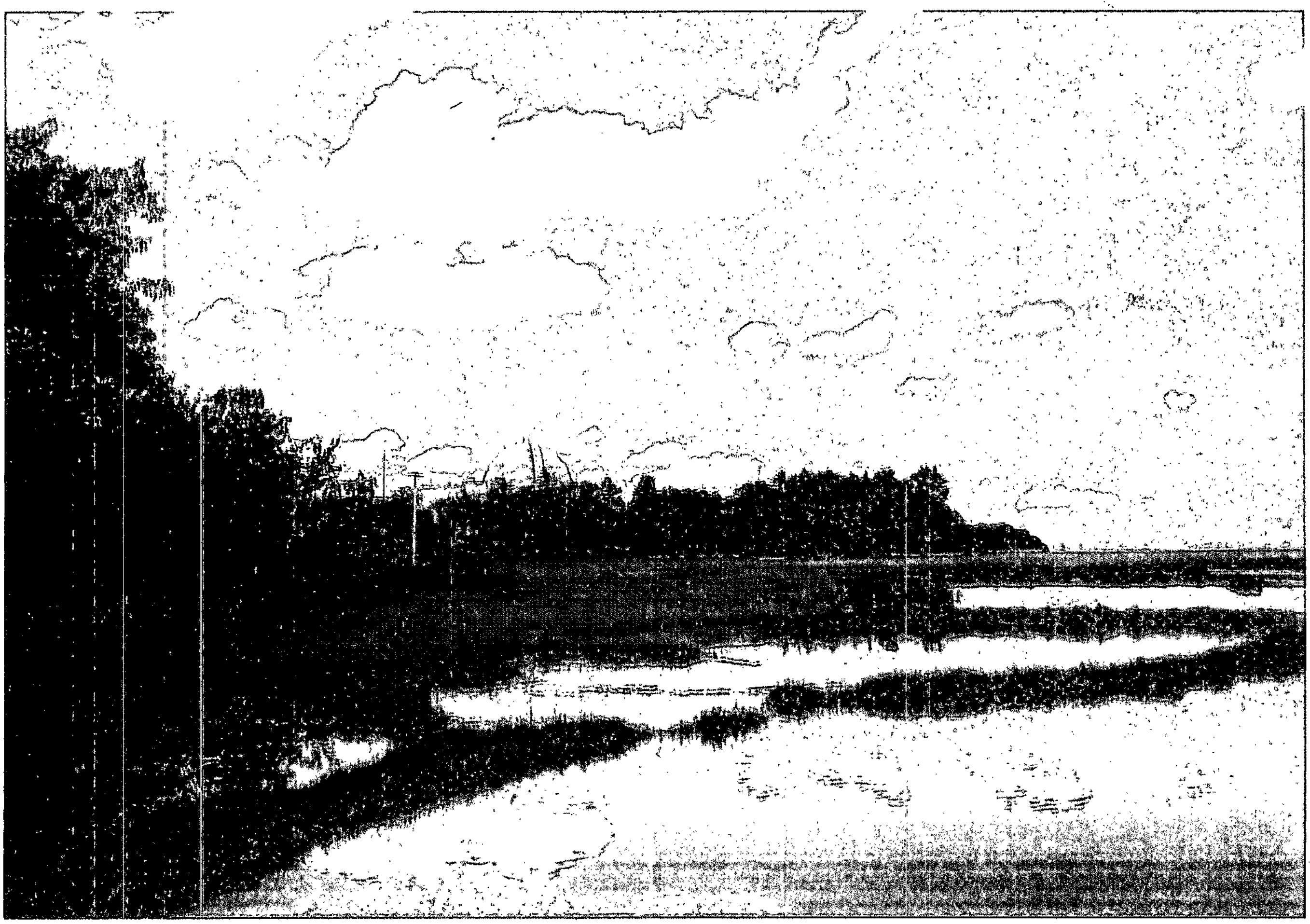
Seabrook Station 2007 Environmental Monitoring in the Hampton - Seabrook Area



A Characterization of Environmental Conditions

FPL Energy
Seabrook Station

SEABROOK STATION
2007 ENVIRONMENTAL MONITORING
IN THE HAMPTON-SEABROOK AREA
A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS

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1.1 APPROACH

Environmental monitoring studies were conducted to determine whether Seabrook Station, which became operational in August of 1990, affected the "Balanced Indigenous Populations of Fish, Shellfish and Wildlife" in the nearfield coastal waters of New Hampshire. An Environmental 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 show this to be true for thermal effects. 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 (when present). 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 Monitoring Program has focused on the major source of variability in each community type and then determined the 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, and size are important for understanding operational impact, if any, should changes occur in these parameters between stations or over time. These parameters were monitored for selected species from each community type. Selected species were chosen for more intensive study based on either their commercial or numerical importance, sensitivity to temperature, potential as a nuisance organism, or habitat preference. Overall community structure of the biota, e.g., the number and type of species, total abundance and the dominance structure, was also reviewed to determine potential plant impact. Trends in these parameters were reviewed against the natural variation in community structure.

A previous Summary Report (NAI 1977) concluded that the balanced indigenous community in the Seabrook study area should not be adversely influenced by loss of individuals

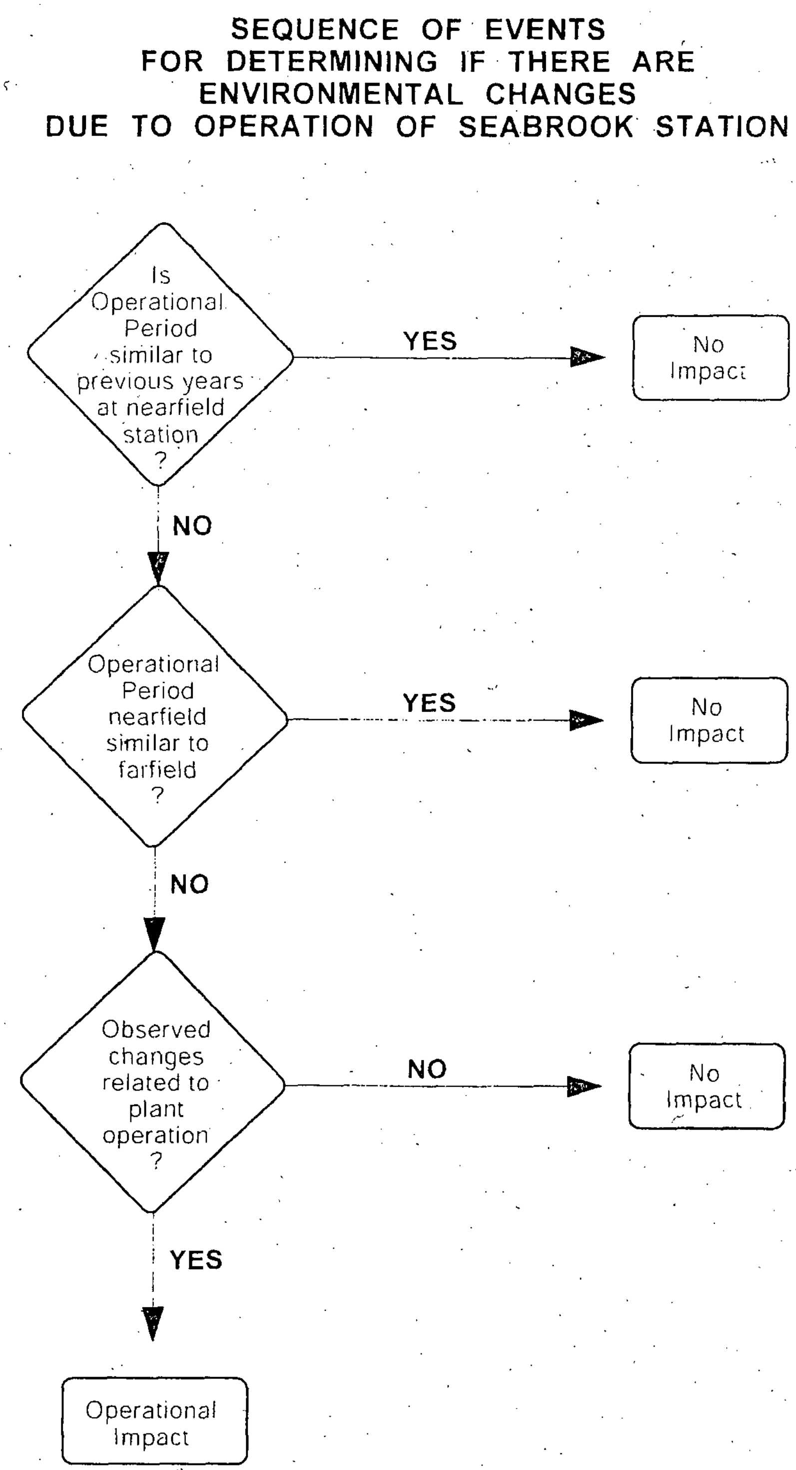

Figure 1-1. Sequence of events for determining if there are environmental changes due to the operation of Seabrook Station. Seabrook Operational Report, 2007.

Table 1-1. Summary of Biological Communities and Taxa Monitored for Each Potential Impact Type. Seabrook Operational Report, 2007.

Monitoring Area	Impact Type	Sample Type	Level Monitored: Community	Level Monitored: Selected Species/ Parameters
Intake	Entrainment	Microzooplankton	*	*
		Macrozooplankton	x	x
		Fish eggs	x	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
		Seals		*
Discharge	Thermal Plume	Nearshore water quality		x
		Phytoplankton	*	*
		Lobster larvae		x
		Intertidal macroalgae and macrofauna	*	*
		Shallow subtidal macroalgae and macrofauna	x	x
		Surface fouling community	*	*
	Turbidity (Detrital Rain)	Mid-depth macrofauna and macroalgae	x	x
		Deep macrofauna and macroalgae	*	*
		Demersal fish	x	x
		Bottom fouling community		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

x denotes current program
* denotes completed program

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 near 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 either the nearfield or farfield areas, and that the balanced indigenous populations have not been affected. Analysis of variance (ANOVA) was an important statistical method used in the Seabrook Environmental 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 Environmental Monitoring Program, the Before and After terms are represented by data collected during the preoperational and operational 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 between the preoperational and operational periods that were 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:

- Is there a mechanism for a potential plant impact?
- What species (in community analyses) are responsible for the observed change?
- Did the change begin before the initiation of plant operation, or is it possibly part of a long-term trend?
- Is the change possibly caused by an unrelated environmental variable?
- What is reported in the recent literature or by investigators in the region?

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. In 2005, the MIXED procedure (SAS Institute Inc. 1999) was used for the first time for the mixed model ANOVA. Comparisons between the MIXED procedure and the previous mixed model (based on the GLM procedure of SAS) are presented in Appendix A of this report. The MIXED procedure differs from the GLM procedure in many ways that are more appropriate for mixed model analysis. The GLM procedure was originally designed as a fixed effects method and the RANDOM statement and TEST option were added to accommodate random effects (Littell et al. 1996, SAS Institute 1999, SAS Institute 2004). In contrast, the MIXED procedure was designed from the beginning to incorporate variance-covariance matrix due to random effects in the inference tests, compute correct standard errors and use more appropriate approximations for denominator degrees of freedom, particularly for unbalanced data (SAS Institute 2004, Spilke et al. 2005).

Results of further investigations of significant differences in community composition or a single species' abundance, density or biomass are developed by the section author, 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 FPL Energy Seabrook and the Ecological Advisory Committee.

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.

Seabrook Station began commercial operation in August 1990 and has operated with an overall (lifetime) capacity factor of 85.8 percent through December 2007 inclusive of refueling outages and other unscheduled outages. For a 31 month period between January 1988 and July 1990, the cooling water system operated at less than half capacity. For this period, the cooling water system operated an average of 27 days per month with an average discharge of 290 MGD and an average temperature rise across the condensers of 1.44 °F. As a base load power plant, Seabrook Station normally operates at 100 percent capacity. Scheduled refueling outages are conducted about every 18 months. Seabrook Station operated with a capacity factor of 98.9 percent during 2007. There was no refueling outage in 2007. Monthly flow rates of the Circulating Water System are provided for the period 1990-2007 in Table 1-2.

A review of the entire program in 1996 resulted in revision of a number of the program elements, which were approved by

Table 1-2. Monthly Flow Characteristics of Seabrook Station Circulating Water System for the Period 1990 Through 2007. Seabrook Operational Report, 2007.

	Average Daily Flow (mgd)																	
Month	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Jan	324	584	585	587	566	576	570	578	635	569	591	288	591	568	567	565	640	637
Feb	564	580	578	587	589	572	507	565	566	567	566	576	574	568	575	572	633	608
Mar	563	580	581	580	573	572	573	571	571	529	588	461	590	567	569	568	616	607
Apr	563	581	576	579	352	573	577	572	580	116	645	574	603	590	572	178	650	615
May	562	581	581	582	188	625	637	345	689	522	668	587	281	647	620	638	663	643
Jun	563	578	593	582	171	662	686	235	417	665	677	679	675	683	656	671	665	668
Jul	582	535	593	578	331	685	689	662	572	679	681	673	691	684	671	671	664	669
Aug	588	253	583	579	681	687	691	674	678	682	682	683	692	687	676	672	660	669
Sep	588	257	314	574	696	686	691	672	682	682	679	681	691	688	679	670	656	668
Oct	590	552	159	574	690	685	678	673	682	680	524	679	658	321	677	669	151	645
Nov	590	590	566	612	692	287	647	666	568	656	60	675	682	655	650	670	539	663
Dec	589	591	563	608	628	486	599	668	602	612	231	675	608	603	606	667	669	626

the Technical and Ecological Advisory Committees. The entrainment and impingement programs were enhanced, and continue to be evaluated, to improve the quality of the data.

Some of the programs had sufficient data to eliminate concerns over the potential for impact, or the variability within the community studied was so high a plant impact was unlikely to ever be detected, or other monitoring programs provided sufficient data to monitor the community in question. These programs included nutrients, phytoplankton, microzooplankton, pelagic fish (gill net sampling program), surface fouling panels, macrobenthos at the deep stations, and macrobenthos at the intertidal stations, and were eliminated. In addition, it was determined that data from the discharge station, P5, were too distant from the discharge to reflect potential effects, and furthermore were essentially the same as data collected from the Intake Station, P2. Collections ceased at Station P5 in 1998.

1.3 SUMMARY OF FINDINGS

Water Quality

Water quality parameters were collected to aid in interpreting information obtained from the Environmental 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, and dissolved oxygen. Potential impacts to water quality related to the operation of Seabrook Station include: (1) temperature changes resulting from the discharge of heated cooling water from the Station condensers, and (2) the discharge of chlorine (sodium hypochlorite) used to prevent biofouling and (3), changes related to the addition of dead entrained plankton to the nearshore marine environment (detrital rain).

The regional weather in the vicinity of coastal New Hampshire in 2007 was nearly normal for annual air temperature and drier than average. Total precipitation in 2007 was 7.8 cm below average with drier-than-normal conditions prevailing from August through November. The average 2007 surface water temperatures at the nearfield (9.4°C) and farfield stations (9.3°C) were higher than the preoperational (nearfield 8.9°C; farfield 8.7°C) but, lower than the nearfield operational period (9.5°C) and equal to the farfield operational (9.3°C) period means. Seasonal patterns for surface water temperature in 2007 were similar to previous years. Annual mean bottom water temperatures in 2007 (nearfield 6.8°C; farfield 6.8°C) decreased from the 2006 averages and were cooler than the preoperational nearfield mean (7.0°C) and equal to farfield average (6.8°C). The 2007 mean bottom temperatures at both stations were below the operational (nearfield 7.4°C; farfield 7.3°C) means. There were no significant differences in surface or bottom water temperatures between periods or stations. The consistency between periods and stations indicated that the operation of Seabrook Station has not significantly affected surface or bottom water temperatures in the study area. During the two and a half-decade study period, the rise in surface temperature between the preoperational and operational periods has been 0.6°C at both stations, while the bottom temperature rose 0.4°C at the nearfield station and 0.5°C at the farfield station. Continuous temperature monitoring at the discharge (DS) and farfield (T7) stations showed monthly mean temperature differences of at most 1.87°C in 2007, consistent with previous years and within NPDES permit conditions. The discharge station was slightly cooler than the farfield station in June through August, due to entrainment of cooler bottom water.

