table 1-2). Similarly, actual densities of larval *M. arenaria* in entrainment samples ranged from 1.8/m^3 in 1991 (NAI 1992) to 61.7/m^3 in 1996, lower than the predicted value. The location of the intake structure in comparison to the area where bivalve larvae samples were collected may have also contributed to the observed differences. The 1976 bivalve larvae samples were collected using oblique tows that sampled the entire water column, while the cooling water system (from which entrainment samples were collected) draws water from the center of the water column. *M. arenaria* larvae were more numerous in the upper portions of the water column (NAI 1974), which were sampled by the oblique tows but not as likely to be entrained by a mid-water intake. The predicted entrainment of *M. arenaria* larvae (NAI 1977)

Table 4-8. **Estimated Number of Bivalve Larvae Entrained (X 10^9) by the Cooling Water System at Seabrook Station from the Third Week in April Through the Fourth Week of October, 1996. Seabrook Operational Report, 1996.**

	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL	%
SPECIES									
Bivalvia	0.1	7.8	253.3	187.5	157.0	50.8	13.1	669.6	1.3
Anomia squamula	0.0	0.4	1018.9	2095.3	16253.9	3698.0	455.1	23521.6	44.8
Hiatella sp.	1.9	495.9	2139.6	1171.1	723.1	122.8	15.8	4670.2	8.9
Macoma balthica	0.0	0.3	0.0	0.0	1.5	0.0	0.0	1.8	<0.1
Modiolus modiolous	0.0	0.0	1592.2	543.6	242.5	1964.2	802.3	5144.8	9.8
Mya arenaria	0.0	0.0	4.4	2.7	1.7	15.7	8.7	33.2	0.1
Mya truncata	0.0	2.7	100.0	3.8	13.7	1.8	1.0	123.0	0.2
Mytilus edulis	0.0	33.4	9256.8	3833.2	4012.0	619.4	177.0	17931.8	34.1
Placopecten magellanicus	0.0	0.3	0.3	7.5	3.8	14.0	5.1	31.0	0.1
Solenidae	0.0	1.1	119.6	71.8	20.0	11.1	18.3	241.9	0.5
Spisula solidissima	0.0	0.0	29.9	16.3	68.0	48.6	8.3	171.1	0.3
Teredo navalis	0.0	0.0	0.0	0.0	0.0	7.2	0.2	7.4	<0.1
TOTAL	2.0	541.9	14515.0	7932.8	21497.2	6553.6	1504.9	52547.4	100.0
% of TOTAL	<0.1	1.0	27.6	15.1	40.9	12.5	2.9		

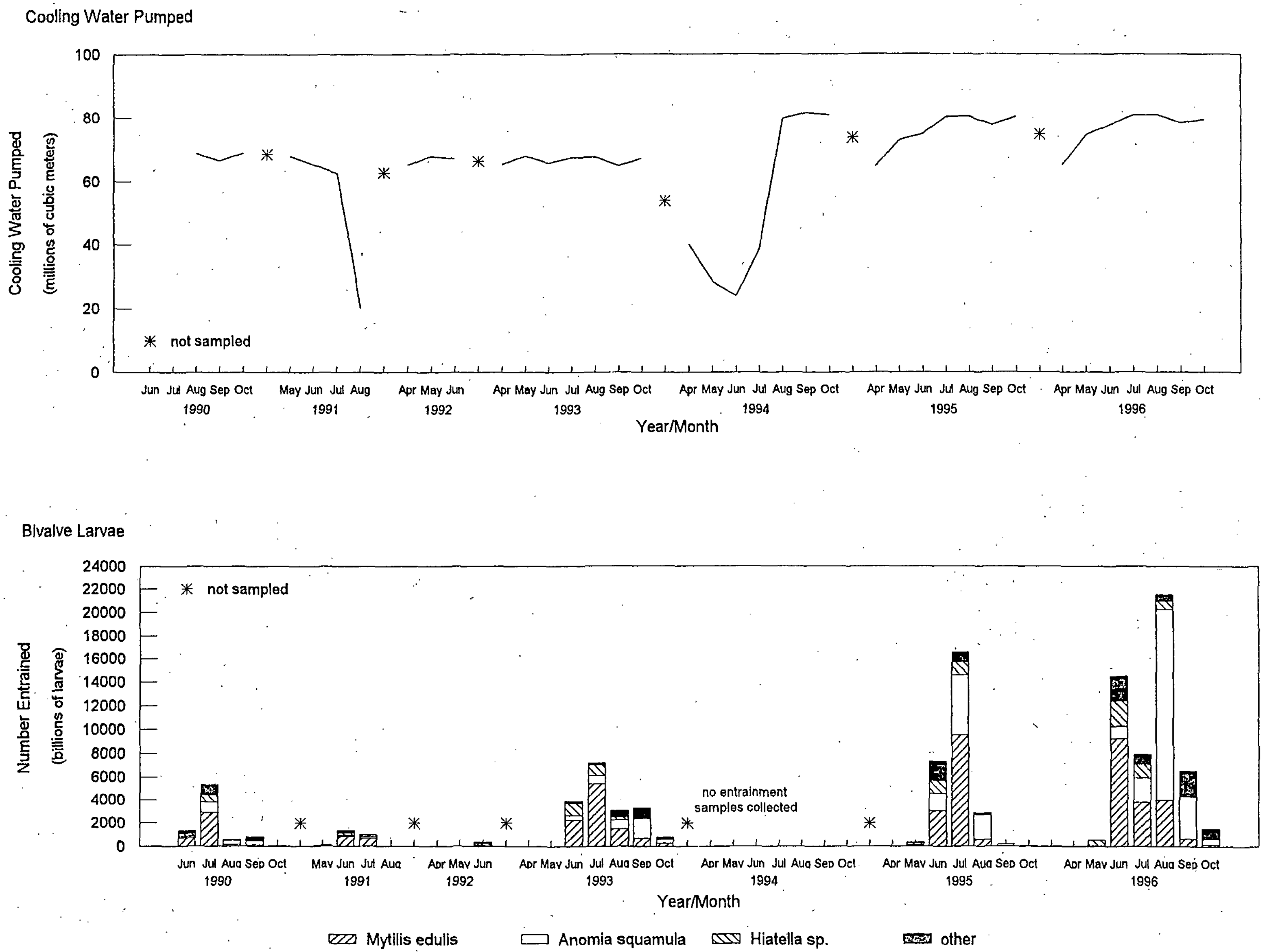


Figure 4-9. Volume of cooling water pumped during the months sampled for **bivalve larvae** and total number of **bivalve larvae** (x 10^9) entrained by Seabrook Station, 1990-1996. Seabrook Operational Report, 1996.

was in effect a worst-case prediction based on one year (1976) of relatively high larval abundance.

The predicted entrainment of *Mytilus edulis* at one unit of Seabrook Station operating at 100% capacity was approximately 900 x 10^9 annually (NAI 1977). This level of entrainment was expected to have negligible impacts on the local population of *M. edulis* due to its high reproductive capacity. Actual entrainment of *M. edulis* ranged from 122 x 10^9 in 1992 to 17,932 x 10^9 in 1996. Entrainment of *M. edulis* larvae at Seabrook Station appears to have had no effect on local populations of adult *M. edulis* monitored through the marine macrobenthos program (Section 6.0).

4.3.3 Macrozooplankton

4.3.3.1 Holoplankton and Meroplankton Community

Preoperational Community

The holoplankton and meroplankton communities showed distinct seasonal changes that were consistent from year to year (Figure 4-10). The population changes of dominant copepods *Calanus finmarchicus* and *Centropages typicus*, along with the larval stages of crustaceans, strongly influenced community structure.

Representing the maturation of the spring spawn of *Calanus finmarchicus*, Group 1 occurred consistently in late spring (Table 4-9). *C. finmarchicus* was clearly dominant at this time, being an order of magnitude higher in abundance than the co-dominants *Eualus pusiolus* and *Evadne* sp. During the summer (Group 2), abundances of *C. finmarchicus* declined slightly and *Centropages typicus* became the dominant species. Rock and Jonah crab larvae, *Cancer* sp., and the shrimp larvae, *Eualus pusiolus*, were also abundant in summer. Abundances of *C. finmarchicus* and the meroplanktonic species declined to very low levels in fall while the abundance of *C. typicus* reached its annual peak, resulting in the formation of Group 3. *C. typicus* dominated fall collections by an order of magnitude over its congeners, *Centropages hamatus* and *Centropages* sp. copepodites. Members of the genus *Centropages* accounted for over 95% of the organisms in Group 3 collections. Low abundances characterized the late fall and early winter (Group 4) collections. These collections were dominated by the copepods *Temora longicornis, C. typicus, Tortanus discaudatus, C. hamatus* and *Pseudocalanus* sp., and by the arrow worm, *Sagitta elegans*.

In contrast to the stable seasonal pattern seen during most of the year, late winter and early spring collections displayed considerable variability. The only annually recurring group during this period was Group 8. Cirripedia spawn in the late winter and barnacle larvae accounted for about two-thirds of the organisms collected in Group 8. *Calanus finmarchicus, Temora longicornis*, and Larvacea were also common. Four other groups occurred sporadically during the preoperational late winter and early spring. *Pseudocalanus* sp. dominated the only preoperational occurrence of Group 5 in February 1987. A unique group (Group 6), dominated by large numbers of *T. longicornis* and *Sagitta elegans* occurred in February 1990. Cirripedia and *C. finmarchicus* occurred together in very high abundances in April 1987 (Group 9). The early cessation of the barnacle spawn in March and April of 1989 resulted in a unique group of low abundance dominated by *C. finmarchicus* and Cirripedia (Group 10).

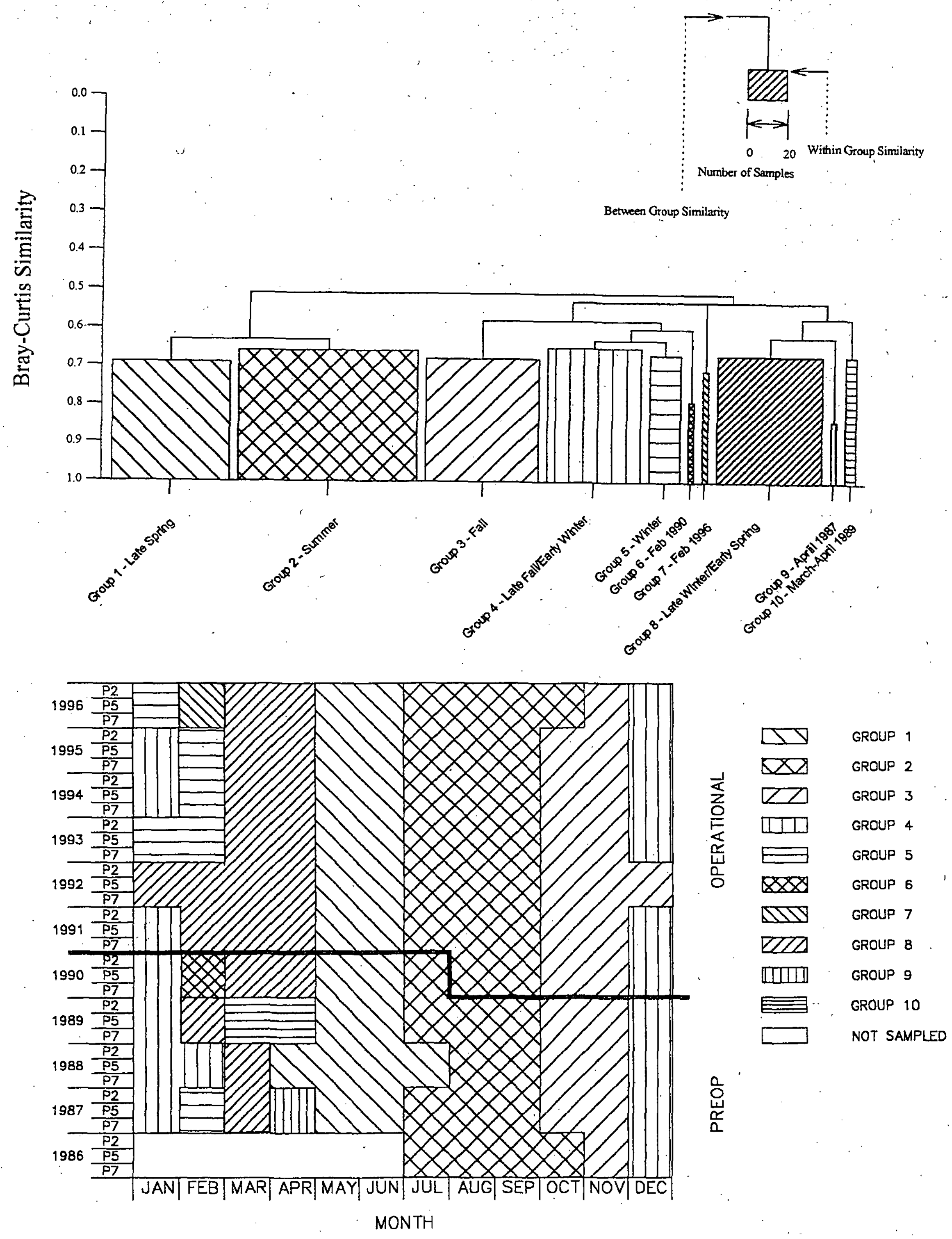


Figure 4-10. Dendrogram and seasonal groups formed by numerical classification of mean monthly $\log_{10}(x+1)$ transformed holoplankton and meroplankton abundances (no./1000 m^3) at the intake (P2), discharge (P5) and farfield (P7) stations 1986-1996.
Seabrook Operational Report, 1996.

Table 4-9. **Geometric Mean Abundance (No./1000m^3) and the 95% Confidence Limits of Dominant Holoplankton and Meroplankton Occurring in Seasonal Groups Formed by Numerical Classification of Macrozooplankton Collections at the Intake (P2), Discharge (P5) and Farfield (P7) Stations, 1986-1996. Seabrook Operational Report, 1996.**

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1 Late Spring (0.69/0.63)	*Calanus finmarchicus*	30	42197	57527	78424	36	52157	81485	127304
	Eualus pusiolus		3386	4844	6932		1805	2544	3585
	Evadne sp.		2358	4491	8552		5024	9734	18856
2 Summer (0.66/0.63)	*Centropages typicus*	39	17875	37103	77012	63	42792	65708	100894
	Calanus finmarchicus		20821	36214	62988		11824	21182	37945
	Cancer sp.		14019	24401	42471		17102	27440	44025
	Eualus pusiolus		3421	6602	12741		2477	4305	7482
3 Fall (0.68/0.58)	*Centropages typicus*	21	29419	52173	92524	42	37759	63494	106769
	Centropages hamatus		2307	4594	9147		95	218	498
	Centropages sp. copepodite		2409	4337	7810		978	1897	3676
4 Late Fall/Early Winter (0.65/0.63)	*Temora longicornis*	27	2135	3462	5613	27	586	1196	2439
	Centropages typicus		1942	3342	5751		2045	3771	6951
	Sagitta elegans		761	1252	2061		792	1153	1677
	Tortanus discaudatus		298	805	2167		457	977	2090
	Centropages hamatus		390	716	1315		17	49	137
	Pseudocalanus sp.		281	561	1118		88	194	425
5 Winter (0.67/0.63)	*Pseudocalanus* sp.	3	235	2754	32158	15	100	213	452
	Temora longicornis		55	1400	35306		495	1181	2817
	Calanus finmarchicus		467	892	1705		217	335	517
	Sagitta elegans		37	469	5787		1027	1588	2455
	Tortanus discaudatus		3	47	523		371	840	1898
6 February 1990 (0.79/0.60)	*Temora longicornis*	3	3226	28662	254624			not represented	
	Sagitta elegans		6896	20601	61540				
7 February 1996 (0.71/0.51)	*Centropages typicus*			not represented		3	75442	143394	272550
	Centropages sp.						4139	10176	25016
8 Late Winter/Early Spring (0.67/0.62)	Cirripedia	15	5692	13415	31614	45	14843	33219	74343
	Calanus finmarchicus		1903	4109	8873		902	2023	4534
	Temora longicornis		313	1295	5340		499	982	1932
	Larvacea		185	888	4250		4142	6655	10692
9 April 1987 (0.84/0.62)	Cirripedia	3	131514	213890	347863			not represented	
	Calanus finmarchicus		28038	184936	1219779				
10 March-April 1989 (0.67/0.57)	*Calanus finmarchicus*	6	4390	7900	14217			not represented	
	Cirripedia		893	3550	14100				

[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 1996

Spatially, no differences among stations were detected by numerical classification. All three stations were grouped together for each collection period.

Operational Period Trends

As defined by numerical classification, the operational holoplankton and meroplankton community was almost identical to the preoperational community from May through December (Figure 4-10). However, the operational community was different from the preoperational community in the first four months of the year. Preoperationally, the period of greatest variability in the community was February through April. Operationally, the period of variability shifted to January and February, followed by the consistent recurrence of the late winter Cirripedia spawn (Group 8) in both March and April every year.

Unlike the preoperational period, operational collections in January have varied in almost every year. In 1992, there was an unusually early Cirripedia spawn (Group 8) and in 1993 and 1996, a winter group (Group 5) occurred. In the operational period, Group 5 was dominated by *Sagitta elegans, Temora longicornis* and *Tortanus discaudatus*. Also common were *Calanus finmarchicus* and *Pseudocalanus* sp. (Table 4-9). In these respects, operational Group 5 resembled preoperational Group 4. These groups differed by the absence of *Centropages typicus* and *Centropages hamatus* in Group 5. January generally corresponded with the end of the annual peak for *C. typicus*, so slight variations in physical (temperature) or biological factors (food, predators) could result in the annual differences. Minimum annual temperatures (Section 2.3.1.1, Figure 2-3) have varied more in the operational period than in the preoperational period.

Another difference in the operational period was the occurrence of a large number of *Centropages typicus* in February 1996, forming a unique group (Group 7). Unique groups (6, 9, and 10) were also seen in the preoperational period.

The abundance of individual taxa within a group was generally consistent between the preoperational and operational periods (Table 4-9). The two exceptions were *Eualus pusiolus* and *Centropages hamatus*. The abundance of *E. pusiolus* in late spring (Group 1) was lower in the operational period; however, summer (Group 2) abundances were similar between the two periods. The abundance of *C. hamatus* was lower in both Groups 3 and 4 during the operational period. Abundances declined to levels where *C. hamatus* was no longer a dominant in the operational period. The decline in the abundance of *C. hamatus* may be related to temperature. Grant (1988) described *C. hamatus* as being less tolerant of warm water than *Centropages typicus*. Warmer operational period temperatures (Section 2.3.1.1) may be favoring *Centropages typicus*, whose abundance was higher in the operational period.

Differences between the operational and preoperational periods were also detected by MANOVA (Wilks' Lambda = 0.18, F = 42.31, p = 0.0001). Large-scale annual variation among copepod populations is common (Jossi and Goulet 1993). Their results also suggested that some taxa alternate between years of high and low abundance. Kane (1993) found interannual variations of orders of magnitude on Georges Bank. Considering the potential for large interannual variation, differences between the preoperational and operational periods were feasible.

Spatial Patterns

Results from numerical classification suggested no differences among the stations in the operational period, consistent with the preoperational period. However, MANOVA detected significant differences among stations (Wilks' lambda = 0.58, F = 2.92, p = 0.0001). The difference in results may have reflected the sensitivity of numerical classification using the Bray-Curtis Similarity Index to the influence of dominant taxa. Differences in holoplankton and meroplankton communities among stations situated about 5 km apart might not be expected. Mackas et al. (1984) noted that biomass can vary at much lower scales than community composition. Large rivers have been known to affect nearby coastal waters (Parsons and Takahashi 1973); the Hampton-Seabrook estuary could affect P2 and P5 without influencing P7.

Both numerical classification and MANOVA detected differences between the preoperational and operational periods. MANOVA detected station differences. Neither test detected any impacts from operation of Seabrook Station on the holoplankton and meroplankton community. The operational period differences detected by numerical classification occurred at both the potential impact sites and at the control site. Similarly, MANOVA testing for potential plant impacts found no significant differences in the interaction of Station X Preop-Op (Wilks' lambda = 0.84, F = 0.82, p = 0.90).

4.3.3.2 Demersal Plankton Community

Preoperational Community

Unlike the holoplankton and meroplankton community, the demersal zooplankton, with the exception of the spring *Mysis* spawn, did not exhibit a strong seasonal pattern. Instead, groups formed by numerical classification indicated strong station differences. Groups were also influenced by the dominant taxa and the total abundance. In general, within-group similarities were weaker than observed for the holoplankton and meroplankton analysis, indicating considerable variation among collections that were grouped together (Figures 4-11, 4-12).

Preoperationally, nine of the ten groups formed by numerical classification occurred at Station P7. The groups occurred in a sporadic manner, generally indicating no seasonal patterns. Only four of the ten groups occurred at the nearfield stations, P2 and P5, and of these, only two groups displayed a consistent pattern.

At the nearfield stations, the demersal plankton community typically alternated between a *Mysis mixta* (Group 1) and *Neomysis americana* (Group 2) dominated community. *M. mixta* dominated collections from March through May by an order of magnitude over co-dominants *N. americana* and *Pontogeneia inermis* (Table 4-10). Grabe and Hatch (1982) reported that *M. mixta* juveniles moved offshore as water temperatures reached 12°C. When *M. mixta* was absent, *N. americana* was the dominant species (Group 2), maintaining high abundances throughout the remainder of the year. The amphipods Oedicerotidae and *P. inermis*, and the cumacean *Diastylis* sp. were also common.

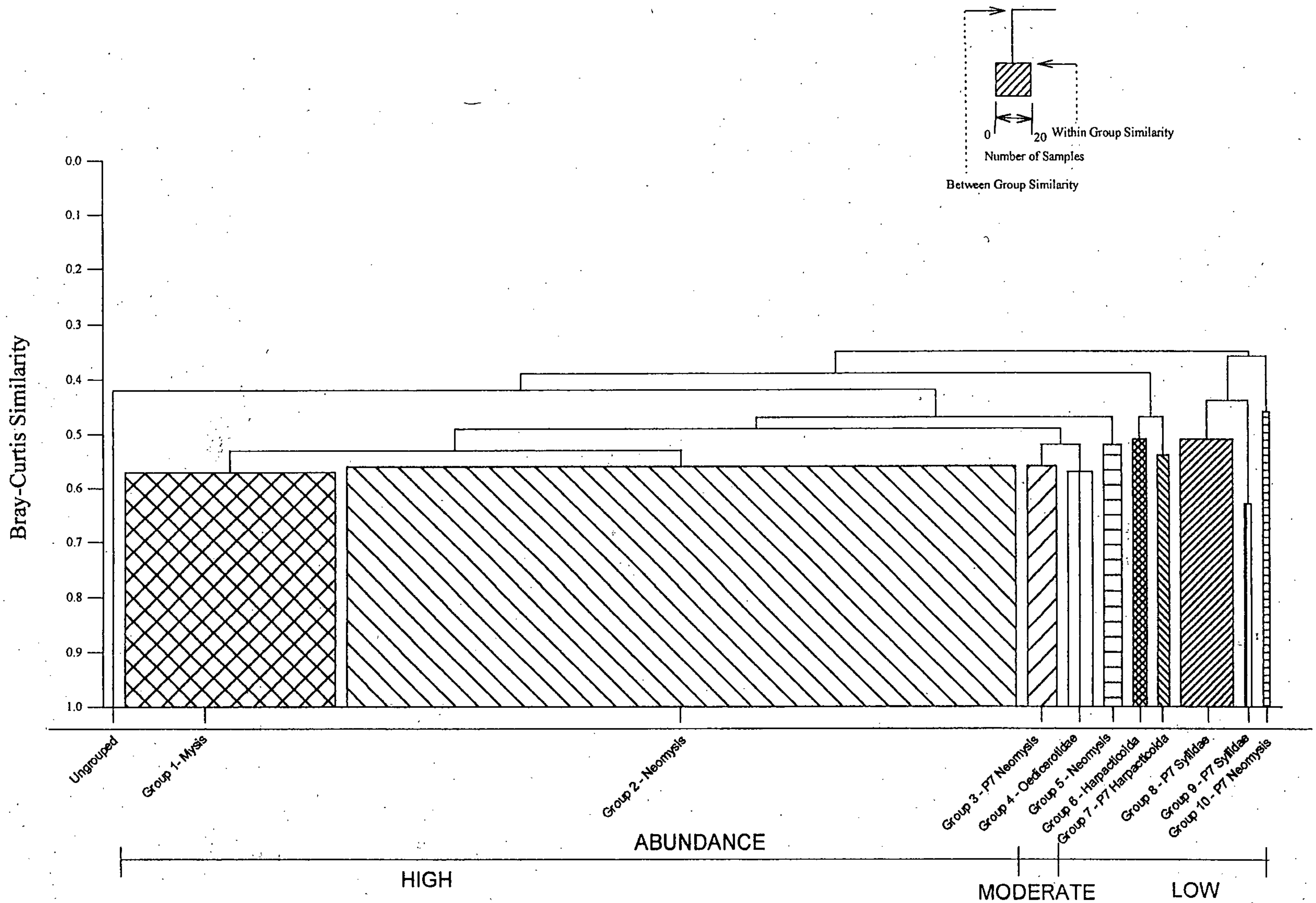


Figure 4-11. Dendrogram of groups formed by numerical classification of mean monthly $\log_{10}(x+1)$ transformed demersal plankton abundances (no./1000 m^3) Seabrook Operational Report, 1996.

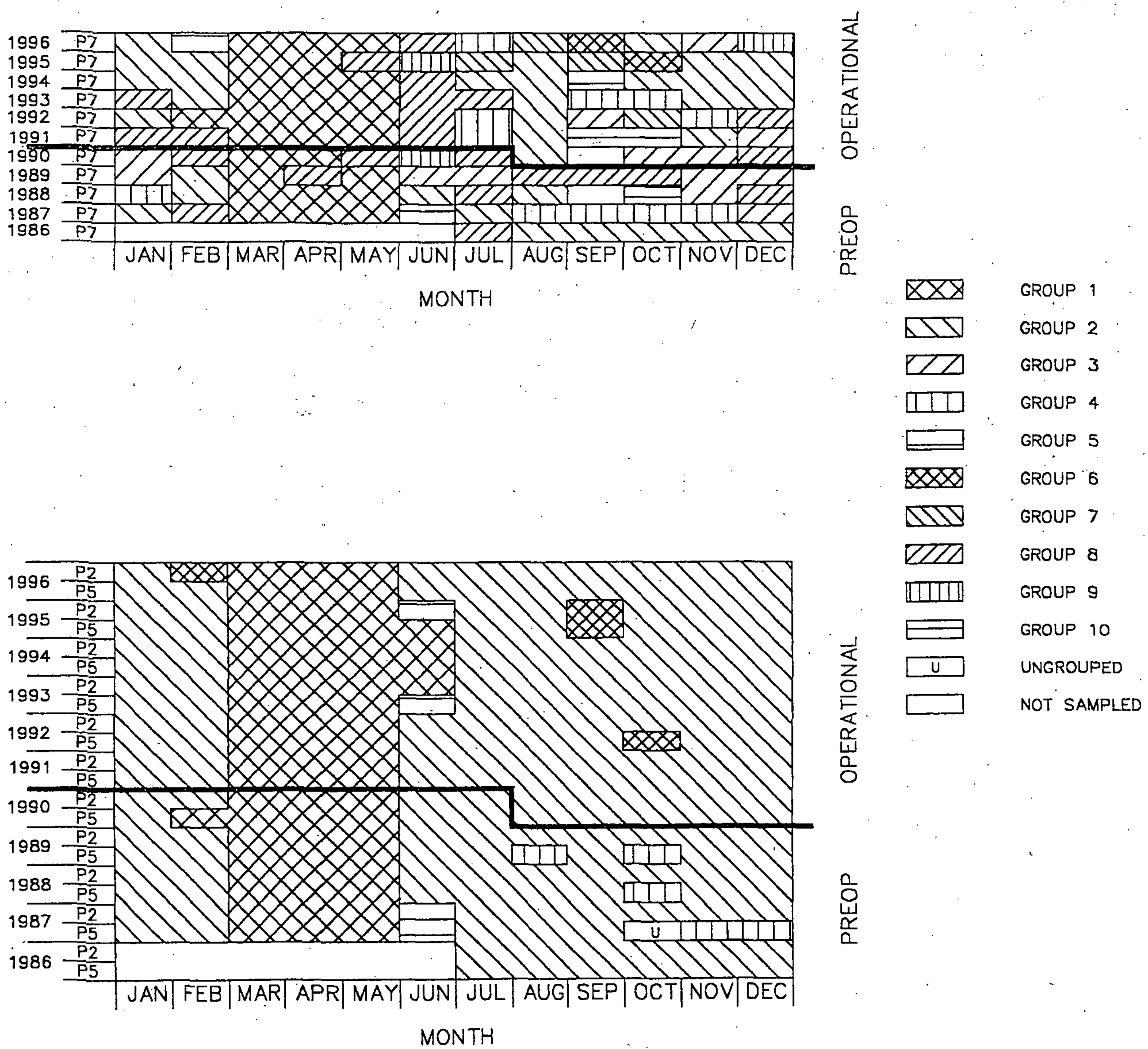


Figure 4-12. Groups formed by numerical classification of demersal plankton abundances displayed by station, month and year. Seabrook Operational Report, 1996.

Table 4-10. Geometric Mean Abundance (No./1000m^3) and the 95% Confidence Limits of Dominant Demersal Plankton Occurring in Groups Formed by Numerical Classification of Macrozooplankton Collections at the Intake (P2), Discharge (P5) and Farfield (P7) Stations, 1986-1996. Seabrook Operational Report, 1996.

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
1 (0.57/0.53)	*Mysis mixta*	35	145	375	966	57	180	320	567
	Neomysis americana		21	43	88		22	35	57
	Pontogeneia inermis		14	23	37		20	31	48
2 (0.56/0.53)	*Neomysis americana*	76	151	273	493	132	122	163	219
	Oedicerotidae		41	65	102		38	52	71
	Pontogeneia inermis		40	55	77		30	40	54
	Diastylis sp.		23	33	48		27	34	44
	Harpacticoida		8	12	18		27	37	49
3 (0.56/0.52)	*Neomysis americana*	8	90	252	701	5	113	185	303
	Syllidae		11	24	55		1	11	57
	Oedicerotidae		3	18	87		2	7	19
4 (0.57/0.52)	Oedicerotidae	10	7	24	82	6	12	46	176
	Neomysis americana		6	17	43		5	24	108
	Pontogeneia inermis		7	12	18		0	4	17
	Diastylis sp.		2	3	7		0	3	18
	Harpacticoida		0	2	6		4	16	56
	Syllidae		1	3	7		2	5	11
5 (0.52/0.47)	*Neomysis americana*	3	6	33	174	5	7	84	924
	Ischyrocerus anguipes		8	31	115		0	2	23
	Pontogeneia inermis		0	12	319		12	41	133
6 (0.51/0.47)	Harpacticoida			not represented		6	11	50	223
	Neomysis americana						2	11	38
	Isopoda						1	5	16
	Calliopius laeviusculus						2	5	9

(continued)

Table 4-10. (Continued)

GROUP[a]	DOMINANT SPECIES[b]	PREOPERATIONAL YEARS[c]				OPERATIONAL YEARS[c]			
		N	LCL	MEAN	UCL	N	LCL	MEAN	UCL
7 (0.54/0.47)	*Pontogeneia inermis*	1	--	6	--	4	0	1	6
	Harpacticoida		--	3	--		3	22	120
	Neomysis americana		--	3	--		0	4	16
	Calliopius laeviusculus		--	1	--		0	1	2
	Syllidae		--	1	--		1	2	3
	Corophium sp.		--	1	--		0	0	0
8 (0.51/0.44)	Syllidae	11	8	17	35	12	17	24	34
	Neomysis americana		1	5	16		1	3	7
	Pontogeneia inermis		1	2	4		0	1	2
	Harpacticoida		1	2	4		1	2	5
9 (0.63/0.44)	Syllidae	1	--	61	--	2	0	14	851
	Neomysis americana		--	0	--		0	1	175
10 (0.46/0.36)	*Neomysis americana*	1	--	4	--	2	8	21	50
	Syllidae		--	2	--		0	1	277
	Gammarus lawrencianus		--	1	--		0	1	118
	Oedicerotidae		--	1	--		0	2	$2x10^6$

[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 1996

Episodes of low demersal plankton abundance resulted in the formation of two additional nearfield preoperational groups. During summer and fall, a group dominated by Oedicerotidae occurred (Group 4). *Neomysis americana* and *Pontogeneia inermis* were also important components of Group 4. In June 1987, low abundances of *N. americana, Ischyrocerus anguipes* and *P. inermis* formed Group 5.

At the farfield station, the *Mysis mixta* spawn (Group 1) also occurred from March through May, but *Neomysis americana* dominated group (Group 2), which composed the majority of nearfield collections, occurred intermittently. Also occurring at the farfield station was a *N. americana* dominated group (Group 3) with Syllidae and Oedicerotidae as co-dominants. Frequent episodes of low demersal abundance resulted in the formation of six additional groups (presented in Table 4-10), briefly described as an Oedicerotidae dominated group (Group 4), two *N. americana* dominated groups (Groups 5 and 10), one Harpacticoid dominated group (Group 7) and two Syllidae dominated groups (Groups 8 and 9).

Operational Period Trends

The demersal zooplankton community in the operational period was generally similar to the preoperational community as described by numerical classification (Figure 4-12). The nearfield stations continued to be dominated by Groups 1 and 2. The farfield station continued to display considerable variability, with no clear seasonal patterns.

Differences between the two operational periods were few. A harpacticoid dominated group unique to operational period (Group 6) occurred at all three stations. This was a low abundance group with *Neomysis americana*, Isopoda, and *Calliopius laeviusculus* also contributing at least 5% to the total abundance (Table 4-10). The Oedicerotidae dominated group (Group 4), which occurred intermittently preoperationally, did not occur at the nearfield station during the operational period. Within each group, the abundances of the dominant taxa were generally similar between the preoperational and operational periods, except for harpacticoids in Group 2, which increased during the operational period. Differences between the preoperational and operational periods were also detected by MANOVA (Wilks' Lambda = 0.71, F = 8.37, p = 0.0001).

Spatial Patterns

Numerical classification detected large station differences. Similarly MANOVA detected significant differences among stations (Wilks' lambda = 0.32, F = 15.38, p = 0.0001). Most species of demersal plankton such as mysids (Wigley and Burns 1971; Pezzak and Corey 1979; Mauer and Wigley 1982), amphipods (Bousfield 1973) and cumaceans (Watling 1979) have preferences based on substrate type, sometimes as specific as narrow ranges of grain size. Many amphipods, such as *Pontogeneia inermis*, are associated with submerged plants and algae.

Both numerical classification and MANOVA detected differences among stations. These differences were consistent between the preoperational and operational periods. MANOVA testing for potential plant impacts found that the Preop-Op X Station interaction term was not significant (Wilks' lambda = 0.89, F = 1.27, p = 0.10), suggesting that Seabrook

Station had no effect on the demersal plankton community.

4.3.3.3 Selected Species

Calanus finmarchicus

Calanus finmarchicus is one of the most abundant copepods in the Gulf of Maine. Its large size and abundance make it an important component in the diets of many of the larger predators, including many fishes.

Copepodites The preoperational and operational seasonal cycle of the copepodites of *Calanus finmarchicus* were similar, although March abundances were lower in the operational period (Figure 4-13). Monthly abundances at Station P2 exhibited a broad peak from spring through summer. Abundances in 1996 showed a pattern similar to previous years. At all stations, the annual mean abundances were lower in 1996 than in the operational and preoperational (all years) periods (Table 4-11). The early warming in May and June could have slowed production in 1996 (Section 2.3.1.1). Davis (1978) suggested that *C. finmarchicus* was not reproductive at temperatures above 12°C,

Abundances in the operational period were not significantly different from the recent (1987-1989) preoperational period (Table 4-12). No differences were detected among stations and the interaction term (Preop-Op X Station) was not significant, indicating no effect from the operation of Seabrook Station.

Adults The preoperational and operational seasonal cycles of adult *Calanus finmarchicus* were not similar (Figure 4-13). During the preoperational years, a peak period occurred from January through March and a larger peak occurred from June through September. During the operational period, a small peak occurred in January and larger peaks occurred in April and August. The change in the annual cycle was consistent at both Stations P2 and P7 (NAI 1996). Abundances in 1996 were unlike previous years. Peaks occurred in February and May, but adults were absent from June through December. In 1996, abundances of *C. finmarchicus* (Table 4-11) were the lowest ever recorded at all three stations (previous lows were in 1990; NAI 1991).

Abundances of adult *Calanus finmarchicus* decreased between the preoperational and operational periods at all stations, but the decrease was greatest at Station P7, resulting in a significant interaction term (Table 4-12, Figure 4-14). The proportionally greater decrease between the preoperational and operational periods at Station P7 is probably due to the high abundances that occurred at Stations P2 and P5 in 1993, but not at P7 (Figure 4-15). Despite the significant interaction term, relative abundances were generally consistent among stations each year. Prior to 1996, abundance was highest each year at Station P5, followed by Stations P2 and P7. This pattern differed only in 1996 when abundance at Station P5 was intermediate between P2 and P7. Because of this consistent relationship of annual means between stations in both the preoperational and operational periods, the significant interaction term is probably not due to the operation of Seabrook Station.

Carcinus maenas

The green crab (*Carcinus maenas*), is a common coastal crab in northern waters. The adult crabs are strictly benthic, but the larval zoea and megalopa are common in the plankton.

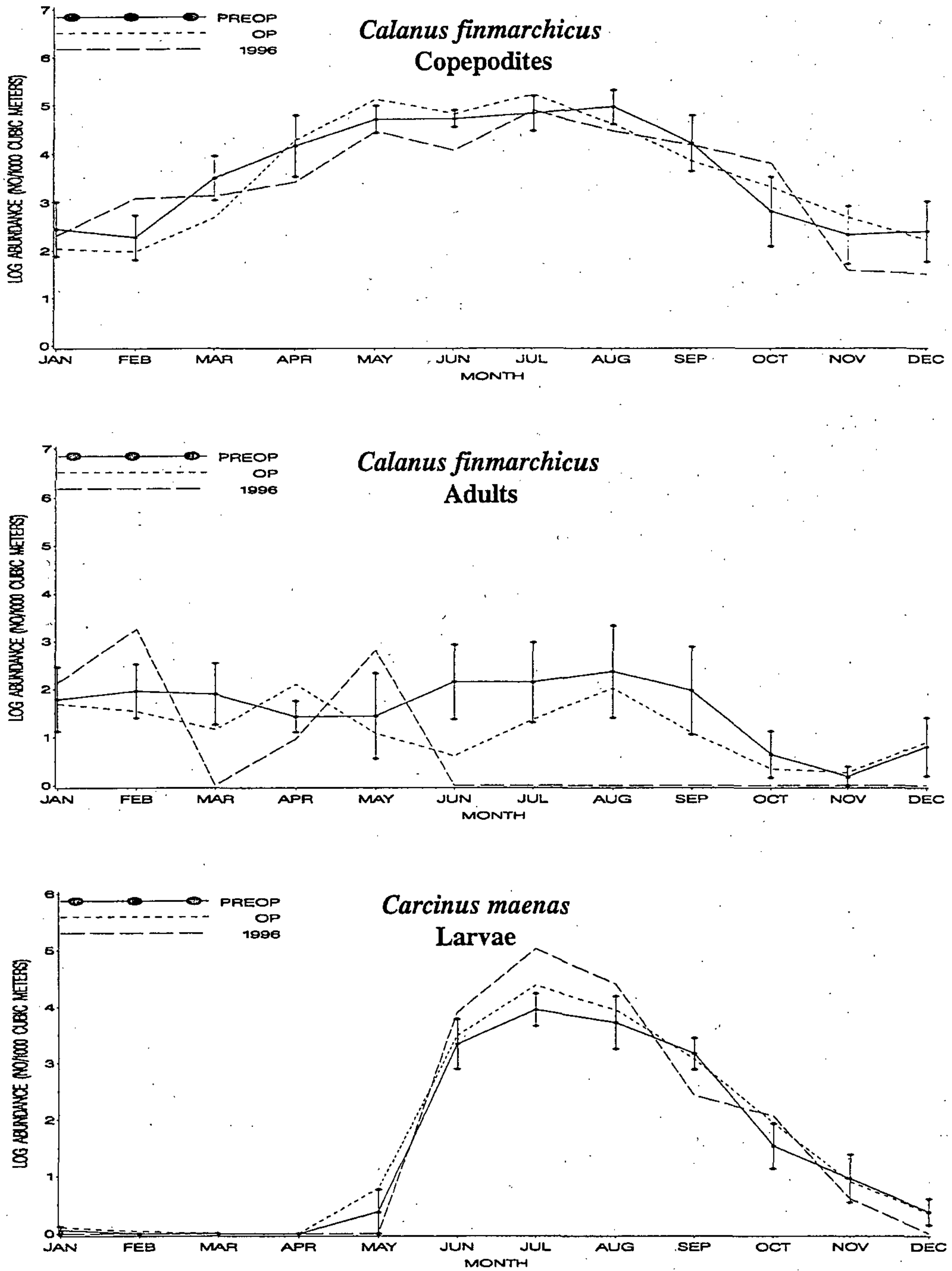


Figure 4-13. Log(x+1) abundance (no./1000 m^3) of *Calanus finmarchicus* copepodites and adults, and *Carcinus maenas* larvae at Station P2; monthly means and 95% confidence intervals during the preoperational period (1978-1984, 1986-1989); and monthly means during the operational period (1991-1996), and in 1996. Seabrook Operational Report, 1996.

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 the Preoperational and Operational Periods (1991-1996), and 1996. Seabrook Operational Report, 1996.

SPECIES/LIFESTAGE (peak period)	STATION	PREOPERATIONAL MEAN[a]	PREOPERATIONAL CV	OPERATIONAL MEAN[b]	OPERATIONAL CV	1996 MEAN
Calanus finmarchicus	P2	4153	6.39	3758	3.5	2603
copepodites	P5	5713	6.99	4839	4.4	2682
(January-December)	P7	2594	7.19	2286	5.0	1409
Calanus finmarchicus	P2	36	26.52	14	25.0	5
adults	P5	26	28.88	17	29.2	4
(January-December)	P7	29	28.96	7	39.7	1
Carcinus maenas	P2	3509	6.73	5281	12.4	8739
larvae	P5	3615	12.92	5555	10.8	3837
(June-September)	P7	4251	6.24	2516	16.6	331
Crangon septemspinosa	P2	257	3.66	224	7.4	170
zoeae and postlarvae	P5	233	6.72	172	12.5	73
(January-December)	P7	161	10.42	87	16.4	29
Neomysis americana	P2	151	18.94	198	7.5	292
all lifestages	P5	45	30.73	66	12.5	102
(January-December)	P7	43	22.03	24	15.7	36

[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, 1991-1996

Table 4-12. **Results of Analysis of Variance Comparing Log (X+1) Transformed Abundances (No./1000m^3) of Selected Macrozooplankton Species from Stations P2, P5 and P7 During the Preoperational (1987-1989) and Operational (1991-1996) Periods. Seabrook Operational Report, 1996.**

SPECIES	SOURCE	d.f.	MS	F	MULTIPLE COMPARISONS
Calanus finmarchicus copepodites (January-December)	Preop-Op[a]	1	1.80	0.98 NS	
	Year (Preop-Op)[b]	7	1.59	0.16 NS	
	Month (Year)[c]	99	10.38	16.62***	
	Station[d]	2	4.10	12.17 NS	
	Preop-Op X Station[e]	2	0.33	3.60 NS	
	Year X Station (Preop-Op)[f]	14	0.10	0.15 NS	
	Error	510	0.62		
Calanus finmarchicus adults (January-December)	Preop-Op	1	2.63	0.33 NS	
	Year (Preop-Op)	7	7.56	1.60 NS	
	Month (Year)	99	5.60	6.50***	
	Station	2	4.46	9.21 NS	
	Preop-Op X Station	2	0.46	10.01**	P5P P5O P2P P2O P7P P7O
	Year X Station (Preop-Op)	14	0.05	0.06 NS	
	Error	510	0.86		
Carcinus maenas larvae (June-September)	Preop-Op	1	0.01	<0.01 NS	
	Year (Preop-Op)	7	3.05	1.05 NS	
	Month (Year)	27	2.82	4.41***	
	Station	2	1.16	3.59 NS	
	Preop-Op X Station	2	0.34	0.46 NS	
	Year X Station (Preop-Op)	14	0.74	1.15 NS	
	Error	162	0.64		
Crangon septemspinosa zoeae and post larvae (January-December)	Preop-Op	1	1.26	0.45 NS	
	Year (Preop-Op)	7	3.02	0.36 NS	
	Month (Year)	99	8.34	24.99***	
	Station	2	7.26	39.58*	P2>P5>P7
	Preop-Op X Station	2	0.19	0.44 NS	
	Year X Station (Preop-Op)	14	0.45	1.34 NS	
	Error	510	0.33		
Neomysis americana all lifestages (January-December)	Preop-Op	1	<0.01	<0.01 NS	
	Year (Preop-Op)	7	6.02	2.65*	
	Month (Year)	99	2.55	4.22***	
	Station	2	42.58	567.29***	P2>P5>P7
	Preop-Op X Station	2	0.09	0.24 NS	
	Year X Station (Preop-Op)	14	0.36	0.60 NS	
	Error	510	0.60		

[a]Preoperational (1987-1989) versus operational (1991-1995) periods, regardless of station; 1987-1989 reflects the period of time that all three stations were sampled coincidentally. [b]Year nested within preoperational and operational periods, regardless of station. [c]Month nested within year, regardless of station. [d]Station P2 vs. station P5 vs. station P7, regardless of year. [e]Interaction between main effects. [f]Interaction of station and year nested within preoperational and operational period.

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)

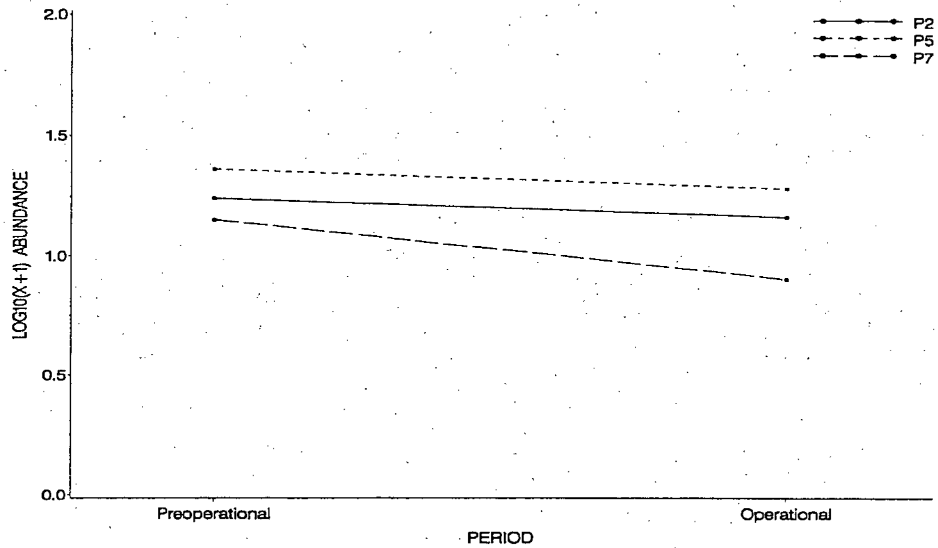


Figure 4-14. A comparison among stations of the mean log(x+1) abundances (no./1000 m^3) of adult *Calanus finmarchicus* during the preoperational (1987-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model. Seabrook Operational Report, 1996.

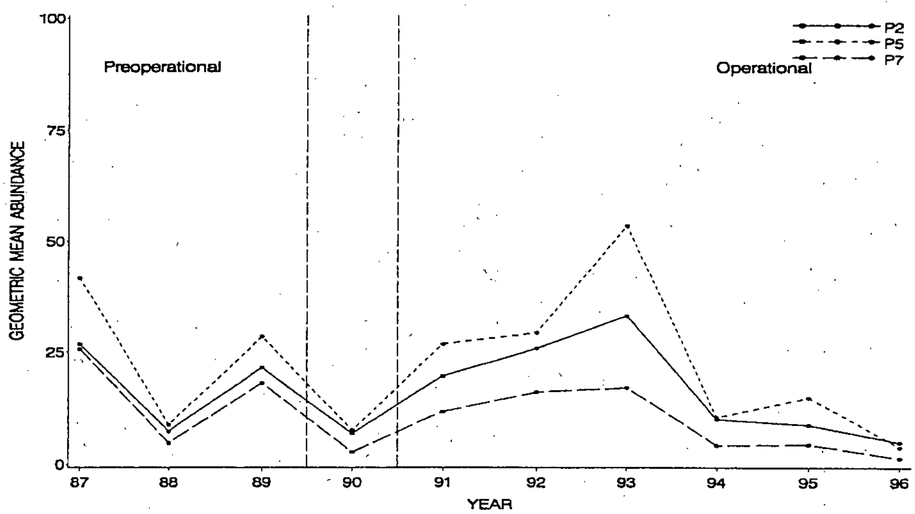


Figure 4-15. Annual geometric mean abundance(no./1000 m^3) of adult *Calanus finmarchicus* by station during the recent preoperational (1987-1989) and operational (1991-1996) periods (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

The seasonal cycle of the larvae of green crabs during the preoperational and operational years was almost identical (Figure 4-13). Larvae first appeared in May, with peak abundances occurring from June through September. The seasonal pattern in 1996 was similar to previous years, although abundances were generally higher from June through August before decreasing in September. Peak period mean abundance in 1996 at Station P2 was higher when compared to the preoperational and operational periods (Table 4-11). Abundance at Station P7 was the lowest ever recorded (previous low was in 1994: NAI 1995b).

Differences in abundance among stations and between the preoperational and operational periods were not significant when tested by ANOVA (Table 4-12). The interaction term (Preop-Op X Station) was not significant, indicating no effect on the larvae of *Carcinus maenas* due to operation of Seabrook Station.

Crangon septemspinosa

The sand shrimp *Crangon septemspinosa* is one of the most abundant coastal shrimps on the North American East Coast. The larval zoea and megalopa (first post-zoeal stage) are planktonic. Juveniles and adults are benthic, but are frequently encountered in plankton tows as demersal plankton.

The seasonal cycle of the zoea and post-larvae of *Crangon septemspinosa* was generally similar in the preoperational and operational years, although late summer abundances in the operational period were typically lower (Figure 4-16). Abundances steadily increased from a low in February to the peak mean abundance from June through September. Abundances in 1996 were similar to previous years, although abundances in August and September were lower than usual. Annual geometric means of *C. septemspinosa* larvae in 1996 were lower than the preoperational and operational means (Table 4-11). Abundances in 1996 were the lowest recorded at Stations P5 and P7 (previous lows were in 1994; NAI 1995b).

There were no significant differences between the recent preoperational (1987-1989) and operational periods (Table 4-12). All three stations were significantly different with mean abundance greatest at Station P2 and least at Station P7. The post-larvae lifestage identified in Seabrook studies included juveniles up to 20 mm long, which were demersal plankton and may account for the significant station differences as the demersal plankton community in the study area displayed large station differences (Section 4.3.3.2). Differences in abundance among stations were consistent between the preoperational and operational periods (Table 4-12) , indicating a broadscale trend not due to the operation of Seabrook Station.

Neomysis americana

The opossum shrimp, *Neomysis americana*, is the most abundant mysid in northeastern coastal waters. It frequently moves up into the water at night and is known to form large aggregations or swarms. It is a favorite prey species of many of the coastal fishes (Mauchline 1980).

In both preoperational and operational periods, the seasonal cycle was generally the same, although abundances in March during the operational period were lower (Figure 4-16). Abundances were lowest in May and June.

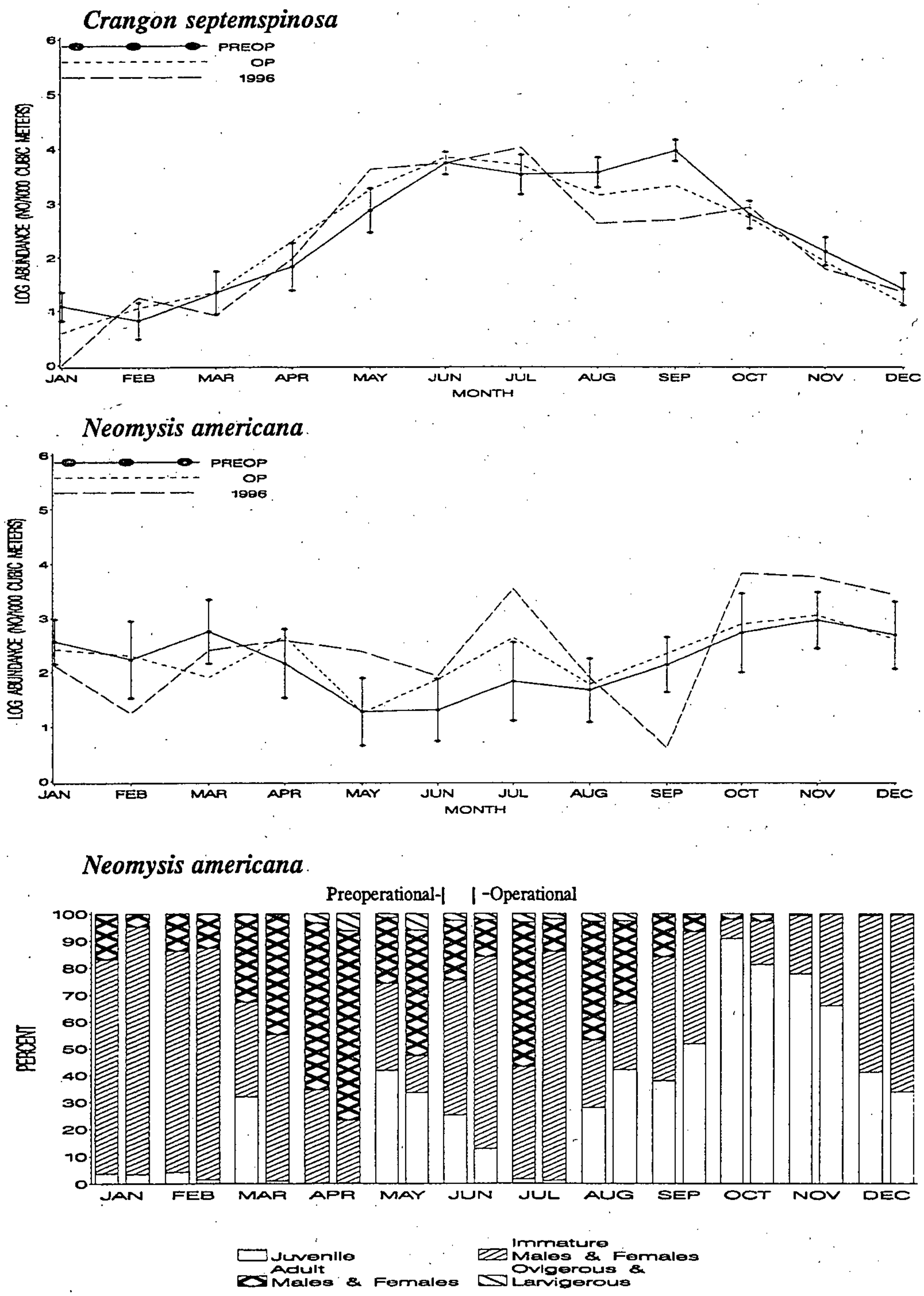


Figure 4-16. Log(x+1) abundance (no./1000 m^3) of *Crangon septemspinosa* (zoea and post larvae) and *Neomysis americana* (all lifestages) at Station P2; monthly means and 95% confidence intervals during the preoperational period (1978-1984, 1986-1989), monthly means during the operational period (1991-1996) and 1996; and mean percent composition of *Neomysis americana* lifestages during the preoperational and operational periods. Seabrook Operational Report, 1996.

Abundances generally increased through the summer to a broad peak lasting through fall and winter. Abundances in 1996 were irregular; low abundance in February, followed by a period of moderate abundances leading to a July peak. Abundance then dropped abruptly to the seasonal low in September. Fall abundances were higher than usual. Average annual abundance in 1996 was higher than in previous years at the nearfield stations (Table 4-11). Mauer and Wigley (1982) noted that spatially, peak abundance occurred where bottom temperatures were less than 8.1°C. High September bottom temperatures were reflected by low abundances (Section 2.3.1.1).

There were no significant differences in abundances between the recent preoperational (1987-1989) and operational periods (Table 4-12). Significant station differences occurred; abundances at the intake station (P2) were greater than the discharge station (P5). Abundances at the farfield station (P7) were significantly less than both of the nearfield stations. The interaction term (Preop-Op X Station) was not significant indicating no effect from operation of the Seabrook Station on *N. americana* (Table 4-12).

The relative abundance of *Neomysis americana* lifestages (Figure 4-14) at Station P2 suggested that two generations per year were produced, similar to the life cycle described by Mauchline (1980) and observed by Wigley and Burns (1971) on Georges Bank. The unusually high abundances in 1996 altered the percent composition of *N. americana* lifestages from what was observed last year (NAI 1996) resulting in a higher percentage in May and a lower percentage in July of adult *N. americana*. Although 1996 appeared to be an anomalous year, the same two-generational lifecycle appeared both preoperationally and operationally.

4.4 CONCLUSION

Naylor (1965) suggested that nearshore marine organisms, although they may be more susceptible to effects of heated effluents than estuarine organisms, were less likely to be impacted because the effluent would be discharged into an essentially open system, which would allow the heat to be efficiently dissipated. The temperature differences among stations and between the preoperational and operational periods in coastal New Hampshire waters were small, generally less than 0.5°C. Such small changes in temperature are well within the range of interannual variability and would not be expected to have any significant biological effects. Entrainment, with individuals being exposed to potentially lethal or physiological altering conditions, would be a direct effect.

Results indicated that neither the heated effluent or entrainment had any measured effect on the plankton communities (Table 4-13). Although each community experienced some changes in abundance or seasonality during the operational period, those changes occurred at the control site as well as at the nearfield stations. Other factors may have affected the plankton communities. Predation (Davis 1984b), food levels and predation (Kane 1993) and temperature and food levels (Ban 1994) have all been described as having effects on copepod population levels or growth.

Most of the selected species experienced either no significant differences operationally or reductions in abundance that were consistent among stations (Table 4-14). However, ANOVA results for adult *Calanus finmarchicus* and copepodite *Eurytemora* sp. abundances displayed a significant Preop-Op X Station interaction term, suggesting a potential plant impact. Comparison

Table 4-13. Summary of Potential Effects, Based on Numerical Classification and MANOVA Results, of the Operation of Seabrook Station on the Indigenous Zooplankton Communities. Seabrook Operational Report, 1996.

COMMUNITY ATTRIBUTE	OPERATIONAL PERIOD SIMILAR TO PREOPERATIONAL PERIOD?	DIFFERENCES BETWEEN OPERATIONAL AND PREOPERATIONAL PERIODS CONSISTENT AMONG STATIONS?
MICROZOOPLANKTON		
Seasonal occurrence	yes[a]	not tested
Abundances	yes[b]	not tested
BIVALVE LARVAE		
Seasonal occurrence	no[a]	yes
Abundances	no[c]	yes
MACROZOOPLANKTON		
Holo/meroplankton		
Seasonal occurrence	no[a]	yes
Abundances	no[c]	yes
Demersal Plankton		
Seasonal occurrence	yes[a]	yes
Abundances	no[c]	yes

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

Table 4-14. Summary of Potential Effects, Based on Anova Results, of the Operation of Seabrook Station on Abundances of Selected Indigenous Zooplankton Species. Seabrook Operational Report, 1996.

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	Preop > Op	No, Op decrease greater at P7
E. herdmani adults	yes	yes
Pseudocalanus/Calanus nauplii	Preop > Op	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	Preop>Op	No, Op decrease greater at P7
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.

of the annual means for *C. finmarchicus* showed variation among stations to be limited to only three of the six operational years, suggesting either a short-term trend or effects from factors other than Seabrook Station. The potential plant impact on copepodites of *Eurytemora* sp. may be the result of an unusual preoperational year (high abundance in 1983). In any case, abundance changes in this larval form was not accompanied by changes in the adult abundances. Operational period abundances were similar in magnitude and variability to two of the three preoperational years tested by ANOVA.

Entrainment does not appear to have affected the bivalve larvae community. The number of entrained larvae was less than predicted for *Mya arenaria*. Actual entrainment levels of *Mytilus edulis* were comparable to predicted levels. Increasing levels of entrainment in the last two operational years were probably a result of increased abundances of larvae in the nearfield area, and an increase in the volume of water pumped during the bivalve larvae season. The year 1996 was unusual, because *Anomia squamula* was entrained more than *M. edulis*, reflecting the likely increased abundance of *A. squamula* offshore. There was no evidence that entrainment of bivalve larvae resulted in decreased abundance of adult *M. arenaria* (Section 8.0), *M. edulis* or *Modiolus modiolus* (Section 6.0).

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Appendix Table 4-1. List of Zooplankton Taxa Cited in this Report. Seabrook Operational Report, 1996.

Protozoa
- Foraminiferida
- Tintinnidae

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
- Syllidae

Hirundinea

Arthropoda
- Branchiopoda
  - *Evadne* Lovén
- Copepoda
  - *Anomalocera opalus* Penell 1976
  - *Calanus finmarchicus* (Gunnerus 1765)
  - *Caligus* Műller 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)

APPENDIX TABLE 4-1. (Continued)

Monstrillidae
Oithona Baird 1843
Pseudocalanus Boeck 1872
Rhincalanus nasutus Giesbrecht 1892
Temora longicornis (Müller 1785)
Tortanus discaudatus (Thompson and Scott 1897)

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
Isopoda
Amphipoda
Calliopius laeviusculus (Krøyer) 1838
Corophium Milne-Edwards
Gammarcus lawrencianus Bousfield 1956
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)

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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. Potential 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, through 1994, 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. There were no significant differences in larval densities between the preoperational and operational periods for Atlantic cod, hake spp., cunner, Atlantic mackerel, winter flounder, and yellowtail flounder. Densities of larval Atlantic herring and pollock were significantly greater in the preoperational period, but the increases were consistent at all stations. Density of larval American sand lance was not significantly different between the preoperational and operational periods at Stations P5 and P7, but increased at Station P7. Examination of the annual time series indicated that the stations generally followed the same trends among years. This consistency among stations suggests that the changes in density are unrelated to plant operation.

There were no significant differences in CPUE of adults between the preoperational and operational periods for pollock, Atlantic silverside, and Atlantic mackerel. CPUE of adult Atlantic herring, Atlantic cod, hakes, winter flounder (seine), and yellowtail flounder was significantly lower in the operational period. These decreases were consistent at all stations and were not due to plant operation. CPUE of adult rainbow smelt decreased significantly between the preoperational and operational periods at all stations, but the decrease was greatest at Station T2. A sharp decline in rainbow smelt CPUE at all stations began in 1988 prior to the beginning of plant operation. The current low CPUE in the operational period at Station T2 is similar to those at the other stations and may be a reflection of high natural variability. CPUE of winter flounder in the trawl decreased between the preoperational and operational periods to a significantly greater extent at Station T2 than at the other stations. The decrease at Station T2 began during the early 1980s before the plant became operational and is probably not due to plant operation.

Entrainment in 1996 was estimated as 926.8 million eggs and 215.7 million larvae. Eggs of Atlantic mackerel (305.1 million) hake (184.0 million) and cunner/yellowtail (110.2 million) were the most numerous entrained. These three taxa have generally been the most numerous entrained by Seabrook Station. Atlantic seasnail (60.6 million), rock gunnel (33.8 million), and grubby (18.6 million) were the most numerous larvae entrained, consistent with previous years. Impingement in 1996 was an estimated 26,825 fish and lobsters which was higher than 1994 (19,212) and 1995 (15,926), probably due to increased storm activity. The most numerous fish impinged was rainbow smelt (4,489) followed by winter flounder (3,231), and pollock (1,835). These three species are usually among the most numerous fishes impinged.

5.0 *FISH*

In comparison to other New England power plants with marine intakes, Seabrook Station entrains relatively few fish eggs and larvae and apparently 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 relatively 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.

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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 on-site settling basin into the Browns River, which ended in April 1994. 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.

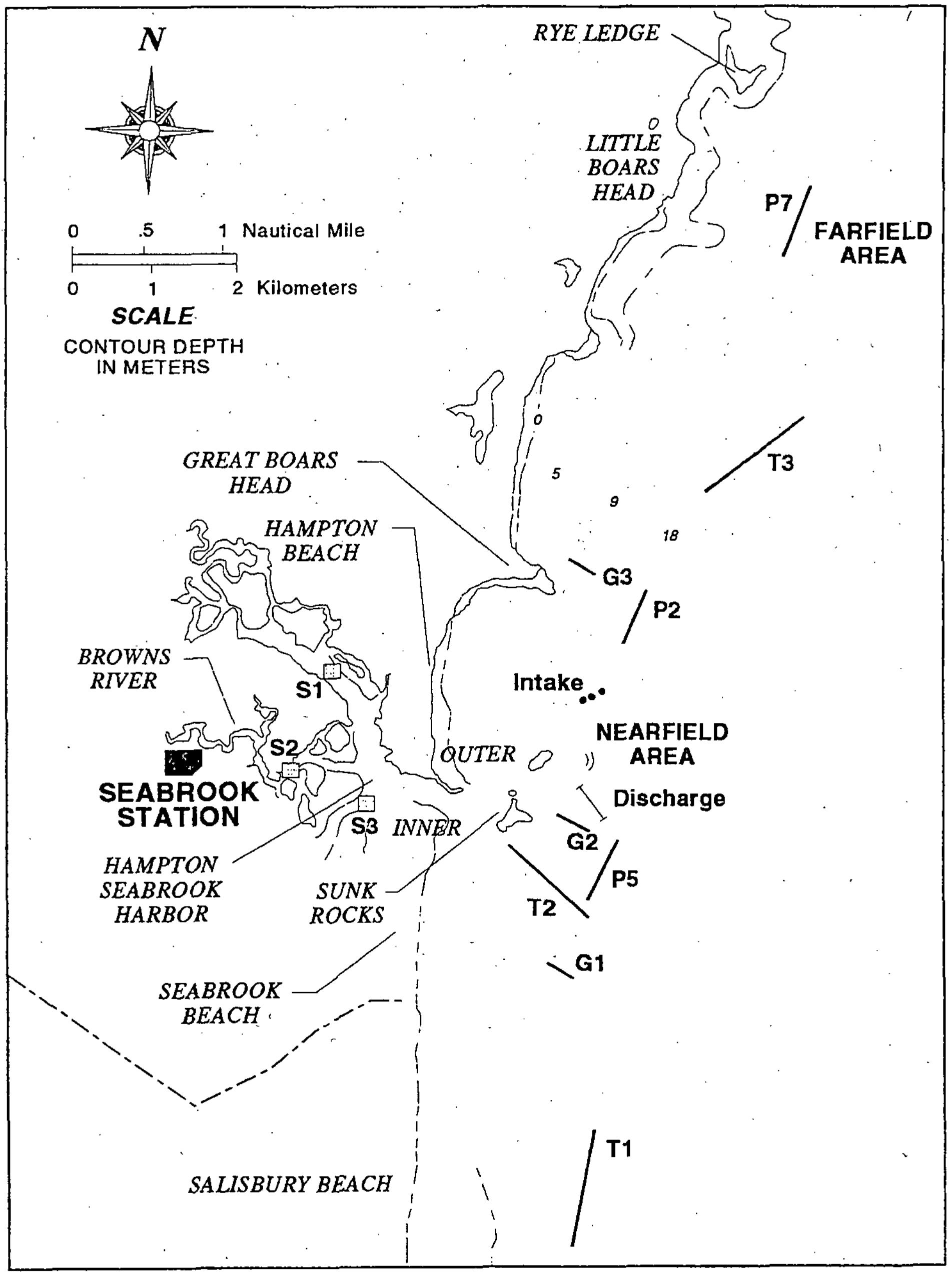
At present, the main objective of the finfish studies at Seabrook Station is to assess whether power plant operation since 1990 has had any measurable effect on the nearshore fish populations. The following report first presents general information on each finfish collection program and then provides 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 1996 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 1996. 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 1985 and from January 1986 through December 1996. Through June 1977, 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.



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, 1996.

On each sampling date and at each station, four samples were collected at night from July 1975 through December 1993. Beginning in January 1994, two tows were collected on each of the four sampling periods each month. 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 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 Sampling

Ichthyoplankton entrainment sampling was conducted up to four times a month by NAESCO biologists within the circulating water pumphouse on-site at Seabrook Station from July 1986 through June 1987 and June 1990 through December 1996. 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 through 1996.

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. The three simultaneuos replicates were summed into one sample during analysis.

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 or four tows was analyzed per date and station, with the remaining tows 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 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. In 1996 no samples were collected at Station T2 in late July, August, late September and October. 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 through 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

Table 5-1. Description of Finfish Sampling Stations. Seabrook Operational Report, 1996.

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)

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), and measured to the nearest 2 cm.

5.2.2.4 Impingement

Fish impinged at Seabrook Station were collected by NAESCO biologists 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, identified to species, and counted by NAESCO biologists. Impingement collections were noted as total counts per species by month.

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). $\text{Log}_{10}(x+1)$ 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. $\text{Log}_{10}(x+1)$ transformed sample densities (number per 1000 m^3) were used. The analysis was restricted to collections from July 1986 through December 1996, 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 nested within year; 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.

Total ichthyoplankton entrainment was estimated by calculating the arithmetic mean density in a sample for each sampling day, multiplying by the daily cooling water volume on the sample day, and multiplying by the number of days in the sampling week. These weekly estimates were summed for a monthly estimate, and monthly estimates were summed for the annual estimate.

From the 88 species collected over the years, 11 taxa were selected for detailed analyses of abundance and distribution and for an assessment of impact by Seabrook Station (Appendix Table 5-1, Table 5-2). These selected 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 the preoperational and operational periods. Geometric means were compared among the preoperational, operational, and 1996 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 varia-

Table 5-2. Selected Finfishes and Sampling Programs That Contributed Abundance Data for Species-Specific Analyses. Seabrook Operational Report, 1996.

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

tion (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, based on 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 for the ichthyoplankton, otter trawl, and gill net programs 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 and Station main effects and the Preop-Op X Station interaction. However, only a significant Preop-Op X Station interaction term would imply power plant effect (Thomas 1977, Green 1979, Stewart-Oaten et al. 1986). Even if significant, 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 ANOVA for the seine monitoring program for estuarine fish in Hampton Harbor was slightly different from the model used for the otter trawl and gill net programs. The seine monitoring program was not a BACI study design as all stations were located in a farfield area (Hampton Harbor). Therefore, the Preop-Op X Station term was dropped, because there was no reasonable mechanism by which plant operation could affect only one station in Hampton Harbor. Potential plant impacts were indicated by significant differences in CPUE between the preoperational and operational periods (Preop-Op term). If there were significant differences between periods, the annual time series of CPUE was examined to determine if the changes began prior to plant operation.

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 5-2), and is noted as such on the ANOVA tables. For larvae, the data were restricted to the period July 1986 through December 1996, and for selected taxa collected by gill net, trawl, and seine, the data used were from July 1975 through December 1996. 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 analyzed in 1994 through 1996).

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 1996, 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).

Eggs from eleven taxa were analyzed (Table 5-3) and the subsequent numerical classification analysis resulted in eight groups (Figure 5-2). A total of 359 monthly "collections" were used for the cluster analysis, with each collection being a monthly average of samples at one station. Each of the 359 monthly collections analyzed fell within one 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

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 1996.[a] Seabrook Operational Report, 1996.**

		NUMBER OF SAMPLES AND DENSITY (EGGS/1000 m³)[d]							
		PREOPERATIONAL PERIOD[e]				OPERATIONAL PERIOD[e]			
GROUP	DOMINANT TAXA[c]	n	LCL	MEAN	UCL	n	LCL	MEAN	UCL
1-Late Fall/Early Winter (0.69/0.49)[b]	Atlantic cod	34	39	58	85	46	23	31	42
	Pollock		5	7	10		1	2	3
2-Winter (0.62/0.49)	Atlantic cod/haddock	19	4	6	8	32	4	6	7
	American plaice		1	1	2		1	2	2
3-Early Spring (0.51/0.38)	American plaice	15	22	38	64	21	36	59	97
	Atlantic cod/haddock		7	15	30		14	20	29
	Fourbeard rockling		4	8	16		<1	<1	<1
4-Mid-Spring (0.74/0.56)	Cunner/Yellowtail flounder	12	175	293	488	18	147	267	485
	Fourbeard rockling		77	235	715		5	12	26
	American plaice		54	73	97		28	46	75
	Atlantic mackerel		18	37	77		107	212	419
5-Late Spring (0.77/0.70)	Cunner/yellowtail flounder	12	8,170	12,200	18,400	18	11,500	15,600	21,000
	Atlantic mackerel		1,670	2,910	5,080		3,340	4,380	5,740
6-Summer (0.75/0.70)	Cunner/yellowtail flounder	26	1,810	3,920	8,450	39	2,370	3,910	6,450
	Fourbeard rockling/hake		310	542	944		276	390	551
	Windowpane		224	299	399		202	281	390
7-Late Summer/Early Fall (0.68/0.62)	Fourbeard rockling/hake	16	78	139	249	21	122	180	265
	Hake		80	126	198		121	199	328
	Windowpane		14	30	62		43	69	110
	Fourbeard rockling		6	16	39		5	9	15
8-Fall (0.59/0.39)	Atlantic cod/haddock	9	10	20	39	21	1	3	5
	Fourbeard rockling/hake		4	10	25		4	7	10
	Hake		6	10	17		3	5	6
	Silver hake		5	8	12		4	8	13
	Fourbeard rockling		1	4	10		1	1	2

[a]Each "sample" consisted of the average of tows within date and dates within month at one station.
[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 1996.

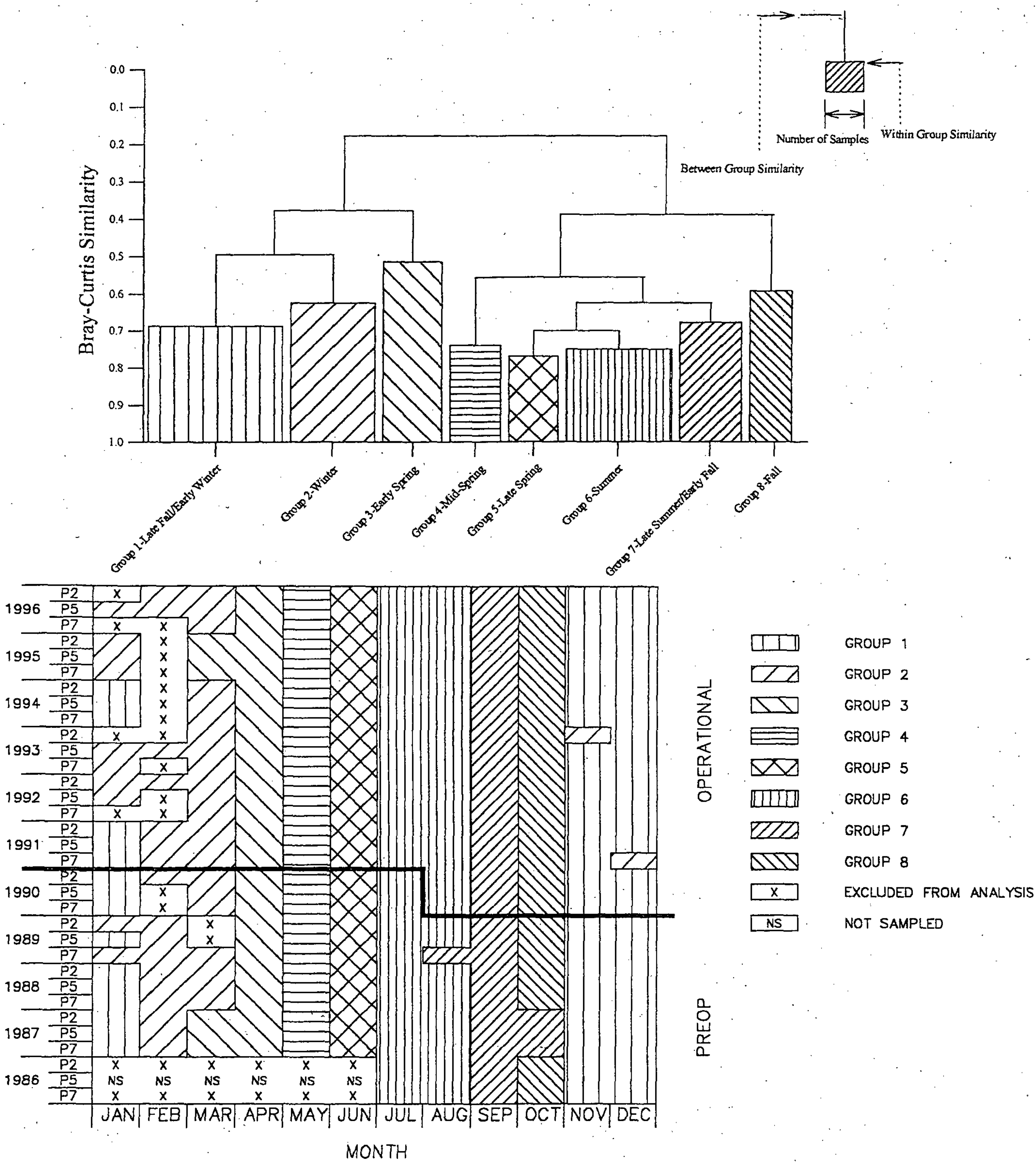


Figure 5-2. Dendrogram and temporal/spatial occurence pattern of **fish egg** assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m^3) at Seabrook intake (P2), discharge (P5), and farfield (P7) stations, July 1986-December 1996. Seabrook Operational Report, 1996.

through April) and Groups 4-8 were taken during the warmer period (May through October). There was no apparent 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 January, February, and March. Group 3, termed early spring, primarily including April collections, had the same two dominant taxa as the previous group but in somewhat higher densities, and with the addition of fourbeard rockling as another dominant species.

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, and Atlantic mackerel (most abundant during the operational period). Group 5, termed the late spring group, consisted of June collections exclusively for all years. The dominant eggs in this group were cunner/yellowtail flounder and Atlantic mackerel. Eggs of these taxa were in much higher abundance than in Group 4 samples. Group 6, termed the summer grouping, consisted of all of the July collections and all but one of the August collections. This group was dominated by eggs of cunner/yellowtail flounder, fourbeard rockling/hake, and windowpane. All three groups of eggs exhibited fairly similar abundance in the preoperational and the operational periods. Group 7 consisted of late summer/early fall collections, primarily during September. The dominant taxa in this group were fairly diverse, probably due to a general decline in egg abundance during this period. The season represented by Group 8 was fall and collections occurred exclusively in October. Some 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 a little lower in the operational period than in the preoperational period.

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 importantly, 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 spatial or temporal distribution of eggs in the Hampton-Seabrook area. The spatial stability was demonstrated by the fact that for 97% of the months in which all three stations were represented in the analysis, 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 ($p = 0.74$). This indicated that the temporal changes in assemblage abundance occurred concurrently at all three stations, including the farfield Station (P7), the control area.

Larvae of 22 fish taxa were selected for numerical classification analysis, which resulted in eight cluster groups (Figure 5-3). Only one monthly observation (Station P2, October 1992) did not group within any of the eight groups. Similar to the egg collection data, two major categories were evident, with collections in Groups 1-5 occurring primarily during the cooler water temperature period (generally October through May) and collections in Groups 6-8 during the warmer period (generally June through September). Group 1, termed fall, consisted mostly of October collections (Figure 5-3). Dominant species were Atlantic herring, fourbeard rockling, silver hake, and windowpane (Table 5-4). Within this group of samples, Atlantic herring larvae were less abundant in the operational period than in the preoperational period. Group 2, 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 3, 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 substantial differences between preoperational and operational geometric means for any of these taxa. American sand lance larvae again dominated in Group 4, termed late winter/early spring. The period of occurrence for collections of this group was relatively long, generally from February through March or April. The geometric mean abundance of American sand lance was higher in the operational period and abundance of rock gunnel was fairly similar between periods. Group 5 occurred during spring and comprised May collections each year, and sometimes April collections. The Atlantic seasnail and American sand lance were the most abundant larvae in this, the most diverse of the eight 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 6 collections occurred exclusively during the late spring and early summer (June and July), representing the first of the warm water groups. The geometric means for the dominant species in this group (cunner, fourbeard rockling, Atlantic mackerel, radiated shanny, and winter flounder) were fairly comparable between the preoperational and operational periods. The annual seasonal patterns of occurrence for Groups 7 and 8 were less consistent than for the other groups.

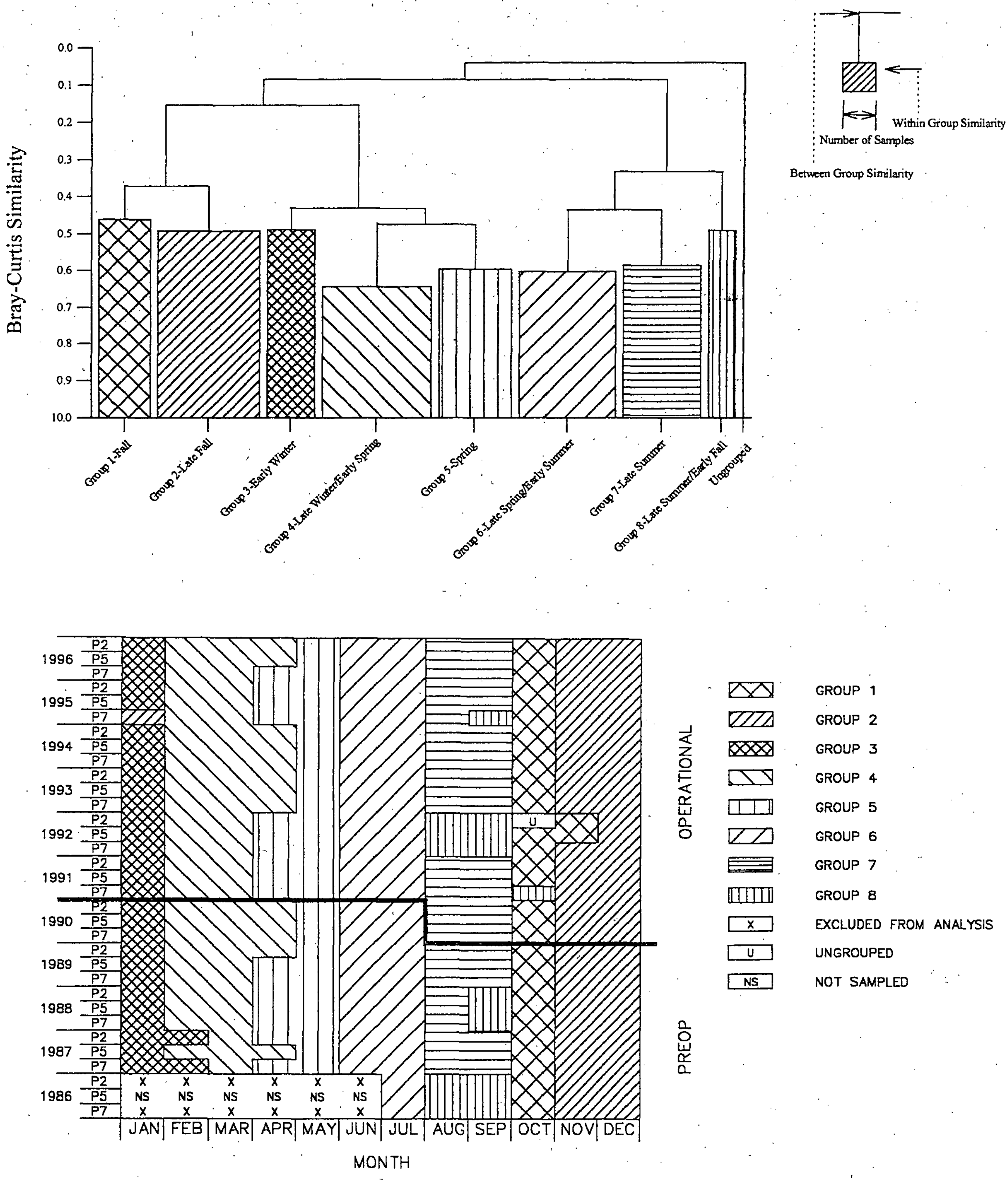


Figure 5-3. Dendrogram and temporal/spatial occurence pattern of **fish larvae** assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m^3) at Seabrook intake (P2), discharge (P5) and farfield (p7) stations, July 1986-December 1996. Seabrook Operational Report, 1996.

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 1996.[a] Seabrook Operational Report, 1996.**

		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-Fall	Atlantic herring	12	5	16	49	21	2	3	4
(0.46/0.37)[b]	Fourbeard rockling		3	5	10		2	3	5
	Silver hake		1	2	4		1	2	3
	Windowpane		1	1	2		<1	1	1
2-Late Fall (0.49/0.43)	Atlantic herring	24	29	50	87	41	12	17	23
3-Early Winter	American sand lance	14	12	24	48	17	18	31	52
(0.52/0.43)	Atlantic herring		2	4	8		1	2	4
	Gulf snailfish		2	4	6		1	2	4
	Pollock		1	3	8		1	2	3
4-Late Winter/ Early Spring	American sand lance	27	215	295	404	44	268	337	423
(0.64/0.47)	Rock gunnel		23	34	51		24	37	55
5-Spring	Atlantic seasnail	19	20	39	75	28	12	18	27
(0.60/0.47)	American sand lance		18	30	49		24	34	49
	Winter flounder		2	5	11		1	2	3
	Grubby		3	5	8		3	5	7
	Radiated shanny		2	5	10		1	3	5
	Gulf snailfish		2	4	7		1	1	2
	American plaice		2	4	6		2	3	4
6-Late Spring/	Cunner	27	40	94	218	36	25	63	154
Early Summer	Fourbeard rockling		28	50	88		24	38	59
(0.60/0.43	Atlantic mackerel		15	27	46		20	36	65
	Radiated shanny		17	26	40		20	27	37
	Winter flounder		8	14	26		7	11	17

(continued)

Table 5-4. (Continued)

GROUP	DOMINANT TAXA[c]	NUMBER OF SAMPLES AND DENSITY (LARVAE/1000 m^3)[d] PREOPERATIONAL PERIOD[e] n	LCL	MEAN	UCL	OPERATIONAL PERIOD[e] n	LCL	MEAN	UCL
7-Late Summer (0.58/0.43)	Cunner	15	101	201	399	35	135	285	602
	Fourbeard rockling		28	62	134		21	33	50
	Hake		4	7	12		10	19	36
8-Late Summer/ Early Fall (0.49/0.33)	Cunner	9	3	6	12	8	1	3	4
	Fourbeard rockling		1	1	3		2	3	5
	Windowpane		<1	1	2		<1	1	2
	Hake		<1	1	1		0	1	3
	Radiated shanny		<1	1	1		<1	1	2
	Witch flounder		<1	1	1		<1	2	3

[a]Each "sample" consisted of the average of tows within date and dates within month at one station.
[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 1996.

Although Group 7 was not present every year, cunner, fourbeard rockling, and hake larvae dominated this group during late summer (August and September). When present, collections at all three stations were generally grouped together (except September 1995). In Group 7, densities were not substantially different between the operational period and the preoperational period. Group 8 was termed late summer/early fall, and included primarily collections from August and September. Three of the six dominant taxa were also present in the previous group, but they were collected at much lower densities in the Group 8 samples. In two years, 1986 and 1992, no samples were classified with Group 7. This indicates lower than usual densities of larvae in August and September for those two years. As the low densities occurred equally in preoperational and operational periods, they were not related to plant operation.

As was the case with eggs, the cluster groups based on larval composition and abundance were strongly related to season but were independent of station, year, and operational status. In 94% of the months in which all three stations were represented in the analysis, 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 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. Eggs belonging to 21 taxa (plus one group of unidentified eggs) and larvae of 30 taxa (plus one group of unidentified larvae) were collected in entrainment samples in 1996 (Table 5-5). Total estimates of entrainment were 926.8 million eggs and 215.7 million larvae for the year. Egg entrainment in previous years ranged from 4.7 million in 1994 (8 months of sampling) to 1,247.7 million in 1990 (7 months of sampling) (Table 5-6). Egg entrainment in 1996 was 926.8 million (12 months of sampling) and was within the range of previous years. Previous larval entrainment ranged from 31.2 million in 1994 (8 months of sampling) to 153.8 million in 1991 (8 months of sampling. The 1996 entrainment estimate (215.7 million) is the highest recorded to date.

Atlantic mackerel, hake, and cunner/yellowtail flounder were the most numerous egg taxa entrained in 1996 (Figure 5-4). These three taxa have consistently been among the most numerous eggs entrained by Seabrook Station, with the exception of 1994 when no samples were collected during the summer high period of egg entrainment (Table 5-6). Atlantic mackerel ranked either first or second in entrainment abundance each year since 1990 (except 1994), and cunner/yellowtail flounder eggs were among the top four egg taxa entrained (except 1994). In 1996, hake eggs ranked second in entrainment abundance, which is the highest ranking observed for this taxon. Atlantic seasnail, rock gunnel and grubby were the three most abundant species of

Table 5-5. Monthly Estimated Numbers of Fish Eggs and Larvae (In Millions) Entrained by the Cooling Water System at Seabrook Station During January Through December 1996. Seabrook Operational Report, 1996.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>EGGS</u>													
American plaice			0.1	3.8	16.4	56.4	1.4						78.2
Atlantic cod	0.4	0.1				1.2	0.1			0.3	4.8	1.2	8.1
Atlantic cod/haddock		0.1				1.3							1.4
Atlantic cod/witch flounder			0.3	1.3	18.1	22.0	4.6	0.9	0.1				47.2
Atlantic mackerel					14.3	284.1	6.6	0.1					305.1
Atlantic menhaden													0.1
Butterfish							0.1	0.1					0.1
Cunner/yellowtail flounder			0.1		3.4	79.2	24.3	3.0	0.3				110.2
Cusk					0.1	1.3	0.4	0.1					1.8
Fourbeard rockling			0.2		0.1	4.6	1.4	1.1	3.6				10.9
Goosefish			0.2	0.1									0.3
Hake						2.7	8.1	10.1	163.0	0.2			184.0
Hake/fourbeard rockling				0.3	2.1	15.8	7.9	5.2	25.7				57.0
Lumpfish				0.1	0.1	1.0							1.2
Pollock												0.4	0.4
Rainbow smelt				0.1									0.1
Silver hake						1.3	23.5	40.6	7.8	0.2	0.3		73.6
Tautog								0.2	0.1				0.3
Unidentified						0.3	0.1	0.1	0.2		0.1	0.1	0.8
Windowpane					0.8	24.5	9.5	4.3	5.1				44.2
Witch flounder									0.1				0.1
Yellowtail flounder				0.8		0.7							1.6
TOTAL	0.4	0.3	0.6	6.7	55.2	496.3	88.0	65.6	206.1	0.7	5.2	1.7	926.8

(continued)

Table 5-5. (Continued)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
LARVAE													
Alligatorfish					0.1								0.1
American plaice					1.9	5.4	0.7	0.1					8.1
American sand lance	0.2	0.8	10.6	1.4	1.1								14.0
Atlantic cod					0.1		0.1						0.3
Atlantic herring	0.5	0.1	0.2							0.8	1.3	1.4	4.3
Atlantic mackerel						0.1							0.1
Atlantic seasnail				1.8	29.6	25.5	3.4	0.2					60.6
Butterfish									0.1				0.1
Cunner							2.1	4.0	3.2				9.2
Fourbeard rockling					0.1	0.3	3.4	7.0	0.6	0.3			11.7
Grubby		0.1	6.0	8.3	4.1	0.1							18.6
Gulf snailfish		1.2	0.8	0.5	0.2	0.1							2.8
Hake							0.1		12.2				12.3
Liparis sp.				0.1	0.3	<0.1							0.4
Longhorn sculpin		0.8	0.3	0.2									1.3
Lumpfish						0.1							0.1
Moustache sculpin		0.3	0.3	<0.1									0.6
Northern pipefish									0.1				0.1
Pleuronectidae							0.3						0.3
Prionotus sp.							0.1						0.1
Radiated shanny					0.1	1.2	0.6						2.0
Rock gunnel		2.6	23.1	6.7	1.3								33.8
Shorthorn sculpin	0.1												0.1
Silver hake						0.1	2.7	5.3	8.7	0.1	<0.1		16.9
Tautog									0.2				0.2
Unidentified		0.1		0.9		0.6	0.5	0.2	0.1				2.5
Unidentified sculpin			0.1	0.1	0.2	0.1							0.6
Windowpane							0.7	1.0	0.1	0.2			2.0
Winter flounder					2.3	4.2	3.7						10.3
Witch flounder							0.5	0.3					0.8
Yellowtail flounder					0.5	0.3	0.6	0.2					1.6
TOTAL	0.7	6.0	41.4	20.2	41.9	38.1	19.4	18.3	25.4	1.3	1.3	1.4	215.7

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 1996. Seabrook Operational Report, 1996.

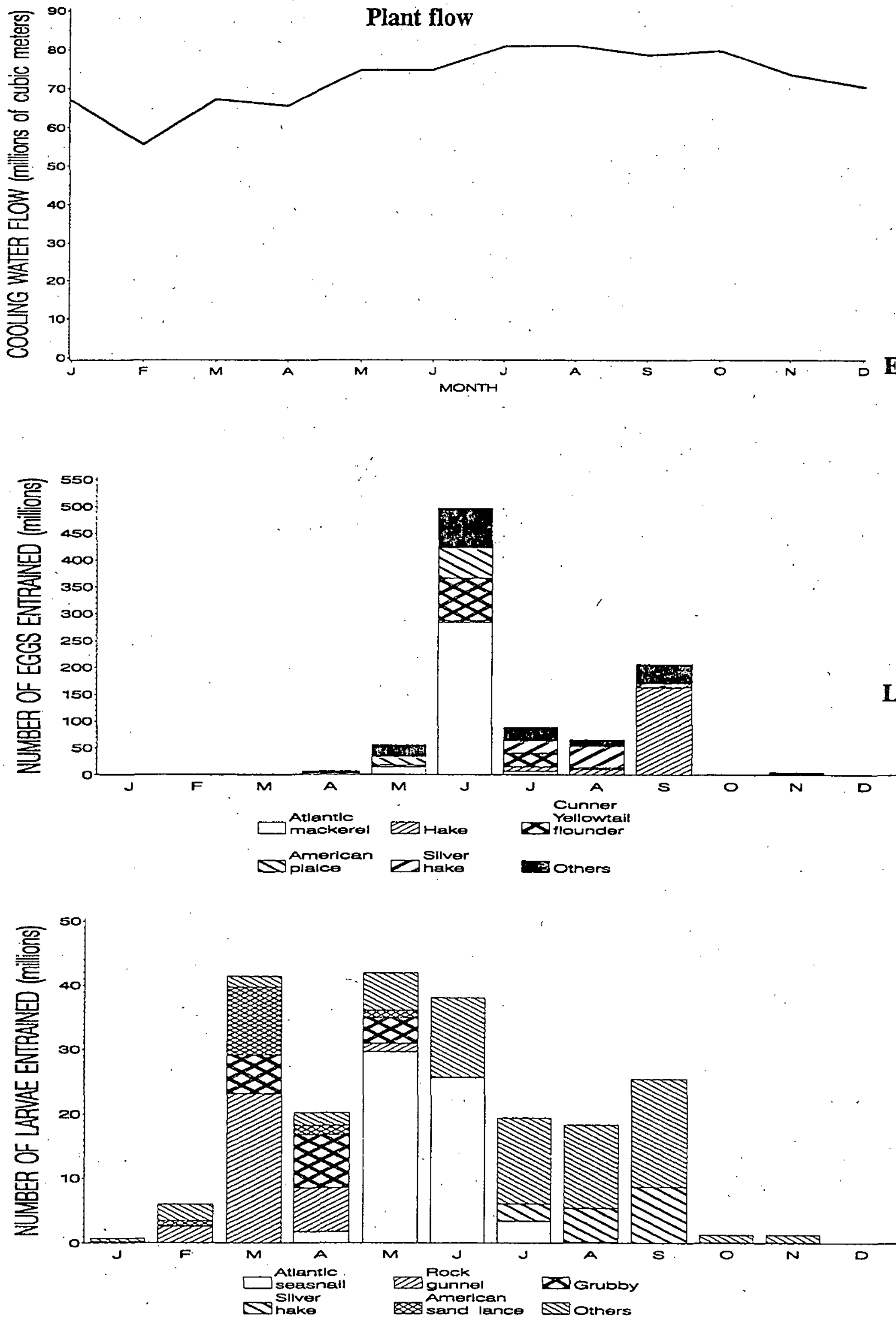
TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[g]
EGGS							
Atlantic mackerel	518.8	673.1	456.3	112.9	0.0	74.5	305.1
Cunner/yellowtail flounder	490.4	716.3	198.6	58.4	0.0	18.6	110.2
Atlantic cod/haddock/witch flounder	29.1	74.5	39.5	50.3	1.0	34.8	48.6
Fourbeard rockling/hake	114.2	35.1	50.6	32.7	1.7	27.5	57.0
Windowpane	36.4	19.9	22.5	29.1	0.1	17.4	44.2
American plaice	2.6	21.0	52.3	19.5	0.4	14.8	78.2
Lumpfish	0.0	0.0	0.0	9.5	0.1	6.0	1.2
Fourbeard rockling	7.4	4.3	0.8	1.4	0.2	4.2	10.9
Unidentified	0.0	2.0	0.0	0.8	0.2	6.4	0.8
Silver hake	11.4	0.0	0.1	0.4	0.4	22.5	73.6
Pollock	0.0	1.0	0.4	0.2	0.1	0.4	0.4
Hake	37.3	2.6	0.0	0.2	0.6	25.1	184.0
Atlantic menhaden	0.0	0.5	1.4	0.1	0.0	0.2	0.1
Cusk	0.1	0.5	0.0	0.1	0.0	0.2	1.8
Tautog	0.0	0.2	0.0	0.0	0.0	0.0	0.3
Atlantic cod	0.0	0.0	0.0	0.0	0.0	2.2	8.1
Atlantic cod/pollock	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Witch flounder	0.0	0.0	0.0	0.0	0.0	0.7	0.1
Yellowtail flounder	0.0	0.0	0.0	0.0	0.0	0.2	1.6
Other	0	0	0.1	0	1.8	2.1	0.6
Total	1247.7	1551.0	822.6	315.6	4.7	255.6	926.8

(continued)

Table 5-6. (Continued)

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[g]
LARVAE							
Atlantic seasnail	11.6	16.0	31.5	64.4	0.0	26.5	60.6
Grubby	0.0	22.4	18.9	13.8	4.9	17.4	18.6
American sand lance	0.0	37.3	18.1	12.0	8.3	9.5	14.0
Atlantic herring	0.7	0.5	4.9	9.6	0.1	11.2	4.3
Rock gunnel	0.0	51.1	45.3	5.7	11.0	15.6	33.8
Unidentified	0.7	2.1	1.4	5.6	0.6	30.4	2.5
Cunner	42.7	<0.1	0.0	4.7	0.1	4.4	9.2
Winter flounder	3.2	9.0	6.2	2.9	0.0	8.0	10.3
Gulf snailfish	0.1	2.8	1.9	2.6	3.5	0.2	2.8
Fourbeard rockling	37.9	0.5	0.1	2.2	0.0	3.9	11.7
American plaice	0.4	1.0	0.8	0.7	0.0	7.9	8.1
Longhorn sculpin	0.0	0.6	0.6	0.4	0.3	0.4	1.3
Moustache sculpin	0.0	0.1	0.3	0.4	2.2	0.0	0.6
Lumpfish	0.6	0.1	0.1	0.2	0.0	0.6	0.1
Unidentified snailfish	0.1	0.3	0.0	0.2	0.0	0.0	0.0
Shorthorn sculpin	0.0	0.2	0.6	0.2	0.1	0.5	0.1
Radiated shanny	4.8	3.1	1.1	0.2	0.0	2.1	2.0
Atlantic cod	0.7	1.5	0.4	0.1	0.0	2.3	0.3
Silver hake	7.7	0.0	0.0	0.1	0.0	0.9	16.9
Windowpane	3.8	<0.1	0.1	0.1	0.1	2.0	2.0
Hake	4.8	0.0	0.0	0.1	0.0	0.7	12.3
Atlantic mackerel	0.2	4.7	0.0	0.0	0.0	0.0	0.1
Yellowtail flounder	0.1	0.3	0.1	0.0	0.0	0.1	1.6
Alligatorfish	0.0	0.1	0.2	0.0	0.2	0.3	0.1
Wrymouth	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Witch flounder	0.3	0.0	0.0	0.0	0.0	0.0	0.8
Tautog	0.3	0.0	0.0	0.0	0.0	0.0	0.2
Pollock	0.2	0.0	0.1	0.0	0.0	0.0	0.0
Fourspot flounder	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Rainbow smelt	0.2	0.0	0.1	0.0	0.0	0.0	0.0
Goosefish	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Atlantic menhaden	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Redfish	0.0	0.0	0.4	0.0	<0.1	0.0	0.0
Haddock	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Unidentified sculpin	0.0	0.0	0.1	0.0	0.0	0.0	0.6
Butterfish	0.0	0.0	0.0	0.0	0.0	0.3	0.1
Other	0.0	0.1	0.3	0.0	0.2	0.0	0.7
Total	121.5	153.8	133.1	126.2	31.2	145.3	215.7

[a]From NAI (1991). Represents only 7 months, August - December.
[b]From NAI (1992). Represents only 8 months, January - July, December.
[c]From NAI (1993). Represents only 8 months, January - August.
[d]From NAI and NUS (1994). Represents only 8 months, January - August.
[e]From NAI (1995). Represents only 8 months, January - March, September - December.
[f]From NAI (1996). Represents 12 months.
[g]Represents 12 months of sampling.



Eggs

Larvae

Figure 5-4. Total monthly cooling water system flow and estimated numbers of fish eggs and larvae entrained during 1996. Seabrook Operational Report, 1996.

larvae identified from entrainment samples in 1996, consistent with their dominance among larvae entrained in previous years (Table 5-6; Figure 5-4). Entrainment of hake and silver hake greatly increased in 1996. The increased entrianment of these species may be related to their increased larval density in the nearshore area in 1996.

Differences in entrainment estimates between larval and egg stages of the same taxa in the same year are due to varying susceptibility of the two developmental stages to entrainment. Some dominant larvae belong to species entrained 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. One exception to this pattern is lumpfish eggs, which have been entrained by Seabrook Station on several occasions despite being demersal and adhesive. It may be possible that clusters of lumpfish eggs attached to the intake structure were dislodged by currents. Behavioral characteristics of some larvae may reduce larval entrainment for some taxa that have high egg 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 since 1990 were compared to estimates from two other New England power plants, Pilgrim and Millstone Stations (Table 5-7). Except for Atlantic seasnail larvae, annual entrainment estimates for Seabrook Station were similar to, or were less than annual estimates 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 1996 was 2.3, an increase from a mean of 1.2 in 1995 (NAI 1996), and the second highest observed during the operational period (Figure 5-5). CPUE in 1996 was generally similar to annual means since the early 1980s (Figure 5-5). Largest catches were made during the first five full years of sampling (i.e., 1976-80). The catch in 1996 was dominated by blueback herring, Atlantic mackerel and alewife (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 G1, the southernmost station, particularly during the first few 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 (1991-96), most of the catch was made up of Atlantic herring, Atlantic mackerel, pollock, and blueback herring.

The spiny dogfish has become increasingly abundant during the operational period, with a geometric mean CPUE of 0.1, which is approximately five times the CPUE determined for the preoperational period. However, CPUE in 1993 through 1996 (<0.1 - 0.1) has decreased

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 1996. Seabrook Operational Report, 1996.**

TAXON	SEABROOK	PILGRIM[a]	MILLSTONE[b]
Cunner/yellowtail flounder/tautog eggs[c]	0[f]-716	860-4122	2,736-5,982
Atlantic mackerel eggs	0[f]-673	337-2066	-
Atlantic herring larvae	<1[f]-11	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	5-114
Atlantic mackerel larvae	0-5	3-66	-
Winter flounder larvae	0[f]-10	9-21	45-514

[a]MRI (1991, 1992, 1993b, 1994, 1995); 1990-1994; Cape Cod Bay.
[b]NUSCO (1994a, 1994b, 1995, 1996); eggs-1990-1993, grubby and American sand lance larvae-1990-1994; winter flounder larvae 1990-1995;
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]Lowest estimate occurred in a year when samples are lacking in some or all of the months when this taxon normally would be entrained (estimate for 1990 was not included for those taxa usually present before June, when the entrainment sampling program was begun).

Gill net

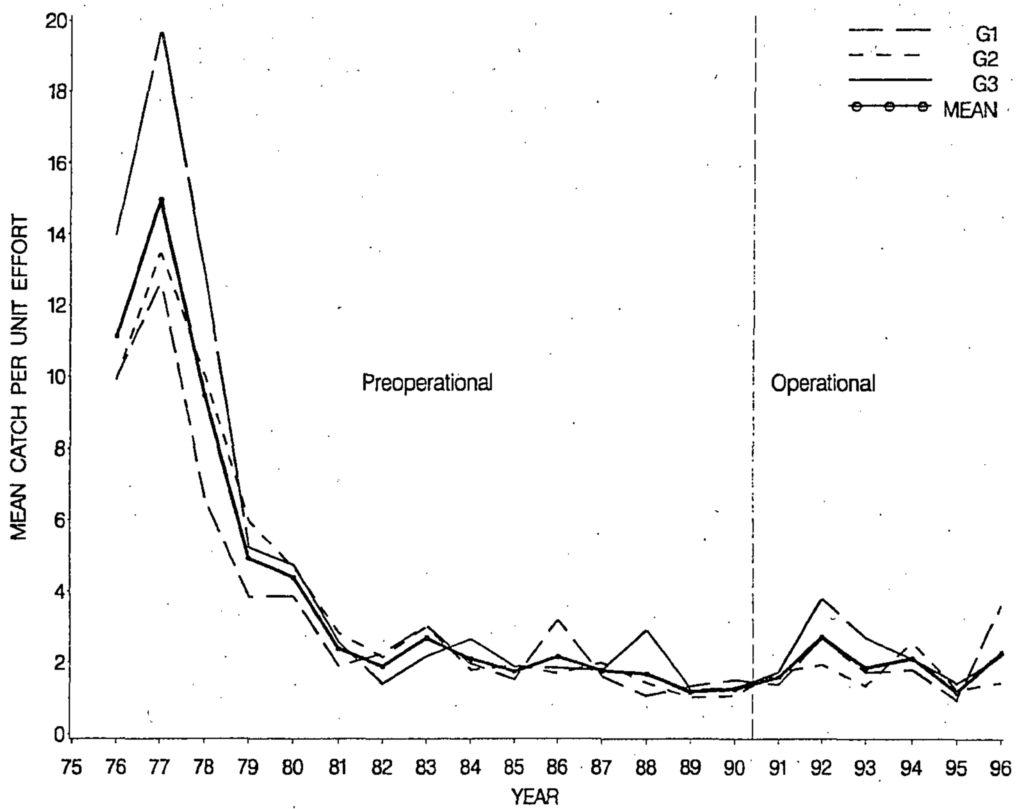


Figure 5-5. Annual geometric mean catch of all species combined per unit effort (number per 24-h set) in gill net samples by station and the mean of all stations, 1976-1996.

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 1996 Mean. Seabrook Operational Report, 1996.

		PREOPERATIONAL		1996[b]	OPERATIONAL	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Atlantic herring	G1	1.0	18	0.2	0.3	22
	G2	1.1	20	<0.1	0.2	33
	G3	1.2	21	0.1	0.4	25
	All Stations	1.1	19	0.1	0.3	23
Atlantic mackerel	G1	0.2	16	0.4	0.3	17
	G2	0.2	15	0.2	0.3	29
	G3	0.3	16	0.3	0.3	15
	All Stations	0.2	15	0.3	0.3	18
Pollock	G1	0.2	17	0.1	0.2	18
	G2	0.3	10	0.1	0.3	16
	G3	0.3	13	0.3	0.2	13
	All Stations	0.3	9	0.2	0.2	13
Spiny dogfish	G1	<0.1	45	0.0	0.1	69
	G2	<0.1	35	0.0	0.1	41
	G3	<0.1	27	0.1	0.2	47
	All Stations	<0.1	30	0.1	0.1	46
Silver hake	G1	0.2	34	0.1	0.1	40
	G2	0.2	35	0.1	0.1	60
	G3	0.3	31	0.1	0.1	31
	All Stations	0.3	33	0.1	0.1	40
Blueback herring	G1	0.2	17	1.1	0.2	50
	G2	0.3	18	0.5	0.2	26
	G3	0.3	24	0.5	0.2	32
	All Stations	0.3	18	0.7	0.2	36
Alewife	G1	0.1	17	0.4	0.1	34
	G2	0.1	14	0.1	0.1	21
	G3	0.1	21	0.3	0.1	35
	All Stations	0.1	14	0.3	0.1	29
Rainbow smelt	G1	<0.1	26	<0.1	0.1	40
	G2	0.1	21	0.1	0.1	29
	G3	0.1	21	<0.1	0.1	39
	All Stations	0.1	18	<0.1	0.1	29
Atlantic cod	G1	0.1	18	<0.1	<0.1	53
	G2	<0.1	22	0.0	<0.1	63
	G3	0.1	13	<0.1	<0.1	63
	All Stations	0.1	13	<0.1	<0.1	43
Other species	G1	0.4	9	0.5	0.3	14
	G2	0.4	11	0.3	0.3	16
	G3	0.3	12	0.3	0.2	21
	All Stations	0.4	10	0.4	0.3	13

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1996 data.
[c]Operational: 1991-1996 geometric mean of annual means.

substantially since the record high CPUE of 0.4 in 1992 (NAI 1993). The abundance of spiny dogfish in the Gulf of Maine has increased continuously since the 1960s, and together with skates makes up about 75% of the fish biomass on Georges Bank (NOAA 1995). The index of spiny dogfish and skate abundance on Georges Bank and the Gulf of Maine has decreased in recent years reflecting a stabilization of stock sizes, particularly for spiny dogfish (NOAA 1995). The recent stabilization in spiny dogfish abundance in the Gulf of Maine and Georges Bank is apparent in the gill net data in the form of consistent CPUE from 1993 though 1996.

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 fish caught at all stations combined in 1996 was 18.2 (Figure 5-6), an increase from the CPUE of 8.4 in 1995 (NAI 1996). The trawl CPUE peaked in 1980 (78.6) and 1981 (77.6), primarily due to large catches of yellowtail flounder. In 1996, catch was dominated by skates, longhorn sculpin, winter flounder, windowpane, and yellowtail flounder (Table 5-9).

Catch of nearly all species in the study area declined from the preoperational to the operational period, particularly for the yellowtail flounder (CPUE of 9.3 and 1.1, respectively). Other species with decreased CPUE included longhorn sculpin (4.1, 3.1), winter flounder (3.5, 2.9), hakes (3.2, 1.2), Atlantic cod (1.8, 0.5), and windowpane (1.3, 1.1). The CPUE of skates (1.9, 2.2) increased and CPUE of pollock (0.4, 0.4) was similar between the preoperational and operational periods. As noted previously, groundfish stocks have all decreased in the Northwest Atlantic, except for skate, the abundance of which is currently very high in this area (NOAA 1995).

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 and skates (operational period) were most common at T1 and T3. However, station to station comparisons are limited by the inability to sample by trawl at Station 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 ANOVAs 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 81% 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

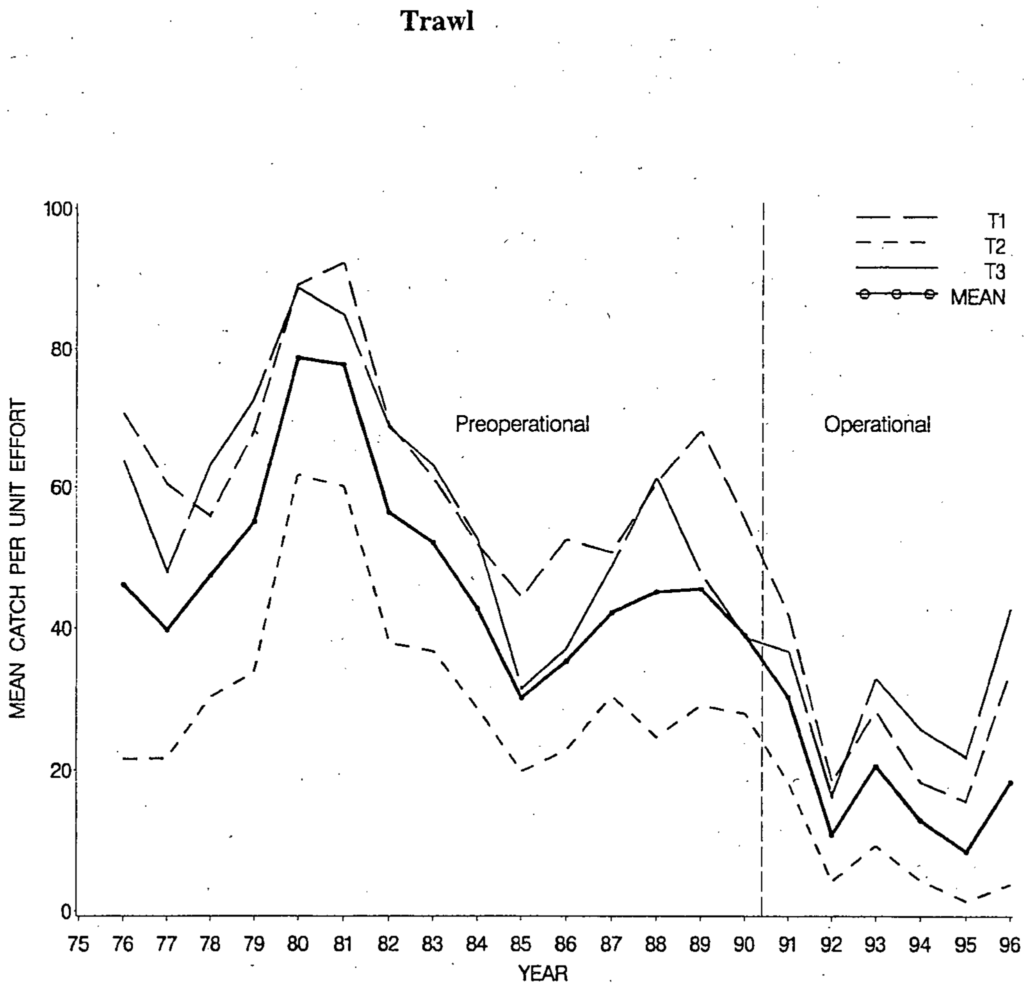


Figure 5-6. Annual geometric mean catch of all species combined per unit effort (number per 10-min tow) in trawl samples by station and the mean of all stations, 1976-1996. Seabrook Operational Report, 1996.

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 1996 Mean. Seabrook Operational Report, 1996.

		PREOPERATIONAL PERIOD[a]		1996[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Yellowtail flounder	T1	20.0	3	3.4	2.1	10
	T2	2.7	8	0.1	0.4	33
	T3	10.2	5	2.3	0.7	12
	All stations	9.3	4	1.9	1.1	11
Longhorn sculpin	T1	4.6	7	3.3	3.4	5
	T2	1.1	12	0.2	0.3	21
	T3	8.3	6	9.2	6.5	4
	All stations	4.1	7	3.5	3.1	4
Winter flounder	T1	3.1	6	3.9	3.1	7
	T2	5.9	6	1.3	1.6	19
	T3	2.2	7	5.1	3.3	6
	All stations	3.5	5	3.5	2.9	7
Hakes[d]	T1	4.1	5	0.9	1.2	17
	T2	1.7	7	0.5	0.4	29
	T3	3.5	5	2.0	1.3	12
	All stations	3.2	4	1.2	1.2	13
Atlantic cod	T1	2.0	10	0.1	0.4	50
	T2	0.7	16	0.1	0.1	38
	T3	3.2	11	0.4	0.9	38
	All stations	1.8	11	0.2	0.5	43
Skates	T1	1.7	15	7.2	2.7	16
	T2	0.6	10	0.9	0.3	36
	T3	3.7	5	9.5	3.6	13
	All stations	1.9	9	5.3	2.2	14
Windowpane	T1	1.9	11	4.6	2.1	12
	T2	0.9	10	0.3	0.4	22
	T3	1.0	13	2.2	0.7	28
	All stations	1.3	10	2.2	1.1	15
Rainbow smelt	T1	1.1	9	0.3	0.4	8
	T2	1.8	9	0.1	0.4	35
	T3	0.8	14	0.2	0.3	24
	All stations	1.1	9	0.2	0.4	21
Ocean pout	T1	0.7	6	0.1	0.1	21
	T2	0.6	8	0.2	0.2	27
	T3	1.4	7	0.3	0.2	24
	All stations	0.8	6	0.2	0.2	23
Silver hake	T1	0.9	16	0.4	0.4	9
	T2	0.2	21	0.0	<0.1	58
	T3	0.8	13	0.1	0.5	19
	All stations	0.7	14	0.2	0.4	13
Pollock	T1	0.3	18	0.2	0.4	31
	T2	0.7	21	0.0	0.4	31
	T3	0.2	20	0.1	0.2	19
	All stations	0.4	18	0.1	0.4	23
Haddock	T1	0.2	34	0.1	<0.1	68
	T2	<0.1	64	0.0	0.0	--
	T3	0.5	28	0.3	0.1	37
	All stations	0.2	28	0.2	0.1	40
Other species	T1	1.6	6	1.9	1.5	12
	T2	1.6	7	0.6	0.7	25
	T3	1.2	7	1.0	1.0	21
	All stations	1.4	5	1.3	1.2	15

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1996 data.
[c]Operational: 1991-1996; geometric mean of annual means.
[d]May include red hake, white hake, spotted hake, or more than one of these species.

seine. Geometric mean CPUE (catch per haul) for all fish caught at all stations during 1996 was 17.1 (Figure 5-7), a slight increase from the CPUE of 14.9 in 1995 (NAI 1996). Overall, seine catches generally were smaller (5.6-24.1) during 1987-96 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). Atlantic silverside has dominated the seine catch in all years sampled. Killifish (mummichog or striped killifish), winter flounder, and ninespine stickleback also contributed frequently to the catch during both the preoperational and operational periods.

Catch by station showed considerable variation over the years (Figure 5-7). In 1996, CPUE was highest at Station S1, due to large catches of Atlantic silverside. 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, tended to approximate the overall mean in 1991-1994, and was above the mean in 1995 and 1996 CPUE at S2, located closest to Seabrook Station, had the largest CPUE in 1993 and was lowest in 1995 and 1996. Trends in CPUE were mostly due to the fluctuations in catch of the dominant species, Atlantic silverside. Winter flounder and rainbow smelt were most

Seine

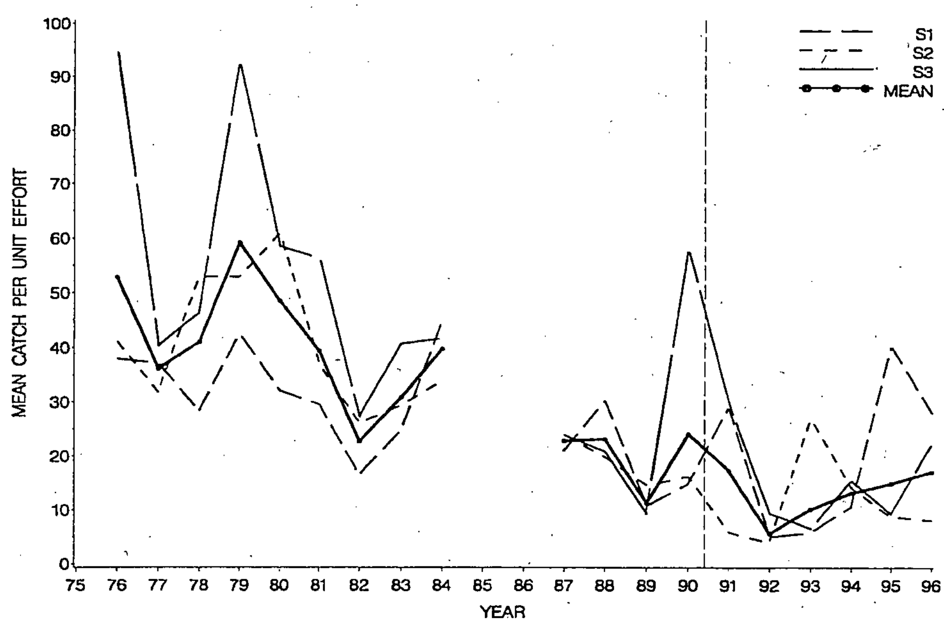


Figure 5-7. Annual geometric mean catch of all species combined per unit effort (number per haul) in seine samples by station and the mean of all stations, 1976-1996. Seabrook Operational Report, 1996.

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 1996 Mean. Seabrook Operational Report, 1996.

		PREOPERATIONAL PERIOD[a]		1996[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
Atlantic silverside	S1	7.2	7	10.0	5.3	13
	S2	6.8	6	3.5	3.9	9
	S3	6.7	10	5.3	4.2	7
	All stations	6.9	7	5.8	4.4	7
Winter flounder	S1	0.9	11	0.8	0.5	25
	S2	1.0	14	0.2	0.2	53
	S3	3.2	9	0.8	1.0	8
	All stations	1.5	8	0.6	0.6	8
Killifishes	S1	1.1	10	2.2	1.2	27
	S2	1.2	19	0.8	0.3	47
	S3	<0.1	27	0.0	<0.1	100
	All stations	0.7	13	0.8	0.4	23
Ninespine stickleback	S1	0.7	20	0.8	0.4	24
	S2	0.8	28	0.2	0.1	31
	S3	0.8	24	0.4	0.2	41
	All stations	0.8	20	0.4	0.2	23
Rainbow smelt	S1	0.1	41	0.2	0.1	44
	S2	0.2	31	0.1	0.2	41
	S3	0.7	21	<0.1	0.3	44
	All stations	0.3	16	0.1	0.2	34
American sand lance	S1	0.1	44	1.1	0.4	32
	S2	0.2	48	0.2	0.2	62
	S3	0.1	28	2.3	0.5	54
	All stations	0.1	28	1.1	0.3	33
Pollock	S1	0.1	40	0.0	<0.1	63
	S2	0.2	40	0.0	<0.1	100
	S3	0.4	36	0.0	0.1	64
	All stations	0.2	35	0.0	<0.1	55
Blueback herring	S1	0.2	29	0.6	0.2	33
	S2	0.1	36	0.0	0.1	100
	S3	0.1	38	0.1	<0.1	63
	All stations	0.1	29	0.2	0.1	32
Atlantic herring	S1	0.1	59	0.1	0.1	36
	S2	0.3	27	0.2	0.1	50
	S3	0.1	24	0.1	0.1	51
	All stations	0.2	19	0.2	0.1	31
Alewife	S1	0.1	38	0.0	<0.1	46
	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	33
Other species	S1	0.8	14	0.2	0.4	32
	S2	1.1	8	0.3	0.5	31
	S3	1.5	12	0.8	1.0	14
	All stations	1.1	9	0.4	0.6	18

[a]Preoperational: 1976-1989; geometric mean of annual means.
[b]Geometric mean of the 1996 data.
[c]Operational: 1991-1996 geometric mean of annual means.

common at S3, whereas killifish were most abundant at S1 and S2, with few taken at S3, likely due to salinity and temperature preferences.

5.3.2.4 Impingement

Seabrook Station operated throughout 1996, with monthly average circulating water flow ranging from 507 to 691 million gallons/day (Table 5-11). During 1996, an estimated 26,825 fish and American lobster were impinged (Table 5-11). Most (37%) fish were impinged in October, followed by November (33%) and January (6%). Increased impingement in the fall and winter in previous years was attributed to northeast storms (NAI and NUS 1994).

In 1996 rainbow smelt (4,489) were the most numerous fish impinged followed by winter flounder (3,231), pollock (1,835), grubby (1,457), and northern pipefish (1,200; Table 5-11). Over 95% of the rainbow smelt impingement occurred in November. Rainbow smelt spawn above the head of tide and move into more saline waters as they mature (Buckley 1989). They are usually considered shallow-water fish and Bigelow and Schroeder (1953) reported that they never have been found more than 2 km from shore or in waters greater than 6 m in depth. The intakes are within the reported offshore range of rainbow smelt, but they are located in deeper water (about 20 m) than the previously reported depth range. In the fall, adult rainbow smelt return to estuaries prior to spawning in the spring (Buckley 1989). The impingement of rainbow smelt in November may be related to this inshore movement to the estuaries prior to spawning.

Winter flounder are commonly captured in otter trawls in the finfish monitoring program, and are an important recreational and commercial fish. Most winter flounder were impinged in October, possibly a result of the movement of juvenile fish out of the estuary in the fall. The majority of pollock were also impinged in October. Pollock are a schooling fish and are common in trawls and gill nets in the monitoring program. Most of the pollock impingement in 1996 (77%) occurred on one date (21 October) and could have been a result of the passage of one or several schools into the intake structure. Grubby are a resident demersal fish that occurred occasionally in otter trawl samples. The majority of grubby impingement occurred during the winter, possibly as a result of storms. The impingement of northern pipefish in 1996 was somewhat unusual, as the total was more than twice that of any previous year (Appendix Table 5-3). Northern pipefish are usually found inshore near saltmarshes, harbors and river mouths, but they occasionally have been found associated with floating seaweed in deeper water (Bigelow and Schroeder 1953). Most northern pipefish impingement in 1996 occurred in April, October and November and may have been associated with floating seaweed or debris.

Since October 1994, impingement monitoring procedures at Seabrook Station have become more accurate (NAI 1995). Prior to that time impingement samples were sorted by plant personnel and small fish were not completely removed from impingement debris, resulting in underestimates due to the incomplete sorting. Starting in October 1994, NAESCO biologists were responsible for the sorting of samples and identification of fishes, and impingement esti-

Table 5-11. Species Composition and Total Number of Finfish and American Lobster Impinged at Seabrook Station by Month During 1996[a]. Seabrook Operational Report 1996.

Species	January	February	March	April	May	June	July	August	September	October	November	December	Total	Percent
Alewife	0	0	0	0	0	0	0	0	0	0	1750	3	1753	6.5
American lobster	0	5	0	0	0	0	4	2	3	3	14	0	31	0.1
American eel	0	0	0	0	0	0	0	0	1	0	5	0	6	<0.1
American sand lance	419	59	16	58	0	0	0	0	0	170	11	90	823	3.1
American shad	0	0	0	0	0	0	0	0	0	0	20	0	20	0.1
Atlantic mackerel	0	0	0	0	0	1	0	0	0	0	0	0	1	<0.1
Atlantic silverside	113	37	16	116	0	0	0	0	8	113	584	132	1119	4.2
Atlantic herring	0	0	0	0	0	0	0	0	0	0	485	0	485	1.8
Atlantic cod	2	1	15	21	1	5	5	3	9	0	32	0	94	0.4
Atlantic torpedo	0	0	0	0	0	0	0	1	0	1	3	0	5	<0.1
Atlantic wolffish	0	0	0	0	0	13	0	0	0	0	0	0	13	<0.1
Atlantic menhaden	0	0	0	0	0	0	0	0	0	61	26	10	97	0.4
Blueback herring	0	0	0	0	0	0	0	0	0	0	105	6	111	0.4
Butterfish	0	0	0	0	0	1	0	0	2	0	0	0	3	<0.1
Cunner	3	3	3	10	39	727	70	3	52	197	14	0	1121	4.2
Cusk	0	0	0	0	0	19	0	0	0	0	0	0	19	0.1
Fourspot flounder	0	0	0	0	1	1	0	0	0	0	0	0	2	<0.1
Grubby	329	225	201	174	13	0	0	1	13	312	115	74	1457	5.4
Haddock	0	0	0	0	0	0	0	0	0	397	0	0	397	1.5
Hake sp.	66	28	12	36	0	0	0	2	1	11	0	0	156	0.6
Herring family	0	9	0	20	0	2	0	0	17	24	0	0	72	0.3
Kingfish	0	0	0	0	0	0	0	0	0	0	2	0	2	<0.1

(continued)

Table 5-11. (Continued)

Species	January	February	March	April	May	June	July	August	September	October	November	December	Total	Percent
Lefteye flounder	0	0	0	0	1	1	0	0	0	0	0	0	2	<0.1
Longhorn sculpin	0	0	0	1	0	3	0	0	0	58	12	10	84	0.3
Lumpfish	10	4	7	7	7	0	0	0	0	0	0	16	51	0.2
Mummichog	0	3	0	0	0	0	0	0	3	23	0	18	47	0.2
Northern pipefish	0	2	28	364	60	0	0	0	5	438	291	12	1200	4.5
Ocean pout	0	0	1	0	0	0	0	0	0	0	0	0	1	<0.1
Pollock	0	2	0	1	6	110	11	11	8	1431	231	24	1835	6.8
Radiated shanny	0	23	3	12	2	0	0	0	0	0	0	0	40	0.1
Rainbow smelt	57	34	0	12	0	0	0	1	1	3	4288	93	4489	16.7
Red hake	3	4	1	415	22	41	0	0	5	460	466	61	1478	5.5
Righteye flounder family	0	4	0	0	0	0	0	0	0	0	0	0	4	<0.1
Rock gunnel	11	1	276	472	36	4	8	15	63	117	105	14	1122	4.2
Sand tiger	0	0	0	0	0	0	0	0	0	57	0	0	57	0.2
Scup	0	0	0	0	0	3	0	0	0	0	6	0	9	<0.1
Sea raven	3	5	11	86	28	39	20	11	54	701	26	31	1015	3.8
Sea lamprey	0	0	1	0	0	0	0	0	0	0	0	0	1	<0.1
Seasnail sp.	40	7	10	54	0	0	0	0	3	851	19	29	1013	3.8
Shorthorn sculpin	73	35	36	16	28	1	3	5	2	65	9	9	282	1.1
Silver hake	0	0	0	0	0	0	0	0	0	6	34	18	58	0.2
Skate sp.	25	0	0	8	2	0	3	1	24	127	8	27	225	0.8
Spiny dogfish	0	0	0	0	0	0	0	0	0	4	2	0	6	<0.1
Striped bass	0	0	0	0	0	0	0	0	0	0	1	0	1	<0.1
Tautog	3	0	0	0	3	28	0	0	0	0	0	0	34	0.1
Threespine stickleback	23	14	25	35	0	0	0	0	0	113	71	39	320	1.2

(continued)

Table 5-11. (Continued)

Species	January	February	March	April	May	June	July	August	September	October	November	December	Total	Percent
Unidentified	51	1	2	8	0	19	3	2	0	0	2	0	88	0.3
White perch	4	0	0	0	0	0	0	0	0	0	0	0	4	<0.1
White hake	0	0	0	0	0	3	0	0	0	964	0	0	967	3.6
Windowpane	89	69	22	122	3	4	0	0	71	522	178	84	1164	4.3
Winter flounder	295	162	34	249	4	1	0	0	0	2390	50	46	3231	12.0
Wrymouth	10	0	3	19	1	0	0	0	0	170	3	0	206	0.8
Yellowtail flounder	4	0	0	0	0	0	0	0	0	0	0	0	4	<0.1
TOTAL	1633	737	723	2316	257	1026	127	58	345	9789	8968	846	26825	
Circulating Water Average Daily Flow (mgd)	570.0	506.9	572.7	576.8	636.8	685.6	688.9	690.5	691.3	678.3	646.9	598.8	214,030[b]	
Rate (# fish/mg)	0.09	0.04	0.04	0.13	0.01	0.05	0.03	<0.01	0.02	0.47	0.46	0.05	0.11	

[a]Data provided by North Atlantic Energy Service Company.
[b]Represents the total flow/year in millions of gallons.
[c]November daily flow is averaged only over 21 days; the CW system did not operate for 9 days during a refueling outage.

(continued)

mates are believed to be more accurate since that time. Impingement estimates for the last quarter of 1994 and all of 1995 and 1996 are substantially higher than previous years, primarily due to the increased efficiency of sample sorting. Additional improvements were made starting in January of 1996. The mesh size in the basket where screen wash debris was collected was reduced to match the size of the mesh on the traveling screen. This ensured that any small fishes impinged on the traveling screen were retained by the collection basket.

Since 1994, Atlantic silverside was the most numerous fish impinged (8,088) followed by grubby (6,550), winter flounder (5,837), rainbow smelt (5,247), and hakes (5,166). These five species represented 50% of the total estimated impingement since 1994 at Seabrook Station (Appendix Table 5-3). The majority of the Atlantic silverside impingement occurred during the winter. 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 estuaries 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. The majority of grubby impingement occurred during the winter. Winter flounder are common in otter trawl samples and the majority of impingement occurred in the winter and early spring. Rainbow smelt are a common inshore fish that is vulnerable to impingement in the fall and winter. Hakes were identified to the species level starting in July 1995 and comprise primarily red and white hake. To maintain the same level of taxonomic consistency throughout the year, red and white hake were pooled into the "hake sp." category. Based on the known depth distribution of these fishes, and the species composition in recent trawl catches, the majority of the hakes historically were probably red hake, which tend to be more common in inshore waters than white hake (Musick 1974). Impingement of hakes at Seabrook Station may occur as juveniles begin to move offshore past the intakes in the colder months.

With the exception of Atlantic silverside and pollock, the majority of the fishes impinged were demersal. Few pelagic fishes such as Atlantic herring, Atlantic mackerel, alewife, and blueback herring are 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 5-12). 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 60,000 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 opera-

Table 5-12. Comparison of Fish Impingement Estimates at Selected New England Power Plants with Marine Intakes. Seabrook Operational Report, 1996.

STATION	SOURCE WATER BODY	RATED CAPACITY (Mwe)	NOMINAL COOLING WATER FLOW ($m^3 \bullet sec^{-1}$)	YEARS OF STUDY	MEAN ANNUAL IMPINGEMENT	CV (%)	RANGE FOR ANNUAL ESTIMATES	MEAN NUMBER PER DAY	REFERENCE
Seabrook	Gulf of Maine	1,150	31.5	1995-1996[a]	21,363[a]		15,932-26,825	58	------
Maine Yankee	Montsweag Bay	855	26.6	1972-77	59,999[b]	34	31,246-73,420[b]	1,395	Evans (1978)
Pilgrim	Massachusetts Bay	670	20.3	1974-94	20,029[c]	115	1,143-87,752[c]	55	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	-	LMS (1987)
Millstone 2	Long Island Sound	870	34.6	1976-87	25,927[d]	59	8,560-60,410[d]	71	NUSCO (1988)
					65,927[e]	214	8,560-511,387[e]	181	

[a] Impingement counts prior to October 1994 were underestimated.
[b] Collected in sampling only, not a calculated annual estimate (11.8% of the total days were sampled).
[c] Estimates adjusted assuming 100% station operation.
[d] Excluding an estimated 480,000 American sand lance taken on July 18, 1984.
[e] Including the sand lance mass impingement episode.

tion) 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, the average number of fish impinged annually was 54,433 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 from the angled screen study 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 from 1976 through 1987 at Millstone Nuclear Power Station Unit 2, located on Long Island Sound (NUSCO 1988). Annual impingement estimates for fish ranged 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 annualmean 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 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, the fish most often impinged are demersal species. 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 (NOAA 1993). Most spawning in the western Gulf of Maine occurs during September and October (Lazzari and Stevenson 1993). 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). 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. However, herring recruitment is a complex interaction among many critical factors, which may differ from year to year (Campbell and Graham 1991). 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 (NOAA 1995). 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). Recent biomass levels have not exceeded pre-collapse levels, but without an offshore fishery to provide long-term catch data, present estimates of stock levels, although large, are imprecise (NOAA 1995).

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). Average larval densities in 1996 decreased from the densities observed in 1995 (NAI 1996), but were higher than the operational period mean (Table 5-13; Figure 5-8). A large decline occurred during the preoperational period at all three ichthyoplankton stations during the late 1970s 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 (1986-96), there were no significant differences 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 through 1979, and remained at relatively low stable levels from 1981 through the present (Figure 5-8). The high abundance in the early preoperational period is reflected in the ANOVA results where CPUE in the preoperational period was significantly higher than the operational period (Table 5-14). The Preop-Op X Station interaction term was not significant indicating that all three stations showed similar trends among years and abundance was not affected by the operation of Seabrook Station (Table 5-14; Figure 5-8).

Atlantic herring, alewife, and blueback herring comprise the taxonomic category "herring family" in the impingement assessment (Table 5-11). Based on the temporal distribution of herrings, Atlantic herring were likely to have been the primary species impinged in the first half of the year. An estimated 72 herring were impinged at Seabrook Station in 1996. Even if all of these are assumed to have been Atlantic herring, the loss of 72 fish is not likely to affect the Atlantic herring resource in the study area.

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 1996. Seabrook Operational Report, 1996.**

		PREOPERATIONAL PERIOD[a]		1996[b]	OPERATIONAL PERIOD[c]	
SPECIES	STATION	MEAN	CV	MEAN	MEAN	CV
American sand lance	P2	159.6	14	155.9	128.4	11
(Jan-Apr)	P5	225.4	14	165.5	182.7	7
	P7	106.0	16	177.5	127.7	10
	All stations	162.5	13	166.1	144.2	9
Winter flounder	P2	12.1	19	11.1	6.1	21
(Apr-Jul)	P5	10.5	18	12.0	7.2	13
	P7	8.0	25	1.1	2.1	47
	All stations	10.8	18	5.9	4.6	10
Atlantic cod	P2	2.5	63	1.2	0.8	51
(Apr-Jul)	P5	2.4	80	1.0	0.9	50
	P7	1.0	73	0.7	0.6	22
	All stations	2.3	63	0.9	0.8	39
Yellowtail flounder	P2	3.4	50	1.7	1.5	50
(May-Aug)	P5	5.0	32	0.8	1.7	52
	P7	2.9	44	0.5	1.3	43
	All stations	3.8	39	1.0	1.5	40
Atlantic mackerel	P2	6.9	31	11.4	7.6	41
(May-Aug)	P5	6.8	50	7.1	5.7	38
	P7	5.9	21	6.3	7.0	37
	All stations	6.9	32	8.0	6.7	38
Cunner	P2	48.5	22	176.9	88.2	33
(Jun-Sept)	P5	55.0	29	176.8	70.5	33
	P7	59.0	23	152.0	81.0	29
	All stations	48.8	23	168.2	79.7	31
Hake[d]	P2	3.9	43	12.2	4.2	66
(Jul-Sept)	P5	3.1	50	14.7	4.9	67
	P7	3.9	48	11.7	4.4	69
	All stations	4.0	39	12.8	4.5	64
Atlantic herring	P2	29.0	34	5.9	7.5	31
(Oct-Dec)	P5	28.8	40	17.5	10.6	21
	P7	33.2	22	6.4	10.2	29
	All stations	29.2	32	8.8	9.3	24
Pollock	P2	6.3	50	0.0	0.6	57
(Nov-Feb)	P5	8.2	52	0.0	0.9	72
	P7	2.4	50	0.0	0.5	77
	All stations	6.8	49	0.0	0.7	66

[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 1995 data.
[c] Operational: August 1990-December 1996; 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 for pollock in 1996 includes November through December of 1995, and January through February 1996.

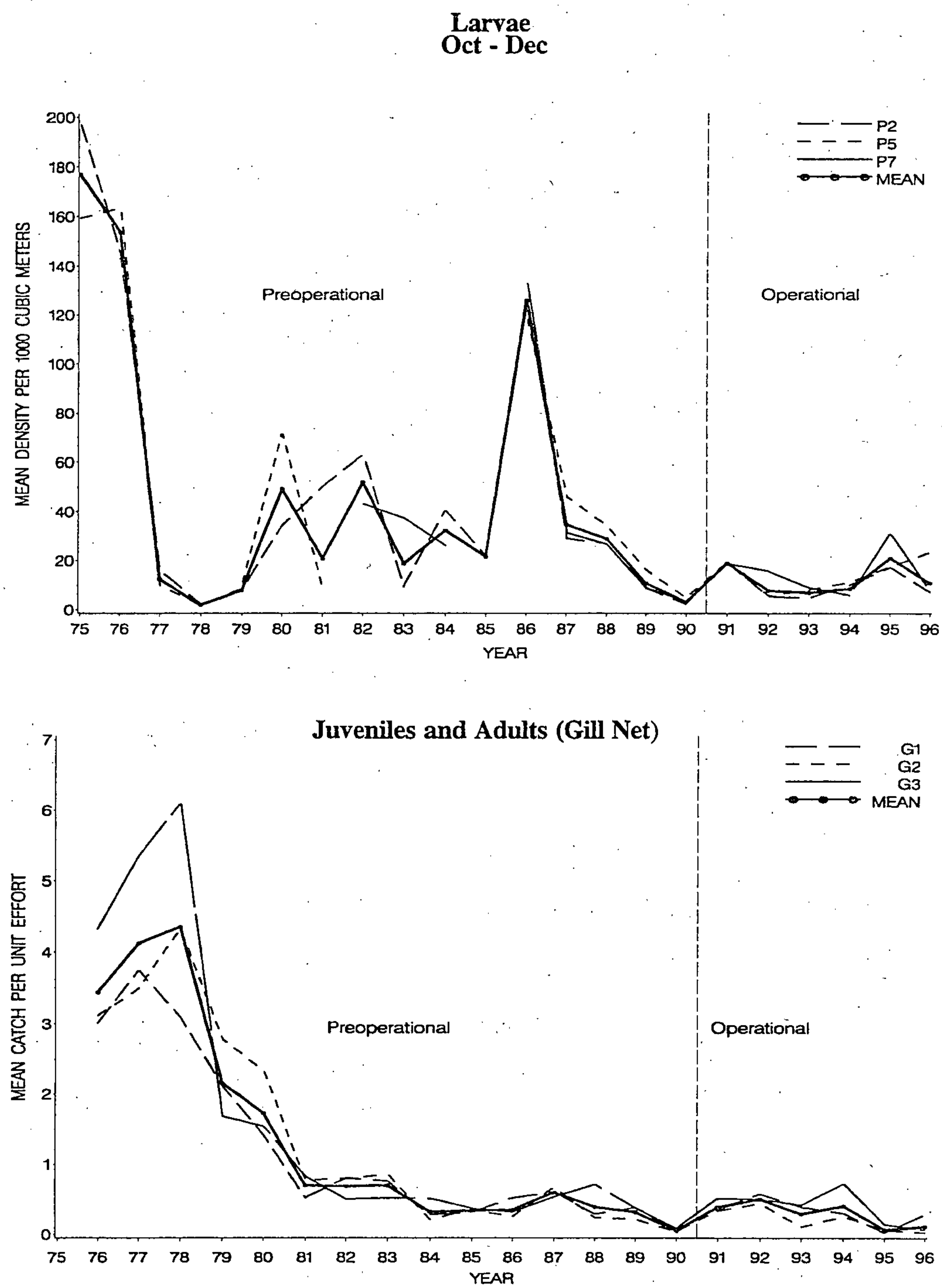


Figure 5-8. Annual geometric mean catch of Atlantic herring per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1996. Seabrook Operational Report, 1996.

Table 5-14. **Results of Analysis of Variance for Atlantic Herring Densities by Sampling Program. Seabrook Operational Report, 1996.**

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton (Oct.-Dec.) (1986-1996)	Preop-Op[a]	1	23.97	7.13*	Op<Preop
	Year (Preop-Op)[b]	9	3.44	1.07 NS	
	Month (Year)[c]	22	3.46	7.91 NS	
	Station[d]	2	0.56	6.18 NS	
	Preop-Op X Station[e]	2	0.09	0.44 NS	
	Station X Year (Preop-Op)[f]	18	0.21	0.49 NS	
	Error	323	0.44		
Gill Net (Sep.-May) (1976-1996)	Preop-Op[g]	1	7.77	5.45*	Op<Preop
	Year (Preop-Op)	19	1.47	4.81***	
	Month (Year)	165	0.29	8.64***	
	Station	2	0.09	4.25 NS	
	Preop-Op X Station	2	0.02	0.48 NS	
	Station X Year (Preop-Op)	38	0.05	1.35 NS	
	Error	330	0.03		

[a] Preop-Op compares 1990-1996 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 Station and Year within Preop-Op.
[g] Preop-Op compares 1990-1996 to 1976-1990, regardless of station.
[h] Waller-Duncan multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

Entrainment and impingement of Atlantic herring appeared to have a small effect on local populations. Atlantic herring accounted for slightly less than 2% of larvae identified in entrainment samples in 1996, with an estimated total of 4.3 million entrained (Table 5-5); however 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 (NOAA 1995), recovery has not yet occurred in the Hampton-Seabrook area to former levels of abundance. This is probably a coast-wide phenomenon, as Atlantic herring also appear to be less available to the nearshore fixed gear fishery along the coast of Maine (NOAA 1995). The recovery on Georges Bank appears to be related to the lack of commercial fishing pressure in recent years (NOAA 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. Spawning usually peaks with the bimonthly spring tides (Buckley 1989). 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. 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-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 (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).

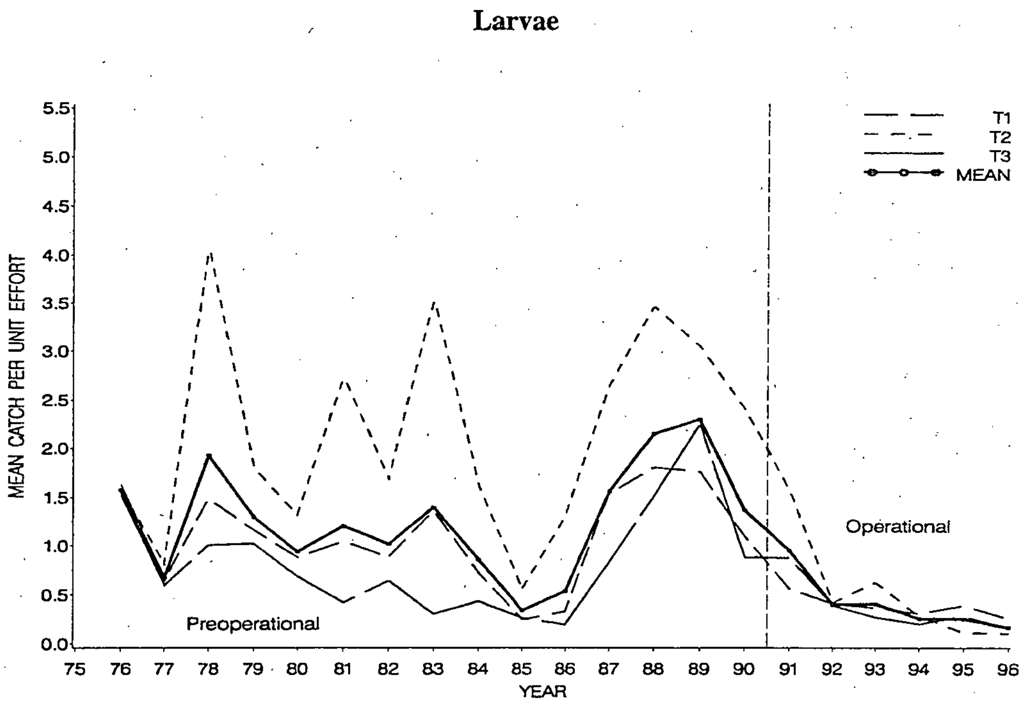
Near Seabrook Station, rainbow smelt were collected by otter trawl mostly from December through April (NAI 1993), which corresponds to the winter-spring spawning run. The annual geometric mean CPUE peaked in 1989 in the late preoperational period, and has steadily declined throughout the operational 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. Historically most rainbow smelt were taken at S3, although none were captured at any station in 1995 (NAI 1996). In 1996, CPUE at each station increased and was similar to the operational mean (Table 5-10). There were significant differences among stations with the highest catches occurring at Station S3 (Table 5-15). The operation of Seabrook Station did not appear to affect rainbow smelt CPUE as there were no significant differences between the preoperational and operational periods (Table 5-15).

The results from the ANOVA indicated that trawl catches varied significantly among stations between the preoperational and operational periods, resulting in a significant Preop-Op X Station interaction term (Table 5-15). CPUE significantly decreased between the preoperational and operational periods at all stations, but the decrease was greatest at Station T2 (Figure 5-10). Mean CPUE was highest at Station T2 during the preoperational period, but during the operational period CPUE was lowest at T2 (Figure 5-10).

There are no apparent reasons for the more pronounced decrease in CPUE of rainbow smelt at T2 between the preoperational and operational periods. The preoperational mean at T2 was higher than at the other stations because it was strongly influenced by high annual means during 1978, 1981, 1983, and 1988, which were followed by large declines. A sharp decline in rainbow smelt CPUE at all stations began in 1988 prior to the beginning of plant operation. The current low CPUE in the operational period at Station T2 is similar to those at the other stations and may be a reflection of the high natural annual variability.

The abundance of rainbow smelt is potentially influenced through impingement and entrainment. Rainbow smelt spawn in the estuary, and the adhesive eggs remain in the estuary and are not subject to entrainment. 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. Larvae also are primarily estuarine and are not subject to a large degree of entrainment through the offshore intakes. Larvae have only been collected in entrainment samples in 1990 and 1992, accounting for a total entrainment estimate of about 300,000 larvae



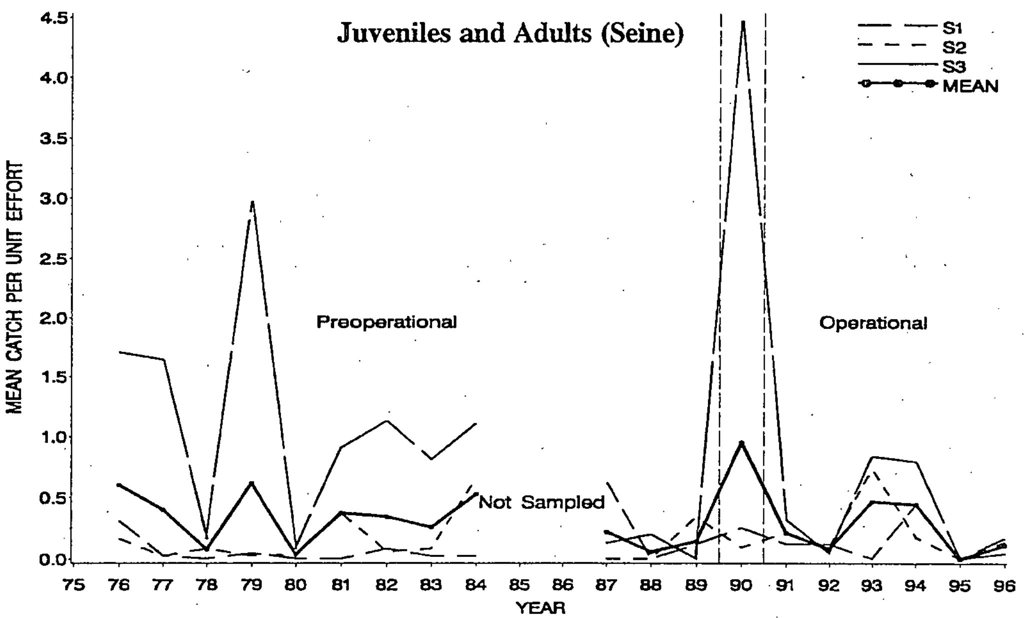


Figure 5-9. Annual geometric mean catch of rainbow smelt per unit effort in trawl (number per 10-min tow) and seine (number per haul) samples by station and the mean of all stations, 1986-1996 (data between two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-15. Results of Analysis of Variance for Rainbow Smelt Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Seine	Preop-Op[a]	1	0.11	1.02 NS	
(Apr-Nov)	Year (Preop-Op)[b]	17	0.11	0.82 NS	
(1976-1996)	Month (Year)[c]	130	0.09	1.53**	
	Station[d]	2	0.98	9.58***	S3 S2 S1
	Station X Year (Preop-Op)[e]	36	0.10	1.74**	
	Error	260	0.06		
Trawl	Preop-Op[f]	1	9.35	8.16*	Op<Preop
(Nov-May)	Year (Preop-Op)	19	0.66	1.36 NS	
(1975-1995)	Month (Year)	126	0.50	6.50***	
	Station	2	0.40	0.71 NS	
	Preop-Op X Station[g]	2	0.55	9.54***	2Pre 1Pre 3Pre 1Op 3Op 2Op
	Station X Year (Preop-Op)	38	0.06	0.74 NS	
	Error	250	0.08		

[a] Preop-Op compares 1990-1996 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 Station and Year within Preop-Op.
[f] Preop-Op compares 1990-1996 to 1986-1990 regardless of station.
[g] Interaction of the two main effects, Preop-Op and Station.
[h] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

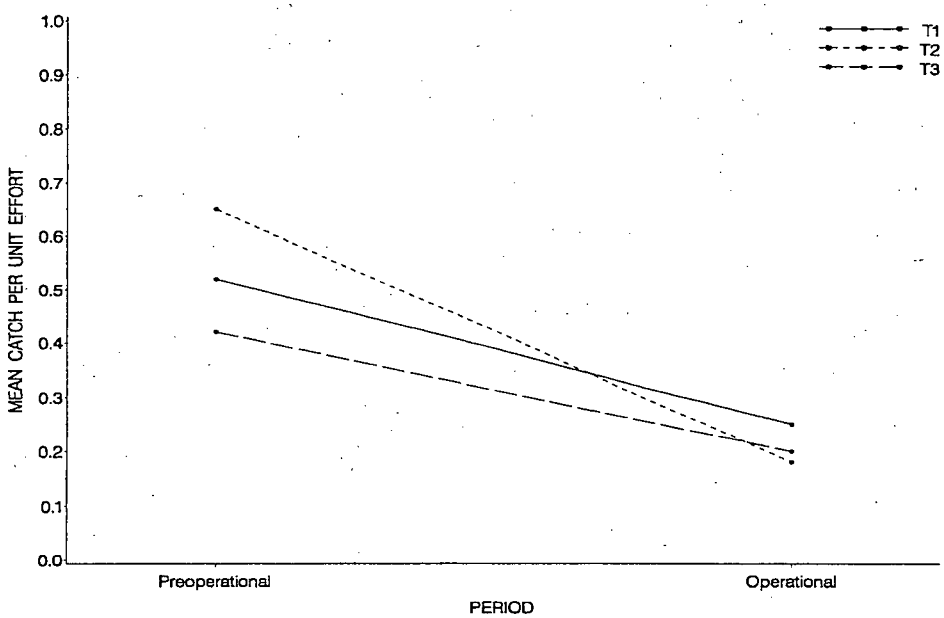


Figure 5-10 A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 10-minute tow) of rainbow smelt caught by trawl during the preoperational (November 1975-May 1990) and operational (November 1990-May 1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-15). Seabrook Operational Report, 1996.

since the beginning of plant operation (Table 5-6). An estimated 4,489 rainbow smelt were impinged in 1996 (Table 5-11). This is the largest annual estimate of rainbow smelt impinged to date, with over 90% of the impingement occurring on two dates in November. The occurrence of a high impingement episode in 1996, coupled with the impingement of a total of 767 smelt in 1994 and 1995 indicates that the November 1996 impingement of rainbow smelt may be an unusual event. It is unlikely that the impingement of 5,247 smelt at Seabrook Station since 1994 has affected the population in the study area, because decreases in the nearshore area began prior to plant operation, and no change in rainbow smelt abundance has been observed in the estuary.

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; NOAA 1995). 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 north-west Atlantic, but for management purposes two stocks (Gulf of Maine, and Georges Bank and South) are recognized in U.S. waters (NOAA 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 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). In the northwest Atlantic, spawning takes place on the continental shelf in areas where eggs and larvae are likely to be retained on the 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. 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).

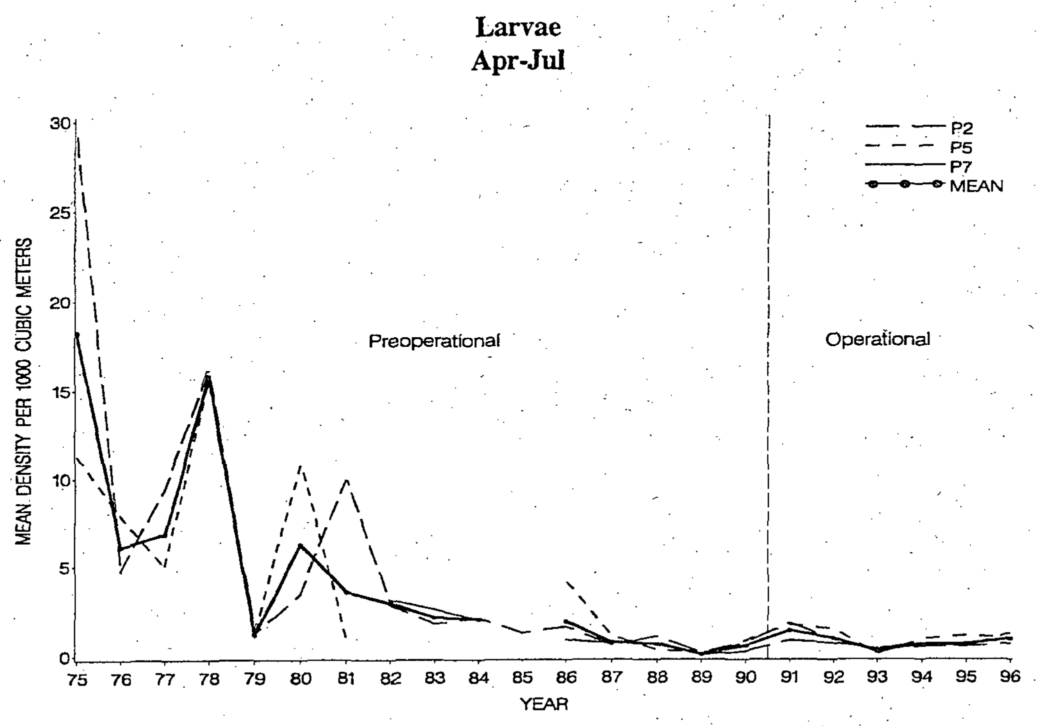
Spatial distribution also changes with age, as cod of ages 1-2, 3, and 4+ in Southern New England and on Georges Bank were distributed at different depths during spring (Wigley and Serchuk 1992). Seasonal distribution shifts are likely associated with water temperature. Suthers and Frank (1989) noted 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). 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, but was related to abundance of both pelagic and demersal juveniles. 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*.

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 13,600 metric tons during 1974-83 and 12,500 metric tons for 1984-89, but rose to 18,700 metric tons in 1990 and to a record 20,300 metric tons in 1991 (NOAA 1995). Landings decreased 11,900 metric tons in 1992 and 11,000 metric tons in 1993. The catch in 1993 was dominated by the weak 1990 year-class and survivors of the strong 1987 year-class. 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 (NOAA 1995).

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 0.42% for Atlantic cod, 0.02% for haddock, and 0.90% 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 1982 to the present (Figure 5-11). This



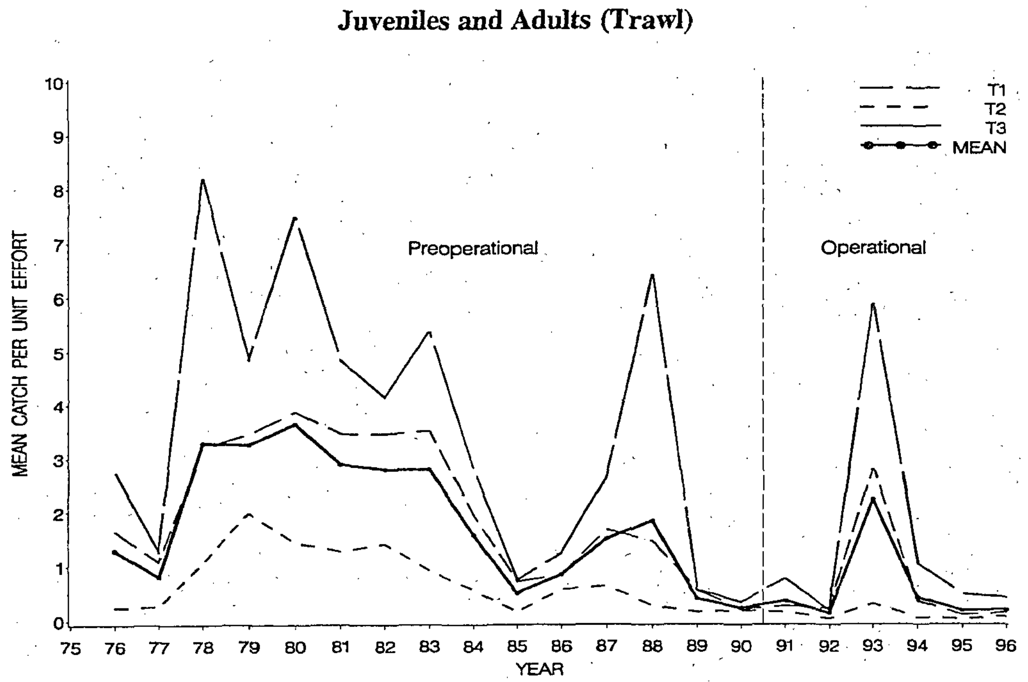


Figure 5-11. Annual geometric mean catch of Atlantic cod per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1976-1996. Seabrook Operational Report, 1996.

decrease in abundance occurred about 10 years before plant operation and was evident in the comparison of preoperational and operational geometric means (Table 5-13). However, there were no significant differences between the preoperational and operational periods (Table 5-16). The Preop-Op X Station term was not significant, indicating that trends among station were consistent between the preoperational and operational periods, and there was no effect due to Seabrook Station.

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 through 1985. 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 through 1996, abundances decreased sharply from the 1993 peak at Stations T1 and T3, and remained low at T2. In agreement with this recent trend, CPUE in the operational period was significantly lower than the preoperational period (Table 5-16). This decline occurred at all stations as indicated by the non-significant Preop-Op X Station interaction term and was not due to the operation of Seabrook Station.

It is very likely that decreases in cod abundance are due to regional declines in Atlantic cod abundance and possibly due to a naturally-occurring increase in temperature (Section 2.0). These changes have no relation to the operation of Seabrook Station. ANOVA results 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 NOAA (1995), 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 94 Atlantic cod were impinged at Seabrook Station in 1996 (Table 5-11). Egg and, in particular, larval entrainment (300,000 in 1996) 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.

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

Table 5-16. Results of Analysis of Variance for Atlantic Cod Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton (Apr-Jul) (1987-1996)	Preop-Op[a]	1	0.67	1.80 NS	
	Year (Preop-Op)[b]	8	0.43	0.76 NS	
	Month (Year)[c]	30	0.64	4.02 ***	
	Station[d]	2	0.19	6.92 NS	
	Preop-Op X Station[e]	2	0.03	0.33 NS	
	Station X Year (Preop-Op)[f]	16	0.08	0.53 NS	
	Error	399	0.16		
Trawl (Nov-Jul) (1975-1996)	Preop-Op[g]	1	10.24	8.06*	Op < Preop
	Year (Preop-Op)	19	1.10	5.65***	
	Month (Year)	168	0.15	3.10***	
	Station	2	4.42	16.03 NS	
	Preop-Op X Station	2	0.27	3.01 NS	
	Station X Year (Preop-Op)	38	0.09	1.80**	
	Error	334	0.05		

[a] Preop-Op compares 1990-1996 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 Station and Year within Preop-Op.
[f] Preop-Op compares 1990-1996 to 1986-1990 regardless of station.
[g] Interaction of the two main effects, Preop-Op and Station.
[h] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

Scotian Shelf and in the Gulf of Maine (NOAA 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. recreational and U.S. and Canadian commercial landings for the Scotian Shelf, Gulf of Maine, and Georges Bank regions increased from a yearly average of about 46,400 metric tons in 1974-83 to 68,500 metric tons by 1986 (NOAA 1995). 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 although an increase was observed in 1993. 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. The 1989-91 year-classes, however, are below average in abundance. The pollock stock is considered by NOAA (1995) to be fully exploited.

Pollock eggs and larvae were collected in relatively low densities (Tables 5-3 and 5-4). Larval pollock abundance generally peaked during November through February (NAI 1993); however, no pollock larvae were captured from November 1995 to February 1996 (Table 5-13). There was a significant decline in the geometric mean density between the preoperational and operational periods, with large annual fluctuations occurring during the preoperational period (Tables 5-13, 5-17; Figure 5-12). Larval densities were significantly lower at the farfield Station P7, than at P5.

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 NOAA (1995). Catch decreased slightly in 1996 compared to 1995 and 1994, but was comparable to 1992 and 1991. However, the ANOVA for gill net catch CPUE showed no significant differences between preoperational and operational periods (Table 5-17).

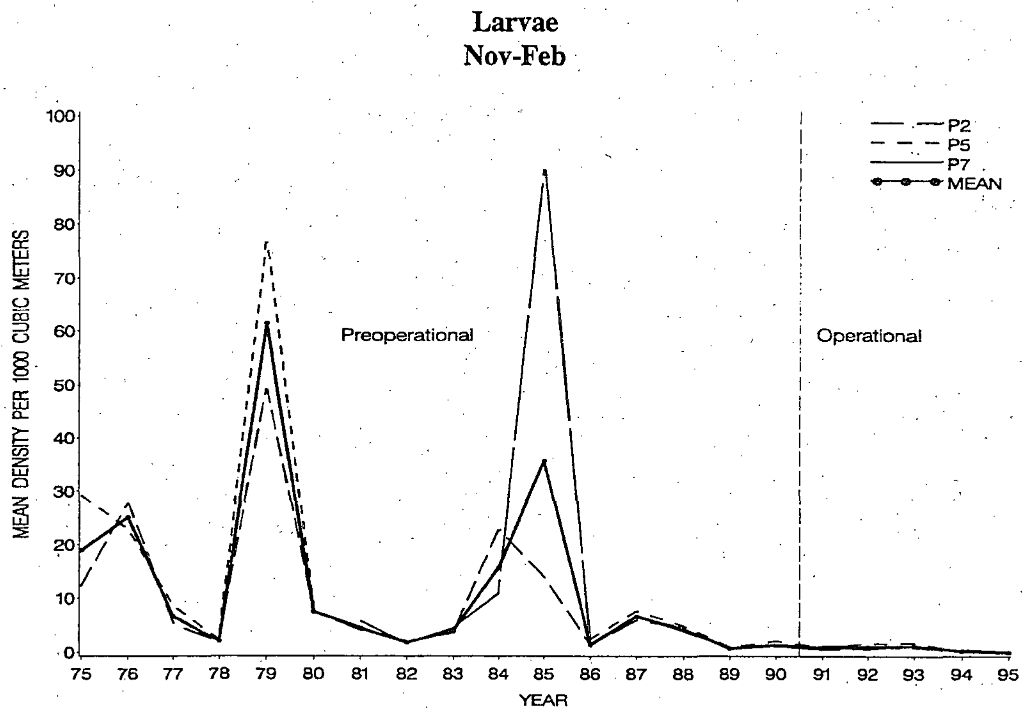
No changes in abundance or distribution can be attributed to station operation. Although larval densities have declined significantly between the preoperational and operational periods, the interaction term for both ichthyoplankton and gill net sampling was not significant, indicating an

Table 5-17. **Results of Analysis of Variance for Pollock Densities by Sampling Program. Seabrook Operational Report, 1996.**

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton (Nov-Feb) (1986-1996)	Preop-Op[a]	1	11.13	5.53*	Op < Preop
	Year (Preop-Op)[b]	8	2.05	2.82*	
	Month (Year)[c]	28	0.82	5.73***	
	Station[d]	2	0.38	28.59**	P5 P2 P7
	Preop-Op X Station[e]	2	0.01	0.23 NS	
	Station X Year (Preop-Op)[f]	16	0.05	0.38 NS	
	Error	380	0.14		
Gill Net (Apr-Dec) (1976-1996)	Preop-Op[g]	1	0.02	0.45 NS	
	Year (Preop-Op)	18	0.06	0.96 NS	
	Month (Year)	159	0.05	4.46***	
	Station	2	0.09	41.84 NS	
	Preop-Op X Station	2	<0.01	0.12 NS	
	Station X Year (Preop-Op)	36	0.02	1.99**	
	Error	317	0.01		

[a] Preop-Op compares 1990-1996 to 1976-1986-199 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 Station and Year within Preop-Op.
[g] Preop-Op compares 1991-1996 to 1975-1989 regardless of station.
[h] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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



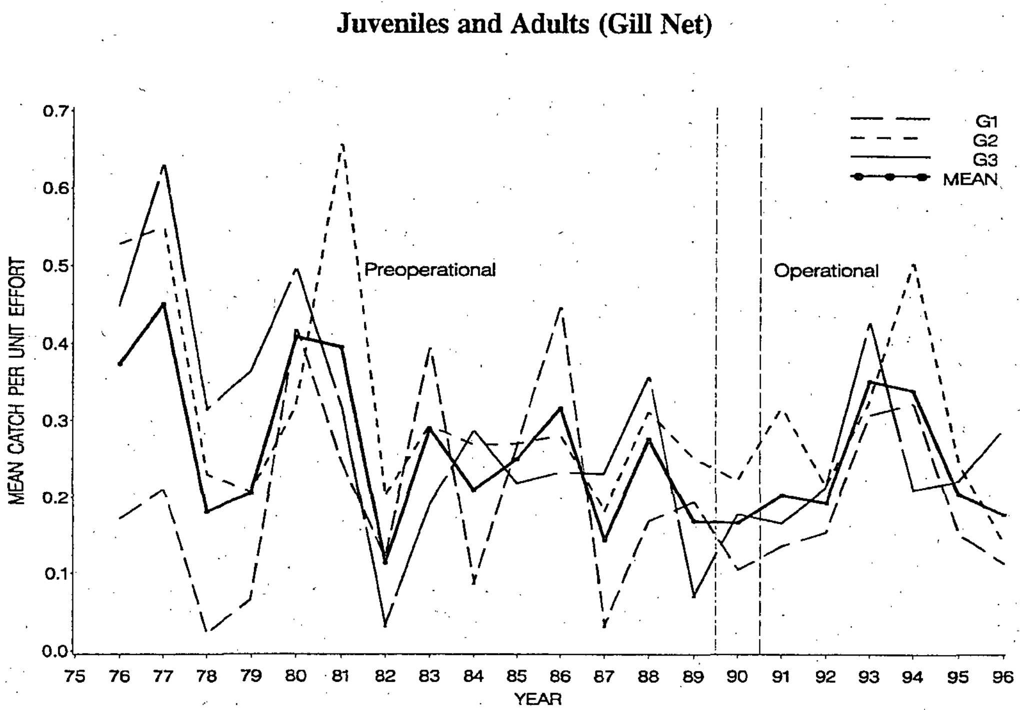


Figure 5-12. Annual geometric mean catch of pollock per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

area-wide decline. Relatively few eggs and larvae were entrained (Table 5-6). Entrainment losses of pollock eggs and larvae at Seabrook Station from 1990 to 1994 were estimated to result in the annual loss of less than 10 equivalent adults annually (Saila et al. 1995). Entrainment of eggs and larvae in 1996 were within the range of previous years, and the number of equivalent adults lost would be similar to the annual estimate of Saila et al. (1995). Pollock ranked third among fishes impinged at Seabrook Station in 1996, with estimated total of 1,835 fish (Table 5-11). 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.

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. 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 (NOAA 1995).

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 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

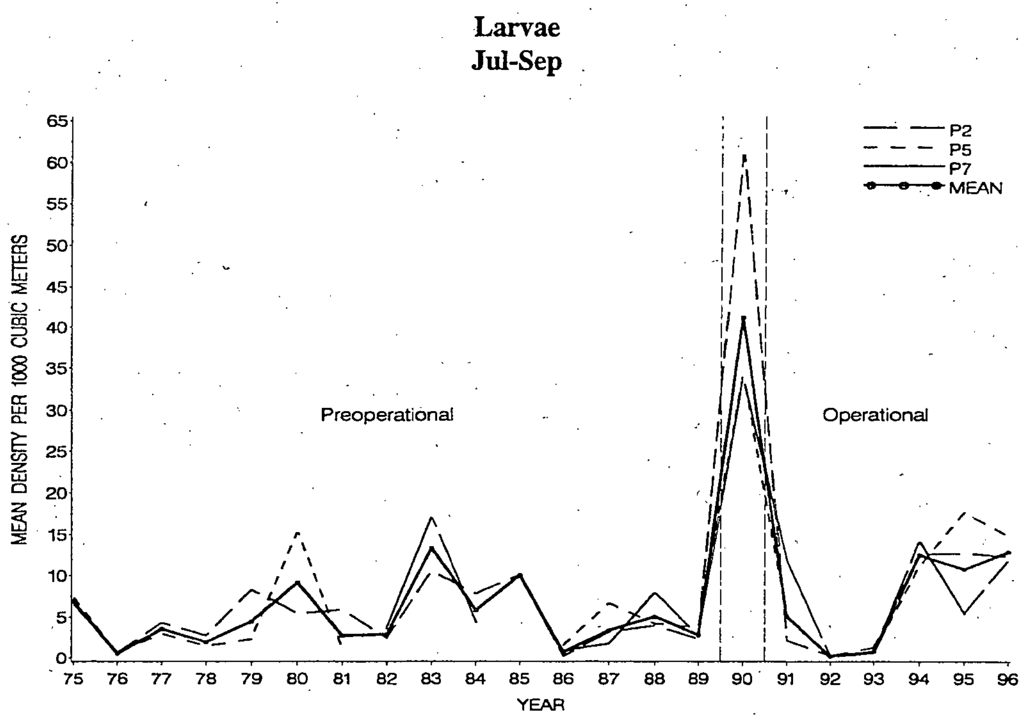
1983; Luczkovitch 1991). Other red hake, however, find shelter under shell or other bottom structures (Steiner et al. 1982).

Based on the depth distribution of the red and white hake, red hake is probably the most common hake in the study area. Recent commercial fishing landings of red hake in the Gulf of Maine and from the northern Georges Bank are very low (< 1,000 metric tons), with an average of only 2,000 metric tons landed over the period of 1974-93 (NOAA 1995). The NMFS trawl survey index showed an increasing trend in abundance from the mid-1970s to a peak in 1989; indices decreased in 1990 through 1993, but remained near the long-term average. Although year-classes produced since 1985 were termed moderate in strength, NOAA (1995) 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 (NOAA 1995). 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, and 9,100 metric tons in 1993. NMFS trawl survey indices have fluctuated considerably, but indications are that abundance increased in 1991 and 1992. NOAA (1995) 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 7,700 metric tons. This species may be overharvested if landings (such as those in 1992 and 1993) 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, although data from this year were excluded from the ANOVA (Figure 5-13). Larval density during 1992 and 1993 were among the years of lowest abundance (Figure 5-13). In 1994, larval density increased and has been relatively stable through 1996. Densities during the operational period were not significantly different from the preoperational period due to the recent increases in 1994 through 1996 (Table 5-18).

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 through 1995 were the lowest of the time-series, but CPUE increased slightly in 1996.

Entrainment and impingement losses due to plant operation did not appear to affect local populations. Entrainment estimates for hake eggs



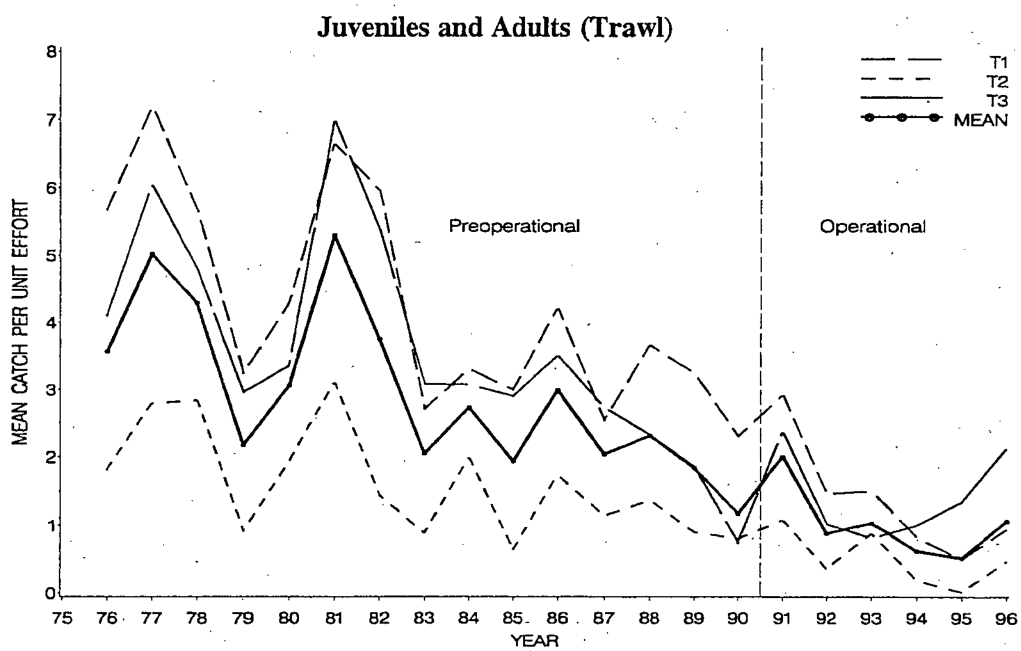


Figure 5-13. Annual geometric mean catch of hakes per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1976-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-18. **Results of Analysis of Variance for Hake[a] Densities by Sampling Program. Seabrook Operational Report, 1996.**

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[i]
Ichthyoplankton (Jul-Sep) (1986-1996)	Preop-Op[b]	1	2.69	0.48 NS	
	Year (Preop-Op)[c]	8	5.74	1.70 NS	
	Month (Year)[d]	20	3.55	6.64***	
	Station[e]	2	0.41	2.46 NS	
	Preop-Op X Station[f]	2	0.17	0.48 NS	
	Station X Year (Preop-Op)[g]	16	0.35	0.66 NS	
	Error	309	0.53		
Trawl (Nov-Jul) (1976-1996)	Preop-Op[h]	1	6.96	17.91**	Op<Preop
	Year (Preop-Op)	19	0.31	0.71 NS	
	Month (Year)	168	0.44	8.52***	
	Station	2	0.96	7.37 NS	
	Preop-Op X Station	2	0.13	2.96 NS	
	Station X Year (Preop-Op)	38	0.04	0.84 NS	
	Error	334	0.05		

[a] May include red hake, white hake, spotted hake, or more than one of these species.
[b] Preop-Op compares 1990-1991 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 Station and Year within Preop-Op.
[h] Preop-Op compares 1990-1991 to 1976-1990 regardless of station.
[i] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

and larvae during 1996 were the highest since Seabrook Station began operation. Entrainment losses of hake eggs and larvae at Seabrook Station from 1990 to 1994 were estimated to result in the loss of less than 1,000 equivalent adults, assuming that red hake were the predominant species entrained (Saila et al. 1995). Entrainment of hake eggs and larvae in 1996 was greater than the sum of the previous years and probably would result in the loss of more than 1,000 equivalent adults (Saila et al. 1995). The highest entrainment estimates occurred in 1990, the year when larvae were most abundant (Table 5-6; Figure 5-13). An estimated 2,601 hakes were impinged at Seabrook Station in 1996 (Table 5-11), which is similar to the amount impinged in 1994 (2,824) and 1995 (2,217) (Appendix Table 5-3).

The ANOVA detected significantly larger preoperational abundances than operational abundances for trawl catches (Table 5-18). However, the interaction term was not significant, suggesting there were no plant effects. The apparent trend in abundance as measured by trawl CPUE at Seabrook Station differs from the trend in indices reported by NOAA (1995) for these species. Since 1976, the NOAA research trawl index for red hake has fluctuated considerably, but with an increasing trend (NOAA 1995). Commercial landings have remained uniformly low throughout this period. White hake have fluctuated without a long-term trend, but increases have occurred since 1989 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 hake species prior to 1995 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 (Figure 5-14). Since then, CPUE has fluctuated around a lower and more consistent average level to the present. Catch at each station tended to follow similar patterns, with the exceptions of Stations S2 in 1993 and S1 in 1995. There were no significant differences in CPUE between the preoperational and operational periods, or among stations, indicating that the operation of Seabrook Station did not affect Atlantic silverside abundance (Table 5-19).

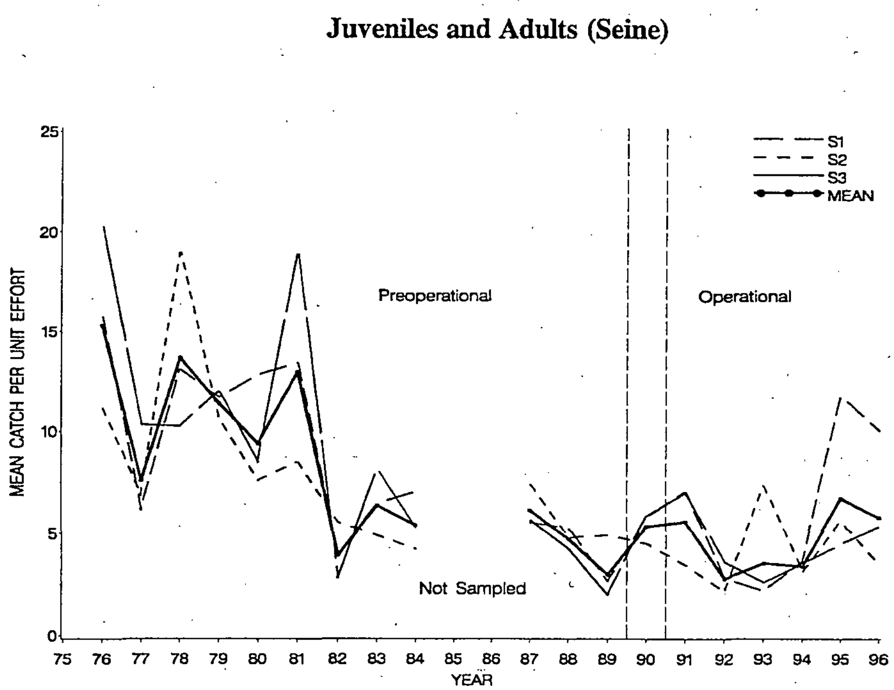


Figure 5-14. Annual geometric mean catch of Atlantic silverside per unit effort in seine (number per haul) samples by station and the mean of all stations, 1976-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-19. Results of Analysis of Variance for Atlantic Silverside Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[f]
Seine (Apr-Nov) (1976-1996)	Preop-Op[a]	1	2.60	3.07 NS	
	Year (Preop-Op)[b]	17	0.86	0.40 NS	
	Month (Year)[c]	130	2.17	14.94***	
	Station[d]	2	0.12	0.85 NS	
	Station X Year (Preop-Op)[e]	36	0.14	0.94 NS	
	Error	260	0.15		

[a] Preop-Op compares 1991-1996 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 Station and Year within Preop-Op.
[f] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

An estimated 1,119 Atlantic silverside were impinged in 1996 (Table 5-11). 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, is no longer a potential impact to resident marine biota. 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 operation of Seabrook Station has not affected 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 70-90 mm 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 5-3 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 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, with the exception of 1987, 1994 and 1995 (Figure 5-15). In 1995, mean density of cunner larvae was the highest observed and was much greater than both the preoperational and operational mean densities (NAI 1996). In 1996, cunner larval densities returned to levels that were similar to the preoperational and operational periods (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, or among stations (Table 5-20).

Cunner/yellowtail flounder egg entrainment in 1996 was estimated at 110.2 million, ranking third among taxa of eggs (Table 5-5). Except for 1995 and 1996, this group has ranked first or second each year that entrainment sampling was

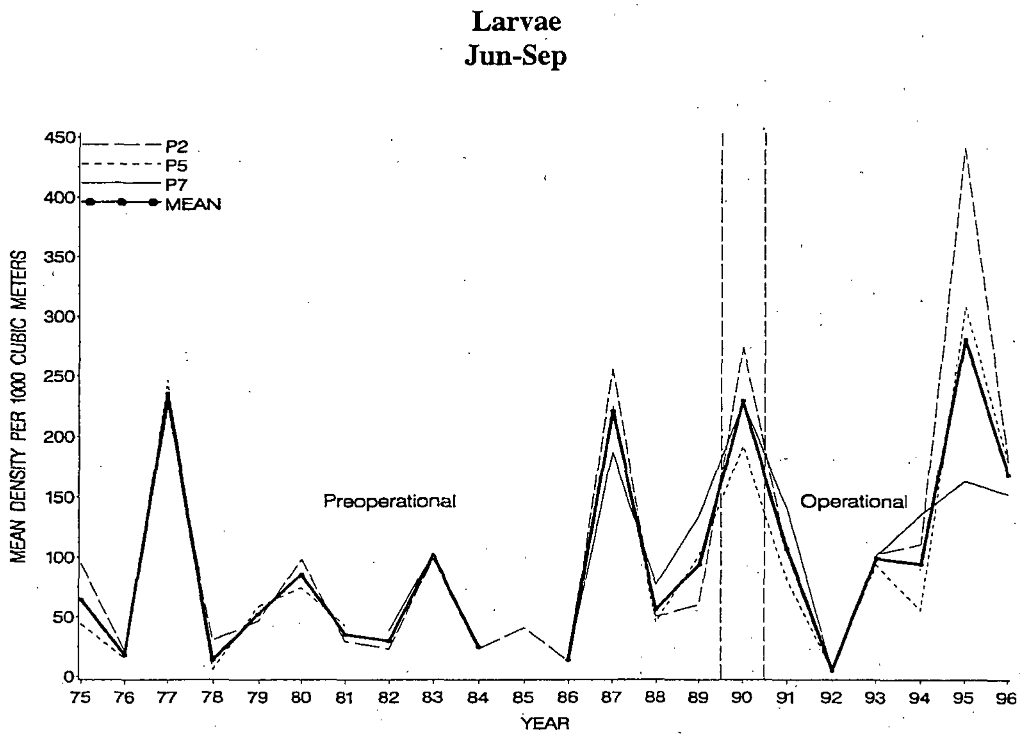


Figure 5-15. Annual geometric mean catch of cunner per unit effort in ichthyoplankton (number per 1000 cubic meters) samples by station and the mean of all stations, 1975-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-20. **Results of Analysis of Variance for Cunner Densities by Sampling Program. Seabrook Operational Report, 1996.**

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton (Jun-Sep) (1987-1996)	Preop-Op[a]	1	1.22	0.09 NS	
	Year (Preop-Op)[b]	7	13.35	1.11 NS	
	Month (Year)[c]	27	12.59	16.06***	
	Station[d]	2	0.15	0.60 NS	
	Preop-Op X Station[e]	2	0.24	0.93 NS	
	Station X Year (Preop-Op)[f]	14	0.26	0.34 NS	
	Error	377	0.78		

[a] Preop-Op compares 1991-1996 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 Station and Year within Preop-Op.