During Seabrook Station's April 2005 refueling outage, plant modifications were completed resulting in an increased level of electrical generation of about 60 megawatts and an increase in heat injected to the ocean. A second phase of the uprate was completed in the November 2006 refueling outage when electrical output was increased by an additional 40 megawatts for a total uprate of about 100 megawatts electric. The ocean thermal monitoring data for 2007 indicated that Seabrook Station operated well within the NPDES Permit thermal limit with the 100 megawatt electric uprate.

Annual mean surface water salinities in 2007 (nearfield and farfield 31.2 PSU) were lower than the preoperational (nearfield 31.6 PSU; farfield 31.5 PSU) means, but equal to the operational (nearfield and farfield 31.2 PSU) means. Bottom salinity levels in 2007 (nearfield 31.9 PSU; farfield 32.0 PSU) were lower than the preoperational (nearfield and farfield 32.2 PSU) means and comparable to the operational (nearfield 31.8 PSU; farfield 31.9 PSU) means. The precipitation in 2007 was 7.8 cm below the average, so other regional factors may be contributing to the lower 2007 mean salinities when compared to the preoperational means. There were no significant differences between stations or periods for surface or bottom salinity, and the relationships between period and station were consistent. The 2007 surface and bottom salinities were very similar to the operational averages.

Annual mean surface DO levels in 2007 (nearfield 10.1 mg/l; farfield 10.0 mg/l) were higher than the preoperational (nearfield and farfield 9.7 mg/l) and operational (nearfield and farfield 9.8 mg/l) means. Bottom DO levels in 2007 (nearfield 9.6 mg/l; farfield 9.4 mg/l) were also higher than the preoperational (nearfield 9.2 mg/l; farfield 9.1 mg/l) and operational means (nearfield and farfield 9.0 mg/l). Bottom DO levels in 2007 increased from the lows of the previous year. There were no significant differences between periods or stations for surface or bottom DO, and the relationships between period and station were consistent. Surface and bottom dissolved oxygen (DO) concentrations in 2007 exhibited a seasonal pattern that was similar to previous years, and the monthly means were usually within or above the preoperational confidence limits. Surface and bottom DO levels increased from the lows of the previous year, when mean monthly levels were often below the 95% confidence limit of the preoperational mean.

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

Zooplankton

Two elements of the zooplankton community, umbonate bivalve larvae and macrozooplankton, were sampled separately to identify spatial and temporal trends at both the community and species level. Initial monitoring characterized the magnitude of preoperational 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.

Large-scale multi-year trends were observed in the bivalve larvae assemblage. In general, abundances were low during the mid 1980s when the assemblage was dominated by *Mytilus edulis* and *Hiatella* sp. Abundance increased substantially in the mid to late 1990s, as *Anomia squamula* also became a dominant species. Larval densities dropped to low levels in 2003 and 2004. In recent years, 2005 to 2007, *Hiatella* sp. and *Mytilus edulis* abundances were similar to the preoperational period, but *Anomia squamula* densities were much greater and it was the sole dominant species in the bivalve larvae assemblage. In contrast to the large temporal trends, differences between the stations were small. Total bivalve larvae abundances in the nearfield and farfield areas followed almost identical trends. Individual species abundances in the operational period demonstrate a high level of similarity between stations and an almost identical community composition. The trends described above occurred simultaneously at both stations.

Mytilus edulis was the selected species of the bivalve larvae assemblage. Average densities of *Mytilus edulis* in 2007 (nearfield: 39,609/1,000 m^3, farfield: 44,609/1,000 m^3) were below the preoperational period means at both stations. Larvae have been appearing earlier in the year than historically observed, a possible result of warmer surface water temperatures. There were no significant differences between the preoperational or operational periods or stations in the density of *Mytilus edulis* and the interaction term was not significant. Annual means at each station were nearly identical in each year of the preoperational and operational periods.

Entrainment collections provide a measure of the actual number of organisms directly affected by Station entrainment. The total number of bivalve larvae entrained in 2007 (5,820 x 10^9) was slightly lower when compared to 2006, and it was the second lowest year recorded for years when complete sampling was done. *Anomia squamula* (3,950 x 10^9) was the most numerous species entrained, followed by *Mytilus edulis* (834 x 10^9), and *Hiatella* sp. (651 x 10^9). Although somewhat atypical of most years, large numbers of *Anomia squamula* were entrained in October, coincident with unusually large numbers of larvae in the coastal waters. Larval density in the entrainment samples was greater than the nearshore samples from July through early September. The difference is probably the result of the mid-depth location of the intake structure and the uneven distribution of larvae in the nearshore waters; offshore samples are collected through the entire water column.

To understand community dynamics better, the macrozooplankton was divided into three assemblages: holoplankton, which spend their entire life in the water column; meroplankton, which spend only a distinct portion of their life cycle in the water column; and hyperbenthos, which live on or near the bottom. Annual holoplankton abundances are generally higher than meroplankton and hyperbenthos abundances due either to the relatively short duration in the plankton (meroplankton) or behavioral differences (hyperbenthos). As both the meroplankton and the hyperbenthos assemblages include ecologically important species (e.g. crab larvae or mysids), separate analyses allow for a more thorough evaluation of the potential effects of operation Seabrook Station.

Numerical classification defined two distinct holoplankton assemblages, one dominated by *Centropages typicus*, the other by *Calanus finmarchicus*. The holoplankton assemblage was dominated by *Centropages typicus* in most years, however the *Calanus finmarchicus* dominated assemblage occurred frequently. The occurrence of these two distinct assemblages appeared to be independent of plant operation, occurred simultaneously at both stations and indicated long-term temporal trends. *Centropages typicus* dominated the holoplankton from 1979 to 1982. *Calanus finmarchicus*-dominated assemblages were more common from 1983 to 1989. Thereafter, *Centropages typicus* dominated the holoplankton for a decade from 1990 to 2001. Abundances of *Centropages typicus* then decreased, shifting dominance back to *Calanus finmarchicus*, whose abundances have been rather consistent throughout the study. The *Calanus finmarchicus* dominated assemblage has occurred since 2002.

Trends in the holoplankton assemblage in coastal New Hampshire are very similar to trends reported in the Gulf of Maine and on Georges Bank. The large increase in abundance in the 1990s of *Centropages typicus* and the dominance of the community by *Calanus finmarchicus* in the 1980's and recent years was observed at both the nearfield and farfield sites and throughout the Gulf of Maine. Factors affecting the holoplankton assemblage occur on a regional scale and any potential plant effects, if present, are very minor.

The selected holoplankton species *Calanus finmarchicus* showed no significant differences in average abundances between periods or stations and the interaction term was not significant. Average densities in 2007 were at record or near-record high levels (nearfield: 15,053/1000 m^3, farfield: 8,314/ 1000 m^3). Average annual densities in the preoperational and operational periods of *Calanus finmarchicus* were very similar.

The meroplankton assemblage was dominated by the larvae of coastal species. Estuarine species were relatively minor contributors to overall abundance and community composition. In general, numerical classification indicated that differences between the preoperational and operational periods were fairly small. The relative stability of the meroplankton assemblage can be attributed to dominance of coastal species, whose adult populations are widely distributed in the Gulf of Maine. Changes in the field sampling method beginning in 1996 may have affected the results of numerical classification for this assemblage. Collections from 2000, 2004, 2005 and 2006 were associated into a new group. Collections from 1996 and 1997 were not paired. In 2007, the field method was again changed and the 2007 collections were paired and associated with the pre-1996 collections.

In 2007, average densities of larvae of the selected meroplankton species, *Crangon septemspinosa*, at the nearfield station (158/1000 m^3) and farfield station (121/1000 m^3) were similar to previous years. There were no significant differences between periods or stations for the density of *Crangon septemspinosa*, and the interaction term was not significant. Average densities of the green crab, *Carcinus maenas*, larvae in 2007 at the nearfield (23/1000 m^3) and farfield station (35/1000 m^3) were also similar to previous years, although the average annual density at Station P2 in the operational period is somewhat greater. There were no significant differences in density of *Carcinus maenas* larvae between periods or stations, and the interaction term was not significant.

Long-term trends were not observed for the hyperbenthic assemblage. There were large differences between the stations, however. The station differences were observed in both the preoperational and operational periods and do not indicate a plant effect. Species composition and abundances at the nearfield station (P2) were similar in the preoperational and operational periods. All of the Station P2 annual means, both preoperational and operational periods, were grouped together by numerical classification and all Station P2 collections were tightly grouped in the MDS ordination. In contrast, many of the recent collections at Stations P7 formed new groups as defined by numerical classification. Since changes in the sampling method, beginning in 1996, two additional groups have been defined by numerical classification that include all of the farfield collections, except for 1996, 2004 and 2006. Species abundances were exceptionally low in these two groups, which distinguishes them from the earlier operational collections at the farfield station. The decrease was generally limited to the larger peracarid species including *Neomysis americana*, resulting in a change of the relative ranking of the dominant taxa. Despite the change in the sampling method initiated in 2007, peracarid abundances remained low at Station P7 in 2007 and the collections were associated with the low abundance years.

Average density of the selected hyperbenthic species, *Neomysis americana*, at the nearfield station (113/1000 m^3) was typical of previous years. The average density at Station P7, the farfield station (27/1000 m^3), was less than the preoperational period mean, but greater the operational period mean. Station differences were significant. There were no significant differences between periods, and the interaction of these main effects was not significant.

Fish Populations

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 traveling screens within the circulating water pumphouse. Local distribution could also potentially be affected by the thermal plume, with some eggs and larvae subjected to thermal shock from 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 populations.

Ichthyoplankton analyses focused on seasonal assemblages of both eggs and larvae, as well as on the larvae of selected species. Previous analyses of temporal (among months and years) trends in egg and larval assemblages identified through the monitoring programs suggest that the operation of Seabrook Station has not altered the seasonal spawning time or the distribution of eggs and larvae in the Hampton-Seabrook area. Current results, comparing annual collections, show a high degree of similarity among annual egg and larvae collections, with no pattern that could be related to plant operation. The fish egg assemblage was dominated by cunner/ yellowtail flounder, Atlantic mackerel, and hakes, with fourbeard rockling/hake, Atlantic cod/haddock, windowpane, and silver hake occurring as secondary dominants. Both the cluster and MDS analyses revealed that stations in both the preoperational and operational years were usually grouped together, indicating a higher degree of similarity in structure between stations than among years. The greater degree of similarity between stations indicated that the factors that control the composition of the egg assemblage appeared to be operating equally in both the nearfield and farfield areas. ANOSIM indicated significant differences between preoperational and operational periods, a result of changes in the community between 1983-1987 and 1988-2007. However, ANOSIM detected no differences between stations. The difference between periods was primarily due to increases in the density of Atlantic mackerel and cunner/yellowtail eggs, and a decrease in density of hake and fourbeard rockling eggs. The interaction of the main effects was not significant.

Fish larvae collections were dominated by cunner, American sand lance, and Atlantic mackerel, with fourbeard rockling, Atlantic herring, rock gunnel, winter flounder, and silver hake as secondary dominants. There were major changes in the fish larvae assemblage between 1982-1988 and 1989-2007, a result of increases in cunner, fourbeard rockling, and silver hake and decreases in American sand lance, Atlantic mackerel, Atlantic herring, and winter flounder. ANOSIM detected significant differences in the fish larvae assemblage between periods, but there were no differences between stations, indicating that the changes in the assemblage were regional, and not due to plant operation. As with fish eggs, collections of larvae on each date were always highly similar between stations. Among the species selected for detailed analyses, there no significant differences in larval abundance between periods or stations for hakes, cunner, American sand lance, Atlantic mackerel, and yellowtail flounder. Only Atlantic herring, Atlantic cod, pollock, and winter flounder larvae had significantly higher abundance during the preoperational period compared to the operational period. The absence of a difference between nearfield and farfield stations and the lack of a significant interaction between periods and stations indicates that there was no effect due to the operation of Seabrook Station.

The geometric mean CPUE (catch per 10-minute tow) of demersal fish at all stations combined in 2007 decreased from the previous year to 37.3, the sixth highest CPUE in the operational period. CPUE of demersal fish has generally increased in the operational period since a record low of 8.4 in 1995. Winter flounder, longhorn sculpin, windowpane, skates (Rajidae), hakes and yellowtail flounder dominated the catch in 2007. During the operational period, these same species predominated, compared with yellowtail flounder, longhorn sculpin, winter flounder, and hakes in the preoperational period. CPUE of most fishes, especially commercially important species, declined between the preoperational and operational periods.

Yellowtail flounder showed the greatest decrease in CPUE from 9.3 in the preoperational period to 2.1 in the operational period. The CPUE of hakes, Atlantic cod, and ocean pout also decreased between periods. The decrease in CPUE of the commercial groundfish species has been attributed to record-high levels of commercial fishing that reduce new year classes before they are able to reproduce (NEFSC 2006; Mayo and Terceiro 2005). There is also a trend of increasing abundances of small elasmobranchs in the Gulf of Maine, as evidenced by an increase in CPUE of skates from 1.9 to 3.7 between periods. The CPUE of winter flounder increased from 3.5 in the preoperational period to 5.0 in the operational period. The increased started in 1995 and this trend is consistent with the most recent management data collected from the Gulf of Maine. Spawning stock biomass of winter flounder has increased through 2001 and the Gulf of Maine winter flounder stock is no longer considered overfished (NEFSC 2006).

CPUE of demersal fish decreased between the preoperational and operational periods for all of the selected demersal species except winter flounder, which increased. However, the changes did not occur equally at all stations resulting in significant interaction terms. Our BACI study design assumed that if there was no plant impact, changes in abundance would occur equally at all stations. However, a significant interaction term could also be caused by a large-scale environmental change that occurred concurrently with plant operation (Smith et al. 1993). A large-scale change could be a region-wide perturbation such as overfishing, climate change, disease, or another regional factor. Under these circumstances, a significant interaction term would result because CPUE would be reduced to very low levels at all stations, including stations where it had previously been high. Any potential plant impact due to the operation of Seabrook Station either did not occur, or was not detectable in the face of overfishing.

The ~~geometric~~ mean CPUE (catch per seine haul) for estuarine fish caught at all stations in 2007 increased from the previous year to11.2. CPUE of most species declined from the preoperational to the operational period, although the species composition has remained similar. Atlantic silverside dominated catches in all years sampled, and its annual trends in CPUE paralleled fluctuations in the total catch.

During 2007, an estimated 22,451 fishes and 21 American lobsters were impinged on the traveling screens at Seabrook Station. This was an increase from last year but was less than the highest impingement estimate since reliable estimates were first made in 1994. About 27% of the estimate occurred in April and was associated with the Patriot's Day storm. Winter flounder (3,949: 18%), rock gunnel (3,174: 14%), northern pipefish (2,374: 11%), American sand lance (2,073: 9%), and windowpane (1,502: 7%) comprised 59% of the fish impinged in 2007. Most impinged fish were probably YOY fish. The design of the Seabrook Station offshore intake, having a mid-water intake fitted with a velocity cap, has apparently resulted in similar or fewer numbers of fish being impinged when compared to other New England coastal power plants.

Entrainment of fish eggs and larvae through the condenser cooling water system is a direct potential impacts of Seabrook Station on the local fish assemblages. Entrainment of eggs in 2007 (715 million) was within the range of previous years. The most numerous eggs entrained in 2007 were cunner/yellowtail flounder (293 million), Atlantic mackerel (154 million), and hake/fourbeard rockling (68 million). Based on larval abundances, almost

100% of the cunner/yellowtail flounder eggs were cunner.

Entrainment of larvae in 2007 (297 million) was the fourth highest estimate to date. Cunner (98 million), rock gunnel (47 million), American sand lance (37 million), and Atlantic seasnail (34 million) were the most abundant taxa entrained in 2007. Entrainment of larvae in 2007 was highest in August, when cunner (95 million) and fourbeard rockling (15 million) were most abundant.