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

conducted during the summer season of high abundance (Table 5-6). Larval entrainment since 1990 has ranged from 0 to 42.7 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), and possible extrusion of larvae through the 505 μm mesh net. 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, in September of 1992, and in April-September of 1994 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 1,121 cunner were impinged at Seabrook Station during 1996 (Table 5-11).

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 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. 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 and Peterson 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.

American sand lance was the dominant larval taxon collected in the ichthyoplankton program (Tables 5-4 and 5-13). 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 increased from 1987 through 1994, and again in 1996 (Figure 5-16). The decline since the 1980s was also apparent in

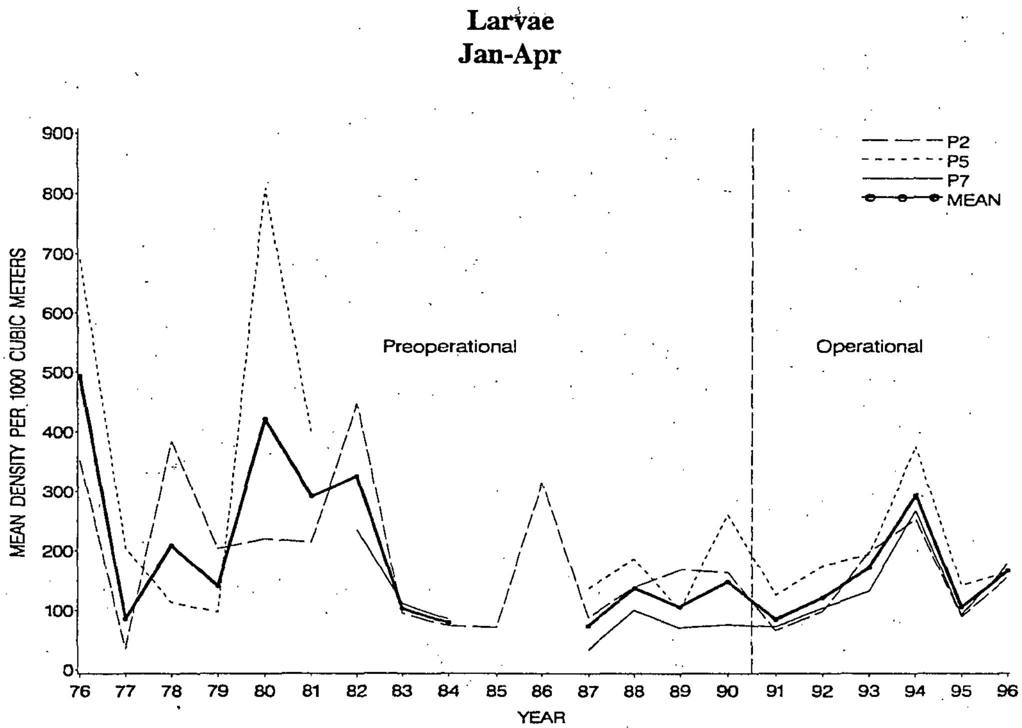


Figure 5-16. Annual geometric mean catch of American sand lance per unit effort in ichthyoplankton (number per 1000 cubic meters) samples by station and the mean of all stations, 1976-1996. Seabrook Operational Report, 1996.

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 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.

Mean larval sand lance abundance in 1996 was similar to the preoperational period mean, and higher than the operational period mean (Table 5-13; Figure 5-16). Annual geometric means have increased from 1991 through 1994, but declined in 1995 and increased in 1996 (Figure 5-16). Densities of sand lance larvae increased between the preoperational and operational periods at Station P7 but were not significantly different at the other stations, resulting in a significant interaction term (Figure 5-17; Table 5-21). The ANOVA used the time period between 1987 and 1996 when all three stations were sampled. Examination of the annual means during this time period indicates that the stations generally followed the same trends among years (Figure 5-16). This consistency in annual means among stations suggests that the changes in density are unrelated to plant operation.

In 1996, an estimated 14.0 million sand lance larvae were entrained. The 1996 estimate was intermediate between the low of no entrainment in 1990 to an estimated 37.3 entrained larvae in 1991. The estimated impingement in 1996 (823 fish) was the lowest recorded to date (Appendix Table 5-3).

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

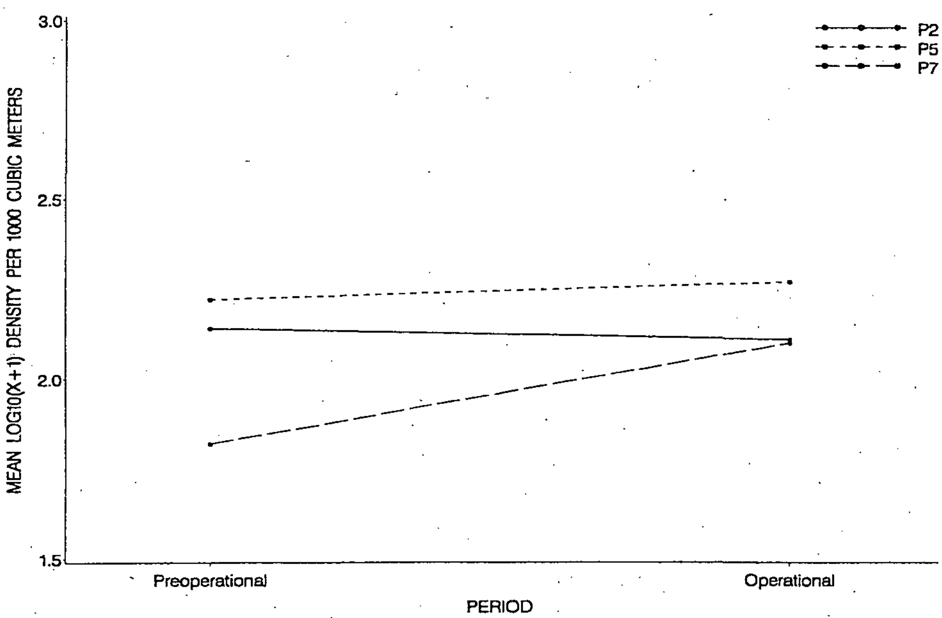


Figure 5-17. A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 10-minute tow) of American sand lance larvae caught during the preoperational (1987-1990) and operational (1991-1996) periods (January - April only) for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-21). Seabrook Operational Report, 1996.

Table 5-21. Results of Analysis of Variance for American Sand Lance Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[g]
Ichthyoplankton (Jan-Apr) (1987-1996)	Preop-Op[a]	1	1.18	0.57 NS	
	Year (Preop-Op)[b]	8	1.33	0.36 NS	
	Month (Year)[c]	30	4.18	7.91***	
	Station[d]	2	2.54	2.72 NS	
	Preop-Op X Station[e]	2	0.92	6.84**	5 Op 5 Pre 2 Pre 2 Op 7 OP 7 Pre
	Station X Year (Preop-Op)[f]	16	0.13	0.25 NS	
	Error	378	0.53		

[a] Preop-Op compares 1991-1996 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 Station and Year within Preop-Op.
[g] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

infrequently. Again, abundance was highest during the late 1970s.

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). 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 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). 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 950; Ware and Lambert 1985; D'Amours et al. 1990).

Presently, biomass of the Atlantic mackerel stock is very high (NOAA 1995). 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 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 32,100 metric tons in 1993; a very strong year-class was produced in 1982 and relatively good ones in 1984-88. In 1994, current spawning stock biomass was estimated to exceed 2 million metric tons, catches can be increased substantially without affecting the spawning stock (NOAA 1995).

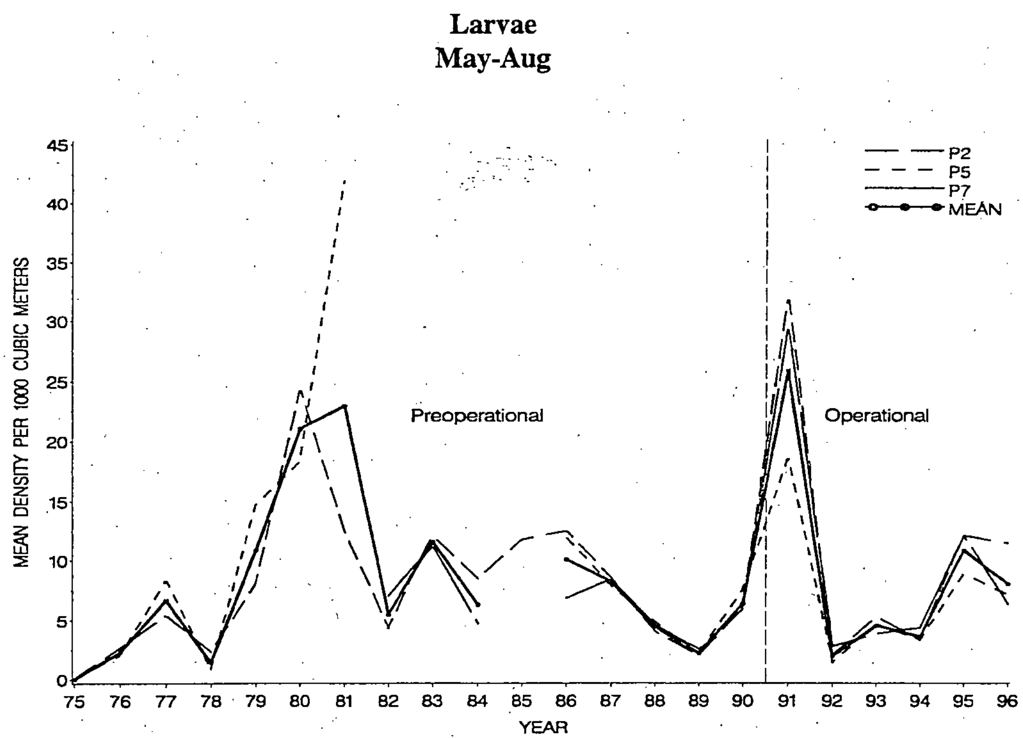
Atlantic mackerel was the second-most abundant egg taxon collected in the ichthyoplankton program (Table 5-3). The larvae were very abundant in ichthyoplankton collections (Table 5-4), but were not dominant in entrainment samples (Tables 5-5 and 5-6). Larvae typically occurred from May through August (NAI 1993) and larval abundance in 1996 was greater than the preoperational and operational period averages (Table 5-13). Annual larval abundances fluctuated, with a peak at Station P5 in 1981 (Figure 5-18). During the period when all three stations were sampled (1986-95), 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 NOAA (1995), 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 indicated that there were no significant differences in CPUE between the preoperational and preoperational periods (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 Atlantic mackerel.

One Atlantic mackerel was impinged at Seabrook Station in 1996 (Table 5-11). 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). 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 shallow estuarine waters and can withstand temperatures of 30 to 32.4°C (Pearcy 1962; Everich and Gonzalez 1977).



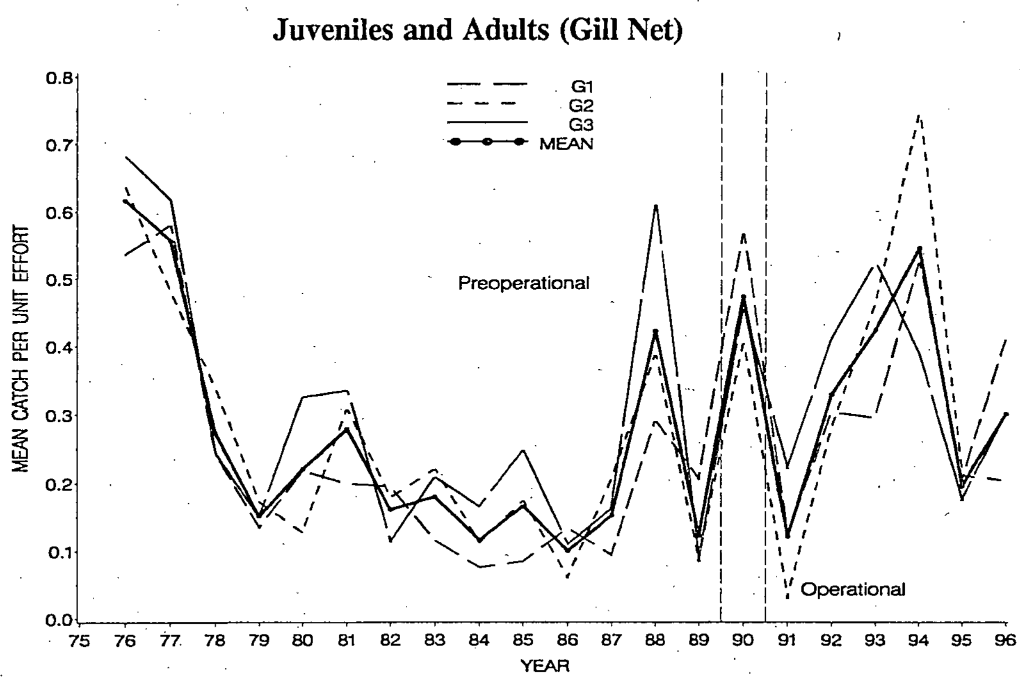


Figure 5-18. Annual geometric mean catch of Atlantic mackerel per unit effort in ichthyoplankton (number per 1000 cubic meters) and gill net (number per 24-h set) samples by station and the mean of all stations, 1975-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-22. Results of Analysis of Variance for Atlantic Mackerel Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton (May-Aug) (1985-1996)	Preop-Op[a]	1	1.06	0.23 NS	
	Year (Preop-Op)[b]	8	4.36	0.51 NS	
	Month (Year)[c]	29	9.33	10.33***	
	Station[d]	2	0.13	0.80 NS	
	Preop-Op X Station[e]	2	0.17	2.00 NS	
	Station X Year (Preop-Op)[f]	16	0.07	0.07 NS	
	Error	405	0.90		
Gill Net (Nov-Jul) (1975-1996)	Preop-Op[g]	1	0.17	1.21 NS	
	Year (Preop-Op)	18	0.16	1.64 NS	
	Month (Year)	99	0.09	6.20***	
	Station	2	0.02	5.88 NS	
	Preop-Op X Station	2	<0.01	0.24 NS	
	Station X Year (Preop-Op)	36	0.02	1.21 NS	
	Error	197	0.02		

[a] Preop-Op compares 1991-1996 to 1987-1990 regardless of station; 1990 was treated as a preoperational year (May-July only: August 1990 data were excluded from the analysis).
[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 Station and Year within Preop-Op.
[g] Preop-Op compares 1991-1996 to 1975-1989 regardless of station.
[h] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

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 (NOAA 1995). 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 (NOAA 1995). Since 1983, a downward trend was observed in landings with a record low of only 700 metric tons taken in 1993. Bottom trawl survey data from the Massachusetts Division of Marine Fisheries spring survey also showed a declining trend since 1983 (NOAA 1995). Lowest values were observed during 1988-93. Continued low landings and trawl catch indices were indications that winter flounder in the Gulf of Maine have been over exploited (NOAA 1995) 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 at all three stations since the mid-1980s (Figure 5-19). Mean larval density in 1996 (all stations combined) increased compared to 1995 and was higher than the operational period mean (NAI 1996) (Table 5-13). There were no significant differences in larval abundance between the preoperational and operational periods or among stations (Table 5-23). 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.

Winter flounder were 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

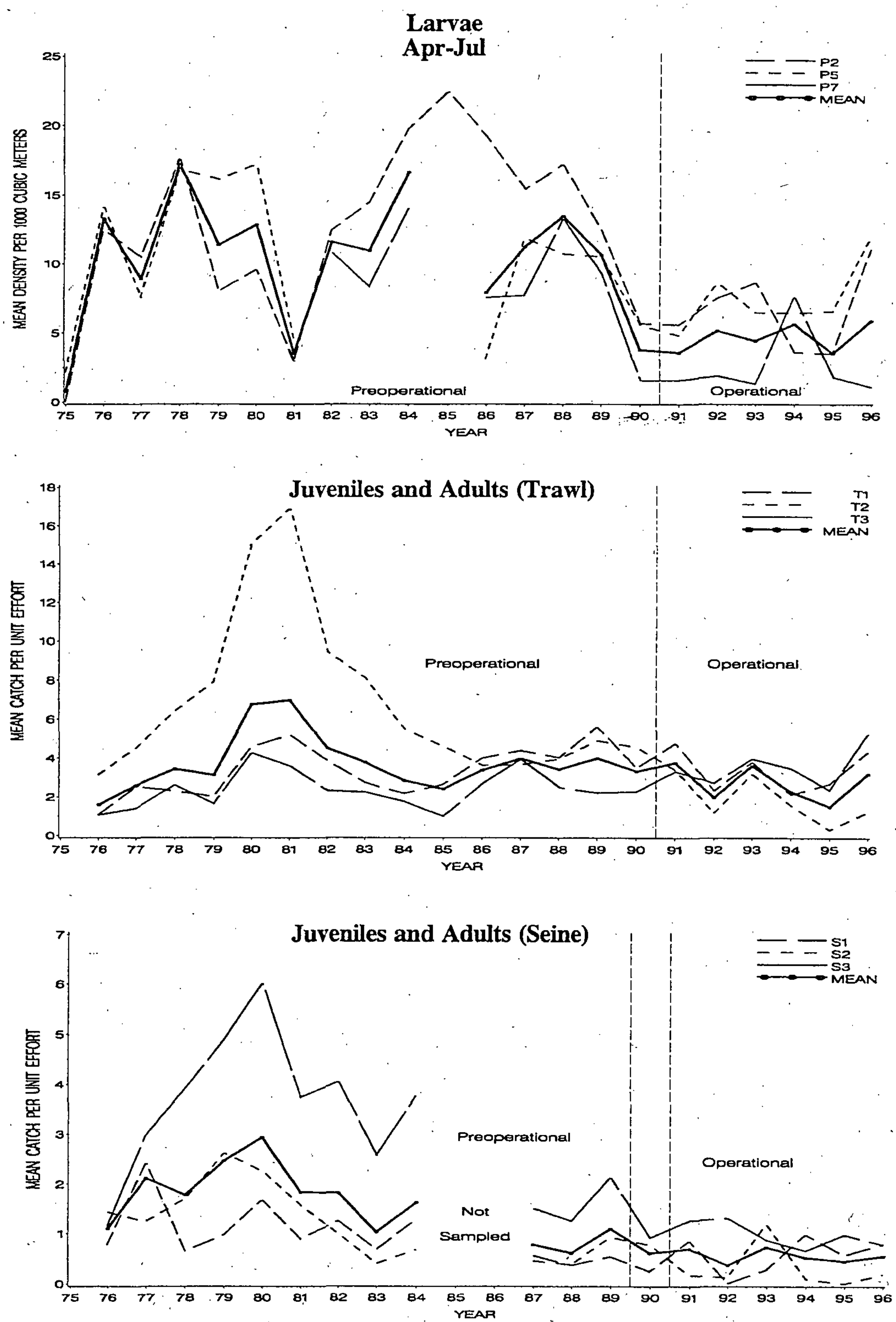


Figure 5-19. Annual geometric mean catch of winter flounder per unit effort in ichthyoplankton (number per 1000 cubic meters), trawl (number per 10-min tow), and seine (number per haul) samples by station and the mean of all stations, 1975-1996 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-23. Results of Analysis of Variance forWinter Flounder Densities by Sampling Program. Seabrook Operational Report, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton (Apr-Jul) (1987-1996)	Preop-Op[a]	1	4.88	4.58 NS	
	Year (Preop-Op)[b]	8	0.74	0.17 NS	
	Month (Year)[c]	30	4.33	10.22***	
	Station[d]	2	4.25	5.48 NS	
	Preop-Op X Station[e]	2	0.77	1.77 NS	
	Station X Year (Preop-Op)[f]	16	0.44	1.03 NS	
	Error	399	0.42		
Trawl (Nov-Jul) (1975-1996)	Preop-Op[g]	1	2.65	0.98 NS	
	Year (Preop-Op)	19	0.46	1.63 NS	
	Month (Year)	168	0.17	3.82***	
	Station	2	0.86	0.35 NS	
	Preop-Op X Station	2	2.40	15.12***	2 Pre 1 Pre 1 Op 3 Op 3 Pre 2 Op[j]
	Station X Year (Preop-Op)	38	0.16	3.53***	
	Error	334	0.05		
Seine (Apr-Nov) (1976-1996)	Preop-Op[h]	1	4.37	18.95***	Op < Preop
	Year (Preop-Op)	17	0.23	1.44 NS	
	Month (Year)	130	0.08	1.77***	
	Station	2	3.59	29.41***	S3 S1 S2
	Station X Year (Preop-Op)	36	0.12	2.60***	
	Error	260	0.05		

[a] Preop-Op compares 1991-1996 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 Station and Year within Preop-Op.
[g] Preop-Op compares 1990-1996 to 1975-1990.
[h] Preop-Op compares 1990-1996 to 1977-1984 and 1986-1989.
[i] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.
[j] 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 ($0.001 \geq p$)

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 1996 (Figure 5-19). 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, 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 low in 1985 (Figure 5-18). CPUE remained relatively stable from 1985 through 1991. In 1995, CPUE was lowest in the time series, but CPUE increased in 1996 to levels similar to the preoperational mean (Table 5-9). 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 early 1980s before Seabrook Station became operational (Figure 5-19). Furthermore, at least one farfield Station (T1) exhibited the same decreasing trends between the preoperational and operational periods as the nearfield Station (T2).

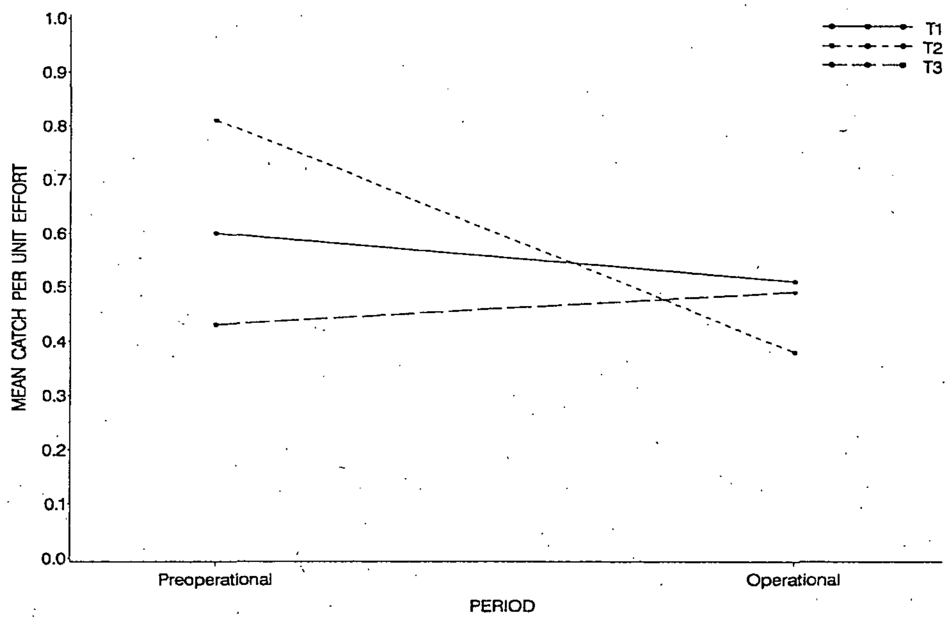


Figure 5-20. A comparison among stations of the mean $\log_{10}(x+1)$ CPUE (number per 10-minute tow) of winter flounder caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 5-23). Seabrook Operational Report, 1996.

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 generally 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 low levels since 1987.

CPUE of winter flounder was significantly higher during the preoperational period than the operational period, and was significantly higher at Station S3 (Table 5-23). CPUE began to decrease at all stations in 1981, and has remained relatively constant since 1987 (Figure 5-19). The significant decrease in CPUE between the preoperational and operational periods is probably not due to the operation of Seabrook Station because it began prior to the plant starting operation. The relative consistency of CPUE since the late preoperational period (1987) is a further indication that plant operations have not affected winter flounder CPUE in the estuary.

Annual entrainment estimates for 1990-96 ranged from a low of 0 in 1994 (8 months of sampling due to outage) to a high of 10.3 million in 1996 (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 9 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 1976-96 were from 45 to 514 million larvae (NUSCO 1996). Entrainment of winter flounder larvae at Seabrook Station from 1990 to 1994 were estimated to result in the loss of less than 4,500 equivalent adults annually (Saila et al. 1995). Entrainment of winter flounder larvae in 1996 was the highest recorded (10.6 million), and probably would result in the loss of more than 4,500 equivalent adults.

In 1996, an estimated 3,231 winter flounder were impinged at Seabrook Station (Table 5-11). This annual impingement is 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 (NOAA 1995), 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, compared to the preoperational period, is unexplained. Although beginning before plant operation in the mid-1980s, 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

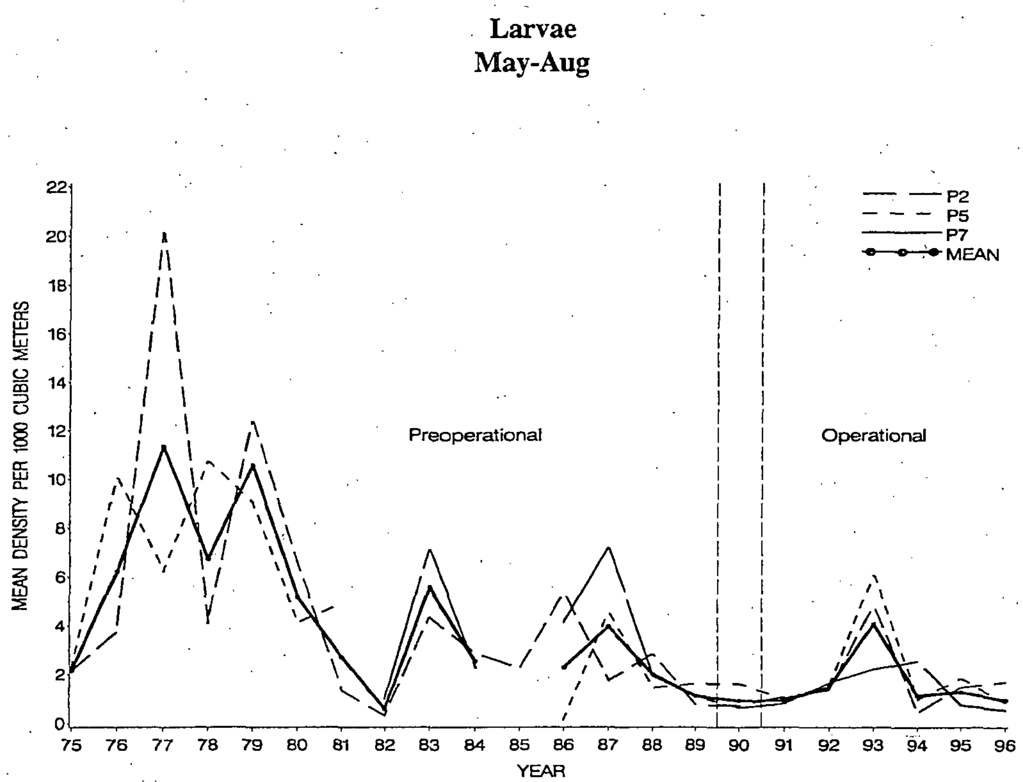
The yellowtail flounder is found from southern Labrador to Chesapeake Bay (Scott and Scott 1988), but its center of abundance is the western

Gulf of Maine and Southern New England (Bigelow and Schroeder 1953). 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 (NOAA 1995). 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 a 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 1996 was lower than the preoperational and operational means (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 not



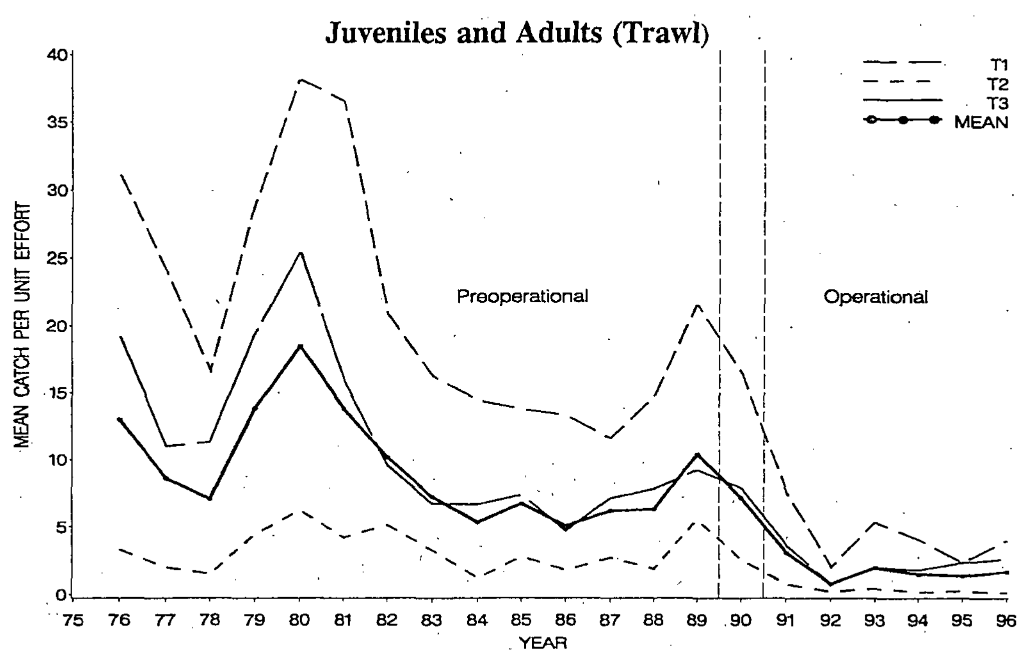


Figure 5-21. Annual geometric mean catch of yellowtail flounder per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-min tow) samples by station and the mean of all stations, 1975-1996 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

Table 5-24. **Results of Analysis of Variance forYellowtail Flounder Densities by Sampling Program. Seabrook Operational Report, 1996.**

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS OF ADJUSTED MEANS[h]
Ichthyoplankton	Preop-Op[a]	1	0.69	0.62 NS	
(May-Aug)	Year (Preop-Op)[b]	8	1.22	0.58 NS	
(1987-1996)	Month (Year)[c]	29	2.07	6.95***	
	Station[d]	2	0.20	0.94 NS	
	Preop-Op X Station[e]	2	0.22	0.65 NS	
	Station X Year (Preop-Op)[f]	16	0.34	1.13 NS	
	Error	405	0.30		
Trawl	Preop-Op[g]	1	42.72	45.09***	Op<Preop
(Nov-Jul)	Year (Preop-Op)	19	0.74	4.89***	
(1975-1996)	Month (Year)	168	0.09	1.33*	
	Station	2	15.13	43.32*	T1>T3>T2
	Preop-Op X Station	2	0.34	2.68 NS	
	Station X Year (Preop-Op)	38	0.13	1.78**	
	Error	334	0.07		

[a] Preop-Op compares 1991-1996 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 Station and Year within Preop-Op.
[g] Preop-Op compares 1990-1996 to 1975-1990.
[h] Duncan-Waller multiple means comparison test used for significant main effects. LS Means used for interaction term.

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

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 NOAA (1995). 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 has remained at low levels since then.

Catches have been consistently and significantly highest at farfield Station T1 and lowest at nearfield Station T2 throughout the 20-year period (Table 5-24); CPUE at T3 tended to approximate the overall mean (Table 5-9; Figure 5-21). This pattern of abundance may reflect habitat preferences of the yellowtail flounder in the Hampton-Seabrook study area. There were no significant differences in CPUE between the preoperational and operational periods (Table 5-24).

In 1996, four yellowtail flounder were impinged at Seabrook Station (Table 5-11). Except for 1994 and 1995, 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. The estimated entrainment in 1996 was 110.2 million eggs. 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. Entrainment of yellowtail flounder larvae in 1996 (1.6 million) was the highest recorded (Table 5-6). 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 (NOAA 1995). No significant effects resulted from the operation of Seabrook Station.

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 through 1 April 1994 of the discharge of the plant settling basin into the Browns River within the Hampton-Seabrook estuary.

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

Table 5-25. **Summary of Potential Effects of the Operation of Seabrook Station on the Ichthyoplankton Assemblages and Selected Fish Taxa. Seabrook Operational Report, 1996.**

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		
	gill net	Op<Preop	yes	increasing	underexploited
Rainbow smelt	trawl	--	no	unknown	lightly to
	seine	Op=Preop	yes		unexploited
Atlantic cod	ichthyoplankton	Op=Preop	yes		
	trawl	Op<Preop	yes	decreasing	overexploited
Pollock	ichthyoplankton	Op<Preop	yes		
	gill net	Op=Preop	yes	stable	fully exploited
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	--	no	decreasing in 1980s now stable (?)	unexploited
Atlantic mackerel	ichthyoplankton	Op=Preop	yes		
	gill net	Op=Preop	yes	increasing	underexploited
Winter flounder	ichthyoplankton	Op=Preop	yes		
	trawl	--	no	decreasing	overexploited
	seine	Op<Preop	yes		
Yellowtail flounder	ichthyoplankton	Op=Preop	yes		
	trawl	Op<Preop	yes	decreasing	overexploited

[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 NOAA (1995).

Station began operation. Several of the decreases seen in the Hampton-Seabrook area simply reflect long-term declining trends of commercial fishes, such as Atlantic cod, winter flounder, yellowtail flounder, and hakes. 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 (NOAA 1995). Regional abundance of both red and white hakes is now increasing, but trawl survey indices reported by NOAA (1995) show erratic changes, likely due to varying year-class strength from year to year. The six-year operational time series in some cases may not be sufficient to differentiate fluctuations in year-class strength from longer-term changes in abundance.

Few pelagic fishes showed significant differences between the preoperational and operational periods. Pelagic fishes in the Gulf of Maine 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 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 (NOAA 1995). For the past five years, abundance of the Atlantic mackerel has generally increased near Seabrook Station, as it has throughout the northwest Atlantic (NOAA 1995). Pollock abundance near Seabrook Station has been variable in recent years. The most recent NOAA evaluation (1995) considered the pollock stock in the Gulf of Maine to be fully exploited and the spawning stock biomass had increased slightly since 1991 (NOAA 1995).

Among the estuarine fish community there were no significant differences in CPUE between the preoperational and operational periods for rainbow smelt and Atlantic silverside. These small, short-lived species appeared to exhibit variable and, perhaps, periodic patterns of annual abundance. It is unlikely that the discharge of Seabrook Station would have significantly affected rainbow smelt or Atlantic silverside given their early life history in estuaries distant from the cooling water discharge and intake. The settling basin discharge into the Browns River no longer presents a potential impact, as this discharge was re-routed through the circulating water system in April 1994.

The ANOVA interaction term was significant only for rainbow smelt and winter flounder in trawl samples, and larval American sand lance, suggesting further investigation into a potential effect of Seabrook Station operation (Table 5-25). Winter flounder abundance at nearfield Station T2 was higher than the farfield Stations T1 and

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.

Abundance of rainbow smelt in trawl samples decreased between the preoperational and operational periods at all stations, but the decrease was greatest at Station T2. The decrease at Station T2 began in 1989 before Seabrook Station became operational. Large changes in CPUE of rainbow smelt at Station T2 appeared to reflect the population dynamics of this species in the study area, because large decreases occurred during the preoperational period. There are no apparent reasons why the plant should affect 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. It is unlikely that the discharge from the settling basin to the Browns River affected rainbow smelt abundance because it ceased in April 1994. Most rainbow smelt have been impinged primarily in November (Table 5-11). An estimated 5,247 rainbow smelt were impinged at Seabrook Station since 1994, with most (4,489) in 1996 (Appendix Table 5-3). The increase in 1996 was due to a few high impingement events in November that were related to storm events (Table 5-11).

Although the interaction term was significant for larval American sand lance, there is little evidence to suggest this was due to plant operation. There were no significant differences between the preoperational and operational periods at the intake and discharge stations, but density increased at the farfield station. Despite the differing trends among stations, annual mean densities tracked each other closely from year to year since 1987. This consistency among stations is not indicative of a plant impact.

Compared to other New England marine power plants, Seabrook Station entrains relatively few fish eggs or larvae and apparently impinges fewer 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.

Predictions of the annual amount of fish eggs and larvae that could potentially be entrained into the cooling water system of Seabrook Station were made for rainbow smelt, winter flounder, Atlantic menhaden, pollock and Atlantic mackerel (NAI 1977). These fishes were identified as Representative Important Species (RIS) by EPA Region I in the late 1970s, based on their commercial and recreational importance. Predictions of entrainment were developed from densities of ichthyoplankton observed in 1973 through 1976 and a pumping rate for one unit operating at 100% theoretical capacity. These worst case entrainment estimates of eggs and larvae were much higher than the actual entrainment from 1990 through 1996 (Table 5-26).

The predicted entrainment was much higher than actual entrainment because the predictions were worst case, based on the highest single monthly

Table 5-26. Actual and Predicted Entrainment of Selected Fish Eggs and Larvae at Seabrook Station, and a Comparison of Peak Densities in 1973-1976 with the Operational Period (1991-1996). Seabrook Operational Report, 1996.

		NUMBER ENTRAINED (x 10^6)								
LIFE STAGE	SPECIES	1991	1992	1993	1994	1995	1996	PREDICTED	PEAK DENSITY (no/1000 m^3) 1973-1976	MEAN DENSITY (no./1000m^3) 1991-1996
EGGS	Atlantic menhaden	0.5	1.4	0.1	0.0	0.2	0.1	133	1,900	13
	Pollock	1.0	0.4	0.2	0.1	0.4	0.4	133	780	4
	Atlantic mackerel	673.1	456.3	112.9	0.0	74.5	305.1	2,655	37,600	13,100
LARVAE	Rainbow smelt	0.0	0.1	0.0	0.0	0.0	0.0	5.5	60	0.5
	Winter flounder	9.0	6.2	2.9	0.0	8.0	10.3	79.0	610	74.1
	Atlantic menhaden	0.0	0.0	0.0	0.0	0.0	0.0	165.5	2,170	0.2
	Pollock	0.0	0.1	0.0	0.0	0.0	0.0	62.0	500	4.3
	Atlantic mackerel	4.7	0.0	0.0	0.0	0.0	0.1	1,130	15,500	209.5

densities in ichthyoplankton samples observed between 1973 and 1976, which were higher than average densities during the operational period. Use of the highest monthly densities resulted in a worst-case estimate of entrainment because it assumed that the highest observed densities will be present for the entire larval season. Further, densities in ichthyoplankton samples tended to be higher than those found in entrainment samples because the entire range of the water column was sampled. Larvae that orient to either the surface or bottom will likely occur in lower densities in entrainment samples drawn from the middle of the water column. Finally, the predicted entrainment estimate assumed that the plant would be operating at 100% capacity all the time. There were periodic outages during the operational period, along with minor fluctuations in pumping rates that resulted in average annual daily flows that were slightly less than the maximum flow of 2.33 x 10^6 m^3 for one unit used in the predictions (see Table 1-2).

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 nearfield 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.

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Appendix Table 5-1. Finfish Species Composition by Life Stage and Gear, July 1975 - December 1996. Seabrook Operational Report, 1996.

SCIENTIFIC NAME	COMMON NAME	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 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
Microgadus tomcod	Atlantic tomcod		R	R		O

(continued)

Appendix Table 5-1. (Continued)

SCIENTIFIC NAME	COMMON NAME	ICHTHYOPLANKTON TOWS		ADULT AND JUVENILE FINFISH		
		EGGS	LARVAE	TRAWLS	GILL NETS	SEINES
Morone americana	white perch					R
Morone saxatilis	striped bass				R	R
Mugil cephalus	striped mullet					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	–	O		R	
Tautogolabrus adspersus	cunner	–	A		O	R
Torpedo nobiliana	Atlantic torpedo			R		
Triglops murrayi	moustache sculpin		O	R		
Ulvaria subbifurcata	radiated shanny		C	O		
Urophycis sp.[i]	hake	C	C	A	O	C

(continued)

Appendix Table 5-1. (Continued)

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. Subsetting Criteria Used in Analyses of Variance for the Selected Finfish Species. Seabrook Operation Report, 1996.

SPECIES	GEAR	SEASON	PREOPERATIONAL	OPERATIONAL	POOLING	DELETIONS
Atlantic cod	Trawl	Nov-Jul	1975-1990	1990-1995	Nov-Dec with following year	Nov-Dec 1995
Atlantic cod	Ichthyo	Apr-Jul	1987-1990	1991-1995	None	None
Atlantic herring	Gill net	Sep-May	1976-1990	1990-1995	Sep-Dec with following year	Sep-Dec 1995
Atlantic herring	Ichthyo	Oct-Dec	1986-1989	1990-1995	None	None
Atlantic silverside	Seine	Apr-Nov	1976-1984; 1986-1989	1991-1995	None	1990
Atlantic mackerel	Gill net	Jun-Nov	1976-1989	1991-1995	None	1990
Atlantic mackerel	Ichthyo	May-Aug	1987-1990	1991-1995	None	Aug 1990
Atlantic sand lance	Ichthyo	Jan-Apr	1987-1990	1991-1995	None	None
Cunner	Ichthyo	Jun-Sep	1987-1989	1991-1995	None	1990
Hakes	Trawl	Nov-Jul	1976-1990	1990-1995	Nov-Dec with following year	Nov-Dec 1995
Hakes	Ichthyo	Jul-Sep	1986-1989	1991-1995	None	1990
Pollock	Gill net	Apr-Dec	1976-1989	1991-1995	None	1990
Pollock	Ichthyo	Nov-Feb	1986-1989	1990-1994	Jan-Feb with previous year	1995
Rainbow smelt	Trawl	Nov-May	1975-1990	1990-1995	Nov-Dec with following year	Nov-Dec 1995
Rainbow smelt	Seine	Apr-Nov	1976-1984;1986-1989	1991-1995	None	1990
Winter flounder	Trawl	Nov-Jul	1975-1990	1990-1995	Nov-Dec with following year	Nov-Dec 1995
Winter flounder	Seine	Apr-Nov	1976-1984; 1986-1989	1991-1995	None	1990
Winter flounder	Ichthyo	Apr-Jul	1987-1990	1991-1995	None	None
Yellowtail flounder	Trawl	Nov-Jul	1975-1995	1990-1995	Nov-Dec with following year	Nov-Dec 1995
Yellowtail flounder	Ichthyo	May-Aug	1987-1990	1991-1995	None	Aug 1990

Appendix Table 5-3. Species Composition, Annual Totals, and Three-year Total of Finfish, and American LobsterImpinged at Seabrook Station From 1994 to 1996. Seabrook Operational Report, 1996[a].

SPECIES	1994	1995	1996	TOTAL
Alewife	0	8	1753	1761
American lobster	31	16	31	78
American shad	0	0	20	20
American sand lance	1215	1324	823	3362
American eel	0	5	6	11
Atlantic menhaden	0	7	97	104
Atlantic torpedo	0	1	5	6
Atlantic silverside	5348	1621	1119	8088
Atlantic tomcod	1	0	0	1
Atlantic wolffish	0	2	13	15
Atlantic cod	58	119	94	274
Atlantic mackerel	0	0	1	1
Atlantic herring	0	0	485	485
Atlantic moonfish	0	3	0	3
Black sea bass	0	3	0	3
Blueback herring	13	0	111	124
Butterfish	3	14	3	20
Cunner	32	342	1121	1495
Cusk	0	0	19	19
Flounders	77	0	0	77
Fourbeard rockling	0	6	0	6
Fourspot flounder	2	1	2	5
Goosefish	3	13	0	16
Grubby	2678	2415	1457	6550
Haddock	0	1	397	398
Hakes	2822	2188	156	5166
Herrings	514	231	72	817
Killifishes	4	0	0	4
Lefteye flounder	0	0	2	2
Longhorn sculpin	105	165	84	354
Lumpfish	182	190	51	423
Mummichog	0	0	47	47
Northern kingfish	0	0	2	2

(continued)

Appendix Table 5-3. (Continued)

SPECIES	1994	1995	1996	TOTAL
Northern pipefish	188	579	1200	1967
Ocean pout	0	6	1	7
Planehead filefish	0	15	0	15
Pollock	1681	899	1835	4415
Radiated shanny	0	92	40	132
Rainbow smelt	545	213	4489	5247
Red hake	1	16	1478	1495
Righteye flounder	0	3	4	7
Rock gunnel	494	1298	1122	2914
Sand tiger	0	0	57	57
Sculpins	205	0	0	205
Scup	0	14	9	23
Sea raven	78	125	1015	1218
Sea lamprey	0	0	1	1
Shorthorn sculpin	14	156	282	452
Silver hake	0	49	58	107
Skates	190	157	225	572
Snailfishes	180	165	1013	1358
Spiny dogfish	1	0	6	7
Striped bass	0	4	1	5
Summer flounder	3	0	0	3
Tautog	0	0	34	34
Threespine stickleback	67	155	320	542
Unidentified	6	40	88	134
White hake	1	7	967	975
White perch	0	0	4	4
Windowpane	980	943	1164	3087
Winter flounder	1435	1171	3231	5837
Wrymouth	55	9	206	270
Yellowtail flounder	0	1149	4	1153
TOTAL	19,212	15,926	26,825	61,963

[a]Impingement data prior to October 1994 was underestimated.

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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. 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 few changes 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 vesiculosus* declined significantly in the same zone. Long-term trends in annual mean percent frequency of occurrence of each of these fucoid species indicates that these changes are not likely related to Station operation. Only one intertidal faunal species, *Ampithoe rubricata*, exhibited a shift in abundance between periods that was inconsistent between nearfield and farfield stations. Densities in the farfield area increased significantly, while they remained stable in the nearfield area. Long-term trends show that the extinction-recolonization cycle that accounts for this shift began well before the start of Station operation. In the shallow subtidal zone, only the kelp *Laminaria digitata,* a minor component of this community, exhibited a change in density between periods that differed between the nearfield and farfield stations. Densities declined significantly in the nearfield area, while they remained stable in the farfield area. At present there is no clear causative factor, either natural or induced by Station operation, that accounts for this decline.

Impacts associated with increased turbidity, such as shifts in community dominance to species more 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 generally revealed a consistency in both the algal and faunal communities, in both the nearfield and farfield areas and between periods. This reflects the more stable natural environment characteristic of deeper benthic habitats. However, a minor difference in the mid-depth faunal community analysis was observed. The community observed in collections from the mid-depth intake and farfield areas in 1996 was unique, whereas this community is typically more similar to a community formed from collections

from the intake, farfield, and discharge areas. Since this minor change occurred simultaneously in the nearfield and farfield areas, it does not likely reflect a station impact. The only change of note in the mid-depth algal community was the continued decline of *Laminaria digitata* densities in the nearfield area. The cause of this decline remains unclear, although the role of grazing by the green sea urchin *Strongylocentrotus droebachiensis* was examined, and found to be statistically significant in the farfield area. *L. digitata* is likely at its physiological limit with respect to water depth at the nearfield station, and was never a dominant part of the kelp assemblage in preoperational years. Its continued decline is likely the result of a combination of physical and biological factors that are currently not fully understood, but that are not likely related to Station operation since the Station has had no measurable effect on local water temperatures, nor have any other plant or animal species exhibited a similar response that might reflect impacts from increased turbidity levels.

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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 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 increases 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 these 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 are 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 are 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

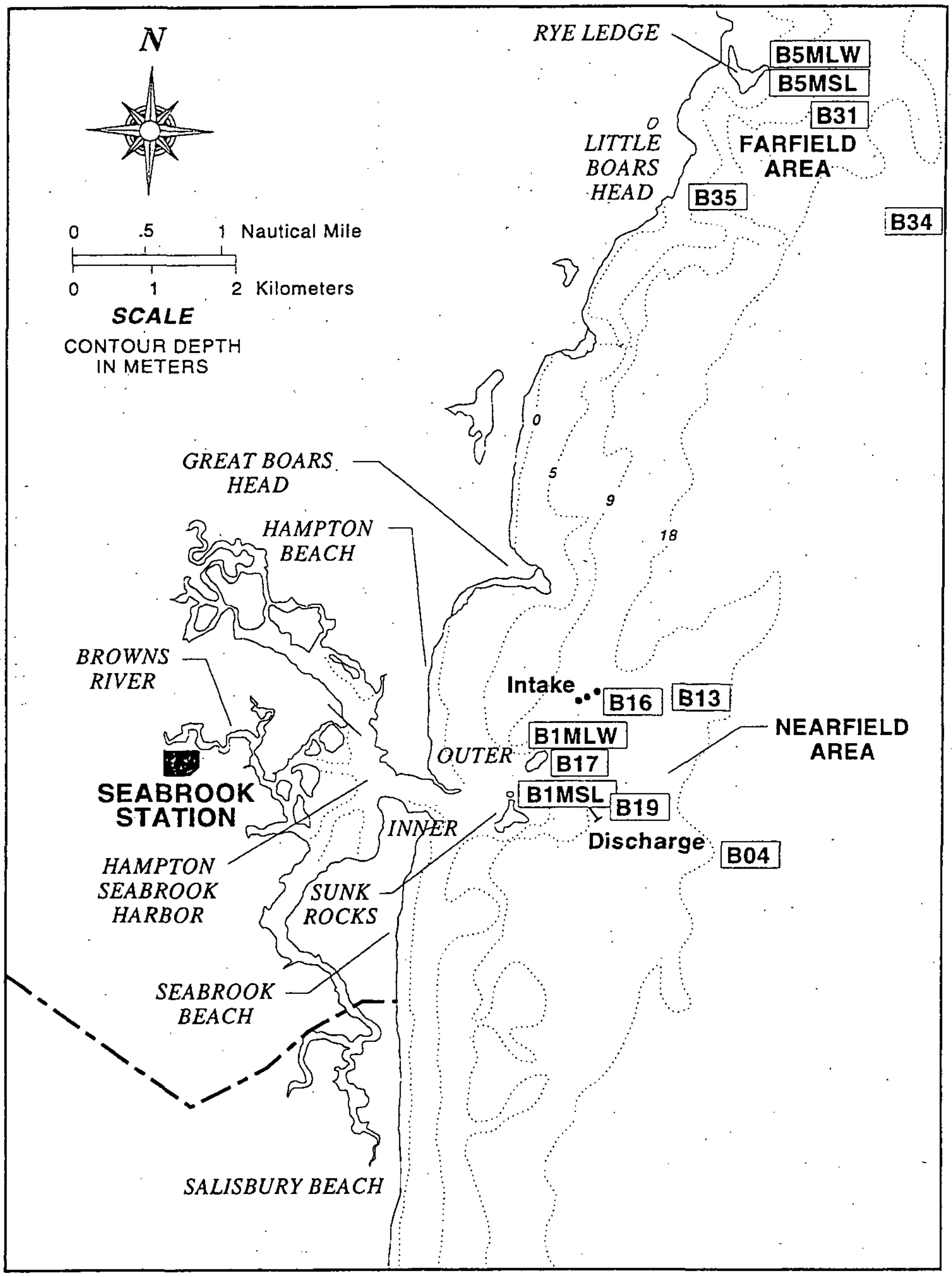
Quantitative (destructive) macrofaunal and macroalgal samples were collected three times annually (May, August, November) at six benthic stations (Fig. 6-1); three nearfield-farfield station pairs were established at lower intertidal (approximate mean low water: B1MLW, B5MLW), shallow subtidal (4-5 m; 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 five nearfield stations (B1, B04, B13, B17, and B19) and one farfield station (B31). Nearfield station B16 was added to the study in 1980. Subsequently, three farfield stations were added, one in 1979 (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 intertidal stations that encompass the low to high tide levels (referred to as 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: the bare rock zone (approximate mean high water or upper intertidal), the predominantly fucoid-covered zone (mean sea level or mid-intertidal), and the *Chondrus crispus*-covered zone (approximate mean low water or lower intertidal). Percent cover of fucoid algae and percent frequency of occurrence of several intertidal species were estimated and recorded according to an established species list. This list includes several perennial and annual algal species, gastropods (*Acmaea testudinalis, Littorina* spp. and *Nucella lapillus*), barnacles 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/Coccotylus* spp.



LEGEND

☐ = benthic samples

Figure 6-1. Marine benthic sampling stations. Seabrook Operational Report, 1996.

and *Ptilota serrata*). Counts of *Modiolus modiolus*, *Strongylocentotus droebachiensis* and the kelp species *Laminaria digitata, L. saccharina*, *Agarum clathratum* 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.

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 algal complex *Phyllophora/Coccotylus* (formerly *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 *Nucella lapillus* and *Ampithoe rubricata* (B1MLW/B5MLW); *Cancer irroratus, C. borealis, Jassa marmorata*, and Asteriidae (B17/B35); *Pontogeneia inermis* and *Strongylocentrotus droebachiensis* (B19/B31, B17/B35); and Mytilidae (B1MLW/B5MLW, B17/B35, B19/B31).

A subsample of individuals of the above referenced taxa collected at each station in May, August and November was measured to the nearest 0.1 mm and enumerated. For all amphipods measured, 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 Destructive Monitoring Program: Community Analyses

Macroalgal and macrofaunal community analyses included numerical classification and analysis of variance (ANOVA; detailed below) of community parameters such as number of taxa and total abundance or biomass from triannual or August-only samples (Table 6-1). Operational/preoperational and nearfield/farfield differences in total abundance or biomass and number of taxa were evaluated using a multi-way analysis of variance procedure (ANOVA, SAS Institute Inc. 1985). A mixed effects ANOVA model 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. The data collected for the ANOVAs met the criteria of a Before-After/Control-Impact (BACI) sampling design as discussed by Stewart-Oaten et al. (1986), where sampling was conducted prior to and during plant operation, and sampling 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 (in some cases) months within year (Month (Year)), which were added to reduce the unexplained variance, and thus, increase 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. An additional term, the interaction of Station and Year within Preop-Op (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 preoperational period for each analysis was specified as the period during which at least one nearfield and one farfield station were sampled concurrently (thus maintaining a balanced model design). Preoperational periods for each analysis are listed on the appropriate figures and tables. The Waller-Duncan or Scheffe's multiple comparison test was used to rank the levels of the main effects (Preop-Op, Station) when they were significantly different. The LS Means procedure was used to rank the levels of the interaction term (Preop-Op X Station) when it was significant.

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 monthly square-root transformed average biomass (macroalgae). Macroalgal species with less than 2% frequency of occurrence and macrofaunal species with less than 6% frequency of occurrence were excluded from the analysis. In all, 35 algal and 94 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 <u>Destructive Monitoring Program: Selected Species Analyses</u>

Some algal and faunal taxa were selected for more detailed analyses due to their ecological or economic importance in the study area. ANOVAs were used to evaluate temporal and spatial differences in algal biomass or faunal abundances obtained from the destructive monitoring program.

Table 6-1. Selected Benthic Taxa and Parameters Used in ANOVA and Wilcoxon's Summed Ranks Tests. Seabrook Operational Report, 1996.

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*, and *Agarum clathratum*	B17 B35 B19, B31	1979-1989, 1991-1996 1982-1989, 1991-1996 1978-1989, 1991-1996	Mean number per sample period and station.	Preop-Op,[c] Station, Year, Month
	Chondrus crispus and *Phyllophora/Coccotylus*	B17, B19, B31 B35	1981-1989, 1991-1996 1982-1989, 1991-1996	Mean % frequency per year. Mean % frequency per year, no transformation.	Preop-Op, Station, Year, Month
	Ptilota serrata	B17, B35 B19, B31	1982-1989, 1991-1996 1981-1989, 1991-1996	Mean % frequency per year. Mean % frequency per year.	Preop-Op (Wilcoxon's) Preop-Op, Station, Year, Month
	Chondrus crispus	B1MLW, B5MLW B17, B35	1982-1989, 1991-1996 1982-1989, 1991-1996	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 - 1996 1982 - 1996 1980 - 1984, 1986 - 1996 1979 - 1984, 1986 - 1996	Amount or number per station, year and replicate; no transformation.	Preop-Op, Station, Year, Month
	Ascophyllum nodosum, *Fucus vesiculosus*, *Fucus distichus* spp. *edentatus*, *Fucus distichus* spp. *distichus*; and *Fucus* sp.	B1MSL, B5MSL	1983-1989, 1991-1996	Mean % frequency per sample period and year.	Preop-Op, Station, Year, Month

(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,* and Mytilidae spat	B1MLW, B5MLW	1978-1989, 1991-1996 1982-1989, 1991-1996	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Jassa marmorata[d] and Mytilidae spat	B17, B35	1978-1989, 1991-1996 1982-1989, 1991-1996	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Asteriidae	B17, B35	1981-1989, 1991-1996 1982-1989, 1991-1996	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Pontogeneia inermis[d], and Mytilidae spat	B19, B31	1978-1989, 1991-1996	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Strongylocentrotus droebachiensis	B19, B31	1985-1989, 1991-1996	"	Preop-Op, Station, Year, Month
	Strongylocentrotus droebachiensis	B17, B35	1985-1989, 1991-1996	"	Preop-Op, Station (Wilcoxon's)
	Total density Number of Taxa	B1MLW, B5MLW; B17, B35; B1; B19, B31; B16, B19, B31; B04, B34, B13	1982 - 1996 1982 - 1996 1980 - 1984, 1986 - 1996 1979 - 1984, 1986 - 1996	Amount or number per year, station and replicate; no transformation for number of taxa.	Preop-Op, Station, Year
	Modiolus modiolus	B19, B31	1980 - 1989, 1991 - 1996	Ranked densities; mean per sample period, no tranformation.	Preop-Op, Station, Year, Month

[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.

6.2.3.3 Non-Destructive Monitoring Program: Selected Species Analyses

Comparisons between preoperational and operational periods were made by means of ANOVA for several subtidal species (kelps and understory algae and associated fauna species) and for several intertidal species (fucoids and associated fauna species). Wilcoxon's summed ranks test (Sokal and Rohlf 1969) was used to examine the differences between periods and between stations for *Ptilota serrota* and *Strongylocentrotus droebachiensis* in the shallow subtidal zone where the ANOVA models were not significant. ANOVA models were used to examine the interaction between period and station for algal species and *Strongylocentrotus droebachiensis* densities (from the subtidal transect program) only, and were structured similarly to those run on collections from the destructive monitoring program. Data transformations were performed prior to running ANOVA models to ensure that assumptions of normality were met. The log (x+1) transformation achieved normality in most cases where untransformed data were non-normal. In the few cases where transformation did not provide an adequate approximation of normality (typically due to multiple zero values in the data set), ANOVA models were not run.

Additional analyses addressing declines in the kelp species *Laminaria digitata*, and the potential role in this decline played by the sea urchin *Strongylocentrotus droebachiensis*, were conducted using data from the subtidal transect program. The relationship between the densities of these two species was examined using a functional regression model (Type II Model) as presented by Ricker (1973). The use of a Type II model instead of a Type I model is justified in this situation since both the independent variable (sea urchin density) and the dependent variable (*L. digitata* density) are subject to natural variability, unlike a laboratory experiment where, at least in theory, the dependent variable is controlled by the researcher (Laws and Archie 1981). The functional regressions conducted used log (x+1) densities collected in 1985 through 1996, excluding 1990.

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; NUSCO 1994). To assess algal community diversity at Seabrook study sites, the number of algal taxa was determined in two ways. Numbers of unique taxa from general collections were used to qualitatively characterize the overall floristic composition at a given study site. The term "unique taxa" includes only those taxa identified to the lowest practicable level. That is, when a taxon that was identified to detailed level (e.g., genus or species level) co-occurred with a higher level taxon (e.g., family level) of which the lower level taxon was also a member, the higher level was excluded from the species count. 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. A total of 146 taxa have been collected from the two programs during the 19-year study (Appendix Table 6-3);

three of these taxa were collected for the first time in 1996: *Chorda tomentosa, Dictyosiphon foeniculaceus,* and *Polysiphonia elongata.*

In 1996, the percent composition of Chlorophyta (18%), Phaeophyta (32%) and Rhodophyta (50%) was similar to the percent composition over all years combined (Chlorophyta: 20%; Phaeophyta: 26%; Rhodophyta: 55%). There was no apparent difference in average percent composition of each group between preoperational (1978-1989) and operational (1991-1996) periods.

During the 1996 sampling year, 93 taxa were collected over all stations (Appendix Table 6-3); the previous operational high of 91 occurred in 1995. The 1996 total ranks third highest over all years studied, with 95 and 96 taxa having been collected in 1983 and 1984, respectively (Appendix Table 6-3). More taxa in the major groups Phaeophyta (29 taxa) and Rhodophyta (47 taxa) were collected in 1996 than in any year in the operational period. Compared to the entire 19-year study period, relatively more phaeophycean taxa and relatively fewer chlorophycean and rhodophycean taxa were collected in 1996.

In general, the assemblage of macroalgal taxa collected over the years at Seabrook sites was very consistent with other New Hampshire studies (Mathieson and Hehre 1986). The floristic affinity ratio (Rhodophyta plus Chlorophyta, divided by Phaeophyta; Cheney 1977 cited in Mathieson et al. 1991) for the preoperational period was 3.0, reflecting an assemblage of plants intermediate between cold-temperate and warm-temperate affinities, while the ratio for the operational period (excluding 1990) was slightly lower, at 2.8, indicating a more cold-temperate assemblage. The ratio for 1996 was 2.2, continuing the trend towards a cold-temperate assemblage.

The numbers of taxa collected in 1996 at each station were within preoperational ranges at all locations except at B31, where the 1996 totals were slightly higher, and at B34 and B1MLW where 1996 totals were slightly lower (Figure 6-2). The 1996 totals at all stations were also comparable to or slightly higher than most other operational years, except at B1MSL and B5MSL, where 1996 totals were the lowest of the period. Patterns of number of taxa collected within and among depth zones were consistent between the preoperational and operational periods. Over all zones, median preoperational total numbers of taxa collected were highest in the lower intertidal (MLW) and shallow subtidal zones, and generally lowest in the deep subtidal zone.

Operational median totals followed the same pattern as preoperational median totals. During the preoperational period, median farfield total numbers of taxa were higher than nearfield totals in the lower intertidal, shallow subtidal, and mid-depth subtidal zones. Median nearfield totals were higher than farfield totals in the mid-intertidal zone and the deep subtidal zone. In 1996 there was only one deviation from this pattern. More taxa were collected from the nearfield shallow subtidal station (40 at B17) than at the farfield station (39 at B35).

<u>Number of Taxa: Quantitative Samples</u>

Quantitative results from the destructive sampling program supported the results from general collections. Mean numbers of taxa collected at farfield intertidal station (B5MLW) were higher than means from nearfield station (B1MLW) during preoperational and operational years and

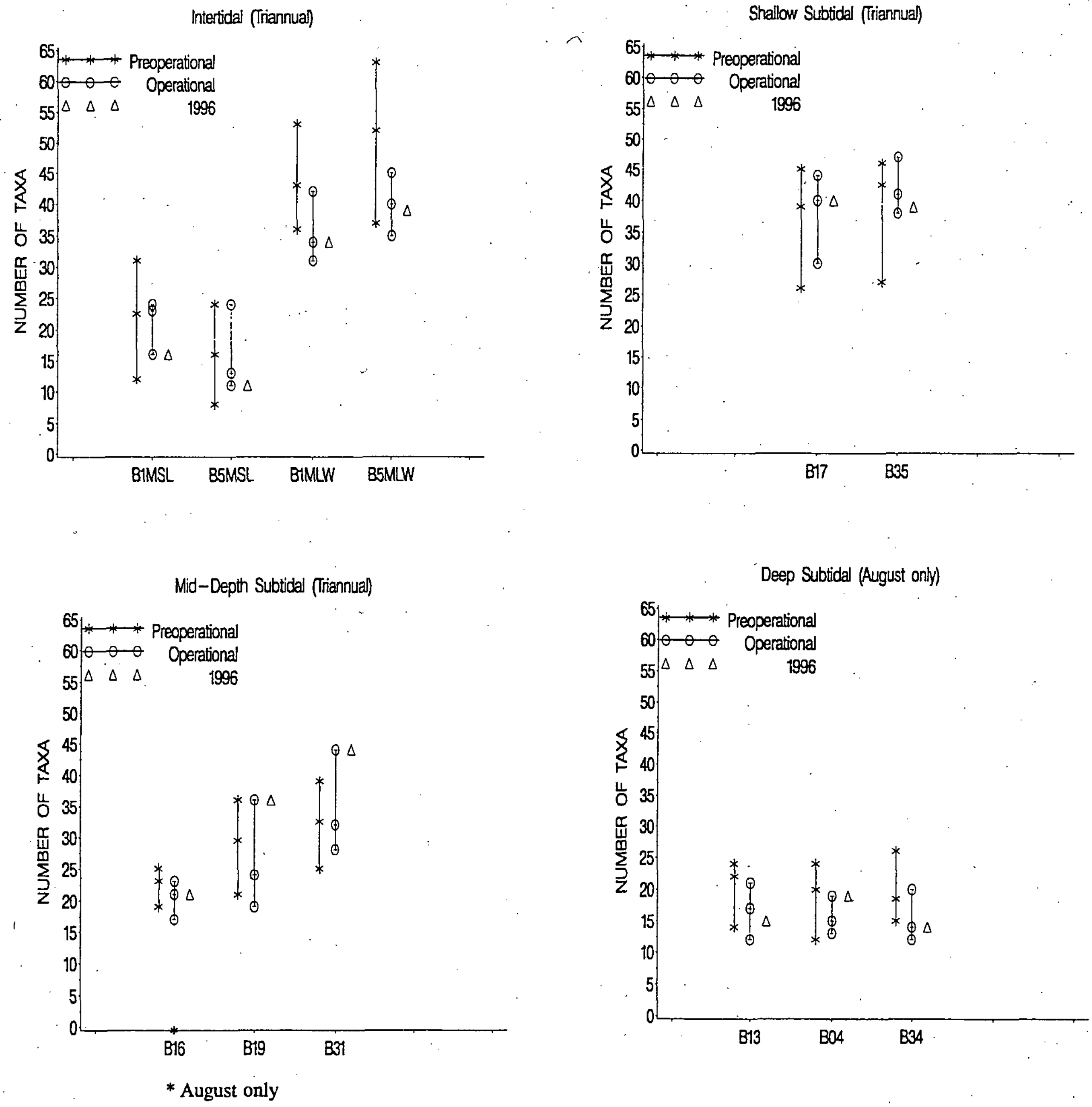


Figure 6-2. Median number and range of unique macroalgal taxa collected in the intertidal and subtidal zones during the preoperational and operational periods (calculated from annual totals) and the 1996 total number of unique taxa. Seabrook Operational Report, 1996.

in 1996 (Table 6-2). Numbers of taxa collected over both stations declined between periods (Table 6-2), but to a slightly greater extent at B5MLW compared to B1MLW, as indicated by a significant Preop-Op X Station interaction term (Table 6-3; Figure 6-3). Differences in annual means between the two stations are subtle, and trends in annual means have tracked one another closely over time (Figure 6-3). The consistency of this trend is not indicative of a station impact.

Numbers of taxa collected in the shallow subtidal zone in 1996 were higher than the preoperational means for both nearfield (B17) and farfield (B35) stations (Table 6-2). The number of taxa found in 1996 at B17 was greater than the operational mean while the number of taxa at B35 was slightly lower than the operational mean. ANOVA results indicate that there were no significant differences in number of taxa between the preoperational and operational periods, or between stations (Table 6-3). The relationship between stations was consistent between the preoperational and operational periods as indicated by the non-significant interaction term (Table 6-3).

At each mid-depth subtidal station in 1996, the number of taxa was higher than both the preoperational and operational means (Table 6-2). ANOVA results indicated that there were no significant differences in number of taxa between the preoperational and operational periods, or among stations (Table 6-3). The relationship among stations was consistent between the preoperational and operational periods as indicated by the non-significant interaction term (Table 6-3).

At each station in 1996, the number of taxa collected in the deep subtidal zone was higher than both the preoperational and operational means (Table 6-2). ANOVA results indicated that there were no significant differences between the preoperational and operational periods, or among stations (Table 6-3). The relationship among stations was consistent between the preoperational and operational periods as indicated by the non-significant interaction term (Table 6-3).

<u>Total Biomass</u>

Biomass generally decreased with increasing depth, similar to patterns observed in the number of taxa collected (Table 6-2). At the two intertidal stations (B1MLW and B5MLW), the mean biomass in 1996 was higher than both preoperational and operational means (Table 6-2). There were no significant differences between stations or periods in mean total biomass, as indicated by the non-significant interaction term in the ANOVA model (Table 6-3).

Mean biomass in 1996 at shallow subtidal Station B17 was slightly lower than the preoperational and operational means, while in 1996 mean biomass at Station B35 was substantially lower (Table 6-2). There were no significant differences between stations or periods in mean total biomass in the shallow subtidal zone (Table 6-3). Because of this consistency, the interaction term in the ANOVA model was not significant.

In 1996, mean biomass was lower than during both the preoperational and operational periods at mid-depth Stations B19 and B16, and lower than the preoperational mean at Station B31 (Table 6-2). Throughout the study, mean total biomass has been significantly higher at the intake station (B16) and lowest at the discharge station (B19), with the

Table 6-2. Arithmetic Means and Coefficients of Variation (CV,%) for Number of Algal Taxa and Total Algal Biomass at Various Depths and Stations During 1996 and During the Preoperational and Operational Periods. Seabrook Operational Report, 1996.

PARAMETER	DEPTH ZONE	STATION	PREOPERATIONAL[a] PERIOD MEAN	PREOPERATIONAL[a] PERIOD CV	1996 MEAN	OPERATIONAL PERIOD MEAN	OPERATIONAL PERIOD CV
Number of taxa (no. per 0.0625 m^2)	Intertidal[b]	B1MLW	15.6	15.8	15.6	15.3	13.6
		B5MLW	22.2	13.6	17.2	19.5	10.6
	Shallow subtidal[b]	B17	14.2	13.0	17.2	15.8	8.0
		B35	18.1	18.1	18.6	19.0	17.3
	Mid-depth[c]	B16	9.0	8.3	10.6	9.9	14.9
		B19	10.2	13.0	11.0	9.7	14.4
		B31	11.1	12.4	16.2	12.2	23.3
	Deep[d]	B04	7.6	10.2	9.8	8.2	13.2
		B13	7.9	8.9	8.8	8.4	14.2
		B34	7.7	7.9	8.0	7.9	14.6
Total biomass (g/m^2)	Intertidal[b]	B1MLW	1042.7	23.7	1162.0	1026.3	12.0
		B5MLW	1034.9	22.9	1062.8	1023.5	7.3
	Shallow subtidal[b]	B17	916.3	13.2	912.2	921.3	10.5
		B35	891.4	15.7	788.3	852.1	19.5
	Mid-depth[c]	B16	779.8	28.1	576.4	615.1	20.7
		B19	308.6	25.8	156.7	298.5	39.0
		B31	471.2	27.5	435.3	389.0	16.7
	Deep[d]	B04	99.6	30.1	85.3	90.2	18.4
		B13	96.0	32.1	82.5	88.0	49.6
		B34	71.3	71.3	30.5	47.1	54.0

[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]Sampled destructively in May, August and November; operational period = 1991-1996.
[c]Station B16 sampled in August only, so means for each station in this depth zone are August-only; operational period = 1990-1996.
[d]All stations sampled in August only; operational period 1990-1996.

Table 6-3. Analysis of Variance Results for Number of Macroalgal Taxa (per 0.0625 m^2) and Total Macroalgal Biomass (g per m^2) Collected in Destructive Samples at Intertidal, Shallow Subtidal, Mid-Depth Subtidal, and Deep Stations During Preoperational and Operational Years. Seabrook Operational Report, 1996.

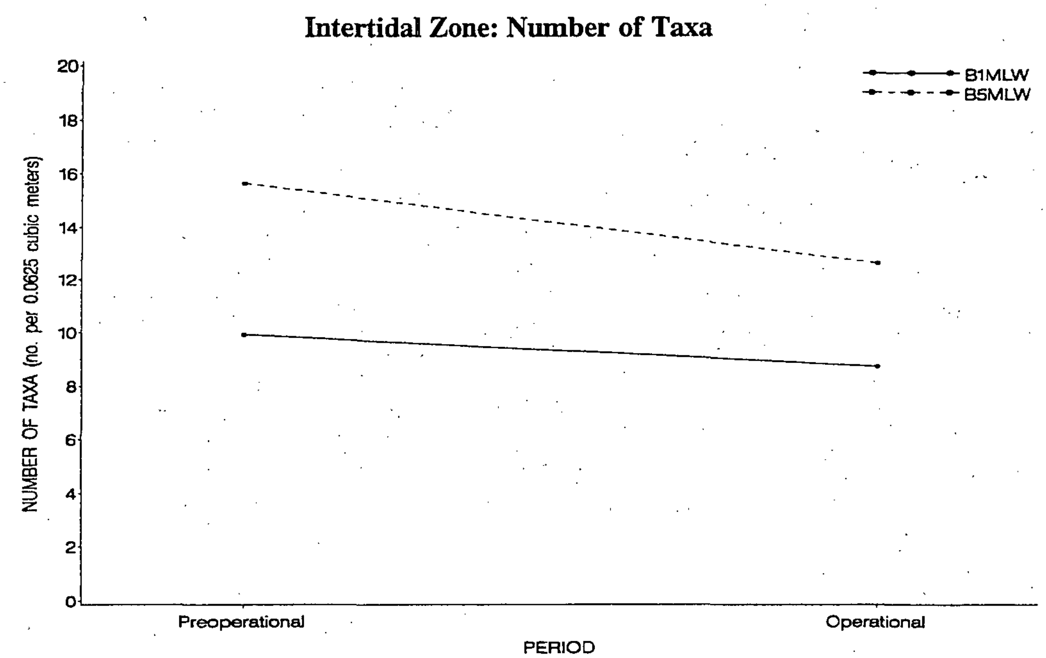
PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Number of Taxa	Intertidal[a]	Preop-Op[c]	1	400.00	3.37 NS	
	(B1MLW,B5MLW)	Station[d]	1	2162.97	28.15 NS	
		Year (Preop-Op)[e]	12	51.29	1.06 NS	
		Month (Year)[f]	28	47.86	6.47***	
		Preop-Op X Station[g]	1	76.75	9.09*	B5Pre > B5Op > B1Pre > B1Op
		Station X Year (Preop-Op)[h]	12	8.44	1.14 NS	
		Error	324	7.40		
	Shallow Subtidal[a]	Preop-Op	1	6.40	0.21 NS	
	(B17,B35)	Station	1	537.00	154.65 NS	
		Year (Preop-Op)	12	41.07	1.30 NS	
		Month (Year)	28	22.70	5.02***	
		Preop-Op X Station	1	3.52	0.25 NS	
		Station X Year (Preop-Op)	12	13.89	3.07***	
		Error	324	4.52		
	Mid-depth[b]	Preop-Op	1	12.52	0.36 NS	
	(B16,B19,B31)	Station	2	102.66	6.42 NS	
		Year (Preop-Op)	14	25.48	4.02***	
		Preop-Op X Station	2	15.95	2.52 NS	
		Station X Year (Preop-Op)	28	6.34	3.10***	
		Error	191	2.05		
	Deep[b]	Preop-Op	1	9.60	1.84 NS	
	(B04,B34,B13)	Station	2	3.90	18.39 NS	
		Year (Preop-Op)	15	7.44	3.06**	
		Preop-Op X Station	2	0.23	0.09 NS	
		Station X Year (Preop-Op)	30	2.43	1.81**	
		Error	204	1.34		

(continued)

Table 6-3. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Total Biomass	Intertidal[a]	Preop-Op	1	263915.27	0.32 NS	
	(B1MLW,B5MLW)	Station	1	485475.42	1.13 NS	
		Month (Year)	28	752353.86	13.76***	
		Year (Preop-Op)	12	592189.10	0.67 NS	
		Preop-Op X Station	1	431354.63	2.25 NS	
		Station X Year (Preop-Op)	12	191159.42	3.50***	
		Error	324	54662.97		
	Shallow Subtidal[a]	Preop-Op	1	11760.99	0.04 NS	
	(B17,B35)	Station	1	163242.10	2.44 NS	
		Month (Year)	28	879192.93	16.33***	
		Year (Preop-Op)	12	338424.54	0.36 NS	
		Preop-Op X Station	1	67388.62	0.53 NS	
		Station X Year (Preop-Op)	12	127235.84	2.36**	
		Error	324	53849.80		
	Mid-Depth[b]	Preop-Op	1	429784.39	2.86 NS	
	(B16,B19,B31)	Station	2	3158990.22	30.15*	B16 > B31 > B19
		Year (Preop-Op)	14	124220.75	1.57NS	
		Preop-Op X Station	2	104704.01	1.33 NS	
		Station X Year (Preop-Op)	28	78920.94	2.23***	
		Error	191	35468.28		
	Deep[b]	Preop-Op	1	13637.43	Non-est.[k]	
	(B04,B34,B13)	Station	2	33550.23	24.62*	B04 B13 > B34
		Year (Preop-Op)	15	5087.60	0.73 NS	
		Preop-Op X Station	2	1400.92	0.20 NS	
		Station X Year (Preop-Op)	30	6988.34	4.87***	
		Error	204	1435.61		

[a]Includes all months (May, August, November).
[b]Includes August only.
[c]Compares Preop to Op, regardless of station; years included in each station grouping: if all three months used, Op years = 1991-1996; if only August data are used, Op years = 1990-1996; Preop years: B1MLW, B5MLW = 1982-1989; B17, B35 = 1982-1989; B16, B14, B31 = 1980-1984, 1986-1989; B04, B34, B13 = 1979-1984, 1986-1989.
[d]Stations within depth zone, regardless of year, month or period.
[e]Year nested within preoperational and operational periods regardless of station.
[f]Month nested within years, regardless of station.
[g]Interaction of the two main effects, Preop-Op and Station.
[h]Interaction of Station and Year within Preop-Op.
[i]NS = not significant ($p > 0.05$); * = significant ($0.05 \geq p > 0.01$); ** = highly significant ($0.01 \geq p > 0.001$); *** = very highly significant ($0.001 \geq p$).
[j]Scheffe's multiple means comparison test used for significant main effects. LS Means used for interaction term. Underlining indicates no significant difference ($\alpha \leq 0.05$).
[k]F value non-estimable due to negative denominator mean square.



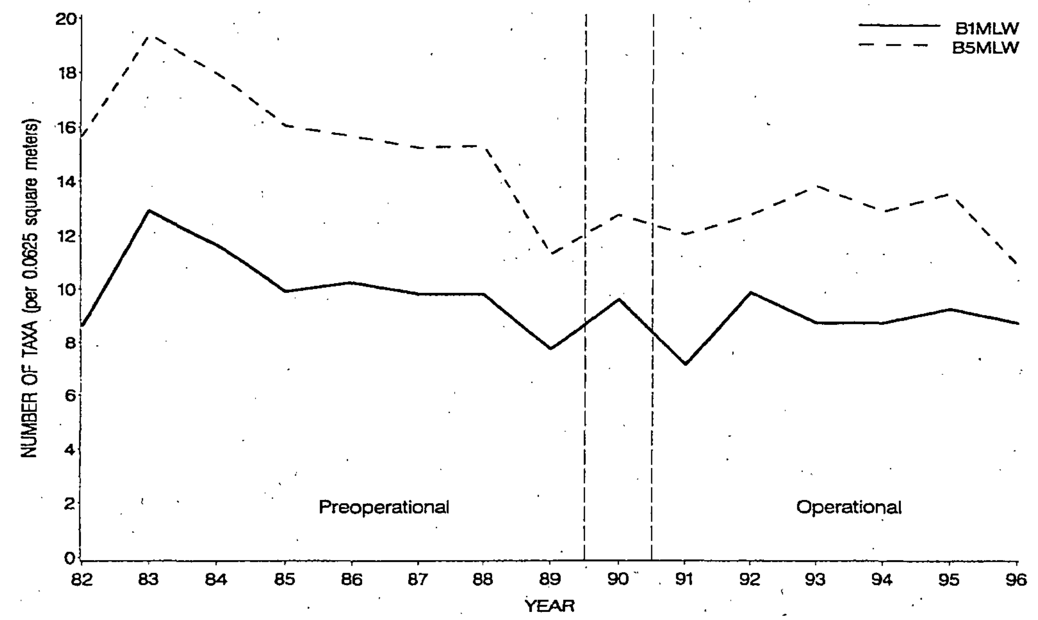


Figure 6-3. Comparison between stations for number of macroalgal taxa (per 0.0625 m^2) in the intertidal zone during the preoperational (1982-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean number of taxa each year (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

farfield station (B31) intermediate (Table 6-3). The consistency of the relationship among the three stations resulted in a non-significant interaction term.

In the deep zone, mean biomass in 1996 was lower than during the preoperational and operational periods at all three stations (B04, B13, and B34; Table 6-2). Mean total biomass was significantly higher at the two nearfield stations (B04 and B13) compared to the farfield station (B34) during both the preoperational and operational periods (Table 6-3). The consistency in mean biomass among the three stations and between the two periods resulted in a non-significant interaction term (Table 6-3).

Macroalgal Community Analysis

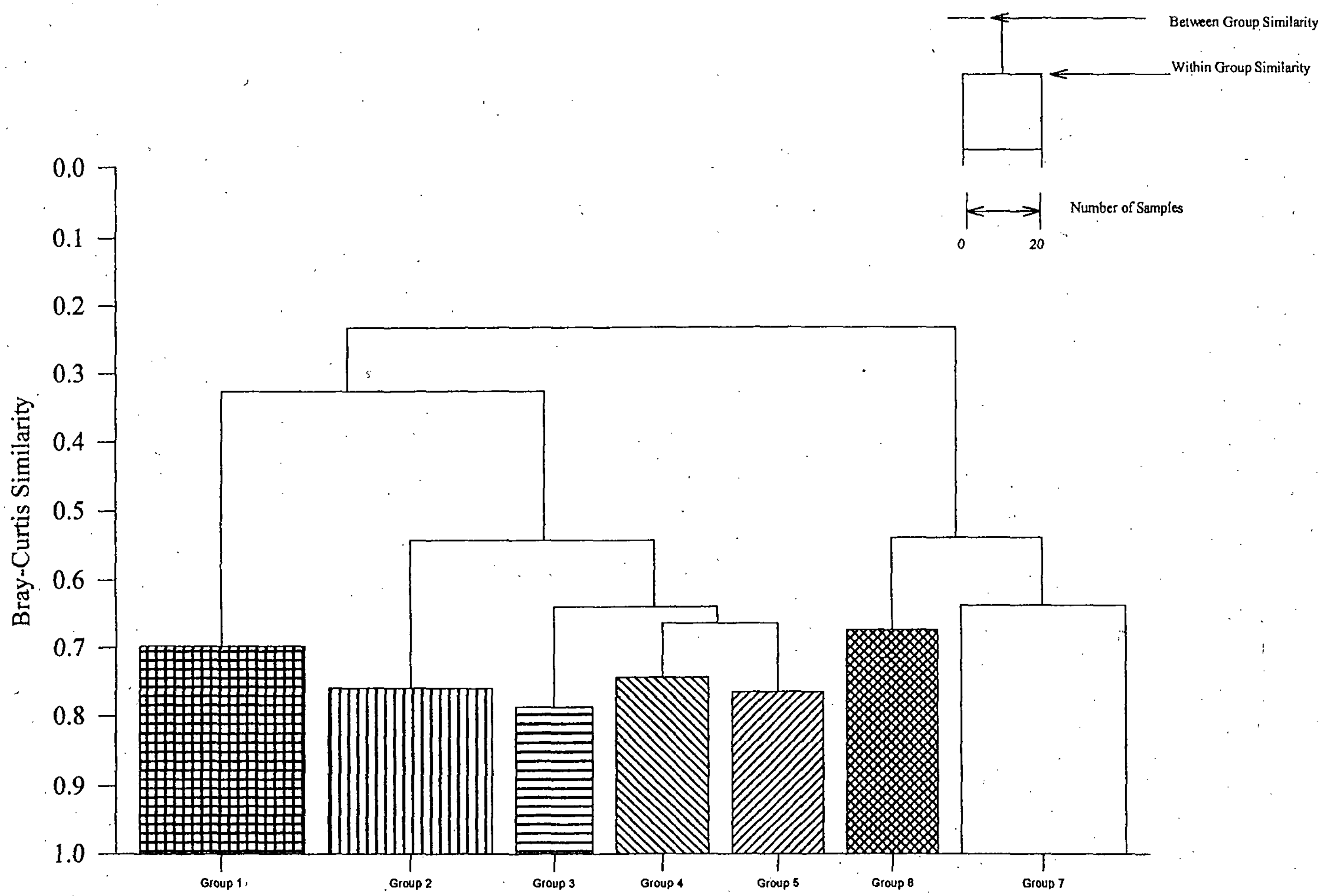
Multivariate community analysis techniques were used in this study to quantify the degree of similarity among all August macroalgal collections made at the macrobenthic sampling stations since 1978. In this case, 175 station/year collections, represented by 35 macroalgal taxa, were grouped into seven groups generally reflecting depth zone. A power plant-induced impact to the macroalgal community could be inferred from the failure of operational years' collections (1990-1996) at a station to be grouped with collections from preoperational years (1989 and earlier) at that station. However, all collections were invariably grouped by depth zone or station, and with one exception, included all years (preoperational and operational; Figure 6-4). Although the dominant taxa at all stations were members of the Rhodophyta, each group was distinguished from the others by the abundance of a characteristic macroalgal species assemblage.

Collections from the intertidal stations (B1MLW and B5MLW) formed Group 1 (Table 6-4). The three dominant taxa in this group (based on percent of total group biomass), in descending order, were *Chondrus crispus*, *Mastocarpus stellatus* and *Corallina officinalis*. *M. stellatus* was restricted to intertidal collections. Group 1 biomass decreased moderately between periods, although the relative contribution to total biomass of each of the three major components of the group remained similar (Table 6-4).

Collections from the two shallow subtidal stations (B17 and B35) comprised Group 2 (Table 6-4). In addition to *C. crispus* and *Phyllophora/Coccotylus* (the two top dominants), shallow subtidal dominants included, in descending order of percent of total biomass, *Ceramium nodulosum*, *Cystoclonium purpureum*, and *Corallina officinalis*. The biomass of Group 2 as a whole (i.e., at Stations B17 and B35), as well as that of its component species, changed little between the preoperational and the operational periods (Tables 6-2, 6-4).

Groups 3, 4 and 5 included only mid-depth Stations B16, B31, and B19 respectively. These three stations were segregated from one another by significant differences in total biomass (as reflected by ANOVA results, Table 6-3) as well as differences in species assemblages (Table 6-4).

Group 3, composed of collections from mid-depth intake Station B16, is characterized by high amounts of *Phyllophora/Coccotylus* and *Phycodrys rubens*, and moderate amounts of *Chondrus crispus*, *Cystoclonium purpureum*, *Ceramium nodulosum*, and *Callophyllis cristata* (Table 6-4). Biomass of the two major contributors to the



Group 1 - Intertidal (B1MLW, B5MLW) - All years
Group 2 - Shallow Subtidal (B17, B35) - All years
Group 3 - Mid-depth Intake (B16) - All years
Group 4 - Mid-depth Farfield (B31) - All years
Group 5 - Mid-depth Discharge (B19) - All years
Group 6 - Deep Intake (B13) - All years and Deep Discharge (B04) in 1996
Group 7 - Deep Discharge (B04) - All years except 1996/Deep Farfield (B34) - All years

Figure 6-4. Dendrogram and station groups formed by numerical classification of August collections of marine benthic algae, 1978-1996. Seabrook Operational Report, 1996.

Table 6-4. Summary of Spatial Associations Identified from Numerical Classification of Benthic Macroalgae Samples Collected in August Destructive Sampling (1978 - 1996). Seabrook Operational Report, 1996.

						GROUP BIOMASS (g/m²)					
						PREOP[b]			OP[c]		
DEPTH ZONE (GROUP)	STATION	MEAN DEPTH (m)	YEARS INCLUDED	WITHIN/ BETWEEN GROUP SIMILARITY	DOMINANT TAXA[a]	LCL	MEAN	UCL	LCL	MEAN	UCL
Intertidal 1	B1MLW B5MLW	MLW MLW	1978 - 1996 1982 - 1996	0.70/0.33	*Chondrus crispus*	796.4	986.2	1175.9	662.0	839.9	1017.7
					Mastocarpus stellatus	106.6	215.2	323.9	71.7	176.2	280.7
					Corallina officinalis	19.9	51.2	82.5	3.9	18.1	32.2
Shallow Subtidal 2	B17 B35	4.6	1978 - 1996 1982 - 1996	0.76/0.54	*Chondrus crispus*	662.6	774.2	885.9	574.0	748.1	922.2
					Phyllophora/Coccotylus	142.8	204.7	266.6	132.3	214.7	297.2
					Ceramium nodulosum	48.6	69.3	90.0	56.6	81.5	106.4
					Cystoclonium purpureum	15.5	56.6	97.7	41.2	72.1	103.1
					Corallina officinalis	28.3	51.6	74.8	29.6	47.2	64.7
Mid-depth Intake 3	B16	9.4	1980 - 1984; 1986 - 1996	0.79/0.64	*Phyllophora/Coccotylus*	304.6	404.5	504.3	231.3	290.3	349.3
					Phycodrys rubens	117.8	188.9	259.9	74.6	126.4	178.1
					Chondrus crispus	26.5	57.0	87.4	0.0	45.2	91.3
					Cystoclonium purpureum	18.0	44.5	71.0	4.8	60.5	116.2
					Ceramium nodulosum	14.3	35.0	55.7	9.0	46.3	83.7
					Callophyllis cristata	23.8	32.5	41.1	20.0	31.8	43.5
Mid-depth Farfield 4	B31	9.4	1978 - 1996	0.74/0.66	*Phyllophora/Coccotylus*	148.5	213.2	277.8	84.7	135.8	187.0
					Chondrus crispus	72.5	114.8	157.1	33.0	88.0	142.9
					Corallina officinalis	71.1	97.8	124.5	66.2	91.9	117.5
					Phycodrys rubens	17.4	22.9	28.4	15.9	29.1	42.2
					Callophyllis cristata	5.0	8.7	12.5	1.8	11.0	20.2
					Membranoptera alata	2.2	5.3	8.5	4.1	8.0	11.9
					Polysiphonia stricta	0.1	0.2	0.3	0.0	7.9	21.1
					Cystoclonium purpureum	0.5	1.2	2.0	0.0	8.0	20.6

(Contin ued)

Table 6-4. (Continued)

DEPTH ZONE (GROUP)	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 5	B19	12.2	1978 - 1996	0.77/0.66	*Phyllophora/Coccotylus*	163.6	201.9	240.1	100.1	169.4	238.7
					Phycodrys rubens	30.9	50.2	69.5	27.1	74.5	121.9
					Corallina officinalis	10.8	15.2	19.6	4.2	7.4	10.6
					Ptilota serrata	9.7	16.0	22.3	0.0	16.9	35.8
					Callophyllis cristata	6.8	12.5	18.2	6.4	12.3	18.3
					Cystoclonium purpureum	1.6	6.0	10.4	2.3	7.6	13.0
					Membranoptera alata	1.9	4.3	6.8	2.4	6.3	10.2
Deep Intake	B13	18.3	1978 - 1984; 1986 - 1996	0.67/0.54	*Phyllophora/Coccotylus*	45.1	68.8	92.6	34.3	65.4	96.5
					Ptilota serrata	7.6	11.5	15.5	3.0	8.5	14.0
					Phycodrys rubens	2.9	5.8	8.8	2.3	5.2	8.1
Deep Discharge 6	B04	18.9	1996[d]		*Polysiphonia stricta*	0.0	2.9	6.2	0.0	2.2	4.3
					Scagelia pylaisaei	0.0	2.9	5.7	0.6	2.7	4.7
					Callophyllis cristata	1.2	2.4	3.6	0.9	1.5	2.2
Deep Discharge/ Farfield 7	B04	18.9 - 21.0	1978 - 1984; 1986 - 1995	0.64/0.54	*Ptilota serrata*	45.7	64.0	82.3	31.6	43.5	55.4
					Phyllophora/Coccotylus	5.9	11.0	16.0	4.1	10.1	16.0
	B34		1979 - 1984; 1986 - 1996		*Corallina officinalis*	3.3	6.9	10.4	0.3	1.4	2.5
					Scagelia pylaisaei	0.1	1.3	2.5	1.9	7.8	13.6
					Phycodrys rubens	0.6	1.0	1.4	0.3	1.4	2.4

[a]Dominant taxa comprise 2% or more of total biomass in either or both of the periods (Preop, Op).
[b]Preop = preoperational period, 1978-1989 (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; B34: 1979 - 1984, 1986-1989).
[c]Op = operational period, 1990-1996.
[d]B04 is normally included in Group 7/Deep Discharge, however the 1996 community was more similar to Group 6.

group, *Phyllophora/Coccotylus* and *P. rubens*, declined between periods. This is reflected in the decline in total biomass for Station B16 (Table 6-2).

Group 4 is composed of collections from mid-depth farfield Station B31. *Phyllophora/Coccotylus* was the dominant taxon during both periods, followed by *Chondrus crispus* and *Corallina officinalis* (Table 6-4). Five other taxa also contributed to 2% or more of group biomass: *Phycodrys rubens*, *Callophyllis cristata*, *Membranoptera alata*, *Polysiphonia stricta*, and *Cystoclonium purpureum*. The biomass of each of the top three taxa declined between periods, while that of the remaining five taxa increased. Overall, biomass at Station B31 declined between periods (Table 6-2).

Collections from the mid-depth discharge station (B19) formed Group 5. *Phyllophora/Coccotylus* was the dominant taxon in this group during both periods. Six additional taxa accounted for 2% or more of this group's total biomass: *Phycodrys rubens*, *Corallina officinalis*, *Ptilota serrata*, *Callophyllis cristata*, *Cystoclonium purpureum*, and *Membranoptera alata* (Table 6-4). Although *Phyllophora/Coccotylus* biomass declined between periods, overall biomass at this station changed little between periods (Table 6-2).

Group 6 consisted of collections from deep intake Station B13 (all years) and 1996 collections from deep discharge station B04. Several taxa were present that accounted for 2% or more of this group's biomass: *Phyllophora/Coccotylus*, *Ptilota serrata*, *Phycodrys rubens*, *Polysiphonia stricta*, *Scagelia pylaisaei* (which was not a dominant in any of the other shallower depth zones), and *Callophyllis cristata*. Previous collections at Station B04 had been associated with Group 7 (Table 6-4), but the 1996 collection was more closely related to Group 6, primarily due to a reduction in the mean biomass of *Ptilota serrata*. In 1996, mean biomass of *Ptilota serrata* at Station B04 was 18.2 g/m^2 (NAI 1997), which was much closer to the mean biomass for Group 6 than Group 7 (Table 6-4). Biomass of each of the dominants in this group declined slightly between periods (Table 6-4).

Group 7 consisted of collections from the two remaining deep stations, B04 (discharge, all years except 1996) and B34 (farfield; Table 6-4). Five taxa comprised the dominants in this group and included in descending order: *Ptilota serrata*, *Phyllophora/Coccotylus*, *Corallina officinalis*, *Scagelia pylaisaei*, and *Phycodrys rubens*. The biomass of *S. pylaisaei* increased by a factor of six between periods, but the biomass of *Ptilota serrata*, which accounted for most of this group's biomass, declined between periods (Table 6-4).

The community analysis techniques described above used biomass values from a large number of algal taxa (35 out of a total of 79, all those with a frequency of occurrence in destructive samples of at least 2% over all depth zones and all years). 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, or may not be included in the analysis at all. Therefore, a further community analysis was performed, examining any trends in the occurrence of rarely encountered species (frequency of occurrence in August destructive samples less than 4% over all years). Of the 39 species that fit the rare designation (Table 6-5), seven were found in both preoperational (1989 and earlier) and operational (1990-1996) periods, but have decreased in frequency of occurrence in the operational period: *Ectocarpus fasciculatus, Polyides rotundus, Leathesia difformis, Cladophora sericea, Ulvaria obscura* v. *blyttii, Porphyra miniata*, and *Palmaria palmata*. Another six species that were found in both periods have become relatively more common in the operational period: *Bonnemaisonia hamifera, Ectocarpus siliculosis, Petalonia fascia, Sphacelaria cirrosa, Enteromorpha intestinalis*, and *Scytosiphon simplicissimus*.

Several taxa have occurred in only the preoperational or operational periods, but not both. Thirteen species were found during August sampling in preoperational years, but have not yet been collected in the operational period: *Monostroma grevillei, Spongomorpha spinescens, Pilayella littoralis, Hincksia granulosa, Enteromorpha prolifera, Dumontia contorta, Ceramium deslongchampii, Spongonema tomentosum, Monostroma oxyspermum, Enteromorpha linza, Plumaria plumosa, Polysiphonia denudata*, and *Entocladia viridis*. Another twelve species were identified for the first time in August samples after Seabrook Station start-up: *Pterothamnion plumula, Chordaria flagelliformis, Isthmoplea sphaerophora, Enteromorpha compressa, Blidingia minima, Urospora penicilliformis, Bryopsis plumosa, Sphacelaria plumosa, Sphacelaria radicans, Punctaria plantaginea, Polysiphonia elongata*, and *Polysiphonia nigra*. Five of these species (*Chordaria flagelliformis, Isthmoplea sphaerophora, Polysiphonia nigra, Urospora penicilliformis*, and *Sphaecelaria plumosa*) were collected during the preoperational period in May or November only. None of the 39 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 in frequency of occurrence during the operational period considered to represent a significant alteration of the established algal community.

Another monitoring study that evaluated 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.

Three rare species (*Bonnemaisonia hamifera, Ectocarpus siliculosus*, and *Petalonia fascia*) showed relatively large increases from preoperational to operational periods (Table 6-5). *Bonnemaisonia hamifera* is a small, bushy red alga 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 prior to 1990 by Mathieson and Hehre (1986), so its presence in small amounts in the study area likely does not reflect a community change. *Ectocarpus siliculosus* ranges from Bermuda to Newfoundland, and as it is common to the New Hampshire coast, its appearance also does not indicate a major change in the community (Taylor

Table 6-5. A Comparison of Percent Frequency of Occurrence of Rarely Found Species (Overall Frequency of Occurrence <4%) in August Destructive Samples Collected During Preoperational (1978-1989) and Operational (1990-1996) Periods, and Over All Years (1978-1996). Seabrook Operational Report 1996.

SPECIES	PREOPERATIONAL	OPERATIONAL	ALL YEARS
Bonnemaisonia hamifera	1.4	7.4	3.8
Ectocarpus fasciculatus	4.7	0.9	3.1
Polyides rotundus	3.1	2.9	3.0
Ectocarpus siliculosus	1.0	3.7	2.1
Leathesia difformis	2.9	0.3	1.9
Cladophora sericea	1.4	0.9	1.2
Petalonia fascia	0.4	2.3	1.2
Ulvaria obscura v. blyttii	1.8	0.3	1.2
Poryphyra miniata	1.4	0.6	1.0
Monostroma grevillei	1.6	0.0	0.9
Palmaria palmata	1.4	0.3	0.9
Sphacelaria cirrosa	0.6	0.9	0.7
Spongomorpha spinescens	1.0	0.0	0.6
Pilayella littoralis	1.0	0.0	0.6
Pterothamnion plumula	0.0	1.4	0.6
Polysiphonia harveyi	0.6	0.6	0.6
Hincksia granulosa	0.8	0.0	0.5
Enteromorpha prolifera	0.6	0.0	0.3
Dumontia contorta	0.6	0.0	0.3
Ceramium deslongchampii	0.6	0.0	0.3
Enteromorpha intestinalis	0.2	0.3	0.2
Chordaria flagelliformis	0.0	0.6	0.2
Scytosiphon simplicissimus	0.2	0.3	0.2
Spongonema tomentosum	0.4	0.0	0.2
Isthmoplea sphaerophora	0.0	0.6	0.2
Monostroma oxyspermum	0.2	0.0	0.1
Enteromorpha compressa	0.0	0.3	0.1
Enteromorpha linza	0.2	0.0	0.1
Blidingia minima	0.0	0.3	0.1
Urospora penicilliformis	0.0	0.3	0.1
Bryopsis plumosa	0.0	0.3	0.1
Sphacelaria plumosa	0.0	0.3	0.1
Sphacelaria radicans	0.0	0.3	0.1
Punctaria plantaginea	0.0	0.3	0.1
Plumaria plumosa	0.2	0.0	0.1
Polysiphonia denudata	0.2	0.0	0.1
Polysiphonia elongata	0.0	0.3	0.1
Polysiphonia nigra	0.0	0.3	0.1
Entocladia viridis	0.2	0.0	0.1

1957, Mathieson and Hehre 1986). *Petalonia fascia* is associated with a cold water habitat, and is typically found in late winter to early spring (Taylor 1957). Since *P. fascia* does not generally favor warm water conditions, its increased presence does not likely reflect changes associated with station operation (i.e., a localized warming of water temperatures due to the thermal effluent). Finally, none of these taxa are considered nuisance species.

Several species showed relatively large decreases in frequency of occurrence between periods. *Leathesia difformis*, described as a summer 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. These trends are the converse of the expected response to a thermal incursion. *Monostroma grevillei* and *Spongomorpha spinescens*, both considered cold water species, have not been found in the operational period. The absence of *M. grevillei* from collections in August from New Hampshire waters is not unusual and *S. Spinescens* is infrequent in August and generally absent from New Hampshire waters in September (Mathieson and Hehre 1986).

Trends observed in taxa appearing for the first time in the operational period are less conclusive. Two taxa, *Bryopsis plumosa* and *Pterothamnion plumula,* are warm water forms more typical of southern New England and even further south along the Atlantic coast. *Polysiphonia elongata* was found for the first time in 1996 August destructive samples (Table 6-5). This alga occurs over a broad geographic range and is common in New England coastal waters (Taylor 1957; Mathieson and Hehre 1986).

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. 1981a; Mathieson and Hehre 1986), and have maintained a high level of stability as reflected in the consistency of the dominant algal species in each zone. The appearance of the two warm-water taxa in 1996 could be due to chance, or it could be related to a long-term regional pattern of increasing water temperatures that is unrelated to Seabrook Station (Section 2.0). In spite of this pattern of increasing temperatures, the 1996 floristic affinity ratio reflects a cold-temperate assemblage. These factors taken together indicate that there has not been a trend toward a community dominated by warm-water species, and that there has been no impact on the local macroalgal community as a result of construction or operation of Seabrook Station.

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 structures support dense stands of the red alga *Chondrus crispus*. The 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 exceeding 1000 g/m^2 (Table 6-6). Mean total biomass in the intertidal zone increased between periods at both the nearfield (B1) and farfield (B5) stations, but this increase was not significant (Table 6-6, Table 6-7). Mean total biomass was slightly higher at the nearfield station than the farfield station during the preoperational and operational periods, and in 1996 (Table 6-6), but this difference was not significant (Table 6-7). Due to this consistency, the interaction term was not significant (Table 6-7).

Substantial, although somewhat smaller, amounts of *Chondrus crispus* were found at shallow subtidal stations, with biomass levels often exceeding 400 g/m^2. Nearfield biomass exceeded farfield biomass in both periods, but this difference was not significant (Tables 6-6, 6-7). Mean total biomass was not significantly different between periods, and the interaction term of the ANOVA model was not significant.

6.3.1.3 Non-Destructive Monitoring Program

Kelp

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 most of these 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 both periods (Table 6-8). In 1996, as in past years, *L. saccharina* was the dominant kelp species at shallow subtidal stations (B17 and B35), while *Agarum clathratum* was the overwhelming dominant at mid-depth stations (B19 and B31, Table 6-8). Moderate amounts of *L. digitata* were found at B35 and B31, but low amounts were found at their nearfield counterparts (Stations B17 and B19, respectively). *Alaria esculenta* was found only at B31 in 1996, but its absence from B19 is not unusual (Table 6-8).

Laminaria digitata densities showed a significant decline (81%) at Station B17 (nearfield shallow subtidal) between periods (Tables 6-8, 6-9). Densities at B35 (farfield) declined moderately (26%) between periods, but this decline was not significant (Tables 6-8, 6-9). These differing rates of decline resulted in a significant interaction term in the ANOVA results, reflecting a possible plant impact (Table 6-9). Although densities at the two stations tracked one another closely during preoperational years, a moderate downward trend in densities at B17 is evident throughout the study period, with a steeper decline occurring between 1988 and 1992 (Figure 6-5). Densities at Station B17 rebounded somewhat between 1993-1994, then declined in 1995, and reached a study period low of 11.1 holdfasts per 100 m^2 in 1996.

Percent cover of *Laminaria digitata* in the shallow subtidal zone has, on average, been below 30% in the farfield area and below 20% in the nearfield area during all years of the study (Figure 6-6).

Table 6-6. Arithmetic Means and Coefficients of Variation (CV,%) for *Chondrus crispus* Biomass (g/m^2) Collected in Triannual (May, August, November) Destructive Samples in the Intertidal and Shallow Subtidal Zones During 1996 and During the Preoperational and Operational Periods. Seabrook Operational Report, 1996.

PARAMETER	DEPTH ZONE	STATION	PREOPERATIONAL[a] PERIOD MEAN	PREOPERATIONAL[a] PERIOD CV	1996 MEAN	OPERATIONAL[b] PERIOD MEAN	OPERATIONAL[b] PERIOD CV
Chondrus crispus biomass (g/m^2)	Intertidal	B1MLW	908.7	27.6	1136.8	971.5	16.6
		B5MLW	787.8	26.9	734.7	800.8	20.3
	Shallow subtidal	B17	644.1	18.9	592.1	648.7	13.9
		B35	477.3	10.9	479.9	437.1	35.1

[a]Preoperational years: Station B1MLW = 1978-1989
Station B5MLW = 1982-1989
[b]Operational years: Both stations = 1991-1996

Table 6-7. 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 - 1996) Periods. Seabrook Operational Report, 1996.

TAXON	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[g]	MULTIPLE COMPARISON OF ADJUSTED MEANS[h] (Ranked in decreasing order)
Chondrus crispus	Intertidal[i] (B1, B5)	Preop-Op[a]	1	81901.9	0.21 NS	
		Year (Preop-Op)[b]	12	473737.86	0.51 NS	
		Month (Year)[c]	28	641447.93	7.22***	
		Station[d]	1	4878550.41	16.24 NS	
		Preop-Op X Station[e]	1	301626.67	0.78 NS	
		Station X Year (Preop-Op)[f]	12	383054.44	4.31***	
		Error	324	88853.23		
	Shallow Subtidal[j] (B17, B35)	Preop-Op	1	75.38	0.87 NS	
		Year (Preop-Op)	12	119.44	0.50 NS	
		Month (Year)	28	227.69	5.46***	
		Station	1	1869.94	89.73 NS	
		Preop-Op X Station	1	20.93	0.38 NS	
		Station X Year (Preop-Op)	12	54.59	1.31 NS	
		Error	324	41.73		

[a]Preop-Op compares 1982 - 1989 to 1991-1996 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 of Station and Year nested within Preop-Op.

[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]Waller-Duncan multiple means comparison test used for significant main effects. LS Means used for interaction term. Underlining indicates no significant difference ($\alpha\leq 0.05$).

[i]Data untransformed.

[j]Data square-root transformed.

Table 6-8. **Preoperational and Operational Means and Coefficients of Variation (CV,%), and 1996 Means for Densities of Kelp Species (#/100 m²) and Percent Frequency of Occurrence of Understory Species and Five Fucoid Species.[a] Seabrook Operational Report, 1996.**

TAXON	STATION	PREOPERATIONAL[b] MEAN	PREOPERATIONAL[b] CV	1996 MEAN	OPERATIONAL[c] MEAN	OPERATIONAL[c] CV
KELPS (#/100 m²)						
Laminaria digitata	B17	213.9	51.0	11.1	39.7	54.9
	B35	155.8	45.5	103.1	115.6	37.1
	B19	139.9	65.7	5.6	11.5	81.5
	B31	500.2	31.0	146.8	175.5	53.0
Laminaria saccharina	B17	415.1	51.8	251.5	291.9	52.5
	B35	325.7	42.2	325.3	325.3	25.9
	B19	59.1	152.2	77.0	21.8	127.7
	B31	95.5	59.1	62.7	83.6	38.8
Alaria esculenta	B19	2.4	307.8	0.0	3.2	155.7
	B31	75.2	115.8	97.6	78.7	53.1
Agarum clathratum	B19	786.6	34.6	755.3	755.3	21.2
	B31	366.4	37.0	833.0	530.3	55.5
UNDERSTORY (% FREQUENCY)						
Chondrus crispus	B17	71.8	7.7	80.0	77.2	9.9
	B35	54.1	16.8	79.0	64.2	16.7
	B19	4.2	116.0	4.0	4.8	77.3
	B31	21.0	42.2	18.7	20.3	28.7
Phyllophora/Coccotylus	B17	20.3	36.7	23.3	20.0	36.7
	B35	19.9	52.2	9.7	22.7	52.4
	B19	34.0	21.3	25.3	29.3	31.3
	B31	31.8	25.5	17.0	23.7	29.0
Ptilota serrata	B17	0.8	126.9	0.0	0.6	178.8
	B35	0.6	122.5	0.0	1.1	142.3
	B19	35.6	25.5	0.0	37.8	59.6
	B31	13.1	37.8	0.0	12.1	86.8

(continued)

Table 6-8. (Continued)

TAXON	STATION	PREOPERATIONAL[b] MEAN	PREOPERATIONAL[b] CV	1996 MEAN	OPERATIONAL[c] MEAN	OPERATIONAL[c] CV
FUCOIDS (% FREQUENCY)						
Ascophyllum nodosum	B1	32.0	18.8	42.0	39.9	6.6
	B5	41.2	21.3	36.0	36.2	7.1
Fucus vesiculosus	B1	47.4	49.4	21.3	6.0	128.5
	B5	27.0	38.9	31.0	18.2	37.4
Fucus distichus	B1	16.2	67.9	10.0	17.6	27.2
subsp. *edentatus*	B5	3.6	264.6	0.0	4.9	133.0
Fucus distichus	B1	0.0	-	5.0	4.8	144.0
subsp. *distichus*	B5	0.0	-	0.0	2.7	102.2
Fucus sp.	B1	7.6	148.9	43.3	33.8	36.0
(juveniles)	B5	0.6	264.6	5.0	8.9	47.8

[a]All taxa recorded along non-destructive subtidal or intertidal 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; for fucoids - Station B1MLW: 1978-1996; Station B5MLW: 1982-1996; Stations B17 and B35: 1983-1989.
[c]1991-1996.
[d]n=number of years, both periods combined.

Table 6-9. **Analysis of Variance Results for Number of Kelps/100 m^2 and % Frequency of Occurrence of Understory Species and Fucoids as Measured in the Non-Destructive Monitoring Program. Seabrook Operational Report, 1996.**

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Laminaria digitata[a] (#/100m^2)	Shallow Subtidal (B17,B35)	Preop-Op[c]	1	3.43	1.95 NS	
		Station[d]	1	1.28	0.74 NS	
		Year (Preop-Op)[e]	12	0.15	1.65 NS	
		Month (Year)[f]	28	0.05	0.72 NS	
		Preop-Op X Station[g]	1	1.72	15.75**	B17Pre B35Pre B35Op > B17Op
		Station X Year (Preop-Op)[h]	12	0.11	1.67 NS	
		Error	27	0.07		
Laminaria digitata[a] (#/100m^2)	Mid-depth (B19,B31)	Preop-Op	1	19.73	5.46 NS	
		Station	1	24.29	7.13 NS	
		Year (Preop-Op)	16	0.43	2.31*	
		Month (Year)	36	0.10	1.86*	
		Preop-Op X Station	1	3.33	23.70***	B31Pre > B31Op B19Pre > B19Op
		Station X Year (Preop-Op)	16	0.14	2.69**	
		Error	36	0.05		
Laminaria saccharina[a] (#/100m^2)	Shallow Subtidal (B17, B35)	Preop-Op	1	0.07	0.95 NS	
		Station	1	0.26	5.35 NS	
		Year (Preop-Op)	12	0.11	0.68 NS	
		Month (Year)	28	0.13	2.38*	
		Preop-Op X Station	1	0.05	0.61 NS	
		Station X Year (Preop-Op)	12	0.08	1.40 NS	
		Error	27	0.06		
Laminaria saccharina[a]	Mid-depth (B19, B31)	Preop-Op	1	2.38	2.45 NS	
		Station	1	11.93	15.07 NS	
		Year (Preop-Op)	16	0.48	1.13 NS	
		Month (Year)	36	0.31	1.84*	
		Preop-Op X Station	1	0.78	2.70 NS	
		Station X Year (Preop-Op)	16	0.29	1.71 NS	
		Error	36	0.17		

(continued)

Table 6-9. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Alaria esculenta[a] (#/100m^2)	Mid-depth (B19,B31)	Preop-Op	1	0.17	4.23 NS	
		Station	1	63.33	Non-est[j]	
		Year (Preop-Op)	16	0.21	1.42 NS	
		Month (Year)	36	0.11	0.82 NS	
		Preop-Op X Station	1	<0.01	<0.01 NS	
		Station X Year (Preop-Op)	16	0.17	1.31 NS	
		Error	36	0.13		
Agarum clathratum[a] (#/100m^2)	Mid-depth (B19,B31)	Preop-Op	1	0.13	0.61 NS	
		Station	1	1.89	35.53 NS	
		Year (Preop-Op)	16	0.21	3.38**	
		Month (Year)	36	0.03	1.95*	
		Preop-Op X Station	1	0.05	1.14 NS	
		Station X Year (Preop-Op)	16	0.05	2.89**	
		Error	36	0.02		
Chondrus crispus[b] (% frequency)	Shallow Subtidal (B17,B35)	Preop-Op	1	1338.67	4.56 NS	
		Station	1	4400.11	71.73 NS	
		Year (Preop-Op)	12	307.02	2.76 NS	
		Month (Year)	28	113.95	1.49 NS	
		Preop-Op X Station	1	61.40	0.83 NS	
		Station X Year (Preop-Op)	12	74.38	0.97 NS	
		Error	27	76.70		
Chondrus crispus[a] (% frequency)	Mid-depth (B19,B31)	Preop-Op	1	<0.01	<0.01 NS	
		Station	1	5704.60	653.45*	B31>B19
		Year (Preop-Op)	13	163.24	1.86 NS	
		Month (Year)	30	55.12	1.17 NS	
		Preop-Op X Station	1	9.42	0.12 NS	
		Station X Year (Preop-Op)	13	79.82	1.69 NS	
		Error	30	47.09		

(continued)

Table 6-9. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Phyllophora/Coccotylus[b] (% frequency)	Shallow Subtidal (B17,B35)	Preop-Op	1	16.24	0.04 NS	
		Station	1	4.77	0.05 NS	
		Year (Preop-Op)	12	385.78	2.18 NS	
		Month (Year)	28	151.21	2.06*	
		Preop-Op X Station	1	90.27	0.90 NS	
		Station X Year (Preop-Op)	12	100.03	1.36 NS	
		Error	27	73.37		
Phyllophora/Coccotylus[b] (% frequency)	Mid-depth (B19,B31)	Preop-Op	1	885.08	5.26 NS	
		Station	1	332.76	5.63 NS	
		Year (Preop-Op)	13	239.38	1.59 NS	
		Month (Year)	30	102.41	1.23 NS	
		Preop-Op X Station	1	59.78	0.46 NS	
		Station X Year (Preop-Op)	13	130.88	1.57 NS	
		Error	30	83.11		
Ptilota serrata (% frequency)	Mid-depth (B19,B31)	Preop-Op	1	0.78	0.98 NS	
		Station	1	4.69	Non-est[k]	
		Year (Preop-Op)	13	0.83	11.15*	
		Month (Year)	30	0.05	1.86*	
		Preop-Op X Station	1	<0.01	<0.01 NS	
		Station X Year (Preop-Op)	13	0.05	1.78 NS	
		Error	30	0.03		
Ascophyllum nodosum[a] (% frequency)	Intertidal (B1,B5)	Preop-Op	1	0.02	0.22 NS	
		Station	1	0.02	0.17 NS	
		Year (Preop-Op)	11	0.01	0.61 NS	
		Month (Year)	26	0.01	1.63 NS	
		Preop-Op X Station	1	0.10	7.08*	B1OP B5Pre B5Op > B1Pre
		Station X Year (Preop-Op)	11	0.01	2.28*	
		Error	26	0.01		

(continued)

Table 6-9. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[i]	MULTIPLE COMPARISON[j] (Ranked in decreasing order)
Fucus vesiculosis[a] (% frequency)	Intertidal (B1, B5)	Preop-Op	1	5.37	1.44 NS	
		Station	1	0.52	0.16 NS	
		Year (Preop-Op)	11	0.65	2.56*	
		Month (Year)	26	0.21	3.49**	
		Preop-Op X Station	1	3.19	31.39***	B1Pre > B5Pre B5Op > B1Op
		Station X Year (Preop-Op)	11	0.10	1.66 NS	
		Error	26	0.06		
Fucus distichus ssp. *edentatus*[a] *(% frequency)*	Intertidal (B1, B5)	Preop-Op	1	1.01	1.61 NS	
		Station	1	10.44	509.55*	B1 > B5
		Year (Preop-Op)	11	0.76	9.11 NS	
		Month (Year)	26	0.16	0.71 NS	
		Preop-Op X Station	1	0.02	0.14 NS	
		Station X Year (Preop-Op)	11	0.15	0.65 NS	
		Error	26	0.23		
Fucus sp. (juveniles)[a] (% frequency)	Intertidal (B1, B5)	Preop-Op	1	14.23	22.24**	Op > Preop
		Station	1	0.23	21.03 NS	
		Year (Preop-Op)	11	0.58	3.20*	
		Month (Year)	26	0.07	1.21 NS	
		Preop-Op X Station	1	0.23	1.35 NS	
		Station X Year (Preop-Op)	11	0.17	2.76*	
		Error	26	0.06		

[a]Data log (X+1) transformed.
[b]Untransformed data.
[c]Compares preoperational period to operational period, regardless of station; years included in each station-species pairing: all fucoids (B1,B5) = 1983-1996; all kelps (B17,B35): 1982-1996; all kelps (B19,B31) = 1978-1996; understory species (B17,B35) = 1982-1996; understory species (B19,B31) = 1981-1996; operational period = 1991-1996.
[d]Stations within depth zone, regardless of year, month or period.
[e]Year nested within preoperational and operational periods regardless of station.
[f]Month (April, July, October) nested within year, regardless of station.
[g]Interaction of the two main effects, Preop-Op and Station.
[h]Interaction of Station and Year within Preop-Op.
[i]NS = not significant ($p>0.05$); * = significant ($0.05 \geq p > 0.01$); ** = highly significant ($0.01 \geq p > 0.001$); *** = very highly significant ($0.001 \geq p$).
[j]Scheffe's multiple means comparison test used for significant main effects. LS Means used for interaction term. Underlining indicates no significant difference ($\alpha \leq 0.05$).
[k]F-value non-estimable due to negative denominator mean square.

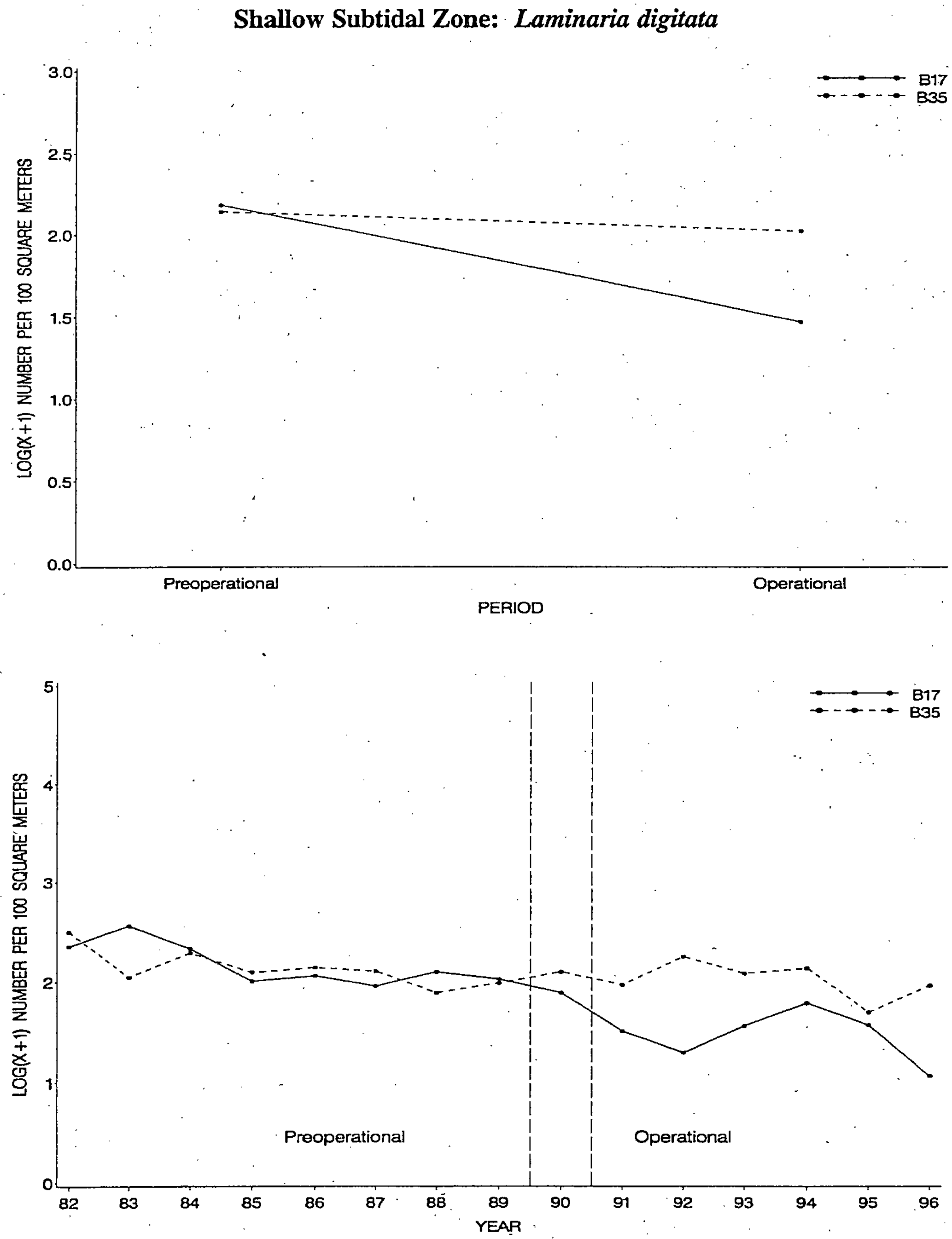
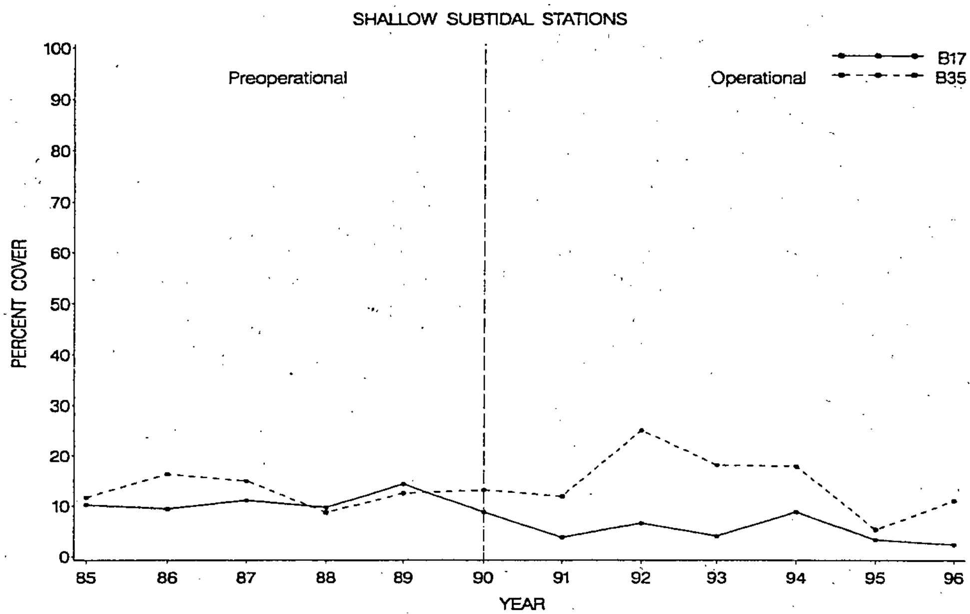


Figure 6-5. Comparison between stations for number of holdfasts/100 m^2 of the kelp *Laminaria digitata* in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.



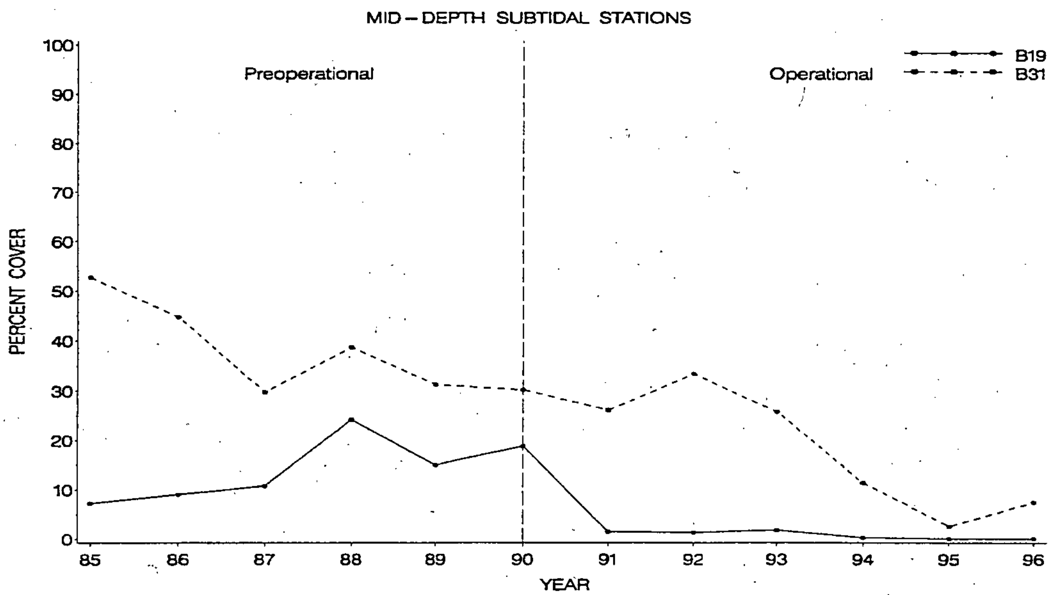


Figure 6-6 Annual mean percent cover of *Laminaria digitata* in the shallow and mid-depth subtidal zones, 1985-1996. Seabrook Operational Report, 1996.

Physical factors are generally favorable to *L. digitata* in this zone in that the substrate is composed of rock outcrops, and water depths are shallow enough to permit adequate light penetration. Therefore there is some other physical or biological factor that has limited the distribution of *L. digitata* in this zone.

The most fully documented physical factor in the study area that could be influenced by station operation is temperature. To date there has been no documented change in water temperatures attributed to Seabrook Station, although a long-term rise in water temperatures has been observed locally and regionally (Section 2.0). A thermal plume study by Padmanabhan and Hecker (1991) indicated that the thermal plume from the discharge is more buoyant than the surrounding waters and rises quickly to the surface. According to a numerical model of the thermal plume, and subsequent field verification, there were no significant temperature increases at the Outer Sunk Rocks, where Station B17 is located in 4-5 m of water. *Laminaria digitata* is slightly more sensitive to temperature during its reproductive phase than is *Laminaria saccharina*, the dominant kelp in the shallow subtidal zone (Hoek 1982; Lüning 1990). Laminarians have a biphasic life cycle in which the gametophytes are microscopic filaments. Due to the difficulty in observing gametophytes in the field, the data available on this life stage come from laboratory studies. *L. digitata* sporophytes are reproductive nearly year-round (Mathieson et al. 1981b); therefore, temperature is not likely to be limiting. There is no information in the literature indicating the seasonal period during which *L. digitata* gametophytes reproduce locally, but gametophytes cannot survive temperatures in excess of 18°C, and require temperatures less than 10°C to become fertile (Hoek 1982, Lüning 1990) suggesting that reproduction occurs in late winter when temperatures are not limiting.

Another physical factor that could influence *L. digitata* survival in this zone is periodic removal by storm events. However, the frond structure of *L. digitata* makes it relatively more resistant to removal by storms compared to *L. saccharina*, and there is not a definitive relationship between known severe storms (e.g., in 1988, Hurricane Bob in 1991, and a second major storm during the fall in 1991) and *L. digitata* densities. One biological factor that could affect *L. digitata* densities is grazing by the green sea urchin *Strongylocentrotus droebachiensis*. This relationship is examined in Section 6.3.2.2.

Densities of *Laminaria digitata* in the mid-depth subtidal zone declined substantially at both stations between periods (Table 6-8), but 1996 values showed slight increases from 1995 (NAI 1996). The decline at the nearfield station (B19) exceeded that at the farfield station (B31), resulting in a significant interaction between period and station that reflects a possible plant impact (Table 6-9; Figure 6-7). Annual means show that densities at the two stations essentially converged in 1988, but began to decline and diverge the following year (Figure 6-7). The decline at B19 was most severe between 1990 and 1991 and between 1993 and 1994.

The percent cover of *L. digitata* in the mid-depth zone declined substantially over time at the farfield station (B31), beginning well before the start of station operation (Figure 6-6). The annual mean percent cover of *L. digitata* at the nearfield station (B19) was generally quite low throughout the

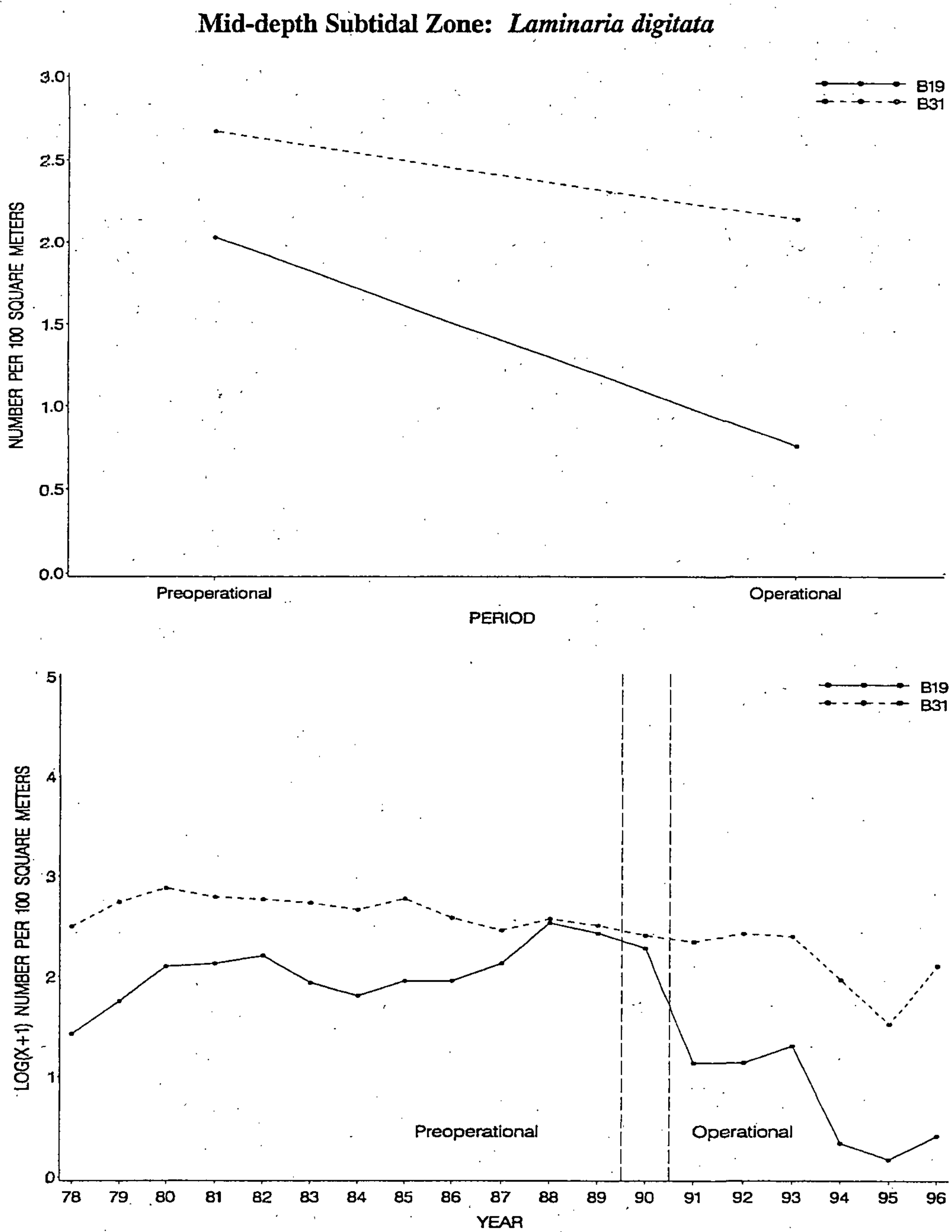


Figure 6-7. Comparisons between stations for number of holdfasts/100 m^2 of the kelp *Laminaria digitata* in the mid-depth subtidal zone during the preoperational (1978-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

entire study, exceeding 20% only in 1988. Following this peak in 1988, the annual mean percent cover declined to less than 5% by 1991, and has remained below 5% ever since. In this depth zone, substrate conditions are more favorable to *L. digitata* in the nearfield area (nearly 100% rock outcrop) compared to the farfield area (roughly 50% rock outcrop, 50% mixed sand and gravel). The major difference between the two stations is depth. *L. digitata* may be at its physiological limit with respect to light penetration at Station B19 (12.2 m), whereas light penetration is probably adequate at Station B31 (9.4 m), assuming that there is no other factor affecting water clarity (Lüning 1990). The stress placed on *L. digitata* in the nearfield area due to water depth may make it more susceptible to disturbance by other physical or biological factors than the population in the farfield area. Due to the depth at B19, the increased water temperatures observed locally and regionally are not likely a contributing factor to the observed decline. Competition among *L. digitata* and other kelp species is also unlikely to be contributing to the decline, since no other kelp species have shown significant increases in density between periods (Table 6-8). However, grazing by sea urchins could affect *L. digitata* in this zone. This is examined in Section 6.3.2.2.

The stability of local patches of kelp populations have been observed to be highly variable (Dayton et al. 1984; Dayton et al. 1992). Important factors contributing to these patterns are recruitment and survivorship which in turn are influenced by disturbance, competition, spore dispersal, long shore currents, temperature, and light availability. Recruitment may be particularly problematic for local kelps as they have a patchy distribution, primarily due to substrate availability. Reed et al. (1988) found that recruitment density of the kelp *Pterygophora* was diminished as little as 3 m from adult plants. Kelp populations were observed to be subject to frequent local extinctions. Reed (1990) also found that favorable sites for recruitment were highly variable in time and proper abiotic conditions can be infrequent. *Laminaria hypoborea*, a species more closely related to *L. digitata*, was found to have a dispersal range of at least 200 m (Fredriksen et al. 1995). Stations B19 and B17 are approximately 9 km from B31 and B35 indicating that recovery from even a single severe disturbance such as grazing by an urchin front or damage by a storm may be dependent on a period of high recruitment coinciding with a winter storm to bring new kelp stock into the area.

Laminaria saccharina density at the nearfield shallow subtidal station (B17) declined between periods (density in 1995 was particularly low). Preoperational, operational, and 1996 densities at the farfield station (B35) were similar (Table 6-8). However, ANOVA results indicated that there were no significant differences in the density of *L. saccharina*between the preoperational and operational periods, or among stations (Table 6-9). The relationship among stations was consistent between periods as indicated by the non-significant interaction term.

In the mid-depth subtidal zone, *Laminaria saccharina* densities declined between periods at both stations (Table 6-8). Densities in 1996 were above the preoperational and operational means at Station B19 (nearfield), but lower than period means at Station B31 (farfield). ANOVA indicated that there were no significant differences in the density of *L. saccharina* between the preoperational and operational periods, or among stations (Table 6-9). The relationship among stations was consistent between periods as indicated by the non-significant interaction term.

Alaria esculenta densities were consistently lower at the nearfield station (B19) than at the farfield station (B31) during both periods and in 1996 (Table 6-8). No *A. esculenta* were collected at the nearfield station in 1996. There were no significant differences between the preoperational and operational periods, and the interaction term was not significant (Table 6-9).

Mean densities of *Agarum clathratum* declined slightly between periods at nearfield Station B19, and increased moderately at farfield Station B31 (Table 6-8). Densities observed in 1996 were higher than in either period at B31, but were the same as the operational mean at B19. There were no significant differences between periods or stations, and the interaction term was not significant (Table 6-9).

<u>Understory Algae</u>

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, which occur beneath and adjacent to kelp canopies, include the foliose red algae *Chondrus crispus*, *Phyllophora/Coccotylus* and *Ptilota serrata*. Patterns of distribution of these species in fixed transects were similar to those observed from biomass collections (Tables 6-4, 6-6). The shallow subtidal zone (B17/B35) was dominated by extensive turfs of the perennial red alga *C. crispus*, with moderate occurrences of *Phyllophora/Coccotylus*. In the mid-depth subtidal zone (B19/B31), *Phyllophora/Coccotylus* and *P. serrata* were dominant at the nearfield station (B19), while at the farfield station (B31), *Phyllophora/Coccotylus* was dominant, followed by *C. crispus* (Table 6-8).

Overall, relationships in patterns of occurrence of understory taxa between depth zones and between nearfield-farfield stations have remained remarkably consistent over the study period. The frequency of occurrence of *Chondrus crispus* in 1996 in the shallow subtidal zone was higher than during either the preoperational and operational periods at either station (Table 6-8). There were no significant differences in *C. crispus* between stations or periods in the shallow subtidal zones and the consistency of this relationship was reflected in the non-significant interaction term (Table 6-9). In the mid-depth zone, the frequency of occurrence in 1996 at Stations B19 and B31 was lower than during either the preoperational or operational period (Table 6-8). The frequency of occurrence of *C. crispus* was significantly greater in the farfield than in the nearfield. However, there were no significant differences between periods, and the interaction between station and period was not significant (Table 6-9).

The frequency of occurrence of *Phyllophora/Coccotylus* in the shallow subtidal and mid-depth zones in 1996 was lower than during either the preoperational and operational periods at all subtidal stations except B17, where the 1996 mean was higher than both period means (Table 6-8). There were no significant differences between stations or periods observed in either depth zone for the frequency of occurrence of *Phyllophora/Coccotylus*, nor was the interaction between station and period significant (Table 6-9).

Ptilota serrata occurred infrequently during both periods in the shallow subtidal area (B17 and B35), and was not found in 1996 (Table 6-8). The shallow subtidal ANOVA model for *Ptilota serrata* was not significant; therefore, a non-parametric test was used. Wilcoxon summed ranks test results show no significant difference between operational and preoperational values at Station B17 ($n=41$, $Z=-1.54$, $p>0.05$) and B35 ($n=41$, $Z=0.25$, $p>0.05$). In 1996, *P. serrata* was absent from both mid-depth stations (B19 and B31, Table 6-8). No between-period differences were detected (Table 6-9), although frequency of occurrence has been consistently greater in the nearfield area than in the farfield area, which is evident in the period means (Table 6-8). There was no significant period-station interaction for *P. serrata* in the mid-depth zone (Table 6-9).

Fucoids

Fucoid abundance was monitored in the mid-intertidal zone at B1 and B5 using fixed-line transects located at mean sea level (MSL). *Ascophyllum nodosum* was a consistently dominant taxon at both study sites over all years, particularly during the operational period (Table 6-8). Percent frequency of occurrence in 1996 was higher than during either the preoperational or operational periods at Station B1, but lower than during the preoperational and operational periods at Station B5 (Table 6-8). Percent frequency of occurrence increased significantly between periods at Station B1, but was not significantly different between periods at Station B5, resulting in a significant interaction term (Table 6-9). Annual means show that the frequencies of occurrence of *A. nodosum* in the nearfield and farfield areas have tracked closely throughout the study period, suggesting that the significant interaction term was not indicative of a power plant impact (Figure 6-8).

Percent frequency of occurrence of *Fucus vesiculosus* in 1996 was lower than during the preoperational period at Station B1 but higher at Station B5 (Table 6-8). Frequency of occurrence decreased substantially between periods at both stations, but to a greater extent at Station B1 compared to Station B5. Although the interaction term in the ANOVA results was significant (Table 6-9), this change in the relationship between the two stations does not appear to be related to the operation of Seabrook Station. The decline in *F. vesiculosus* began in the preoperational period (1988), and continued into the operational period. Beginning in 1993 there appears to be a trend of increasing frequency at both stations (Figure 6-9). Similar long-term decline and recovery cycles that were unrelated to power plant operation have been observed in other monitoring studies (NUSCO 1996).

Fucus distichus subsp. *edentatus* was a persistent component of the rockweed community at both stations, although generally at lower abundance levels than the fucoids discussed above. This species occurred less frequently in 1996 at Station B1 than during either the preoperational or operational periods. No *F. distichus* subsp. *edentatus* plants were found at B5 in 1996 (Table 6-8). The frequency of occurrence has been consistently higher at B1 as is supported by the significant station term in the ANOVA results (Table 6-9). No significant differences were found between periods or for the interaction term. *Fucus distichus* subsp. *distichus* was not collected during the preoperational period; 1996 densities were higher than the operational mean at B1, but none was

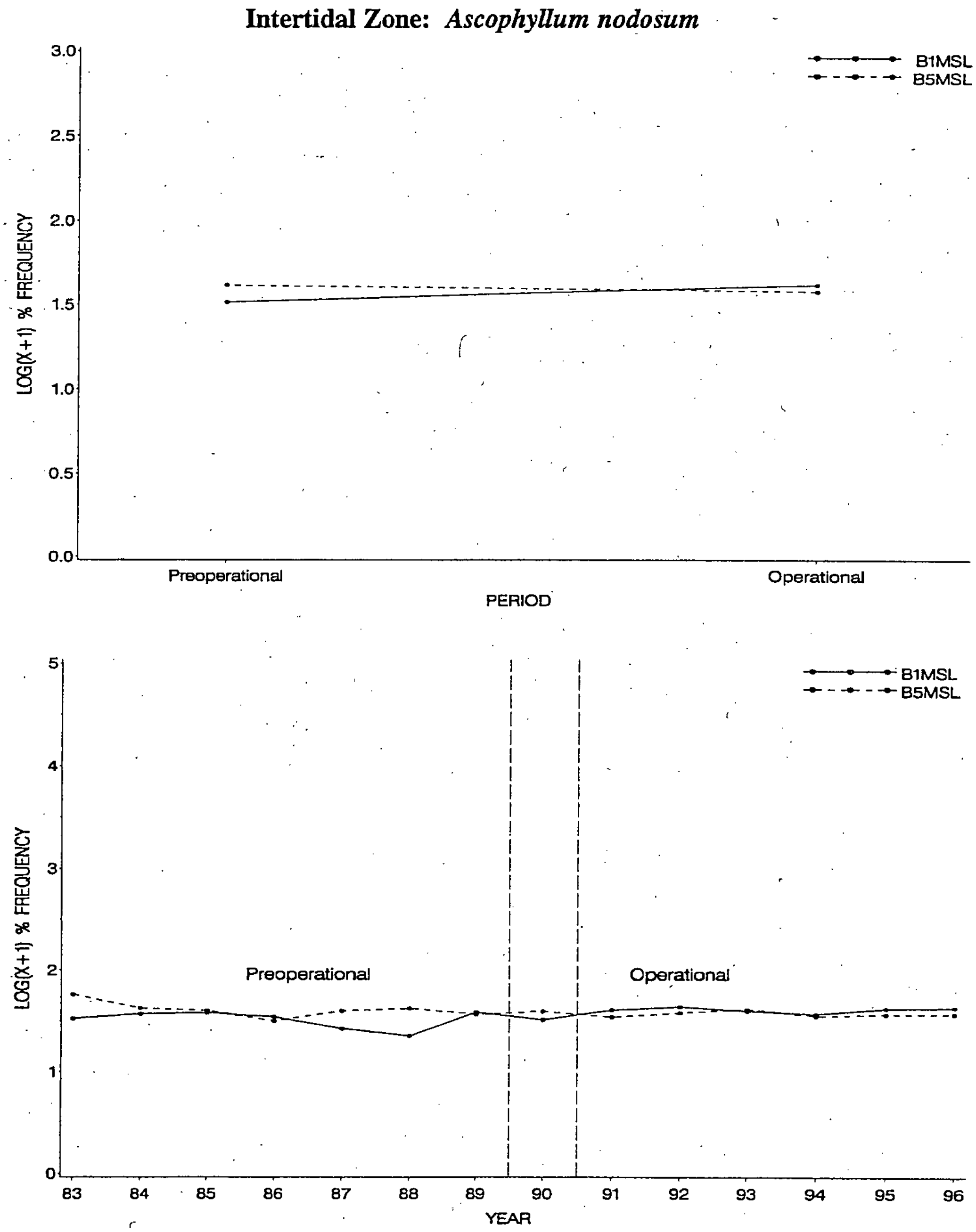
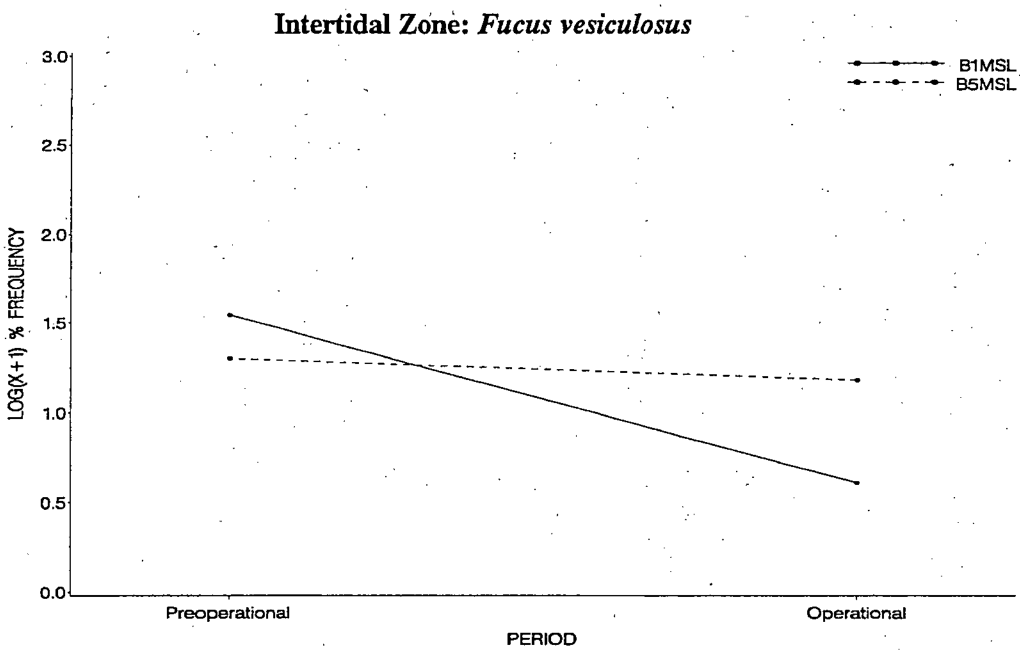


Figure 6-8. Comparison between stations for annual mean percent frequency of occurrence of the fucoid *Ascophyllum nodosum* in the intertidal zone during the preoperational (1983-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean percent frequency of occurrence each year (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.



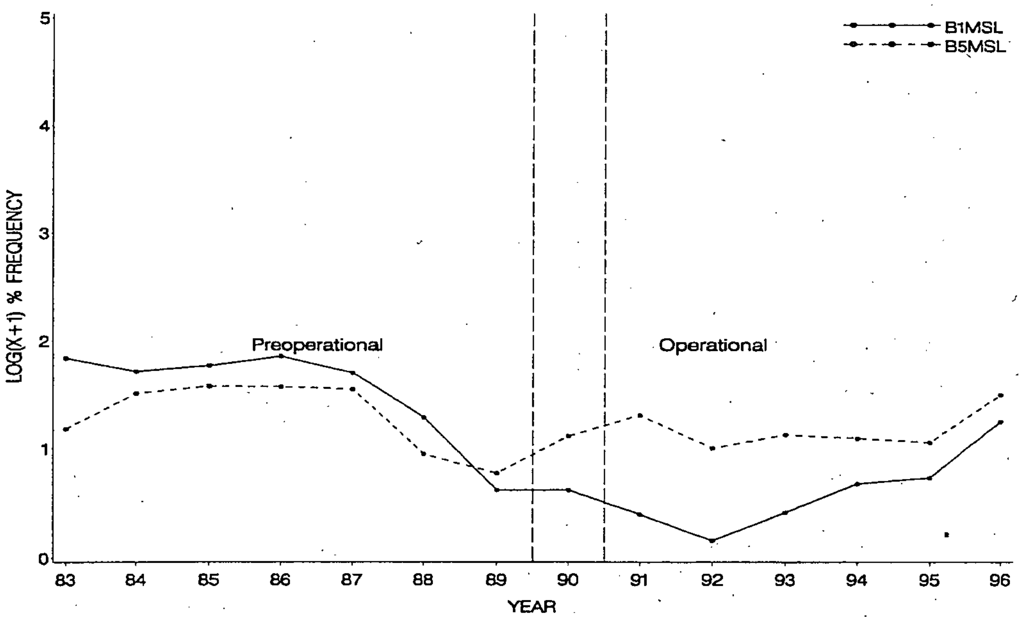


Figure 6-9. Comparison between stations for annual mean percent frequency of occurrence of the fucoid Fucus vesiculosus in the intertidal zone during the preoperational (1983-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean percent frequency of occurrence each year (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 1996.

preoperational period; 1996 densities were higher than the operational mean at B1, but none was found at B5 (Table 6-8).

Juvenile *Fucus* sp. occurred more frequently at Station B1 in 1996 than during the preoperational and operational periods. These plants also occurred more frequently in 1996 at Station B5 compared to the preoperational period (Table 6-8). Mean percent frequencies during the operational period were significantly higher than during the preoperational period at both stations (Table 6-9). There were no significant differences between stations, and the interaction term was not significant.

Intertidal Communities

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). 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. 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.

At Seabrook intertidal study sites, much of the high intertidal zone, denoted as Bare Ledge (MHW), 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 during much of the preoperational and operational periods; however, heavy sets of fucoid germlings occasionally occurred, resulting in high frequencies of occurrence in some years (Table 6-10). 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 (NAI 1995). By comparison, no fucoids were found in any months in 1996 (Table 6-10). Frequency of occurrence of fucoids has historically been higher at the farfield station (B5); the median has typically exceeded 80%, and has been relatively constant seasonally (Table 6-10). Frequencies in 1996 were substantially lower than the preoperational and operational medians.

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. Conditions for establishment and growth of these species on

Table 6-10. Percent Cover and Percent Frequency of Occurrence[a] of Dominant Perennial and Annual Macroalgal Species at Fixed Intertidal Non-Destructive Sites During the Preoperational and Operational Periods and in 1996. Seabrook Operational Report, 1996.

ZONE[b]	TAXA (DATA TYPE[c])	AREA (STATION)	APR	JUL	DEC
Bare Ledge					
	Fucoid Species[d] (%F)				
		Nearfield (B1)			
		Preoperational[e]	6 (0-81)	19 (0-94)	6 (0-94)
		Operational[f]	0 (0-69)	0 (0-75)	12 (0-81)
		1996	0	0	0
		Farfield (B5)			
		Preoperational	82 (0-100)	97 (12-100)	100 (0-100)
		Operational	94 (38-94)	100 (31-100)	87 (0-100)
		1996	9	6	6
	Urospora pencilliformis/ *Ulothrix flacca* (%F)				
		Nearfield (B1)			
		Preoperational	45 (0-99)	0 (0-0)	0 (0-0)
		Operational	39 (0-55)	0 (0-33)	0 (0-0)
		1996	22	33	0
		Farfield (B5)			
		Preoperational	73 (0-100)	0 (0-0)	0 (0-0)
		Operational	22 (0-82)	0 (0-0)	0 (0-64)
		1996	30	0	0
Fucoid Ledge					
	Fucoid Species (%C)				
		Nearfield (B1)			
		Preoperational	93 (25-98)	93 (60-100)	68 (25-95)
		Operational	80 (45-95)	99 (34-100)	69 (40-80)
		1996	81	99	80
		Farfield (B5)			
		Preoperational	95 (60-100)	98 (65-100)	95 (80-98)
		Operational	78 (60-100)	86 (52-100)	90 (67-100)
		1996	81	92	67
	Fucoid Species (%F)				
		Nearfield (B1)			
		Preoperational	94 (69-100)	88 (75-100)	81 (38-94)
		Operational	92 (56-100)	100 (81-100)	87 (56-100)
		1996	97	100	94
		Farfield (B5)			
		Preoperational	85 (62-100)	85 (69-100)	91 (62-100)
		Operational	84 (75-94)	82 (62-94)	85 (63-88)
		1996	75	75	72

(continued)

Table 6-10. (Continued)

ZONE[b]	TAXA (DATA TYPE[c])	AREA (STATION)	APR	JUL	DEC
Chondrus Zone					
	Chondrus crispus (%F)				
		Nearfield (B1)			
		Preoperational	45 (20-53)	34 (20-38)	45 (28-53)
		Operational	42 (17-59)	24 (3-49)	41 (25-68)
		1996	50	49	68
		Farfield (B5)			
		Preoperational	45 (0-72)	48 (41-55)	41 (39-48)
		Operational	44 (31-59)	43 (15-65)	54 (39-59)
		1996	61	53	55
	Mastocarpus stellatus (%F)				
		Nearfield (B1)			
		Preoperational	47 (21-69)	66 (65-71)	48 (32-67)
		Operational	41 (31-59)	62 (16-74)	47 (31-73)
		1996	52	72	56
		Farfield (B5)			
		Preoperational	47 (0-53)	51 (41-63)	44 (43-56)
		Operational	37 (20-49)	45 (22-63)	30 (21-45)
		1996	20	34	28
	Corallina officinalis (%F)				
		Farfield (B5)			
		Preoperational	30 (15-57)	52 (33-61)	52 (31-65)
		Operational	59 (49-77)	61 (55-74)	65 (45-72)
		1996	77	74	72

[a]Median and range for preoperational and operational periods (based on annual means) and annual mean for 1996.

[b]Bare Ledge: approximately mean high water;
Fucoid Ledge: approximately mean sea level;
Chondrus Zone: approximately mean low water.

[c]Data Type %F = Percent frequency of occurrence based on point contact line sampling.
%C = Percent coverage of substratum based on fixed 0.25 m^2 quadrats.

[d]Includes all *Fucus* spp. and *Ascophyllum nodosum*.

[e]Preoperational period = 1982-1989

[f]Operational period = 1991-1996

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). It is not uncommon for these algae to be absent during an entire year. In 1996 these species occurred in April and July at B1 (nearfield) and only in April at B5 (farfield; Table 6-10). This is the first time these species have occurred at either station in any year in July.

A distinct horizontal band of fucoids delineates the mid-intertidal zone (Fucoid Ledge, or MSL) 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 (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 substratum cover and percent frequency of occurrence (Table 6-10). 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 did not change substantially between the preoperational and operational periods during July or December, but declined modestly in April at both stations. Percent cover at farfield Station B5 in December 1996 (67%) was the lowest recorded during any year at that station. However, percent frequency of occurrence in December at B5 was typical of past years (Table 6-10). Overall, percent frequency of occurrence was similar between stations and during both the preoperational and operational periods, and frequencies recorded in 1996 were within ranges for previous years at both stations.

The low intertidal or *Chondrus* zone (MLW) 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 6-10). Operational medians were lower than preoperational medians at both stations during each month, except in December at Station B5, when the operational median exceeded the preoperational range (Table 6-10). The frequencies of *C. crispus* observed in 1996 were generally higher than typically observed, with overall high values recorded in July and December at Station B1. The April 1996 value observed at Station B5 was the highest for the operational period at that station (61%), but still within the preoperational range.

At Station B1, the percent frequency of occurrence of *Mastocarpus stellatus* in 1996 was higher than preoperational and operational medians in each month, while the percent frequencies recorded at Station B5 in 1996 were lower than period means in each month (Table 6-10). At both stations, the 1996 observations were within the range of previous years' observations. During both periods and in 1996, *M. stellatus* was generally more common in the nearfield area than in the farfield area.

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 6-10). The frequency of occurrence of this species has increased throughout the operational period, such that operational medians exceeded preoperational medians in each month. Frequencies observed in 1996 were the highest observed over all years, in each month.

6.3.2 <u>Marine Macrofauna</u>

6.3.2.1 Horizontal Ledge Communities

<u>Number of Taxa and Total Density</u>

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 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), although the distinction was less apparent in 1996 because of the relatively low numbers at the subtidal stations (Table 6-11). In contrast, total faunal density was highest at the intertidal and shallow subtidal stations, and lowest densities were observed at the deep subtidal stations.

The mean number of taxa collected at the nearfield intertidal site (B1MLW) in 1996 was similar to the preoperational period mean. At B5MLW (farfield) the number of taxa collected in 1996 was the lowest to date. On average, fewer taxa were collected at B1MLW than at B5MLW during the operational period (Table 6-11). Overall, the number of taxa collected in the intertidal zone was not significantly different between periods, and there were no significant differences between stations (Table 6-12). Total faunal density at both intertidal stations increased substantially between 1995 (NAI 1996) and 1996 (Table 6-11). However, there was no significant difference in overall intertidal density between periods (Table 6-12). Although nearfield densities exceeded farfield densities over both periods, these differences were not significant. The interaction term in the ANOVA results was not significant (Table 6-12).

Mean numbers of taxa collected at both shallow subtidal stations (B17 and B35) in 1996 (Table 6-11) were lower than in the preoperational and operational periods (Table 6-11). Over both stations combined, however, no significant difference between preoperational and operational period means was detected and there were no significant differences between stations (Table 6-12). The interaction term in the ANOVA results was not significant (Table 6-12). Total faunal density was reduced in 1996 from that measured in 1995 (NAI

Table 6-11. Preoperational and Operational Arithmetic Means and Coefficients of Variation (CV,%) and 1996 Means of the Number of Taxa Collected, and Geometric Mean Densities and Coefficients of Variation for Non-Colonial Macrofauna Collected in August at Intertidal, Shallow Subtidal, Mid-Depth and Deep Stations. Seabrook Operational Report, 1996.

DEPTH ZONE	STATION	PREOPERATIONAL[a]		1996	OPERATIONAL[b]	
		MEAN	CV	MEAN	MEAN	CV
MEAN NO. OF TAXA (per 0.0625 m^2)						
Intertidal	B1MLW	49	18.5	45	38	16.5
	B5MLW	48	16.5	35	41	10.0
Shallow subtidal	B17	58	11.4	41	60	14.5
	B35	55	9.0	40	51	14.2
Mid-depth	B16	70	11.8	41	67	19.5
	B19	68	18.3	50	65	19.1
	B31	51	16.5	32	50	25.9
Deep	B04	63	13.8	45	68	25.6
	B13	54	13.9	39	53	23.6
	B34	64	22.0	34	59	25.7
TOTAL FAUNAL DENSITY (#/m^2)						
Intertidal	B1MLW	122795	5.3	229214	99042	7.0
	B5MLW	68684	5.1	39773	63736	6.5
Shallow subtidal	B17	23373	4.6	10826	21250	6.1
	B35	28372	4.6	8406	24618	8.0
Mid-depth	B16	31590	6.0	6896	15830	7.4
	B19	12785	6.7	10698	13270	6.3
	B31	16240	11.4	5563	12625	5.9
Deep	B04	4936	5.7	2137	4845	9.4
	B13	6073	10.5	2926	11482	11.8
	B34	5523	9.3	2299	5366	8.9

[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: 1990-1996.

Table 6-12. **Analysis of Variance Results for Number of Macrofaunal Taxa (per 0.0625 m²) and Total Macrofaunal Density (per m²) Collected in August at Intertidal (1982-1996) and Shallow (1982-1996), Mid-Depth (1980-1984; 1986-1996), and Deep Subtidal Stations (1979-1984; 1986-1996). Seabrook Operational Report, 1996.**

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	2989.46	5.43 NS	
		Station[b]	1	0.87	<0.01 NS	
		Year (Preop-Op)[c]	17	418.37	4.27**	
		Preop-Op X Station[d]	1	211.33	2.17 NS	
		Station X Year (Preop-Op)[e]	13	97.69	1.53 NS	
		Error	132	63.88		
	Shallow Subtidal (B17, B35)	Preop-Op	1	45.80	0.07 NS	
		Station	1	1227.11	3.82 NS	
		Year (Preop-Op)	17	353.72	4.51**	
		Preop-Op X Station	1	321.50	4.11 NS	
		Station X Year (Preop-Op)	13	78.33	1.06 NS	
		Error	132	74.23		
	Mid-depth (B16, B19, B31)	Preop-Op	1	239.80	0.23 NS	
		Station	2	8169.68	212.01**	B16 B19 B31
		Year (Preop-Op)	17	1236.36	4.77***	
		Preop-Op X Station	2	40.49	0.16 NS	
		Station X Year (Preop-Op)	31	260.70	2.53***	
		Error	211	103.07		
	Deep (B04, B34, B13)	Preop-Op	1	5.04	<0.01 NS	
		Station	2	3084.13	7.33 NS	
		Year (Preop-Op)	16	1775.82	7.14***	
		Preop-Op X Station	2	419.18	1.69 NS	
		Station X Year (Preop-Op)	31	248.73	2.12***	
		Error	212	117.45		

(Continued)

Table 6-12. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	df	MS	F[a]	MULTIPLE COMPARISONS[f] (Ranked in decreasing order)
Total Faunal Density	Intertidal (B1MLW, B5MLW)	Preop-Op	1	0.17	0.54 NS	
		Station	1	1.66	84.63 NS	
		Year (Preop-Op)	17	0.55	2.21 NS	
		Preop-Op X Station	1	0.02	0.08 NS	
		Station X Year (Preop-Op)	13	0.25	5.74***	
		Error	132	0.04		
	Shallow Subtidal (B17, B35)	Preop-Op	1	0.11	0.29 NS	
		Station	1	0.24	23.01 NS	
		Year (Preop-Op)	17	0.47	5.09**	
		Preop-Op X Station	1	0.01	0.11 NS	
		Station X Year (Preop-Op)	13	0.09	1.93*	
		Error	132	0.05		
	Mid-depth (B16, B19, B31)	Preop-Op	1	1.04	1.01 NS	
		Station	2	1.26	2.50 NS	
		Year (Preop-Op)	17	0.82	2.76**	
		Preop-Op X Station	2	0.50	1.67 NS	
		Station X Year (Preop-Op)	31	0.30	3.76***	
		Error	211	0.07		
	Deep (B04, B34, B13)	Preop-Op	1	0.51	0.32 NS	
		Station	2	1.30	2.36 NS	
		Year (Preop-Op)	16	1.30	4.80***	
		Preop-Op X Station	2	0.55	2.02 NS	
		Station X Year (Preop-Op)	31	0.27	4.19***	
		Error	212	0.06		

[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 Preop-Op.
[f]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).
[g]Waller-Duncan multiple means comparison test used for significant main effects. LS means used for interaction term. Underlining indicates no significant difference (α=0.05).

1996) and lower than the preoperational and operational period means for both shallow subtidal stations (Table 6-11). Faunal densities were not significantly different between periods within this depth zone (Table 6-12). In both periods, farfield densities exceeded nearfield densities, but these differences were not significant. Because of this consistency, the interaction term of the ANOVA results was not significant (Table 6-12).

Mean numbers of taxa collected at two of the mid-depth stations (B16 and B31) were lower in 1996 (Table 6-11) than in 1995 (NAI 1996). Mean numbers of taxa at all three mid-depth stations in 1996 were less than the preoperational and operational period means (Table 6-11). The number of taxa collected at each station was similar between periods (Table 6-11), and overall there was no significant difference in the number of taxa collected in this zone between periods (Table 6-12). The numbers of taxa collected at the intake (B16) and discharge (B19) stations were similar in both periods, and were significantly greater than those collected at the farfield (B31) station (Tables 6-11, 6-12). Because of the consistency of these relationships, the interaction term of the ANOVA results was not significant (Table 6-12). Total faunal densities were lower in 1996 at B16 and B31 (Table 6-11) than in 1995 (NAI 1996). Densities at all mid-depth stations were lower in 1996 than preoperational and operational period means (Table 6-11). No significant differences among the station means between periods (Preop-Op X Station interaction term) were observed (Table 6-12).

The mean number of taxa collected at the deep water stations (B04, B13, and B34) in 1996 was less than in the preoperational and operational periods (Table 6-11). However, there were no significant differences between periods (Table 6-12). Over both periods, the number of taxa collected at the nearfield (discharge) station was highest, and the number collected at the intake station (B13) was the lowest, but these differences were not statistically significant (Table 6-12). As these relationships were consistent in both periods, the Preop-Op X Station interaction term was not significant (Table 6-12). Total faunal densities were similar among the three stations during the preoperational period and in 1996, although the operational period mean density at the intake station (B13) was more than double the preoperational and operational period densities at the other two stations (Table 6-11). Total faunal densities at the intake station (B13) have been substantially higher than at the other deep stations frequently, but not consistently, during the preoperational and operational periods (NAI 1996). No significant differences were observed in the ANOVA results for the interaction term (Preop-Op X Station; Table 6-12).

Macrofaunal Community Analysis

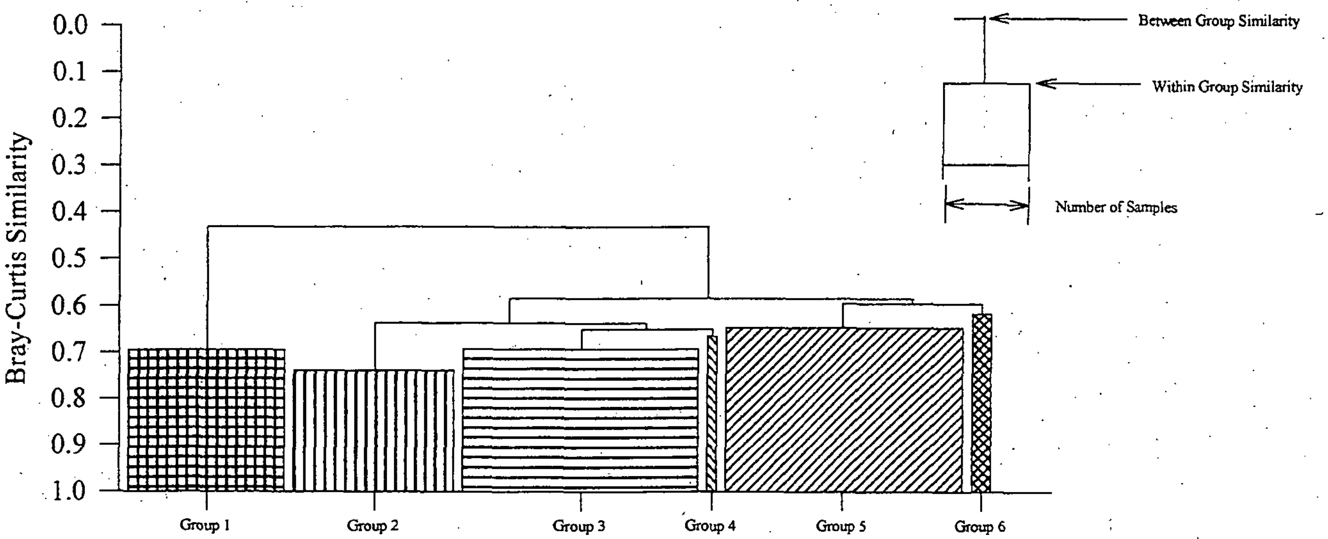
The noncolonial macrofauna associated with hard substrata in the vicinity of Seabrook Station comprise a diverse community. Over 400 taxa have been collected in August destructive samples since 1978, some with densities of over 100,000 individuals/m^2. Very few of these animals are "habitat formers" (cf. macroalgal section), and most are motile. The faunal species assemblages, therefore, are not as distinct as those of the algae. 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 175 station/year collections are illustrated in Figure 6-10.

As with the macroalgal collections (Figure 6-6), the macrofaunal assemblage at intertidal stations (B1MLW and B5MLW) comprised a distinct entity (Group 1; Figure 6-10), characterized by extremely high densities of mytilid spat (ca. 50,000-70,000 individuals/m^2; Table 6-13). These mussels accounted for about 65% 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., and oligochaetes 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 *J. marina*, *N. lapillus* and *T. minuta*, this group separated from other groups because of very low densities of primarily 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 6-10 and Table 6-13). *Lacuna vincta* was the most abundant species at the shallow subtidal stations (ca. 5,000-7,000/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 spat were dominants at these stations (ca. 3,000-5,000/m^2), although their densities declined between periods, and 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, Calliopius laeviusculus, Ischyrocerus anguipes*, and *Jassa marmorata*; the caprellid amphipod *Caprella septentrionalis*; and echinoderms in the family Asteriidae) exhibited consistent densities between preoperational and operational periods (Table 6-13).

Group 3 included most collections from mid-depth intake Station B16, mid-depth discharge Station B19 and mid-depth farfield Station B31 (Table 6-13). Group 3 dominant taxa included species identified as among the most abundant in the other groups. In addition, both the bivalve *Anomia* sp. and the pycnogonid arthropod *Achelia spinosa* were relatively abundant at the mid-depth stations. 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 again dominant in Group 3 at similar densities as the shallow subtidal assemblage, but *Lacuna vincta*, which was dominant in Group 2, was present at much lower densities.

Collections from mid-depth intake (B16) and farfield (B31) stations in 1996 formed a separate group (Group 4) most closely related to Group 3. The faunal community in this small group was composed of the same taxa as those dominating Group 3, but abundances varied between the groups (Table 6-13). In particular, *Caprella septentrionalis* was higher in abundance and



Group 1 - Intertidal: B1MLW (1978-1996); B5MLW (1982-1996)
Group 2 - Shallow Subtidal: B17 (1978-1989, 1991-1996); B35 (1982-1996);Mid-depth: B16(1982)
Group 3 - Shallow Subtidal: B17 (1990)
Mid-depth: B16 (1980-1981, 1983-1984, 1986-1995); B19 (1979-1996); B31 (1979-1988, 1990-1995)
Group 4 - Mid-depth: B16 (1996), B31 (1996)
Group 5 - Mid-depth: B31 (1989)
Deep: B04 (1979,1981-1984,1986-1996);B13 (1978-1981,1983-1984,1986-1996); B34 (1979, 1981-1984,1986-1996)
Group 6 - Mid-depth: B19 (1978); B31 (1978)
Deep: B04 (1978); B34 (1980)

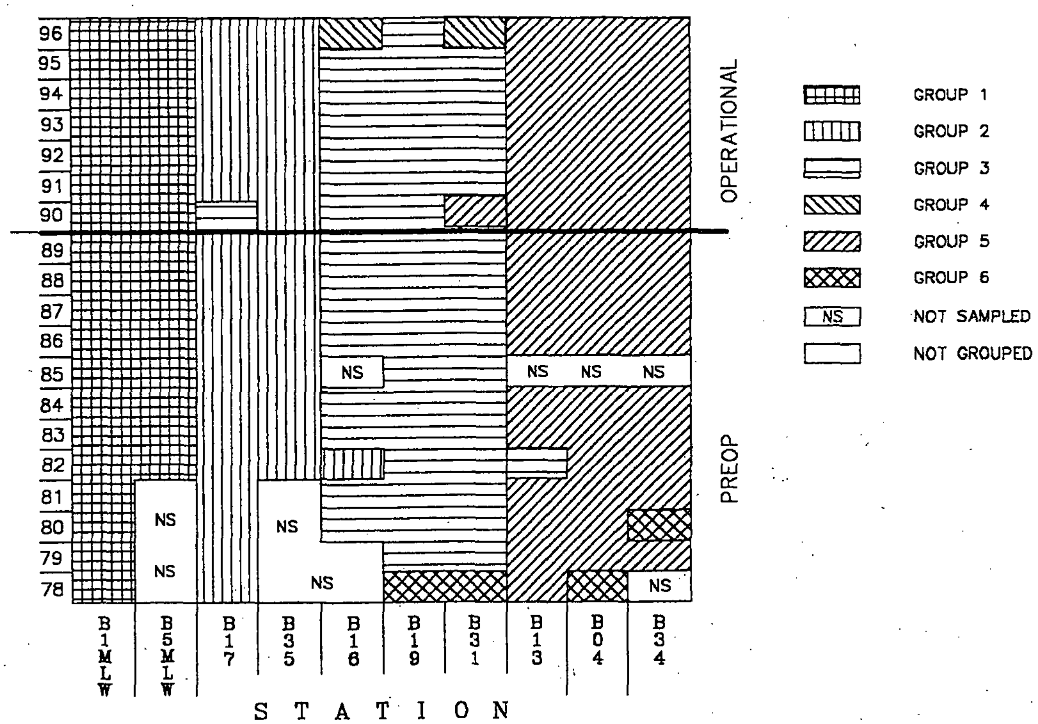


Figure 6-10. Dendrogram and annual station groups formed by numerical classification of August collections of marine macrofauna, 1978-1996. Seabrook Operational Report, 1996.

Table 6-13. **Station Groups Formed by Cluster Analysis with Preoperational and Operational (1990-1996) Geometric Mean Density (per m^2) and 95% Confidence Limits of Dominant Macrofauna Taxa (Non-Colonial) Collected Annually in August from 1978 Through 1996. Seabrook Operational Report, 1996.**

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	32240	55639	96021
	Nearfield (BIMLW; 1978-96)		*Lacuna vincta*	2035	3209	5060	2565	4068	6451
	Farfield (B5MLW; 1982-96)		*Turtonia minuta*	1367	2707	5360	764	1436	2701
			Jaera marina	2116	3626	6216	498	835	1400
			Hiatella sp.	1464	2604	4631	577	1189	2450
			Nucella lapillus	925	1501	2432	706	1332	2512
			Oligochaeta	1203	2030	3423	210	586	1630
2	Shallow Subtidal	0.74/0.64	*Lacuna vincta*	3512	5052	7268	5236	7409	10484
	Nearfield (B17; 1978-89, 1991-96)		Mytilidae	3128	5112	8353	1191	2867	6900
	Farfield (B35; 1982-96)		*Idotea phosphorea*	1679	2125	2690	1154	1611	2249
	Mid-Depth		*Pontogeneia inermis*	1320	1987	2991	772	1330	2292
	Inkake (B16; 1982)		*Jassa marmorata*	1150	1632	2316	400	931	2170
			Caprella septentrionalis	509	797	1247	310	468	706
			Asteriidae	392	599	914	281	596	1263
			Idotea balthica	324	689	1463	217	430	851
			Calliopius laeviusculus	372	537	775	173	391	879
			Ischyrocerus anguipes	345	596	1031	138	306	675
3	Mid-Depth	0.69/0.65	Mytilidae	3040	5356	9436	2879	5039	8819
	Intake (B16; 1980-81, 1983-84, 1986-95)		*Pontogeneia inermis*	1076	1621	2441	838	1274	1938
	Discharge (B19; 1979-96)		*Caprella septentrionalis*	721	1068	1584	918	1562	2657
	Farfield (B31; 1979-88, 1990-95)		*Anomia* sp.	496	732	1080	528	796	1201
	Shallow		*Hiatella* sp.	426	644	975	305	461	695
	Nearfield (B17; 1990)		*Lacuna vincta*	266	388	566	496	789	1257
			Asteriidae	189	272	392	197	333	564
			Achelia spinosa	104	171	282	125	243	471
4	Mid-Depth	0.67/0.65	*Caprella septentrionalis*	--	--	--	281	3053	33073
	Intake (B16; 1996)		*Anomia* sp.	--	--	--	0	809	5.00E7
	Farfield (B31; 1996)		*Pontgeneia inermis*	--	--	--	10	748	53198
			Lacuna vincta	--	--	--	146	593	2408
			Mytilidae	--	--	--	0	439	7.71E5
			Hiatella sp.	--	--	--	0	196	1.62E6
			Asteriidae	--	--	--	7	168	3750
			Ischyrocerus anguipes	--	--	--	0	144	1.48E5
			Idotea phosphorea	--	--	--	0	109	7.37E6

(continued)

Table 6-13. (Continued)

GROUP NO.	NAME/LOCATION (STATION/YEARS)	SIMILARITY (WITHIN/ BETWEEN GROUP)	DOMINANT TAXA	PREOPERATIONAL			OPERATIONAL		
				LCL	MEAN	UCL	LCL	MEAN	UCL
5	Deep	0.65/0.60	*Anomia* sp.	200	312	484	341	506	751
	Intake (B13; 1978-81, 1983-84, 1986-96)		Mytilidae	144	269	502	171	371	801
	Discharge (B04; 1979-84, 1986-96)		*Pontogeneia inermis*	219	303	420	146	238	387
	Farfield (B34; 1979, 1981-84, 1986-96)		Asteriidae	177	234	310	243	286	336
	Mid-depth		*Hiatella* sp.	96	180	337	120	280	650
	Farfield (B31; 1989)		*Caprella septentrionalis*	105	156	231	117	172	252
			Tonicella rubra	128	154	184	66	82	103
			Balanus crenatus	12	53	226	61	268	1175
			Musculus niger	63	99	155	54	78	114
			Achelia spinosa	57	87	131	34	59	102
6	Mid-depth	0.62/0.60	*Pontogeneia inermis*	83	817	7986	--	--	--
	Discharge (B19; 1978)		*Caprella septentrionalis*	149	235	369	--	--	--
	Farfield (B31; 1978)		Asteriidae	96	221	507	--	--	--
	Deep		*Anomia* sp.	84	211	528	--	--	--
	Discharge (B04; 1978)		*Hiatella* sp.	19	166	1365	--	--	--
	Farfield (B34; 1980)		*Lacuna vincta*	36	158	670	--	--	--
			Mytilidae	3	148	5052	--	--	--
			Strongylocentrotus droebachiensis	20	79	310	--	--	--
			Tonicella rubra	7	55	381	--	--	--
			Musculus niger	10	54	281	--	--	--
			Ampithoe rubricata	23	50	105	--	--	--
			Achelia spinosa	23	49	104	--	--	--
			Ophiura sp.	3	47	591	--	--	--

Mytilidae was lower in abundance in Group 4 compared to Group 3. No preoperational period collections were present in this group.

Group 5 contained most collections from deep intake Station B13, deep discharge Station B04, and deep farfield Station B34 (Figure 6-10 and Table 6-13). The assemblage was characterized by low mean densities ($<600/m^2$) of the dominant taxa (including *Anomia* sp., Mytilidae, and *Pontogeneia inermis*) in both preoperational and operational periods. Means and 95% confidence intervals were similar for the dominant taxa in both periods.

Several preoperational period collections from mid-depth (1978 discharge B19 and farfield B31) and deep (1978 discharge B04 and 1980 farfield B34) stations formed a separate group (Group 6) that was closely related to Group 5. The primary distinction between the two groups was due to the higher abundances of *Pontogeneia inermis* and the presence of *Lacuna vincta* as a dominant in Group 6. No operational period collections were present in this group.

In general, macrofaunal collections made at stations located in the same depth strata (i.e., intertidal, shallow subtidal, etc.) clustered together. The collections made during the operational years (1990-1996) at each station were similar enough to be grouped with the majority, if not all, of those made in the preoperational years, with the primary exception of the 1996 collections at mid-depth stations B16 and B31. This is the first operational year that these stations differed from the rest of the preoperational or operational collections. In addition, the change occurred in both the nearfield and the farfield. It is unlikely, then, that the difference in community structure is attributable to the operation of Seabrook Station. The similarity of the benthic communities at other stations in 1996 to overall preoperational and operational periods indicates that no nearfield-farfield or temporal changes to the macrofaunal community have resulted from operation of Seabrook Station.

__Intertidal Communities (Non-Destructive Monitoring Program)__

Faunal abundance patterns on local rocky shores exhibit zonation patterns 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. and *Semibalanus* 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); similarly, temporal variability in barnacle frequency of occurrence has been observed in Seabrook study quadrats (Table 6-14). 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, preoperational and operational measurements were similar at each station,

Table 6-14. Percent Frequency of Occurrence of Dominant Macrofauna at Fixed Intertidal Non-Destructive Sites During the Preoperational and Operational Periods and in 1996. Seabrook Operational Report, 1996.

ZONE	TAXA	AREA (STATION)	APR	JUL	DEC
Bare Ledge					
	Balanus/Semibalanus complex				
		Nearfield (B1)			
		Preoperational[a]	61 (1-100)	41 (9-79)	9 (0-63)
		Operational[a]	41 (12-90)	63 (0-98)	35 (1-81)
		1996[b]	12	28	22
		Farfield (B5)			
		Preoperational	89 (58-100)	85 (24-100)	72 (5-88)
		Operational	86 (36-95)	67 (13-87)	9 (0-54)
		1996	80	72	4
	Littorina saxatilis				
		Nearfield (B1)			
		Preoperational	7 (0-44)	57 (0-88)	16 (0-88)
		Operational	31 (0-56)	81 (0-100)	25 (0-100)
		1996	0	19	0
		Farfield (B5)			
		Preoperational	50 (0-100)	66 (0-94)	75 (0-100)
		Operational	22 (0-81)	25 (0-69)	22 (0-81)
		1996	19	0	13
Fucoid Ledge					
	Mytilidae				
		Nearfield (B1)			
		Preoperational	72 (21-100)	76 (27-100)	78 (43-100)
		Operational	56 (23-91)	72 (11-99)	65 (19-95)
		1996	56	68	72
		Farfield (B5)			
		Preoperational	8 (2-100)	1 (0-88)	8 (0-100)
		Operational	10 (5-24)	14 (0-77)	11 (0-63)
		1996	24	14	14
	Littorina obtusata				
		Nearfield (B1)			
		Preoperational	6 (0-19)	10 (0-25)	6 (0-19)
		Operational	6 (0-31)	25 (0-62)	9 (0-81)
		1996	13	31	6
		Farfield (B5)			
		Preoperational	3 (0-50)	16 (0-38)	16 (0-69)
		Operational	15 (0-25)	35 (25-50)	25 (0-56)
		1996	19	28	9

(continued)

Table 6-14. (Continued)

ZONE	TAXA	AREA (STATION)	APR	JUL	DEC
Chondrus Zone					
	Mytilidae				
		Nearfield (B1)			
		Preoperational	90 (54-95)	89 (71-95)	65 (15-85)
		Operational	81 (26-95)	74 (14-95)	65 (48-93)
		1996	84	95	74
		Farfield (B5)			
		Preoperational	49 (10-72)	63 (23-80)	26 (0-49)
		Operational	52 (0-88)	81 (27-92)	46 (8-87)
		1996	77	82	68
	Nucella lapillus				
		Nearfield (B1)			
		Preoperational	75 (13-100)	100 (100-100)	56 (31-88)
		Operational	31 (19-81)	100 (94-100)	38 (9-100)
		1996	31	100	9
		Farfield (B5)			
		Preoperational	94 (75-100)	38 (13-56)	69 (56-81)
		Operational	86 (37-100)	78 (37-94)	45 (19-94)
		1996	78	69	34
	Littorina littorea				
		Nearfield (B1)			
		Preoperational	0 (0-0)	0 (0-13)	0 (0-6)
		Operational	3 (0-19)	16 (0-38)	12 (0-50)
		1996	19	13	6
		Farfield (B5)			
		Preoperational	81 (75-100)	100 (94-100)	88 (44-94)
		Operational	91 (78-100)	100 (81-100)	75 (56-94)
		1996	78	81	88
	Acmaea testudinalis				
		Nearfield (B1)			
		Preoperational	13 (6-38)	13 (0-25)	13 (6-81)
		Operational	27 (0-44)	12 (6-25)	12 (0-81)
		1996	34	6	25
		Farfield (B5)			
		Preoperational	0 (0-44)	0 (0-13)	0 (0-25)
		Operational	12 (6-13)	6 (0-25)	6 (0-44)
		1996	13	6	6

[a]preoperational and operational period median and range percent frequency
[b]1996 mean percent frequency

with values somewhat higher at farfield Station B5 compared to nearfield Station B1 (Table 6-14). Measurements made in 1996 indicated that, compared to operational and preoperational median values, barnacle densities were lower in April and December at both B1 and B5. Barnacle densities observed in 1996 fell within previously observed ranges, however.

The herbivorous snail, *Littorina saxatilis*, is an important grazer in the high intertidal zone. Like barnacles, abundances of *L. saxatilis* displayed great seasonal and year-to-year variability during the preoperational and operational periods at both stations (Table 6-14). Densities of *L. saxatilis* continued to be reduced in 1996 as was observed in 1995 (NAI 1996), although densities were within the range previously observed in both the preoperational and operational periods.

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 percent frequencies (preoperational, operational, and 1996) exceeding 50% for all sampling periods (Table 6-14). The preoperational and operational seasonal median frequencies were all less than 15% at farfield Station B5, with similar values in July and December 1996. April 1996 values reached an operational period high, but were within the preoperational period range and below the values observed at nearfield Station B1. Mussels are typically outcompeted by barnacles at B5 (NAI 1993). Operational period ranges generally fell within preoperational period ranges at both stations, with operational period medians slightly lower than preoperational period medians in all sampling periods at nearfield Station B1 and higher at farfield Station B5.

The herbivorous snail *Littorina obtusata* is a common mid-intertidal resident at both stations. Overall, operational period frequencies were generally higher than those during preoperational years, a trend which was apparent at both nearfield and farfield stations (Table 6-14). Frequencies in 1996 were within or above ranges observed during the preoperational period at both stations except in July, where frequencies exceeded the preoperational ranges only at Station B1, as it had in 1995 (NAI 1996).