Equivalent Adult (EA) analyses of seven commercially-important fishes indicated that entrainment and impingement in 2007 resulted in the estimated loss of about four (yellowtail flounder) to 2,055 (winter flounder) fish.

Marine Macrobenthos

Horizontal rock ledge is the predominant benthic habitat near Seabrook Station's offshore intake and discharge. These rocky surfaces support a diverse community of attached macroalgae and macrofauna. Studies were designed to identify the species inhabiting nearby 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 dominant taxa since the operation of Seabrook Station began in 1990. Possible impacts include temperature-related changes in areas potentially exposed to the buoyant thermal plume, the shallow-subtidal zone. 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 affectting benthic organisms in the mid-depth zone.

Potential Thermal Effects

Hydrodynamic modeling and subsequent field verification studies of the Seabrook Station discharge plume have indicated that shallow subtidal areas experience temperature increases of <1°F (Padmanabhan and Hecker 1991). Temperature monitoring of bottom waters at the subtidal stations from 1998 through 2000 (NAI 2001) indicated that the thermal plume is not affecting the subtidal stations.

The shallow subtidal benthic community (5-6 m) has not been significantly impacted by the operation of Seabrook Station. Total faunal density, total algal biomass and number of algal taxa, as well as results of numerical classification of algal and faunal communities, showed no significant changes between the preoperational and operational periods and the trends between the preoperational and operational periods at both the nearfield and farfield stations were consistent. However, the number of macrofaunal taxa, when both stations were combined, was lower during the operational period compared to the preoperational period, a trend that appeared to be regional and not a local impact of Seabrook Station. Results of numerical classification for both algae and fauna show a high level of similarity between the two main assemblages, and 2007 collections were included in the main assemblages. Since the main assemblages include both preoperational and operational years, there is no evidence that the operation of Seabrook Station has altered macrobenthic assemblages. When potential effects of plant operation on selected species in the shallow subtidal zone were examined, none were found on the dominant alga, *Chondrus crispus*, Mytilidae (mussels), Asteriidae (sea stars) or the tubiculous amphipod, *Jassa falcata*. However, density of the subdominant kelp species, *Laminaria digitata*, declined significantly between periods at both stations, but the decline was greater at the nearfield station (Preoperational: 213.9/100 m^2; Operational: 16.7 /100 m^2) compared to the farfield station (Preoperational: 155.8/100 m^2; Operational: 73.6/100 m^2). Investigation of possible factors in its decline has not definitively revealed a cause. Sea urchins, a potential grazer of *Laminaria digitata*, were eliminated as a possibility because of their low abundance at the shallow subtidal stations. Bottom temperatures at the shallow subtidal stations were within suitable ranges for *Laminaria digitata*. The long-term rise in average annual surface and bottom temperatures may be a factor, although the increase (0.6°C) occurred at both stations. Episodic removal by storms may contribute to the annual variation in the shallow subtidal zone, although the lack of recovery from the lows of 2000 remains unexplained. Since declines began at both stations before initiation of plant operation, the observed trends may be related to large-scale regional processes. A significant decline in the dominant kelp *Laminaria saccharina* occurred at the nearfield station between the periods (Preoperational 415.1/100 m^2; Operational: 151.8/100 m^2), but there was no decline at the farfield station (Preoperational: 325.7/100 m^2; Operational: 336.6/100 m^2). In 2007, densities at both stations are among the lowest for the time series, even though the farfield station reached the peak density of the study period in 2005. Despite the differing trends at the stations between periods, annual means at each station roughly tracked each other during the study period suggesting a regional trend. The regional decline of *Laminaria* spp. beds has been documented in the Gulf of Maine (Harris and Tyrrell 2001), off Nova Scotia (Scheibling and Hennigar 1997) and in the western North Atlantic (Steneck et al. 2004), and causes such as overfishing, climate change and invasive species have been suggested.

Potential Turbidity Effects

Turbidity was monitored at the mid-depth stations in May and October 1998. Turbidity was significantly higher at the nearfield station, but this was attributed to its proximity to the outlet of Hampton Harbor rather than the discharge from the plant. Turbidity levels in the water ebbing from Hampton Harbor were much higher than levels in the plant discharge plume.

Macrofaunal density, number of taxa, and community structure, as well as algal biomass in the mid-depth zone (9-12 m) have shown no changes during the operation of Seabrook Station. The number of algal taxa increased significantly at the farfield station (Preoperational: 11.0; Operational: 13.6), but was not significantly different at the nearfield (discharge) station (Preoperational: 10.1; Operational: 9.9). Algal community structure as determined through numerical classification has typically been stable throughout the study period with collections divided into two major groups by station with a mix of preoperational and operational collections in each group. However, in 2007 the nearfield station was an outlier. It was characterized by lower biomass of nearly all species compared to Group 1, which comprised all previous collections from the nearfield station. Four farfield collections taken from 2001 through 2004 distinguished themselves by having lower overall biomass and being dominated by the cold-water perennial *Chondrus crispus*, the coralline alga characteristic of "urchin barrens" *Corallina officinalis*, and the annual *Polysiphonia stricta*.

At the species level, nearfield-farfield relationships at the mid-depth stations remained stable over time for *Agarum clathratum* (kelp), *Laminaria saccharina* (kelp) *Phyllophora/Coccotylus* (red understory alga), *Ptilota serrata* (red understory alga), Mytilidae (mussel) spat, *Pontogeneia inermis* (amphipod), large and small *Strongylocentrotus droebachiensis* (urchins), and *Modiolus*

modiolus (horse mussel). Only the kelps *Laminaria digitata* and *Alaria esculenta* showed changes. Densities of *L. digitata* declined at both nearfield and farfield stations, but to a greater extent at the nearfield (Preoperational: 139.9/100 m^2; Operational: 8.4/100 m^2) than the farfield (Preoperational: 500.2/100 m^2; Operational: 168.3/100 m^2). The cause of this regional decline remains unclear. A potential increase of bottom water temperature due to plant operation was ruled out as a factor, as was increased turbidity due to the plant discharge. Grazing by the green sea urchin, *Strongylocentrotus droebachiensis,* could have reduced the density of *L. digitata.* These two species had a statistically significant inverse relationship at the farfield station during years when sea urchins were abundant (1993 through 1996 with the peak density of 8.5 urchins/m^2). Higher turbidity at the nearfield station, a result of its proximity to Hampton Harbor, in combination with greater water depth and competition with the dominant kelp, *Agarum clathratum,* has potentially put *L. digitata* near its physiological limit. This in turn makes it more susceptible to disturbance and other negative influences, adversely affecting its population levels. Although the interplay of physical and biological factors related to the decline in *L. digitata* are not fully understood, similar declines have been documented at various locations throughout the western North Atlantic (Scheibling and Hennigar 1997, Harris and Tyrrell 2001, Steneck et al. 2004), suggesting that large-scale, regional phenomena may be involved.

Abundance of *Alaria esculenta* changed at the farfield station between periods, but not the nearfield station. *A. esculenta* is a kelp that prefers a strong surge, which may explain why it was historically present in very low abundance at the nearfield station (the deepest station). Densities of *A. esculenta* declined at the farfield station (Preoperational: 75.2/100 m^2; Operational: 44.6/100 m^2), but remained low at the nearfield station (Preoperational: 2.4/100 m^2; Operational: 2.5/100 m^2). The change occurred only at the farfield station which is not affected by the operation of Seabrook Station, and historically has shown wide variations in annual means.

Epibenthic Crustacea

The objective of the epibenthic crustacea monitoring program is 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 are done to determine if the discharge from Seabrook Station has had any measurable effect on these species.

Lobster larval densities during 2007 (1.3 to 2.0/1000 m^2) were higher than both the preoperational means (0.4 to 0.6/1000m^2) and operational means (0.9 to 1.1/1000m^2) at each of the three stations (intake, P2; discharge, P5; and farfield, P7). The lobster larval density in 2007 increased from the previous year and was above the upper 95% confidence limit of the operational mean density at all three stations. Weekly patterns of mean lobster larval density in 2007 were different from preoperational and operational patterns with the absence of larvae during the fourth week of June and August when larvae are normally present, and the presence of second major peak in density in the second week of September. Density of larval lobsters was significantly higher in the operational period and there were no significant differences between stations. The interaction between periods and stations was not significant, an indication that changes in CPUE between periods have been consistent at both stations, and were not affected by the operation of Seabrook Station.

The catch of lobsters (all categories) was adjusted to a standard soak time of two days

($CPUE_2$) for the 15-trap effort because there was a significant relationship between catch and soak time. Total $CPUE_2$ in 2007 decreased from the previous year at the nearfield (95.3) and farfield station (115.5), and was greater than both the preoperational (nearfield: 65.4; farfield: 81.2) and operational (nearfield: 87.8; farfield: 100.6) means. There were no significant differences in $CPUE_2$ of total lobsters between periods or stations. The interaction between periods and stations was not significant.

$CPUE_2$ of legal-size lobsters was significantly lower in the operational period (nearfield: 3.7; farfield: 3.4) than in the preoperational period (nearfield: 5.5; farfield 5.6) at both stations, likely a result of increases in the legal size-limit and commercial overexploitation. The average legal-size $CPUE_2$ in 2007 (nearfield 4.0; farfield: 3.9) was lower than the preoperational averages and higher than the operational averages.

Changes in water temperature in a given year can affect lobster catches in subsequent years as warmer water temperatures increase survival of larvae and age-0 lobsters. There was a significant correlation between $CPUE_2$ of legal-sized lobsters and mean June through November surface water temperatures lagged by six years at the nearfield (r_s=0.50) and farfield stations (r_s=0.50). For sublegal-size lobsters, $CPUE_2$ was significantly correlated with June-November surface temperatures lagged by six years at the nearfield and farfield stations (r_s=0.62, 0.49, respectively). This trend agrees with those reported by other investigators (Flowers and Saila 1972, Dow 1977, Fogarty 1988, Campbell et al. 1991, and Koeller 1998). Warm summer water temperatures may stimulate rapid growth of planktonic stages and enhance early settlement, resulting in increased survival of young lobsters.

In 2007, an estimated 21 lobsters were impinged in the Station's circulating water system. A total of 294 lobsters have been impinged since 1990. The current level of impingement does not affect the indigenous population.

Mean density of *Cancer* spp. (*Cancer borealis* and *Cancer irroratus*) larvae in 2007 (nearfield: 4,742/1000 m^3; farfield 9,017/1000 m^3) was lower than the operational means at both stations (nearfield: 11,492/1000 m^3; farfield 12,068/1000 m^3). The 2007 mean at the nearfield station was lower than the preoperational mean (9,532/1000 m^3) and higher than the preoperational mean at the farfield station (8,426/1000 m^3). There were no significant differences between the preoperational and operational periods, or between stations, and the interaction was not significant.

Jonah crab $CPUE_2$ in 2007 at the nearfield station (12.2) and the farfield station (6.7) was lower than the operational period means (nearfield: 14.7; farfield: 8.7) and the preoperational period mean at the farfield station (9.6). $CPUE_2$ at the nearfield station in 2007 was identical to the preoperational mean. There were no significant differences in $CPUE_2$ of Jonah crab between stations or periods and the interaction was not significant. Annual $CPUE_2$ at each station has followed similar trends among years, except in 2007 the $CPUE_2$ continued to decrease at the nearfield station but increased from last year at the farfield station.

There was no significant relationship between catch and soak time for rock crab, therefore catch was not adjusted for soak time. Rock crab CPUE in 2007 at the nearfield (2.4) and farfield stations (1.8) was less than the operational mean (nearfield: 2.9; farfield: 4.8) and, at the nearfield station was less than the preoperational mean (2.6). CPUE in 2007 at the farfield station (1.8) was greater than the preoperational mean (1.5). The CPUE increased significantly between periods at the farfield station but there was no significant difference at the nearfield station, resulting in a significant interaction. Segmented regression indicated that CPUE at the farfield station has been increasing steadily since 1982, before Seabrook Station became operational. The increase at the farfield station may be attributable to behavioral interactions with lobsters caught in the same traps or other biological interactions.

Softshell Clam

The objectives of the softshell clam (*Mya arenaria*) monitoring program are to determine the spatial and temporal patterns of abundance of various lifestages of *Mya arenaria* in the vicinity of Hampton Harbor. Pelagic lifestages 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 the Station's Settling Basin discharge, which was 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. In 2007, larvae were first observed in the fourth week of May and peak densities occurred in the first week of June. Geometric mean density of soft-shell clam larvae in 2007 at Station P2 ($5.8/m^3$) was similar to the preoperational and operational means and at Station P7 ($3.4/m^3$) was below the preoperational and operational means. There were no significant differences in mean larval abundance between the preoperational and operational periods or between stations. An estimated 5 billion soft-shell clam larvae were entrained in 2007. This estimate was the within the range of previous years.

Mean density of YOY clams (1-25 mm) in 2007 at all flats ($9.7/m^2$) increased from 2006 but was lower than the preoperational ($52.8/m^2$) and operational ($27.8/m^2$) means. Density of yearling clams (26-50 mm) in 2007 ($0.4/m^2$) was lower than both the preoperational ($3.9/m^2$) and the operational ($1.1/m^2$) means. Density of yearlings has been declining since 1995, and is presently lower than adult clams, indicating a potentially diminished recruitment of adults in future years. Average density of adult clams in 2007 ($3.1/m^2$) decreased from 2006 ($4.8/m^2$), and was higher than the preoperational mean ($2.2/m^2$) and lower than the operational mean ($3.4/m^2$).

There were no significant differences in mean density between the preoperational and operational periods for YOY and adult clams. For the first time, density of yearlings in the operational period was significantly lower than in the preoperational period.

In 2007, the mean density of seed clams (1-12 mm) in Hampton Harbor ($0.6/m^2$) decreased from 2006 ($8.7/m^2$) and was substantially lower than the preoperational ($36.8/m^2$) and operational ($39.5/m^2$) means. Average density of seed clams in 2007 in the farfield Plum Island Sound area ($26.3/m^2$) was also lower than the previous year ($42.1/m^2$), and lower than the preoperational (107.0 per m^2) and the operational ($28.5/m^2$) means. Hampton Harbor seed clam density in 2007 was the lowest recorded by the monitoring program to date. Nonetheless, there were no significant differences in seed clam density between the preoperational and operational periods or between areas.

Recruitment and survival of soft-shell clams in Hampton Harbor appeared to be highly variable and controlled by a variety of abiotic and biotic factors. Currents and sediment transport may affect larval and YOY density. There did not appear to be a direct relationship between early and later lifestages. Annual density of clam larvae explained 22% of the variability of recruitment of YOY, indicating that post-settlement processes are probably more important in controlling the recruitment of YOY. Furthermore, removal of larvae through entrainment probably has not affected recruitment. There was no significant relationship between annual entrainment of soft-shell clam larvae and recruitment of YOY clams.

Trends in clam density may be related to various forms of predation. The green crab, an introduced species in New England, is a major predator of soft-shell clams. In previous studies, only yearling clams had the expected negative relationship between clam density and green crab CPUE. Recreational clamming has also likely had an effect on adult clam density. Digging pressure does not appear to be related to YOY and yearling clam density. Density of adults at all flats has increased since 2004, possibly as a result of reductions in clamming days starting in 2003.

The two potential mechanisms by which the operation of Seabrook Station could affect soft-shell clams in Hampton Harbor are incursions of the thermal plume into the harbor and entrainment of larvae into the cooling water system of the plant. Numeric modeling and subsequent field verification indicate that the thermal plume does not enter the harbor and is not a potential impact (Padmanabhan and Hecker 1991). Larval density showed no significant differences between the preoperational and operational periods. In addition, densities of larvae are not strongly related to sets of YOY. No significant differences occurred between periods for YOY clam densities. Therefore, removal of larvae through entrainment into the cooling water system of the plant has had no apparent effect on YOY clam density. A significant difference between periods was found this year for yearlings, with higher densities in the preoperational period than in the operational period. However, on average, more adults were found during the operational period, although the differences between periods were not significant. The differences in clam density were probably due to many physical and biological variables that include post-settlement processes such as transport by water currents, predation, and recreational harvesting, which influence the survival of each size class differently.