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 zone (Table 6-14). Frequency of occurrence estimates during 1996 at nearfield Station B1 were at or above the preoperational and operational period median values, recovering from the unusually low values observed in 1995 (NAI 1996). At the farfield station (B5), abundances in 1996 were higher than the medians for both operational and preoperational periods. 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 6-14). 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 80% frequency of occurrence during both preoperational and operational periods (Table 6-14). Frequencies at the nearfield station (B1) never exceeded 50% during this study, and many times, *L. littorea* was absent from the nearfield study site. 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. The occurrence of *L. littorea* in 1996 was higher than in the preoperational period, reflecting the same pattern of distribution previously observed. Another low intertidal grazer, the limpet *Acmaea testudinalis*, occurred in low to moderate frequencies in most years at nearfield Station B1 and was less common at farfield Station B5 (Table 6-14). Operational period ranges for individual months were generally similar to preoperational ranges. Within each station, preoperational and operational ranges for the year were identical (0-81% at B1, 0-44% at B5). Seasonal and spatial distribution patterns observed in 1996 for *A. testudinalis* were similar to historical patterns.

<u>Subtidal Fouling Community (Bottom Panel Monitoring Program)</u>

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* sp. complex, *Anomia* sp., *Hiatella* sp., 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 6-15).

Subtidal barnacles in the Seabrook area are represented primarily by two species, *Balanus crenatus* and *Semibalanus balanoides*. Peak settlement usually occurs in early spring, often resulting in highest densities in the January-April exposure period, as occurred in 1996 (Table 6-15). However, settlement can be protracted and variable from year to year. For example, substantial densities of barnacles were found at both nearfield and farfield stations in August 1995 (NAI 1996) and 1996, 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, and this relationship continued in 1996 (Table 6-15).

Anomia sp. (jingle shells) consistently display peak settlement during the September-December exposure period, a period when water temperatures are rapidly cooling (cf. Fuller 1946).

Table 6-15. **Estimated Density (per 0.25 m²) 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 1981-1996 (Except 1985). Seabrook Operational Report, 1996.**

TAXA	STATION	PERIOD/YEAR	APRIL MEAN	APRIL CV[c]	AUGUST MEAN	AUGUST CV	DECEMBER MEAN	DECEMBER CV	ALL SEASONS MEAN	ALL SEASONS CV
Balanus sp.	Nearfield	Preop[a]	17053	81	6403	78	9	144	7822	110
	(B19)	Op[b]	14277	120	11281	59	508	237	8689	135
		1996	40933	-	8184	-	0	-	16372	132
	Farfield	Preop	40962	55	7917	78	14	121	16298	133
	(B31)	Op	24864	113	11689	56	239	107	12264	153
		1996	78500	-	16884	-	591	-	31992	128
Anomia sp.	Nearfield	Preop	<1	<1	31	219	1232	92	421	167
	(B19)	Op	44	170	53	105	1878	122	658	233
		1996	0	-	1	-	336	-	112	172
	Farfield	Preop	0	0	36	117	993	125	343	164
	(B31)	Op	8	99	76	171	1182	94	422	194
		1996	0	-	33	-	1088	-	374	166
Hiatella sp.	Nearfield	Preop	1	200	3966	65	27	115	1331	171
	(B19)	Op	2	107	5082	87	8	120	1697	203
		1996	0	-	1038	-	0	-	346	173
	Farfield	Preop	<1	<1	11659	91	16	131	3892	173
	(B31)	Op	2	99	10507	94	61	204	3523	209
		1996	0	-	1146	-	0	-	382	173
Mytilidae	Nearfield	Preop	2	150	367	67	58	98	142	139
	(B19)	Op	63	120	1981	102	37	56	694	208
		1996	61	-	77	-	2	-	47	85
	Farfield	Preop	8	138	5035	200	36	100	1693	171
	(B31)	Op	17	120	3229	84	46	85	1097	195
		1996	21	-	2685	-	13	-	906	170

[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 = 1991-96

Nearfield (B19) densities exceeded farfield (B31) densities in both the preoperational and operational periods (Table 6-15). However, this relationship was reversed in 1994 through 1996 (NAI 1995, 1996; Table 6-15). *Anomia* sp. densities were higher in the operational period than the preoperational period at both stations.

Another species of interest is the small crevice-seeking bivalve, *Hiatella* sp., which historically has settled during the May-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 (Table 6-15). In 1996, densities were similar at both stations and below preoperational and operational period means.

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* sp., i.e., peak recruitment occurred during the May-August exposure period, with densities typically higher at the farfield station than the nearfield station in both the preoperational and operational periods (Table 6-15). Temporal and spatial recruitment patterns observed in 1996 were similar to those of past years.

6.3.2.2 Selected Benthic Species

Mytilidae

Representatives of the family 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, the bivalve family 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 6-16). Annual mytilid 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 (Petraitis 1991). For example, 1993 mytilid densities were higher than other operational years (NAI and NUS 1994); in 1994 (NAI 1995) and 1995 (NAI 1996) they were generally lower. Abundances were again higher in 1996 at both intertidal stations. There were no significant differences in mytilid abundances either between operational periods or between intertidal stations (Table 6-17). No significant Preop-Op X Station interaction was detected for the intertidal stations.

Mytilids were also among the dominant taxa at shallow subtidal Stations B17 and B35 (Table 6-16). As in the case of the intertidal stations, substantial recent year-to-year variability in mytilid density was observed at the shallow subtidal stations. Densities higher than preoperational or operational period means that

Table 6-16. Geometric Mean Densities (No./m^2) and Coefficients of Variation (CV,%) of Selected Benthic Macrofauna Species Collected During Preoperational and Operational Periods and During 1996. Seabrook Operational Report, 1996.

TAXON	STATION[a]	PREOPERATIONAL[b]		1996	OPERATIONAL[c]	
		MEAN	CV	MEAN	MEAN	CV
Mytilidae	B1MLW	121297	8	230914	90021	10
	B5MLW	72831	7	39316	34140	12
	B17	2580	18	882	2012	23
	B35	4449	14	1933	4453	21
	B19	1947	23	3036	1782	29
	B31	6196	17	713	3066	16
Nucella lapillus	B1MLW	1970	11	1048	1357	15
	B5MLW	905	10	491	807	14
Asteriidae	B17	590	12	764	746	10
	B35	184	23	303	199	28
Pontogeneia inermis	B19	604	15	137	368	22
	B31	404	15	89	224	25
Jassa marmorata	B17	1045	14	332	689	18
	B35	1888	15	346	1625	18
Ampithoe rubricata	B1MLW	19	92	11	3	90
	B5MLW	3	125	173	141	11
Strongylocentrotus droebachiensis	B19	66	36	199	110	28
	B31	31	35	43	41	31
Modiolus modiolus[d]	B19	100	14	96	79	22
	B31	89	27	56	75	44

[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, 1991-1996, for all stations.
[d]Arithmetic mean of annual means. Preop = 1980-1989, Op = 1991-1996.

were observed in 1993 (NAI and NUS 1994) were followed by substantial declines in 1994 (NAI 1995) and 1995 (NAI 1996). Densities continued to be lower than average in 1996 (Table 6-16). There were no significant differences in abundances between the two shallow subtidal stations, between preoperational and operational periods or in the Preop-Op X Station interaction (Table 6-17).

Mytilids were also abundant at mid-depth stations (B19, B31) relative to other taxa collected at these locations (Table 6-16). Densities at nearfield Station B19 recovered in 1996 to previously observed levels although they continued to be low at farfield Station B31. There were no significant differences in abundance between the two mid-depth stations, between preoperational and operational periods or in the Preop-Op X Station interaction (Table 6-17).

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 this study ranged from 1 to 25 mm, with the majority collected as newly settled spat measuring 2 to 3 mm. Mytilids generally have been largest in the intertidal zone, a trend which has been consistent over both periods (Table 6-18). Intertidal mytilids typically were slightly larger at the farfield station (B5MLW) than at the nearfield station (B1MLW) during the preoperational period, but averaged the same length at both stations in the operational period. In 1996, mytilids were smaller than preoperational and operational averages at both stations.

Mytilids generally were smaller in the subtidal zones than in the intertidal zone. Subtidal operational period mean lengths were similar to preoperational mean lengths at the shallow subtidal stations (B17, B35). There was little difference in mean length between the two stations during 1996, operational years or preoperational years. At mid-depth stations (B19, B31), mean lengths of mytilids were larger at the farfield than the nearfield station during both the preoperational and the operational periods. Mean lengths were similar at the two stations in 1996.

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 were similar at nearfield Station B1MLW and farfield Station B5MLW (Tables 6-16 and 6-17). Densities in 1996 were below 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 6-17).

Nucella lapillus shell length measurements from intertidal collections were also made as part of the 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 1996, a trend observed during the preoperational and operational periods (Table 6-18). Operational mean lengths at both stations were below the respective preoperational means, but mean length in 1996 was larger than the preoperational mean at B1MLW.

Table 6-17. Analysis of Variance Results Comparing Log-Transformed Densities of Selected Benthic Taxa Collected in May, August and November at Near- and Farfield Station Pairs During Preoperational (1978 - 1989) and Operational (1991 - 1996) Periods. Seabrook Operational Report, 1996.

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	4.83	2.38 NS	
(<25 mm)	(B1, B5)	Year (Preop-Op)[c]	12	1.72	1.13 NS	
		Month (Year)[d]	28	1.11	10.07***	
		Station[e]	1	9.84	11.77 NS	
		Preop-Op X Station[f]	1	0.84	1.56 NS	
		Station X Year (Preop-Op)[g]	12	0.53	4.84***	
		Error	324	0.11		
	Shallow Subtidal	Preop-Op	1	0.21	0.06 NS	
	(B17, B35)	Year (Preop-Op)	12	4.00	1.30 NS	
		Month (Year)	28	2.69	10.94***	
		Station	1	7.79	33.74 NS	
		Preop-Op X Station	1	0.23	0.35 NS	
		Station X Year (Preop-Op)	12	0.67	2.74**	
		Error	316	0.25		
	Mid-Depth	Preop-Op	1	3.31	0.57 NS	
	(B19, B31)	Year (Preop-Op)	16	6.03	1.67 NS	
		Month (Year)	36	1.90	5.80***	
		Station	1	15.19	8.80 NS	
		Preop-Op X Station	1	1.74	0.82 NS	
		Station X Year (Preop-Op)	16	2.07	6.31***	
		Error	419	0.33		

(continued)

Table 6-17. (Continued)

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	df	MS	F[b]	MULTIPLE COMPARISONS[c] (Ranked in decreasing order)
Nucella lapillus	Intertidal (B1MLW, B5MLW)	Preop-Op	1	0.65	0.55 NS	
		Year (Preop-Op)	12	1.24	1.00 NS	
		Month (Year)	28	1.11	9.37***	
		Station	1	6.90	36.16 NS	
		Preop-Op X Station	1	0.19	0.74 NS	
		Station X Year (Preop-Op)	12	0.26	2.17*	
		Error	324	0.12		
Asteriidae	Shallow Subtidal (B17, B35)	Preop-Op	1	0.97	0.42 NS	
		Year (Preop-Op)	12	2.63	1.72 NS	
		Month (Year)	28	0.96	7.49***	
		Station	1	23.18	62.22 NS	
		Preop-Op X Station	1	0.38	0.53 NS	
		Station X Year (Preop-Op)	12	0.70	5.45***	
		Error	316	0.13		
Pontogeneia intermis	Mid-Depth (B19, B31)	Preop-Op	1	6.16	7.08*	Preop>Op
		Year (Preop-Op)	16	1.22	0.70 NS	
		Month (Year)	36	1.59	6.76***	
		Station	1	4.47	220.93 NS	
		Preop-Op X Station	1	0.03	0.07 NS	
		Station X Year (Preop-Op)	16	0.41	1.74*	
		Error	419	0.24		
Jassa marmorata	Shallow Subtidal (B17, B35)	Preop-Op	1	0.98	0.40 NS	
		Year (Preop-Op)	12	2.92	1.75 NS	
		Month (Year)	28	1.40	4.39***	
		Station	1	9.97	70.64 NS	
		Preop-Op X Station	1	0.14	0.24 NS	
		Station X Year (Preop-Op)	12	0.59	1.86*	
		Error	316	0.32		

(continued)

Table 6-17. (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	48.44	0.75 NS	
		Year (Preop-Op)	12	6.85	2.50*	
		Month (Year)	28	0.94	2.95***	
		Station	1	54.52	0.90 NS	
		Preop-Op X Station	1	60.81	28.14***	B5Op B1Pre B5Pre B1Op
		Station X Year (Preop-Op)	12	2.15	6.70***	
		Error	324	0.32		
Strongylocentrotus droebachiensis	Mid-Depth (B19, B31)	Preop-Op	1	3.15	1.13 NS	
		Year (Preop-Op)	16	3.31	1.61 NS	
		Month (Year)	36	1.68	3.59***	
		Station	1	16.12	67.46 NS	
		Preop-Op X Station	1	0.25	0.29 NS	
		Station X Year (Preop-Op)	16	0.85	1.82*	
		Error	419	0.47		
Strongylocentrotus droebachiensis (from subtidal transect program)[j]	Mid-Depth (B19, B31)	Preop-Op	1	23.00	5.24 NS	
		Year (Preop-Op)	9	3.32	3.63*	
		Month (Year)	22	0.36	1.04 NS	
		Station	1	0.12	0.06 NS	
		Preop-Op X Station	1	1.97	2.18 NS	
		Station X Year (Preop-Op)	9	0.90	2.61*	
		Error	22	0.35		
Modiolus modiolus (adults)	Mid-Depth (B19, B31)	Preop-Op	1	80057.95	203.49 NS	
		Year (Preop-Op)	14	16455.75	0.76 NS	
		Month (Year)	32	4551.51	1.85**	
		Station	1	16805.99	5.15 NS	B31>B19
		Preop-Op X Station	1	3500.81	0.18 NS	
		Station X Year (Preop-Op)	14	19557.30	7.95***	
		Error	1080	2460.18		

[a]Log_{10} (x+1) density, except for *M. modiolus* adults, which was based on untransformed densities.
[b]Preop-Op compares 1982-1989 to 1991-1996 regardless of station for B1MLW/B5MLW and B17/B35.
Preop-Op compares 1978-1989 to 1991-1996 regardless of station for B19/B31.
Preop-Op compares 1980-1989 to 1991-1996 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 Preio-Op.
[h]NS = not significant ($p>0.05$); * = significant ($0.05>p>0.01$); ** = highly significant ($p\leq0.01$); ***= very highly significant ($p\leq0.001$)
[i]Waller-Duncan multiple means comparison test used for significant main effects. LS Means used for interaction term. Underlininig indicates no significant difference (α=0.05).
[j]Adult urchins from subtidal transect program; preoperational years = 1985-1989, operational years = 1991-1996.

Table 6-18. Annual Mean Lengths (mm) and Coefficients of Variation (CV,%) of Selected Benthic Species Collected at Nearfield-Farfield Station Pairs During the Preoperational and Operational Periods and in 1996. Seabrook Operational Report, 1996.

		PREOPERATIONAL[a]		1996	OPERATIONAL[b]	
TAXON	STATION	MEAN	CV	MEAN	MEAN	CV
Mytilidae[c]	B1MLW	3.1	64.7	2.8	3.0	55.1
	B5MLW	3.3	53.1	2.4	3.0	58.3
	B17	2.3	63.4	2.7	2.5	53.6
	B35	2.5	64.8	2.5	2.4	55.6
	B19	2.4	73.7	2.0	1.9	53.7
	B31	2.8	77.8	2.1	3.1	70.6
Nucella lapillus	B1MLW	6.9	80.5	8.5	6.5	71.7
	B5MLW	6.0	87.9	5.9	5.1	79.5
Asteriidae	B17	5.0	86.0	4.2	5.0	70.5
	B35	6.7	98.5	6.4	5.6	92.8
Pontogeneia inermis	B19	5.1	39.4	7.2	5.5	34.9
	B31	5.3	29.2	5.5	5.4	27.1
Jassa marmorata	B17	4.2	26.6	4.1	4.2	27.6
	B35	3.9	27.2	4.0	4.0	27.4
Ampithoe rubricata	B1MLW	7.0	36.2	7.6	8.2	40.3
	B5MLW	7.8	34.6	7.3	7.3	42.3
Strongylocentrotus droebachiensis	B19	1.9	95.2	2.8	2.5	86.3
	B31	1.9	56.9	1.6	3.3	132.5

[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, 1991-1996.
[c]Individuals measuring >25 mm were excluded.

Asteriidae

The sea star family Asteriidae 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*, were 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 1996 slightly exceeded preoperational and operational means at both stations (Table 6-16). No significant difference in densities was measured between farfield station (B35) and nearfield station (B17), or between the preoperational and operational periods, and the Preop-Op X Station interaction was not significant (Table 6-17).

The sizes of Asteriidae collected over the study period generally have been consistent, and the vast majority of individuals collected were juveniles (Table 6-18). Larger Asteriidae were collected at farfield Station B35 during the preoperational period and in the operational period until 1994, when substantially smaller individuals appeared at this station (NAI 1995). In 1995 (NAI 1996) and 1996, however, the historical tendency of larger Asteriidae at farfield Station B35 was again observed (Table 6-18).

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 the water column (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. Temporally, mean densities were significantly higher during the preoperational period for both mid-depth locations (Table 6-17). The densities observed in 1996 were the lowest observed during the operational period at each station, continuing to support this trend. No significant difference in densities between stations was detected, and the Preop-Op X Station interaction term was not significant (Table 6-17).

Pontogeneia inermis can reach lengths of up to 11 mm (Bousfield 1973); however, at Seabrook mid-depth stations, mean lengths were approximately 5 mm (Table 6-18). Mean length at farfield Station B31 was slightly larger than at nearfield Station B19 in the preoperational period, but this pattern was reversed in 1996, causing a shift in the overall operational period relationship. Mean length during the operational period was slightly larger than during the preoperational period at both stations. In 1996, mean length at Station B19 was larger than the preoperational and operational averages.

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 and among the dominant taxa at shallow subtidal stations (Table 6-16). Annual mean densities during 1996 were less than preoperational and operational period means at both stations (Table 6-16) as they were in 1995 (NAI 1996). No significant differences between the preoperational and operational period mean densities or between nearfield (B17) and farfield (B35) densities were observed, nor was the Preop-Op X Station interaction significant (Table 6-17).

Jassa marmorata can reach a maximum length of up to 9 mm (Bousfield 1973), and growth rate and molting frequency of this species are strongly related to temperature (Franz 1989). Lengths of *J. marmorata* in this study averaged approximately 4 mm, with mean lengths slightly higher at the nearfield station (B17) than at the farfield station (B35) during both preoperational and operational periods and in 1996 (Table 6-18).

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 6-16). Abundance increased in 1993 and 1994, declined in 1995, and remained at low levels in 1996 at nearfield Station B1MLW (Figure 6-10). However, a dramatic increase in *A. rubricata* abundance occurred at the farfield station (B5MLW) from 1987-1991 followed by stable densities through 1996. 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 6-17, Figure 6-11).

Ampithoe rubricata reach a maximum size of 20 mm (Bousfield 1973). During our studies, average lengths generally ranged from 7 to 10 mm (Table 6-18), with a variety of size classes observed. During the preoperational period, mean length was larger at the farfield station, with the opposite observed 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;

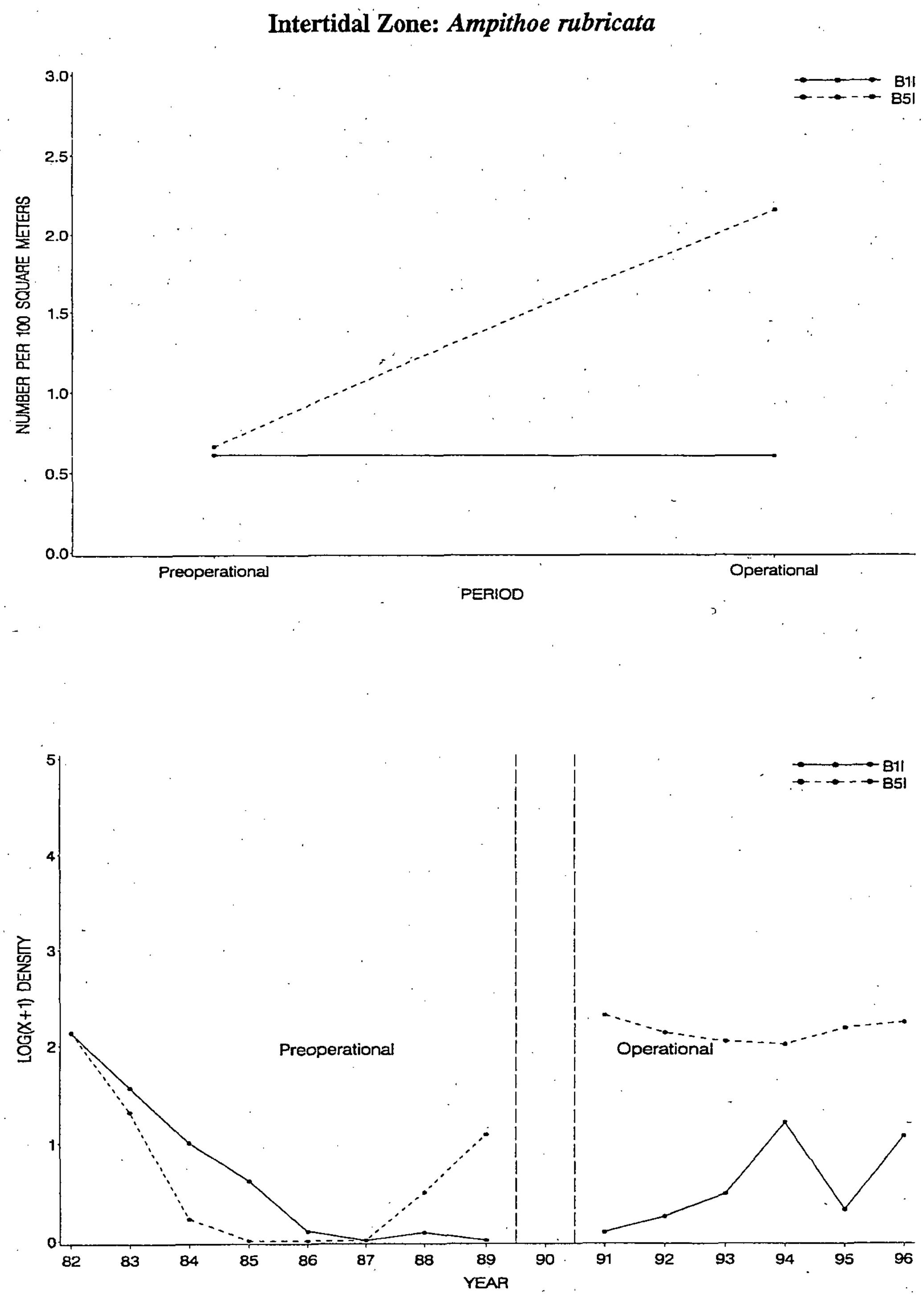


Figure 6-11. Comparisons between stations for annual mean densities of *Ampithoe rubricata* in the intertidal zone during the preoperational (1978-1989) and operational (1991-1996) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year. Seabrook Operational Report, 1996.

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 local extinction caused by disease or fishing pressure, allowing foliose algae to recolonize denuded areas (Steneck et al. 1994).

Sea urchins were most abundant in the mid-depth zone in both preoperational and operational periods, with higher densities measured at nearfield Station B19 (Table 6-16). Between-period and between-station differences were not significant, and the Preop-Op X Station interaction term was not significant (Table 6-17).

Sea urchins collected in destructive samples were small (Table 6-18), and not considered a dominant factor in structuring communities at any depth zone. Most sea urchins collected were juveniles, with mean length approximately 2 mm during the preoperational period at both nearfield and farfield stations. Mean length was somewhat larger during the operational period. In 1996 mean length was larger than the preoperational average at Station B19, but smaller at Station B31. The average length during the operational period at Station B31 was larger than that at Station B19.

Sea urchin densities were also estimated in subtidal transect sampling. These densities were evaluated more closely to evaluate their possible role in the decline of *Laminaria digitata* densities. Several studies in the Gulf of Maine and the Maritime provinces of Canada have documented the complete removal of kelp beds by sea urchins (Breen and Mann 1976; Wharton and Mann 1981; Steneck et al. 1994). Wharton and Mann (1981) determined that once urchin populations reached densities of 2-10/m^2 (off the coast of Nova Scotia), urchins began to over-graze local kelp beds. Although the annual mean densities of recently-settled sea urchins (collected in the destructive monitoring program) have been relatively high, particularly at the nearfield mid-depth station (B19) in the operational period (nearly 200/m^2 in 1996, Table 6-16), annual mean densities of adult sea urchins collected in the subtidal transect program have generally been moderate. In the Seabrook study area, urchin densities in the shallow subtidal zone have only exceeded 5/m^2 in 1994 and were generally much lower (Table 6-19). Sea urchin densities have also generally been moderate in the mid-depth subtidal zone, although densities have reached levels as high as 10/m^2 at the nearfield station, and 20/m^2 at the farfield station (Table 6-19). These levels could be sufficient to cause over-grazing of kelp beds, but are far below densities seen in urchin barrens (Wharton and Mann 1981).

The same ANOVA model applied to sea urchin densities measured in the destructive monitoring program was applied to sea urchin densities collected in subtidal transect studies. The model for the shallow subtidal stations was not significant ($P=0.08$), and the non-parametric Wilcoxon summed ranks test indicated no differences between preoperational and operational mean densities for either Station B17 ($Z = 0.276$, $p = 0.78$) or B35 ($Z = 0$, $p = 1.00$), and no differences between stations in either the preoperational ($Z = 0.211$, $p = 0.83$) or operational periods ($Z = 0.244$, $p = 0.81$). The ANOVA model applied

Table 6-19. Mean Densities (per m²) and Range of *Strongylocentrotus droebachiensis* Observed in Subtidal Transects During Preoperational (1985-1989) and Operational (1991-1996) Periods and During 1996. Seabrook Operational Report, 1996.

	PREOPERATIONAL		1996	OPERATIONAL	
STATION	MEAN	RANGE	MEAN	MEAN	RANGE
B17	0.29	0.00-3.98	0.01	0.07	0.00-0.93
B35	0.04	0.00-0.19	0.00	0.36	0.00-5.07
B19	0.10	0.00-0.50	0.13	1.60	0.00-10.00
B31	0.05	0.00-0.62	1.53	3.67	0.00-20.36
ALL STATIONS	0.12	0.00-3.98	0.42	1.42	0.00-20.36

to urchin densities in the mid-depth zone showed no significant station or period differences, nor was the interaction term significant (Table 6-17).

Although there were no statistically significant changes in sea urchin densities between periods, examination of annual means in conjunction with annual mean densities of *Laminaria digitata* indicate a possible relationship between the two in the mid-depth zone (Figure 6-12). Figure 6-12 shows a clear spike in sea urchin densities in 1993-1994, which corresponds temporally with the sharp decline in *L. digitata* densities after the start of the operational period. A smaller spike in sea urchin densities was evident in the shallow subtidal zone, but a correspondence between densities of *L. digitata* and sea urchins was not as evident as in the mid-depth zone (Figure 6-13). A functional regression model was applied to log (x+1) transformed densities of *L. digitata* and *S. droebachiensis*, with the latter established as the independent variable. There was no significant relationship between *L. digitata* and sea urchin densities in the shallow subtidal zone at either station, nor was there a significant relationship in the nearfield area (B19) of the mid-depth zone (Table 6-20). There was, however, a significant negative relationship between densities at the farfield station (B31) in the mid-depth zone (Table 6-20, Figure 6-14). This suggests that, at least in the farfield area of the mid-depth zone, sea urchin grazing (or some other factor affecting both species) may be influencing the density of *Laminaria digitata*.

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

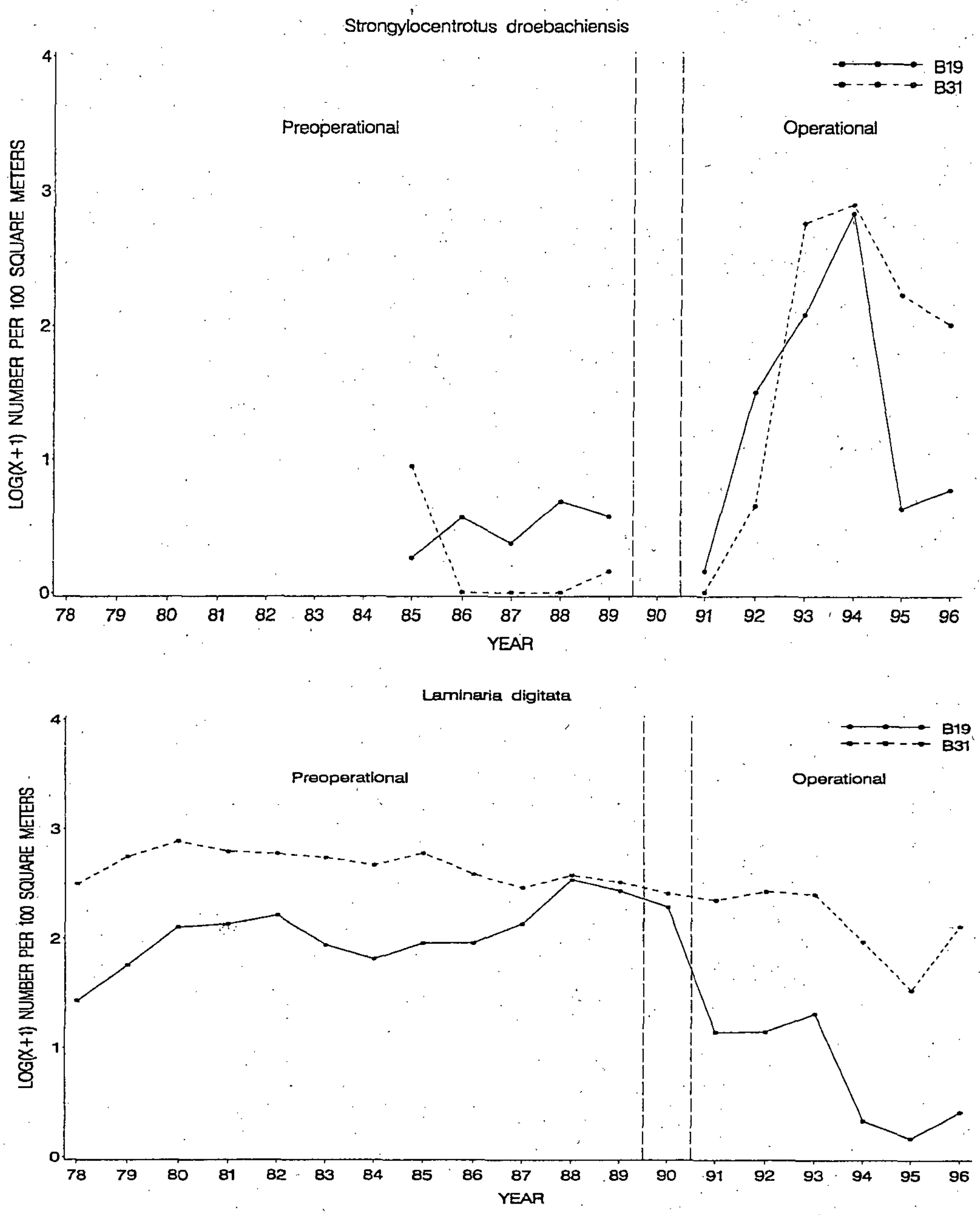


Figure 6-12. Annual mean densities of *Laminaria digitata* and *Strongylocentrotus droebachiensis* (log(x+1) number/100 m^2) in the mid-depth subtidal zone, 1978-1996. Data between vertical lines were not used in ANOVA models. Seabrook Operational Report, 1996.

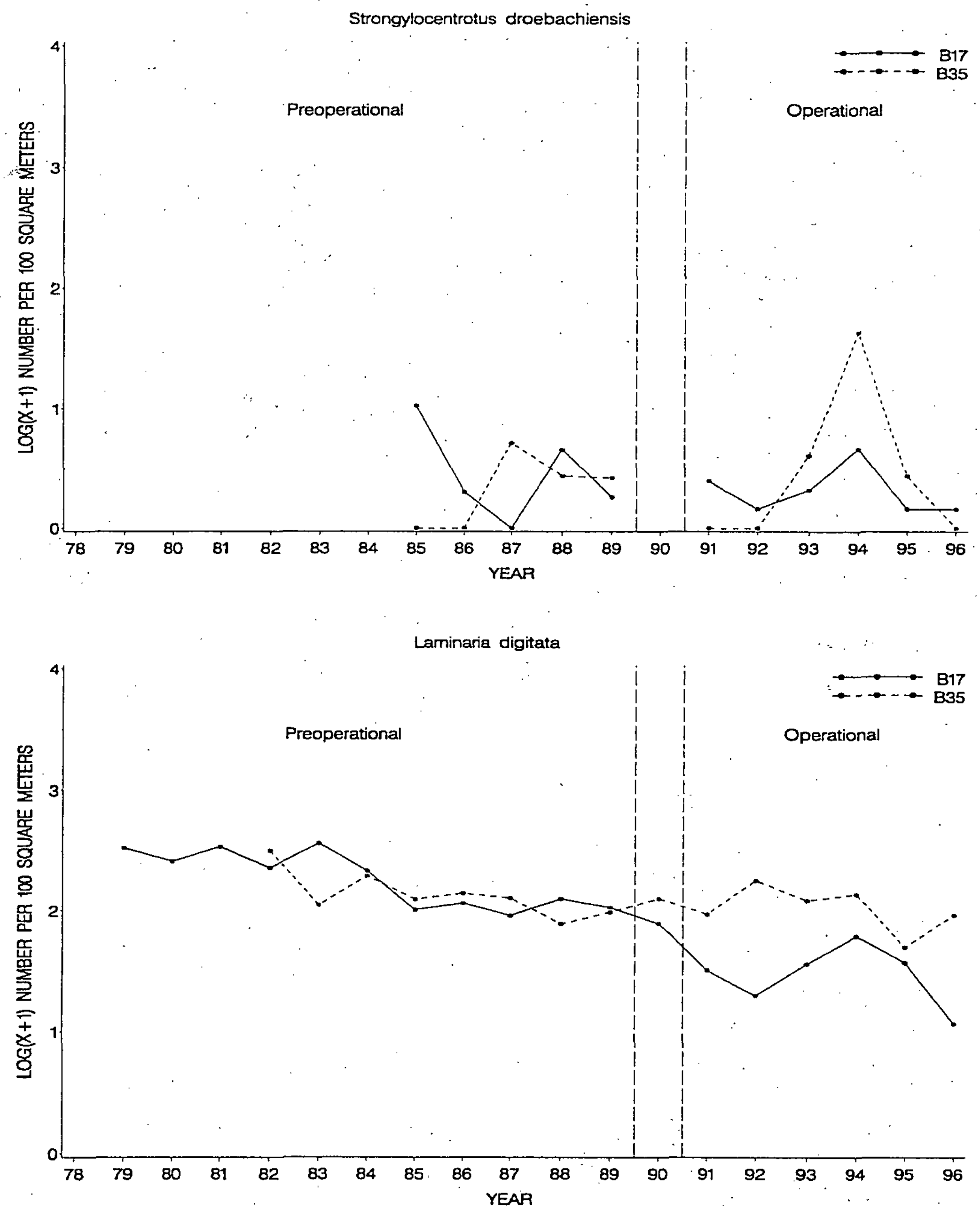


Figure 6-13. Annual mean densities of *Laminaria digitata* and *Strongylocentrotus droebachiensis* (log(x+1) number/100 m^2) in the shallow subtidal zone, 1978-1996. Data between vertical lines were not included in ANOVA models. Seabrook Operational Report, 1996.

Table 6-20. Results of Functional (Type II) Regression Evaluating the Effect of *Strongylocentrotus droebachiensis* Densities[a] on Densities of *Laminaria digitata*[a]. Seabrook Operational Report, 1996.

STATION	DEPTH ZONE	r[b]	PROB > |r|	INTERCEPT	SLOPE
B17	Shallow	0.257	0.149	NS[c]	NS
B35	Subtidal	0.091	0.616	NS	NS
B19	Mid-depth	-0.297	0.090	2.243	-0.876
B31	Subtidal	-0.552	0.001	2.662	-0.304

[a]Densities are log (x+1) numbers per 100m^2.
[b]Pearson Correlation Coefficient.
[c]regression not significant.

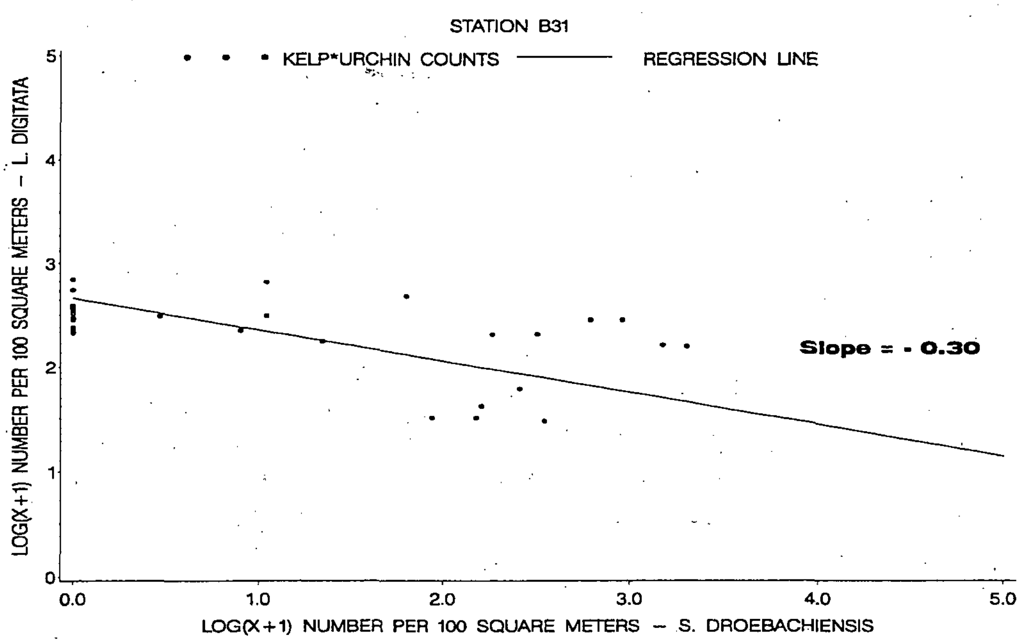


Figure 6-14. Density of *Laminaria digitata* holdfasts as a function of density of *Strongylocentrotis droebachiensis* at mid-depth station B31 (farfield). Counts included for the years 1985-1989 and 1991-1996. Correlation coefficient r = -0.552 (p = 0.001). Seabrook Operational Report, 1996.

was lower than the preoperational and operational period means. Densities over the two stations combined were not significanlty different between the preoperational and operational periods, although mean density at Station B31 was significantly higher than that at Station B19 (Table 6-17). The relationship between the two stations was consistent between the preoperational and operational periods as indicated by the non-significant Preop-Op X Station interaction term (Table 6-17).

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 have been well-documented in monitoring studies conducted on intertidal and shallow subtidal communities in the vicinity of other coastal nuclear power plants. Documented impacts included elimination or reduced abundance of cold-water species, and increased abundance of warm-water tolerant or opportunistic species. These changes led 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 commonly observed 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 Station 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).

Intertidal Zone

Nearfield-farfield relationships were consistent between the preoperational and operational periods for all algal and faunal community-level parameters analyzed, with the exception of the number of algal taxa observed in the intertidal zone (Table 6-21). The number of algal taxa declined over time in both the nearfield (Station B1) and farfield (Station B5) areas of the intertidal zone, but to a slightly greater extent in the farfield area (Table 6-3, Figure 6-3). The closeness with which annual mean total numbers of taxa track one another at these two stations, and the fact that the downward trends begin in the early preoperational period, indicates that this statistically significant difference is not likely related to plant operation. Furthermore, community structure in the intertidal zone, for algae and fauna, remained consistent between periods.

Although on a community level very few changes were noted, several nearfield-farfield differences were noted at the species level (Table 6-22). In the case of *Ascophyllum nodosum*, a between-period difference in percent frequency of occurrence was not evident at the farfield station, but a small significant between-period increase was noted at the nearfield station (Table 6-3, Figure 6-8). During most years, the annual mean percent frequency of occurrence of this species was nearly equal at the nearfield and farfield areas. A brief departure from this pattern occurred in 1987-1988, when percent frequency of occurrence dropped in the nearfield area, resulting in a decrease in the preoperational average. After the 1987-1988 decline, densities at the two stations resumed their parallel trends (Figure 6-8). The consistency of the relationship of annual mean percent frequency of occurrence between the two stations (Figure 6-8) suggests that the significant interaction is not due to station operation. Similarly, annual mean percent frequency of occurrence for *Fucus vesiculosus* highlights a cyclical pattern that is quite similar between stations, with a diverging pattern evident only in 1989-1991 (Figure 6-9). The interaction is probably not due to Seabrook Station because the divergence in annual mean frequency of occurrence began before the plant became operational, and both stations have shown similar trends in recent years (Figure 6-9). There were differing trends between stations in abundances of *Ampithoe rubricata* between the preoperational and operational periods (Table 6-22). However,

Table 6-21. Summary of Evaluation of Potential Thermal Plume Effects on Intertidal and Shallow Subtidal Benthic Communities in the Vicinity of Seabrook Station. Seabrook Operational Report, 1996.

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	—	NF: Op<Preop FF: Op<<Preop
		Total biomass	Yes	Yes
		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 Subtidal	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes

[a]Abundance, number of taxa, biomass and total density evaluated using ANOVA; community structure evaluated using numerical classification, by year and station.
[b]Operational period = 1990-1996 (August only); evaluated using Preop-Op term of ANOVA model when the interaction term was not significant.
[c]NF = nearfield, FF = farfield; evaluated using Preop-Op X Station interaction term of ANOVA model.

Table 6-22. Summary of Evaluation of Potential Thermal Plume Effects on Representative Important Benthic Taxa in the Intertidal and Shallow Subtidal Zones in the Vicinity of Seabrook Station. Seabrook Operational Report, 1996.

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
		Ascophyllum nodosum	—	NF: Op>Preop FF: Op=Preop
		Fucus vesiculosus	—	NF: Op<Preop FF: Op=Preop
		Fucus sp. (juveniles)	Op>Preop	Yes
	Shallow Subtidal	*Chondrus crispus*	Yes	Yes
	Shallow Subtidal	*Laminaria saccharina*	Yes	Yes
	Shallow Subtidal	*Laminaria digitata*	—	NF: Op<Preop FF: Op=Preop
Macrofauna	Intertidal	*Ampithoe rubricata*	—	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
	Shallow Subtidal	Mytilidae	Yes	Yes

[a]Conclusions derived from ANOVA when the interaction term was not significant or nonparametric analysis for Preoperational versus Operational periods.

[b]NF = nearfield, FF = farfield; evaluated using Preop-Op X Station interaction term of ANOVA model. Note that nonparametric tests do not test for significant station differences or station-period interactions.

examination of annual abundances revealed that these shifts began prior to station operation (Figure 6-11). 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 increased and stabilized in the operational period, with some minor recolonization observed at the nearfield station beginning in 1992. As this cycle of local extinction and recolonization began prior to 1990, it is not related to operation of Seabrook Station. Abundances of the remaining two intertidal selected faunal species were consistent among stations and between periods.

Numerical classification of macroalgal and macrofaunal biomass and abundance revealed that stations and depth zones had similar assemblages with no evidence of differences between preoperational and operational periods. This suggests that the important structuring mechanisms creating differences between stations and periods are most likely natural factors that are unrelated to station operation. Consistent with this was the examination of rarely found algal taxa, which provided no evidence of a proliferation of warm water species, the appearance of nuisance species, or a decline in cold-water species, indicating that the thermal plume has had no effect on species composition.

Shallow Subtidal Zone

Relationships among stations for numbers of macroalgal taxa collected and total macroalgal biomass were consistent between periods in this zone (Tables 6-21, 6-22). This was true as well for *Chondrus crispus* biomass, density of the kelp *Laminaria saccharina*, density of all selected macrofaunal taxa, and macrofaunal total numbers of taxa and total density. The density of the kelp *Laminaria digitata*, however, declined between periods at the nearfield station (B17), while density remained stable at the farfield station (B35). The relatively low densities and low percent cover of *Laminaria digitata* observed in both the nearfield and farfield areas suggests that *L. digitata* is limited by some physical or biological factor in this zone. Both substrate and water depth are adequate at both stations, and temperatures in both surface and bottom waters are not limiting to the survival of adult plants. The lack of a significant negative relationship between densities of *L. digitata* and *Strongylocentrotus droebachiensis* suggests that grazing pressure may not totally explain the observed decline in *L. digitata*. Given the weak presence of this kelp species in the shallow subtidal zone during all years of the study, it is likely that even a minor change in physical or biological factors could have been sufficient to cause the decline observed after the start of station operation. The influence of station operation in this decline remains unclear, as does the influence of other biological and physical factors such as competition with other algal species, grazing pressure, and a regional increase in water temperatures.

6.4.3 Evaluation of Potential Turbidity Effects on the Mid-Depth/Deep Benthic Communities

Nearfield mid-depth and deep subtidal study sites represent macrobenthic communities in closest proximity to the Seabrook Station discharge. However, due to their position in the water column (9-21 m) relative to the near-surface thermal plume, temperature effects at these sites are unlikely. The potential for higher sedimentation rates resulting from increased levels of suspended particles in discharge waters relative to the surrounding waters could affect 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 with a shallow nearshore intake and a deep offshore discharge (Osman et al. 1981; Schroeter et al. 1993). At the California power plant, fine inorganic sediments from nearshore waters were transported to the deep offshore discharge. 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 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.

Mid-Depth Zone

The numbers of taxa and total algal biomass and faunal density remained consistent between periods in the mid-depth zone (Table 6-23). Community structure as measured by the cluster analysis indicated little change between periods, with minor exceptions. In 1996, the faunal community from the intake (B16) and farfield (B31) stations was unique, whereas this community is typically most similar to that formed from collections from Station B16, Station B19 (discharge), and Station B31. High numbers of *Caprella septentrionalis* and lower numbers of Mytilidae characterized the 1996 B16/B31 collections, distinguishing them from the larger group. As this is the first year that this grouping has occurred, and it occurred in both the nearfield and farfield areas, it is unlikely that its occurrence is related to station operation.

On the species level, nearfield-farfield relationships changed over time only for the kelp species *Laminaria digitata* (Table 6-24). Densities of *L. digitata* declined in both the nearfield (Station B19) and farfield (B31) areas, but to a greater extent in the nearfield area (Figure 6-6). Although annual mean densities show a decline beginning at both stations as early as 1988-1989, the decline accelerated in the nearfield between 1990-1991, indicating a possible station impact. Densities at both stations declined through 1995, then increased slightly in 1996. The percent cover of *L. digitata* also declined in both the nearfield and farfield areas prior to the start of operations at Seabrook Station (Figure 6-7). As with densities, the decline is considerably steeper at the nearfield station compared to the farfield station. The relatively deeper water at the nearfield station likely accounts for many of the differences observed in percent cover and density between the nearfield and farfield areas. The relatively greater stress endured by the nearfield population due to increased depths, and therefore lower light intensity, could make that population more vulnerable to minor physical and biological influences. Although there is a clear trend of

Table 6-23. Summary of Evaluation of Potential Turbidity Effects on Benthic Communities in the Mid-Depth and Deep Subtidal Zones in the Vicinity of Seabrook Station. Seabrook Operational Report, 1996.

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-estimable[d]	Yes
		Community structure	In most cases	NF = FF except B04, 1996
Macrofauna	Mid-depth	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	In most cases	NF = FF except 1996, B16, B31; 1990 B31
	Deep	No. of taxa	Yes	Yes
		Total density	Yes	Yes
		Community structure	Yes	Yes

[a]Abundance, number of taxa, biomass, and total density evaluated using ANOVA; community structure evaluated using numerical classification by year and station.
[b]Operational period = 1990-1995 (August only); evaluated using Preop-Op term of ANOVA model when the interaction term was not significant.
[c]NF = nearfield, FF = farfield; evaluated using Preop-Op X Station interaction term of ANOVA model.
[d]Period differences non-estimable due to negative denominator mean square.

Table 6-24. Summary of Evaluation of Potential Turbidity Effects on Representative Important Benthic Taxa in the Mid-Depth and Deep Subtidal Zones in the Vicinity of Seabrook Station. Seabrook Operational Report, 1996.

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*	—	NF: Op<<Preop FF: Op<Preop
		Laminaria saccharina	Yes	Yes
Macrofauna	Mid-depth	*Pontogeneia inermis*	Yes	Yes
		Modiolus modiolus	No	Yes
		Mytilidae	Yes	Yes
		Strongylocentrotus droebachiensis	Yes	Yes

[a]Conclusions derived from ANOVA when the interaction term was not significant or nonparametric analysis for Preoperational versus Operational periods.
[b]NF = nearfield, FF = farfield; evaluated using Preop-Op X Station interaction term of ANOVA model. Note that nonparametric tests do not test for significant station differences or station-period interactions.

creasing urchin densities that corresponds to a clear trend of decreasing *L. digitata* densities in the nearfield area (Figure 6-12), the relationship between the two is not statistically significant. The lesser decline in *L. digitata* density observed at the farfield station is statistically related to increased sea urchin densities (Figures 6-12, 6-14). As noted for the shallow subtidal zone, the influence of station operation on the decline in *L. digitata* in the nearfield area is unclear, as are the influences of competition and the observed regional increase in water temperatures. Results of the functional regression analysis indicate that grazing pressure may also be an important factor controlling the density of *L. digitata* in the mid-depth subtidal zone.

Deep Subtidal Zone

All aspects of the deep subtidal algal and faunal communities remained consistent between the preoperational and operational period except for a very minor change in the algae community groups (Table 6-22). The 1996 algal community from the discharge station (B04) was most similar to the community from the intake station (B13), whereas it has previously been most similar to the community from the farfield station (B34, Figure 6-4). The main difference in the 1996 discharge station community was a higher-than-typical amount of *Phyllophora/Coccotylus* and a lower-than-typical amount of *Ptilota serrata* (Table 6-4). There is not enough information to indicate whether or not this change is associated with station operation. In general, there is no evidence that the operation of Seabrook Station has affected this zone.

6.4.4 Overall Effect of Seabrook Operation on the Local Marine Macrobenthos

Current 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 between the preoperational and operational periods, most were either part of an area-wide trend (occurring at both nearfield and farfield stations), or part of an historical trend that began prior to commercial operation of Seabrook Station. However, a decline in *Laminaria digitata* in the nearfield areas of both the shallow and mid-depth subtidal zones has been observed in the operational period. The nearfield population of *L. digitata*, a subdominant throughout the study period, has been reduced by a combination of physical and biological factors that is unclear at present. Increases in both sea urchin densities and regional water temperatures, are factors that could contribute to the observed decreases in *L. digitata* in the shallow and mid-depth subtidal zones. The role of Seabrook Station in the observed declines in *L. digitata* also remains unclear, as no other species or community characteristics have displayed a response similar to that exhibited by *L. digitata*. However, power plant influence seems unlikely, as no clear impact mechanism has been demonstrated.

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Appendix Table 6-1. **Marine Macrobenthos Sampling History. Seabrook Operational Report, 1996.**

STATIONS		SAMPLING METHOD	MONTHS	YEARS
FARFIELD STATIONS				
Intertidal:	B5MLW	Destructive	May, August, November	1982-1996
	B5MSL	Non-destructive	April, July, November	1983-1996
Subtidal:	B35 (shallow)	Destructive	May, August, November	1982-1996
		Non-destructive	April, July, October	1978-1996
	B31 (mid-depth)	Destructive	May, August, November	1978-1996
		Non-destructive	April July, October	1978-1996
		Panel Studies	Short Term, Long Term[a]	1982-1996
	B34 (deep)	Destructive	August	1979-1996
		Panel Studies	Short Term, Long Term[a]	1986-1996
NEARFIELD STATIONS				
Intertidal:	B1MLW	Destructive	May, August, November	1978-1996
	B1MSL	Non-destructive	April, July, November	1983-1996
Subtidal:	B17 (shallow)	Destructive	May, August, November	1978-1996
		Non-destructive	April, July, October	1979-1996
	B16 (mid-depth)	Destructive	August	1980-1984, 1986-1996
	B19 (mid-depth)	Destructive	May, August, November	1978-1996
		Non-destructive	April, July, October	1978-1996
	B04 (deep)	Destructive	August	1982-1996
		Panel Studies	Short Term, Long Term	1978-1996
	B13 (deep)	Destructive	August	1986-1996
		Panel Studies	Short Term, Long Term	1978-1996

[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, 1996.

Mollusca		
	Polyplacophora	
		Tonicella rubra (Linnaeus 1767)
	Gastropoda	
		Acmea testudinalis (Müller 1776)
		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		
	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)
		Calliopius laeviusculus (Liljeborg 1865)
		Ischyrocerus anquipes (Kroyer 1838)
		Jassa marmorata (Holme 1903)
		Pontogeneia inermis Krøyer 1842
		Caprella septentrionalis Krøyer 1838
Echinodermata		
	Echiniodea	
		Strongylocentrotus droebachiensis (Müller 1776)
	Stelleriodea	
		Asteriidae
		Ophuira sp. (Lamarck 1801)

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SUMMARY

An estimated 27 to 33 seals have been entrapped by Seabrook Station's cooling water intakes between 1993 and 1996. Seal species entrapped were the harbor seal (*Phoca vitulina*), harp seal (*Phoca groenlandica*) and hooded seal (*Cystophora cristata*). These seal entrapments are considered incidental lethal takings under the Marine Mammal Protection Act and have been reported to the National Marine Fisheries Service (NMFS), Northeast Region, the federal agency responsible for the protection of marine mammals. Since mid-August 1996, necropsies of seal remains have been performed by the New England Aquarium, which also has the lead responsibility for administering the Marine Mammal Stranding Network for the region.

There was limited use of the Seabrook Station offshore area by seals of any species during the preoperational period, and seals were, therefore, not included in the environmental monitoring program. Entrapment of seals since 1993 has resulted in actions by North Atlantic to assess and address this issue.

The entrapment of seals in recent years coincides with increased numbers of seals observed along the nearby coastline and the overall growth of the seal population in the Gulf of Maine. Based on the large seal population in the region and the small number of seals entrapped by the Station's cooling water intakes, the operation of Seabrook Station has had and is anticipated to have a negligible effect on the population or stocks of seal species.

LIST OF TABLES

7.1 METHODS

Weekly visual inspections of Seabrook Station's Circulating Water System and Service Water System forebays were conducted from January 1995 to November 1996. Inspection frequency increased to at least once per day beginning in December 1996. Prior to 1995, seal remains were recovered only from the weekly screenwash debris assessments.

Recovered seal carcasses and seal skulls were delivered for identification and necropsy to the New England Aquarium in Boston, Massachusetts. Observations made and recorded by the New England Aquarium include the species, age, sex, weight, general health, and stomach contents of entrapped seals, when possible. Data gained from these necropsies may be useful in determining the reasons for the seal entrapments and in evaluating potential means of eliminating or reducing the entrapments.

The National Marine Fisheries Service (NMFS) in Gloucester, Massachusetts was immediately notified by telephone when an intact seal carcass was identified either in the forebays or in screenwash debris and a written report was submitted to the NMFS within 14 days.

7.2 RESULTS AND DISCUSSION

7.2.1 Seal Entrapments

Intact seal carcasses and seal remains have been identified in Seabrook Station's cooling system intake forebays and screenwash debris since 1993 as an apparent result of live seals entering the Station's intake structures and then being drawn through the intake tunnel to the pumphouse. The seal species entrapped by Seabrook Station from 1993-1996 were predominantly the harbor seal (*Phoca vitulina*) although one harp seal (*Phoca groenlandica*) and one hooded seal (*Cystophora cristata*) were also identified. Ten of the twelve seals for which age estimates were made were determined to be young-of-the-year. Because observations sometimes consist of only partial remains, it was not always possible to determine if the remains were from only one or from more seals. The estimate of the total number of seals entrapped through 1996 is between 27 and 33. A summary of the estimated number of seals entrapped by year from 1993 to 1996 is shown in Table 7-1.

Entrapped seals were first observed in October, 1993, eight years after cooling water was first pumped through the offshore intake structures in 1985 and more than three years after Seabrook Station began commercial operations in August, 1990. The cooling system operated intermittently and at reduced flow rates during the period 1985 to 1990.

Table 7-1. Estimated Number of Seals Entrapped in the Cooling Water System of Seabrook Station During 1990 through 1996. Seabrook Operational Report, 1996.

YEAR	NUMBER OF SEALS ENTRAPPED
1990	0
1991	0
1992	0
1993	2
1994	7
1995	6-7
1996	12-17
TOTAL	27-33

In some instances, intact seal carcasses were washed from the traveling screens and observed in screenwash debris where they were easily recovered. At other times they were discovered floating in the cooling water system forebays from which recovery is difficult. Fourteen of the 18 intact seal carcasses observed from 1993 through 1996 were recovered and transported to the New England Aquarium, where necropsies were performed. In addition to the intact carcasses, skull fragments and other bones have been recovered from screenwash debris. Whenever possible, recovered skulls or skull fragments were also analyzed by the New England Aquarium. Table 7-2 (Page 7-3) provides a list of seal remains by date of first observation, condition of remains and necropsy results, if available. When only seal skulls and bones were observed, the date of entrapment could have been a significant length of time before the observation date.

Although seal takes are possible year-round, there appears to be a seasonal relationship. Table 7-3 provides the distribution by month of the observations of the 18 seal carcasses that have been discovered in an intact condition from 1993 through 1996. Because they were intact when discovered, it is reasonable to assume that the seals were entrapped close to the date of observation. On this basis, Table 7-3 indicates that most entrapments occur from August through October.

Because the low horizontal flow velocity (0.5 feet per second) into the intakes is unlikely to draw seals involuntarily inside the intake structure, it is likely that seals that are ultimately entrapped first swim into a velocity intake cap, either out of natural curiosity or in search or pursuit of prey. Inside the intake velocity cap, the flow rate

Table 7-3. Number of Intact Seal Carcasses Recovered by Month, 1993 to 1996. (All were Harbor Seals.) Seabrook Operational Report, 1996.

MONTH	NUMBER OF SEALS
Jan	0
Feb	0
Mar	0
Apr	0
May	0
Jun	1
Jul	0
Aug	5
Sep	3
Oct	6
Nov	2
Dec	1
TOTAL	18

increases as the seal approaches the center vertical riser shaft that connects to the intake tunnel. This increasing velocity and downward-turning flow may cause the seal to be drawn into the riser. The seals may become disorientated from the relative lack of light inside the velocity cap, and the downward current may prevent an effective escape response. This would especially be the case for young-of-the-year seals, which are relatively inexperienced and lack the swimming strength of older seals. A seal that is unable to exit, is subsequently drawn through the 3-mile intake tunnel where it drowns in passage and is carried into a pumphouse forebay.

During full power operations, Seabrook Station operates with all cooling water system and two

Table 7-2. Observations of Seal Remains at Seabrook Station by Date Including Necropsy Results Where Available. Seabrook Operational Report, 1996.

Date Observed	Description (Remains recovered from screenwash debris unless otherwise noted.)	Necropsy Results (All necropsies performed by the New England Aquarium, unless otherwise noted.)
10/25/93	Intact seal carcass recovered.	Harbor seal.
12/93	Several seal bones.	Bones were from a seal as identified by a local medical examiner.
10/94	Seal skull.	No recorded information.
10/27/94	Intact seal carcass recovered.	Harbor seal.
10/27/94	Intact seal carcass recovered.	Harbor seal.
11/07/94	Intact seal carcass observed in SW Forebay and not recovered.	A New England Aquarium Tag was recovered from screenwash debris on 11/23/94. This tag could have been from the seal observed on 11/7/94. According to the New England Aquarium the tagged seal was a male four month old harbor seal pup, rescued and treated by the Aquarium and released with this tag from Biddeford, Maine on 9/25/94.
11/30/94	Two seal skulls. One probably from seal observed on 11/07/94.	No recorded information.
11/30/94	Seal skull. Probably from seal not previously observed.	No recorded information.
01/24/95	Seal skull. Probably from seal entrapped in late 1994 and not previously observed.	No recorded information.

(continued)

Table 7-2. (Continued)

Date Observed	Description (Remains recovered from screenwash debris unless otherwise noted.)	Necropsy Results (All necropsies performed by the New England Aquarium, unless otherwise noted.)
03/14/95	Seal skull. Probably from seal entrapped in early 1995.	Harbor seal.
05/23/95	Seal skull. Probably from another seal entrapped in early 1995.	Hooded seal (probable identification based on limited skull fragments.
06/23/95	Intact seal carcass recovered. Seal appeared to have been entrapped recently. In good condition.	Harbor seal.
08/16/95	Intact seal carcass observed in cooling water (CW) Forebay and not recovered.	No recorded information.
09/21/95	Intact seal carcass observed in service water (SW) Forebay and not recovered.	No recorded information.
11/14/95	Intact seal carcass observed in SW Forebay and not recovered.	No recorded information.
12/19/95	Partial skull. Probably from seal observed in either 8/95 or 9/95 or a seal not previously observed.	Harp seal.
06/07/96	Skull fragments. Probably from seal observed in either 8/95 or 9/95 or a seal not previously observed.	Harbor seal. Frontal skull bones and attached crania from young-of-the-year.

(continued)

Table 7-2. (Continued)

Date Observed	Description (Remains recovered from screenwash debris unless otherwise noted.)	Necropsy Results (All necropsies performed by the New England Aquarium, unless otherwise noted.)
08/09/96	Intact seal carcass recovered from SW Forebay.	Harbor seal.
08/13/96	Skull fragment.	No recorded information.
08/27/96	Skull fragment	Harbor seal. Partial cranium and first cervical vertebrae and nasal bones from a sub-adult (estimated 1-3 years old).
08/27/96	Skull fragment.	Harbor seal. Occipital bone and lower jaw from a young-of-the-year. It is possible the skull is from one of the seals whose remains were recovered on 6/7/96. Bone pieces are too badly damaged and worn to reconstruct for certain.
08/27/96	Intact seal carcass recovered.	Harbor seal. Young-of-the-year female about 40 lbs. and 85 cm. long. Badly decomposed. Seal appears to have been in good health. No parasites. Stomach contained 1.5 lbs. of recently ingested stomach contents. Appears to have been entrapped while or shortly after feeding.
09/08/96	Intact seal carcass recovered from SW Forebay.	Harbor seal. Young-of-the-year male about 40 lbs. and 89 cm. long. Badly decomposed. Seal appears to have been in good health. No parasites. Stomach contained recently ingested fish parts. Appears to have been entrapped shortly after feeding.
09/14/96	Intact seal carcass recovered from CW Forebay.	Harbor seal. Young-of-the-year female about 45 lbs. and 93 cm. long. Badly decomposed. Seal appears to have been in good health. No parasites or signs of disease. Stomach contained a few fish bones.
09/17/96	Intact seal carcass recovered from CW Forebay.	Harbor seal. Young-of-the-year male about 45 lbs. and 96 cm. long. Moderately decomposed. No sign of prior disease or parasites. Signs of hemorrhage around thorax indicates probable live entrapment. No stomach contents.

(continued)

Table 7-2. (Continued)

Date Observed	Description (Remains recovered from screenwash debris unless otherwise noted.)	Necropsy Results (All necropsies performed by the New England Aquarium, unless otherwise noted.)
10/20/96	Intact seal carcass recovered.	Harbor seal. Young-of-the-year male about 40 lbs. and 90 cm. long. Decomposed around head, front and rear flippers. Average to fair body condition for juvenile seal. No sign of prior disease, significant parasites or trauma. Seal appears to have been in good health and feeding immediately prior to entrapment. Stomach contained about 300 grams of semi-digested fish and squid beaks.
10/20/96	Intact seal carcass recovered.	Harbor seal. Young-of-the-year female about 45 lbs. and 90 cm. long. Average to good flesh with slight decomposition. No sign of prior disease or significant parasites, hemorrhage into anterior chamber of both eyes, some slight superficial bruising around left eye, light ectoparasite load on head and rear flippers. Seal appears to have been in good health and feeding regularly immediately prior to entrapment. Shows signs similar to seals recovered from nets (eye hemorrhage). Signs are consistent with live entrapment during feeding.
10/20/96	Intact seal carcass recovered.	Harbor seal. Young-of-the-year female about 45 lbs. and 87 cm. long. Average to good flesh with slight decomposition. No sign of prior disease, significant parasites or trauma. Seal appears to have been in good health and feeding immediately prior to entrapment. Stomach contained about 200 grams of semi-digested fish.
12/31/96	Intact seal carcass recovered from SW Forebay.	Harbor seal. Adult male about 150 lbs. and 130 cm. long (approximate due to decomposition). Appears to have been an average to well fleshed adult seal. Seal was decomposed, pieces of skull and flippers missing skin and blubber sloughing. Poor condition of carcass makes determination difficult, however, seal appears to have been robust adult male with no serious pre-existing disease or heavy parasite load. Seal appears to have died suddenly shortly after feeding. Stomach contained 400 grams of semi-digested fish.

service water system pumps in operation. For an object traveling with the current under these conditions, the minimum transit time from the offshore intake structures to the forebay is approximately 80 minutes. Transit time is longer if fewer pumps are operating. A seal entrapped in the intake would not be able to survive an 80 minute or longer transit to the forebays.

7.2.2 Population Dynamics and Distribution of Seal Species Entrapped

The populations of all four seal species likely to be entrapped by Seabrook Station, harbor seal, harp seal, hooded sea and gray seal *(Halichoerus grypus)* have been increasing in the Gulf of Maine since the passage of the Marine Mammal Protection Act (MMPA) in 1972 (Kenney and Gilbert 1994; Blaylock et al. 1995). This is particularly well documented for harbor and gray seals, the two most common seals in the Gulf of Maine. Harbor seals have increased nearly five-fold (Blaylock et al. 1995), while the gray seal population has also increased greatly along the New England coast (Gilbert pers. comm. in Blaylock et al. 1995). Harbor and gray seals have also been dispersing southward from Maine rookeries (Paton 1988; Payne and Schneider 1984). Harp and hooded seal populations may also be increasing in U.S. waters as evidenced by increased sightings and strandings (Blaylock et al. 1995).

Harbor seal population censuses have been made for the coast of Maine in 1981, 1982, 1986 and 1993 (Kenney and Gilbert 1994). Estimates were based on aerial surveys taken along the Maine coast during the May to June pupping season. This technique was used because seals regularly haul out to give birth, nurse, thermoregulate and rest (Kenney and Gilbert 1994). The largest number of seals at haul-out sites have been observed during the pupping season (Sullivan 1980; Brown and Mate 1983). Population estimates from these surveys represent the minimum population size because the census is not corrected for seals that may be in the water at the time of counting (Kenney and Gilbert 1994). Since adult and juvenile males typically only haul out about once every six low tides, the total population in the surveyed areas may be underestimated by about 30 to 40% (Gilbert pers comm.). In addition, not all potential haul-out locations are surveyed, particularly sites that may be upstream in tidal rivers (Gilbert pers. comm.). The annual changes in these minimum counts, however, provide a relative index of population growth. According to the 1993 census, the minimum uncorrected population estimate of harbor seals along the Maine coast at that time was 28,810 (Blaylock et al. 1995). This represents an annual rate of increase of 8.7% along the Maine coast between 1981 and 1993.

Most of the seals taken by the operation of Seabrook Station were harbor seals. Over 80% of the harbor seals, for which ages have been estimated, were young-of-the-year. Although no local census data specific to New Hampshire waters is available, the adjacent Southern Maine coast (Pemaquid Point to the Isles of Shoals) is on the southern edge of the breeding range for harbor seals. Pups make up a greater percentage of the population in the Downeast (Cobscook Bay to Schoodic Point) and Middle (Schoodic Point to Pemaquid Point) coast regions (Kenney and Gilbert 1994). In the Southern coast region, only 8.3% of the seals counted in the 1993 survey were pups. The furthest south that newborn pups have been observed was a single observation of one pup on Shag Rock in the Isles of Shoals, about 10 miles north of the Seabrook Station intakes.

The gray seal range is centered in the Gulf of St. Lawrence and is distributed primarily in eastern Canadian waters (Blaylock et al. 1995). Small numbers of animals including pups, however, have been observed on several isolated islands along the Maine coast and in Nantucket-Vineyard Sound, Massachusetts (Katona et al. 1993; Rough 1995). Although range-wide gray seal population estimates are not known, the estimate for individuals that are one year or older rose from between 100,000 and 130,000 animals in the North Atlantic in 1986 (Stobo and Zwanenburg 1990) to 143,000 animals in 1993 (Mohn and Bowen 1994). Gray seals were occasionally observed in the summers on the coast of Maine during the mid-1970s and the 1980s but have become more common in the 1990s. The population in Maine waters has increased from about 30 in the early 1980's (Gilbert pers. comm. in Blaylock et al. 1995) to between 500-1,000 animals in 1993 (Kenney and Gilbert 1994). The minimum uncorrected population estimate for all US waters is about 2,000 seals in 1994 (Blaylock et al. 1995).

No estimate exists for the number of harp or hooded seals in US waters, as these species are found primarily in northern Canadian waters. The population of both species appears to be growing in Canadian waters (Blaylock et al. 1995). The total population of harp seals in Canada was estimated at approximately 3 million seals (Shelton et al. 1992) and the average annual growth rate was estimated as 7% (Stenson 1993). The total estimated population of hooded seals in Canada was about 400,000 to 450,000 seals (Stenson 1993) and the population appears to be increasing.

7.2.3 Effects of Seabrook Station Operation

The populations of the seal species entrapped by Seabrook Station are increasing and their ranges are extending further south (Blaylock et al. 1995). As discussed below, the small number of seals entrapped as a result of the operation of Seabrook Station, has not impacted, and is unlikely to impact the population or stocks of these seal species.

The Marine Mammal Protection Act as amended in 1994 requires the NMFS to produce stock assessment reports for all marine mammal stocks in waters within the US Exclusive Economic Zone. As part of that assessment, NMFS is required to estimate the potential biological removal (PBR) for each stock of each species. The PBR is the maximum number of marine animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing the stock to reach or maintain its optimum sustainable population (OSP). If the number of animals removed from the stock exceeds the PBR, the stock is declared "strategic", and additional conservation measures are initiated (Barlow et al. 1995). If the number removed is less than PBR, the stock is considered to be within the range of OSP.

The determinations of PBR were published by NMFS in Blaylock et al. (1995). For harbor seals, the PBR was determined to be 1,729 seals. The total annual take estimated from sources other than Seabrook Station was 476 harbor seals (Blaylock et al. 1995; p. 113). The maximum estimated annual mortality at Seabrook Station was 17 in 1996 which is less than 4% of the total take and 1% of the PBR. Therefore, the additional take from this source does not change the status of the stock or impact the stock of harbor seals significantly.

No PBR has been calculated for harp or hooded seals because data are not available to estimate the stocks in US waters. However, because they must be considered a part of the Canadian stocks (where reproduction occurs), and because numbers are increasing in Canada, the incidental takes at Seabrook Station are insignificant. The population of both species appear to be expanding seasonally southward into US waters. Prior to the late 1980s, few were recovered in the Gulf of Maine. Since then, strandings have increased by an order of magnitude (Mooney-Seus and Stone 1995).

7.3 SUMMARY OF 1997 ACTIVITIES

Provided below is a brief summary of Seabrook Station's activities related to seal entrapments. A more detailed discussion will be included in the 1997 Environmental Monitoring Report.

Nine intact seals were recovered from Seabrook Stations cooling water system in 1997, including seven harbor seals and two gray seals. These were the first gray seals entrapped by the Station.

In June 1997, North Atlantic submitted to the National Marine Fisheries Service an application for a small take exemption permit for the incidental taking of a small number of seals as a result of Station operations. In parallel with the permit application, North Atlantic began feasibility studies to determine if there is an effective, implementable means to eliminate or minimize seal entrapments. Studies that are underway include consideration of structural barriers and acoustic deterrent devices as well as any other measures that may be viable.

Seal monitoring activities of the nearfield area in the vicinity of Seabrook Station's offshore intake structures began in March 1997 and involved a weekly count of the number of seals hauled out at low tide on the Inner Sunk Rocks. This monitoring program was initiated to determine if there is a correlation between the observed relative seal abundance at the Inner Sunk Rocks and the entrapment of seals at Seabrook Station, and to develop a relative index of the magnitude of seal usage of the waters in the vicinity of Seabrook Station.

Aerial surveys of seal populations periodically conducted along the coast of Maine by Dr. James Gilbert of the University of Maine, were extended in 1997 to include coastal New Hampshire.

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8.0 *EPIBENTHIC CRUSTACEA*

SUMMARY

Several epibenthic crustacea species including the American lobster and rock and Jonah crabs, are important invertebrate predators in the study area. The local lobster population also supports a substantial commercial fishery. Lobster larvae have been relatively rare in the study area during both the preoperational and operational periods, averaging less than 2 per 1000 square meters of water surface. The larvae, predominantly Stage IV, typically had peak abundances in July and August during both periods. There were no significant differences in mean density of lobster larvae between the preoperational and operational periods, or among stations. Adult lobster catches (all sizes) were typically highest from August through November during both periods. This seasonal cycle was observed during both the preoperational and operational periods. Total catch in 1996 was the highest observed to date. However, average CPUE at the farfield station decreased significantly between the preoperational and operational periods, while average CPUE at the nearfield station increased. The opposite trends in CPUE between the nearfield and farfield stations may be due to increased commercial and recreational lobstering activity in the nearfield area. Furthermore, CPUE at the nearfield and farfield stations have become more similar in the operational period. Catches of legal-sized lobsters were significantly lower during the operational period at both stations, likely a result of increases in the legal-size limit and commercial over-exploitation. There was no evidence of an effect from Seabrook Station operation.

Cancer spp. 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. There were no significant differences in mean CPUE between the preoperational and operational periods, or between stations for adult Jonah and rock crabs. Adult rock crabs were less abundant than Johah crabs, likely due to the rock crab's preference for sandy substrate, which is less common in the study area. There was no evidence of an effect of Seabrook Station on local Jonah or rock crab populations.

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8.1 INTRODUCTION

The objective of the epibenthic crustacea monitoring program was to determine if seasonal, spatial, and annual trends in larval density and catch per unit effort (CPUE) 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) were related to effects from the operation of Seabrook Station. The planktonic larval stages of *Cancer* species may potentially be affected by mechanical damage or temperature increase associated with entrainment within the cooling system of the plant. Lobster larvae may be entrained in the buoyant discharge plume, which may affect survival, 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)

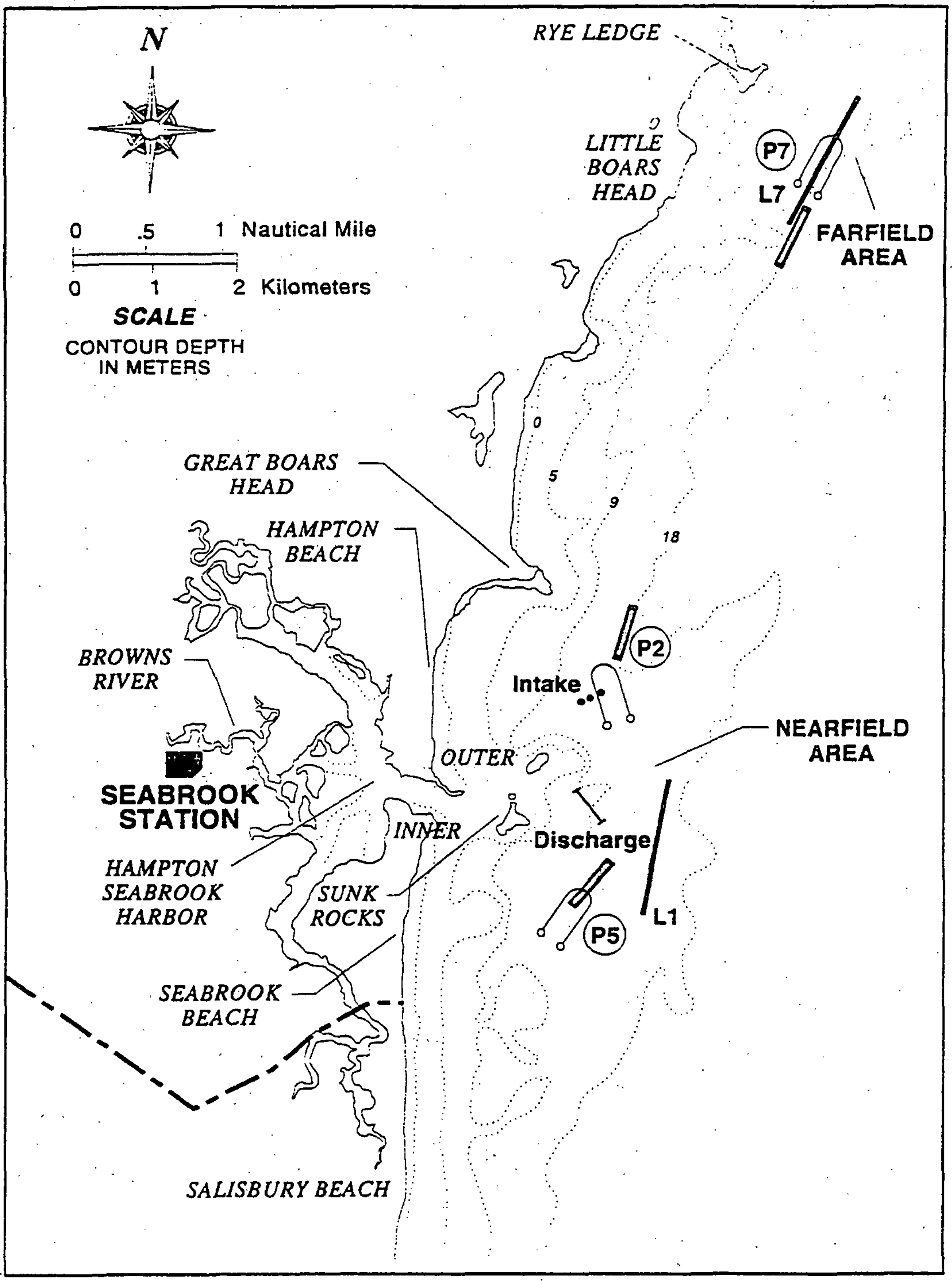
To monitor the distribution of American lobster larvae, neuston samples were collected once a week, during the day, from May through October along horseshoe-shaped tows approximately 800-m long on a side. These tows were centered at the intake (P2), discharge (P5), and farfield (P7) stations (Figure 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 (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 5 minutes. The volume filtered was determined with a General Oceanics® digital flowmeter. Volumes averaged 500 m^3 for 10-minute tows, and 200 m^3 for 5-minute tows. 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



LEGEND

= Lobster larvae (neuston)

P = Jonah and rock crab larvae (macrozooplankton)

L = Lobster traps (15 traps)

Figure 8-1. Epibenthic crustacea (American lobster, Jonah and rock crabs) sampling stations. Seabrook Operational Report, 1996.

to the nearest 1/8 inch. 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. Lobster larvae (Stages I-IV) were enumerated and live larvae were 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) through 1995. Beginning in 1996, only one tow was analyzed. 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 (1991-1996) and recent preoperational (1988-1989, when all three stations were sampled concurrently) periods at the nearfield, intake, and farfield stations. Collections made in 1990 were deleted from the analyses because Seabrook Station became operational in August of 1990, during the larval and adult sampling season. 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 legal and sublegal lobsters and crabs for the preoperational (1982-1989) and operational (1991-1996) periods.

A mixed effects ANOVA model was used to test the null hypothesis that spatial and temporal differences during the preoperational and operational periods were not significantly ($p \leq 0.05$) different. The data 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 stations 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-station 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)), months within year (Month(Year)) and the interaction of Station and Year within Preop-Op (Station X Year(Preop-Op)). These terms were added to reduce the unexplained variance and increase the sensitivity of the F-test. For 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 correlation analysis was performed between lobster CPUE and bottom water temperature to further investigate the relationships between environmental variables and lobster catch. Water temperature data are not collected as part of the lobster monitoring program, therefore, bottom temperatures measured at Stations P5 and P7 were used as representative of bottom water temperatures at Stations L1 and L7, respectively. Stations P5 and P7 are located within 500 m of Stations L1 and L7, and provide the best available estimates of bottom water temperature at the lobster monitoring stations. The analysis was performed between lobster catch in a given year and mean bottom water temperatures in that year. A lag function was used to determine if bottom water temperature in a given year affected lobster catch in following years.

8.3 RESULTS

8.3.1 American Lobster

Lobster Larvae

Annual mean lobster larvae densities in 1996 were higher than preoperational (1988-1989) densities and higher than or equal to operational mean (1991-1996) densities at each station (Table 8-1), continuing the trends observed in 1991 through 1995 (NAI 1992, 1993, 1995, 1996; NAI and NUS 1994). Average larval densities during the five-year operational period were not significantly different from the average densities during the preoperational period, and there were no significant differences among the three stations during the 1988-1996 study period (Table 8-2). The interaction term (Preop-Op X Station) was not significant, indicating that trends between the preoperational and operational periods were consistent among stations.

Monthly patterns in 1996 were similar to previous years (Figure 8-2a). In 1996, high densities of lobster larvae occurred at the nearfield station P2 in June and July, while lower 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 that found peak abundances occur sometime from July 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). 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. Frequency of molting and growth rate may increase with increasing temperature (Mariano 1993).

The increases in density in 1996 and the operational period, compared to the preoperational period, were due mainly to higher densities in Stage I and Stage IV larvae. Historically, Stage IV larvae have been the most numerous of the four larval stages (Figure 8-2b). Stage I larvae were the second-most abundant in 1996 and during the preoperational and operational periods. Stage II and Stage III larvae have historically been least abundant, and densities in 1996 were slightly higher than the preoperational densities and similar to the operational densities. Stage I lobster larvae predominated in the majority of other studies, mainly from southern New England, as reviewed by Fogarty and Lawton (1983). Stage IV larvae,

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 1996. Seabrook Operational Report, 1996.**

		PREOPERATIONAL[a]		1996[b]	OPERATIONAL[c]	
SPECIES (period sampled)	STATION	MEAN	CV	MEAN	MEAN	CV
Lobster larvae (May-Oct)	P2	0.4	22.7	1.1	0.9	22.8
	P5	0.4	33.3	0.9	0.8	21.5
	P7	0.6	28.0	1.1	1.1	23.4
Lobster, total (Jun-Nov)	L1	70.7	20.4	114.0	75.5	39.4
	L7	87.2	16.9	114.5	76.0	39.5
Lobster, legal (Jun-Nov)	L1	6.0	29.6	2.7	2.8	30.0
	L7	6.0	37.2	2.5	2.5	49.7
Lobster, female (Jun-Nov)	L1	39.0	19.4	60.0	40.5	37.4
	L7	47.2	17.0	61.4	40.9	38.4
Lobster, egg-bearing (Jun-Nov)	L1	0.6	17.1	0.5	0.5	22.5
	L7	0.6	31.8	0.7	0.7	23.8
Cancer spp. larvae (May-Sep)[d]	P2	9,532	5.2	11,415	15,384	8.7
	P5	5,064	5.6	8,395	11,081	7.6
	P7	8,426	5.7	7,233	13,057	6.7
Jonah crab, total (Jun-Nov)	L1	12.3	52.7	6.3	11.6	30.3
	L7	9.4	31.4	2.2	4.9	64.4
Jonah crab, female (Jun-Nov)	L1	9.5	50.6	4.5	8.5	27.2
	L7	6.7	30.1	1.5	3.1	72.8
Rock crab, total (Jun-Nov)	L1	2.4	78.9	1.5	2.8	76.6
	L7	1.5	133.5	3.5	2.8	47.7
Rock crab, female (Jun-Nov)	L1	0.5	119.4	0.1	0.5	138.9
	L7	0.3	148.7	0.5	0.6	127.0

[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]1996 mean; mean of the total number of samples collected during the period sampled.
[c]Operational: 1991-96, 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, 1996.**

SPECIES	SOURCE OF VARIATION[a]	df	MS	F[b]	MULTIPLE COMPARISONS[c]
Lobster larvae (May-Oct)	Preop-Op	1	2.01	12.17 NS	
	Station	2	0.03	0.38 NS	
	Year (Preop-Op)	6	0.14	0.46	
	Week (Year)	147	0.33	8.00***	
	Preop-Op X Station	2	0.07	1.85 NS	
	Station X Year (Preop-Op)	12	0.04	0.86 NS	
	Error	339	0.04		
Lobster (total catch) (Jun-Nov)	Preop-Op	1	1,870.64	0.03 NS	
	Station	1	32,076.65	1.15 NS	
	Year (Preop-Op)	12	61,521.99	1.72 NS	
	Month (Year)	69	33,954.69	42.18***	
	Preop-Op X Station	1	27,687.27	7.85*	7 Pre 7 Op 1 Op 1 Pre
	Station X Year (Preop-Op)	12	3,603.02	4.48***	
	Error	1711	804.91		
Lobster (legal size) (Jun-Nov)	Preop-Op	1	4,694.87	13.58**	Op<Preop
	Station	1	6.77	0.34 NS	
	Year (Preop-Op)	12	358.35	2.94**	
	Month (Year)	69	115.07	12.74***	
	Preop-Op X Station	1	19.75	1.04 NS	
	Station X Year (Preop-Op)	12	19.19	2.12*	
	Error	1711	9.03		
Cancer spp. larvae (May-Sep)	Preop-Op	1	2.83	1.42 NS	
	Station	2	0.83	8.44 NS	
	Year (Preop-Op)	7	1.98	0.14 NS	
	Month (Year)	36	7.55	9.70***	
	Preop-Op X Station	2	0.83	8.44 NS	
	StationX Year (Preop-Op)	14	0.11	0.14 NS	
	Error	204	0.78		

(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	1,607.04	0.83 NS	
	Station	1	8,530.97	6.27 NS	
	Year (Preop-Op)	12	1,592.31	0.99 NS	
	Month (Year)	69	1,065.33	14.98***	
	Preop-Op X Station	1	1,349.98	2.20 NS	
	Station X Year (Preop-Op)	12	682.58	9.60***	
	Error	1601	71.13		
Rock Crab (Jun-Nov)	Preop-Op	1	173.41	0.63 NS	
	Station	1	80.89	0.98 NS	
	Year (Preop-Op)	12	323.22	2.14*	
	Month (Year)	69	99.88	6.13***	
	Preop-Op X Station	1	81.88	1.22 NS	
	Station X Year (Preop-Op	12	73.62	4.52***	
	Error	1600	16.30		

[a]Preop-Op = Preoperational period (Lobster and *Cancer* spp. larvae, all stations: 1988, 1989; Adult lobster and crabs: 1982-1989); Operational period: 1991-96 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 ($\alpha \leq 0.05$) among least squares means with a paired t-test.

Lobster Larvae

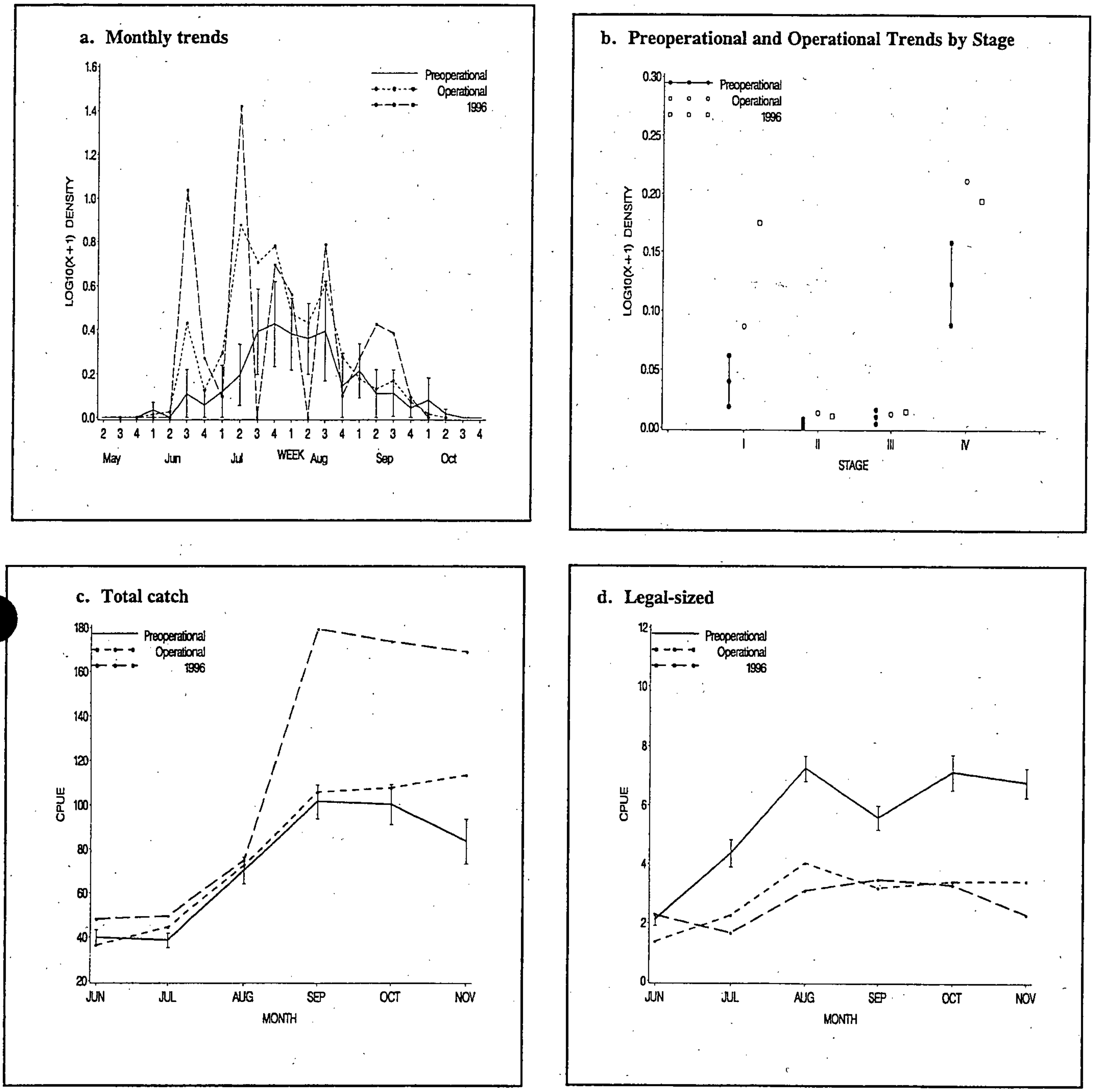


Figure 8-2. Preoperational mean with 95% confidence limits, and 1996 and operational means of a. weekly density (no./1000 m^2) of lobster larvae at Station P2, b. lobster larvae density by lifestage at P2, c. monthly CPUE (no. per 15 traps) of total (legal and sublegal) lobster at Station L1, and d. monthly CPUE (no. per 15 traps) of legal-sized lobster at Station L1. Seabrook Operational Report, 1996.

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 1996 total CPUE for lobsters at both the nearfield (L1) and farfield (L7) stations was higher than the average CPUE for the preoperational and operational periods (Table 8-1), and the highest observed during the entire study period (Figure 8-3a and b). The historically high total CPUE in 1996 was primarily due to high catches of sublegal lobsters and was a continuation of a trend first observed in 1995 (NAI 1996). In 1996, the monthly pattern in total CPUE at L1 was similar to that observed in the preoperational and operational periods, with a peak in the late summer and fall (Figure 8-2c). However, the magnitude of the peaks in CPUE in 1996, especially in the months of August through November, was much higher than either the preoperational or operational period means and similar to the pattern observed in 1995 (NAI 1996).

Monthly variations in lobster catches were due in part to regional temperature changes. Warmer temperatures, such as those measured throughout the study area in the operational period (Section 2.0), tend to increase the activity level of adults, increasing the probability 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).

Total lobster CPUE was positively correlated with bottom water temperature at Station L1 (nearfield) for a given year and for the following year (Table 8-3). There were no significant correlations for legal-sized lobsters at Station L1. At Station L7 (farfield), there were no significant correlations between total lobster CPUE and bottom water temperature, but CPUE of legal sized lobsters was positively correlated with bottom water temperature in a given year. There were no significant correlations between lobster CPUE and bottom water temperature beyond one year at either station.

Despite the high catches in 1996, average CPUE declined significantly between the preoperational and operational periods at the farfield station (L7), but increased at the nearfield station (L1) resulting in a significant Preop-Op X Station interaction term (Table 8-2; Figure 8-4). Differing preoperational and operational trends between stations were first observed in 1991 and have continued each year since then (NAI 1992, 1993, 1995, 1996; NAI and NUS 1994).

Analysis of the historical trends at each station can indicate when major changes in CPUE occurred. During the preoperational period, CPUE was decreasing at both stations (non-parametric slopes, L1 =-2.5 no./15 traps; L7 =-5.3 no./15 traps) and CPUE was higher at Station L7 than at L1 each year (Figure 8-5). In the operational period, CPUE at both stations increased (non-parametric slopes, L1 = 9.3 no./15 traps; L7 = 10.4 no./15traps) and the differences in CPUE between stations were very small. The positive trend in the operational period at both stations was primarily due to high numbers of sub-legal lobsters in 1995 and 1996. In the preoperational period, total lobster CPUE

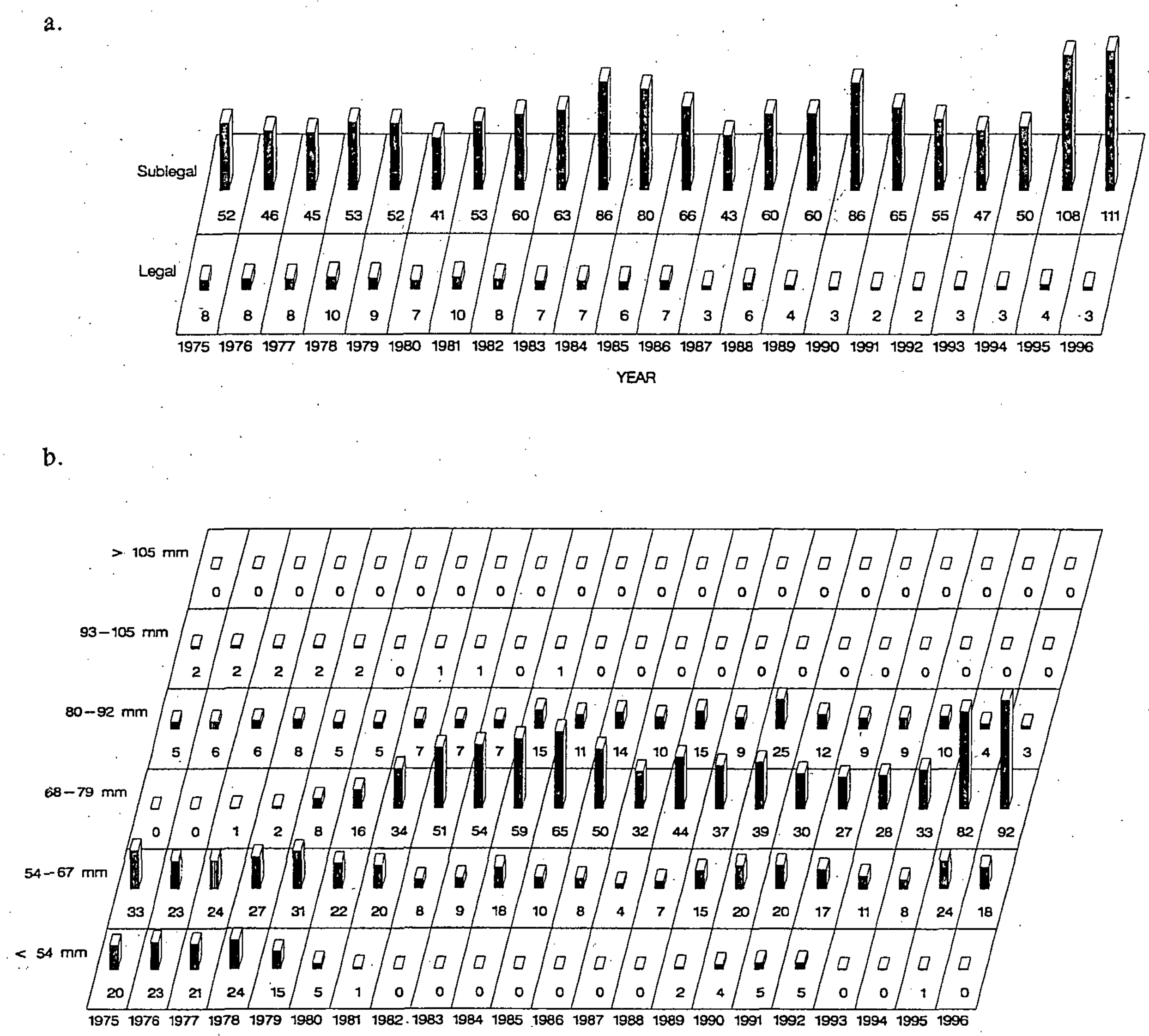


Figure 8-3. a. Catch (no. per 15 trap effort) of legal-sized and sublegal-sized lobster at Station L1 and b. size-class distribution at Station L1 from 1975-1996. Seabrook Operational Report, 1996.

Table 8-3. Results of Correlation Analysis Between Bottom Water Temperature, and Total and Legal-Sized Lobster Catch Per Unit Effort at Stations L1 and L7. Seabrook Operational Report, 1996.

STATION	TOTAL LOBSTER		LEGAL LOBSTER	
	CURRENT YEAR	FOLLOWING YEAR	CURRENT YEAR	FOLLOWING YEAR
L1	*	*	NS	NS
L7	NS	NS	*	NS

NS = Not Significant (p>0.05)
* = Significant (0.05 ≥p>0.01)
** = Highly significant (0.01≥p>0.001)

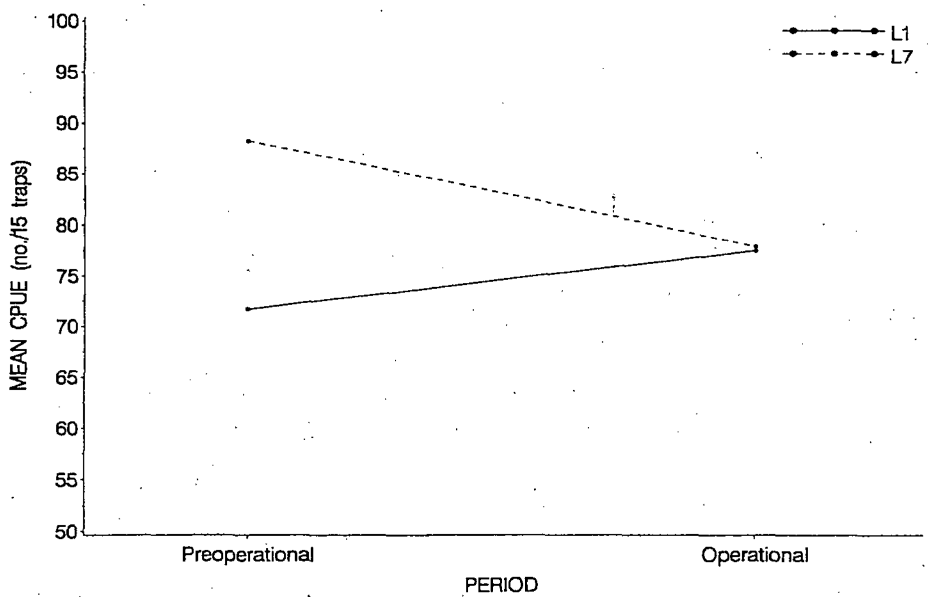


Figure 8-4. A comparison of the mean CPUE (no. per 15 traps) for total lobster by station during the preoperational (1982-84; 1986-89) and operational (1991-1996) periods when the interaction term (Preop-Op X Station) of the ANOVA model was significant (Table 8-2). Seabrook Operational Report, 1996.

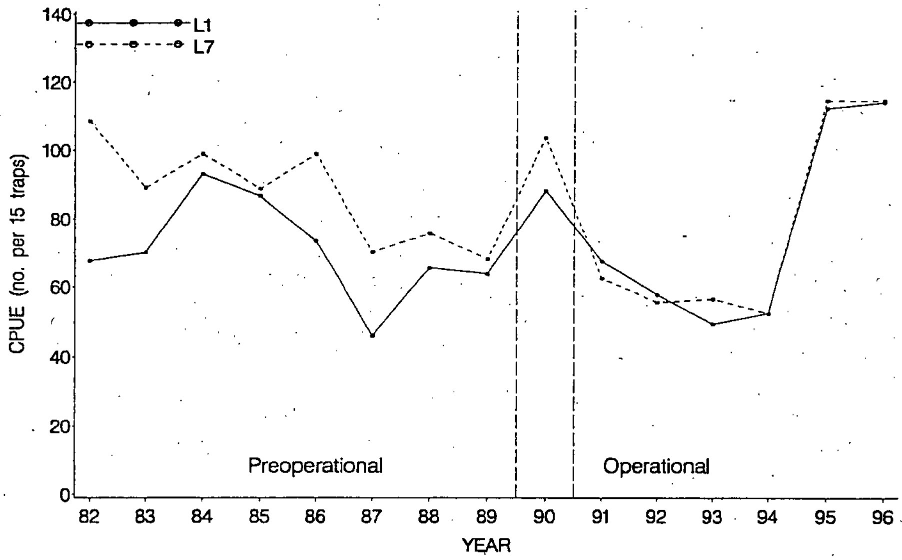


Figure 8-5. Annual mean CPUE (no. per 15 traps) for total lobster, 1982-1996 (data between the two dashed lines excluded from the ANOVA model). Seabrook Operational Report, 1996.

was significantly higher at Station L7, while during the operational period there were no significant differences between stations (Table 8-2).

Legal-sized Lobster

During 1996, average CPUE of legal-sized lobsters was lower than or equal to the operational average and lower than the preoperational average (Table 8-1). Legal-sized lobsters composed about 2% of the average operational total catch at both the nearfield station and farfield stations, lower than the preoperational averages of 8% and 7%, respectively. During the six-year operational period, the average annual legal catch at both stations was significantly lower than the preoperational average (Table 8-2). There was no significant difference in CPUE between the nearfield and farfield stations (Table 8-2). As the decrease between the preoperational and operational periods was consistent between stations, there was no significant interaction term. The monthly pattern of legal-sized lobster catches in 1996 showed a broad August through October peak as opposed to the August peaks observed in the preoperational and operational periods (Figure 8-2d).

Catches of legal-sized lobsters were affected by fisheries regulations. The legal-size limit for lobsters was increased in 1984, 1989, and in 1990, and is currently defined as a carapace length of 82.6 mm (3-1/4 in). Each increase in the legal size proportionally reduced the catch of legal-sized lobsters (Figure 8-3a).

Size Class and Sex Distribution

The majority of lobsters collected at the nearfield station in 1996 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 1981 (Figure 8-3). CPUE in this size class was the highest observed to date, for any size class, contributing substantially to the high total lobster CPUE. Lobsters measuring 54-67 mm (2-1/8 - 2-5/8 in) ranked second in abundance in 1996, similar to most previous years.

In 1996, female lobster CPUE averaged 60.0 at the nearfield station, 53% of the total lobsters collected (Table 8-1). During the preoperational and operational periods, the proportion of females were 55% and 54%, respectively at the nearfield station. Similar proportions were observed at the farfield Rye Ledge Station both in 1996 (54%) and during both the preoperational and operational periods (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 1996, CPUE averaged 0.5 at the nearfield station (L1), representing 0.4% of the total catch. CPUE of egg-bearing females at Rye Ledge (L7) was slightly higher and averaged 0.7, 0.6% of the total catch (Table 8-1). During the preoperational period, egg-bearing females accounted for 0.8% of the total catch at the nearfield station, and 0.7% at the farfield station. Egg-bearing females accounted for 0.7% (nearfield) and 0.9% (farfield) of the total operational period catches. 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 1996, 31 lobsters were impinged in the plant's cooling water system, matching the historical high of 31 in 1994 (Table 8-4). This is an increase compared to 1995 when only 16 were impinged.

Table 8-4. Number Lobsters Impinged in the Cooling Water System of Seabrook Station During 1990 Through 1996. Seabrook Operational Report, 1996.

YEAR	NUMBER OF LOBSTERS IMPINGED
1996	31
1995	16
1994	31
1993	1
1992	6
1991	29
1990	4
TOTAL	118

In previous years, impingement ranged from one (1993) to 31 (1994).

8.3.2 Jonah and Rock Crabs

Larvae

Density of *Cancer* spp. (*Cancer borealis* and *Cancer irroratus*) larvae in 1996 was lower than operational period densities at all stations, and higher than preoperational period densities at Stations P2 and P5 (Table 8-1). There were no significant differences in density between the preoperational and operational periods or among stations (Table 8-2). The Preop-Op X Station interaction term was not significant, indicating that trends in *Cancer* spp. larval density were similar between the preoperational and operational periods and that there has been no effect due to the operation of Seabrook Station (Table 8-2). The seasonal trend of occurrence at nearfield Station P2 in 1996 and for the operational period was similar to preoperational years (Figure 8-6a). Densities were low from January through April, peaked in July or August, then decreased through December. Densities in 1996 were above the upper 95% confidence limit for the preoperational period in June and July and below the lower limit in May and November.

Total Catch: Juveniles and Adults

The 1996 mean CPUE for Jonah crab (*Cancer borealis*) at both nearfield and farfield stations was lower than both the preoperational and operational averages (Table 8-1). Highest catches in 1996 and the preoperational and operational periods at the nearfield station occurred in August (Figure 8-6b). Monthly mean catches in 1996 were generally below preoperational and operational means except during November.

There were no significant differences in Jonah crab CPUE between the preoperational and operational periods, or between the nearfield and farfield stations (Table 8-2). Trends in CPUE at each station were consistent between the preoperational and operational periods as indicated by the non-significant Preop-Op X Station interaction term (Table 8-2). As a result, there is no evidence that the operation of Seabrook Station has affected Jonah crab CPUE.

Trends in female Jonah crab CPUE paralleled those of total catch. Female crab catches in 1996 were 71% and 68% 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 71% at the near- and farfield stations, respectively (Table 8-1). During the operational period, 73% of the Jonah crabs at the nearfield station were female, and 63% were female at the farfield station.

Rock crabs (*Cancer irroratus*) were less abundant than Jonah crabs in the study area (Table 8-1), probably a result of the rock crab's preference for sandy habitat rather than the cobble-rock that predominates in the study area (Jefferies 1966) and possibly behavioral interactions (Richards et al. 1983). In 1996, rock crab CPUE at the nearfield station continued the decrease from the high CPUE observed in 1992 (NAI 1993) and was lower than the preoperational and operational means (Table 8-1). At the farfield station, CPUE was the second highest observed in the operational period and was higher than both the preoperational and operational means (Table 8-1).

There were no significant differences in rock crab CPUE between the preoperational and operational periods, or between stations (Table 8-2). The

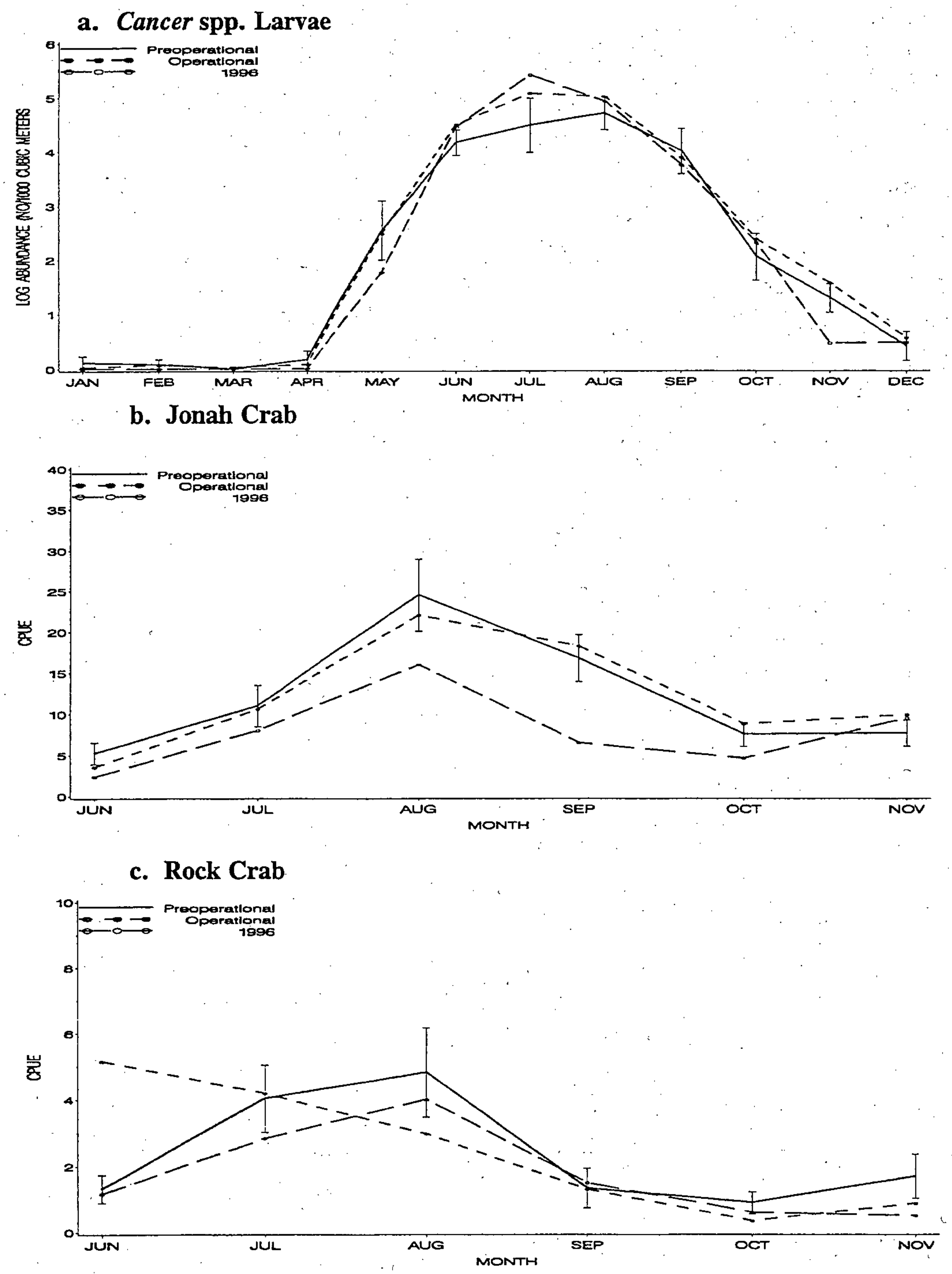


Figure 8-6. Monthly means and 95% confidence intervals of $\log_{10}(x+1)$ density (no./1000 m^3) of a. *Cancer* spp. larvae at Station P2, and monthly mean catch per unit effort (15 traps) of b. Jonah and c. Rock crabs at Station L1 during the preoperational period (1978-1984; 1986-1989: larvae. 1975-1984; 1986-1989: adults) and monthly means during the operational period (1991-1996) and in 1996. Seabrook Operational Report, 1996.

interaction of these two main effects was also not significant, indicating that the operation of Seabrook Station had no effect on the CPUE of rock crab (Table 8-2). In 1996, average monthly CPUE of rock crab peaked in August, similar to the preoperational period, whereas average monthly CPUE during the operational period was highest in June and generally declined in subsequent months (Figure 8-6c).

Female rock crab CPUE in 1996 was lower than operational and preoperational means at the nearfield station, and lower than the operational mean at the farfield station (Table 8-1). Female rock crabs composed approximately 20% of the average total catch at each station during the preoperational period. The proportion was 18% (nearfield) and 21% (farfield) during the operational period, and 7% (nearfield) and 14% (farfield) in 1996 (Table 8-1).

8.4 DISCUSSION

8.4.1 American Lobster

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 could influence larval survival, molting and successful bottom settlement (Stage IV larvae only). 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 off 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 in some studies (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. There were no significant differences in average lobster larvae density between the preoperational and operational periods and trends in density were consistent among stations (Table 8-5). Densities of both Stage I and Stage IV larvae increased between the preoperational and operational periods. Increases in Stage I larvae are likely related to increases in numbers of breeding females, or in the success of their reproduction. In a study in Jaddore Harbor, Nova Scotia, presence of Stage I larvae has been linked to the presence of breeding females (Dibacco and Pringle 1992). Regional fishing regulations have increased protection of the lobster population over the past decade by 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 (1975-96). Even so, most females that are legal-sized (minimum carapace length of 83 mm) have not attained sexual maturity,which typically occurs at a carapace length of 90-100 mm in the Gulf of Maine, (NHFG 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. The consistency in density between the preoperational and operational

Table 8-5. Summary of Potential Plant Effects on Abundance of Epibenthic Crustacea. Seabrook Operational Report, 1996.

Parameter Measured	Operational Period Similar to Preoperational Period[a]	Differences Between Preoperational and Operational Periods Consistent Among Stations[b]
Lobster: Larvae	Yes	Yes
Lobster: Total Catch	Yes	nearfield: Op>Preop farfield: Op<Preop
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)

periods and among stations, indicates that the operation of Seabrook Station has had no detectable effect on density of lobster larvae.

Bottom-dwelling juvenile and adult lobsters would most likely be susceptible to the potential effects of plant operation resulting from changes in their food source which might arise from the effects of increased detritus and turbidity around the discharge area. Temperature changes can also affect lobster activity, likelihood of capture, and migratory behavior (Dow 1969, Campbell 1986).

Average total lobster CPUE at the farfield station decreased between the preoperational and operational periods, while CPUE increased at the nearfield station resulting in a significant interaction term (Table 8-5, Figure 8-4). Similar differing trends in CPUE at the nearfield and farfield stations between the preoperational and operational periods have also been observed in 1993 through 1995 (NAI 1996, 1995; NAI and NUS 1994), which may indicate a plant effect. However, differing trends in CPUE between stations were also observed in some years during the preoperational period (1983 and 1986, Figure 8-5), which indicates that factors other than plant operation such as changes in water temperature, habitat, and lobstering activity may be having an effect on the distribution of lobsters in the study area.

Changes in water temperature can affect lobster catches. Decreases in lobster landings have been correlated with decreasing water temperature (Fogarty 1988; Campbell et al. 1991). Bottom water temperature increased significantly at both the nearfield and farfield areas between the preoperational and operational periods (see Section 2.0), and is not attributable to the operation of the plant because it occurred in both areas. Even though bottom water temperature increased significantly at both the nearfield and farfield areas, total lobster CPUE increased only at Station L1, and decreased at Station L7.

Changes in habitat can also affect lobster distribution. Lobster population and density can be significantly higher in the habitat provided by kelp beds (Bologna and Steneck 1993). Kelp appears to provide shelter for lobsters and can increase the local carrying capacity of potential lobster habitats. Differential changes in the kelp community at the two lobster monitoring stations might explain some of the differences in lobster CPUE between the preoperational and operational periods. However, macroalgae are not common at either station, based on observational dives made in June of 1997 to describe the habitat at each station. Station L1 is located in 16-22 m of water with a substrate of sand cobble and small boulders. Station L7 is located in 21-24 m of water with a substrate of rock, ledge and larger boulders interspersed with areas of sand and gravel. Macroalgae and kelp were not common at either station, although some *Agarum* sp. was observed at Station L7.

It does not appear that the kelp community (*Laminaria*spp. and *Agarum clathratum*) affected lobster distribution in 1996, assuming that the observations made in June 1997 were valid for 1996. Kelps were not common at either station, and CPUE of lobsters is at a historic high at both stations. The status of the kelp community at Stations L1 and L7 prior to 1997 is unknown, but an abundant kelp community could have existed previously, especially at Station L1. Depths at Station L1 are within the range for all kelps, but due to the deeper depth, *A. clathratum* would be more abundant at Station L7 (Villalard-Bohnsack 1995).

Commercial and recreational lobstering activities can affect lobster distribution by removing legal-sized lobsters. It is possible that an increase in lobstering activity in a small area can also cause an increase in the number of sublegal lobsters by reducing competition for food and habitat. According to the lobsterman conducting the sampling for this program, the density of lobster traps in the nearfield area has greatly increased in recent years, and is much greater than in the farfield area. All lobster traps (with the exception of those used in this study) are required to be equipped with escape vents that allow undersized lobsters to exit the trap. However, these sublegal lobsters are still able to eat the bait in the trap before exiting. Furthermore, every time a trap is hauled, the old bait is discarded overboard providing an additional food source. The high density of baited lobster traps may be attracting sublegal lobsters to the nearfield area.

Average catches of legal-sized lobsters during the operational period were lower than preoperational catches, with similar trends at nearfield and farfield stations (Table 8-5). Historically, in this study, percentages of legal-sized lobsters have decreased with each increase in the legal-size limit, as would be expected. The area-wide decline in legal-sized lobster CPUE observed in this study during the operational period is consistent with increases in the legal size limit and 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" to "overexploited." Intense commercial fishing may in part account for the significant decline in legal-sized lobster catch at both stations during the operational period. In 1993, the NOAA Autumn Survey Index (kg per trawl tow) decreased, and commercial landings increased slightly. 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 1995). Inshore landings increased by 6% between 1992 and 1993, due entirely to catch increases from Maine (NOAA 1995). In 1994, NHFG (1995) reported a slight increase in legal lobster CPUE along coastal New Hampshire.

Impingement of lobsters in the cooling water system was not expected because of the off-bottom intake location. During the operational period (1990-96) 118 lobsters were impinged; nearly 16% (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.

There is no evidence that the operation of Seabrook Station has affected the lobster resources of the study area. Impingement of adults has been minimal. The distribution of larval lobsters, and legal lobsters has been consistent among stations between the preoperational and operational periods and CPUE of total lobsters in 1996 was the highest observed in the study period. In the operational period, CPUE of total lobsters decreased at the farfield station, and increased at the nearfield station. The change in distribution is probably not due to the operation of Seabrook Station because similar changes in CPUE occurred in the preoperational period, and may be related to increased fishing efforts in the nearfield area.

8.4.2 Jonah and Rock Crabs

There were no significant differences in *Cancer* sp. larval density between the preoperational and operational periods. Trends in larval density at each station were similar between the preoperational and operational periods indicating that there was no effect due to the operation of Seabrook Station (Table 8-5).

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 of Jonah or rock crab between the preoperational and operational periods (Table 8-5). Furthermore, the nearfield and farfield stations showed similar trends between the preoperational and operational periods. The similarity in trends at the nearfield and farfield stations between periods indicates that the operation of Seabrook Station has had no effect on the CPUE of Jonah or rock crab.

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9.0 SOFT-SHELL CLAM (MYA ARENARIA)

SUMMARY

Since Hampton-Seabrook estuary contains the majority of New Hampshire's stock of the recreationally important soft-shell clam, an extensive program that started in 1974 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 (1990-1996) showed a seasonal cycle that was similar to previous years, and mean abundances were not significantly different between the preoperational and operational periods. Mean density of young-of-the-year clams (1-25 mm) in 1996 at all flats was relatively high compared to the historical average. Density of yearling clams (26-50 mm) in 1996 decreased slightly compared to 1995 and was within the range of previous years. Density of adult clams (>50 mm) in 1996 was the highest observed in the operational period, and among the highest observed since 1974. There were no significant differences in mean density between the preoperational and operational periods for YOY and yearlings, indicating that the operation of Seabrook Station has not affected the density of these lifestages. Although the density of adults was significantly greater during the operational period, this result cannot be attributed to the operation of Seabrook Station. 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. Recruitment success is apparently unrelated to larval density. There was no significant relationship between mean larval density during the summer and mean YOY density in October. This indicated that factors other than larval supply are important in controlling the recruitment of YOY clams, and removal of larvae through entrainment has had no effect on settlement of YOY clams. Predation by humans (recreational digging) had varying effects on the densities of clam lifestages. There was no clear, consistent relationship between digging pressure and density of YOY and yearling clams. High levels of digging pressure appeared to reduce the density of adult clams. Sarcomatous neoplasia, a lethal form of leukemia in clams, has spread to all flats in Hampton Harbor, and may be a partial cause of reduced densities of YOY and yearling clams.

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9.1 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, and determine whether these patterns have been affected by operation of Seabrook Station. Planktonic larval stages may be subject to impacts from Seabrook Station due to entrainment through the offshore intake structure into the circulating water system (see Section 4.3.2.3). Larval entrainment might result in a reduction in benthic stages (after settlement to the bottom) if a significant relationship were to exist between larval supply and settlement. Benthic stages in the Hampton-Seabrook estuary were also potentially affected by the station's settling basin discharge. The discharge from the basin ceased in April of 1994, and was shown to have no detectable impact on clam populations in the Hampton-Seabrook estuary (NAI 1996). Other factors unrelated to Seabrook Station that may affect the clam density, such as predation, disease, and recreational clamming were also considered. Nearfield/farfield comparisons of seed clam densities (1-12 mm) were made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich, MA, both before and during plant operation to test whether the population in Hampton Harbor has been affected.

9.2 METHODS

9.2.1 Bivalve Larvae

The spatial and temporal distributions of 12 species of umboned bivalve larvae, including soft-shell clam, 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 9-1). 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).

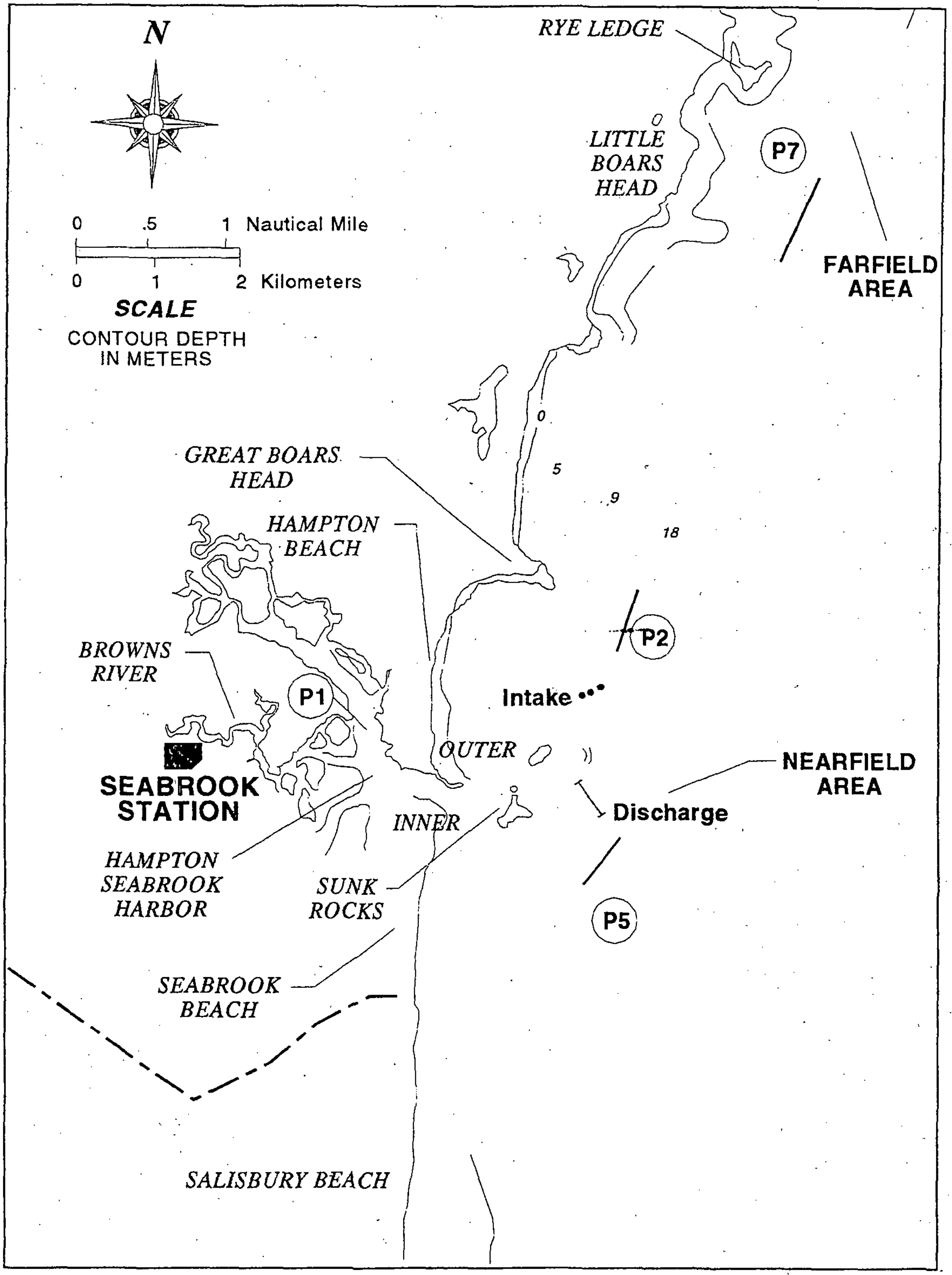
9.2.2 Hampton Harbor Population Survey

The five largest flats in the Hampton-Seabrook estuary (Figure 9-2) were surveyed in the late fall from 1974-1996 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. Clams measuring more than 25 mm in length were not collected at Flats 3 and 5, because the density has historically been extremely low.

Clams were grouped into the following size classes based on length to the nearest mm:

Young-of-the-year (YOY)	1-25 mm (seed clams 1-12 mm)
Yearling	26-50 mm
Adult	>50 mm

These age class designations were based on examination of clam length frequencies starting in 1974 (NAI 1990; 1991; 1992; 1993; 1994;



LEGEND

—— = Bivalve Larvae Stations
P1, P2, P5, P7

Figure 9-1. Bivalve larvae (including *Mya arenaria*) sampling stations. Seabrook Operational Report, 1996.

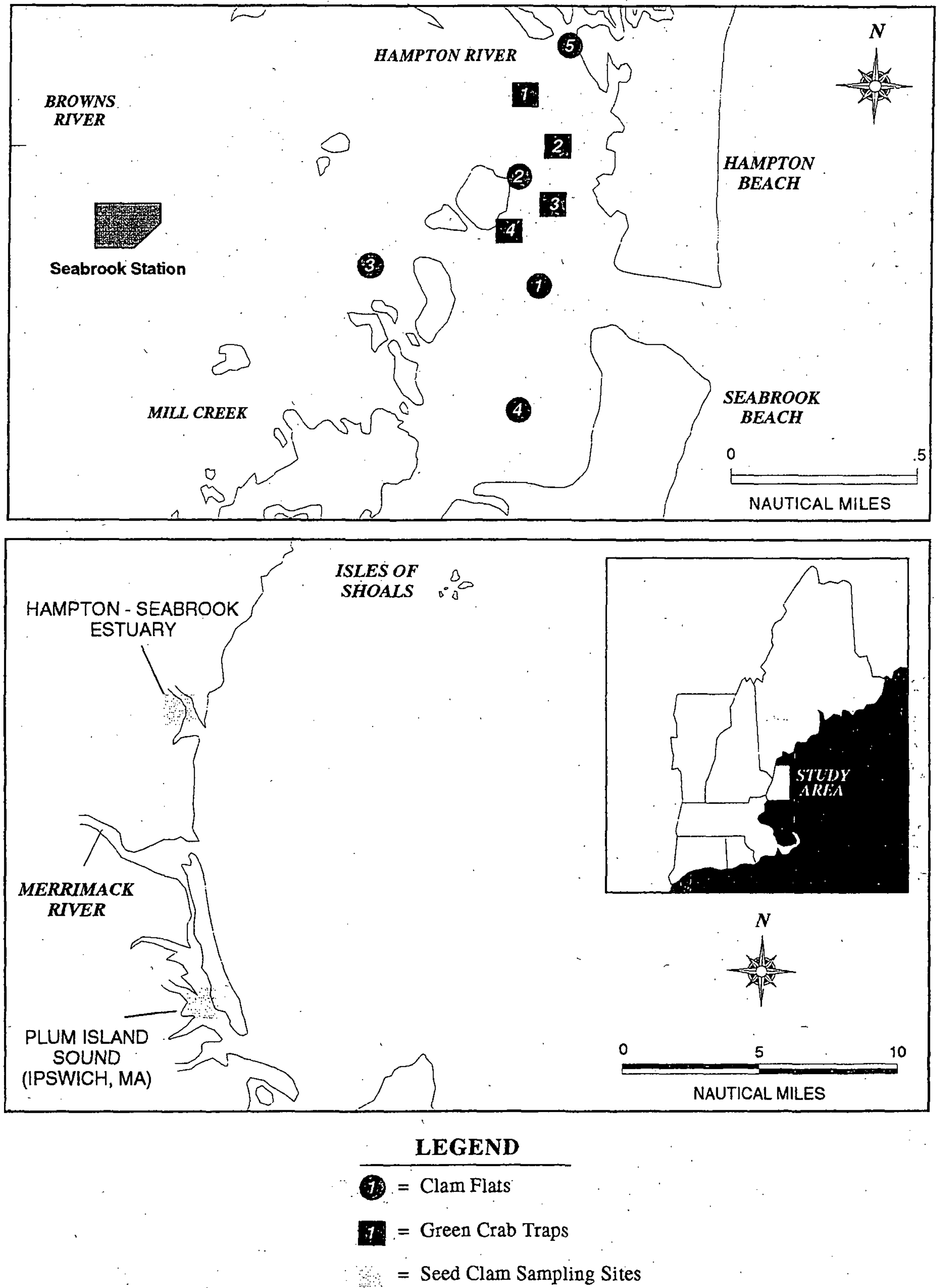


Figure 9-2. Hampton-Seabrook estuary and Plum Island Sound soft-shell clam *(Mya arenaria)* and green crab *(Carcinus maenas)* sampling areas. Seabrook Operational Report, 1996.

1995a) and the life table in Brousseau (1978a). They differ from the age class designations used in previous reports (NAI 1996) by extending the upper limit of YOY clams to 25 mm, a more conservative estimate of the upper limit of YOY clam lengths. As a result the former category "spat" with lengths from 6-25 mm was eliminated, and a new category "yearlings" with lengths from 26-50 mm was created. This category may also include some fast-growing YOY. All designations of clam age classes based on length are approximate, especially for older ages, because age classes can overlap in length. The new age class designations are probably more appropriate because they are based on the examination of our empirical data and the published literature.

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.

9.2.3 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 (<1.0 mm). Sampling sites were fixed at locations shown in Figure 9-2. Hampton-Seabrook estuary and Plum Island Sound soft-shell clam sampling areas were located where the abundance of clams has been high historically.

9.2.4 Green Crab *(Carcinus maenas)*

Beginning in 1978, green crabs (*Carcinus maenas* Linnaeus 1758) were collected at four estuarine locations on the perimeter of Flat 2 in Hampton Harbor where the abundance of clams has been high historically (Figure 9-2). 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).

9.2.5 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.

Clam populations in Hampton Harbor could possibly be affected through entrainment of larval clams into the cooling water system of Seabrook Station. Potential impacts were investigated using a mixed effects analysis of variance (ANOVA) on log(x+1) transformed density (n=number of samples). The main effects were spatial (among stations or areas/flats), temporal (among weeks and years for larvae and years only for adults), and plant operation (between preoperational and operational periods) variation. The ANOVA for larvae used weekly means of log(x+1) density collected from 1988-1996, when all three stations were sampled concurrently. The ANOVA model for benthic stages used log(x+1) densities from the total number of samples taken from 1974-1996 in the Hampton Harbor survey, and from 1987-1996 for the nearfield/farfield survey. The nearfield/farfield and bivalve larvae monitoring programs were a BACI (Before/After-Control/Impact) study design, in which samples were collected before and after plant operation began, and in both control (farfield) and potential impact (nearfield) locations (Green 1979). In the ANOVA used in this study, the Preop-Op and Station terms account for the before/after and control/impact variability, respectively. Possible plant impacts may be indicated by a significant Preop-Op X Station interaction term. If the interaction term was 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.

The Hampton Harbor Monitoring Program for adult clams was not a BACI study design as all stations were located in a single area (Hampton Harbor). The putative plant effect, reduction of benthic stages due to entrainment of larvae, might be detected through a significant Preop-Op term, indicating differences in clam densities before and after plant operation began, assuming that there were no region-wide trends during the study period.

To investigate the relationship between digging effort and clam density, a time series of the annual geometric mean density of YOY, yearling, adult clams, and digger trips were plotted for Flats 1 and 4, which received the majority of the digging effort in Hampton Harbor. The annual estimated digger trips was based on the sum of estimated weekly digger trips during the period the flats were open (January 1 through Memorial Day, and Labor Day through December 31, except when closed by NHFG). The weekly effort was based on actual counts on Fridays and estimated Saturday counts (NAI 1991). Digging effort data exists for 1980 through 1989 for Flats 1 and 4. All flats were closed to digging due to coliform pollution from the fall of 1989 through 1993, and Flat 1 was reopened intermittently beginning in 1994.

9.2.6 <u>The Relationship Between Larval and Young-of-the-Year Clam Densities</u>

Defining the relationship between the abundance of larvae and older lifestages is critical in the understanding of the population dynamics of an exploited species. A species with a strong positive relationship between the abundance of early and older lifestages may be sensitive to changes in the mortality of the early life stages. Reduced mortality of the early life stage can result in increased abundance of adults. A negative relationship between early and older lifestages can be an indicator of density dependent growth, as intraspecific competition reduces the number of larvae available for settlement. The lack of a significant relationship between early and older lifestages may be indicative of a species with highly variable recruitment whose population density may be determined more by environmental or physical factors and predation than by the abundance of larvae.

Initial concerns were that entrainment of soft-shell clam larvae through the Seabrook Station intakes could reduce the number of larvae available for settlement, and thus reduce the number of adults available for harvesting. A functional regression (Ricker 1973) was used to determine if there was a significant relationship between annual mean densities of larvae and YOY clams. Annual geometric mean density of clams 1-25 mm (dependent variable) as determined in the annual clam flat survey was regressed on annual geometric mean density of larvae at Station P1 in Hampton Harbor (independent variable) for the period 1987 through 1996. The regression was calculated for each of the five flats in Hampton Harbor and for all flats combined. Samples collected prior to 1 June were deleted from the analysis to remove empty samples (0 catch) from the analysis. Samples collected within four weeks prior to the annual survey were not included in the analysis to allow larvae to settle and grow to a minimum of 1 mm.

9.3 RESULTS

9.3.1 Larvae

Soft-shell clam larvae occurred most weeks from late May through October during preoperational years at nearfield Station P2 (Figure 9-3). Maximum densities were typically recorded in late summer or early fall, and a secondary peak usually occurred in early summer. In 1996, larvae were first observed during the first week in June, and peak abundances occurred in late June. This peak was the second highest weekly mean recorded at the nearfield station (P2) during the operational period. Smaller peaks in larval abundance occurred in late August and early October. Geometric mean densities at each station in 1996 were either similar to or larger than preoperational means, and larger than the operational means (Table 9-1). There were no significant differences in larval densities between the preoperational and operational periods (Table 9-2). Trends in larval abundance among stations were similar between the preoperational and

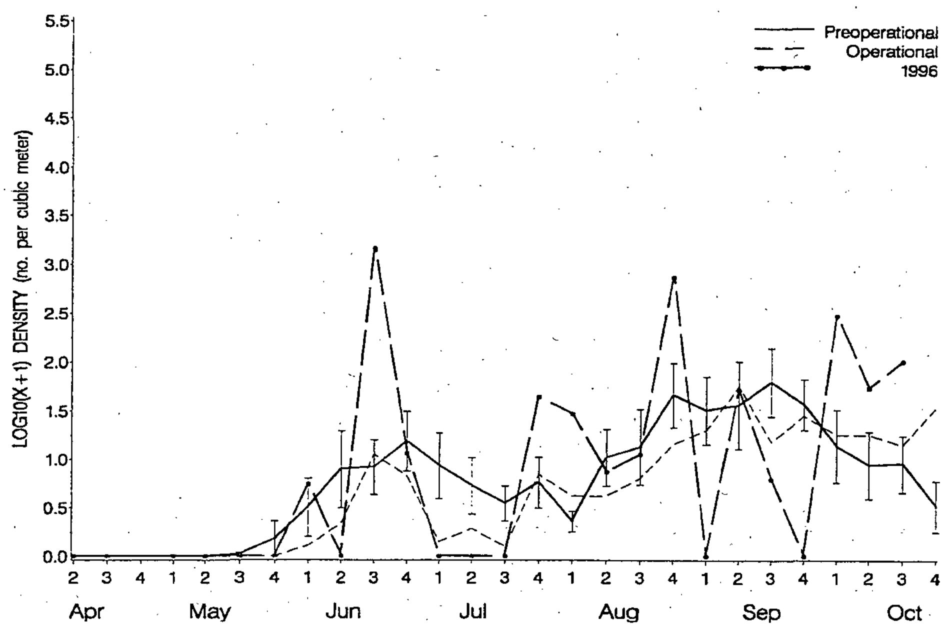


Figure 9-3. Weekly mean and 95% confidence interval of $\log_{10}(x+1)$ density (no. per cubic meter) of *Mya arenaria* larvae at Station P2, during the preoperational (1978-1989) and operational (1991-1996) periods and in 1996. Seabrook Operational Report, 1996.

Table 9-1. 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 1996. Seabrook Operational Report, 1996.

		PREOPERATIONAL[a]		1996	OPERATIONAL[a]	
LIFESTAGE	AREA	MEAN[b]	CV	MEAN[b]	MEAN[b]	CV
Larvae	P2	5.5	17.7	6.9	3.8	19
	P5	5.0	12.0	4.9	3.3	24
	P7	5.7	13.0	5.9	3.8	27
1-25 mm (young-of-the-year)	HH-1	6.1	55	9.6	4.7	47
	HH-2	10.1	57	14.0	6.5	33
	HH-4	19.7	40	14.6	6.0	49
	All	10.1	49	12.2	5.4	41
26-50 mm (yearlings)	HH-1	1.6	108	1.8	0.8	75
	HH-2	0.4	116	0.5	0.4	105
	HH-4	1.7	100	1.4	1.1	40
	All	1.2	97	1.1	0.7	67
>50 mm (adults)	HH-1	0.6	76.6	1.6	0.8	33
	HH-2	0.4	96.5	1.5	0.4	93
	HH-4	0.5	78.2	2.3	2.0	11
	All	0.5	76.5	1.7	0.8	36
1-12 mm (seed clams)	Hampton Harbor	5.7	70.8	50.3	8.4	68
	Plum Is. Sound	17.1	68.5	5.2	7.2	83

[a]Larvae PREOP = 1988, 1989; OP = 1991-96. Hampton Harbor (HH) PREOP = 1974-1989; OP = 1990-1996.
Hampton Harbor-Plum Is. PREOP = 1987-1989; OP = 1990-1996
[b]PREOP and OP means = mean of annual means. 1996 mean = mean of the number of samples.

Table 9-2. **Results of Analysis of Variance Comparing *Mya Arenaria* Larval, Spat, Juvenile and Adult Densities During Preoperational and Operational Periods. Seabrook Operational Report, 1996.**

MYA ARENARIA LIFESTAGE	STATION/FLAT	SOURCE OF VARIATION	df	MS	F	MULTIPLE COMPARISONS[j] (in decreasing order)
larvae[a]	NEARFIELD (P2, P5) FARFIELD (P7)	Preop-Op[c,d]	1	3.52	4.29 NS	
		Year (Preop-Op)[e]	6	1.11	0.74 NS	
		Week (Preop-Op X Year)[f]	193	1.46	5.99***	
		Station[g]	2	0.21	Non-est.[k]	
		Preop-Op X Station[h]	2	<0.01	0.01 NS	
		Area X Year (Preop-Op)[i]	12	0.30	1.22 NS	
		Error	349	0.22		
	HAMPTON HARBOR			21.99	1.64 NS	
1-25 mm[b] young-of-the-year	1, 2, 4	Preop-Op	1	13.12	10.11***	
		Year (Preop-Op)	21	16.55	13.88***	4>2>1
		Area	2	1.34	2.96***	
		Area X Year (Preop-Op)	44			
		Error	1797			
26-50 mm[b] yearlings	1, 2, 4	Preop-Op	1	5.00	0.53 NS	
		Year (Preop-Op)	21	9.05	7.74***	
		Area	2	18.23	16.09***	4>1>2
		Area X Year (Preop-Op)	44	1.24	8.69***	
		Error	3157	0.14		
>50 mm[b] adult, legal	1, 2, 4	Preop-Op	1	7.76	4.62*	Op>Preop
		Year (Preop-Op)	21	1.63	4.48***	
		Area	2	2.98	8.43**	4 1 2
		Area X Year (Preop-Op)	44	0.38	6.09***	
		Error	3157	0.06		
1-12 mm[b] seed	NEARFIELD/FARFIELD Hampton Harbor Plum Island Sound	Preop-Op	1	0.40	0.21 NS	
		Year (Preop-Op)	8	1.00	0.60 NS	
		Area	1	1.21	0.46 NS	
		Preop-Op X Area	1	2.57	1.53 NS	
		Area X Year (Preop-Op)	8	1.68	3.81**	
		Error	180	0.44		

[a]Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1988, 89 and op = 1991-96.
[b]For Hampton Harbor Survey preop = 1974-89 and op = 1990-96. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-96.
[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 area and year 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≥p>0.01)
** = Highly significant (0.01≥p>0.001)
*** = Very highly significant (0.001≥p)

operational periods and were not affected by the operation of Seabrook Station.

Sexual maturity in soft-shell clam 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). Soft-shell clams from Cape Ann Massachusetts, spawned in the spring at temperatures greater than 4-6 °C and again in the summer at 15-18 °C (Brousseau 1978b). Other factors that affect spawning 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 demonstrated 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 may largely originate from 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).

9.3.2 Hampton Harbor Survey

Young-of-the-year (1-25 mm). This size class contains recently settled clams that have not yet experienced a winter. Historically, YOY clam density has been highly variable. In 1996, mean densities of young-of-the-year (YOY) clams at Flats 1 and 2 were higher than both the preoperational and operational means, and densities at Flat 4 were higher than the operational mean densities (Table 9-1). The high densities in 1996 follow near record lows in 1995 at Flats 1 and 4 (NAI 1996). This size class appears to undergo an approximate three-year periodicity in abundance with peaks occurring in 1976-77, 1980-81, 1984, 1987, 1989-90, 1993 and 1996 (Figure 9-4).

There were no significant differences in YOY clam density between the preoperational and operational periods, indicating that the operation of Seabrook Station has not affected YOY clam densities (Table 9-2). Mean densities were significantly higher at Flat 4 and 2 than at Flat 1 (Table 9-2).

Yearling (26-50 mm). Trends in the 26-50 mm size class indicate the survival success of YOY (1-26 mm) that have over-wintered, along with any fast-growing YOY. In 1996, yearling size class densities decreased at all flats compared to 1995 (Figure 9-5). Mean densities in 1996 at Flat 4 was lower than the preoperational mean, and within the range of previous years (Table 9-1). Mean density at Flats 1 and 2 in 1996 was higher than both the preoperational and operational means (Table 9-1). There were no significant differences in density of yearling clams between the preoperational and operational periods (Table 9-2). Mean density of yearling clams were significantly higher at Flat 4, than at Flats 1 and 2 (Table 9-2).

The time series for yearling density at all three flats indicates that the flats generally showed the same trends in density from year to year (Figure 9-5). Density at all flats was high from 1977 through

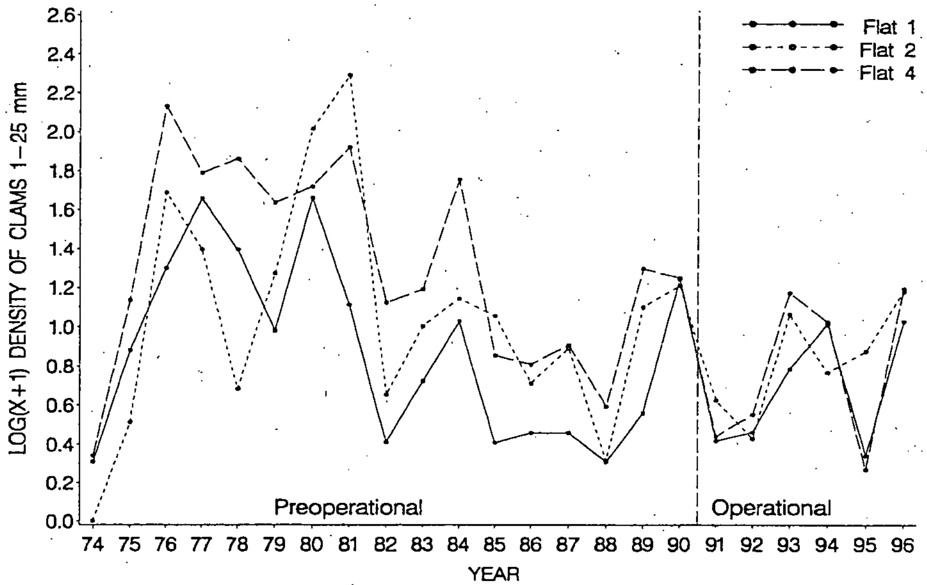


Figure 9-4. Annual mean $\log_{10}(x+1)$ density (number per square foot) of clams 1-25 mm, 1974-1996. Seabrook Operational Report, 1996.

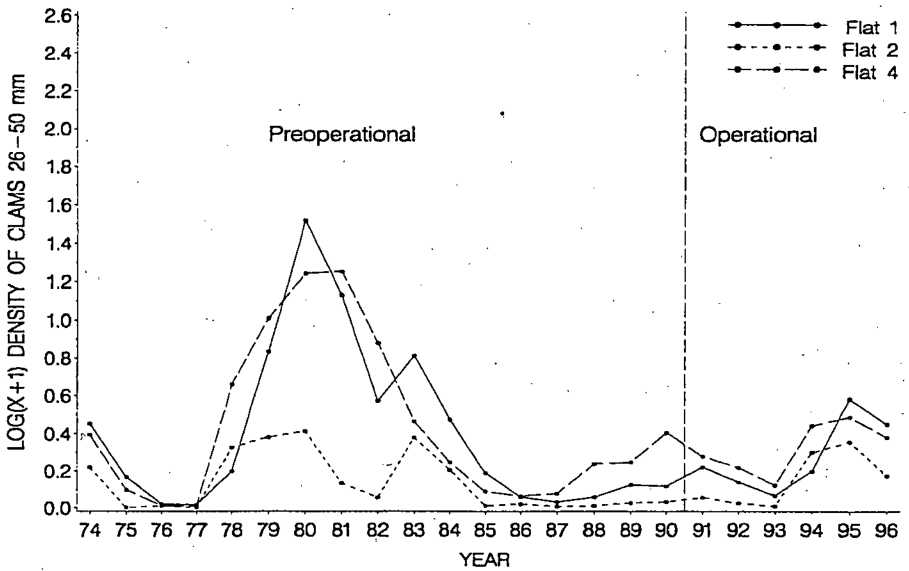


Figure 9-5 Annual mean $\log_{10}(x+1)$ density (number per square foot) of clams 26-50 mm, 1974-1996. Seabrook Operational Report, 1996.

1983, followed by a low density period from 1985 though 1993. Yearling density peaked in 1994 and 1995, and decreased slightly in 1996.

Adults (>50 mm). Clams measuring more than 50 mm are at least 2 years of age (Brousseau 1978a) and considered adults in this study. In 1996, mean densities of adults were among the highest recorded at each flat (Figure 9-6), and higher than the preoperational and operational means (Table 9-1). At Flats 2 and 4, the 1996 densities were the second-highest recorded and at Flat 1 density was the fourth-highest (Figure 9-6). Density was significantly higher during the operational period, indicating that Seabrook Station did not adversely affect adult densities (Table 9-2).

Density of adults was significantly higher at Flat 4, and lower at Flat 2 (Table 9-2). Mean density at all three flats appeared to follow similar trends among years (Figure 9-6). Densities at all flats during the preoperational period were elevated in the mid-1970s through the early 1980s, similar to trends noted in Maine and Massachusetts (Crago 1993). In the operational period, there has been a trend of increasing densities of adults at all flats.

9.3.3 Nearfield/Farfield Study

In 1996, the mean density of seed clams (1-12 mm) in Hampton Harbor (nearfield area) was higher than both the preoperational and operational means (Table 9-1) and the highest annual mean recorded since monitoring began in 1987. Densities of seed clams in 1996 in Plum Island Sound (farfield area) were lower than preoperational and operational mean densities (Table 9-1). 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, as indicated by the non-significant Preop-Op X Station interaction term (Table 9-2).

9.3.4 Effects of Predation and Perturbation

Clams in Hampton Harbor have historically been subjected to predation from two major sources: green crab, which consume clams up to about 50 mm in length (Ropes 1969), and humans who dig adult soft-shell clam and also cause mortality to smaller clams following substrate disturbance. 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 9-7). Monthly mean green crab abundance during the operational period was lower than the preoperational period every month except January and December (Figure 9-7). In 1996, monthly mean abundance of green crab was higher than both the preoperational and operational monthly mean every month except January and June.

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 (Figure 9-8) for the most part corroborate their findings although there are exceptions. During the winters (January-March) when the minimum temperature was relatively high (1983-1988), green crab abundance in the following fall was also high. In 1992, the minimum temperature was low, but the fall green crab abundance was at its highest level to date. In 1993 and 1994, when the minimum winter temperature was low, green crab abundance declined from the

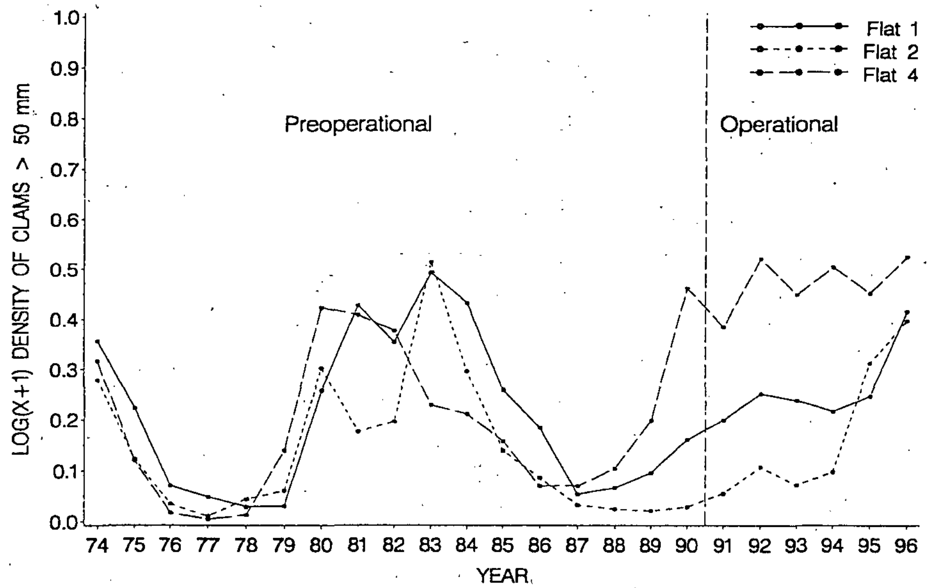


Figure 9-6. Annual mean $\log_{10}(x+1)$ density (number per square foot) of clams > 50 mm, 1974-1996. Seabrook Operational Report, 1996.

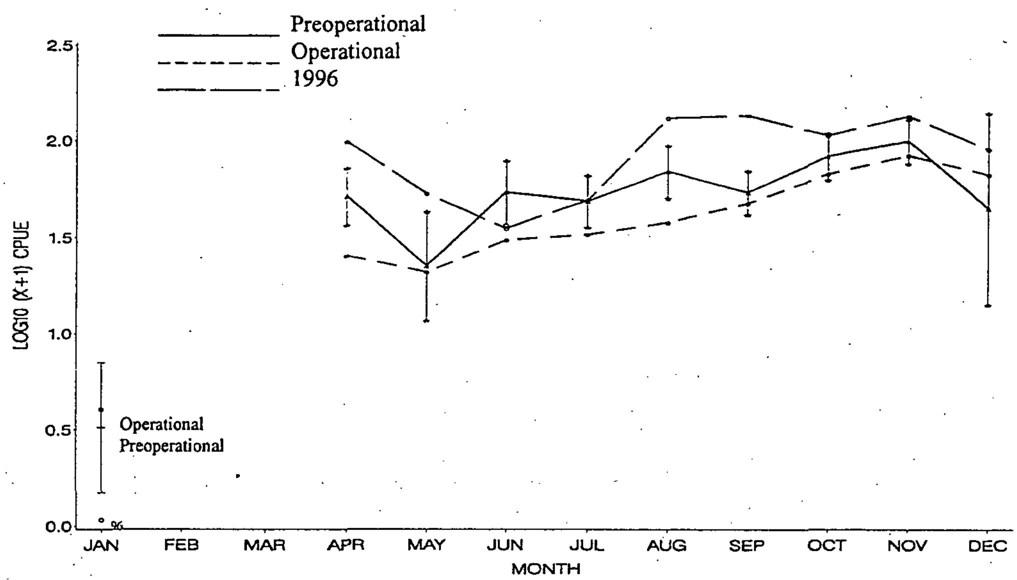


Figure 9-7. Mean $\log_{10}(x+1)$ monthly catch per unit effort and 95% confidence intervals of green crabs (*Carcinus maenas*) collected during preoperational years (1983-1989), operational years (1991-1996), and 1996. Seabrook Operational Report, 1996.

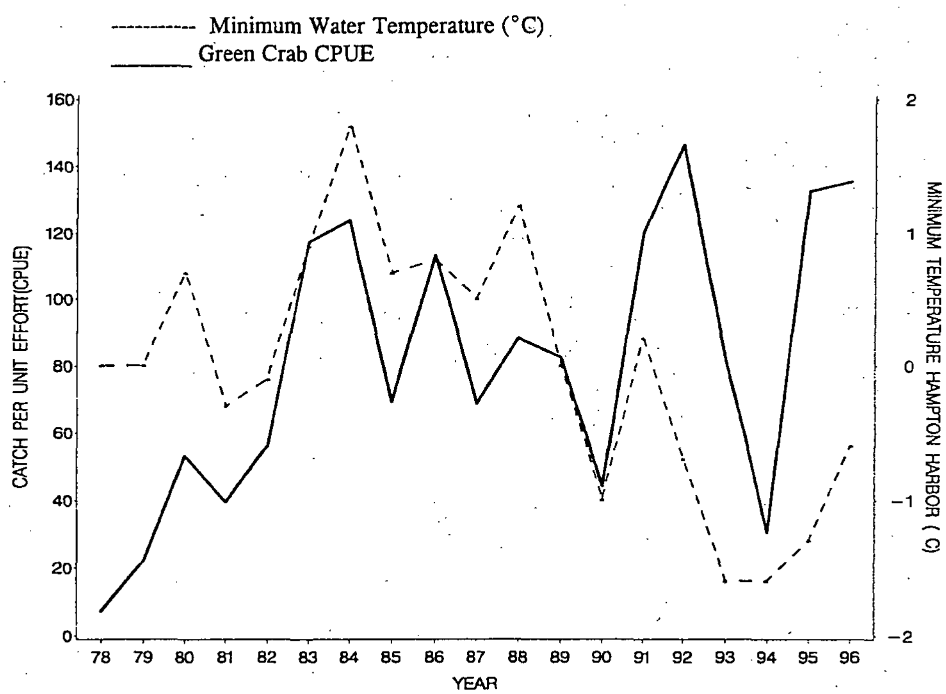


Figure 9-8. Mean fall (October-December) catch per unit effort of green crabs in Hampton-Seabrook Harbor and its relationship to minimum winter water temperature from 1978-1996. Seabrook Operational Report, 1996.

previous years. In 1995 and 1996, the minimum water temperatures increased slightly over the previous years, but CPUE of green crabs was high (Figure 9-9). It is likely that many factors, both physical and biological, are involved in controlling green crab CPUE. Green crabs were not found in New England before the early 1900s (Gosner 1978), and the local population has generally increased since the late 1970s (Figure 9-8).

The number of digger trips has varied by more than an order of magnitude since monitoring began in 1980. Recreational clam digging on the Hampton Harbor flats could be a significant source of mortality for both adult (>50 mm) and smaller clams. Prior to the closing in 1989, Flats 1 and 4 received the majority of the digging pressure. Digging effort at Flat 1 increased from 1980 to a peak in 1986 and then declined rapidly to a low in 1989 (Figures 9-9, 9-10, 9-11). The 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 flat reopened to digging in 1994 and effort has declined since then, primarily due to closures associated with coliform pollution. At Flat 4, there was a rapid increase in digging effort in the early 1980s, followed by a general decline to an historic low in 1989. The flat was closed to digging in the fall of 1989 and has not reopened since then.

There was no clear, consistent relationship between digging effort and density of YOY clams (1-25 mm) at Flats 1 and 4 (Figure 9-9). At Flat 1 there appeared to be a negative relationship between

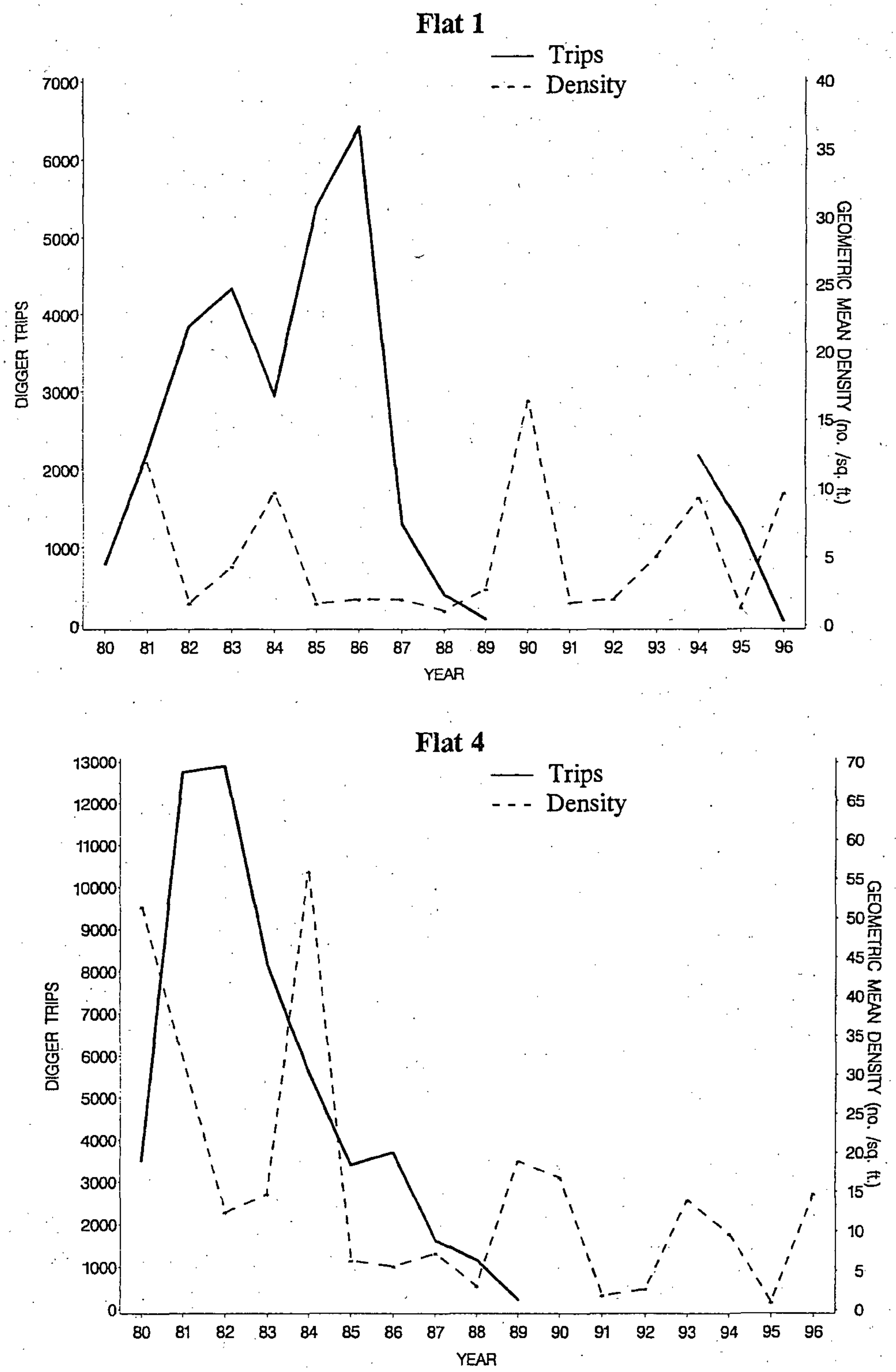
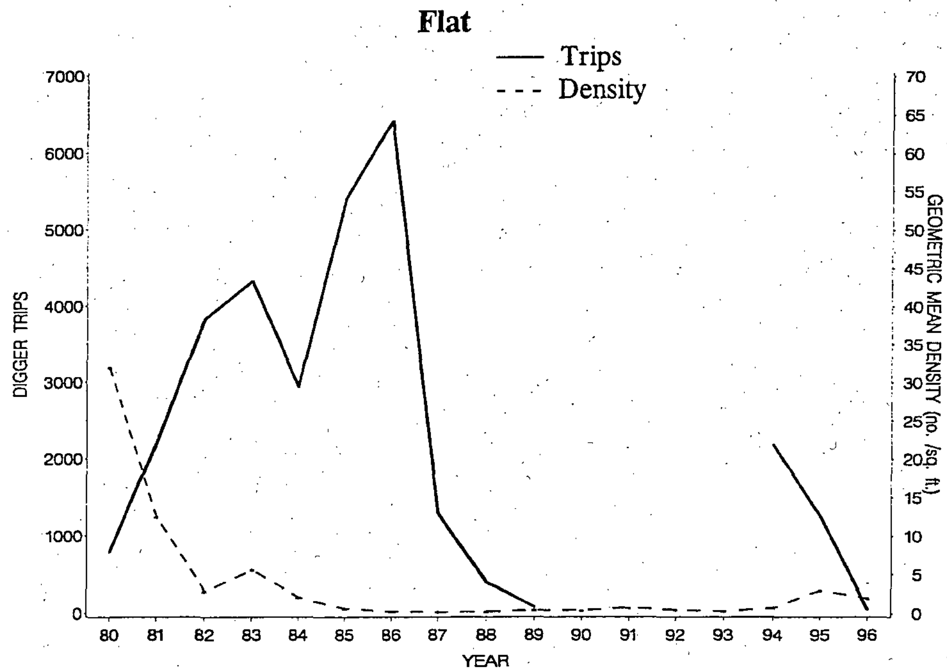


Figure 9-9. The relationship betweem digging pressure and denstiy of young-of-the-year clams (1-25 mm) from 1980 through 1996 at Flats 1 and 4 in Hampton Harbor. Seabrook Operational Report, 1996.



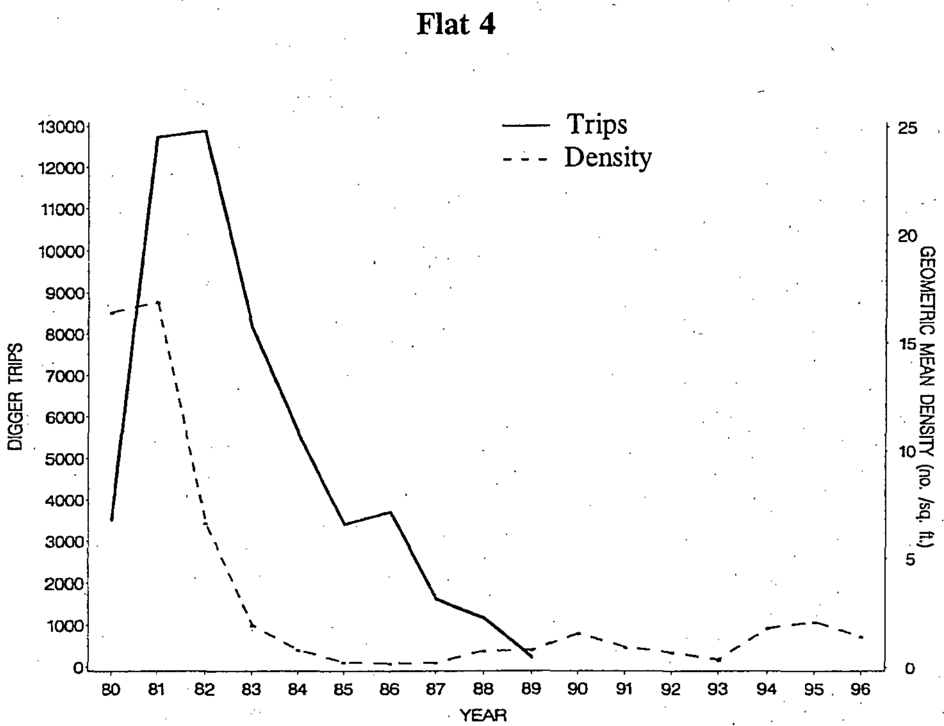


Figure 9-10. The relationship between digging pressure and density of yearling Clams (26-50 mm) from 1980 through 1996 at Flats 1 and 4 in Hampton Harbor. Seabrook Operational Report, 1996.

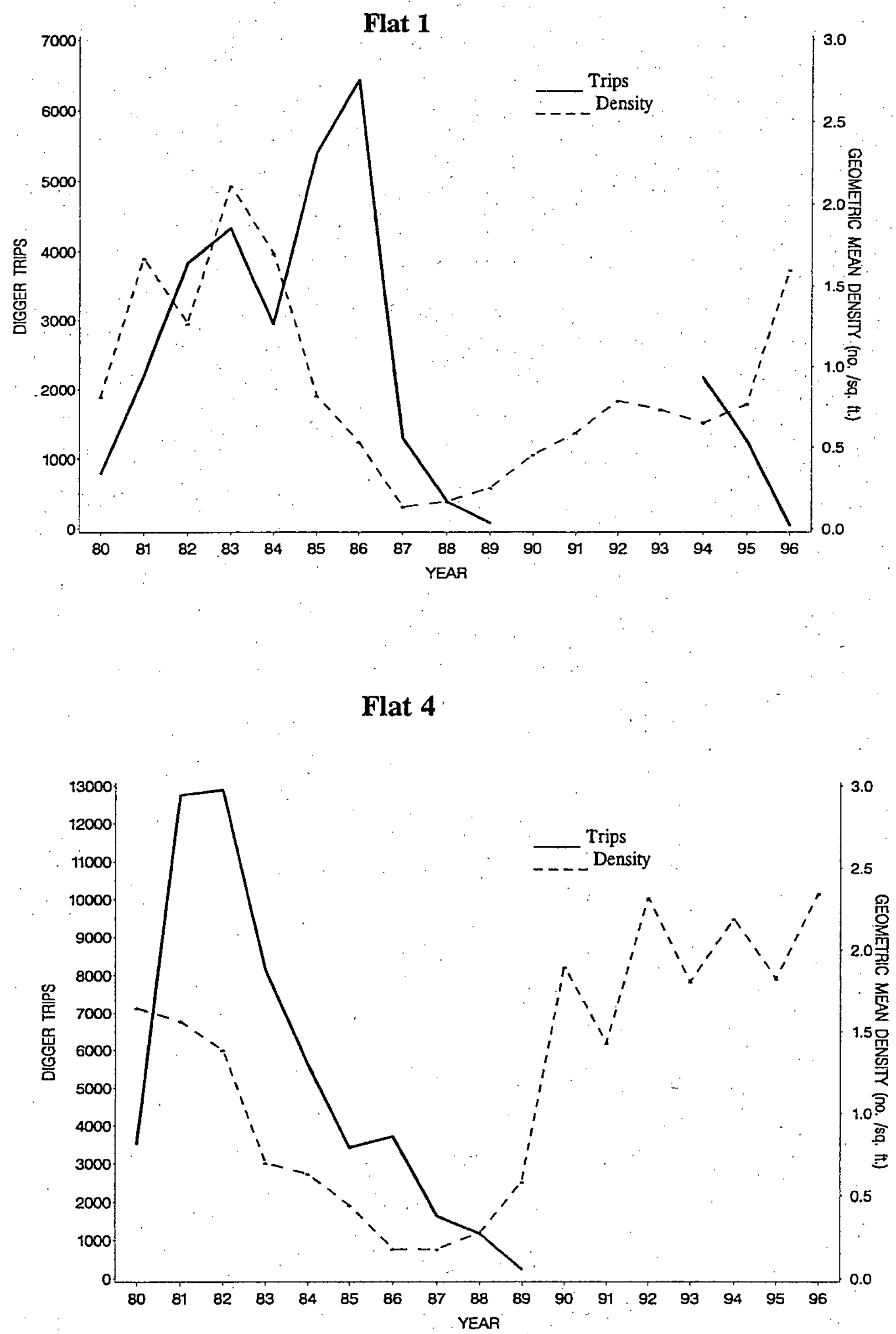


Figure 9-11. The relationship between digging pressure and density of adult clams (> 50 mm) from 1980 through 1996 at Flats 1 and 4 in Hampton Harbor. Seabrook Operational Report, 1996.

digging effort and YOY clam density from 1980 through 1986. Density of YOY clams was highest in 1980, and then declined rapidly in the mid 1980s as digging effort increased. After digging stopped in 1989, there was an increase in YOY clam density the following year in 1990. However, YOY clam density did not consistently increase in the either the absence of digging pressure (1990 through 1993), or with reduced digging pressure (1994 through 1996). At Flat 4, there was a general decrease in both digging pressure and YOY clam density from 1981 through 1989, with the exception of a heavy set of YOY clams in 1984. In the absence of digging from 1989 through 1996, YOY clam density increased rapidly and then decreased cyclically through 1996.

As with YOY clams, there was no clear relationship between density of yearling clams (26-50 mm) and digging pressure at Flats 1 and 4 (Figure 9-10). At Flat 1, density of yearling clams declined precipitously in the early 1980s as digger effort increased. However, density of yearling clams did not increase in the period 1990 through 1996 when digging pressure was very low. At Flat 4 both densities of yearling clams, and digging pressure decreased from 1981 through 1989. After digging pressure stopped in 1989, density of yearling clams increased, but not to the levels observed in the early 1980s.

Densities of adult clams (>50 mm) may be related to digging pressure (Figure 9-11). At Flat 1, density of adult clams began to decrease in 1984 following a peak in digging pressure in 1983. By 1986 and 1987, density of adult clams were near historic lows and digging pressure was highest. After digging stopped in 1989, density of adult clams began to slowly increase, even in the face of renewed low level digging pressure in 1994 through 1996. At Flat 4, densities of adult clams and digging pressure decreased from 1981 through 1989 when the flat was closed. There was rebound in densities of adults from 1990 through 1996 when there was no digging pressure.

9.3.5 Effect of Disease

Sarcomatous neoplasia, a lethal form of leukemia in soft-shell clam, was identified in a limited number of individuals taken from Hampton Harbor clam 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 soft-shell clam populations may reach 100 percent with complete mortality of infected clams (Farley et al. 1986). The incidence of sarcomatous neoplasms in the Hampton Harbor clam population was observed in October 1986 and February 1987 to be 6% at Flat 1 and 27% at Flat 2 (Hillman 1986, 1987). 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). However, a recent survey in May of 1996 of Flats 1, 2 and 4 indicated that neoplasia had spread to Flat 4 as the disease was present in all clams sampled (n=10/flat). Densities of adult clams (>50 mm) have increased greatly at all flats in the operational period despite the presence of neoplasia (Figure 9-6). However, yearling densities have decreased in 1996 (Figure 9-5), and may result in a decrease in adult clams in the next few years.

9.3.6 The Relationship Between Larval and Young-of-the-Year Clam Densities

Functional regressions between annual geometric mean densities of larval and YOY soft-shell clams were significant for every flat and for all flats combined (Table 9-3). Despite the significant regressions, the strengths of relationships between larval density and density of YOY clams were very weak as indicated by the low correlation coefficients. The relationship between larval and YOY abundance was strongest at Flats 2 and 4 where variability in larval abundance accounted for about 22-25% (r^2) of the variability in YOY abundance. The relationship was much weaker at the other flats and for all flats combined, where the abundance of clam larvae accounted for only 8% of the variability in YOY clams (Table 9-3).

Table 9-3. Results of the Functional Regression and Correlation Analyses Between Geometric Mean Density Young-of-the-year (No./ft^2) and Larval *Mya Arenaria* (No./m^3) in Hampton Harbor. Seabrook Operational Report 1996.

FLAT	FUNCTIONAL REGRESSION SIGNIFICANCE (t)	PEARSON CORRELATION COEFFICIENT (r)	COEFFICIENT OF DETERMINATION (r^2)
1	2.84*	0.12 NS	0.01
2	7.01**	0.47 NS	0.22
3	2.75*	0.02 NS	<0.01
4	3.12*	0.50 NS	0.25
5	3.11*	0.42 NS	0.17
All flats combined	2.91*	0.27 NS	0.08

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

The lack of a strong relationship between densities of larvae and YOY clams indicates that larval supply is probably not a major factor in determining the density of YOY clams (Figure 9-12). It is obvious that some minimum density of larvae is necessary to ensure settlement of spat. However, it appears that hydrodynamic factors such as bedload sediment transport may be more important than larval supply in the recruitment of soft-shell clam (Emerson and Grant 1991). Bedload sediment transport can affect recruitment of YOY soft-shell clams by either passively removing newly settled spat, or by transporting spat in from other areas.

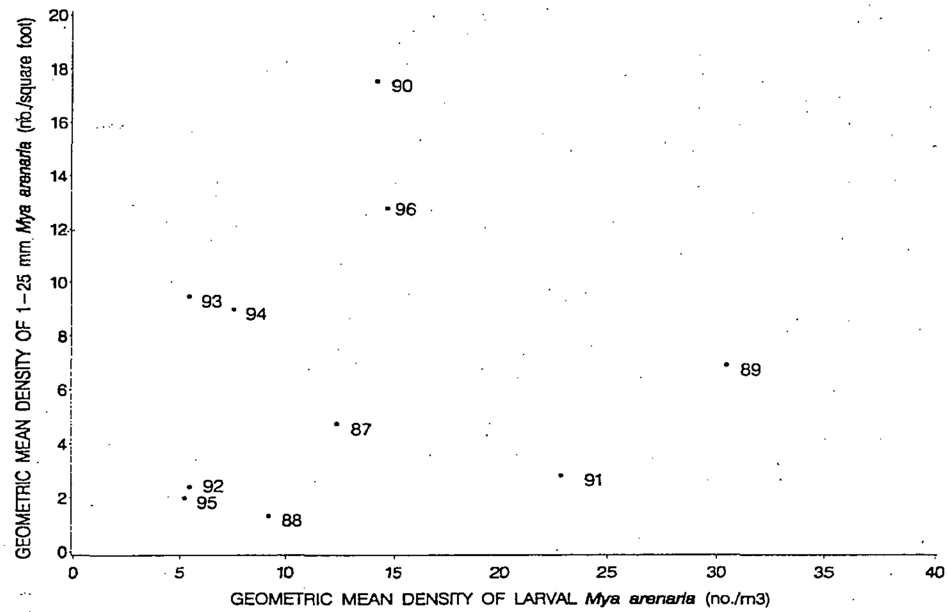


Figure 9-12. The relationship between geometric annual mean density of larval (no./m^3), and 1-25 mm *Mya arenaria* (no./ft^2) in Hampton Harbor 1987-1996. Seabrook Operational Report, 1996.

9.4 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 in 1974 to characterize the variability in the population for all lifestages, and relate this variability to natural or power plant-related factors.

Recruitment and survival of the soft-shell clam population in Hampton Harbor is affected by a variety of physical and biological factors that must be considered in impact assessment. Recruitment from larvae to YOY is not well understood, but is apparently not strongly related to the abundance of larval stages (NAI 1982). Larval density was not significantly correlated with density of YOY clams (Section 9.3.6) within the ranges of larval densities observed in this study. Therefore, the removal of clam larvae from the nearshore waters of New Hampshire through entrainment into the cooling water system of the plant probably has had no effect on YOY clam density. Successful YOY sets have occurred approximately every three years in the preoperational period, as well as during 1993 and 1996 in the operational period (Figure 9-4). The reason for this approximate three year cycle is unknown, but its continuation into the operational period is an indication that the operation of Seabrook Station has not disrupted the factors controlling YOY clam abundance.

Survival of the YOY set to yearling (26-50 mm) depends on a number of factors including the level of predation and disease. The preoperational period includes "boom and bust" cycles of yearlings dictated apparently in part by predation, at least for the smaller size classes. In 1991 and 1992, densities of yearling clams were lower than those during preoperational years, coinciding with a period of high green crab abundance. Densities of yearling clams in 1994 increased, during a period of low green crab abundance (Figures 9-5; 9-8). Densities of yearling clams were low in 1996 at all flats (Figure 9-5) probably the result of increased green crab abundance following a relatively mild winter. Other factors were likely involved in changes in yearling densities from 1994 to 1996, but the dominant factor appears to have been predation by green crabs.

An important factor affecting the long-term trends in clam abundance is human predation by clam diggers. The Hampton Harbor clam flats were reopened to recreational digging in the fall of 1994 for the first time since 1989. Clam diggers turn over the substrate with clam forks in their attempt to find clams. The population is reduced by harvesting of clams (fishing mortality), or through mortality of unrecovered clams that are left behind (incidental mortality). Unrecovered clams are either broken by the clam fork, or are exposed to increased predation and unfavorable environmental conditions such as smothering or desiccation. Medcof and MacPhail (1964) estimated that each digging with a 4-tined clam fork causes a 80% reduction in harvestable adults due to fishing mortality (30%) and incidental mortality (50%). Smaller size classes that are not harvested are reduced by 50% only due to incidental fishing mortality. However, more recent research by Robinson and Rowell (1990) indicates that overall incidental fishing mortality is probably less than 20%. In sandy substrates similar to Hampton Harbor, incidental fishing mortality may be even lower because clams can more easily rebury themselves (Robinson and Rowell 1990).

Settlement of YOY clams may be enhanced through the habitat modifications caused by intense clam digging. Heavy recruitment of clams has been observed in areas adjacent to structures protruding from sediment surface such as stones, branches, and in areas where the sediment has been disturbed as part of clam harvesting activities (Heinig 1996). The numerous pits caused by clam digging are areas of reduced shear stress where organic material and fauna accumulate (Savidge and Taghon 1988). Pits resulting from clam digging may be areas where the reduced shear stress could cause clam larvae to settle that would otherwise pass across the sediment surface (Emerson and Grant 1991). If clam digging results in increased recruitment, then density of YOY clams could be higher in years of intense digging pressure. This relationship would probably not carry over to the following year as winter storms would smooth out digging pits.

Data from Hampton Harbor do not support the hypothesis of increased digging pressure resulting in increased settlement. There was no clear relationship between digging effort and density of YOY and yearling clams at Flats 1 and 4 (Figure 9-9). At Flat 1, some of the poorest years of recruitment (1985 and 1986) occurred in some of the years of highest digging pressure. Two of the highest years of YOY recruitment (1980 and 1990) occurred in years with light and no digging pressure respectively (Figure 9-9). Data from Flat 4 indicated similar results. Two of the poorest years of recruitment (1982 and 1983) occurred in years of high digging pressure. Furthermore, there was no consistent decrease in YOY density at Flat 4 after digging pressure stopped in 1989. In fact, relatively good sets of YOY clams occurred in 1993 and 1996 in the absence of digging pressure (Figure 9-9).

Many factors in addition to digging pressure, such as predation by green crabs and sediment bedload transport (Emerson and Grant 1991) probably affect recruitment of YOY clams. Predation by green crabs could mask any relationship between digging pressure and settlement. The annual clam survey is held in the fall after potential heavy predation by green crabs in the summer could have reduced YOY clam density. Sediment bedload transport has been shown to completely remove recently settled clams from an area and redistribute them elsewhere. The best way to assess the relationship between digging pressure and recruitment is in the form of a carefully controlled and replicated experiment where predators are removed, and adjacent areas of the flats receive different treatments of disturbance and non-disturbance.

High digging pressure appeared to reduce densities of adult clams (Figure 9-11). Total mortality is higher for adult clams because the majority are removed by the diggers. Of those remaining, the larger surface area of adult clams may make them more likely to be damaged or speared by clam forks resulting in increased mortality. Following a peak in digging pressure at Flat 1 in 1986, density of adult clams dropped to the lowest recorded level (Figure 9-11). After digging ended in 1989, density of adult clams increased slowly in the 1990s. The recent resumption of low level digging pressure at Flat 1 in 1994 through 1996 does not appear to have affected the recovery of clam stocks. At Flat 4, high levels of digging pressure in 1981 through 1984 coincided with reductions in adult clam density. Density of adult clams began to increase in 1988 at low digging pressure, and increased dramatically in 1990 through 1996 in the absence of digging pressure.

A factor likely to affect growth and survival of juvenile and adult soft-shell clams was the presence of sarcomatous neoplasia, a lethal form of blood cancer. Neoplasia was present in 1986 and 1987 at Flats 1 and 2 and was absent at Flat 4 (Hillman 1986, 1987). A recent survey in May of 1996 indicated that neoplasia had spread to Flat 4. Significant increases in adult clam densities in the operational period occurred primarily at Flat 4, where neoplasia was historically rare during preoperational years. Despite the presence of the disease, densities of adult clams increased at Flat 4 in 1996 (Figure 9-6), although densities of yearlings may have started to decrease (Figure 9-5). The presence of neoplasia may be an important factor affecting clam densities on Flat 4 as yearling clams mature.

Differences in density of seed clams (1-12 mm) between the preoperational and operational periods were similar at Hampton Harbor (nearfield) and Plum Island Sound (farfield). Similarly, the differences in larval densities between periods were similar at the nearfield and farfield stations. These trends indicate that the operation of Seabrook Station has not affected densities of seed or larval clams.

Any influence on the densities of larval and older life stages of soft-shell clam due to the operation of Seabrook Station was not detected in this study (Table 9-4). There were no significant differences in clam density in Hampton Harbor between the preoperational and operational periods, with the exception of clams >50 mm. Density of this size class was greater in the operational period and this difference cannot be attributed to station operation.

The key to monitoring the effects of plant operation on the soft-shell clam population is understanding the long-term cycles of this species and the multi-

Table 9-4 Summary of Evaluation of Effects of Operation of Seabrook Station on Soft-shell Clam. Seabrook Operational Report, 1996.

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 (1-20 mm)	Yes	N/A[c]
	Yearling (21-50 mm)	Yes	N/A[c]
	Adult (>50 mm)	No (Op>Preop)	N/A[c]
HAMPTON HARBOR/ PLUM ISLAND SOUND	Young-of-year (1-12 mm)	Yes	Yes

[a]Operational period for larvae = 1991-96; 1->50 m size classes = 1990-96; 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.
[c]No nearfield to farfield comparisons appropriate.

tude of factors that affect them. 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 lack of a relationship between this variability and the start-up and operation of Seabrook Station, there is no indication that Seabrook Station has had an effect on the Hampton Harbor *Mya* population.

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APPENDIX A. COMPARISON OF MIXED AND FIXED ANOVA MODELS

Both the mixed and fixed model ANOVAs where calculated to allow comparisons between the two models. The mixed model ANOVA considers all space (station) and time (week, or month) variables as random because they represent a small fraction of the possible locations and times of sampling (Underwood 1994). Preop-Op is considered a fixed variable because both levels of this variable (preoperational and operational periods) were sampled. The fixed model considers all variables to be fixed. Appendix A in NAI (1995) presents further discussion of the differences between the two ANOVA models.

When the results for all the ANOVAs calculated in 1996 were pooled, the mixed model detected fewer significant differences for the Preop-Op, Station, and Preop-Op X Station (interaction) terms than the fixed model. The mixed model detected 17 significant differences between the preoperational and operational periods, 12 significant differences among stations, and 14 significant interaction terms. The fixed model detected 67 significant Preop-Op terms, 68 significant Station terms, and 21 significant interaction terms. For the important interaction term, it is interesting to note that four of the significant interactions detected by the mixed model were not detected by the fixed model. Despite the differences between the two models, the use of random variables is considered appropriate for most environmental sampling programs, or any program where the investigator has little control over the variable being investigated, and is using relatively small samples to describe a larger area or time (Snedecor and Cochran 1967; Winer 1971, Underwood 1981; Underwood 1984).

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TABLE A-1. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR WATER QUALITY CHARACTERISTICS AMONG STATIONS P2, P5, AND P7 DURING RECENT PREOPERATIONAL YEARS (1987-1989) AND OPERATIONAL (1991-1996) YEARS. SEABROOK OPERATIONAL REPORT, 1996.

PARAMETER	SOURCE OF VARIATION[a]	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[g]
Surface Temperature	Preop-Op[b,c]	5.70*	858.63***	Op>Preop
	Station[d]	56.33*	51.38***	P5>P2>P7
	Preop-Op X Station[e]	0.05 NS	0.96 NS	
Bottom Temperature	Preop-Op	12.03*	1218.35***	Op>Preop
	Station	59.98*	16.33***	P5>P2>P7
	Preop-Op X Station	0.35 NS	0.31 NS	
Surface Salinity	Preop-Op	0.12 NS	12.97**	Op<Preop
	Station	1.02 NS	3.96*	P2 P5 P7
	Preop-Op X Station	5.33*	3.46*	2Pre 5Pre 2Op 7Op 7Pre 5Op
Bottom Salinity	Preop-Op	0.45 NS	41.23***	Op<Preop
	Station	6.74 NS	6.16**	P7>P5 P2
	Preop-Op X Station	0.70 NS	0.95	
Surface Dissolved Oxygen	Preop-Op	6.00*	176.52***	Op<Preop
	Station	3.14 NS	7.53**	P5>P2>P7
	Preop-Op X Station	7.11**	2.59 NS	5Pre 2Pre 7Pre 5Op 2Op 7Op
Bottom Dissolved Oxygen	Preop-Op	0.39 NS	44.82***	Op<Preop
	Station	4.75 NS	13.58***	P5>P2>P7
	Preop-Op X Station	2.93 NS	2.96 NS	
Orthophosphate	Preop-Op	0.04NS	0.89 NS	
	Station	Non-est[f]	3.27*	P7 P2 P5
	Preop-Op X Station	0.01	0.01 NS	
Total Phosphorus	Preop-Op	0.01 NS	0.65 NS	
	Station	6.61 NS	2.33 NS	
	Preop-Op X Station	0.56 NS	0.40 NS	

(continued)

TABLE A-1. (Continued)

PARAMETER	SOURCE OF VARIATION[a]	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[g]
Nitrate	Preop-Op	1.69 NS	1.20 NS	
	Station	15.10 NS	5.89 **	P7 P2>P5
	Preop-Op X Station	0.22 NS	0.49 NS	
Nitrite	Preop-Op	1.69 NS	12.41**	Op>Preop
	Station	5.27 NS	4.39*	P7>P2 P5
	Preop-Op X Station	0.71 NS	0.94 NS	
Ammonia	Preop-Op	0.61 NS	68.19**	Op>Preop
	Station	3.58 NS	1.71 NS	
	Preop-Op X Station	1.31 NS	0.57 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
[f]Non-estimable due to negative denominator mean square
[g]Underlining indicates no significant difference.