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2.0 SUMMARY

Coastal New Hampshire water quality was characterized and potential plant impacts were assessed by measuring water temperature, salinity and dissolved oxygen. The regional climate in 2007 had near normal temperatures and snowfall and had 7.8 cm less precipitation than normal. Near-drought conditions prevailed from August through November. Mean monthly surface water temperatures in 2007 at the intake (P2) were above the 95% confidence limits of preoperational years in five months. Bottom temperatures were within the 95% confidence limits of the preoperational period for nine months. Annual mean surface water temperatures in 2007 (P2: 9.4, P7: 9.3 °C) were above the preoperational period averages (P2: 8.9 °C, P7: 8.7 °C) and similar to the operational period averages (P2: 9.5 °C, P7: 9.3 °C). Annual mean bottom water temperatures in 2007 (P2 and P7: 6.8 °C) were colder than the operational (P2: 7.4 °C, P7: 7.3 °C) and preoperational (P2: 7.0 °C) averages except at Station P7, where they were equal (6.8 °C). There were no significant differences between periods or stations and the interaction between period and station was not significant, indicating that the temperature increase during the operational years was regional and occurred at both stations.

Surface water temperatures at the discharge (DS) and farfield (T7) stations were continuously monitored to ensure compliance with Seabrook Station's National Pollutant Discharge Elimination System (NPDES) permit. According to the provisions of the NPDES permit, the average monthly increase in surface water temperature due to the thermal component of the discharge cannot exceed 5°F (2.8°C) within 300 feet (90.9 m) of the discharge. Compliance with this permit requirement was again demonstrated in 2007.

In 2007, annual mean surface salinities (P2 and P7: 31.2 PSU) were equal to the averages for the operational period, but below the averages for the preoperational period (P2: 31.6, P7: 31.5 PSU), possibly an indication of regional freshening. The 2007 bottom salinities (P2: 31.9, P7: 32.0 PSU) were above the averages for the operational period (P2: 31.8, P7: 31.9 PSU), but below the averages for the preoperational period (P2 and P7: 32.2 PSU). Surface and bottom salinities at both stations in 2007 and for the operational period were below the preoperational average. Mean monthly surface salinity at Station P2 in 2007 was below the preoperational 95% confidence limits during January, May, October and November. There were no significant differences between stations or periods and the interaction was not significant for surface or bottom salinity, an indication that the freshening during the operational period was regional.

Monthly mean surface dissolved oxygen (DO) levels in 2007 at Station P2 were within the 95% confidence limits of the preoperational average for every month except April, August, September, November and December when they exceeded the preoperational confidence limits. Monthly mean bottom DO levels in 2007 were within the 95% confidence limits of the preoperational average in every month except April, August, November and December when they exceeded them. The minimum DO value in 2007 was 6.9 mg/l and occurred in October at the bottom at Station P7. In 2007, DO was within the range that would support local marine life all year. In 2007, annual mean surface (P2: 10.1 and P7: 10.0 mg/l) DO values increased from the lows of the time series that occurred in the previous year. They were above the averages for the preoperational (P2 and P7: 9.7 mg/l) and operational (P2 and P7: 9.8 mg/l) periods. Likewise, the 2007 bottom values (P2: 9.6, P7: 9.4 mg/l) were above the averages for the preoperational (P2: 9.2 and P7: 9.1 mg/l) and

operational periods (P2 and P7: 9.0 mg/l). There were no significant differences between periods or stations and the interaction was not significant for surface or bottom DO.

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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. 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.

Seabrook Station employs a once-through circulating water system. Ambient ocean water is drawn into the system from approximately 7,000 feet (2,100 m) offshore through three intake structures. Heated water from the plant is discharged into a 16,500 foot (5,000 m) tunnel in bedrock and exits to the ocean through a multiport diffuser system approximately 5,500 feet (1,700 m) 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 (2.8°C) within the nearfield jet-mixing region. This applies at the surface of the receiving waters within 300 feet (90.9 m) 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. As part of Seabrook Station's NPDES permit compliance program, 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. The NPDES Permit limits for Total Residual Oxidant (TRO) are 0.2 ppm daily maximum and 0.15 ppm monthly average. In 2007, the daily maximum ranged from 0.00 ppm in February to 0.13 ppm in May, August and September. The average monthly TRO ranged from 0.00 ppm from January through March and in December to 0.08 in July (FPL Energy Seabrook Station 2007).

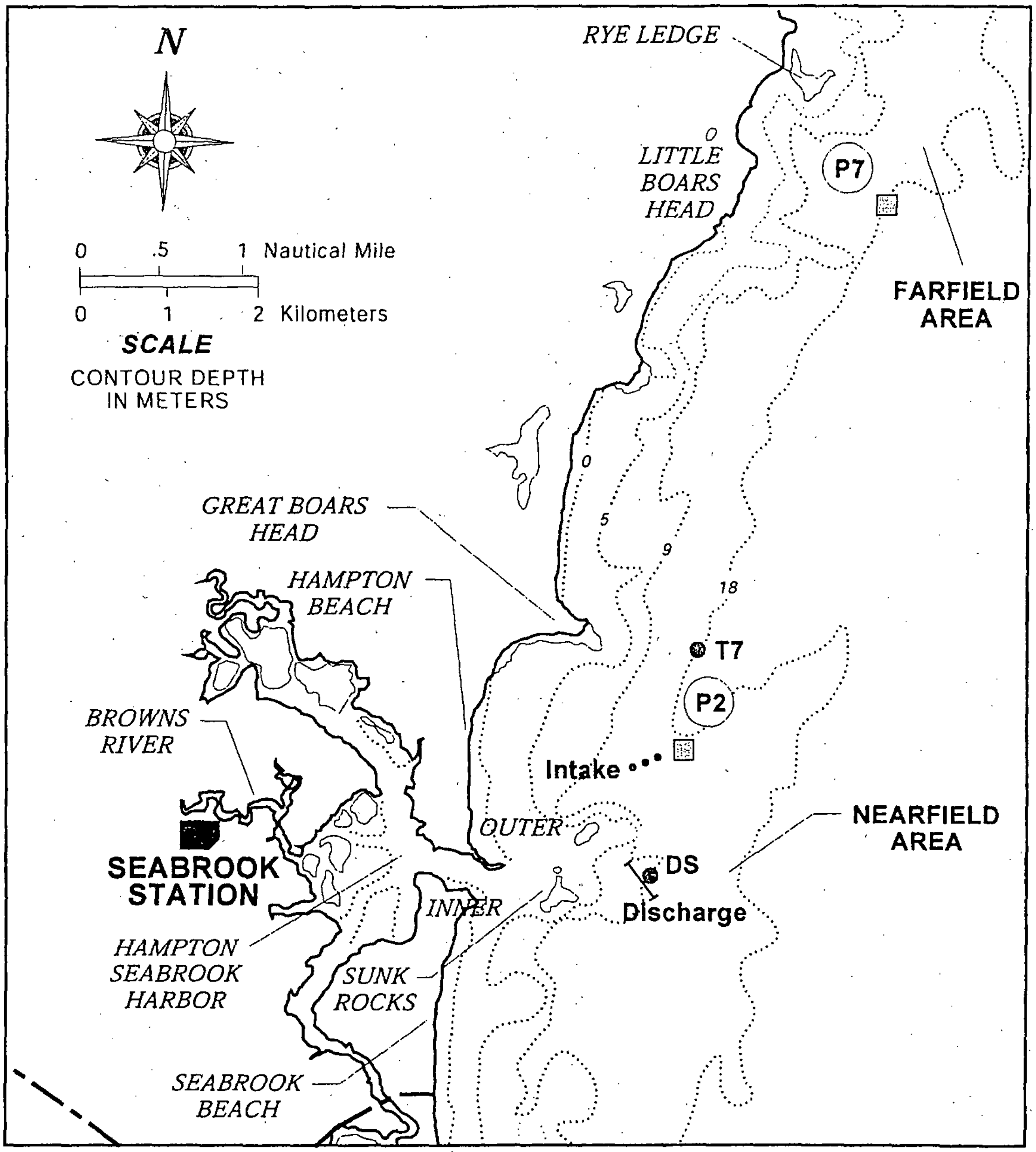
2.2 METHODS

2.2.1 Field Methods

Temperature, dissolved oxygen, and salinity measurements began in 1979 at the Intake Station P2 and in 1982 at the Farfield Station P7 (Figure 2-1). Sampling at Stations P2 and P7 has continued to the present. Sampling at Station P5, which was located near the discharge, and nutrient sampling at all stations was discontinued at the end of 1997.

From 1979 to 1994, temperature and salinity profiles were taken in two-meter increments four times per month, 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. In 1995 and 1996, temperature profiles continued to be collected using a YSI Model 33 S-C-T Meter. Salinity samples were collected at near surface (-1 m) and near-bottom (1 m above bottom) depths, placed in wax-sealed glass bottles and analyzed in the lab using a YSI Model 34 S-C-T Meter. Beginning in 1997, temperature and salinity were recorded in situ using a YSI 600XL Water Quality Monitor with the same sampling schedule as in previous years (weekly). Data were downloaded weekly.

From 1979 to 1996, duplicate dissolved oxygen samples were collected at near-surface (-1 m) and near-bottom (1 m above bottom)



LEGEND

▫ = water quality stations

● = continuous temperature monitoring stations

Figure 2-1. Water quality sampling stations. Seabrook Operational Report, 2007.

depths. Samples were fixed in the field with manganese sulfate and alkaline iodide-azide, and analyzed by titration within eight hours of collection. Beginning in 1997, dissolved oxygen profiles were recorded in situ using a YSI 600XL Water Quality Monitor at the same depths as previous measurements, and data were downloaded weekly.

Continuous surface water 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). Monitors were retrieved by divers usually every two weeks and the data downloaded to a personal computer. 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.

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 estuarine fisheries study sites.

2.2.2 Laboratory Methods

All dissolved oxygen analyses prior to 1997 were performed according to EPA Methods for Chemical Analyses of Water and Wastes (USEPA 1979) and Standard Methods (APHA 1989). Beginning in 1997, temperature, salinity and oxygen were recorded in situ using a YSI 6000XL Water Quality Monitor.

2.2.3 Analytical Methods

Water quality was evaluated to determine seasonal patterns and to detect trends among years, particularly in relation to plant operation. Operational, preoperational and 2007 means and their 95% confidence limits (Sokal and Rohlf 1981) were tabulated. Monthly means and confidence limits for the preoperational period were compared graphically to the monthly means for 2007 and the operational period to provide a visual estimate of their magnitude and seasonality. Annual means and their 95% confidence limits were presented to show any long-term trends.

All analyses used untransformed weekly data. Only near-surface and near-bottom measurements were used from Stations P2 and P7. Monthly means for each depth were computed by averaging all weekly collections within a month. Annual means and their 95% confidence limits were computed from the 12 monthly means. Preoperational and operational period means and their confidence limits were computed from the annual means.

Period (preoperational vs. operational) and station differences and the interaction between them were evaluated using a mixed linear model analysis using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. A mixed model based on a 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) 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 both stations were sampled concurrently (thus maintaining an equal number of years between stations within the preoperational period). Collections from 1990, the year the plant began to operate intermittently, occurred during the transition from preoperational to operational periods and were excluded from the analysis. The inference test for Preop-Op was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS Institute, Inc. 1999). The likelihood ratio test was used to test the significance for random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects.

2.3 RESULTS

2.3.1 Nearshore Water Quality

Nearshore water quality was monitored at two water quality stations and two continuous temperature-monitoring stations (Figure 2-1). Sampling at the water quality stations characterized temperature, salinity and dissolved oxygen that could affect the local biological communities and provided information for testing any potential plant impacts. The continuous temperature monitors verified compliance with the NPDES permit conditions.

2.3.1.1 Water Quality Stations

Climate

Coastal New Hampshire lies about 80 kilometers north of Boston, Massachusetts on the western Atlantic seaboard. Coastal waters are affected by local climate conditions including input from rivers, as well as from offshore water masses. Based on records from Boston, 2007 air temperature was nearly normal and precipitation was 7.8 cm below normal.

Air temperature in Boston in 2007 (11.0 °C) was equal to the historical average (Boston Sunday Globe 2007). The average monthly air temperature ranged from -3.2 °C in February to 22.7 °C in July. February averaged 2.9 °C below normal and July was 0.6 °C below normal. Total precipitation in 2007 was 100.3 cm, 7.8 cm below the historical average. April was the wettest month (17.0 cm) followed by July and December (13.3 cm each). A four month period of drier than normal weather began in August (1.7 cm), and near-drought conditions occurred across the region. Precipitation in December (13.3 cm) was slightly above normal. Total snowfall for 2007 was 111.8 cm, which is nearly normal (111.4 cm). More than half of the snow fell in December (70.4 cm).

Additional climatic and oceanographic context for the 2007 Seabrook Station observations was provided by the Gulf of Maine Ocean Observing System (GoMOOS 2007). The GoMOOS project, started in 2001, is a national pilot program designed to collect and disseminate hourly oceanographic data. Data for 2001 – 2007 are available online (www.gomoos.org), and sea surface temperature and salinity data along with air temperature data, were retrieved from Buoy B, located in the western Gulf of Maine roughly half-way between Hampton Harbor and Portland, Maine.

Air temperature records from Buoy B (Figure 2-2) show the average monthly temperature ranged from –3.3°C in February to 18.1°C in August. Boston air temperatures were also coldest in February (-3.2°C), and generally followed the same trend, although the offshore temperatures were more moderate.

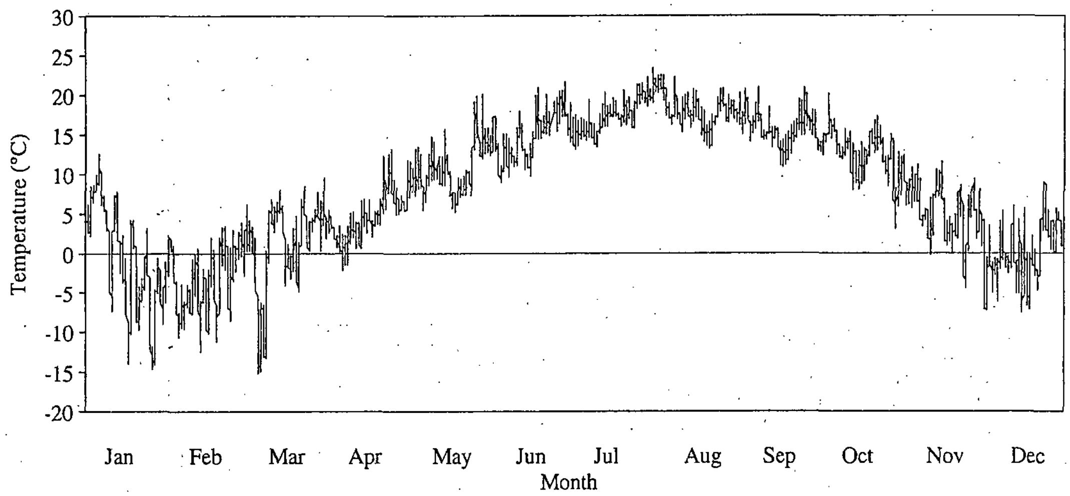


Figure 2-2. Hourly Air Temperatures (°C) Measured at GoMOOS Buoy B in the Western Gulf of Maine in 2007. Seabrook Operational Report, 2007.

Surface and bottom temperatures at Station P2 in 2007 generally followed a well-established monthly pattern, although in 2007 highest surface temperatures occurred in July rather than August. (Figure 2-3). Monthly surface temperatures were within the 95% confidence limits of the preoperational average in seven months, and were above the upper 95% confidence limits in January, February, June, July and October. Highest bottom water temperatures occurred in October rather than September. Bottom water temperatures were above the confidence limits in January and below the confidence limits in May and September.

Monthly mean surface and bottom temperatures were similar at Stations P2 and P7 throughout the year (Figure 2-4), although surface temperatures were slightly warmer at Station P2 from June to August. Monthly surface temperature at Stations P2 and P7 peaked in July and were lowest in March. Surface temperatures at Stations P2 and P7 generally exhibited a similar pattern to those observed at the offshore GoMOOS Buoy B in 2007, although temperatures at Buoy B were highest in August. Monthly mean bottom water temperatures at Station P2 and P7 were almost identical with the exception of January when temperatures were warmer at Station P7 and October when they were warmer at Station P2.

In the preoperational and operational periods, the annual mean surface temperatures were 0.2°C higher at Station P2 compared to Station P7, but in 2007 there was 0.1°C difference between stations (Table 2-1). Annual mean bottom temperatures were also warmer at Station P2 in the preoperational (0.2°C) and operational (0.1°C) periods. In 2007, annual mean bottom temperatures were

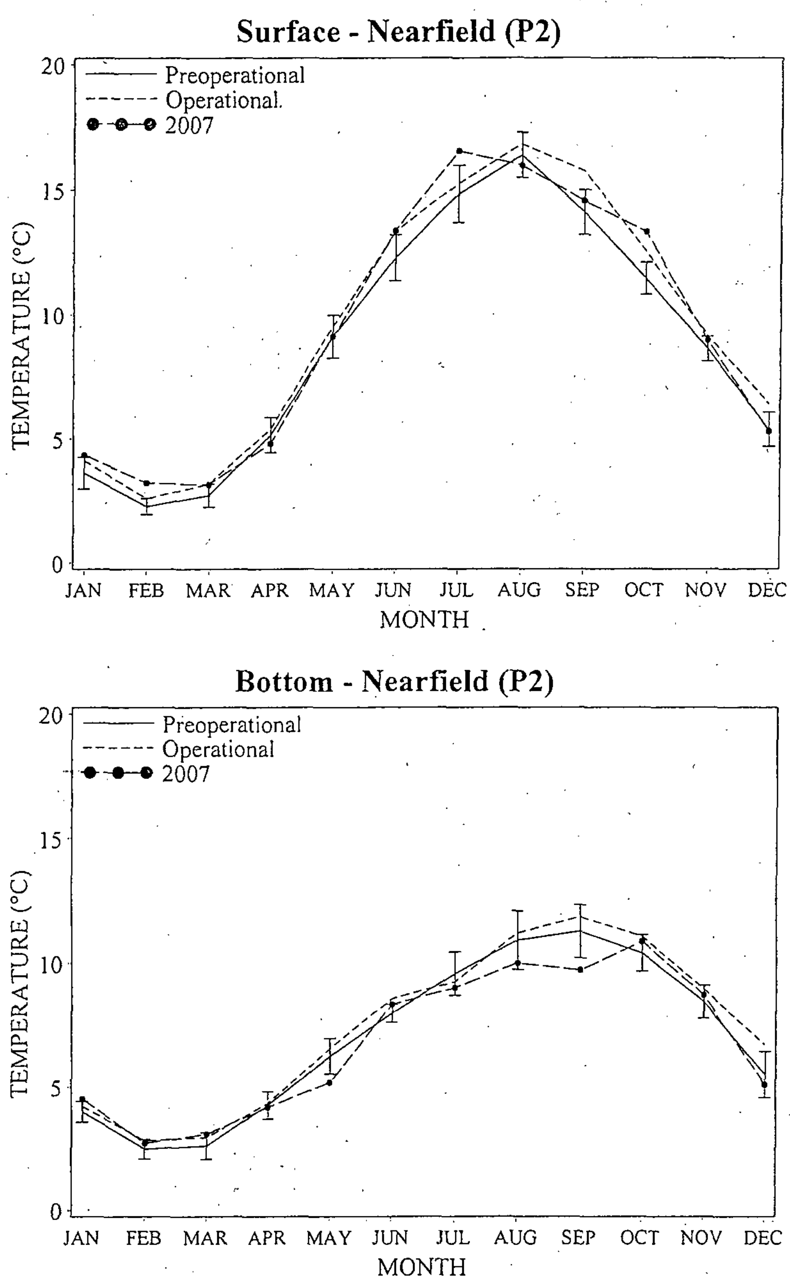


Figure 2-3. Surface and bottom temperature (°C) at nearfield Station P2, monthly means and 95% confidence intervals during the preoperational period (1979-1989) and operational period (1991-2007), and monthly means in 2007. Seabrook Operational Report, 2007.

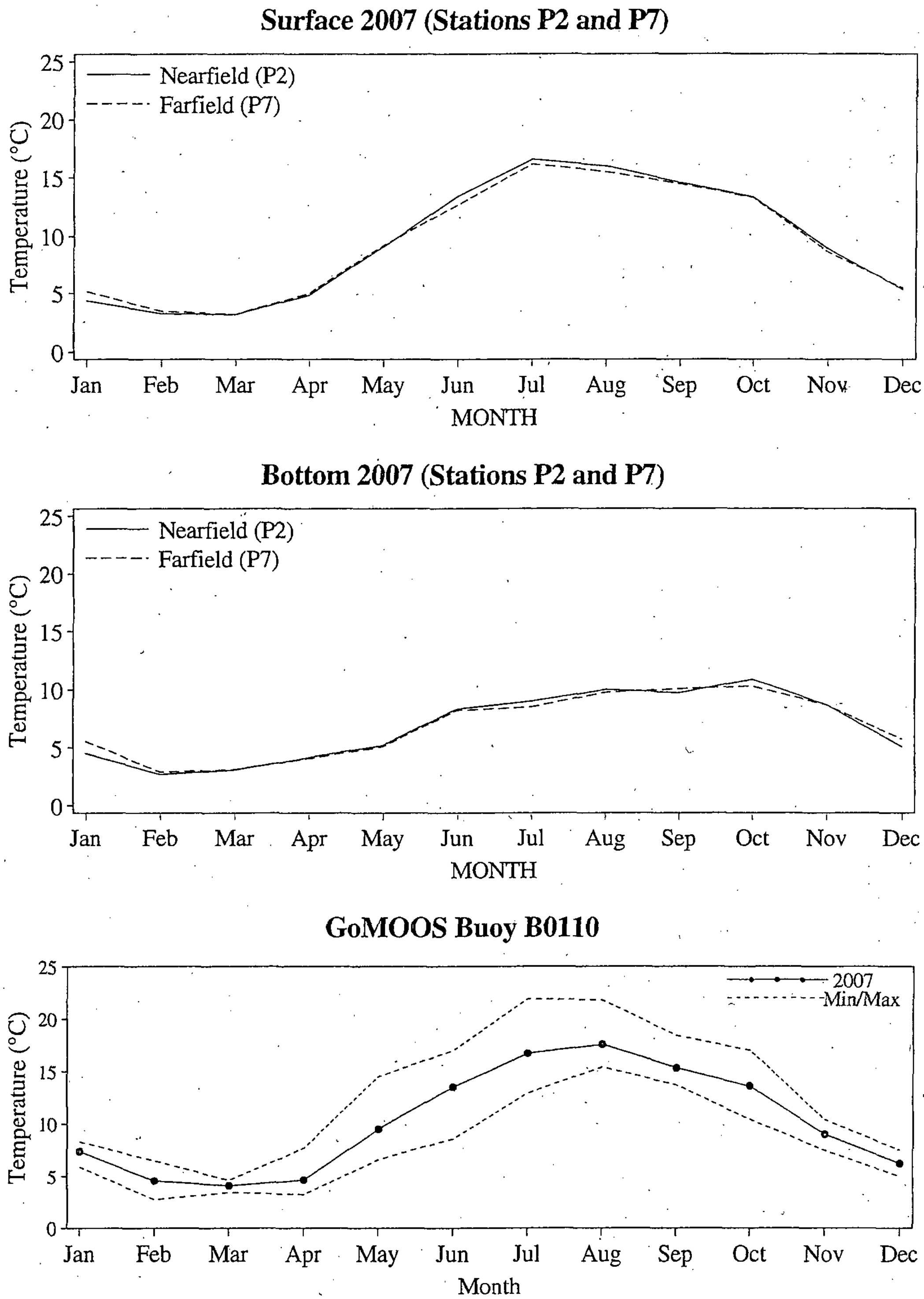


Figure 2-4. Monthly mean surface and bottom temperatures measured at Stations P2 and P7 in 2007, and monthly mean, minimum and maximum sea surface temperatures (°C) measured at GoMOOS Buoy B in 2007. Seabrook Operational Report, 2007.

Table 2-1. Annual Means and Upper and Lower Confidence Limits and Minima and Maxima of Water Quality Parameters Measured During Plankton Cruises at Stations P2 and P7 During the Preoperational and Operational Years, and the Annual Mean, Minimum and Maximum in 2007. Seabrook Operational Report, 2007.

		PERIOD												
		Preoperational[a]					Operational Years[b]					2007		
		LCL[c]	Mean[d]	UCL[e]	min	max	LCL	Mean	UCL	MIN	MAX	Mean	MIN	MAX
Temperature (°C)														
Surface	P2	8.5	8.9	9.2	0.2	19.3	9.3	9.5	9.7	0.0	21.6	9.4	2.3	21.6
	P7	8.4	8.7	9.0	0.1	19.3	9.1	9.3	9.6	0.2	21.0	9.3	2.5	21.0
Bottom	P2	6.6	7.0	7.4	0.0	16.7	7.0	7.4	7.7	0.1	17.7	6.8	2.5	12.0
	P7	6.3	6.8	7.3	0.4	16.4	6.9	7.3	7.6	0.2	18.5	6.8	2.3	11.1
Salinity (PSU)														
Surface	P2	31.3	31.6	31.9	24.7	34.2	30.9	31.2	31.5	25.5	34.2	31.2	28.8	33.2
	P7	31.1	31.5	31.9	19.6	34.6	30.9	31.2	31.5	25.2	34.4	31.2	27.6	32.8
Bottom	P2	32.0	32.2	32.4	29.0	34.5	31.6	31.8	32.0	26.9	34.3	31.9	30.2	34.3
	P7	32.0	32.2	32.5	29.2	34.4	31.7	31.9	32.1	26.2	34.7	32.0	30.2	34.5
Dissolved Oxygen (mg/l)														
Surface	P2	9.5	9.7	9.9	6.5	16.0	9.6	9.8	9.9	4.2	13.9	10.1	8.4	11.6
	P7	9.6	9.7	9.8	6.3	16.2	9.6	9.8	9.9	5.2	14.7	10.0	8.2	11.5
Bottom	P2	9.0	9.2	9.5	6.2	16.1	8.8	9.0	9.3	2.6	12.6	9.6	7.2	11.8
	P7	8.9	9.1	9.3	4.7	16.0	8.8	9.0	9.2	3.4	12.2	9.4	6.9	11.0

[a] Preoperational years: P2 = 1979–1989
P7 = 1982–1989
[b] Operational years: P2 and P7 = 1991–2007
[c] LCL = Lower 95% confidence limit
[d] Mean of annual means
[e] UCL = Upper 95% confidence limit

equal at Station P2 and Station P7. The average surface temperatures at both stations in 2007 were warmer than the preoperational means, but below the operational period mean temperatures at Stations P2 (0.1°C) and equal at Station P7. Mean bottom water temperatures in 2007 were below the operational period means at Stations P2 (0.6°C) and P7 (0.5°C) (Table 2-1, Figure 2-5). Analysis of variance (ANOVA) did not find any significant differences in surface or bottom water temperature for the main effects of Preop-Op (Period) and Station or for the interaction between them (Table 2-2). Since the temperature increase during the operational period occurred at both the nearfield and farfield stations, it is a regional occurrence, not a localized effect due to the operation of Seabrook Station.

Heating of the surface water in the spring and summer can cause thermal stratification,

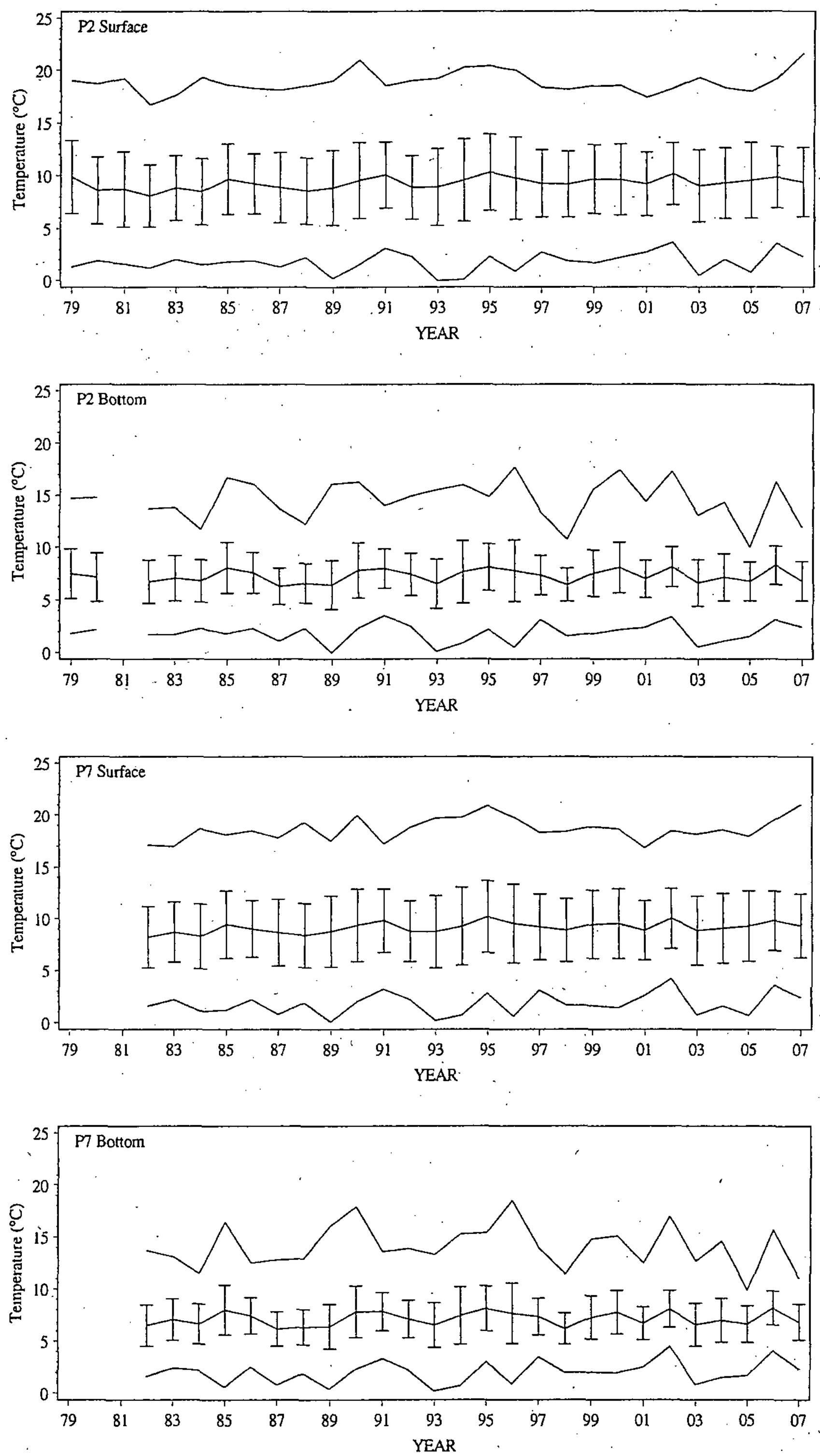


Figure 2-5. Time-series of annual means and 95% confidence intervals, and annual minima and maxima of surface and bottom temperatures (°C) at Stations P2 and P7, 1979-2007. Seabrook Operational Report, 2007.