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 MIXED MODEL AND THE 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 (1991-1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[d]
PHYTOPLANKTON: P2 VS P7 (PREOP = 1982-1984; OP = 1991-1996)[a]			
Preop-Op[b]	0.21 NS	39.71***	Op>Preop
Station	0.90 NS	5.56*	P2>P7
Preop-Op X Station[c]	3.11 NS	1.21 NS	
CHLOROPHYLL *a*: P2, P5, P7 (PREOP = 1987-1989; OP = 1991-1996)			
Preop-Op	<0.01 NS	0.08 NS	
Station	2.73 NS	3.52*	P5 P2 P7
Preop-Op X Station	1.98 NS	1.21 NS	
***SKELETONEMA COSTATUM*: P2 VS. P7 (PREOP = 1982-1984; OP = 1991-1996)**			
Preop-Op	3.78 NS	49.19***	Op>Preop
Station	3.99 NS	3.84 NS	
Preop-Op X Station	0.71 NS	1.09 NS	
***SKELETONEMA COSTATUM*: P2 VS. P5 (PREOP = 1979-1981; OP = 1991-1996)**			
Preop-Op	8.36*	43.34***	Op>Preop
Station	17.49 NS	3.64 NS	
Preop-Op X Station	0.22 NS	0.26 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.
[d]Underlining indicates no significant difference.

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 MIXED MODEL AND THE FIXED MODEL FOR (X+1) TRANSFORMED DENSITY (No./m^3) OF SELECTED MICROZOOPLANKTON SPECIES AMONG PREOPERATIONAL YEARS (1982-84) AND OPERATIONAL YEARS (1991-96) AND NEARFIELD (STATION P2) VS. FARFIELD (STATION P7) AREAS. SEABROOK OPERATIONAL REPORT, 1996.

SPECIES/LIFESTAGE	SOURCE OF VARIATION[a]	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[b]
Eurytemora sp. copepodite	Preop-Op	1.70 NS	20.19***	Op<Preop
	Station	0.18 NS	0.37 NS	
	Preop-Op X Station	7.87*	1.50 NS	P7Pre P2Pre>P2Op P7Op
Eurytemora herdmani adult	Preop-Op	5.02 NS	40.15***	Op<Preop
	Station	0.70 NS	1.26 NS	
	Preop-Op X Station	5.00 NS	1.59 NS	
Pseudocalanus/Calanus sp. nauplii	Preop-Op	17.40**	106.95***	Op<Preop
	Station	212.40 NS	0.43 NS	
	Preop-Op X Station	0.05 NS	0.03 NS	
Pseudocalanus sp. copepodite	Preop-Op	1.41 NS	3.93 *	Op<Preop
	Station	0.05 NS	0.01 NS	
	Preop-Op X Station	0.21 NS	0.29 NS	
Pseudocalanus sp. adult	Preop-Op	3.00 NS	19.62***	Op<Preop
	Station	7.02 NS	0.03 NS	
	Preop-Op X Station	0.05 NS	0.05 NS	
Oithons sp. nauplii	Preop-Op	0.26 NS	4.39*	Op>Preop
	Station	17.87 NS	2.79 NS	
	Preop-Op X Station	0.68 NS	0.17 NS	
Oithona sp. copepodite	Preop-Op	2.51 NS	39.57***	Op>Preop
	Station	9.48 NS	5.05*	P2>P7
	Preop-Op X Station	0.80 NS	0.55 NS	
Oithona sp. adult	Preop-Op	1.53 NS	23.07***	Op>Preop
	Station	31.63 NS	2.27 NS	
	Preop-Op X Station	0.27 NS	0.09 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
[b]Underlining indicates no significant difference.

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 MIXED MODEL AND THE FIXED MODEL FOR INTAKE (P2), DISCHARGE (P5) AND FARFIELD (P7) WEEKLY ABUNDANCES OF *MYTILUS EDULIS* DURING PREOPERATIONAL (1988-1989) AND OPERATIONAL (1991-1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

SOURCE OF VARIATION[a]	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Preop-Op	0.38 NS	66.87***	Op>Preop
Station	3.01 NS	2.46 NS	
Preop-Op X Station	1.71 NS	0.84 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 MIXED MODEL AND THE FIXED MODEL FOR ABUNDANCES OF SELECTED MACROZOOPLANKTON SPECIES FROM STATIONS P2, P5, AND P7 DURING PREOPERATIONAL (1987-1989) AND OPERATIONAL (1991-1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

SPECIES[a]	SOURCE[b]	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[f]
Calanus finmarchicus	Preop-Op[c]	0.98 NS	2.95 NS	
copepodites	Station[d]	12.17 NS	6.16**	<u>P5 P2</u> P7
(January-December)	Preop-Op X Station[e]	3.60 NS	0.52 NS	
Calanus finmarchicus	Preop-Op	0.33 NS	3.13 NS	
adults	Station	9.21 NS	4.89**	P5 P2 P7
(January-December)	Preop-Op X Station	10.01**	0.55 NS	<u>P5 Pre P5 Op P2 Op P7 Pre P7 Op</u>
Carcinus maenas	Preop-Op	<0.01 NS	0.002 NS	
larvae	Station	3.59 NS	1.62 NS	
(June-September)	Preop-Op X Station	0.46 NS	0.53 NS	
Crangon	Preop-Op	0.45 NS	3.75 NS	
septemspinosa	Station	39.58*	20.20***	P2>P5>P7
zoeae and post larvae	Preop-Op X Station	0.44 NS	0.57 NS	
(January-December)				
Neomysis americana	Preop-Op	<0.01 NS	<0.01 NS	P2>P5>P7
all lifestages	Station	567.29***	68.55***	
(January-December)	Preop-Op X Station	0.24 NS	0.14 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 (1991-1996) 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.
[f]Underlining indicates no significant difference.

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 MIXED MODEL AND THE FIXED MODEL FOR ATLANTIC HERRING DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	7.13*	56.35***	Op<Preop
(Oct-Dec)	Station[b]	6.18 NS	1.29 NS	
(1986-1996)	Preop-Op X Station[c]	0.44 NS	0.20 NS	
Gill Net	Preop-Op[d]	5.45*	219.73***	Op< Preop
(Sep-May)	Station	4.25 NS	2.51 NS	
(1976-1996)	Preop-Op X Station	0.48 NS	0.60 NS	

[a] Preop-Op compares 1990-1996 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 1990-1996 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 MIXED MODEL AND THE FIXED MODEL FOR RAINBOW SMELT DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[e]
Trawl	Preop-Op[a]	8.16*	123.99***	Op<Preop
(Nov-May)	Station[b]	0.71 NS	4.70**	
(1975-1996)	Preop-Op X Station[c]	9.54**	7.09**	2Pre 1Pre 3Pre 1Op 3Op 2Op
Seine	Preop-Op[d]	1.02 NS	1.75 NS	
(Apr-Nov)	Station	9.58**	15.63**	S3 S2 S1
(1976-1996)				

[a] Preop-Op compares 1990-1996 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 1990-1996 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 MIXED MODEL AND THE FIXED MODEL FOR ATLANTIC COD DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[e]
Ichthyoplankton	Preop-Op[a]	1.80 NS	4.24 NS	
(Apr-Jul)	Station[b]	6.92 NS	1.24 NS	
(1987-1996)	Preop-Op X Station[c]	0.33 NS	0.20 NS	
Trawl	Preop-Op[d]	8.06*	191.02***	Op<Preop
(Nov-Jul)	Station	16.03 NS	77.62***	
(1975-1996)	Preop-Op X Station	3.01 NS	4.91**	3Pre 1Pre 3Op 2Pre 1Op 2Op

[a] Preop-Op compares 1991-1996 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 1990-1996 to 1975-1990, regardless of station.
[e]underlining indicates no significant differences.

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 MIXED MODEL AND THE FIXED MODEL FOR POLLOCK DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[e]
Ichthyoplankton	Preop-Op[a]	5.53*	78.93***	Op<Preop
(Nov-Feb)	Station[b]	28.59*	3.10*	P5 P2 P7
(1986-1996)	Preop-Op X Station[c]	0.23 NS	0.11 NS	
Gill Net	Preop-Op[d]	0.45 NS	1.34 NS	
(Apr-Dec)	Station	41.84 NS	6.77**	G2 G3 G1
(1976-1996)	Preop-Op X Station	0.12 NS	0.21 NS	

[a] Preop-Op compares 1990-1995 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 1990-1996 to 1975-1989, regardless of station.
[e] Underlining indicates no significant differences.

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-10. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR HAKE[a] DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[b]	0.48 NS	5.15*	Op>Preop
(Jul-Sep)	Station[c]	2.46 NS	0.81 NS	
(1986-1996)	Preop-Op X Station[d]	0.48 NS	0.31 NS	
Trawl	Preop-Op[e]	17.91**	82.25***	Op<Preop
(Nov-Jul)	Station	7.37 NS	14.17***	T1>T3>T2
(1976-1996)	Preop-Op X Station	2.96 NS	2.34 NS	

[a] Hake = red, white, and spotted hakes.
[b] Preop-Op compares 1991-1996 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 1990-1996 to 1976-1990, regardless of 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-11. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR ATLANTIC SILVERSIDE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Seine (Apr-Nov) (1976-1996)	Preop-Op[a]	3.07 NS	18.06***	Op<Preop
	Station[b]	0.85 NS	0.74 NS	

[a] Preop-Op compares 1991-1996 to 1976-1984 and 1986-1989, regardless of station.
[b] Stations regardless of year or 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 ($0.001 \geq p$)

TABLE A-12. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR CUNNER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL
Ichthyoplankton	Preop-Op[a]	0.09 NS	1.58 NS
(Jun-Sep)	Station[b]	0.60 NS	0.20 NS
(1987-1996)	Preop-Op X Station[c]	0.93 NS	0.32 NS

[a] Preop-Op compares 1991-1996 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 MIXED MODEL AND THE FIXED MODEL FOR AMERICAN SAND LANCE DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[d]
Ichthyoplankton	Preop-Op[a]	0.58 NS	2.31 NS	
(Jan-Apr)	Station[b]	2.72 NS	5.40 NS	
(1987-1996)	Preop-Op X Station[c]	6.84**	1.76 NS	5Op 5Pre 2Pre 2Op 7Op 7Pre

[a] Preop-Op compares 1991-1996 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]Underlining indicates no significant differences.

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-14. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR ATLANTIC MACKEREL DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	0.23 NS	1.23 NS	
(Nov-Feb)	Station[b]	0.80 NS	0.14 NS	
(1986-1996)	Preop-Op X Station[c]	1.99 NS	0.19 NS	
Gill Net	Preop-Op[d]	1.21 NS	11.50**	Op>Preop
(Apr-Dec)	Station	5.88 NS	1.42 NS	
(1976-1996)	Preop-Op X Station	0.24 NS	0.25 NS	

[a] Preop-Op compares 1991-1996 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 1991-1996 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-15. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR WINTER FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS[f]
Ichthyoplankton	Preop-Op[a]	4.58 NS	11.50**	Op<Preop
(Apr-Jul)	Station[b]	5.48 NS	9.74***	P5 P2 P7
(1987-1996)	Preop-Op X Station[c]	1.77 NS	1.77 NS	
Trawl	Preop-Op[d]	0.98 NS	45.68***	Op<Preop
(Nov-Jul)	Station	0.35 NS	13.01***	T2>T1>T3
(1975-1996)	Preop-Op X Station	15.12***	16.54***	2Pre 1Pre 1Op 3Op 3Pre 2Op
Seine	Preop-Op[e]	18.85**	77.51***	Op<Preop
(Apr-Nov	Station	29.41***	59.30***	S3 S1 S2
(1976-1996)				

[a] Preop-Op compares 1991-1996 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 1990-1996 to 1975-1990.
[e] Preop-Op compared 1991-1996 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 MIXED MODEL AND THE FIXED MODEL FOR YELLOWTAIL FLOUNDER DENSITIES BY SAMPLING PROGRAM. SEABROOK OPERATIONAL REPORT, 1996.

PROGRAM/ MONTHS USED	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS OF ADJUSTED MEANS
Ichthyoplankton	Preop-Op[a]	0.62 NS	2.32 NS	
(May-Aug)	Station[b]	0.94 NS	0.63 NS	
(1987-1996)	Preop-Op X Station[c]	0.65 NS	0.82 NS	
Trawl	Preop-Op[d]	45.09***	554.65***	Op<Preop
(Nov-Jul)	Station	43.32*	186.34***	T1>T3>T2
(1975-1996)	Preop-Op X Station	2.68 NS	4.36*	1Pre 3Pre 2Pre 1Op 3Op 2Op

[a] Preop-Op compares 1991-1996 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 1990-1996 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 ($0.001 \geq p$)

TABLE A-17. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE 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, 1996.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F^d FOR MIXED MODEL	F^d FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	3.37 NS	53.78***	Op<Preop
		Station[b]	28.15 NS	285.51***	B5>B1
		Preop-Op X Station[c]	9.09*	9.11**	B5Pre>B5Op>B1Pre>B1Op
	Shallow Subtidal (B17, B35)	Preop-Op	0.21 NS	1.32 NS	
		Station	154.65 NS	112.32***	B35>B17
		Preop-Op X Station	0.25 NS	0.78 NS	
	Mid-depth (B16, B19, B31)	Preop-Op	0.36 NS	4.83*	
		Station	6.42 NS	39.64***	
		Preop-Op X Station	2.52 NS	6.15**	B31Op>B31Pre><u>B19Pre B16Op B19Op B16Pre</u>
	Deep (B04, B34, B13)	Preop-Op	1.84 NS	6.48*	Op<Preop
		Station	18.39 NS	2.62 NS	
		Preop-Op X Station	0.09 NS	0.15 NS	
Total Biomass	Intertidal (B1MLW, B5MLW)	Preop-Op	0.32 NS	4.43*	Op<Preop
		Station	1.13 NS	9.59**	B1>B5
		Preop-Op X Station	2.25 NS	8.90**	B1Pre><u>B1Op B5Op B5Pre</u>
	Shallow Subtidal (B17, B35)	Preop-Op	0.42 NS	0.21 NS	
		Station	2.44 NS	3.00 NS	
		Preop-Op X Station	0.53 NS	1.21 NS	
Total Biomass	Mid-depth (B16, B19, B31)	Preop-Op	2.86 NS	10.39**	Op<Preop
		Station	30.15*	76.42***	B16>B31>B19
		Preop-Op X Station	1.33NS	2.56 NS	

(continued)

TABLE A-17. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Total Biomass	Deep	Preop-Op	Non-est[f]	6.35*	Preop>Op
	(B04, B34, B13)	Station	24.62*	15.64***	B4 B13>B34
		Preop-Op X Station	0.20 NS	0.65 NS	

[a]Compares Preop to Op, regardless of station; years included in each station grouping (Op Years = 1990-1996 for all):
B1MLW, B5MLW: 1982-1996
B17, B35: 1982-1996
B16, B19, B31: 1980-1984, 1986-1996
B04, B34, B13: 1979-1984, 1986-1996
[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 ($\alpha \leq 0.05$) among the underlined least squares means.
[f]Non-estimatable due to negative mean square denominator.

(continued)

TABLE A-18. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR *CHONDRUS CRISPUS* BIOMASS (g/m^2) AT INTERTIDAL AND SHALLOW SUBTIDAL STATION PAIRS FOR THE PREOPERATIONAL (1982 - 1989) AND OPERATIONAL (1991 - 1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

TAXON	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON (RANKED IN DECREASING ORDER)
Chondrus crispus	Intertidal[e] (B1, B5)	Preop-Op[a]	0.21 NS	0.82 NS	B1>B5
		Station[b]	16.24 NS	50.82***	
		Preop-Op X Station[c]	0.78 NS	3.46 NS	
	Shallow Subtidal[f] (B17, B35)	Preop-Op	0.87 NS	1.79 NS	B17>B35
		Station	89.73 NS	45.57***	
		Preop-Op X Station	0.38 NS	0.46 NS	

[a]Preop-Op compares 1982 - 1989 to 1991-1996 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.

TABLE A-19. COMPARISON OF ANOVA RESULTS FOR MACROALGAE BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR PREOPERATIONAL (1982-1989) AND OPERATIONAL (1991-1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Laminaria digitata (#/100m²)	Shallow Subtidal (B17, B35)	Preop-Op[a]	1.95 NS	42.80***	Op<Preop
		Station[b]	0.74 NS	16.33***	B35>B17
		Preop-Op X Station[c]	15.75**	22.76***	B17Pre B35Pre B35Op>B17Op
Laminaria digitata (#/100m²)	Mid-depth (B19, B31)	Preop-Op	5.46 NS	248.77***	Op<Preop
		Station	7.13 NS	307.51***	B31>B19
		Preop-Op X Station	23.70***	41.93***	B31Pre>B31Op B19Pre>B19Op
Laminaria saccharina (#/100m²)	Shallow Subtidal (B17, B35)	Preop-Op	0.45 NS	0.73 NS	
		Station	5.35 NS	3.31 NS	
		Preop-Op X Station	0.61 NS	1.19 NS	
Laminaria saccharina (#/100m²)	Mid-depth (B19, B31)	Preop-Op	2.45 NS	11.61**	Op<Preop
		Station	15.07 NS	57.81***	B31>B19
		Preop-Op X Station	2.70 NS	3.79 NS	
Alaria esculenta (#/100m²)	Shallow Subtidal (B19, B31)	Preop-Op[a]	4.23 NS	1.15 NS	
		Station[b]	Non-est.[f]	422.69***	B31>B19
		Preop-Op X Station[c]	<0.01 NS	<0.01 NS	
Agarum clathratum (#/100m²)	Mid-depth (B19, B31)	Preop-Op	0.61 NS	5.16*	Op>Preop
		Station	35.53 NS	71.72***	B19>B31
		Preop-Op X Station	1.14 NS	2.09 NS	
Chondrus crispus (% frequency)	Shallow Subtidal (B17, B35)	Preop-Op[a]	4.56 NS	14.26***	Op>Preop
		Station[b]	71.73 NS	53.22***	B17>B35
		Preop-Op X Station[c]	0.83 NS	1.24 NS	
Chondrus crispus (% frequency)	Mid-depth (B19, B31)	Preop-Op	<0.01 NS	<0.01 NS	
		Station	653.45*	98.99***	B31>B19
		Preop-Op X Station	0.12 NS	0.17 NS	
Phyllopora /Coccotylus (% frequency)	Shallow Subtidal (B17, B35)	Preop-Op[a]	0.04 NS	0.37 NS	
		Station[b]	0.05 NS	0.01 NS	
		Preop-Op X Station[c]	1.36 NS	1.48 NS	

(continued)

TABLE A-19. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Pyllophora/Coccotylus	Mid-depth	Preop-Op	5.26 NS	9.07**	Op<Preop
(% frequency)	(B19, B31)	Station	5.63 NS	3.45 NS	
		Preop-Op X Station	0.46 NS	0.61 NS	
Ptilota serrata	Mid-depth	Preop-Op[a]	0.98 NS	21.82***	Op>Preop
(% frequency)	(B19, B31)	Station[b]	Non-est.[f]	133.76***	B19>B31
		Preop-Op X Station[c]	<0.01 NS	<0.01 NS	
Ascophyllum nodosum	Intertidal	Preop-Op	0.22 NS	2.45 NS	
(% frequency)	(B1, B5)	Station	0.17 NS	1.86 NS	
		Preop-Op X Station	7.08*	11.68**	B1Op B5Pre B5Op>B1Pre
Fucus vesiculosis	Intertidal	Preop-Op[a]	1.44 NS	73.45***	Op<Preop
(% frequency)	(B1, B5)	Station[b]	0.16 NS	7.44**	B5>B1
		Preop-Op X Station[c]	31.39***	43.61***	B1Pre>B5Pre B5Op>B1Op
Fucus distichus ssp.	Intertidal	Preop-Op	1.61 NS	4.99*	Op>Preop
edentatus	(B1, B5)	Station	509.55*	51.35***	B1>B5
(% frequency)		Preop-Op X Station	0.14 NS	0.10 NS	
Fucus spp. (juveniles)	Intertidal	Preop-Op[a]	22.24**	152.71***	Op>Preop
(% frequency)	(B1, B5)	Station[b]	21.03 NS	51.48***	B1>B5
		Preop-Op X Station[c]	1.35 NS	2.44 NS	

[a]Compares Preop to Op, regardless of station; years included in each station grouping (Op Years = 1990-1994 for all):
B1MLW, B5MLW: 1982-1996
B17, B35: 1982-1996
B16, B19, B31: 1980-1984, 1986-1996
B04, B34, B13: 1979-1984, 1986-1996
[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.

(continued)

TABLE A-20. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE 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, *1996.*

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
Number of Taxa	Intertidal (B1MLW, B5MLW)	Preop-Op[a]	5.43 NS	37.62***	Pre>Op
		Station[b]	<0.01 NS	<0.01 NS	
		Preop-Op X Station[c]	2.17 NS	3.43 NS	
	Shallow Subtidal (B17, B35)	Preop-Op	0.07 NS	0.83 NS	
		Station	3.82 NS	15.90***	B17>B35
		Preop-Op X Station	4.11 NS	4.85*	B17Op B17Pre B35Pre B35Op
	Mid-depth (B16, B19, B31)	Preop-Op	0.23 NS	1.81 NS	
		Station	212.01**	65.41***	B16 B19 B31
		Preop-Op X Station	0.16 NS	0.31 NS	
	Deep (B04, B34, B13)	Preop-Op	<0.01 NS	0.01 NS	
		Station	7.33 NS	22.98***	B04>B34>B13
		Preop-Op X Station	1.69 NS	3.12*	B04Op B04Pre B34Pre B34Op B13Pre B13Op
Total Biomass	Intertidal (B1MLW, B5MLW)	Preop-Op	0.54 NS	2.76 NS	
		Station	84.63 NS	27.97***	B1MLW>B5MLW
		Preop-Op X Station	0.08 NS	0.44 NS	
	Shallow Subtidal (B17, B35)	Preop-Op	0.29 NS	2.34 NS	
		Station	23.01 NS	4.39*	B35>B17
		Preop-Op X Station	0.11 NS	0.16 NS	
Total Biomass (Cont.)	Mid-depth (B16, B19, B31)	Preop-Op	1.01 NS	9.51**	Preop>Op
		Station	2.50 NS	11.28***	B16 B31 B19
		Preop-Op X Station	1.67 NS	4.29*	B16Pre B16Op B31Pre B19Pre B19Op B31Op

(continued)

TABLE A-20. (Continued)

PARAMETER	DEPTH ZONE (STATIONS)	SOURCE OF VARIATION	F[d] FOR MIXED MODEL	F[d] FOR FIXED MODEL	MULTIPLE COMPARISON[e] (RANKED IN DECREASING ORDER)
	Deep	Preop-Op	0.32 NS	5.77*	Op>Preop
	(B04, B34, B13)	Station	2.36 NS	14.54***	B13 <u>B34 B04</u>
		Preop-Op X Station	2.02 NS	6.00**	B13Op <u>B13Pre B34Op B34Pre B04Pre B04Op</u>

[a]Compares Preop to Op, regardless of station; years included in each station grouping (Op Years = 1990-1996 for all):
B1MLW, B5MLW: 1982-1996
B17, B35: 1982-1996
B16, B19, B31: 1980-1984, 1986-1996
B04, B34, B13: 1979-1984, 1986-1996
[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 ($\alpha\leq 0.05$) among the underlined least squares means.

(continued)

TABLE A-21. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE 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 - 1996) PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	F[e] FOR MIXED MODEL	F[e] FOR FIXED MODEL	MULTIPLE COMPARISON[f] (RANKED IN DECREASING ORDER)
Mytilidae (<25 mm)	Intertidal (B1, B5)	Preop-Op[a]	2.38 NS	38.46***	Preop>Op
		Station[b]	11.77 NS	81.95***	B1>B5
		Preop-Op X Station[c]	1.56 NS	6.34*	B1Pre B1Op B5Pre B5Op
	Shallow Subtidal (B17, B35)	Preop-Op	0.06 NS	0.82 NS	
		Station	33.74 NS	29.40***	B35>B17
		Preop-Op X Station	0.35 NS	1.18 NS	
	Mid-depth (B19, B31)	Preop-Op	0.57 NS	8.37**	Preop>Op
		Station	8.80 NS	40.35***	B31>B19
		Preop-Op X Station	0.82 NS	5.44*	B31Pre B31Op B19Pre B19Op
Nucella lapillus	Intertidal (B1MLW, B5MLW)	Preop-Op	0.55 NS	5.25*	Preop<Op
		Station	36.16 NS	51.96***	B1>B5
		Preop-Op X Station	0.74 NS	0.92 NS	
Asteriidae	Shallow Subtidal (B17, B35)	Preop-Op	0.42 NS	6.50*	Preop<Op
		Station	62.22 NS	157.87***	B17>B35
		Preop-Op X Station	0.53 NS	2.77 NS	
Pontogeneia inermis	Mid-Depth (B19, B31)	Preop-Op	7.08*	25.34***	Preop>Op
		Station	220.93 NS	19.70***	B19>B31
		Preop-Op X Station	0.07 NS	0.05 NS	
Jassa marmorata	Shallow Subtidal (B17, B35)	Preop-Op	0.40 NS	2.98 NS	
		Station	70.64 NS	27.98***	B35>B17
		Preop-Op X Station	0.24 NS	0.92 NS	

(continued)

TABLE A-21. (Continued)

TAXA[a]	DEPTH ZONE (STATION)	SOURCE OF VARIATION	F[e] FOR MIXED MODEL	F[e] FOR FIXED MODEL	MULTIPLE COMPARISON[f] (RANKED IN DECREASING ORDER)
Ampithoe rubricata	Intertidal (B1MLW, B5MLW)	Preop-Op	0.75 NS	125.50***	Op>Preop
		Station	0.90 NS	163.26***	B5>B1
		Preop-Op X Station	28.14***	145.71***	B5Op <u>B5Pre B1Pre B1Op</u>
Strongylocentrotus droebachiensis	Mid-Depth (B19, B31)	Preop-Op	1.13 NS	6.60**	Op>Preop
		Station	67.46 NS	36.56***	B19>B31
		Preop-Op X Station	0.29 NS	0.24 NS	
Modiolus modiolus (adults)	Mid-Depth (B19, B31)	Preop-Op	203.49 NS	30.40***	Op<Preop
		Station	5.15 NS	6.24*	B19>B31
		Preop-Op X Station	0.18 NS	1.47 NS	

[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 1990-1996 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 ($0.05\geq p>0.01$); ** = highly significant ($0.01\geq p>0.001$); *** = very highly significant ($p\leq 0001$).
[f]Underlining indicates that t-tests showed no significant differences ($\alpha\leq 0.05$) among the underlined least squares means.

(continued)

TABLE A-22. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE 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, 1996.

SPECIES	SOURCE OF VARIATION[a]	F[b] FOR MIXED MODEL	F[b] FOR FIXED MODEL	MULTIPLE COMPARISONS[c] (ranked in decreasing order)
Lobster larvae (May-Oct)	Preop-Op	12.17*	48.58***	Op>Preop
	Station	0.38 NS	0.38 NS	
	Preop-Op X Station	1.85 NS	1.60 NS	
Lobster (total catch) (Jun-Nov)	Preop-Op	0.03 NS	2.21 NS	
	Station	1.15 NS	39.39***	
	Preop-Op X Station	7.85*	31.21***	7 Pre 7 Op 1 Op 1 Pre
Lobster (legal size) (Jun-Nov)	Preop-Op	13.58**	515.88***	Op>Preop
	Station	0.34 NS	1.35 NS	
	Preop-Op X Station	1.04 NS	2.57 NS	
Cancer spp. larvae (May-Sep)	Preop-Op	0.27 NS	3.85 NS	
	Station	0.12 NS	1.13 NS	
	Preop-Op X Station	0.42 NS	0.13 NS	
Jonah Crab (Jun-Nov)	Preop-Op	0.83 NS	21.38***	Op<Preop
	Station	6.27 NS	143.83***	L1>L7
	Preop-Op X Station	2.20 NS	23.51***	L1Pre L1Op L7Pre L7Op
Rock Crab (Jun-Nov)	Preop-Op	0.63 NS	10.26**	Op>Preop
	Station	0.98 NS	7.09**	L1>L7
	Preop-Op X Station	1.22 NS	3.87*	L1Op L7Op L1Pre L7Pre

[a]Preop-Op = Preoperational period (Lobster and *Cancer* spp. larvae, all stations: 1988, 1989; Adult lobster and crabs: 1982-1989); Operational period: 1991-96 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 ($\alpha \leq 0.05$) among least squares means with a paired t-test.

TABLE A-23. COMPARISON OF ANOVA RESULTS BETWEEN THE MIXED MODEL AND THE FIXED MODEL FOR *MYA ARENARIA* LARVAL, SPAT, JUVENILE AND ADULT DENSITIES DURING PREOPERATIONAL AND OPERATIONAL PERIODS. SEABROOK OPERATIONAL REPORT, 1996.

MYA ARENARIA LIFESTAGE	STATION/FLAT	SOURCE OF VARIATION	F FOR MIXED MODEL	F FOR FIXED MODEL	MULTIPLE COMPARISONS[h] (in decreasing order)
larvae[a]	NEARFIELD (P2, P5)	Preop-Op[c,d]	4.29 NS	14.25**	Op<Preop
	FARFIELD (P7)	Station[e]	non-est[g]	0.78 NS	
		Preop-Op X Station[f]	0.01 NS	0.01 NS	
	HAMPTON HARBOR				
1-20 mm[b] young-of-the-year	1, 2, 4	Preop-Op	1.65 NS	45.96***	Op>Preop
		Area	12.46 NS	40.40***	4>2>1
21-50 mm[b] yearlings	1, 2, 4	Preop-Op	0.08 NS	31.83***	Op>Preop
		Area	15.61 NS	77.24***	4>1>2
>50 mm[b] adult	1, 2, 4	Preop-Op	4.62 NS	66.39***	Op>Preop
		Area	8.43 NS	51.31***	4>1>2
	NEARFIELD/FARFIELD				
1-12 mm[b]	Hampton Harbor	Preop-Op	0.21 NS	0.82 NS	
	Plum Island Sound	Area	0.46 NS	2.88 NS	
		Preop-Op X Area	1.53 NS	5.20 NS	

[a]Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1988, 89 and op = 1991-96.
[b]For Hampton Harbor Survey preop = 1974-89 and op = 1990-96. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-96.
[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 ($0.05 \geq p > 0.01$)
** = Highly significant ($0.01 \geq p > 0.001$)
*** = Very highly significant ($0.001 \geq p$)

2

North Atlantic

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The Northeast Utilities System

August 8, 2001
NPDES Permit No. NH0020338
NYE-01015
CR# 00-12958

Mr. Phil Colarusso, Marine Biologist
Office of Ecosystem Protection
U.S Environmental Protection Agency
1 Congress Street, Suite 1100
Boston, MA 02114-2023

Seabrook Station
Response to EPA's Essential Fish Habitat Information Request

North Atlantic Energy Service Corporation (North Atlantic) the operator of Seabrook Station submits our response (Enclosure) to your requests for Essential Fish Habitat information[1]. The report contains four sections which assess:

- Assess the Impacts of Impingement and Entrainment on the Essential Fish Habitat Species
- Assess the Impact of the Thermal Plume on Normal Fish Movement
- Assess the Impact of Plant Operation on the Major Food Items of the Essential Fish Habitat Species
- Assess the Impact of Plant Operation on Habitat Forming Species

The report concludes that Seabrook Station's impingement and entrainment impacts on Essential Fish Habitat species is insignificant when compared to the regional commercial or recreational take for those species. There is also no evidence that the operation of Seabrook Station has affected the prey items of Essential Fish Habitat species. Finally, the thermal plume does not appear to have any major impact on movement of Essential Fish Habitat species.

[1] EPA Letter dated November 2000, from P. Colarusso (EPA) to J. Hart (Seabrook Station) and meeting on July 10, 2001 between P. Colarusso (EPA), D. Houlihan (EPA), P. Geoghegan (NAI) and R. Sher (Seabrook Station) to discuss draft Seabrook Station Essential Fish Habitat Analysis

This report was reviewed and approved by Seabrook Station's Ecological Advisory Committee members Dr. John Tietjen, (emeritus, City University of New York), Dr. Saul Saila (emeritus, University of Rhode Island), Dr. Robert Wilce (emeritus, University of Massachusetts), and Dr. W. Huntting Howell (University of New Hampshire).

If you have additional questions, please contact John B. Hart at (603) 773-7762.

Very truly yours,

NORTH ATLANTIC ENERGY SERVICE CORP.

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ENCLOSURE TO NYE-01015

Seabrook Station
Essential Fish Habitat Analysis

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EXECUTIVE SUMMARY

The area surrounding the intake and discharge structures for Seabrook Station has been designated by the National Marine Fisheries Service as essential fish habitat (EFH) for 23 species. Analyses were made of the effect of the operation of Seabrook Station on the EFH. These analyses focused on impact of impingement and entrainment on EFH species (Section I), the impacts of the thermal plume on normal fish movement (Section II), the impacts of plant operation on the major forage species of the EFH species (Section III), and the impact of plant operation on habitat-forming species (Section IV).

The impact of losses due to impingement and entrainment was assessed by using the Equivalent Adult (EA) method of estimating the number of adults that would have resulted from the entrained ichthyoplankton and impinged fish. In general, EA losses due to entrainment were greater than impingement losses. EA losses were very small in comparison to the commercial landings in New Hampshire and Maine. The EA estimates were also very small in comparison to the recreational landings from New Hampshire and Maine, with the possible exception of winter flounder.

The thermal plume at Seabrook Station did not appear to have any major impact on the movement of EFH species. The thermal plume rises quickly to the surface and should not have any effect on the movement of benthic or demersal organisms. Among pelagic species, the impact appears to be minimal. The highest monthly mean temperature recorded in the jet mixing zone at 100 m from the discharge was 18.8 °C. Although this may be out of the preferred temperature range for some species such as pollock or Atlantic mackerel, all of the pelagic EFH species have been captured in warmer water. The discharge is located offshore where there are no geographic barriers to fish movement. Therefore, the greatest potential impact to fish movement may be an avoidance of higher water temperatures in an area less than 100 m from the discharge. This will not be a serious impact because fish will be able to move around the potential area of higher water temperatures.

There was no evidence that the operation of Seabrook Station has affected the prey items of the EFH species. Abundance of prey items in all communities (phytoplankton, zooplankton, benthic invertebrates, and fishes) either has remained similar between the preoperational and operational periods, or has changed between periods to similar extents in both the nearfield and farfield areas. The consistency in trends between periods in the nearfield and farfield areas indicates that there have been no detectable changes in these communities due to the operation of Seabrook Station.

In general, habitat-forming species have shown little change at the nearfield area between the preoperational and operational periods. Dominant understory algal species and juvenile blue mussels in the intertidal, shallow subtidal, and mid-depth zones have not shown significant differences in abundance or biomass between periods. Changes in the canopy species, which may provide a refuge for juvenile EFH species, were observed throughout the study area. However, fucoids continued to provide a dense cover regardless of the species.

The canopy and understory structure provided by kelps to the EFH species has been the same throughout the study period, despite a possible change in species composition. *Laminaria digitata* decreased significantly in the nearfield shallow subtidal and mid-depth zones, compared to the farfield zones. However, it was replaced by *Agarum clathratum*, which may have a competitive advantage in the deeper depths of the nearfield area. In terms of fish habitat, there is probably little difference between these two large, structurally complex kelp species. Both species continued to provide cover and structure for both predator and prey species.

Data from the Seabrook Station Environmental Monitoring Program indicate the operation of Seabrook Station has not measurably affected EFH near the intake and discharge structures. The intake structures are located about 1.6 km offshore in about 18 m of water with mid-depth openings and velocity caps. This design has contributed to relatively low impingement and entrainment losses. The thermal plume is discharged through 22 nozzles designed for maximum dilution of the plume. The design and location of the intake and discharge structures have resulted in minimal impact to essential fish habitat due to the operation of Seabrook Station.

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THE IMPACT OF THE OPERATION OF SEABROOK STATION ON ESSENTIAL FISH HABITAT

INTRODUCTION

The area surrounding the intake and discharge structures for Seabrook Station has been designated by the National Marine Fisheries Service (NMFS) as essential fish habitat (EFH) for 23 species (Table I-1). EFH is defined in the Magnuson-Stevens Fishery Conservation and Management Act as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." EFH has been delineated for all species that have federal fishery management plans. An analysis of Seabrook Station's impact on Essential Fish Habitat is required as part of the power plant's NPDES Permit renewal process. In a letter from Phil Colarusso (Office of Ecosytem Protection, US EPA) to John Hart (Manager, Environmental, Government and Owner Relations for Seabrook Station) a request was made to use existing data to: (1) assess the impact of impingement and entrainment on the EFH species, (2) assess the impacts of the thermal plume on normal fish movement, (3) assess the impacts of plant operation on the major forage species of the EFH species, and (4) assess the impacts of plant operation on habitat-forming organisms.

Section I addresses the impact of impingement and entrainment on the EFH species. Impingement is defined as the entrapment of fishes on the traveling screens located in front of the circulating water pumps in the forebay of the circulating water pumphouse. Entrainment is defined as the passage of ichthyoplankton through the traveling screens and into the cooling water system of the plant. Seabrook Station's three velocity cap intake structures are designed to minimize fish and invertebrate impingement and entrainment due to their offshore location and mid-depth openings. The three intake structures are located about 1.6 km (1 mile) offshore in water 18 m (60 ft) deep. The intake openings are about 3 m (10 ft) above the seafloor and about 12 m (40 ft) below the surface.

The impact of losses due to entrainment and impingement was assessed by using the Equivalent Adult (EA) method of estimating the number of adults that would have resulted from the entrained larvae and impinged fishes (Goodyear 1978). These losses were put into perspective by comparing them with recreational and commercial fish landings data for New Hampshire and Maine. Landings from both New Hampshire and Maine were used because together they present a more complete indication of landings from the Gulf of Maine than landings from the 18-mile coastline of New Hampshire alone. Landings from Massachusetts were not included because data included landings from Buzzards Bay and south and east sides of Cape Cod that are not in the Gulf of Maine.

Section II addresses the impacts of the thermal plume on normal fish movement. The extent of the thermal plume is defined through existing temperature monitoring programs and numeric modeling. Temperature and catch data from fish resource assessment programs in Massachusetts Bay and the Gulf of Maine were used to define the temperatures at which normal movement could occur.

Section III addresses the impacts of plant operation on the forage species of the EFH species. Major food items of the EFH species were identified and existing data from the Seabrook Station Environmental Monitoring Program were used to assess the impacts of plant operation on these food items.

I. ASSESS THE IMPACT OF IMPINGEMENT AND ENTRAINMENT ON THE EFH SPECIES

IMPINGEMENT IMPACTS

Impingement assessments at Seabrook Station have historically focused on fishes. Impingement of longfin inshore squid, and northern shortfin squid has not been assessed, however, squid impingement appears to be rare based on the observations of field technicians. Although not officially recorded, the field technicians who have conducted impingement monitoring since 1998 cannot recall a single incident of squid impingement. Atlantic sea scallop and Atlantic surfclam are benthic organisms and not susceptible to impingement.

Among the 19 EFH fish species, no redfish spp., Atlantic halibut, or bluefin tuna have ever been impinged. The intakes for Seabrook Station are located in 15-18 m of water, and redfish spp. are most common in water deeper than 100 m (Pikanowski et al. 1999). Atlantic halibut are relatively rare in the study area and have occurred in fewer than 1% of the trawl samples (NAI 2000). Bluefin tuna are strong swimming, pelagic, migratory fish that could be expected to escape impingement if they encountered the intake structure.

Impingement of American plaice, Atlantic cod, Atlantic herring, Atlantic mackerel, butterfish, goosefish, haddock, ocean pout, pollock, red hake, scup, silver hake, summer flounder, windowpane, winter flounder, and yellowtail flounder have occurred at Seabrook Station. Annual mean impingement was less than 10/year for American plaice, Atlantic mackerel, goosefish, ocean pout, and scup from 1995 through 2000 (Table I-2). Annual mean impingement was slightly higher for Atlantic cod (69/year), Atlantic herring (240/year), butterfish (43/year), haddock (67/year), silver hake (62/year), and yellowtail flounder (222/year). Losses of these magnitudes (<250/year) are insignificant for these common marine fishes and are expected to have no effect on stock level.

Greater quantities of pollock (2,596/year), red hake (1,109/year), windowpane (665/year), and winter flounder (1,626/year) have been impinged at Seabrook Station (Table I-2). The following section discusses the seasonal and annual impingement of these fishes and estimates the number of equivalent adults potentially resulting from immature fishes impinged in the most recent years of 1998 through 2000. The number of equivalent adults was estimated using the following expression:

$$N_R = N_0\, e^{-m(t_R - t_0)}$$

where:
- N_R = the number of mature fish at age R (years)
- N_0 = the number of fish impinged
- m = the instantaneous juvenile natural mortality rate (per month)
- t_R = age (months) at maturity
- t_0 = age (months) at impingement

The juvenile natural mortality rate (m) was estimated using the method of Saila et al. (1997) (Table 3). The juvenile natural mortality rate was estimated by subtracting egg mortality (Z_e) and larval mortality for the length range between hatching and transformation ($Z_{l,r}$) from preadult mortality for the time between egg deposition and maturity (Z_p).

$$m = Z_p - Z_e - Z_{l,r}$$

Z_p was estimated as $-\log_e(2/f_a)$, where f_a is the average lifetime fecundity (Appendix Table 1). Z_e for red hake and pollock was estimated using the method of Pepin (1991):

$$Z_e = 0.65\exp(0.066T).$$

where: T= the mean temperature during the spawning season. (T = 11.67 for red hake, 5.51 for pollock)

Z_e for winter flounder was estimated as 1.628 (NUSCO 1987).

$Z_{l,r}$ was estimated as the slope of the regression line between $\log_e$ frequency (y axis) on length in mm (x axis) for the range of lengths between hatching and transformation. This range was 4-7 mm for pollock, 2-6 mm for red hake, and 3-7 mm for winter flounder. Although windowpane are among the most numerous fish impinged, EA calculations for the impingement of windowpane were not possible because larval length data are not collected as part of the monitoring program.

For young-of-the-year (YOY) pollock and red hake, t_0 was estimated as the time between an assumed spawning date and the peak YOY impingement month at Seabrook Station, based on 1995-2000 data. Assumed spawning dates were based on published information in addition to the seasonal occurrence of eggs in entrainment samples collected in years when sampling occurred in all months (1995 through 2000) and in ichthyoplankton samples. Pollock were assumed to spawn in December and their peak YOY impingement typically occurred in August, so t_0 for pollock was 8 months. Red hake were assumed to spawn in August and their peak YOY impingement typically occurred in March, so t_0 for red hake was 7 months. Winter flounder peak impingement usually occurred at the same time of year as spawning (in March), so t_0 was 12 months for impinged juveniles under 130 mm TL, 24 months for impinged juveniles between 130 and 229 mm inclusive. Fish larger than 230 mm were assumed to be mature. Assigned lengths at age and lengths at maturity were based on the data in Witherell and Burnett (1993).

Marine commercial and recreational landings data for New Hampshire were obtained from the web site of the National Marine Fisheries Service, Fisheries Statistic and Economics Division, Silver Spring, MD. Recreational landings estimates of Atlantic herring, red hake, and yellowtail flounder were imprecise as the standard error of the estimate was as large as the estimate. Due to this imprecision, NMFS urges caution in the use of these estimates, and therefore they are not reported here.

Pollock

Impingement of pollock ranged from 379 in 1997 to 11,392 in 1999, and was less than 2,000/year for all years except 1999 (Table I-2). The estimated annual mean impingement for the years 1995 through 2000 at Seabrook Station was about 2,600 pollock/year. Pollock impingement was usually highest from June through November, and most of these fish were YOY less than 200 mm in total length (Figure I-1). During most years a smaller number of age 1 fish (200-299 mm: Cargnelli et al. 1999c) were also impinged. An exception occurred in 2000 when more age 1 and older pollock were impinged than YOY. Pollock can be reproductively mature at age 1 (O'Brien et al. 1993) so most pollock impinged between 1998 and 2000 were not of reproductive age.

The number of equivalent adults potentially resulting from impingement of YOY pollock can be estimated for each year by applying a monthly juvenile mortality rate (0.62: Table 3) to the annual estimate of YOY impingement for the four months between impingement and maturity and adding in the impingement of age 1 and older fish. Assuming that all pollock less than 200 mm are YOY, and all age 1 pollock are mature, the impingement of pollock in 1998 though 2000 potentially resulted in the loss of about 173 (1998) to 2,388 (1999) equivalent adult (age 1 and older) pollock (Table I-4). Saila et al. (1997) estimated that impingement of juvenile pollock at Seabrook Station in 1994 and 1995 potentially resulted in 135 and 136 equivalent adults.

An estimated mean of 406,000 pollock/year were landed by marine recreational anglers each year between 1995 and 2000 in New Hampshire and Maine. The estimated mean length of these fish was 283 mm (11.1 inches) fork length. Bigelow and Schroeder (1953) stated that pollock are 12-13 inches (presumably total length) at age 2. Therefore, it appears that the mean age of pollock taken by recreational anglers in New Hampshire and Maine is about age 2. Estimates of the number of equivalent age 2 pollock resulting from impingement at Seabrook Station were made by applying a survival rate of 0.82/year (from Saila et al. 1997; Table I-2) to the EA estimates of age 1 pollock in Table I-4 resulting from impingement of YOY and age 1 fish. Using this survival rate, an estimated mean 828 equivalent age 2 pollock resulted from impingement from 1998 through 2000. This estimate is about 0.4% of the estimated recreational catch. An estimated 4.6 million pounds of pollock were landed each year in New Hampshire and Maine between 1995 and 1999. The minimum commercial size limit for pollock is 483 mm (19 inches; age 3 to age 4). The annual impingement of about 2,600 pollock (age 2 and younger) at Seabrook Station is a small fraction of the 4.6 million pound commercial take.

Red Hake

Hakes were not identified to the species level until 1996. The term "hakes" encompassed primarily red and white hakes. Even after 1996 some hakes impinged were either too small, or were in too poor condition to be definitively identified. Most of the fish in the "hake" category were probably red hake based on the depth distribution of red hake (Musick 1974) and the ratio of positively identified red to white hake. Therefore, the conservative assumption will be made that all "hakes" were red hake.

Impingement of red hake ranged from 225 in 2000 to 2,204 in 1995 with an annual mean impingement of about 1,100/year (Table I-2). Red hake were impinged primarily between October and April with little impingement during the warmer months. Most red hake impinged were less than 180 mm (Figure I-2) and were probably age YOY (Steimle et al. 1999c). Red hake reach maturity at about age 1 (O'Brien et al. 1993) and most of the impinged red hake were probably immature fish.

The number of equivalent adults potentially resulting from impingement of YOY red hake can be estimated for each year by applying a monthly juvenile mortality rate (0.55: Table I-3) to the estimate of YOY impingement for the seven months between impingement and maturity, and adding in the impingement of age 1 and older fish. Assuming all red hake less than 180 mm are YOY and all red hake are mature at age 1, the impingement of red hake in 1998 though 2000 potentially resulted in the loss of about 10 (2000) to 83 (1999) equivalent adult (age 1 and older) red hake (Table I-4). Saila et al. (1994) estimated that impingement of juvenile red hake in 1994 and 1995 resulted 101 to 202 age 1 equivalent adult red-hake.

Estimates of the recreational take of hakes in New Hampshire and Maine were small and imprecise. The commercial landings for hakes in New Hampshire and Maine averaged 30,000 pounds/year between 1995 and 1999.

Windowpane

EA estimates for windowpane were not made because larval length data, hence larval mortality data, for this species are not collected as part of the Monitoring Program. Most windowpane impinged were less than 160 mm (Figure I-3) and probably were YOY (Chang et al. 1999). Estimates of windowpane impingement ranged from 168 in 1997 to 1,164 in 1996 with mean impingement of 665/year (Table I-2). Most impingement occurred during the winter with February the peak month. The windowpane stock in the Gulf of Maine is not considered overfished (NMFS 1998). The estimate of commercial landings of windowpane in New Hampshire and Maine between 1995 and 1999 was 1,600 pounds/year.

Winter flounder

Winter flounder impingement ranged from 102 in 2000 to 3,642 in 1999 with an annual mean impingement of about 1,600/year (Table I-2). Most impinged winter flounder were age 1 or approaching age 1 (less than 130 mm; Figure I-4) and impingement occurred primarily between October and April each year. Winter flounder reach maturity at age 3; therefore, most of the winter flounder impinged were immature.

The number of equivalent adult winter flounder impinged was estimated by applying a juvenile natural mortality rate (0.25: Table I-3) to age-specific impingement estimates. Assuming all winter flounder become mature at age 3, the impingement of winter flounder in 1998 through 2000 potentially resulted in the loss of about 13 (2000) to 126 (1999) equivalent adult winter flounder (Table I-4). Saila et al. (1997) estimated that impingement of juvenile winter flounder in 1994 and 1995 at Seabrook Station resulted in the potential loss of 8 to 7 equivalent adult winter flounder.

An estimated mean of 25,000 winter flounder/year were landed by recreational anglers in New Hampshire and Maine waters between 1995 and 2000. An annual mean of 67,000 pounds/year of winter flounder was landed commercially in New Hampshire and Maine from 1995 through 1999. The number of equivalent adults resulting from impingement at Seabrook Station is a small fraction of the recreational or commercial take.

ENTRAINMENT IMPACTS

Estimates of entrainment of fish eggs and larvae have been made at Seabrook Station since 1990. Eggs and larvae of many of the EFH species either have never been collected in entrainment samples, or were rarely present. No eggs of Atlantic halibut, Atlantic herring, bluefin tuna, ocean pout, redfish spp., summer flounder, or scup have been found in entrainment samples. The life histories of these fishes make entrainment of their eggs unlikely. Atlantic herring and ocean pout eggs are demersal and adhesive and not susceptible to entrainment. Redfish spp. are livebearers and the development of the egg occurs internally. Bluefin tuna, summer flounder, scup and butterfish spawn primarily in areas further to the south. Eggs of goosefish, and winter flounder are rarely collected because they are not readily susceptible to entrainment in a mid-water intake. Goosefish eggs are shed in surface oriented 6-12 m long veils or rafts (Steimle et al. 1999a), and the eggs of winter flounder are demersal and adhesive (Bigelow and Schroeder 1953).

No larvae of Atlantic halibut, bluefin tuna, ocean pout, or scup have been collected. Larvae of butterfish, goosefish, haddock, pollock, and redfish spp. are relatively rare, as less than 100,000 are entrained each year (Appendix Table I-1).

The impacts of entrainment at Seabrook Station were assessed for commonly entrained species using the EA method (Goodyear 1978; Saila et al. 1997). One of the input parameters for the EA methodology is the larval mortality rate. This can be derived from larval length data where the slope of the line describing the relationship between the natural log of larval abundance and length represents the mortality rate. Larval length measurements of EFH species in the Seabrook Station Environmental Monitoring Program were made for Atlantic cod, Atlantic herring, Atlantic mackerel, pollock, red hake, winter flounder, and yellowtail flounder. Therefore, EA estimates were made only for these species. EA estimates were not made for the remaining EFH species because there were not sufficient data (no larval length data collected) available from the Monitoring Program. Among the species for which no EA estimates were made, American plaice, silver hake, and windowpane eggs or larvae are commonly entrained. Starting in 2002, larval length measurements will be made for each of the EFH fish species, which may allow calculation of larval mortality rates for additional EFH species, especially for commonly entrained species such as American plaice, silver hake, and windowpane.

Entrainment data in the years 1998 through 2000 were used for the EA estimates because during these years samples were collected using a 0.333-mm mesh net and samples were collected during both day and night. This monitoring program is an improvement over the previous program, which involved sample collection during the daytime only, using a larger mesh (0.505 mm) net. These data represent the most recent and complete estimates of entrainment available. The methodology used for the EA estimates was the same as NAI (2000) and Saila et al. (1997). Adult equivalencies for eggs were estimated as follows:

$N_a = 2\ N_i / f_a$ (equation 1)

where,
N_a = number of equivalent adults,
N_i = estimated number of eggs entrained, and
f_a = average lifetime egg production (Appendix Table I-2).

For larvae, adult equivalencies were estimated separately by 0.5-mm length classes. First the probability of survival from the egg stage to the size entrained was estimated as:

$S_e = 1 / \exp[Z_e + Z_L (i\text{-}h)]$ (equation 2)

where,
S_e = probability of survival from egg to size entrained,
Z_e = egg mortality,
Z_L = larval mortality per mm
i = length in mm when entrained, and
h = predominant size at hatching in mm.

Then the adult equivalent for each size class of entrained larvae was estimated as:

$N_a = 2\ N_i / (S_e\ f_a)$ (equation 3)

where,
N_a = number of equivalent adults,
N_i = estimated number of larvae entrained,
S_e = probability of survival from egg to size entrained, and
f_a = average lifetime egg production.

The number of equivalent adults estimated by this method represents the number that would have survived to the age at first spawning, which is age 3 for winter flounder, age 2 for yellowtail flounder and age 1 for Atlantic cod, Atlantic mackerel, pollock, and red hake. A small proportion of

Atlantic herring (1%: O'Brien et al. 1993) mature at age 2, but since 99% do not mature until age 3 or older, the EA estimates for this species represent age 3 fish. Input parameters and their sources for the EA estimates for these species are presented in Table I-5.

Atlantic Cod

Atlantic cod eggs are found in three taxonomic groups: Atlantic cod, Atlantic cod/haddock, and Atlantic cod/witch flounder (Appendix Table I-1). Few haddock larvae have been collected in the study area so all eggs in the Atlantic cod/haddock group were assumed to be Atlantic cod. Witch flounder larvae are common, so the ratio of Atlantic cod to witch flounder larvae each year from 1998 through 2000 was used to estimate the annual number of Atlantic cod eggs in the Atlantic cod/witch flounder category. Based on these assumptions, an estimated 30.6 million (2000) to 83.7 million (1998) cod eggs were entrained from 1998 to 2000. Assuming the lifetime egg production in Appendix Table I-2, an average of 323 equivalent adult Atlantic cod per year potentially resulted from entrainment of Atlantic cod eggs in 1998 through 2000.

Entrainment of Atlantic cod larvae from 1998 to 2000 ranged from 2.2 million in 1998 to 0.4 million in 2000. The annual estimated equivalent adults from entrainment of these larvae ranged from 82 (1998) to 8 (2000). The total equivalent adult losses due to entrainment of Atlantic cod eggs and larvae were:

	1998	1999	2000	Mean
Eggs	498	290	182	323
Larvae	82	41	8	44
Total	542	322	359	408

An estimated 187,000 Atlantic cod per year were landed in New Hampshire and Maine between 1995 and 2000 by recreational anglers and commercial fishermen landed estimated 5,511,000 pounds of Atlantic cod per year in New Hampshire and Maine between 1995 and 1999.

Atlantic Herring

Atlantic herring eggs are demersal and adhesive, and are deposited on offshore gravel banks at depths of 11 to 50 m (Reid et al. 1999). No Atlantic herring eggs have been collected in entrainment samples at Seabrook Station.

Entrainment of Atlantic herring larvae was highest in 1995 when an estimated 11.2 million were entrained (Appendix Table I-1). From 1998 through 2000, entrainment ranged from 0.2 million in 2000 to 9.5 million in 1998. The estimated number of equivalent adults resulting from entrainment of Atlantic herring larvae averaged 368/year between 1998 and 2000. Although more than ten times more larvae were entrained in 1998 and 1999 than in 2000, the estimate of equivalent adults for 2000 is only 5 to 6 times smaller because more larvae of larger lengths were entrained in 2000. These larger and older larvae were closer to maturity and made a greater contribution to the equivalent adult estimate than smaller larvae.

	1998	1999	2000	Mean
Eggs	0	0	0	0
Larvae	437	575	92	368
Total	437	575	92	368

Recreational anglers do not usually capture Atlantic herring and estimates of the recreational take are small and imprecise. The estimated commercial harvest of Atlantic herring landed in New Hampshire and Maine between 1995 and 1999 was 102 million pounds per year.

Atlantic Mackerel

Atlantic mackerel eggs are among the most numerous entrained at Seabrook Station and estimates ranged from 673.1 million in 1991 to none entrained in 1994 (Appendix Table I-1). For the period 1998 through 2000, entrainment estimates ranged from 39.3 million in 1998 to 266.9 million in 2000. Assuming the average lifetime egg production in Appendix Table I-2, an average of 97 equivalent adults per year potentially resulted from Atlantic mackerel egg entrainment from 1998 through 2000.

Entrainment of Atlantic mackerel larvae ranged from none collected in several years to 4.7 million in 1991, the year of highest egg abundance (Appendix Table I-1). From 1998 to 2000, entrainment of Atlantic mackerel ranged from none collected in 1998 to 0.3 million in 2000. Atlantic mackerel larvae are fast growing and the duration of the larval stage is relatively short (Studholme et al. 1999). Atlantic mackerel larvae are also fast swimming, therefore it is not surprising that relatively few larvae are entrained. The estimated number of equivalent adults resulting from Atlantic mackerel larval entrainment ranged from 1 in 2000 to zero in 1998. The total equivalent adult losses due entrainment of Atlantic mackerel eggs and larvae from 1998 through 2000 were:

	1998	1999	2000	Mean
Eggs	32	37	221	97
Larvae	0	<1	1	1
Total	32	37	222	98

The estimated recreational take of Atlantic mackerel landed in New Hampshire and Maine between 1995 and 2000 was 1.7 million fish per year. The estimated commercial take was 51,000 pounds per year.

Pollock

Entrainment of pollock eggs has been relatively consistent since Seabrook Station became operational in 1990 (Appendix Table I-1). The highest estimate of 2.9 million eggs occurred in 1998 and less than 100,000 eggs were entrained in 2000. Assuming the average lifetime egg production in Appendix Table I-2, an average of 7 equivalent adults per year potentially resulted from pollock egg entrainment from 1998 through 2000. Saila et al. (1997) estimated that zero to 7 equivalent adults per year resulted from pollock egg entrainment from 1990 through 1995 at Seabrook Station.

Entrainment of pollock larvae has been relatively low (Appendix Table I-1). Less than 100,000 pollock larvae were entrained in 1998 and none were found in samples in 1999 and 2000. Based on these entrainment levels, an estimated 1 equivalent adult pollock resulted from entrainment of pollock larvae in 1998. Saila et al. (1997) estimated that 1 to 3 equivalent adults resulted from pollock entrainment each year from 1990 through 1995 at Seabrook Station. The total equivalent adult losses due entrainment of pollock eggs and larvae from 1998 through 2000 were:

	1998	1999	2000	Mean
Eggs	19	1	<1	7
Larvae	1	0	0	<1
Total	20	1	<1	7

An estimated 406,000 pollock per year were landed in New Hampshire and Maine by recreational anglers between 1995 and 2000. The commercial take between 1995 and 1999 landed in New Hampshire and Maine was 4.6 million pounds.

Red Hake

In this EA analysis the conservative assumption was made that all hake eggs are red hake, although it is probable that at least white hake eggs are also included in this category. Red hake eggs are also found in the category hake/fourbeard rockling eggs. The ratio of larval hake to larval fourbeard rockling can be used to estimate the number of hake eggs in the hake/fourbeard rockling egg category. The annual ratio for each year from 1998 through 2000 was used to estimate the number of hake eggs for each of these years. Based on these ratios, the estimated hake egg entrainment was 8.6 million in 1998, 7.1 million in 1999, and 125.6 million in 2000. Assuming the average lifetime egg production in Appendix Table I-2, an average of 137 equivalent adults per year potentially resulted from red hake egg entrainment from 1998 through 2000. Saila et al. (1997) estimated that 7 to 442 equivalent adults per year resulted from hake egg entrainment from 1990 through 1995 at Seabrook Station.

The conservative assumption was made for this EA analysis that all hake larvae collected were red hake. Entrainment of hake larvae in 1998 and 1999 was relatively low, but reached record levels in 2000, consistent with the high levels of hake and hake/fourbeard rockling egg entrainment in 2000. An estimated average of 175 equivalent adults per year potentially resulted from entrainment of hake larvae in 1998 through 2000. Saila et al. (1997) estimated that zero to 359 equivalent adults per year potentially resulted from entrainment of hake larvae in 1990 through 1995. The total equivalent adult losses due entrainment of red hake eggs and larvae from 1998 through 2000 were:

	1998	1999	2000	Mean
Eggs	25	21	366	137
Larvae	12	<1	513	175
Total	37	21	879	312

The estimated recreational take of hakes (all *Urophycis* spp. combined) landed in New Hampshire between 1995 and 2000 was 14,500 per year (there were no data from Maine). The estimated commercial landings in New Hampshire and Maine for hakes was 30,000 pounds per year between 1995 and 1999.

Winter Flounder

Winter flounder eggs are demersal and adhesive and it is unusual for them to be found in the water column and subject to entrainment by the cooling water intakes which are located about 3 m above the seafloor. An argument could be made that winter flounder eggs in the water column have become detached from the bottom and are nonviable. In this analysis the conservative assumption will be made that all entrained winter flounder eggs are viable. An estimated 300,000 winter flounder eggs were entrained in 2000, the only year they were collected. This level of entrainment resulted in the potential loss of 38 equivalent adults in 2000.

Entrainment of winter flounder larvae from 1998 through 2000 ranged from 4.7 million in 1998 to 14.3 million in 2000; the highest entrainment estimate to date (Appendix Table I-1). An estimated average of 2,085 equivalent adult winter flounder per year resulted from entrainment of winter flounder eggs and larvae from 1998 through 2000. Saila et al. (1997) estimated that 1,897 to 4,401 equivalent adult winter flounder per year resulted from larval entrainment at Seabrook Station from 1990 through 1995. The total equivalent adult losses due entrainment of winter flounder eggs and larvae from 1998 through 2000 were:

	1998	1999	2000	Mean
Eggs	0	0	38	13
Larvae	1064	1411	3742	2072
Total	1064	1411	3780	2085

The estimated recreational landings of winter flounder in New Hampshire and Maine were 25,000 per year between 1995 and 2000. The estimated commercial landings in New Hampshire and Maine were 67,000 pounds per year between 1995 and 1999.

Yellowtail Flounder

Yellowtail flounder eggs are grouped with the morphologically similar cunner eggs into the cunner/yellowtail flounder group. The number of yellowtail flounder eggs in this group was estimated for each year between 1998 and 2000 using the annual (1998-2000) ratio of cunner to yellowtail flounder larvae. Based on these ratios, the estimated number of yellowtail flounder eggs entrained was 1.9 million in 1998, 33.7 million in 1999, and 3.1 million in 2000. Entrainment of these eggs resulted in an estimated average of 6 equivalent adults per year between 1998 and 2000.

Entrainment of yellowtail flounder larvae has been as high as 1.6 million in 1996, but ranged from 0.3 million in 1998 and 2000 to 0.8 million in 1999 (Appendix Table I-1). An estimated average of 3 equivalent adults per year resulted from yellowtail flounder entrainment between 1998 and 2000. The total equivalent adult losses due entrainment of yellowtail flounder eggs and larvae from 1998 through 2000 were:

	1998	1999	2000	Mean
Eggs	1	16	1	6
Larvae	1	4	3	3
Total	2	20	4	9

The estimates of recreational landings of yellowtail flounder in New Hampshire and Maine were small and imprecise. Commercial landings between 1995 and 1999 in New Hampshire and Maine were 137,000 pounds per year.

CONCLUSIONS

Table I-6 presents a summary of EA losses for EFH species due to impingement and entrainment at Seabrook Station. These losses are put into perspective by comparing them with recreational and commercial catches. Commercial catch data are presented in pounds, while the EA and recreational landings data are presented as numbers of fish. The impacts of impingement and entrainment at Seabrook Station on EFH species were insignificant when compared to the regional commercial or recreational take for most species.

Losses due to entrainment were larger than impingement losses for red hake and winter flounder. Impingement losses of pollock were greatest due to exceptionally high impingement in the summer of 1999, which resulted in a high estimate of equivalent adult loss. These findings are consistent with previous analyses of the impacts of impingement and entrainment at Seabrook Station (Saila et al. 1997). Losses due to impingement may be further reduced by periodic cleanings of the intake structures. The formation of a fouling community on the intakes has the potential to create habitat for fishes especially rock gunnel, grubby, and cunner. Although none of these fishes are EFH species, they have the potential to be prey items for the EFH species. The intakes have been cleaned at least annually since 1999 and are presently scheduled to be inspected and cleaned twice a year to prevent the formation of a fouling community. Prior to 1999, the intakes were cleaned approximately every three years during alternate refueling outages.

The estimated average EA losses for winter flounder (2,144 age 3 fish) due to impingement and entrainment were about 9% of the recreational take, but a small fraction of the annual commercial landings in New Hampshire and Maine. However, the annual estimates of recreational winter flounder landings from Maine were very small and imprecise, except for the 1997 estimate. Annual estimated recreational landings in Maine from 1995 through 2000 ranged from zero in 2000 to 27,000 winter flounder in 1997, with the estimates for the remaining years all less than 1,000 fish. In addition, the standard errors of the annual estimates were about as large as the estimate every year except 1997, indicating a high degree of imprecision. It is possible that the relatively precise 1997 estimate of 26,820 winter flounder is more representative of the annual recreational landings in Maine from 1995 through 2000. If this is the case, than the EA losses at Seabrook Station may be as small as 5% of the recreational landings from New Hampshire and Maine. Saila et al. (1997) estimated the number of equivalent adult winter flounder resulting from entrainment at Seabrook Station between 1990 and 1995 and compared the EA estimate to the daily catch of a class 2 trawler. The highest EA estimate was 4,401 winter flounder for the year 1991. They found that 4,401 equivalent adult winter flounder represented less than a three-day catch of a class 2 trawler. The highest EA estimate due to entrainment for the years 1998 through 2000 was about 3,780 adult winter flounder in 2000. This estimate is similar to the highest estimate of Saila et al. (1997) and is small compared to the daily landings of a small commercial trawler.

The results of this study confirm those of Saila et al. (1997). EA losses of EFH species appear to be higher due to entrainment than impingement, and total EA losses appear to be an ecologically insignificant fraction of any sustainable stock.

Pollock

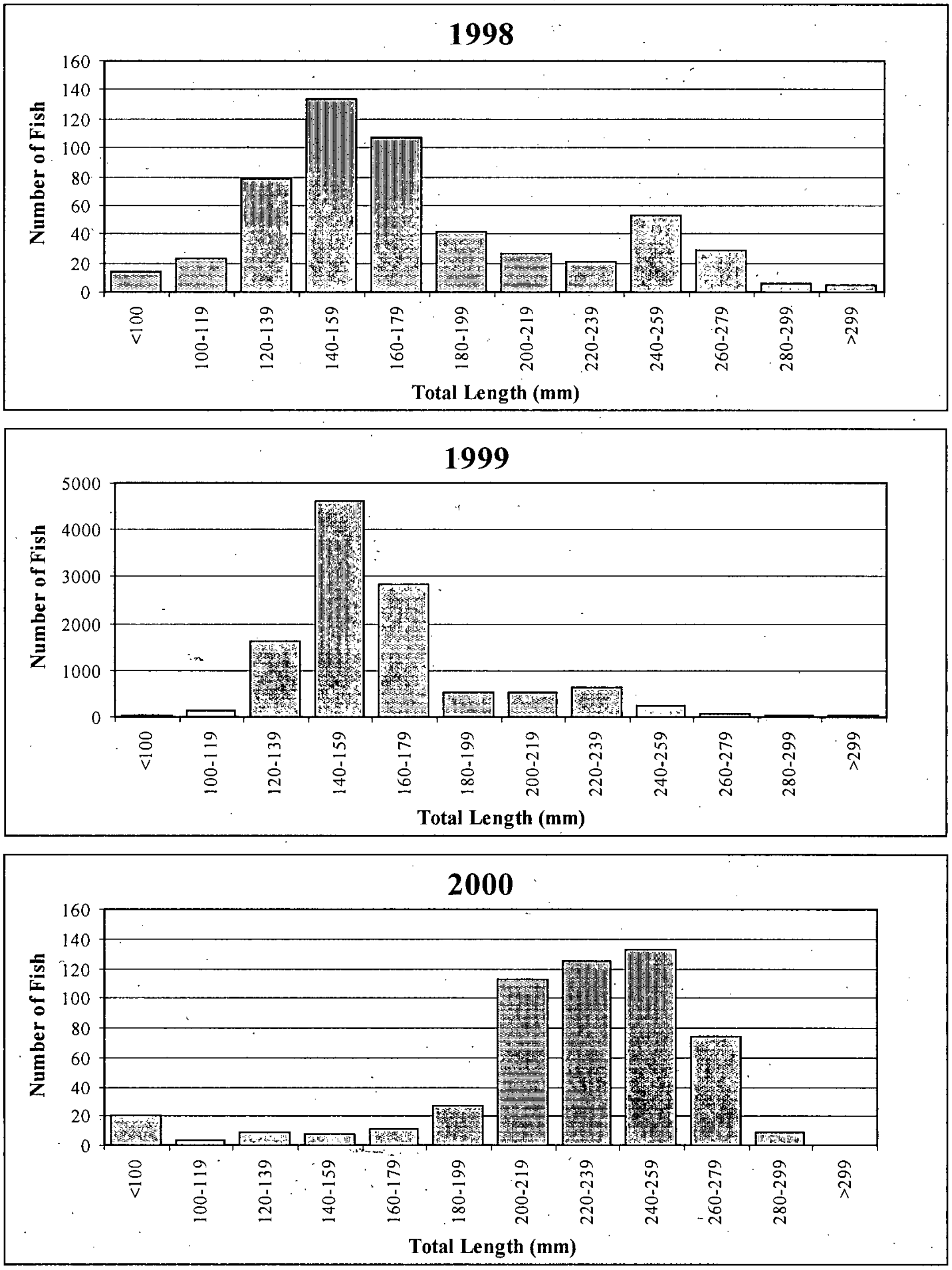

Figure I-1. Length frequency diagrams of pollock impinged at Seabrook Station, 1998 through 2000.

Red hake

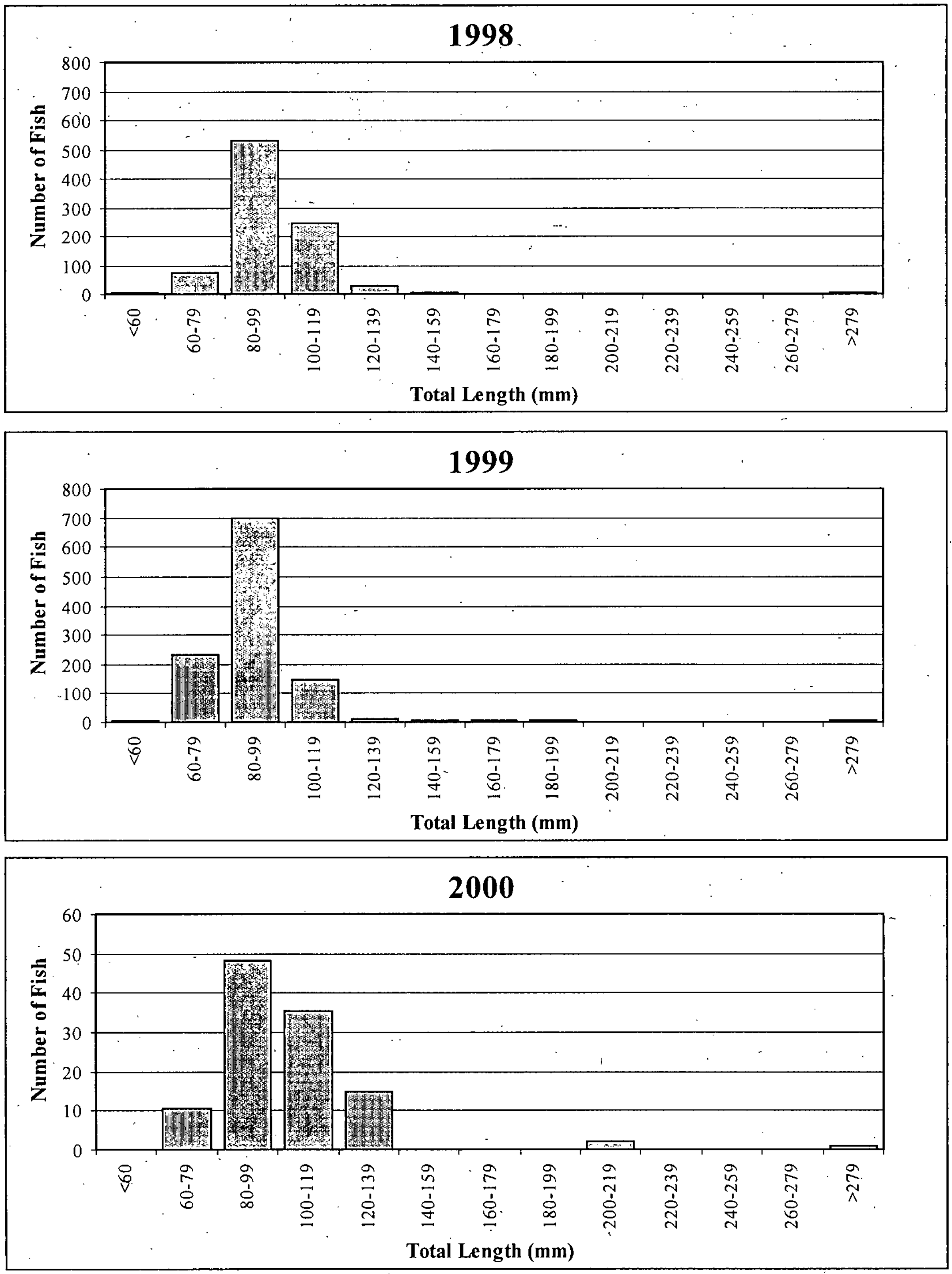

Figure I-2. Length frequency diagrams of red hake impinged at Seabrook Station, 1998 through 2000.

Windowpane

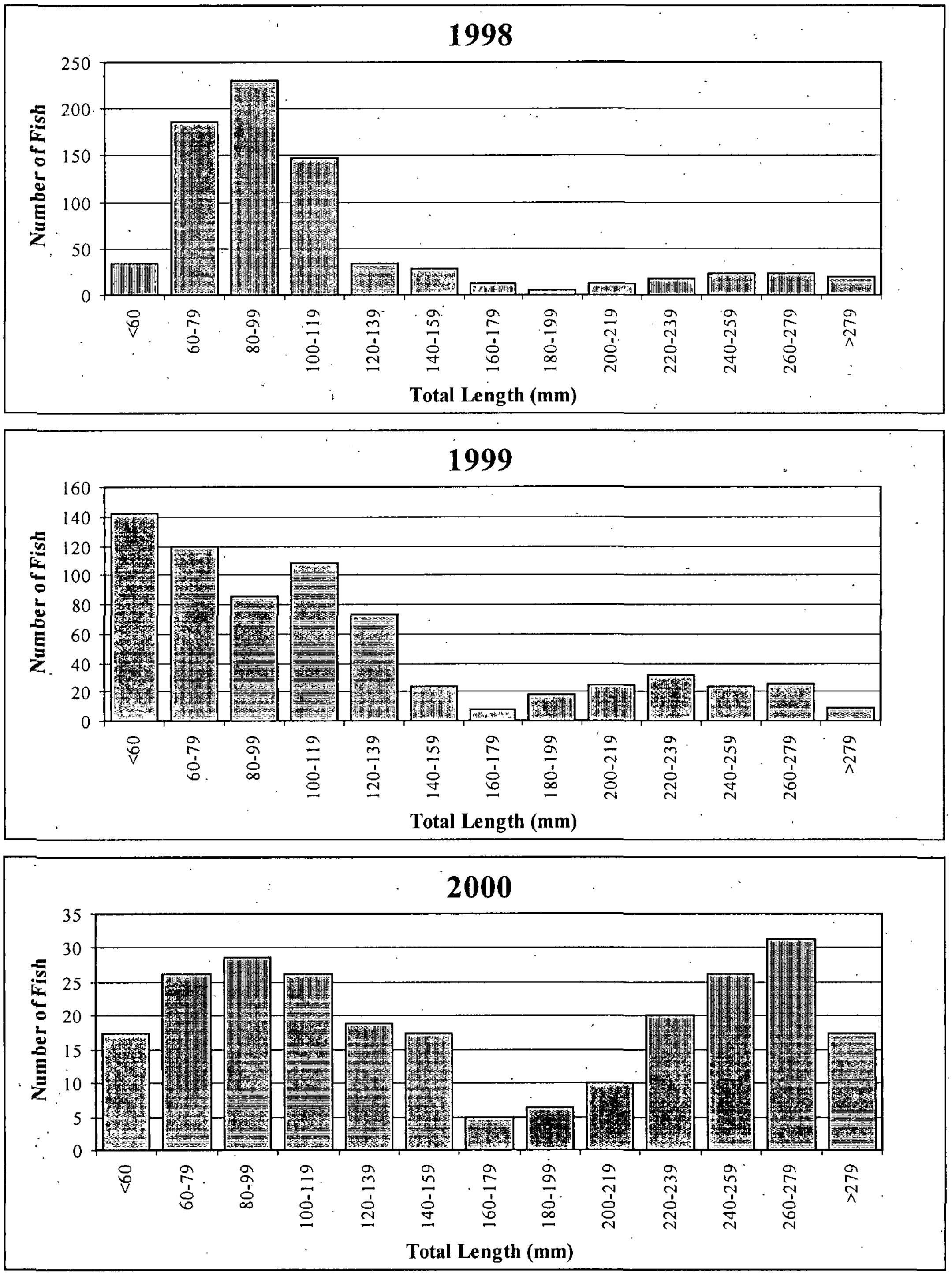

Figure I-3. Length frequency diagrams of windowpane impinged at Seabrook Station, 1998 through 2000.

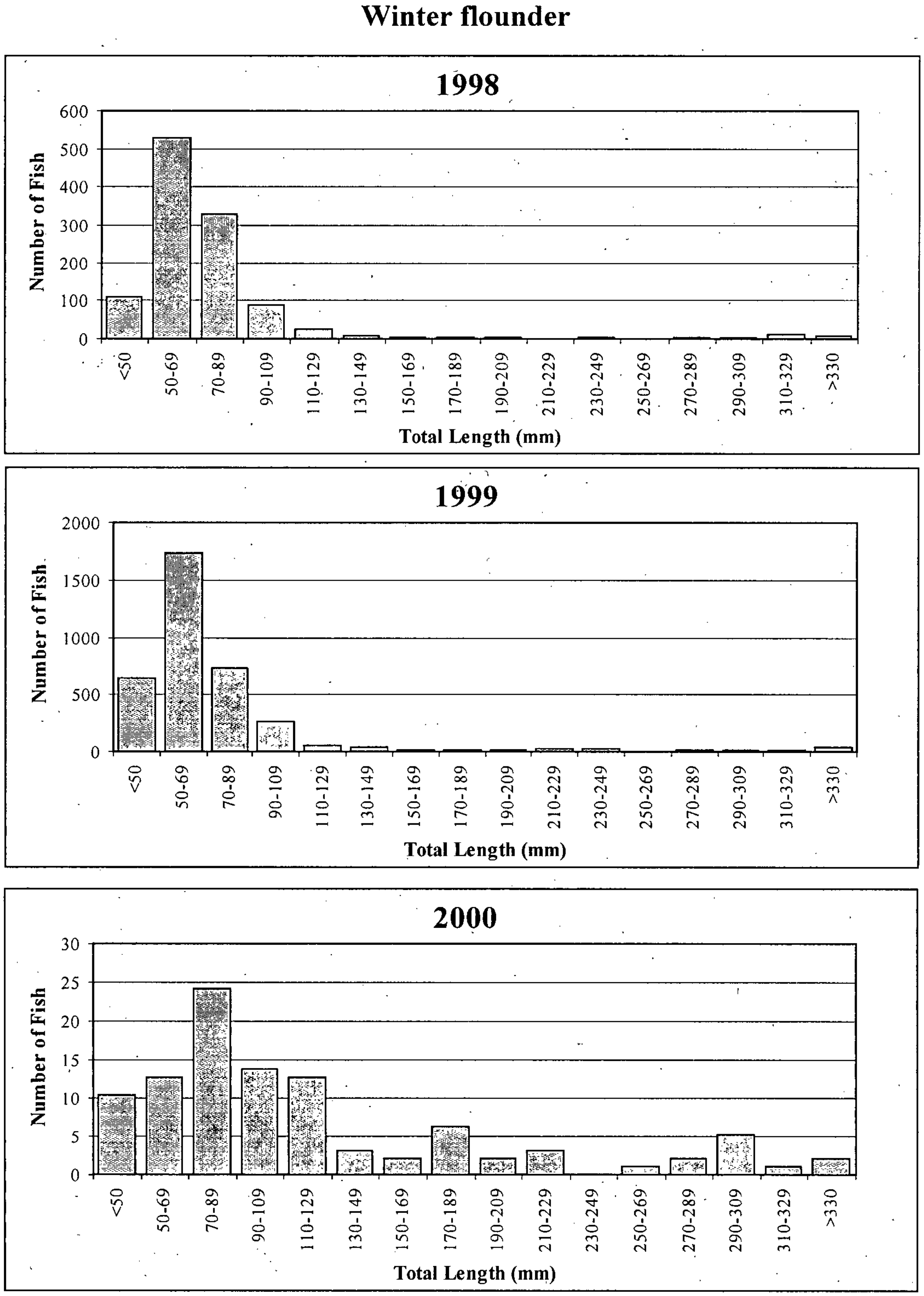

Figure I-4. Length frequency diagrams of winter flounder impinged at Seabrook Station, 1998 through 2000.

Table I-1. **Common and scientific names of fishes and mollusks associated with essential fish habitat near the Seabrook Station intake and discharge structures.**

Common Name	Scientific Name
American plaice	*Hippoglossoides platessoides*
Atlantic cod	*Gadus morhua*
Atlantic halibut	*Hippoglossus hippoglossus*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Atlantic sea scallop	*Placopecten magellanicus*
Atlantic surfclam	*Spisula solidissima*
Bluefin tuna	*Thunnus thynnus*
Butterfish	*Peprilus triacanthus*
Goosefish (monkfish)	*Lophius americanus*
Haddock	*Melanogrammus aeglefinus*
Longfin inshore squid	*Loligo pealeii*
Northern shortfin squid	*Ilex illecebrosus*
Ocean pout	*Macrozoarces americanus*
Pollock	*Pollachius virens*
Red hake	*Urophycis chuss*
Redfish spp.	*Sebastes* spp.
Silver hake (whiting)	*Merluccius bilinearis*
Summer flounder	*Paralichthys dentatus*
Scup	*Stenotomus chrysops*
Windowpane	*Scophthalmus aquosus*
Winter flounder	*Pseudopleuronectes americanus*
Yellowtail flounder	*Limanda ferruginea*

Table I-2. Annual impingement of fishes at Seabrook Station.

	Year							
Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**	**Mean**
American plaice	0	0	0	0	2	0	2	0.3
Atlantic cod	119	94	69	38	66	29	415	69.2
Atlantic herring	0	485	350	582	20	5	1442	240.3
Atlantic mackerel	0	1	0	0	0	0	1	0.2
Butterfish	14	3	223	9	5	1	255	42.5
Goosefish	13	0	0	7	17	15	52	8.7
Haddock	1	397	0	1	3	2	404	67.3
Ocean pout	6	1	0	7	3	2	19	3.2
Pollock	899	1835	379	536	11392	534	15575	2595.8
Red hake[a]	2204	1634	493	907	1188	225	6651	1108.5
Scup	14	9	0	3	1	0	27	4.5
Silver hake	49	58	108	13	100	41	369	61.5
Windowpane	943	1164	168	772	692	251	3990	665.0
Winter flounder	1171	3231	468	1143	3642	102	9757	1626.2
Yellowtail flounder	1194	4	23	11	97	0	1329	221.5
All Others	9,299	17,909	8,365	11,169	14,013	6,075	66,830	11,138
Total	15,926	26,825	10,646	15,198	31,241	7,282	107,118	17,853

NR = Not reported

[a] Includes "hakes" plus red hake.

Table I-3. Mortality (Z) and fecundity (f_a) parameter estimates for juvenile fishes impinged at Seabrook Station 1998 through 2000.

Parameter	Species		
	Winter flounder	Pollock	Red hake
Z_e (egg mortality)	1.628	0.94	1.41
$Z_{l,r}$ (larval mortality/length range)	0.96 (3-7 mm)	4.19 (4-7 mm)	5.24 (2-6 mm)
f_a (lifetime average fecundity)	157714	302199	685991
Z_p (preadult mortality)	11.16	11.93	12.75
$Z_{j,t}$ (juvenile mortality)	8.57 (34 months)	6.8 (11 months)	6.1 (11 months)
m (juvenile mortality/month)	0.25	0.62	0.55

Table I-4. Equivalent adult estimates of pollock, red hake, windowpane, and winter flounder impinged at Seabrook Station, 1998 through 2000.

		Estimated Number Impinged				Estimated Equivalent Adults Resulting From Ages				Total
Species	Year	Age 0	Age 1	Age 2	Age 3 and Older	Age 0	Age 1	Age 2	Age 3 and Older	
Pollock	1998	396	136	4	0	33	136	4	0	173
	1999	9834	1518	40	0	830	1518	40	0	2388
	2000	81	453	0	0	7	453	0	0	460
Mean										1007
Red Hake	1998	895	2	6	0	56	2	6	0	64
	1999	1106	7	7	0	69	7	7	0	83
	2000	109	2	1	0	7	2	1	0	10
Mean										52
Windowpane	1998	671	17	12	84					
	1999	559	26	25	90	Equivalent adult calculations not possible				
	2000	140	11	10	95					
Mean										
Winter Flounder	1998	0	1081	26	36		2	1	36	39
	1999	0	3415	114	114		7	5	114	126
	2000	0	74	17	12		0	1	12	13
Mean										59

Table I-5. Input parameters for equivalent adult analysis resulting from entrainment of eggs and larvae at Seabrook Station 1998-2000.

Species	Parameter					
	fa[a]	(age in years)	Ze[b]	Z_l[c]	(range in mm)	h[d] (mm)
Atlantic cod	336000	1	0.83	1.82	(3.5-10.0)	3.5
Atlantic herring	320040	3	1.17	0.14	(7.5-21.5)	7.5
Atlantic mackerel	2420832	1	1.31	1.16	(3.0-7.5)	3.0
Pollock	302199	1	0.94	1.40	(3.5-7.0)	3.5
Red hake	685991	1	1.41	1.31	(2.0-6.0)	2.0
Winter flounder	157714	3	1.03	0.76	(3.0-9.0)	3.0
Yellowtail flounder	4241076	2	1.03	0.78	(3.0-10.0)	3.0

[a] Appendix Table 1
[b] From Pepin (1991: Ze = 0.65 exp (0.066T)
T = 3.72 Atlantic cod
8.89 Atlantic herring
10.61 Atlantic mackerel
5.57 pollock
11.67 red hake
6.94 winter flounder
6.94 yellowtail flounder
[c] Slope of the regression line of $\log_e$ abundance (Y axis) on length in mm (X axis).
[d] Estimated length at hatching.

Table I-6. **Mean annual equivalent adult losses of EFH species impinged (1995-2000) and entrained (1998-2000) at Seabrook Station in comparison with recreational (no. of fish) and commercial (lbs) catch data from New Hampshire and Maine.**

Species	Equivalent Adults Impingement	Equivalent Adults Entrainment	Equivalent Adults Total	Recreational Catch (no. of fish)	Commercial Catch (pounds)
Atlantic Cod	NA[a]	408	408	187,000	5,511,000
Atlantic Herring	NA[a]	368	368	NA[b]	102,000,000
Atlantic Mackerel	NA[a]	98	98	1,700,000	51,000
Pollock	1,007	7	1,014	406,000	4,630,000
Red Hake	52	312	364	NA[b]	30,000[c]
Winter Flounder	59	2,085	2,144	25,000	67,000
Yellowtail Flounder	NA[a]	9	9	NA[b]	137,000

[a] Impingement losses are assumed to be minimal (see Table I-2).
[b] Estimates of recreational landings were small and imprecise.
[c] Includes red and white hake.

Appendix Table I-1. Annual Estimated Numbers of Fish Eggs and Larvae Entrained (in millions) by the Cooling Water System at Seabrook Station from June 1990 Through December 2000. Seabrook Operational Report, 2000.

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[f]	1997[f]	1998[f]	1999[f]	2000[f]
Eggs											
American plaice	2.6	21.0	52.3	19.5	0.4	14.8	78.2	15.6	13.7	24.8	16.7
Atlantic cod	2.5	4.9	1.8	0.0	0.2	2.2	8.1	2.9	8.4	5.3	2.9
Atlantic cod/haddock	0.0	0.2	0.6	50.3	0.3	2.2	1.4	0.2	0.3	0.4	1.6
Atlantic cod/witch flounder	26.2	69.4	37.1	0.0	0.5	32.6	47.2	8.9	77.3	47.2	59.0
Atlantic mackerel	518.8	673.1	456.3	112.9	0.0	74.5	305.1	23.1	39.3	44.6	266.9
Butterfish	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	<0.1	0.0
Cod family	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	<0.0	0.0
Cunner/yellowtail flounder	490.4	664.1	198.6	58.4	0.0	18.6	110.2	186.1	56.2	232.4	1001.9
Goosefish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9
Hake	37.3	2.6	0.0	0.2	0.6	25.1	184.0	68.6	7.4	6.1	114.0
Hake/fourbeard rockling	114.2	35.1	50.6	32.7	1.7	27.5	57.0	45.0	31.1	24.8	231.1
Pollock	0.0	1.0	0.4	0.2	0.1	0.4	0.4	0.2	2.9	0.2	<0.1
Red hake	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Silver hake	11.4	0.0	0.1	0.4	0.4	22.5	73.6	271.1	18.6	139.9	90.4
Windowpane	36.4	19.9	22.5	29.1	0.1	17.4	44.2	28.5	17.9	43.2	95.1
Winter flounder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Yellowtail flounder	0.0	0.0	0.0	0.0	0.0	0.2	1.6	0.0	0.0	0.0	0.10
TOTAL (All Species)	**1247.7**	**1551.3**	**822.6**	**315.6**	**4.8**	**255.9**	**926.4**	**692.7**	**286.7**	**593.9**	**261.2**

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[f]	1997[f]	1998[f]	1999[f]	2000[f]
Larvae											
American plaice	0.4	1.0	0.8	0.7	0.0	7.9	8.1	7.0	2.9	4.9	1.6
Atlantic cod	0.7	1.5	0.4	0.1	0.0	2.3	0.3	0.7	2.2	1.0	0.4
Atlantic herring	0.7	0.5	4.9	9.6	0.1	11.2	4.3	2.1	9.5	8.6	0.2
Atlantic mackerel	0.2	4.7	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.1	0.3
Butterfish	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0
Goosefish	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Haddock	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hake	4.8	0.0	0.0	0.1	0.0	0.7	12.3	1.7	<0.1	0.1	29.8
Pollock	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	0.0
Redfish	0.0	0.0	0.4	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0
Silver hake	7.7	0.0	0.0	0.1	0.0	0.9	16.9	69.0	0.2	0.4	33.2
Summer flounder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	0.0
Windowpane	3.8	0.05	0.1	0.1	0.05	2.0	2.0	5.6	1.4	3.7	2.3
Winter flounder	3.2	9.0	6.2	2.9	0.0	8.0	10.3	2.2	4.7	7.4	14.3
Yellowtail flounder	0.1	0.3	0.1	0.0	0.0	0.1	1.6	0.5	0.3	0.8	0.3
TOTAL (All Species)	**121.5**	**153.8**	**133.1**	**126.1**	**31.2**	**145.3**	**215.7**	**373.4**	**134.1**	**171.8**	**261.2**

[a] Represents only 7 months, August - December.
[b] Represents only 8 months, January - July, December.
[c] Represents only 8 months, January - August.
[d] Represents only 8 months, January - August.
[e] Represents only 8 months, January - March, September - December.
[f] Represents 12 months.