Table 2-2. Results of Analysis of Variance Comparing Water Quality Parameters Between Stations P2 and P7 During the Preoperational (1982-1989) and Operational (1991-2007) Periods. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Surface Temperature	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 299	1.18	0.2777	
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0	0.00	0.9977	
	Month(Year)[c]	24.08	4251.37	<0.0001*	
	Station[d]	0.01	1.41	0.2355	
	Preop-Op X Station[e]	0	0.00	0.9995	
	Station X Year (Preop-Op)[f]	0	0.00	0.9977	
	Error	1.87			
Bottom Temperature	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 299	1.26	0.2634	
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0	0.00	0.9995	
	Month(Year)[c]	9.88	3296.71	<0.0001*	
	Station[d]	0.01	1.29	0.2566	
	Preop-Op X Station[e]	<0.01	0.00	0.9997	
	Station X Year (Preop-Op)[f]	0	0.00	0.9998	
	Error	1.33			
Surface Salinity	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 22.9	2.15	0.1561	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.20	18.11	<0.0001*	
	Month(Year)[c]	1.09	1347.54	<0.0001*	
	Station[d]	<0.01	0.00	0.5000	
	Preop-Op X Station[e]	0	0.00	0.5000	
	Station X Year (Preop-Op)[f]	0	0.00	0.4996	
	Error	0.55			
Bottom Salinity	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 22.9	3.73	0.0660	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.13	38.15	<0.0001*	
	Month(Year)[c]	0.38	1272.93	<0.0001*	
	Station[d]	<0.01	2.01	0.0782	
	Preop-Op X Station[e]	0	0.00	0.4996	
	Station X Year (Preop-Op)[f]	0	0.00	0.5000	
	Error	0.23			
Surface Dissolved Oxygen	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 299	0.28	0.5952	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0	0	0.4994	
	Month(Year)[c]	0.9827	1821.23	<0.0001*	
	Station[d]	<0.01	0	0.5000	
	Preop-Op X Station[e]	0	0	0.5000	
	Station X Year (Preop-Op)[f]	0	0	0.4996	
	Error	0.35			
Bottom Dissolved Oxygen	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 299	0.64	0.4255	
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	<0.01	0	0.4997	
	Month(Year)[c]	1.78	2437.81	<0.0001*	
	Station[d]	<0.01	1.51	0.1093	
	Preop-Op X Station[e]	0	0	0.5000	
	Station X Year (Preop-Op)[f]	0	0	0.5000	
	Error	0.40			

Table 2-2. (Continued)

[a] Preop-Op compares 1978-1989 to 1991-2007 regardless of station
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year. (Apr, Jul, Oct)
[d] Stations (Nearfield=P2, Farfield = P7) 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

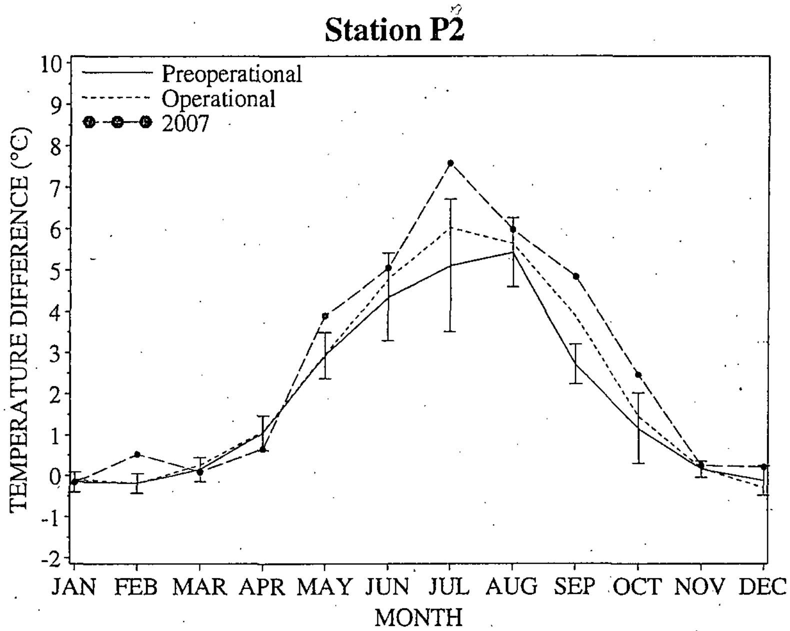
which can affect the vertical distribution of pelagic organisms and nutrient cycling. Stratification in the nearshore waters typically began in May and lasted through September (Figure 2-6). Stratification in the operational and preoperational periods at Stations P2 and P7 was similar. In 2007, stratification occurred from May through October at both stations. Monthly mean differences between surface and bottom water temperatures in 2007 were within the preoperational confidence limits except for February, May, July, September and October, when they were above the upper 95% confidence interval at both stations. The relatively cool bottom temperatures may have contributed to stratification in 2007 (Figure 2-6).

Salinity

Nearshore salinity is affected by runoff from nearby land masses, precipitation, and the mixing of water masses. Several major freshwater sources influence salinities in the nearshore area off Hampton Harbor, including the Androscoggin and Kennebec Rivers (Franks and Anderson 1992) as well as the Saco River in Maine, the Piscataqua River in New Hampshire and the Merrimack River in Massachusetts (NAI 1977).

Mean monthly surface salinity at Station P2 in 2007 was lower than the preoperational 95% confidence limits during January, May, October and November (Figure 2-7). The 2007 monthly surface salinity range (29.4 PSU in May to 32.4 PSU in February) was similar to the range of monthly means during the operational period (29.8 PSU in May to 32.2 PSU in February). The spring rainfall (10.9 cm in April 2007 and 17.0 cm in May) is likely to have caused the drop in salinities during those months. Surface salinities measured at GoMOOS Buoy B in 2007 had a similar pattern to those at Station P2 and the low for the year also occurred in May. Average monthly surface salinity during the operational period was lower than the preoperational salinity in every month, indicating that the surface water may be freshening. Bottom salinity at Station P2 in 2007 was lower than the preoperational lower confidence limits in January and October through December, and ranged from 31.2 PSU in May to 32.7 PSU in March (Figure 2-7). Average monthly bottom salinity in the operational period ranged from 31.1 PSU in May to 32.4 PSU in January and December. Average monthly bottom salinity during the operational period was lower than the preoperational salinity in every month, in part due to the low salinity values in 2005.

Annual mean surface and bottom salinities in 2007 at P2 (surface: 31.2 PSU, bottom: 31.9 PSU) and P7 (surface: 31.2 PSU, bottom: 32.0 PSU) were within the 95% confidence limits of the operational averages and the preoperational averages with the exception of bottom salinity at Station P2 which was below



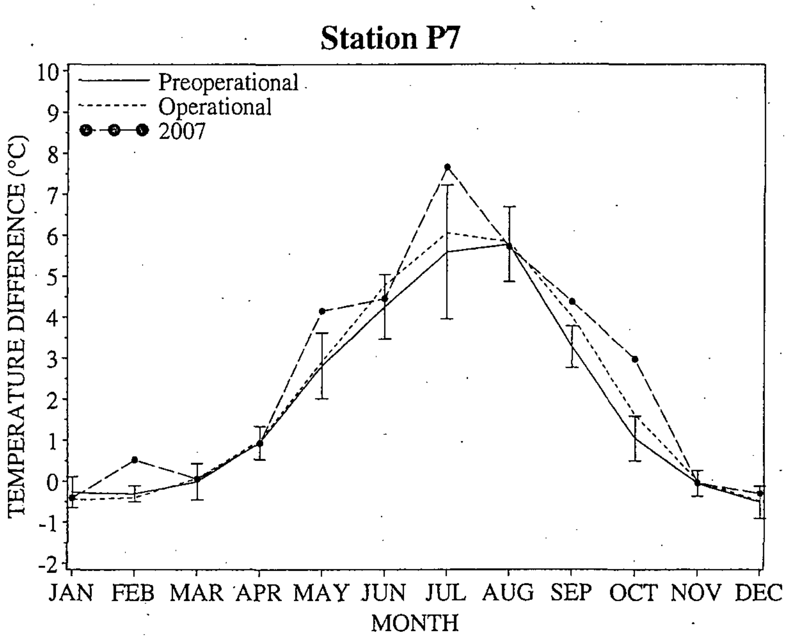


Figure 2-6. Monthly mean difference and 95% confidence intervals between surface and bottom temperatures (°C) at Stations P2 and P7 during the preoperational period (1979-1989) and monthly means during the operational period (1991-2007) and in 2007. Seabrook Operational Report, 2007.

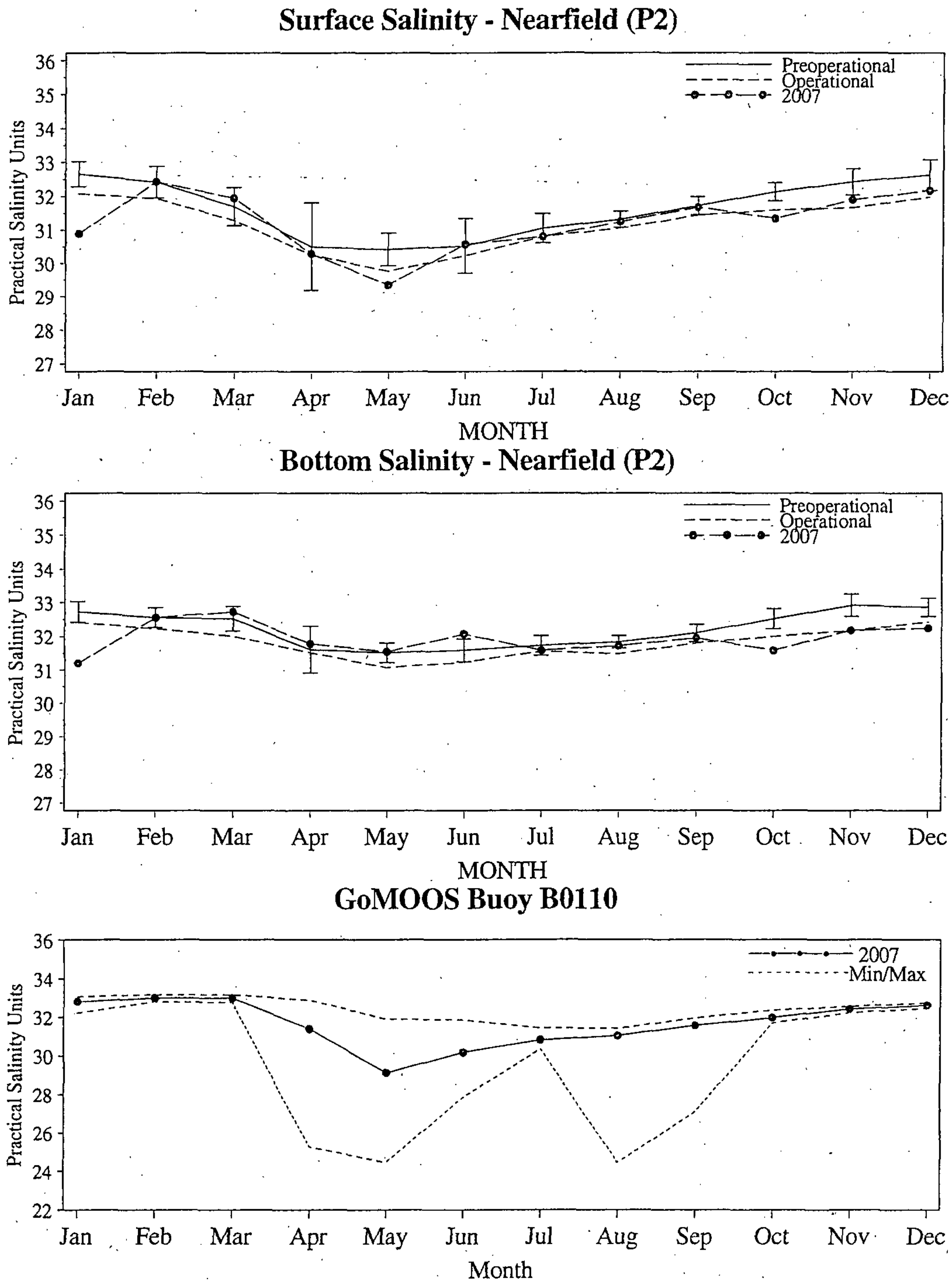


Figure 2-7. Surface and bottom monthly mean salinity and 95% confidence intervals measured during the preoperational and operational periods at Station P2, and monthly mean, minimum and maximum surface salinities (PSU) measured at GoMOOS Buoy B. Seabrook Operational Report, 2007.

the 95% confidence limits of the operational period (Table 2-1). In 2007, salinities rebounded from the lows of 2005, in part due to below normal precipitation in January and from August through November. Long-term patterns in annual surface and bottom salinity from 1982 through 2007 indicated that similar conditions and trends occurred at both stations (Figure 2-8). There were no significant differences between stations, periods (Preoperational and Operational) or for the interaction term between stations and periods, suggesting that there was no local effect at the discharge station (Table 2-2).

Average surface and bottom salinities at both stations (P2 and P7) were lower in the operational period when compared to the preoperational period (Table 2-1), although the differences were not significant (Table 2-2). Surface waters were noticeable fresher during the 1990s when compared to previous years (Drinkwater et al. 2003; Mountain 2004). Smith et al. 2001 attributed this large scale freshening to the increased freshwater and ice cover on the Labrador Shelf. The freshening of 1990s coincided with the first decade of the operation of Seabrook Station, and occurred throughout the region. Observations made at the Maine Department of Marine Resources West Boothbay Harbor long-term environmental monitoring station from 1966 through 1997 also showed a slight long-term decrease in salinity, which also suggests a regional trend. This station is fairly comparable to the Seabrook water quality stations, and it was located in a more protected location with relatively little freshwater input to the harbor. Long term (1966-1985) annual mean surface salinities (taken at -1.7m MLW) at the West Boothbay Harbor station ranged between 30 and 32 ppt (MDMR 1987), and then declined from 30.7 ppt in 1990 to 29.0 ppt in 1996, the last year that salinity was monitored (MDMR 1991, 1992, 1993, 1994, 1995, 1996, and 1997).

Dissolved Oxygen

Several factors affect dissolved oxygen in nearshore waters, including temperature, which affects the solubility of oxygen, and the mixing of water masses. Photosynthetic organisms produce oxygen, and respiration by all organisms consumes oxygen. Low dissolved oxygen levels are known to have adverse effects on many marine organisms.

Dissolved oxygen (DO) concentrations at Station P2 followed a seasonal pattern similar to that observed in previous years (Figure 2-9). Lower water temperature, phytoplankton blooms and reduced abundance of consumers increase DO concentrations in the winter and spring. In 2007, surface DO value exceeded the 95% confidence limits of the preoperational average in April, August, September, November and December. Monthly mean bottom DO values in 2007 were within the corresponding preoperational confidence limits every month except for April, August, November and December, when levels exceeded the confidence limits. The lowest monthly mean bottom DO (7.5 mg/l) occurred in October, when the thermocline was still strong (Figure 2-6). The minimum DO value (6.9 mg/l) occurred in October at the bottom at Station P7. By December, after the thermocline had dissipated, the monthly average oxygen increased to 10.2 mg/l.

The 2007 annual mean surface DO concentrations at Stations P2 and P7 (Station P2: 10.1 mg/l, Station P7: 10.0 mg/l) were above the corresponding preoperational and operational confidence limits (Table 2-1). Mean surface dissolved oxygen in 2007 at Station P2 was above the means for all years except 1980 and 2001; at Station P7 it was above the mean for all years except 2001 and 2003 (Figure 2-10). In 2007, the mean bottom dissolved oxygen levels were 9.6 mg/l and 9.4 mg/l at Stations P2 and P7, respectively, above

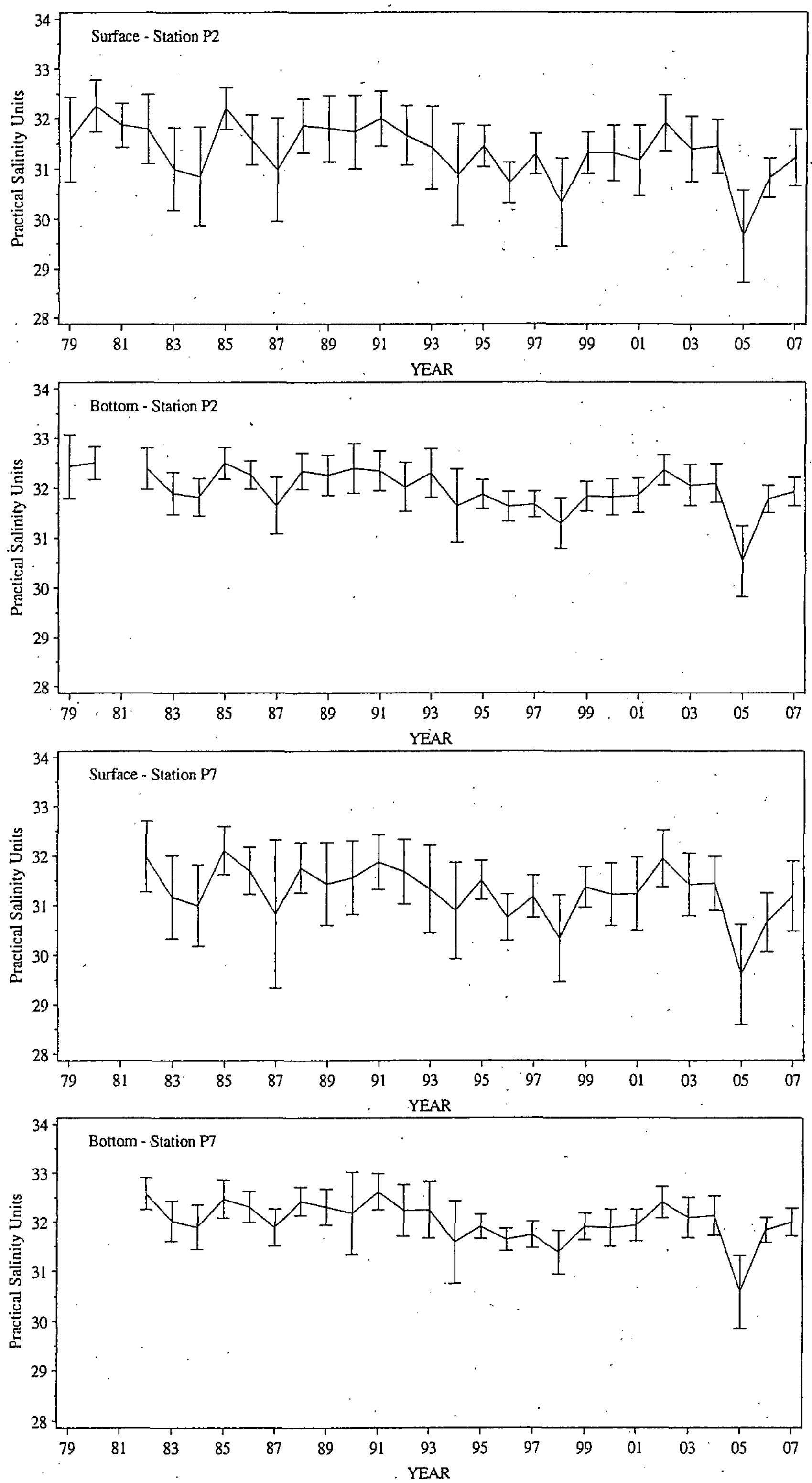
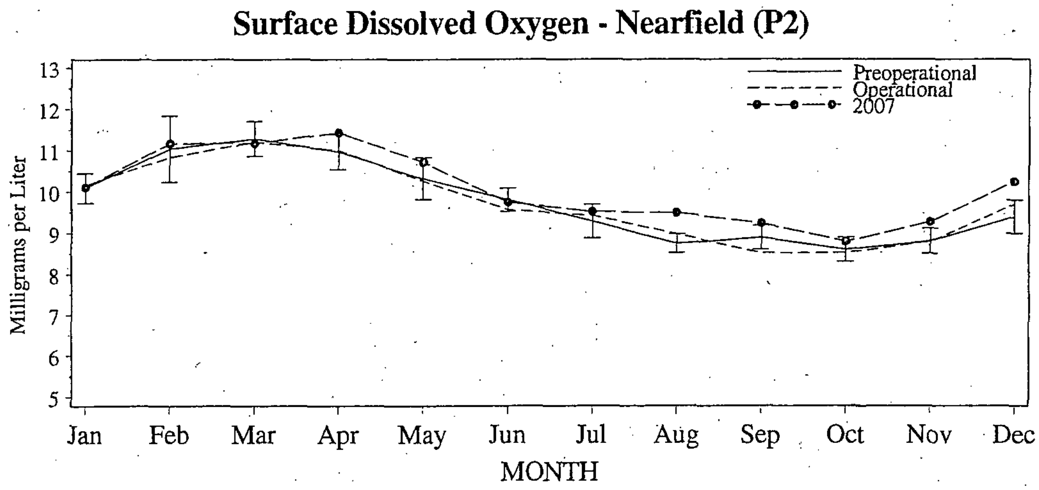


Figure 2-8. Time-series of annual means and 95% confidence intervals of surface and bottom salinity (PSU) at Stations P2 and P7, 1979-2007. Seabrook Operational Report, 2007.



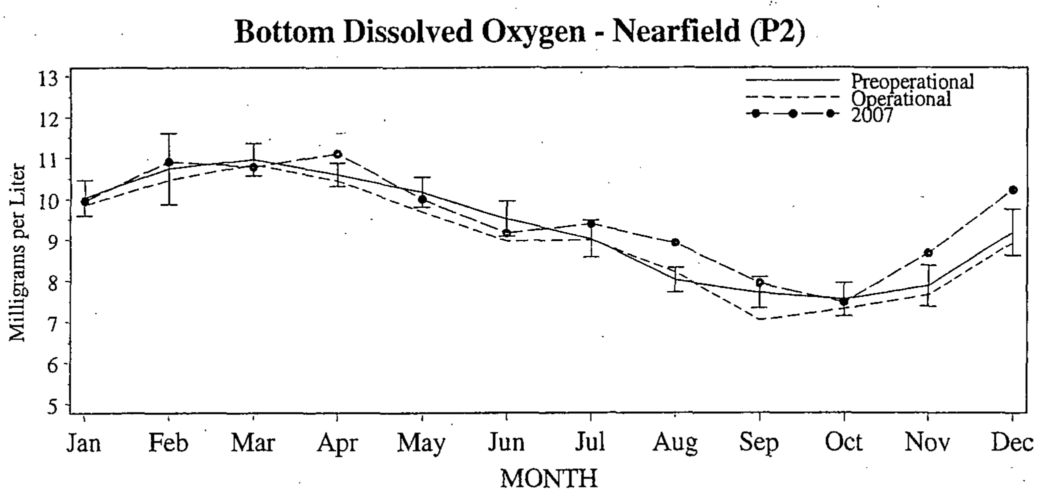


Figure 2-9. Surface and bottom dissolved oxygen (mg/l) at nearfield Station P2: monthly means and 95% confidence intervals during the preoperational and operational periods and in 2007. Seabrook Operational Report, 2007.

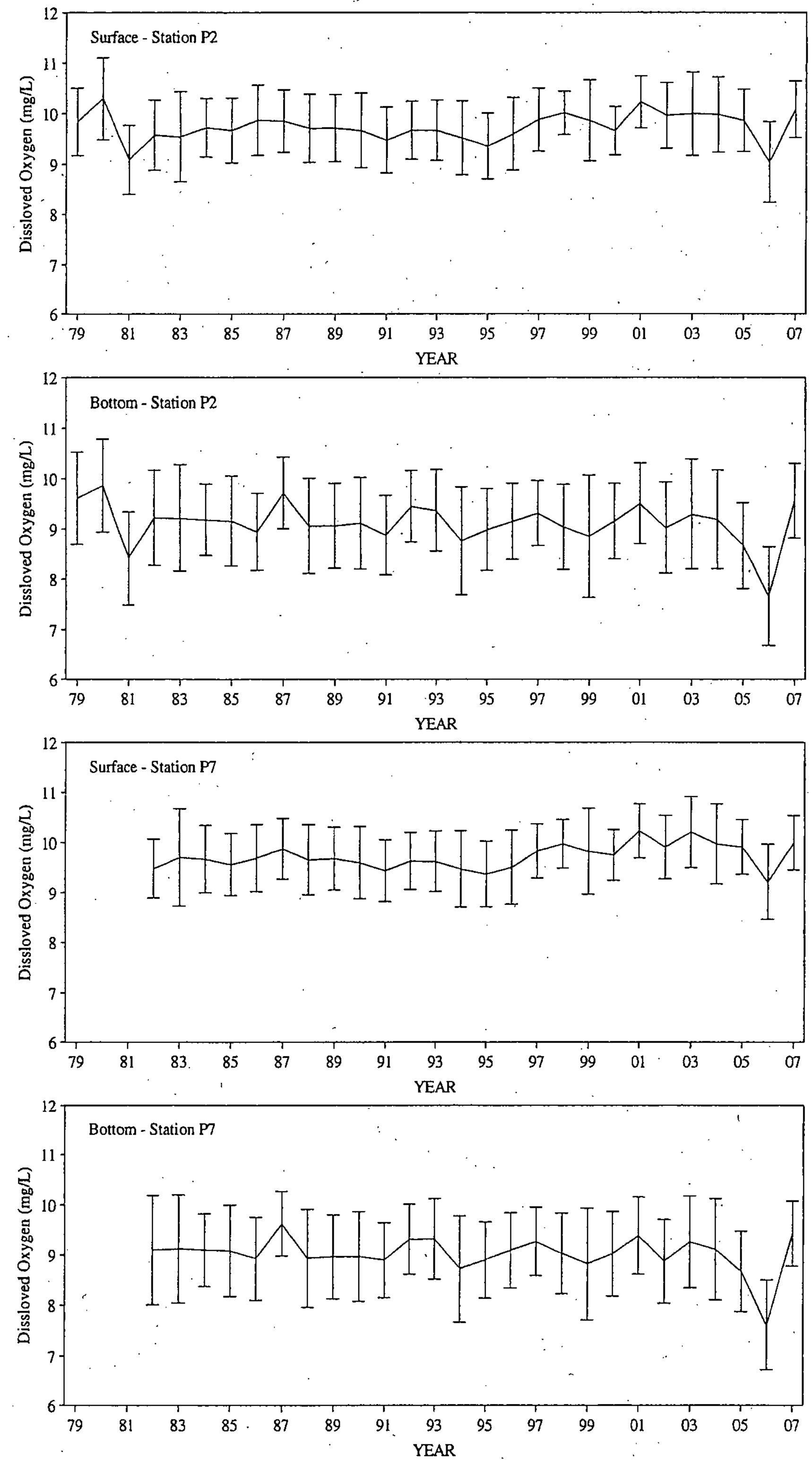


Figure 2-10. Time-series of annual means and 95% confidence intervals of surface and bottom dissolved oxygen (mg/l) at Stations P2 and P7, 1979-2007. Seabrook Operational Report, 2007.

the means for the preoperational and operational periods at both stations (Table 2-1). Annual mean bottom dissolved oxygen in 2007 at Station P2 was above the means for all years except 1979, 1980 and 1987; at Station P7 it was above the mean for all years except 1987 and 2001 (Figure 2-10). There were no significant differences between stations or periods and the interaction between stations and periods was not significant, an indication that the operation of Seabrook Station does not affect dissolved oxygen (Table 2-2).

2.3.1.2 Continuous Temperature Monitoring

Surface temperatures in 2007 and most years at the discharge (DS) and farfield (T7) stations (Figure 2-11, Appendix Table 2-1) followed the seasonal pattern observed at Stations P2 and P7 (Figure 2-4). In 2007, the monthly mean differences in temperature between the discharge jet-mixing region (Station DS) and the surrounding waters (Station T7) were always less than 5°F (2.8°C), which is in compliance with the NPDES permit (Table 2-3). During every retrieval effort divers observed Station DS to be within the thermal plume. Temperature differences in 2007 between the nearfield and farfield areas were smallest in June and September. During the period of summer stratification, in June through September, the average temperature in the discharge area was cooler than the surrounding waters, probably due to the entrainment of cooler bottom water by the discharge plume (NAESCO 1999). A similar pattern has been observed in previous years (Appendix Table 2-1). The annual mean surface temperatures at the discharge (10.5°C) and farfield (9.8°C) stations in 2007 were within the range of previous years (Table 2-4).

A 100-megawatt electric uprate was completed in November 2006, resulting in an increase in heat released into the ocean. The ocean thermal monitoring data for 2007 indicated that Seabrook Station operated well within the NPDES Permit thermal limit for the 100 megawatt electric uprate.

2.3.2 Estuarine Water Quality

Monthly averages of surface water salinity and temperature at high and low slack tides in Hampton Harbor were used to examine seasonal and annual water quality patterns in the Hampton-Seabrook estuary.

Temperature

Surface temperatures at high-tide in 2007 followed the general pattern observed at the surface in the nearshore area, as would be expected considering the proximity of the estuary station to the nearshore area, February being the coldest months for all years (Figure 2-12). Monthly mean temperatures in 2007 were above the 95% confidence limits for all years in January, June, and October and were below the historical lower confidence limits from March through May, July, August, and December. The annual mean high-tide temperature in 2007, 9.0°C, was below the average (9.4°C) for the study period (Table 2-5).

Low-tide temperatures in 2007 followed a similar monthly pattern to that observed in previous years (Figure 2-12). Monthly mean temperatures in 2007 were above the 95% confidence limits over all years in January, June, July, September and October and were below the historical lower confidence limits from February through April and December. The 2007 annual mean low-tide temperature of 10.2°C was similar to the long-term average of 10.1 (Table 2-5). The minimum temperature recorded during 2007 was -1.7°C and occurred at low tide on February 5, while the maximum was 31.1°C and occurred on July 30 at low tide.

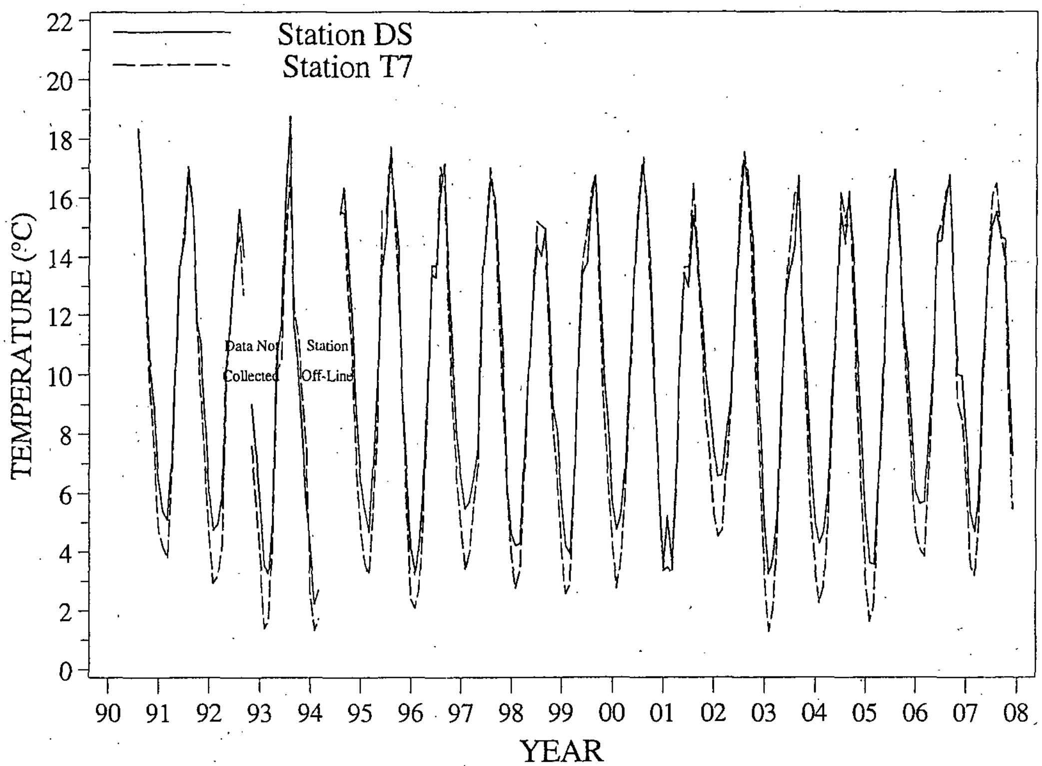


Figure 2-11. Comparison of monthly averaged continuous temperature (°C) data collected at the surface at discharge (DS) and farfield (T7) stations during commercial operation, August 1990-December 2007. Seabrook Operational Report, 2007.