Appendix Table I-2. **Lifetime fecundity schedule for Atlantic cod, Atlantic herring, Atlantic mackerel, pollock, red hake, winter flounder and yellowtail flounder. (Survival proportions derived from NOAA 1998; Fraction mature from O'Brien 1993).**

	Age	Survival Proportion	Fraction Mature	Mean Fecundity	Egg Production
Atlantic cod					
	1	1	0.23	21510	4947
	2	0.571242	0.60	83109	28485
	3	0.326318	0.88	183243	52620
	4	0.186406	0.97	321113	58062
	5	0.106483	0.99	496172	52306
	6	0.060828	1.00	708003	43066
	7	0.034747	1.00	956272	33228
	8	0.019849	1.00	1240697	24627
	9	0.011339	1.00	1561037	17700
	10	0.006477	1.00	1917081	12417
	11	0.0037	1.00	2308640	8542
Fecundity: May (1965)					336000
Atlantic herring					
	3	1	0.48	21802	10465
	4	0.778821	0.99	48100	37087
	5	0.6065621	1	77381	46936
	6	0.4724033	1	104521	49376
	7	0.3679176	1	127123	46771
	8	0.2865419	1	144738	41474
	9	0.2231649	1	157896	35237
	10	0.1738055	1	167455	29105
	11	0.1353634	1	174272	23590
Fecundity: Kelly and Moring (1986)					320040

Age	Survival Proportion	Fraction Mature	Mean Fecundity	Egg Production
Atlantic mackerel				
1	1	0.20	183654	36731
2	0.786647	0.63	328750	162924
3	0.618814	0.99	462149	283124
4	0.486789	1.00	588478	286464
5	0.382931	1.00	709798	271804
6	0.301232	1.00	827270	249200
7	0.236963	1.00	941634	223133
8	0.186406	1.00	1053406	196362
9	0.146636	1.00	1162957	170532
10	0.115351	1.00	1270574	146562
11	0.090741	1.00	1376480	124903
12	0.071381	1.00	1480854	105705
13	0.056152	1.00	1583844	88935
14	0.044171	1.00	1685573	74454
				2420832
Fecundity: Morse (1980)				
Pollock				
1	1	0.24	8115	1948
2	0.818731	0.50	10142	4152
3	0.66898	0.70	11156	5224
4	0.526765	0.92	168750	81780
5	0.349938	1.00	223192	78103
6	0.187683	1.00	339827	63780
7	0.082993	1.00	419460	34812
8	0.033776	1.00	491383	16597
9	0.01464	1.00	592362	8672
10	0.006121	1.00	636344	3895
11	0.002476	1.00	730744	1810
12	0.001014	1.00	807372	819
13	0.000415	1.00	889185	369
14	0.00017	1.00	975156	166
15	6.96E-05	1.00	1037828	72
Source: Saila et al. (1997)				302199

	Age	Survival Proportion	Fraction Mature	Mean Fecundity	Egg Production
Red hake					
	1	1	0.04	156637	6265
	2	0.606562	0.73	249325	110399
	3	0.367918	0.99	326692	118994
	4	0.223165	1.00	462133	103132
	5	0.135363	1.00	732992	99220
	6	0.082106	1.00	912603	74930
	7	0.049803	1.00	877988	43726
	8	0.030208	1.00	1449275	43780
	9	0.018323	1.00	1654144	30309
	10	0.011114	1.00	2293885	25495
	11	0.006741	1.00	2578819	17385
	12	0.004089	1.00	3021598	12356
Source: Saila et al. (1997)					685991
Winter flounder					
	3	1	0.16	223735	35798
	4	0.280869	0.61	378584	64863
	5	0.0679	1.00	568243	38584
	6	0.016415	1.00	785897	12900
	7	0.003968	1.00	1004776	3987
	8	0.000959	1.00	1201125	1152
	9	0.000232	1.00	1366951	317
	10	5.61E-05	1.00	1502557	84
	11	1.36E-05	1.00	1598597	22
	12	3.28E-06	1.00	1682208	6
	13	7.92E-07	1.00	1754800	1
	14	1.91E-07	1.00	1809000	0
	15	4.63E-08	1.00	1845800	0
Source: Saila et al. (1997)					157714
Yellowtail flounder					
	2	1	0.88	590213.2	519388
	3	0.7408413	1	997403.7	738918
	4	0.5488458	1	1447244	794314
	5	0.4066076	1	1931716	785450
	6	0.3012317	1	2445704	736723
	7	0.2231649	1	2985609	666283
					4241076
Fecundity: Howell and Kesler (1977)					

II. ASSESS THE IMPACT OF THE THERMAL PLUME ON NORMAL FISH MOVEMENT

The impact of the thermal plume of Seabrook Station on normal fish movement was assessed by first defining the extent of the thermal plume, and then identifying those fish among the EFH species that are potentially affected by the plume. The thermal plume is discharged through 11 riser shafts each spaced about 30.5 m apart for a total diffuser length of 305 m. Each riser shaft terminates in a pair of nozzles with an inner diameter of 0.8 m. The nozzles are pointed up from the horizontal at an angle of about 22.5° with 50° spacing between their centerlines. The nozzles rise about 2-3 m above the seafloor in depths of 15-18 m.

A thermal plume modeling and field verification study indicated that there was an area of 12.9 ha (32 acres) in the vicinity of the discharge where there was a greater than 1.7°C (3 °F) rise in surface temperature (Padmanabhan and Hecker 1991). Furthermore, the plume being less dense than the surrounding ambient waters, rose almost directly to the surface and began to spread out in the top 3 to 5 m of the water column. Padmanabhan and Hecker (1991) found that there were no significant increases in surface temperature at the Outer Sunk Rocks, located about 500 m to the northwest of the discharge.

Continuous monitoring of the thermal plume at the surface has been conducted at two stations since the plant became operational in August of 1990. One station (DS) was located in the nearfield jet mixing region within 100 m of the discharge and the second reference station (T7) was located about 2.5 km north of the discharge (Figure II-1). The NPDES permit for Seabrook Station requires that the monthly mean difference in temperature (delta-T) between the two stations cannot exceed 2.8°C (5° F). This permit requirement has never been exceeded, and on only four occasions (February and August 1993; February 1996; February 2000) did the monthly mean delta-T exceed 2.0°C (3.6° F). During the summer and fall, when water temperatures are highest, a negative delta-T can occur where cool bottom water is entrained with the less dense thermal plume and brought to the surface (Appendix Table II-1). This results in surface water temperatures near the discharge that can be as much as 1.9°C (3.4° F) cooler than at the reference station 2.5 km to the north.

Calculation of a monthly mean delta-T has the potential to obscure individual data points within the month when the delta-T may be much higher. However, this is not the case for Seabrook Station. The quantity of heat rejected to the ocean is proportional to the electrical output of the station. Seabrook Station is a baseload plant, meaning that it tends to operate at or near 100% capacity for long periods, and then does not operate at all during outages. There are no wide variations in the electrical output of the plant on a daily basis; therefore, the temperature of the thermal plume does not vary widely. The standard deviation of the monthly mean temperature at the discharge station is generally an order of magnitude less than the mean, which is further evidence of the consistency of the temperature of the thermal plume within a month.

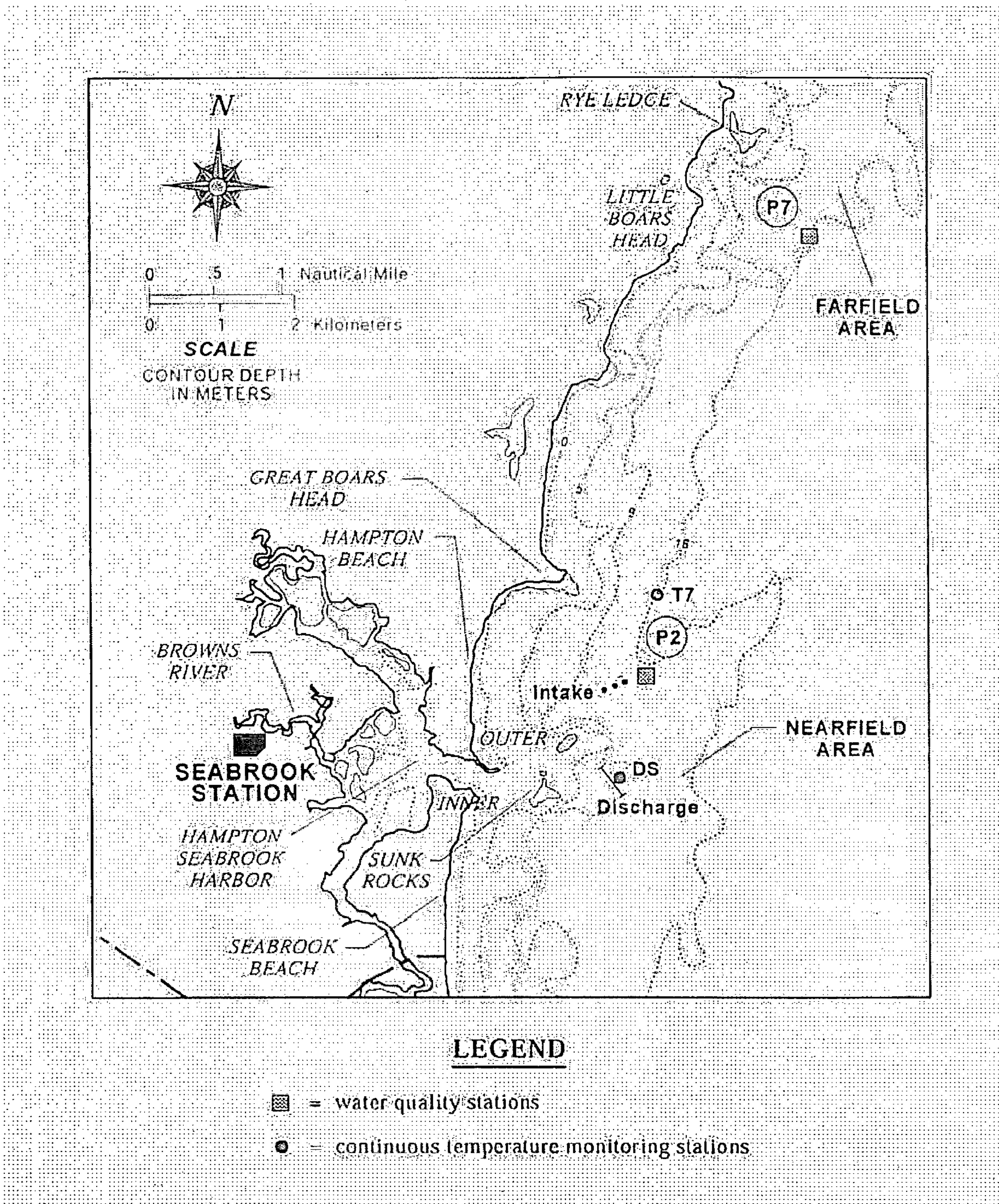

Figure II-1. Water quality sampling stations.

Monitoring of bottom water temperatures has also been conducted in association with the macrobenthos monitoring program. Bottom water temperature at a nearfield benthic station (B19) (about 200 m from the discharge) and a reference station (B31) located outside of the influence of the plume were monitored continuously during 1998 and 1999 (NAI 2000). Although there were significant differences in monthly mean bottom water temperatures between the two stations, the mean differences were less than 0.5°C (0.9°F). Furthermore, the nearfield station was not consistently warmer than the farfield station. Therefore, it was concluded that the thermal plume was not affecting bottom water temperatures at the nearfield subtidal station.

Determining the location of the thermal plume depends on which isotherm is used to define the plume. The benthic temperature monitoring program and thermal plume modeling all indicated that the thermal plume rises rapidly to the surface. Continuous thermal plume monitoring indicated that for most months between August 1990 and December 2000, the monthly mean increase in surface temperature was less than 2.0°C (3.6°F) within 100 m of the discharge. Based on these thermal observations, it appears that the habitat most likely affected by the thermal plume would be the upper water column in the immediate vicinity of the discharge. The thermal data collected to date indicates that the normal movement of benthic and demersal organisms will not be affected by the thermal plume because there are no thermal impacts at or near the bottom.

The normal movements of pelagic organisms have the greatest potential to be affected by the thermal plume. Among the EFH species, these would include pollock, Atlantic herring, butterfish, Atlantic mackerel, bluefin tuna, longfin inshore squid, and northern shortfin squid. With all of these species, there is the potential for avoidance of the immediate area around the discharge. However, because the discharge is located offshore, there are no barriers to movement around the thermal plume, as opposed to a discharge in a restricted river or estuary that might form a thermal barrier to movements. Avoidance of the immediate area around the discharge is a possibility, but this would not preclude the completion of any normal seasonal movements because fish would be able to move around the plume.

Empirical studies were made of the abundance of Atlantic herring, pollock, and Atlantic mackerel from 1975 through 1996 (NAI 1998). Experimental gill nets were set for two consecutive 24-hour periods twice per month (prior to July 1986) and once per month (starting in July 1986) at three stations. A discharge station (G2) was located about 250 m southwest of the discharge and two other stations were located 2 km south of the discharge (G1), and 2.5 km north of the discharge (G3). There were no significant differences in CPUE (catch per 24-hour set) among stations, or between the preoperational and operational periods for pollock or Atlantic mackerel. CPUE of Atlantic herring was significantly higher in the preoperational period due to extremely high catches at all stations in 1977. The decrease in CPUE in the operational period was not due to station operation because it occurred at all three stations.

Table II-1 presents the months of highest abundance in the study area for the pelagic EFH species in the study area. The ranges of monthly mean water temperatures for 1990 through 2000 at the discharge station (DS) are also presented for the periods of highest abundance to provide a measure of water temperature within 100 m of the discharge. The Massachusetts Division of Marine Fisheries (MDMF) conducts a fisheries resource survey in Massachusetts Bay in the spring and fall. The water temperatures associated with the catches in Massachusetts Bay in the spring and fall are presented to provide a measure of temperatures that are not limiting to distribution of these fishes in Massachusetts Bay. For Atlantic herring the range of monthly mean water temperatures at the discharge station were within the range of temperatures in Massachusetts Bay where catches of these fishes were made.

These data indicate that the water temperatures at the discharge station will not interfere with the normal movement of Atlantic herring.

Pollock occur in the study area for much of the year, but are most common in May through June and October through December (NAI 1993). Monthly mean water temperature at the discharge station ranged from 9.6 to 13.8°C in the spring and 5.6 to 14.3°C in the fall. The upper ends of these ranges are higher (spring: +0.8°C; fall: +3.3°C) than the highest temperatures associated with pollock catches in Massachusetts Bay. Based on these temperature ranges, it is possible that pollock will avoid the immediate area around the discharge in the fall.

Atlantic mackerel occur in the study area from June through November (NAI 1993) and monthly mean water temperature at the discharge station can range from 8.0 (November 1993) to 18.8°C (August 1993). The laboratory studies of Olla et al. (1975, 1976 cited in Studholme et al. 1999) indicated increased swimming speeds of Atlantic mackerel at water temperatures above 15.8°C, possibly a result of thermal avoidance. However, Bigelow and Schroeder (1953) indicated that Atlantic mackerel are found at water temperatures as high as 20°C. Based on these data, Atlantic mackerel may avoid the immediate area around the intake during periods of highest water temperature.

Butterfish occurred only occasionally (between 1 and 10% of samples) in gill net samples and were rare (<1% of samples) in otter trawl samples in the study area. Butterfish are more common south of Cape Cod and occur in the study area typically only in the late summer and fall. Catches of butterfish in the MDMF resource survey were much higher in the fall in Massachusetts Bay (Cross et al. 1999). The highest monthly mean water temperature observed for the summer and fall at the discharge station, 18.8°C in August 1993, was lower than the range reported for butterfish catches in Massachusetts (7-22°C; Cross et al. 1999). Therefore, it is not expected that water temperatures at the discharge will interfere with normal movement of butterfish.

Bluefin tuna have never been captured as part of the Seabrook Station Environmental Monitoring Program. These large pelagic fishes could probably avoid any of the sampling gear used in the study. For the same reason, it could reasonably be expected that bluefin tuna could easily avoid, and move around the thermal plume if necessary.

Northern shortfin squid and longfin inshore squid are not enumerated as part of the Seabrook Station Environmental Monitoring Program. Northern shortfin squid are more common in the Gulf of Maine in the summer and fall as adults migrate from the outer continental shelf to inshore waters (Cargnelli et al. 1999f). During this inshore migration they might be found off the coast of New Hampshire and may encounter the thermal plume from Seabrook Station. Despite this inshore migration, they were rare in the fall MDMF inshore trawl surveys (Cargnelli et al. 1999f). Adult northern shortfin squid have been captured at water temperatures ranging from -0.5 – 27.3°C (Whitaker 1980 cited in Cargnelli et al. 1999f) and are usually not found in waters shallower than 18 m. In the Northeast Fisheries Science Center (NEFSC) bottom trawl survey they were captured at temperatures ranging from 4-19°C. In the summer more than 70% were captured at water temperatures of 5-9 °C and in the fall more than 70% were captured at 8-12 °C (Cargnelli et al. 1999f). The monthly mean water temperature at the discharge station ranged from 8.0 to 18.8°C in the summer and fall. Because they have been captured at water temperatures as high as 19°C in the NEFSC bottom trawl survey (and higher in other surveys), water temperatures at the discharge station do not appear to be high enough to preclude their normal movements.

Adult longfin inshore squid migrate to inshore waters as shallow as 6-28 m in the summer (Cargnelli et al. 1999e). During this inshore migration they may be in shallow enough water to encounter the thermal discharge plume from Seabrook Station. Most longfin inshore squid were captured at depths of 10-20 m and temperatures of 11-16°C in the summer in the NEFSC trawl survey, but they occurred at temperatures as high as 26°C (Cargnelli et al. 1999e). In the MDMF inshore trawl survey most were found in the fall at 16-20°C and depths of 10-15 m. However, some were captured at water temperatures as high as 22°C. The highest monthly mean water temperature at the discharge station was 18.8°C, and this does not appear to be high enough to preclude the normal movements of longfin inshore squid.

SUMMARY

The thermal plume does not appear to have any major impact on movement of the EFH species. The plume rises quickly to the surface and therefore should not have any effect on the movements of benthic or demersal organisms. Among the pelagic species, the impact appears to be minimal. The highest ambient monthly mean temperature recorded in the jet mixing zone at 100 m from the discharge was 18.8°C. Although this may be out of the preferred temperature range of some species such as pollock or Atlantic mackerel, all of the pelagic EFH species have been captured in warmer water. It is possible that warmer water temperatures can occur within 100 m of the discharge. Thermal plumes can form a barrier to fish movement when they extend across the width of a geographic restriction in a river or estuary. The discharge from Seabrook Station is located offshore where there are no geographic restrictions. Therefore, the greatest potential impact to fish movement may be an avoidance of an area less than 100 m from the discharge. This will not be a serious impact as fish will be able to move around a potential area of high water temperature, and continue with their normal movements.

Table II-1. Season of highest abundance of pelagic EFH species off Seabrook, New Hampshire, range of water temperatures at the discharge station, and period of highest abundance in Massachusetts Bay with associated water temperatures.

Species	Season of highest abundance	Range of monthly mean water temperatures at discharge station (DS)	Range of water temperatures associated with catches in Massachusetts Bay[a]	Reference
Atlantic herring	April-May	5.0-10.7°C	Spring: 2-12°C	Reid et al. 1999
	October – December	5.6-14.3°C	Fall: 5-20°C	
Pollock	May-June	9.6-13.8°C	Spring: 3-13°C	Cargnelli et al. 1999c
	October-December	5.6-14.3°C	Fall: 8-11°C	
Atlantic mackerel	June-November	8.0-18.8°C	Spring: 11-16°C Fall: 5-15°C	Studholme et al. 1999
Butterfish	August – November	8.0-18.8°C	Fall: 7-22°C	Cross et al. 1999
Northern shortfin squid	Not enumerated but found from 40-90 m in summer and <130 m in fall	8.0-18.8°C	Summer: 70% occurred at 5-9°C; Fall: 70% occurred at 8-12°C; Can occur as high as 19°C	Cargnelli et al. 1999f
Longfin inshore squid	Not enumerated but found from 10-20 in summer and 20-70 m in fall	8.0-18.8°C	Summer: 11-16°C Fall: 10-14°C Can occur as high as 26°C	Cargnelli et al. 1999e

[a] Temperature and occurrence data for squids are from the NEFSC trawl surveys on the east coast.

Appendix Table II-1. 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 2000. Seabrook Operational Report, 2000.

Month	1990			1991			1992		
	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]
Jan	--[b]	--	--	6.47	4.71	1.76	6.02	4.32	1.70
Feb	--	--	--	5.38	4.17	1.21	4.74	2.92	1.82
Mar	--	--	--	5.11	3.78	1.33	4.94	3.16	1.78
Apr	--	--	--	6.99	6.37	0.62	5.93	4.26	1.67
May	--	--	--	10.43	10.21	0.22	10.52	10.32	0.20
Jun	--	--	--	13.81	13.70	0.11	11.94	11.84	0.10
Jul	--	--	--	14.58	15.02	-0.44	13.81	14.16	-0.35
Aug[a]	18.16	18.36	-0.20	16.86	17.06	-0.20	15.61	14.69	0.92
Sep	16.31	16.09	0.22	15.66	15.69	-0.03	14.03	12.69	1.34
Oct	13.04	12.11	0.93	11.87	11.68	0.19	--	--	--
Nov	10.24	9.44	0.80	11.00	9.33	1.67	9.01	7.59	1.42
Dec	8.91	7.32	1.59	8.45	6.81	1.64	7.32	5.61	1.71

Month	1993			1994[d]			1995		
	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]
Jan	5.69	3.80	1.89	4.12	2.57	1.55	6.37	4.66	1.71
Feb	3.52	1.38	2.14	2.23	1.32	0.91	5.41	3.54	1.87
Mar	3.26	1.63	1.63	2.69	1.73	0.96	4.67	3.23	1.44
Apr	5.04	4.44	0.60	--	--	--	6.86	5.33	1.53
May	10.74	10.02	0.72	--	--	--	9.56	8.20	1.36
Jun	11.65	10.53	1.12	--	--	--	13.63	15.58	-1.95
Jul	15.92	14.54	1.38	--	--	--	14.76	15.48	-0.72
Aug[a]	18.77	16.69	2.08	15.44	15.53	-0.09	17.40	17.71	-0.31
Sep	11.62	12.19	-0.57	16.33	15.47	0.86	15.93	15.28	0.65
Oct	10.13	11.27	-1.14	13.94	12.69	1.25	14.27	13.08	1.19
Nov	8.03	9.33	-1.30	11.77	10.37	1.40	9.17	9.11	0.06
Dec	5.64	7.55	-1.91	8.74	6.90	1.84	6.76	5.53	1.23

(continued)

Appendix Table II-1. Continued

Month	1996			1997			1998		
	DS	T7	ΔT[c]	DS	T7	ΔT[c]	DS	T7	ΔT[c]
Jan	4.08	2.40	1.68	6.57	4.91	1.66	4.64	3.89	0.75
Feb	3.21	2.07	1.14	5.47	3.37	2.10	4.21	2.75	1.46
Mar	4.20	2.69	1.51	5.71	4.03	1.68	4.29	3.31	0.98
Apr	6.06	5.00	1.06	6.48	5.53	0.95	7.17	6.39	0.78
May	9.57	9.26	0.31	7.52	6.91	0.61	9.82	9.84	-0.02
Jun	13.40	13.72	-0.32	13.46	13.33	0.13	12.19	12.29	-0.10
Jul	13.29	13.68	-0.39	14.89	15.21	-0.32	14.39	15.19	-0.80
Aug[a]	16.10	17.04	-0.94	16.60	17.01	-0.41	14.01	15.06	-1.05
Sep	17.14	16.22	0.92	16.01	15.51	0.50	14.84	14.95	-0.11
Oct	13.24	11.97	1.27	13.21	11.97	1.24	12.04	10.88	1.16
Nov	10.55	8.90	1.65	10.53	9.02	1.51	8.89	8.04	0.86
Dec	7.90	6.51	1.39	6.27	5.98	0.29	8.13	6.52	1.61

Month	1999			2000		
	DS	T7	ΔT[c]	DS	T7	ΔT[c]
Jan	5.72	3.97	1.76	5.72	4.17	1.55
Feb	4.19	2.56	1.63	4.75	2.74	2.01
Mar	3.92	2.84	1.08	5.32	3.89	1.42
Apr	6.25	6.23	0.02	6.79	5.97	0.82
May	10.46	10.61	-0.14	10.32	9.63	0.69
Jun	13.41	13.99	-0.59	13.27	13.29	-0.02
Jul	13.81	14.94	-1.13	15.71	15.93	-0.23
Aug[a]	15.81	16.21	-0.39	17.05	17.37	-0.32
Sep	16.71	16.82	-0.12	15.89	15.31	0.58
Oct	13.29	12.05	1.24	13.46	12.48	0.97
Nov	10.28	8.83	1.44	9.37	9.31	0.07
Dec	8.46	6.47	1.99	6.28	6.15	0.13

[a]Commercial operation began in August, 1990. [b]Data either not collected, or an equipment failure occurred. [c]ΔT = Surface discharge - surface farfield temperatures (°C) [d]Seabrook Station was offline April-July.

III. ASSESS THE IMPACT OF PLANT OPERATION ON THE MAJOR FOOD ITEMS OF THE EFH SPECIES

The impact of plant operation on major prey items of the EFH species was assessed by first identifying the major prey items for each of the species (Table III-1). Primary references for this effort were Bowman et al. (2000) and the EFH source documents referenced in Table III-1. The impact of plant operation on these prey items was assessed by using the existing data and analyses in the most recent Operational Report (NAI 2000). NAI (2000) is the primary reference for assessing the impact of plant operation on prey species unless another reference is cited.

PREY ITEMS OF EFH SPECIES

American plaice

This flatfish feeds opportunistically primarily on invertebrates, especially echinoderms and mollusks. Brittle stars (Ophiuroidea) and bivalves were major food items for American plaice in the Gulf of Maine. These items were more important to larger American plaice while polychaetes were more predominant in the stomachs of smaller fish.

Atlantic cod

The Atlantic cod has a varied diet. Crustaceans such as amphipods, mysids, and decapods are important prey items for smaller Atlantic cod. As Atlantic cod grow larger, they become piscivorous and can feed on Atlantic herring, sand lance, and silver hake.

Atlantic halibut

Atlantic halibut feed almost exclusively on invertebrates until they reach about 30 cm in length. Fish become a more important food item for larger Atlantic halibut. Decapods (*Crangon septemspinosa, Dichelopandalus leptocerus*) annelids and mollusks are important invertebrate prey items for smaller Atlantic halibut. Larger Atlantic halibut feed on silver hake, sand lance, longhorn sculpin, and ocean pout.

Atlantic herring

Atlantic herring are opportunistic planktivorous fish that feed primarily on available zooplankton including crustaceans such as copepods (*Calanus* sp.) and euphausiids (*Thysanoessa raschii, Meganyctiphanes norvegica*). Fish do not ordinarily make up an important part of their diet.

Atlantic mackerel

Atlantic mackerel of all sizes feed primarily on crustaceans such as copepods (*Centropages* sp.), amphipods (*Gammarus annulatus*), and mysids (*Neomysis americanus*). As they grow larger, they can feed on small silver, red and white hakes, and sculpin, as well as squid.

Bluefin tuna

This large predator is primarily piscivorous. Atlantic herring, Atlantic mackerel, silver hake, and squid have been reported form their stomachs as well as euphausiids (Bigelow and Schroeder 1953).

Butterfish

Butterfish feed on planktonic prey including Thaliaceans, (Larvacea and Hemimyaria), mollusks (squid and *Clione* sp.), crustaceans (copepods, amphipods, and decapods) and polychaetes (Tomopteridae and Goniadidae). Fish are not a major part of their diet.

Goosefish

Goosefish become piscivorous at lengths of 5-20 cm soon after they settle to bottom. Fish and squid are the major component of their diet although they can feed on decapods. Almost any fish may become a food item for goosefish, although most prey items are demersal fishes. Herring, gadids, and flounders are important prey items for goosefish.

Haddock

Juveniles and adult haddock are indiscriminant feeders on invertebrates including bivalves, polychaetes, amphipods (*Unciola irrorata*), euphausiids (*Meganyctiphanes norvegica*), decapods, mysids, and brittle stars. Fish are not a major portion of their diet.

Ocean pout

Ocean point primarily feed on benthic invertebrates. Echinoderms, especially sand dollars and brittle stars are important prey items. Bivalves, copepods, amphipods, polychaetes, and crustaceans are also prey items. Fish are not a major food item.

Pollock

Juvenile pollock feed on invertebrates such as chaetognaths and crustaceans, especially amphipods and euphausiids such as *Meganyctiphanes norvegica.* As pollock mature, fish and squid become major food items. Fish preyed upon include Atlantic herring and sand lance.

Red hake

Red hake feed on a variety of invertebrates including euphausiids (*Meganyctiphanes norvegica)*, amphipods, decapods, and mysids. Fish become an important food item for red hake larger than 16 cm. Fish preyed upon include silver hake, gadids, and sand lance.

Redfish spp.

Redfish of all sizes feed on the pelagic calanoid-euphausiid assemblage. Juvenile and adult fish feed on euphausiids, mysids, and bathypelagic fish. The euphausiid *Meganyctiphanes norvegica* and calanoid copepods are important food items. Proportion of fish in diet is correlated with body size.

Silver hake

The diet of silver hake consists mainly of euphausiids, decapods, squid, and fish. The euphausiid *Meganyctiphanes norvegica* is an important food item. Silver hake less than 20 cm eat primarily euphausiids and shrimp. Larger silver hake (> 35 cm) are more piscivorous and feed on herrings, sand lance, and other fishes.

Summer flounder

Smaller summer flounder (<100 mm) feed on crustaceans and polychaetes. For juveniles 20-60 mm, the polychaete *Streblospio benedicti* was the most important food component. Clam siphons, mysids, palaemonid shrimp, calanoid copepods were also important food items. In the size range of 100-200 mm, the mysid *Neomysis americana* and fishes became increasingly important food items. As summer flounder grow fish become a larger component of their diet. Atlantic silversides, mummichogs, sticklebacks, and sand lance are prey items for summer flounder.

Scup

Juvenile scup (<150 mm) feed on polychaetes, epibenthic amphipods, and other small crustaceans, mollusks and fish eggs and larvae. Adult scup are benthic feeders and forage on small crustaceans, polychaetes, mollusks and small squid. Plant detritus, insect larvae, hydroids, sand dollars and small fish are also food items. Although fish are not a major food item, scup can be piscivorous as sand lance have been found in their stomachs.

Windowpane

Windowpane feed primarily on invertebrates such as amphipods *(Gammarus americana*), mysids (*Neomysis americana*), and decapods (*Crangon septemspinosa*). Windowpane are not primarily piscivorous, but they can prey upon small sand lance.

Winter flounder

Winter flounder are opportunistic and omnivorous feeders primarily on invertebrates. Amphipods and harpacticoid copepods were important foods for recently metamorphosing flounders. Amphipods (*Pontogeneia inermis*) and polychaetes (*Spiophanes bombax, Asabellides oculata*), gradually become more important for both YOY and yearling flounder. Winter flounder can feed upon other small flatfish.

Yellowtail flounder

Benthic macrofauna are the primary food items for yellowtail flounder. Amphipods such as *Unciola* spp. and *Ericthonius* spp. and polychaetes such as *Chone infundibuliformis* and *Spiophanes bombyx* are important food items. Juvenile yellowtail flounders appear to feed primarily on polychaetes while adults feed on crustaceans.

Atlantic sea scallop

Atlantic sea scallops are primarily suspension or filter feeders. Their food items include phytoplankton, diatoms, and microscopic animals with detritus and associated bacteria also contributing. Inshore scallops can also feed on seaweed and seagrass detritus while offshore scallops feed primarily on phytoplankton and resuspended organic material.

Atlantic surfclam

The Atlantic surfclam is a planktivorous siphon feeder and they feed primarily on phytoplankton, especially diatoms, and ciliates.

Longfin inshore squid

Small immature longfin inshore squid feed on planktonic organisms. Juveniles, 4.1- 6 cm, feed on euphausiids and arrow worms. Larger squid, 6.1-10 cm, feed on small crabs, polychaetes and shrimp. Adults, 12.1-16 cm feed on fish, including clupeids and myctophids, and squid. Larger adults (>16 cm) can feed on silver hake, mackerel, herring, menhaden, weakfish and silverside and other squid.

Northern shortfin squid

Northern shortfin squid feed primarily on fish, squid, and crustaceans such as amphipods, euphausiids, and decapods. Larger prey items include small Atlantic cod, Arctic cod and redfish, mackerel, Atlantic herring, haddock, sculpins, and other squid.

DISCUSSION

The food items used by the fishes and invertebrates of concern occur in many different trophic levels and habitats. Despite this diversity in prey items, they can be grouped for convenience into four functional groups: phytoplankton, zooplankton, benthic invertebrates, and fishes. Most of the EFH species use more than one of these groups as major prey items. The impact of plant operation on these functional groups can be assessed by using existing information from the Seabrook Station Environmental Monitoring Program (NAI 2000), and earlier reports.

Phytoplankton

Atlantic sea scallop and Atlantic surfclam are filter feeders for which phytoplankton is a major food source. Aspects of the phytoplankton community in the Hampton Seabrook area were monitored for 19 years as part of the Seabrook Station Environmental Monitoring Program. The phytoplankton community was extremely variable in both space and time but some generalizations were possible. Diatoms were the dominant phytoplankter in most years with peaks in abundance in the spring and fall. However, in some years (1978, 1979, 1981, 1983, 1992, 1994, and 1997) the Prymnesiophyceae taxon *Phaeocystis pouchetti* was dominant. The phytoplankton community has been monitored since 1992 in Massachusetts Bay as part of the Massachusetts Water Resources Authority monitoring program. Blooms of *Phaeocystis pouchetti* were observed in Massachusetts Bay in 1992 and 1997 (Libby et al. 2000). There were no detectable differences in the phytoplankton community between the preoperational and operational periods, or among stations, however, the variability of this community limited the power of such comparisons (NAI 1998a). Blooms of *Alexandrium tamarense*, the species that causes paralytic shellfish poisoning, were rare in the Operational Period (NAI 1998) indicating that plant operation did not contribute to blooms of nuisance species. There was no evidence that the operation of Seabrook Station affected the phytoplankton community in the study area. Therefore, it is not expected that the operation of Seabrook Station will affect the food items for Atlantic sea scallop and Atlantic surf clam.

Zooplankton

Although many of the EFH species feed on zooplankton to some degree, those that feed primarily on zooplankton might be more vulnerable to disruption in the zooplankton community. Pelagic fishes such as Atlantic herring, Atlantic mackerel, and butterfish feed to a great degree on the zooplankton community. Atlantic cod, Atlantic halibut, haddock, pollock, red hake, silver hake, longfin inshore squid and northern shortfin squid also feed on the zooplankton community, typically when young.

In the zooplankton community, crustaceans (copepods, amphipods, decapods, mysids, euphausiids) and bivalve larvae are important prey items for the EFH species. The zooplankton community has been studied as part of the Seabrook Station Monitoring Program since 1978. Community analysis of the zooplankton community has taken place as well as analysis of the population trends of selected species. The zooplankton community was divided into four groups for analysis. The holoplankton assemblage consists of zooplankters that are pelagic throughout their entire life cycle. Copepods, cladocerans, and euphausiids are members of this assemblage, with the copepods *Centropages typicus* and *Calanus finmarchicus* as the dominant species. The meroplankton assemblage consists of species that spend a distinct portion of their life cycles in the plankton and is represented by the decapods *Eualus pusiolus* and *Crangon septemspinosa*. The hyperbenthos assemblage includes benthic species that migrate into the water column on a regular basis and organisms that are concentrated in the water immediately adjacent to the bottom. The mysid *Neomysis americana* is a dominant member of this community. The bivalve larvae assemblage, which could be considered part of the meroplankton, was dominated by the larvae *Mytilus edulis* and *Anomia squamula*. Numerical classification and multidimensional scaling (MDS) (Clarke and Warwick 1994) were used to evaluate community structure between periods and stations.

There have been significant changes in the holoplankton and meroplankton assemblages between the preoperational and operational periods (NAI 2000). In the holoplankton community, abundance of *Centropages typicus* and *Calanus finmarchicus* increased slightly between periods. Both of these copepods are prey items for planktivorous fishes including Atlantic herring and Atlantic mackerel. However, the major difference between periods was the increased annual variability in the abundance of these species. The changes in the holoplankton assemblage occurred in both the nearfield and farfield and could not be attributed to the operation of Seabrook Station.

There were also changes in the meroplankton assemblage between the preoperational and operational periods (NAI 2000). The abundance of Cirrepedia sp. (barnacle) larvae increased between the preoperational and operational periods. Larvae of the decapods *Cancer* sp., *Eualus pusiolus* and the medusoid stage of the cnidarian *Obelia* sp. increased slightly between periods. Decapods were identified as major prey items for several of the EFH species including Atlantic cod, Atlantic halibut, Atlantic herring, butterfish, goosefish, haddock, red hake, silver hake, summer flounder, and windowpane. As with the holoplankton assemblage, these changes were observed at both nearfield and farfield stations and cannot be attributed to plant operation.

The hyperbenthic assemblage was dominated by *Neomysis americana* in both the preoperational and operational periods (NAI 2000). *N. americana* is a mysid that is an important food item for many of the EFH species including windowpane. Atlantic cod, haddock, red hake, redfish spp., and summer flounder also feed on mysids. There were no significant differences in assemblage composition between periods, but there were significant differences between stations. *N. americana* and several other species of hyperbenthos were more abundant in the nearfield area. However, these differences were attributed to differences in habitat between the two stations because the differences were present in both the preoperational and operational periods.

The bivalve larvae assemblage has remained relatively unchanged throughout the study period (NAI 2000). Preoperational and operational period years were similar and there were no significant differences in assemblage composition between stations. Bivalve larvae were identified as prey items for Atlantic herring.

The microzooplankton community in the Hampton-Seabrook area was studied from 1982 though 1997. Microzooplankton was defined as zooplankton that were retained in a 0.076-mm mesh net. Dominant members of the microzooplankton community included four copepod taxa: *Oithona* sp., Copepoda nauplii, *Pseudocalanus/Calanus* nauplii, and *Pseudocalanus* sp. These copepod taxa are prey items for Atlantic herring. Numerical classification suggested that there were no changes in community composition since plant operation began (NAI 1998a). Similarly, analysis of community composition using numerical classification indicated that there were no differences in community composition between the nearfield and farfield areas.

Benthic Invertebrates

Echinoderms, some amphipods and mysids, decapods, polychaetes and bivalves are benthic invertebrates that are major food items for many of the EFH species including ocean pout and scup, and the flatfishes American plaice, summer flounder, windowpane, winter flounder, and yellowtail flounder. Longfin inshore squid, northern shortfin squid, Atlantic cod, Atlantic halibut, haddock, pollock, red hake, redfish spp., and silver hake also use benthic invertebrates listed above as a food source during some portion of the life cycle. Not all of these prey species are strictly benthic, and some can be considered part of the hyperbenthic assemblage previously discussed in the zooplankton community.

Quantitative benthic samples were taken in August at four stations in the Hampton-Seabrook area as part of the Seabrook Station Environmental Monitoring Program. Two stations were located at depths of 4-5 m (B17: nearfield; B35: farfield) and two stations were located at depths of 9-12 m (B19: nearfield; B31: farfield). Sampling at these stations began in 1982 at Stations B17 and B35, and in 1986 at Stations B19 and B31. These four stations were primarily located on hard substrate as this is the primary habitat found in the intake and discharge areas.

Numerical classification and MDS (Clarke and Warwick 1994) indicated that the macrofaunal invertebrate community at 4-5 m depth was very similar between the nearfield and farfield areas and between the preoperational and operational periods (NAI 2000). Mytilidae, the gastropod *Lacuna vincta*, and the amphipods *Jassa marmorata*, and *Pontogeneia inermis* were dominant members of this community.

The mid-depth (9-12 m) macrofaunal community was also very similar between the nearfield and farfield areas and between the preoperational and operational periods as indicated by numerical classification and MDS. Mytilids were the dominant taxon with the amphipods *Pontogeneia inermis*, and *Caprella septentrionalis*, the mollusks *Anomia* sp., *Lacuna vincta*, and *Hiatella* sp. also abundant.

Lacuna vincta, a gastropod, mytilidae, isopods, amphipods and seastars (an echinoderm) were dominant members of the shallow subtidal benthic invertebrate community. In the mid-depth community mytilids were most abundant followed by amphipods, other mollusks, and echinoderms.

These invertebrates were major food items for some of the demersal EFH species including American plaice, Atlantic cod, Atlantic halibut, haddock, ocean pout, red hake, redfish spp. summer flounder, scup, winter flounder, and yellowtail flounder. The similarity in community composition of benthic invertebrates between nearfield and farfield areas, and between periods is an indication that the operation of Seabrook Station has not affected the benthic food sources of the EFH species.

Many of the EFH species including American plaice, summer flounder, winter flounder and yellowtail flounder feed on invertebrates found in soft-bottom habitat. The soft-bottom community near the intakes and discharges consisted primarily of sand substrate (NAI 1981). This habitat was studied extensively from 1975 through 1980 but the program was discontinued in 1980 because the data was extremely variable and judged not useful for assessing plant impact, particularly the station near the intake. Because the program was discontinued, there are no data from the operational period and assessing the impact of plant operation on this community is not possible with existing data. The most abundant taxa found in the sand habitat were the amphipods *Acanthohaustorius millsi*, *Protohaustorius deichmannae*, and the mollusk *Tellina agilis*. Although not specifically cited as prey items for the EFH species, these organisms could be food for any predator that feeds on benthos. *A. millsi* and *P. deichmannae* are amphipods adapted to a shifting sand habitat (Bousfield 1973). *T. agilis* is a deposit feeding mollusk with a long inhalant siphon that could serve as a food item (Gosner 1979).

Fish

Longfin inshore squid, northern shortfin squid, Atlantic cod, Atlantic halibut, goosefish, pollock, red hake, redfish spp., silver hake, and summer flounder are EFH species that use fish as a major food item. Atlantic herring, sand lance, silver hake and other gadids are the fish species often cited as prey items for the EFH species, although many fish predators are opportunistic and will prey on appropriately sized fish. Most of these common prey items are demersal fishes with the exception of Atlantic herring, which is considered pelagic.

The demersal fish community has been studied in the Hampton-Seabrook area since 1975. Otter trawl samples were collected either weekly or twice per month at three stations. During that time there have been major changes in the abundance and species composition of this community (NAI 2000). Catch per unit effort (CPUE) of demersal fishes peaked in 1980 and 1981, and 1988 and 1989 primarily due to high abundance of yellowtail flounder and winter flounder. CPUE was lowest in 1992 and 1995 and has increased since then. There has been a significant negative trend in the CPUE of demersal fishes since the project began. However, this trend has occurred at both nearfield and farfield stations indicating that the reduction was due to a regional decrease in the abundance of demersal fishes. Commercial overfishing is the most likely cause for the overall reduction in the abundance of demersal fishes in the study area (NAI 2000).

The species composition of the demersal fish community has changed since monitoring began. CPUE of most fishes, especially commercially important demersal fishes such as yellowtail flounder, hake sp., Atlantic cod, silver hake and haddock, has declined. In contrast, CPUE of small elasmobranchs such as skates and dogfishes has increased. The reduction in the abundance of demersal fishes may have resulted in a "competitive release" where elasmobranchs have replaced gadids and flounders (Fogarty and Murawski 1998). The changes in the species composition of the demersal fish community occurred at nearfield and farfield stations and are most likely due to commercial overfishing, rather than any potential impact due to the operation of Seabrook Station.

Analyses were made of the CPUE of two gadids (Atlantic cod, hake sp.) that were among the demersal fishes cited as food items for the EFH species. CPUE of both Atlantic cod and hake sp. declined significantly between the preoperational and operational periods. Although the decline was greater at some of the stations, the overall trend was one of significant decline in abundance at both nearfield and farfield stations.

Gill nets were used to monitor the pelagic fish community from 1975 through 1996 at three stations in the study area. CPUE of gill nets was highest in 1977 due to extremely high catches of Atlantic herring (NAI 1998b). After 1977, CPUE declined to relatively low levels and was very consistent after 1981. Trends in CPUE at all three stations were almost identical indicating that operation of Seabrook Station was not affecting the pelagic fish community in the nearfield area.

Atlantic herring is a pelagic fish cited as a major prey item for several of the EFH species. Analyses of the CPUE of Atlantic herring were made for the period 1975 through 1996 (NAI 1998b). CPUE declined significantly between the preoperational and operational periods, but there were no significant differences among stations. The consistency in CPUE among stations between periods in an indication that the operation of Seabrook Station has not affected the CPUE of Atlantic herring.

CONCLUSIONS

There is no evidence that the operation of Seabrook Station has affected the prey items of the EFH species. Abundance of prey items in all communities (phytoplankton, zooplankton, benthic invertebrates, and fishes) either has remained similar between the preoperational and operational periods, or has changed between periods to similar extents in both the nearfield and farfield areas. The consistency in trends between periods in the nearfield and farfield areas indicates that there have been no detectable changes in the study area due to the operation of Seabrook Station.

Table III-1. Summary of the food habits of EFH designated fishes.

Species	Invertebrate Prey	Fish Prey	Comments	Reference
American plaice	echinoderms, mollusks, amphipods, shrimp, polychaetes	Fish not a major food item	Flexible and opportunistic feeders	Johnson et al. (1999)
Atlantic cod	crustaceans, amphipods, mysids, decapods	Atlantic herring, sand lance, silver hake	Varied diet	Fahay et al. (1999)
Atlantic halibut	decapods, annelids, mollusks	silver hake, longhorn sculpin, sand lance, ocean pout, alewife	Primarily feed on invertebrates until 30 cm; fish more important when older	Cargnelli et al. (1999a)
Atlantic herring	zooplankton, copepods, euphausiids, decapods, bivalve larvae	Do not feed on fish	Opportunistically feed on available zooplankton	Reid et al. (1999)
Atlantic mackerel	copepods, amphipods, mysids, squid	silver, red, white hakes, herring, sculpin,.	Small mackerel feed on invertebrates; larger on fish	Studholme et al. (1999)
Bluefin tuna	euphausiids, squid	Atlantic herring,	Primarily	Bigelow and

Species	Invertebrate Prey	Fish Prey	Comments	Reference
		Atlantic mackerel, silver hake	piscivorous	Schroeder (1953)
Butterfish	thaliaceans, squid, copepods, amphipods decapods, polychaetes	Fish not a major food item	Feed primarily on planktonic prey	Cross et al. (1999)
Goosefish	decapods, squid	Primarily demersal fishes	When >40 cm eat few invertebrates; adults are opportunistic fish eaters	Steimle et al. (1999a)
Haddock	polychaetes, euphausiids, amphipods, decapods, mysids, bivalves, echinoderms	Fish not a major food item	Opportunistic feeders on invertebrates	Cargnelli et al. (1999b)
Ocean pout	echinoderms, bivalves, copepods, amphipods, polychaetes	Fish not a major food item	Echinoderms can be a major food item	Steimle et al. (1999b)
Pollock	chaetognaths, euphausiids, amphipods, squid	Atlantic herring, sand lance	41-65 mm: crustaceans important; 66-95 mm: fish important; >95 mm squid important	Cargnelli et al, (1999c)
Red hake	euphausiids, amphipods, decapods, mysids	silver hake, gadids, sand lance	Adults are more piscivorous	Steimle et al. (1999c)
Redfish	copepods, euphausiids, mysids	bathypelagic fishes	Fish become more important food item with size.	Pikanowski et al. (1999)
Silver hake	euphausiids, decapods, squid	Variety of fish, herrings, sand lance	<20 cm feed on crustaceans; 20-34 mm mixture; >35 mm mostly fish	Morse et al. (1999)
Summer flounder	polychaetes, copepods, mysids, amphipods, decapods	Atlantic silverside, mummichogs, sticklebacks	Polychaetes and fish more important in older flounder	Packer et al. (1999a)
Scup	polychaetes, amphipods, mollusks, squid	Fish not a major food item	As scup grow they feed on larger food items	Steimle et al. (1999d)
Windowpane	amphipods, mysids and decapod shrimp	Fish not a major food item	Can feed on fish eggs and larvae	Chang et al. (1999).
Winter flounder	amphipods, harpacticoids, polychaetes, annelids	Fish not a major food item	Opportunistic and omnivorous feeders; from 25-225 mm annelids and amphipods dominate diet	Pereira et al. (1999)
Yellowtail flounder	amphipods, polychaetes,	Fish not a major food item	Juveniles prey mostly on	Johnson et al. (1999)

Species	Invertebrate Prey	Fish Prey	Comments	Reference
	echinoderms		polychaetes and adults on crustaceans	
Atlantic sea scallop	phytoplantkon, diatoms, organic material		Suspension or filter feeders	Packer et al. (1999b)
Atlantic surfclam	phytoplankton, diatoms, ciliates		Planktivorous siphon feeder	Cargnelli et al. (1999d)
Longfin inshore squid	euphausiids, arrow worms, polychaetes, decapods, squid	herrings, silver hake, mackerel, silversides		Cargnelli et al. (1999e)
Northern shortfin squid	amphipods, euphausiids, decapods, and squid	cod, redfish, mackerel, herrings, haddock, sculpins		Cargnelli et al. (1999f)

IV. ASSESS THE IMPACT OF PLANT OPERATION ON HABITAT FORMING SPECIES

INTRODUCTION AND METHODS

This section describes potential impacts of plant operation on habitat-forming organisms found near the Seabrook Station discharge structures. The potential impacts due to the discharge include exposure of habitat-forming organisms to the thermal plume and exposure to increased turbidity levels caused by conversion of entrained organisms into detritus. These issues were investigated in a special study (NAI 1998) and it was concluded that the thermal plume was not affecting nearfield kelp populations, and increased turbidity in the nearfield area was due to the tidal discharge from Hampton Harbor. The intertidal, shallow subtidal, and mid-depth subtidal communities have been studied as part of the Seabrook Station Environmental Monitoring Program. Results from the monitoring program are summarized in this section along with the known biological habitat requirements of the EFH species. Potential changes to the known biological habitat used by the EFH species that can be attributed to plant operation will be identified.

The predominant benthic marine habitat near Seabrook Station's discharge is rocky ledge. These rock surfaces support diverse communities of attached macroalgae and macrofauna, which create substrate for a multitude of organisms. These "habitat forming species" include encrusting algae and attached macroinvertebrates that cover the rock and support understory and canopy-creating macroalgae and epifauna. When essential fish habitat is considered, the traditional habitat-forming species are expanded to include those that create refugia and support prey items for juvenile and adult EFH species. Substrate complexity in the rock ledge and boulder fields augments refugia created by habitat formers. Ojeda and Dearborn (1990, 1991), in their study in coastal Maine, a habitat similar to that at Seabrook Station, determined that intertidal rocky substrate was an important feeding habitat for juvenile pollock. Gut contents revealed typical intertidal dominants such as *Jaera marina, Gammarellus angulosus,* and juvenile blue mussels. Shallow subtidal habitat was an important nursery area for juvenile pollock and Atlantic cod. Other EFH species inhabiting the shallow subtidal zone included Atlantic mackerel, yellowtail flounder, and winter flounder. Analysis of the gut contents included amphipods that inhabit algae (*Calliopius laeviusculus, Gammarellus angulosus, Jassa marmorata)* along with dominant blue mussels (*Mytilus edulis*). These results emphasize the importance of habitat formers in providing refuge for fish and habitat for their prey.

The macrobenthic community in Seabrook Station's discharge zone varies with depth. Intertidal (approximate mean low water, Station 1MLW), shallow subtidal (4-5 m, Station 17), and mid-depth (12 m, Station 19) zones have distinct assemblages in terms of dominant species and abundance and biomass. The following species were defined as habitat forming (Table IV-1) based on their abundance or dominance and ability to provide structure in each depth zone.

Field and laboratory methods for collection and processing macrobenthic samples are described in NAI (2000). Station locations are presented in Figure IV-1.

The effects of the operation of Seabrook Station on habitat forming species were assessed at both the species level and the community level. Operational/preoperational and nearfield/farfield differences in abundance or biomass of key species were evaluated using a multi-way analysis of variance procedure (ANOVA, SAS Institute Inc. 1985). A mixed effects ANOVA model 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. The data collected for the ANOVAs met the criteria of a Before-After/Control-Impact (BACI) sampling design as discussed by Stewart-Oaten et al. (1986), where sampling was conducted prior to and during plant operation, and sampling locations included both potentially impacted and non-impacted sites. A potential plant effect is suggested by significant interaction term of the preoperational- operational and nearfield-farfield variables. A comparison of macroalgal and macrofaunal community composition during operational and preoperational periods was done using numerical classification methods (Boesch 1977). The analysis was done by grouping collections by depth zone: intertidal (Stations B1MLW and B5MLW); shallow subtidal (Stations B17 and B35); and mid-depth (Stations B19 and B31). The Multi-Dimensional Scaling (MDS) method was used to enhance interpretation of community analysis. Spatial and temporal differences were also assessed by the analysis of similarities (ANOSIM) procedure (Clarke 1993). Analytic details are described in NAI (2000). Evidence of a plant effect on habitat forming species would be deduced indirectly by observing changes in the macroalgal and macrofaunal community.

RESULTS

Intertidal zone

Rocky ledge in the mid-intertidal zone is covered with up to 90% fucoid spp. (mainly *F. vesiculosus* and *Ascophyllum nodosum,* NAI 2000). The lower intertidal zone is characterized by a dense cover of *Chondrus crispus*, a foliose red algae that forms the substrate for other algae and macroinvertebrates. *Mastocarpus stellatus* can be considered a secondary dominant, with mean biomass at the nearfield zone (50 g/m^2) two orders of magnitude less than *Chondrus* (1,030 g/m^2) over the study period (NAI 2000). Percent frequency of occurrence of *M. stellatus* averaged approximately 50% in the lower intertidal zone. Juvenile blue mussels (Mytilidae) are the most abundant organisms in the intertidal zone, averaging 121,297 per m^2 at the nearfield station during the preoperational period and 87,730 per m^2 during the operational period. Mussels colonize available space in the mid- and lower intertidal zone. Percent frequency of occurrence ranges from approximately 70% in the mid-intertidal zone to over 80% in the lower intertidal zone throughout the study period (NAI 2000).

There was no significant change in the habitat forming species that cover the majority of the intertidal zone: *Chondrus crispus* biomass and Mytilidae abundances showed no significant differences between the preoperational and operational periods (Table IV-2). *Mastocarpus stellatus* percent frequencies were similar throughout the study period, although were not statistically tested. *Ascophllum nodosum* showed a significant decrease in percent frequency at the nearfield station while no significant differences occurred at the farfield station (Table IV-2, Figure IV-2. Despite this significant interaction, both stations tracked closely in their annual trends, and there was no evidence of an operational effect on this species. *Fucus vesiculosus* showed a significant increase at the nearfield station, while there was no significant difference at the farfield station (Table IV-2, Figure IV-3). This species showed a large decline at both stations prior to 1990, when the plant became operational. The preoperational decrease in percent frequency was larger at the nearfield station, creating a significant interaction term. Percent frequencies have recovered at both stations, suggesting that a long-term cycle may be occurring.

Community analysis provides additional evidence that there has been no change in habitat forming species during the operational period. The macroalgal and macrofaunal communities at intertidal 1MLW were similar between preoperational and operational periods (NAI 2000). The intertidal nondestructive monitoring program results suggest that frequencies of macrofaunal and macroalgae species that are monitored as part of this program have been similar throughout the study period.

Shallow Subtidal Zone

The shallow subtidal zone is characterized by a dense cover of *Chondrus crispus*, with *Phyllophora/Coccotylus* (a complex of *Phyllophora pseudoceranoides* and *Coccotylus* (formerly *Phyllophora*) *truncatus)*, a secondary dominant. *Chondrus crispus* biomass averaged 650 g/m^2 at nearfield station B17, with over 70% frequency of occurrence during the study period. *Phyllophora/Coccotylus* biomass averaged 149 g/m^2, with approximately 21% frequency of occurrence (NAI 2000). The kelp overstory was composed mainly of *Laminaria saccharina* and *L. digitata* during the preoperational period and primarily *L. saccharina* during the operational period. Juvenile blue mussels completed the major habitat forming species in the shallow subtidal zone, averaging 2,580 per m^2 during the preoperational period and 1,654 per m^2 during the operational period at Station B17 (NAI 2000).

There was no significant change between the preoperational and operational periods in the understory species in the shallow subtidal zone. Biomass of *Chondrus crispus* and percent frequency of *Phyllophora/Coccotylus* was not significantly different between periods (Table IV-2, NAI 2000). Abundance of Mytilidae, the dominant habitat forming macrofaunal species, was also not significantly different between preoperational and operational periods. Among the canopy species, the overall trend at the nearfield station was a decrease in kelp numbers between preoperational and operational periods. However, the difference was statistically significant only for *Laminaria digitata*, which showed a difference that was not similar between stations (Table IV-2). Numbers of *L. digitata* decreased at both stations, but the decrease was greater at the nearfield station B17 (Figure IV-4). *L. digitata* decreased from 213.9 per 100 m^2 during the preoperational period to 28.6 per 100 m^2 during the operational period at Station B17. At Station B35, average number of individuals decreased from the preoperational (155.8 per 100 m^2) to the operational (104.5 per 100 m^2) periods. Despite the decrease in numbers, percent cover has remained relatively stable and low throughout the study period, less than 20% at the nearfield station (Figure IV-5). Numbers of *L. saccarhina* decreased from 415.1 per 100 m^2 during the preoperational period to 254.9 per 100 m^2 at Station B17 during the operational period. This species increased slightly at Station B35 between preoperational (325.7 per 100 m^2) and operational (372.5 per 100 m^2) periods. These differences were not statistically significant.

Numerical classification analysis suggested that the shallow subtidal macroalgal understory community differed between stations, but was similar throughout the study period (NAI 2000). The macrofaunal species assemblage was highly similar between preoperational and operational periods. These results suggest that although the number of kelps decreased at shallow subtidal depths, especially at the nearfield station, there were no effects on the understory algae or macrofaunal community.

Mid-Depth Zone

The mid-depth zone is characterized by the reduction in algal cover and concomitant decrease in macrofauna, compared to shallower depth zones. The understory is composed primarily of *Phyllophora/Coccotylus* (180.6 g/m^2, 31-34% frequency of occurrence at the nearfield station), with an overstory of kelps (NAI 2000). *Agarum clathratum* is the most abundant kelp species (786.6 per 100 m^2 preoperationally, 1036.6 per 100 m^2 operationally), along with *Laminaria digitata* and *L. saccharina*. Juvenile blue mussels continue to be the most abundant macrofaunal species, averaging 1,947 per m^2 at the nearfield station B19 during the preoperational period and 1,420 per m^2 during the operational period. The macroalgae and macrofaunal communities differed between nearfield and farfield stations, as demonstrated by community analysis. This is likely a result of the depth differences (12.2 m at Nearfield Station B19; 9.4 m at Farfield Station B31), in combination with substrate differences. The nearfield station is composed of rock outcrop, while the farfield station is approximately half rock outcrop and half sand and gravel (NAI 2000).

The operation of Seabrook Station appeared to have no effect on understory and macrofauna habitat formers. Biomass and percent frequency of dominant macroalgae *Phyllophora/Coccotylus* were similar between preoperational and operational periods at the nearfield station, although not statistically tested (NAI 2000). The dominant macrofaunal organism and important habitat former Mytilidae showed no significant differences in abundance during the operational period. Numerical classification results confirm that the understory algae and macrofaunal community was similar between preoperational and operational periods at the nearfield stations. This provides further evidence that primary habitat formers were not affected by the operation of Seabrook Station.

Changes in the nearfield kelp community occurred during the operational period. Numbers of *Laminaria digitata* showed a significant decrease at both stations during the operational period, but the decrease was greatest at the nearfield station (Table IV-2, Figure IV-6). Percent cover paralleled the decrease in numbers. Percent cover was less than 20% at the nearfield station (B19) during most of the preoperational period, and decreased to less than 5% during the operational period (Figure IV-5). This species may be at its physiological limit at this station, because of the increased depth and higher turbidity compared to the farfield station (NAI 2000). Competition with dominant kelp species *Agarum clathratum* may also be a contributing factor (Figure IV-7). Densities of both species at the nearfield station were similar in 1978, the beginning of the study period. Numbers of *A. clathratum* increased during the preoperational period until a decline in 1988-1991, which was experienced by both species. Numbers of *A. clathratum* recovered, but numbers of *L. digitata* have remained low.

Dominance by *Agarum clathratum* may have impaired *Laminaria digitata* recruitment and recovery. At the farfield station, *A. clathratum* has historically been a co-dominant with *L. digitata* (Figure IV-7). The decline in *L. digitata* during the operational period coupled with the increase in *A. clathratum* at the farfield station loosely parallels the trend at the nearfield station, but is much less extreme. Two other kelp species in the mid-depth zone were both an order of magnitude less abundant that the dominants. *L. saccharina* numbers at the nearfield station decreased during the operational period from 59.1 per 100 m^2 to 4.8 per 100 m^2 (NAI 2000). Numbers at the farfield station remained essentially the same (94-95 per 100 m^2). *Alaria esculenta* was relatively rare at the nearfield station, less than 8 per 100 m^2. Neither species showed a significant change in density between the preoperational and operational periods (NAI 2000).

BIOLOGICAL HABITAT REQUIREMENTS OF EFH DESIGNATED SPECIES

The habitat requirements of the EFH designated species are described in a series of NOAA Technical Memorandums entitled Essential Fish Habitat Source Documents. These documents provide the best available description of the habitat requirements of the fishes with management plans, based on the current scientific literature. However, they should not be viewed as definitive because much more work is needed in describing the habitat requirements of fishes. The biological habitat, meaning that habitat provided by habitat-forming organisms such as macroalgae, is not well described in the scientific literature for all fishes. The Essential Fish Habitat Source Documents provide good descriptions of the physico-chemical habitat requirements such as water temperature, salinity, depth, and substrate characteristics. However, the current state of knowledge does not allow accurate descriptions of the biological habitat requirements. Descriptions of the biological habitat requirements are lacking for several of the EFH species including American plaice, Atlantic halibut, Atlantic mackerel, Atlantic surf clam, bluefin tuna, butterfish, haddock, northern shortfin squid, ocean pout, pollock, redfish spp., silver hake, windowpane, and yellowtail flounder.

This section summarizes the known biological habitat descriptions of the EFH species and relate it to the habitats that occur near the intake and discharge structures (nearfield area) of Seabrook Station. The focus will be on the juvenile and adult stages because the eggs and larval stages are usually pelagic, and not influenced by benthic biological habitat. Although the biological habitat is not well described for several of the EFH species, any plant action that decreases the habitat diversity or complexity can be assumed to decrease the habitat value of the nearfield area.

Atlantic cod

Atlantic cod juveniles often recruit to nearshore areas where they use seagrass beds for shelter from predators (Fahay et al. 1999; Suthers and Frank 1989). Specifically, eelgrass beds (*Zostera marina*) have been cited as important habitat for juvenile Atlantic cod (Gotceitas et al. 1997). Survival of juvenile cod was found to be higher in structurally complex habitats and growth was highest in eelgrass beds (Tupper and Boutilier 1995). Emergent epifauna was found to significantly decrease predation mortality of age-0 Atlantic cod (Lindholm et al. 1999).

Eelgrass is specifically cited as important habitat for juvenile Atlantic cod. No eelgrass is found in the nearfield area of the Seabrook Station intakes because the depths (12-18 m) are too great. Although not specifically cited in the scientific literature, it is reasonable to expect that the complex structure afforded by benthic macroalgae could provide shelter for juvenile Atlantic cod. There have been changes in the community composition of the macroalgal community, especially in the mid-depth zones. Density of *Laminaria digitata* has decreased in the operational period, but it appears that is has been replaced by *Agarum clathratum* which would provide similar habitat to fishes.

Atlantic herring

Atlantic herring are pelagic fishes found primarily in the water column as juveniles and adults. Juvenile Atlantic herring recruit to nearshore areas and estuaries in the early spring. There appears to be no documented association between juvenile or adult Atlantic herring occurrence and biological habitat. The success of Atlantic herring recruitment appears to be associated with various physical factors, including sea surface temperature, residual surface currents, or atmospheric-pressure gradients (Lazzari et al. 1997). Eggs of Atlantic herring can be deposited on macrophytes; however the intake and discharge area is not near any known Atlantic herring spawning area (Reid et al. 1999).

Atlantic sea scallop

Survival of newly settled Atlantic sea scallop appears to be higher in complex habitats that include sedentary branching animals and plants, and other hard surfaces (Packer et al. 1999b). Sea scallops have been cited as settling on the red alga *Rhodomela conferroides,* the hydroid *Hydrallmania,* and on amphipod tubes. During the second growing season, sea scallops may leave the original settlement surface and attach themselves to shells and bottom debris.

There are various amounts of data available from the monitoring program regarding *Rhodomela conferroides*, *Ampithoe rubricata*, and *Hydrallmania. R. conferroides* has occurred in the study area every year since 1979. Although there have been no specific analyses to document changes in the abundance of *R. conferroides*, it does not appear to be especially abundant as it is not a dominant species in any depth zone (NAI 2000). The tube building amphipod *Amipthoe rubricata* has significantly increased in abundance in the operational period in the nearfield intertidal zone. However, in 1999 abundance increased greatly at the farfield station and densities were almost identical between the two stations. No information is available from the monitoring program on the abundance of *Hydrallmania.*

Goosefish

Adult goosefish are ambush predators that spend most of their time resting on the bottom in a depression or partially covered in sediment (Steimle et al. 1999a). Although biological habitat requirements are not specifically documented, it would be expected that a complex habitat with opportunity for camouflage would be preferable. The lack of a documented impact on the subtidal community in the nearfield area is an indication that goosefish biological habitat has not been affected by plant operation.

Longfin inshore squid

The juvenile and adult stages of longfin inshore squid are primarily pelagic (Cargnelli et al. 1999e) and do not appear to be associated with any particular biological habitat. The eggs of longfin inshore squid are found attached to small boulders on sandy and muddy bottoms, and attached to aquatic vegetation such as *Fucus* sp., *Ulva lactuca*, *Laminaria* sp., and *Porphyra* sp. (Cargnelli et al. 1999e). Eggs are usually deposited in depths greater than 50 m, which is deeper than the 12-18 m depths of the intake and discharge area.

Red hake

Juvenile red hake become demersal at lengths of about 35-40 mm (Steimle et al. 1999c). Shelter is critical at this stage and newly settled red hake are often found in depressions. Older juvenile red hake commonly are found with living Atlantic sea scallops where they can be found under the scallops or within the mantle cavity (Steimle et al. 1999c). Juvenile red hake can continue to use the adult sea scallops as shelter until the red hake are 10-13 cm TL. Atlantic sea scallop therefore could be considered a habitat-forming organism for juvenile red hake.

Population levels of adult Atlantic sea scallop are not assessed through the Seabrook Station Environmental Monitoring Program. However, the nearfield area does not appear to support large populations of adult Atlantic sea scallop and may not be good habitat for juvenile red hake. Adult sea scallops are usually found on coarse substrate, usually gravel, shells, and rock. Although the substrate in the vicinity of the intakes and discharges consists of sand, cobbled substrate, and hard substrate (NAI 1977), diver observations from the preoperational through the operational period indicates that sea scallops are not common in the nearfield area. Plant operation does not appear to have affected juvenile red hake habitat (sea scallops) because sea scallops were not numerous in the nearfield area in either the preoperational or operational periods.

Summer flounder

Summer flounder are rare in the study area, occurring in less than 1% of otter trawl samples. Most of the data regarding the biological habitat of summer flounder are from areas to the south of New Hampshire. Juvenile summer flounder were captured near stands of *Agardhiella tenera* when grass shrimp were also present (Packer et al. 1999a). *A. tenera* has not been collected during the monitoring program. There is evidence that summer flounder prefer the edge habitat between open areas and stands of eelgrass or macroalgae. Summer flounder may use these areas to avoid predation and conceal themselves from prey.

Summer flounder are so rare in the study area that any changes in occurrence due to plant operation are not likely to be detected. The nearfield area is too deep to support eelgrass and the macroalgae community has not shown any changes that can be attributed to plant operation.

Scup

Scup are not common in the study area occurring in less than 10% of otter trawl samples, primarily in the late summer and fall. Scup are most common in the mid-Atlantic Bight (Steimle et al. 1999d). Juvenile scup recruit to nearshore and estuarine areas and have been collected in a variety of habitats including eelgrass beds. It is not likely that plant operation has affected scup biological habitat because scup are so rare in the study area, and the nearfield area is too deep to support eelgrass beds.

Winter flounder

Winter flounder use a variety of habitats throughout their life cycle. The demersal and adhesive eggs can be deposited on several types of substrate including macroalgae, although most eggs are deposited on gravel substrate (Crawford and Carey 1985). Juvenile winter flounder were found in a variety of habitats including macroalgae (*Ulva*), eelgrass, and adjacent unvegetated areas (Pereira et al. 1999). However, habitat use by juvenile winter flounder appears to be very variable among systems and from year to year (Pereira et al. 1999).

The potential winter flounder biological habitat found in the nearfield area is macroalgae. There has been no detectable impact on macroalgae in the nearfield area due to plant operation.

DISCUSSION

In general, species traditionally thought of as habitat forming species have shown little change at the nearfield station between the preoperational and operational period. Dominant understory algal species and juvenile blue mussels, which cover rock ledge in intertidal, shallow subtidal and mid-depth zones, have not shown a significant difference in abundance or biomass between periods. These species probably provide cover for juvenile life stages of EFH species and food, cover, and habitat for their prey species. Changes in overstory or canopy species, which may provide a refuge for juvenile life stages of EFH species, were observed throughout the study area. In the intertidal zone, *Ascophyllum nodosum* increased significantly at the nearfield station without a corresponding increase at the farfield station. The time series of both stations shows parallel trends, with no evidence of a plant effect. Numbers of *Fucus vesiculosus* decreased significantly at the nearfield station, with no significant decrease between periods at the farfield station. The time series for this species show a decrease at both stations that began prior to plant operation (preoperational period). Fucoids in the intertidal zone continue to provide a dense cover, regardless of the species. The community of understory macroalgae and macrofauna has not shown a change during the operational period, suggesting that changes in the fucoids have not affected other elements of the community.

The canopy and understory structure provided by kelps to the EFH species has been the same throughout the study period, despite a possible change in species composition. Numbers of the subdominant kelp *Laminaria digitata* decreased significantly in the shallow subtidal and mid-depth zones; however, decreases were greater at the nearfield station. The reasons for the decline are unclear, but factors such as grazing pressure by the green sea urchin *Strongylocentrotus droebachiensis*, fouling by the bryozoan *Membranipora membranacea* and a regional increase in water temperature are potential contributing factors. Nearfield-farfield station differences, especially the increased depth and increased turbidity (due to proximity to the tidal discharge from Hampton Harbor) at mid-depth Station B19, may have placed *L. digitata* at a competitive disadvantage to *Agarum clathratum*. In terms of fish habitat, there is probably little difference between these two kelp species as both can provide cover and structure for both predators and prey species. This change may have created a different microhabitat. However, understory algae and macrofaunal community composition has remained similar throughout the study period.

In terms of habitat for the EFH species, the intertidal, shallow subtidal and mid-depth hard substrate communities continue to provide structure and habitat for the EFH species, even though the composition of the benthic communities may have changed with time.

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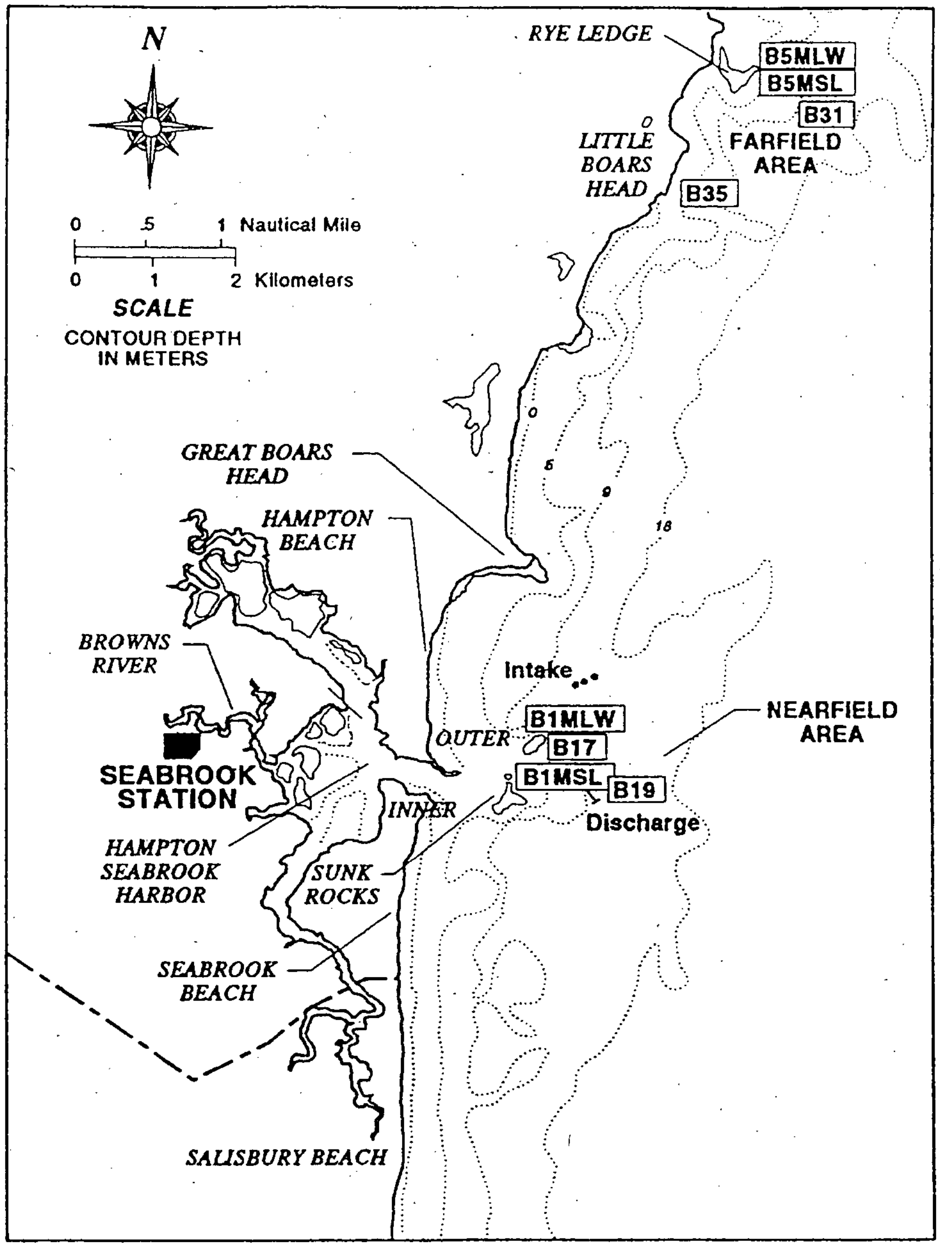


LEDGEND

☐ = benthic samples

Figure IV-1. Marine benthic sampling stations.

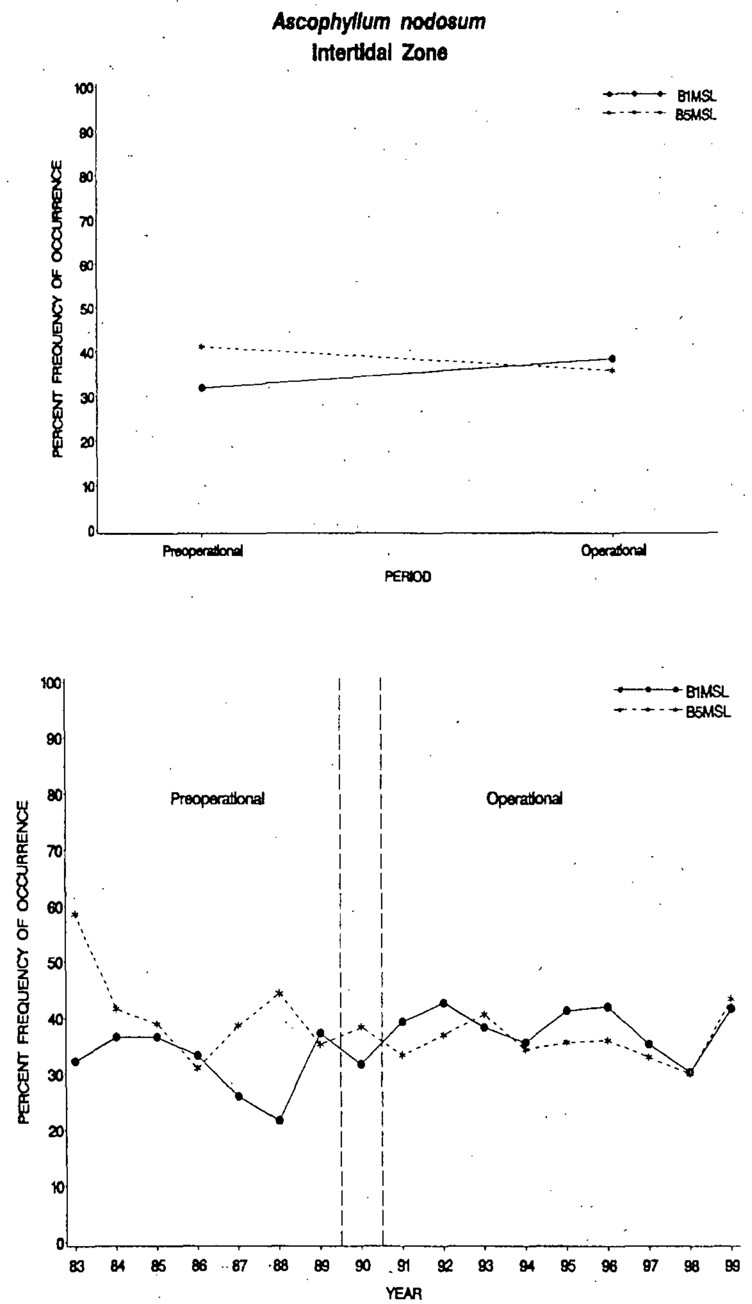
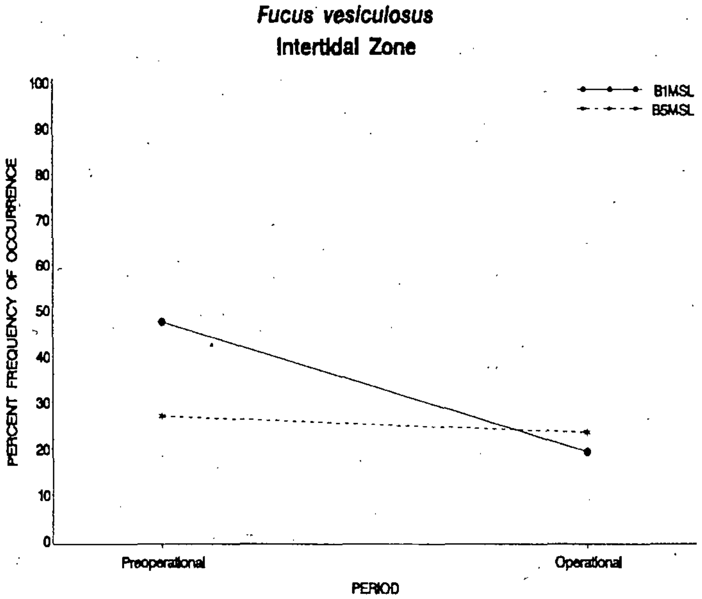


Figure IV-2. Comparison between stations of annual mean percent frequency of occurrence of the fucoid *Ascophyllum nodosum* in the intertidal zone during the preoperational (1983-1989) and operational (1991-1999) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean percent frequency of occurrence each year (data between the two vertical dashed lines were excluded from the ANOVA model).



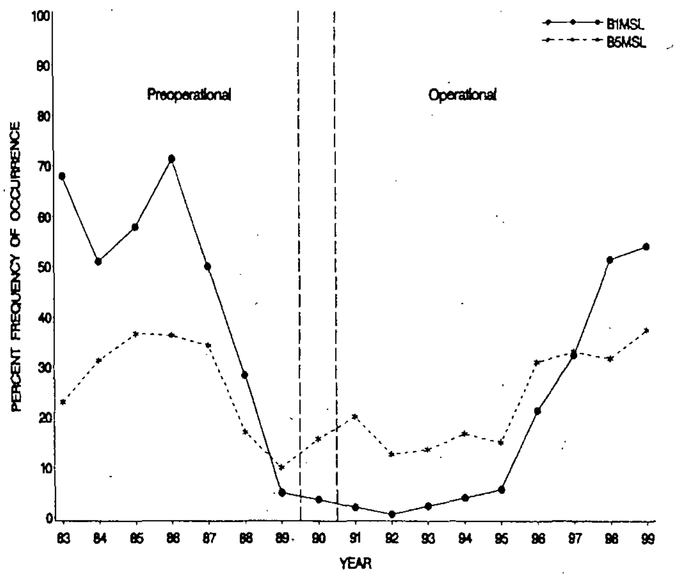
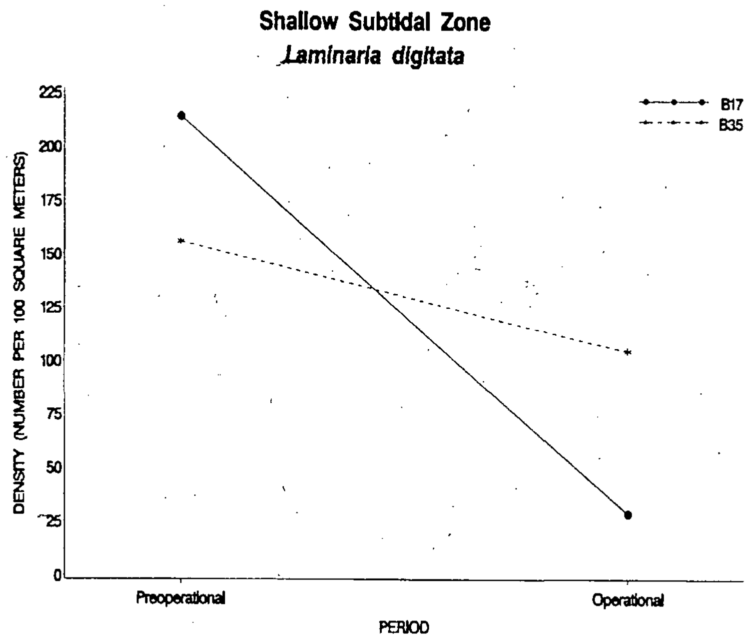


Figure IV-3. Comparison between stations of annual mean percent frequency of occurrence of the fucoid *Fucus vesiculosus* in the intertidal zone during the preoperational (1983-1989) and operational (1991-1999) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean percent frequency of occurrence each year (data between the two vertical dashed lines were excluded from the ANOVA model).



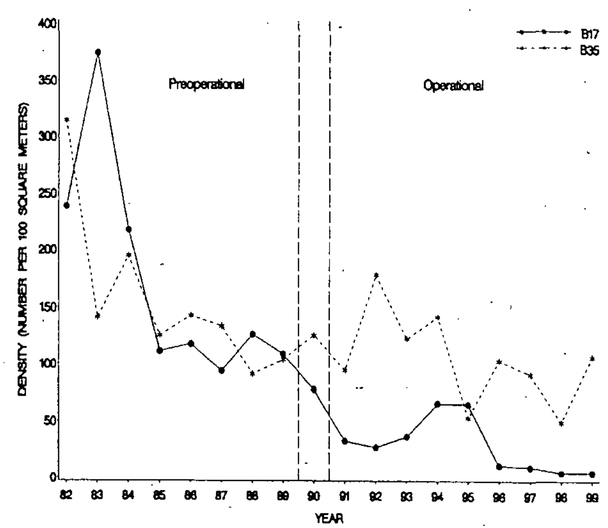
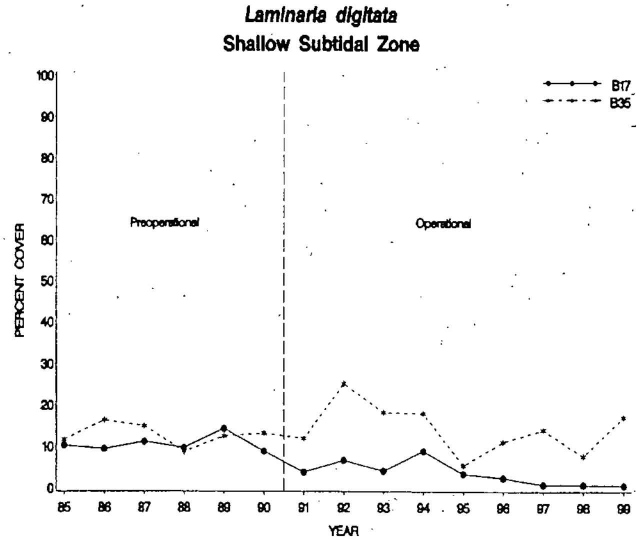


Figure IV-4. Comparison between stations of number of holdfasts/100 m^2 of the kelp Laminaria digitata in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-1999) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year (data between the two vertical dashed lines were excluded from the ANOVA model).



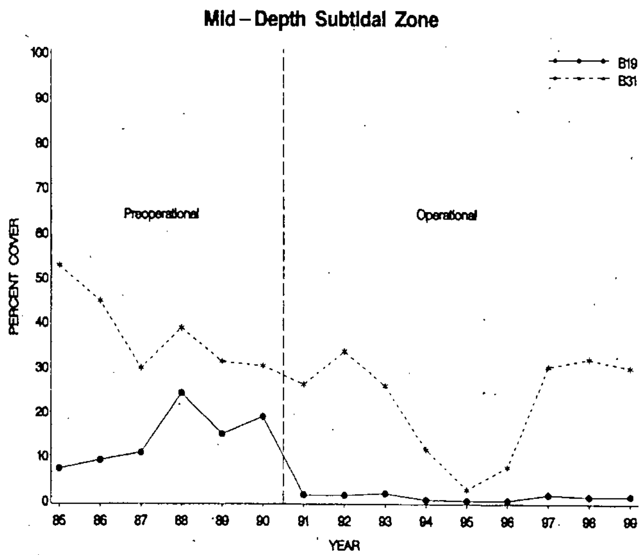
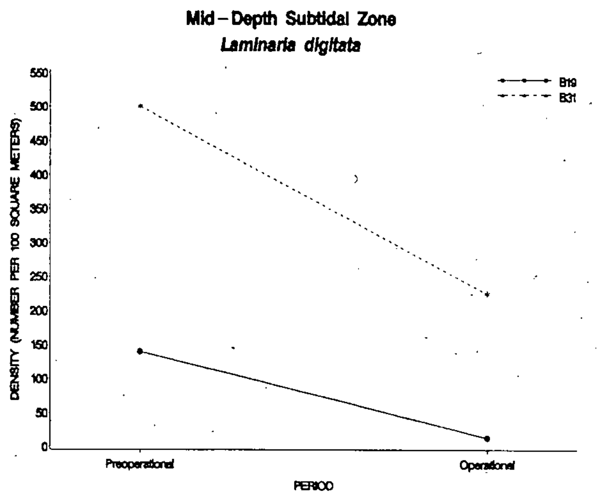


Figure IV-5. Annual mean percent cover of *Laminaria digitata* in the shallow and mid-depth subtidal zones, 1985-1999.



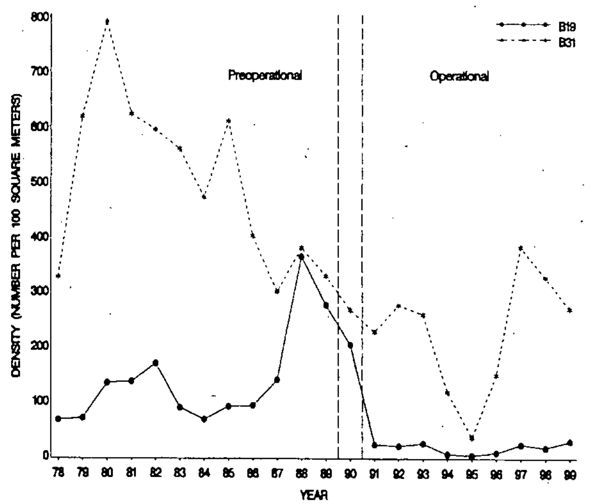
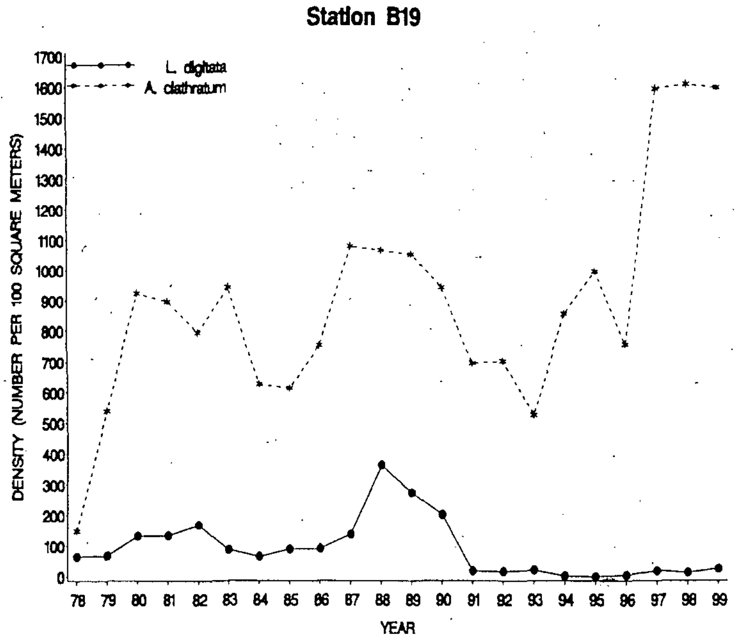


Figure IV-6. Comparison between stations of number of holdfasts/100 m^2 of the kelp *Laminaria digitata* in the mid-depth subtidal zone during the preoperational (1978-1989) and operational (1991-1999) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year (data between the two vertical dashed lines were excluded from the ANOVA model).



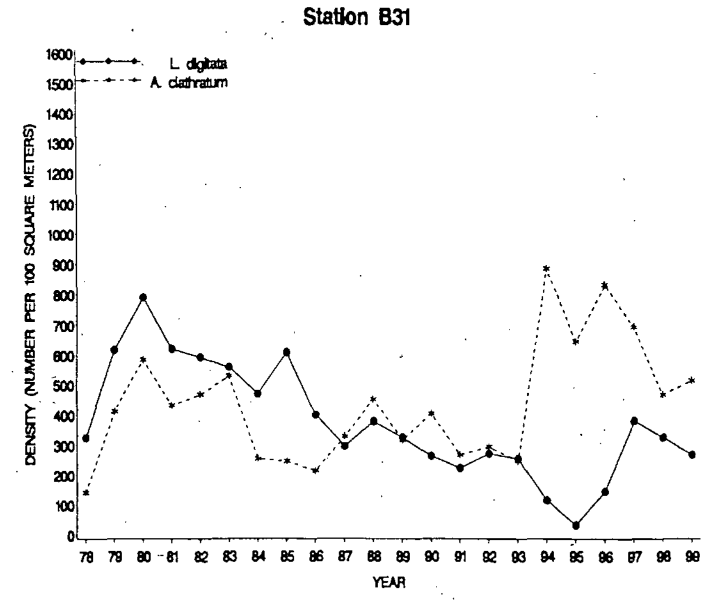


Figure IV-7. Annual mean densities (number per 100 m^2) of *Laminaria digitata* and *Agarum clathratum* in the mid-depth subtidal zone (Stations B19 and B31), 1978-1999.

Table IV-1. Habitat forming macrobenthic species in the intertidal, shallow subtidal, and mid-depth zones.

Depth Zone (Station)	Species	Type	Common name
Intertidal (1MLW)	*Ascophyllum nodosum*	Brown algae	Knotted wrack
	Fucus vesiculosus	Brown algae	Rockweed
	Chondrus crispus	Red algae	Irish moss
	Mastocarpus stellatus	Red algae	Red weed
	Mytilidae	Bivalve	Juvenile blue mussel
Shallow subtidal (17)	*Chondrus crispus*	Red algae	Irish moss
	Phyllophora/Coccotylus	Red algae	Red leaf weed
	Laminaria saccharina	Brown algae	Kelp
	Laminaria digitata	Brown algae	Horsetail Kelp
	Mytilidae	Bivalve	Juvenile blue mussel
Mid-depth (19)	*Phyllophora/Coccotylus*	Red algae	Red leaf weed
	Laminaria digitata	Brown algae	Horsetail Kelp
	Agarum clathratum	Brown algae	Sea colander
	Mytilidae	Bivalve	Juvenile blue mussel

Table IV-2. Summary of potential effects on habitat-forming organisms.

Depth Zone	Species	Parameter	Operational and Preoperational Periods Similar	Nearfield-Farfield differences consistent between periods?
Intertidal	*Ascophyllum nodosum*	Percent frequency	No	Nearfield: Op>Preop Farfield: Op=Preop
	Fucus vesiculosus	Percent frequency	No	Nearfield: Op<Preop Farfield: Op=Preop
	Chondrus crispus	Biomass, Percent frequency	Yes	Yes
	Mastocarpus stellatus	Percent frequency	Yes*	Yes*
	Mytilidae	Density	Yes	Yes
Shallow subtidal	*Chondrus crispus*	Biomass	Yes	Yes
	Phyllophora/Coccotylus	Percent frequency	Yes	Yes
	Laminaria saccharina	Number of plants	Yes	Yes
	Laminaria digitata	Number of plants	No	Nearfield: Op<<Preop Farfield: Op<Preop
	Mytilidae	Density	Yes	Yes
Mid-depth	*Phyllophora/Coccotylus*	Percent frequency	Yes *	Yes*
	Laminaria saccharina	Number of plants	Yes	Yes
	Laminaria digitata	Number of plants	No	Nearfield: Op < <Preop Farfield: Op < Preop
	Agarum clathratum	Number of plants	Yes	Yes
	Mytilidae	Density	Yes	Yes

* Qualitative results only; not tested statistically