Table 2-3. Monthly Mean Surface Temperature (°C) and Temperature Differences (ΔT, °C) Between Discharge (DS) and Farfield (T7) Stations Collected From Continuously-Monitored Temperature Sensors, January-December 2007 Seabrook Operational Report, 2007.

Month	2007 DS	2007 T7	2007 ΔT
Jan	8.07	6.52	1.56
Feb	5.36	3.49	1.87
Mar	4.69	3.19	1.51
Apr	5.91	5.14	0.76
May	10.49	9.92	0.57
Jun	13.49	13.64	-0.14
Jul	15.06	16.07	-1.01
Aug	15.53	16.49	-0.96
Sep	14.69	14.77	-0.07
Oct	14.61	13.83	0.78
Nov	10.76	9.06	1.70
Dec	7.24	5.46	1.79

Table 2-4. **Annual Mean Surface Temperatures (°C)[a] and 95% Confidence Limits at Stations DS and T7 During Operational Monitoring. Seabrook Operational Report, 2007.**

YEAR	DS			T7		
	LCL[b]	Mean[c]	UCL[d]	LCL	Mean	UCL
1990	8.5	13.3	18.2	7.0	12.7	18.3
1991	7.9	10.6	13.2	6.9	9.9	12.9
1992[e]	6.8	9.4	12.1	5.3	8.3	11.4
1993[f]	6.1	9.2	12.3	5.5	8.6	11.8
1994	4.6	9.4	14.3	3.3	8.3	13.4
1995	7.5	10.4	13.3	6.3	9.7	13.1
1996	6.8	9.9	13.0	5.7	9.1	12.6
1997	7.5	10.2	13.0	6.3	9.4	12.5
1998	7.0	9.6	12.1	6.1	9.1	12.0
1999	7.3	10.2	13.0	6.3	9.6	12.9
2000	7.4	10.3	13.2	6.4	9.7	12.9
2001	7.1	9.8	12.4	6.4	9.4	12.3
2002	8.5	11.1	13.6	7.1	10.1	13.1
2003	6.5	9.4	12.2	5.2	8.8	12.3
2004	7.2	10.0	12.8	5.8	9.1	12.4
2005	6.9	9.9	12.9	5.8	9.2	12.6
2006	8.2	10.8	13.3	7.0	10.1	13.1
2007	7.9	10.5	13.1	6.6	9.8	13.0

[a] Monitoring conducted by YAEC from 1991–1995.
[b] LCL = Lower Confidence Limit.
[c] Mean of monthly means.
[d] UCL = Upper Confidence Limit.
[e] Data not collected in October 1992.
[f] Data not collected from April through July 1994.

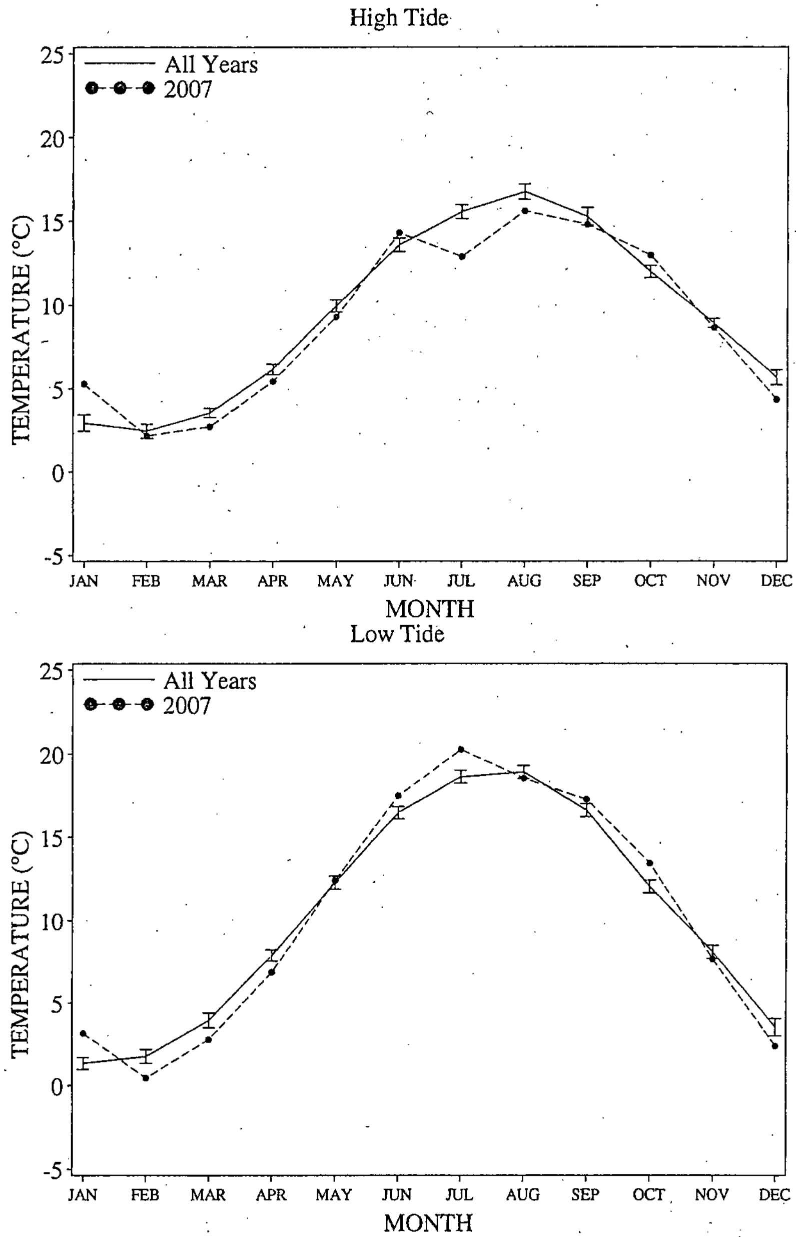


Figure 2-12. Monthly means and 95% confidence intervals of temperature (°C) measured at low and high slack tides in Hampton Harbor from May 1979 – December 2007, and monthly means in 2007. Seabrook Operational Report, 2007.

Table 2-5. Annual Mean[a] and 95% CL[b] of Temperature (°C) and Salinity (PSU) Taken at Both High and Low Slack Tide in Hampton Harbor from 1980-2007. Seabrook Operational Report, 2007.

Year	High Tide				Low Tide			
	Temp	CL	SAL	CL	Temp	CL	SAL	CL
1980	9.1	3.6	32.0	0.5	9.6	4.4	29.9	1.4
1981	9.3	3.8	31.5	0.4	10.1	4.4	28.9	1.1
1982	9.2	3.5	31.2	0.6	10.2	4.1	27.3	1.5
1983	9.9	3.4	30.1	0.9	10.4	4.3	25.5	2.4
1984	9.4	3.1	30.2	0.9	10.4	4.1	25.8	2.3
1985	10.1	3.3	32.2	0.3	10.6	4.2	29.1	1.0
1986	9.4	3.0	31.5	0.4	10.0	3.9	27.7	1.3
1987	8.9	3.5	30.7	0.9	10.0	4.3	27.5	2.2
1988	9.2	3.3	31.3	0.4	9.7	3.9	27.8	1.0
1989	9.2	3.3	31.4	0.7	10.2	4.4	28.0	1.2
1990	9.7	3.6	31.3	0.6	10.3	4.3	27.2	1.2
1991	9.8	3.1	30.9	0.4	11.1	4.0	28.0	0.9
1992	8.6	2.9	29.4	1.6	9.1	4.0	27.2	1.6
1993	8.7	3.5	29.5	1.1	9.5	4.4	26.8	1.9
1994	9.1	3.7	30.9	0.8	9.8	4.6	27.8	1.9
1995	9.9	3.4	31.5	0.2	10.2	4.3	28.7	1.4
1996	9.4	3.5	30.4	0.5	10.2	4.1	26.8	1.4
1997	9.2	3.1	31.0	0.6	9.9	4.3	28.1	1.7
1998	9.1	3.0	29.9	1.1	10.3	4.0	26.7	2.2
1999	9.9	3.4	31.1	0.5	10.5	4.4	28.5	1.6
2000	9.6	3.4	31.2	0.6	10.2	4.2	28.1	1.3
2001	9.2	3.4	31.3	0.6	10.2	4.2	27.9	3.1
2002	10.2	3.2	31.9	0.5	10.7	4.3	29.4	1.2
2003	9.2	3.8	31.3	0.6	10.3	4.0	27.3	1.9
2004	9.4	3.5	31.5	0.7	9.7	4.4	28.5	1.4
2005	9.6	3.7	29.8	0.8	10.1	4.7	25.8	1.6
2006	10.1	3.1	30.8	0.5	10.6	4.1	26.5	1.9
2007	9.0	3.2	31.2	0.6	10.2	4.6	28.0	2.0
Overall[c]	**9.4**	**0.2**	**31.0**	**0.3**	**10.1**	**0.2**	**27.7**	**0.4**

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

Salinity

Monthly mean high-tide salinities in 2007 were above the 95% confidence limits of the long-term means in February, March and August (Figure 2-13). In general, the departures from the long-term averages were smaller than those noted for low-tide salinities. In 2007, the annual average high-tide salinity was 31.1 PSU, near the long-term average of 31.0 PSU (Table 2-5).

The salinity at low tide in the estuary was affected by below average precipitation in January and from August through November. Monthly mean salinity at low tide in 2007 was above the long-term upper confidence limit in February and from July through December (Figure 2-13). Salinity in 2007 was below the long-term confidence limit in March, May and June. Annual mean salinity in 2007 at low tide was 28.0 PSU, 0.3 PSU above the long-term average of 27.7 PSU (Table 2-5). The minimum salinity recorded in 2007 was 18.6 PSU and occurred at low tide on June 6, while the maximum was 32.7 PSU an occurred at high tide on February 20.

2.4 DISCUSSION

A brief characterization of the nearshore waters is provided to aid in the interpretation of the results of monitoring the biological communities. Each parameter has a seasonal cycle that was similar in the preoperational and operational periods. Thermal stratification typically occurred in the late spring and summer. Surface waters during stratification become slightly warmer, fresher and more oxygenated than the bottom waters. When thermal stratification ended in the fall, the differences between the surface and bottom became negligible.

The nearshore waters of New Hampshire are affected by larger oceanographic patterns as well as local conditions. The North Atlantic Oscillation (NAO), the natural fluctuation in atmospheric pressure differences observed in Lisbon, Portugal and Stykkisholmur, Iceland greatly affects weather patterns on both sides of the North Atlantic (Hurrell 1995). Over the last 3 decades, the phase of the NAO has been shifting from mostly negative to mostly positive. During a positive NAO, warmer conditions prevail in the northeastern US and parts of northern Europe and the sea surface temperature reflects a warm anomaly in the mid-latitudes (Visbeck et al 2001). The positive phase of the NAO may be reflected in the slightly warmer water temperatures observed in this program.

The saline waters in the Gulf of Maine come from two primary sources. Relatively cold and low salinity water from the Scotian Shelf enters the Gulf in the surface layers around Cape Sable (Mountain 2004). Relatively warm and saline water from the offshore slope region enters the Gulf at depth through the Northeast Channel. The properties of the Scotian shelf water and the Slope water inflows have been described by Smith (1983) and Ramp et al. (1985), respectively. These two inflows progressively mix as they move in a general counterclockwise circulation around the Gulf, as the Gulf of Maine Coastal Current (GMCC). It typically diverges into the Eastern Maine Coastal Current (EMCC) and Western Maine Coastal Current (WMCC) at the mouth of the Penobscot Bay, although there is strong seasonal and interannual variability in both the strength of the current and the degree of connectivity of its principal branches (Pettigrew et al. 2005). Through extensive hydrographic surveys from 1998 through 2001, Pettigrew et al. (2005) found that in 1998 there was almost no leakage of the EMCC into the WMCC and suggested that fresher water from the Penobscot Bay comprised the bulk of the WMCC. They found that the nearshore stations on the western inner shelf (nearest to where the discharge of

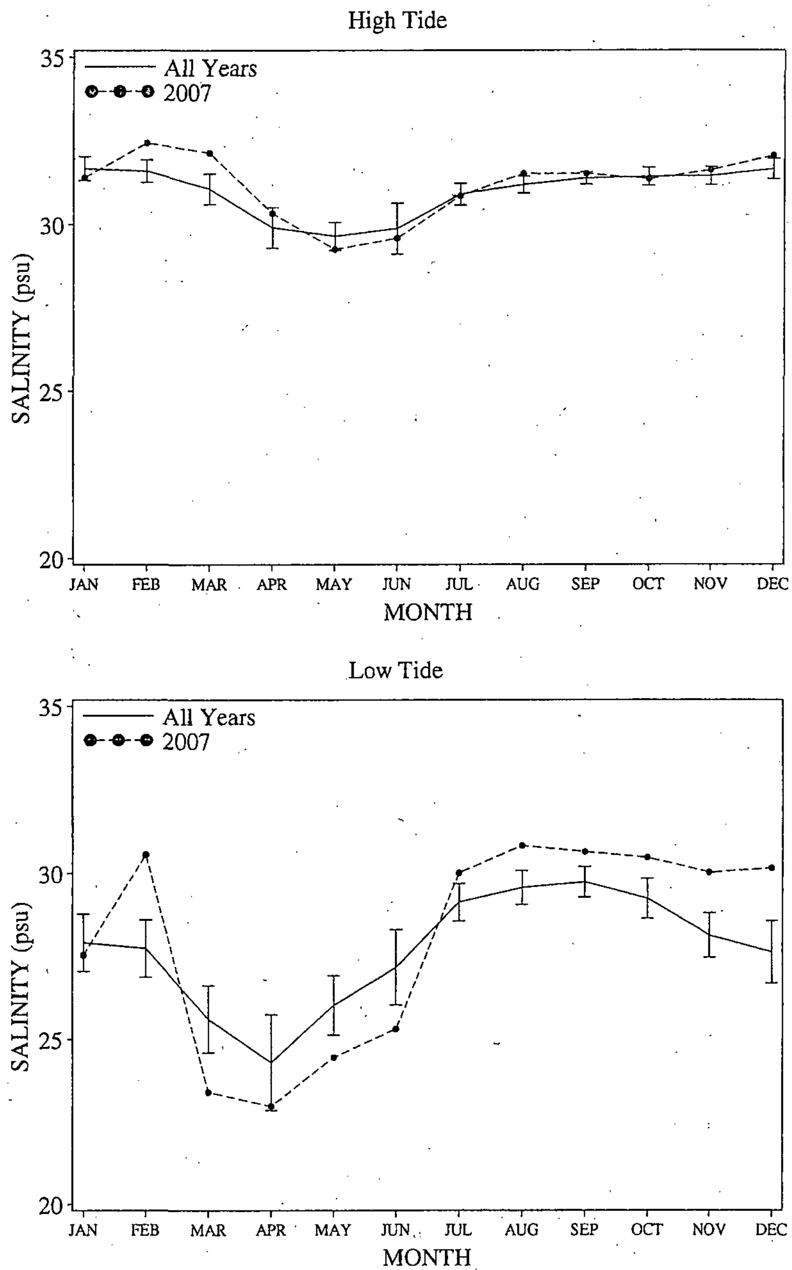


Figure 2-13. Monthly means and 95% confidence intervals of salinity (PSU) measured at low and high slack tides in Hampton Harbor from May 1979 – December 2007, and monthly means in 2007. Seabrook Operational Report, 2007.

Seabrook Station is located) were more influenced by the runoff from rivers, including the Kennebec, Saco and Merrimack Rivers, than stations further offshore. In contrast, 2000 was a year of almost continuous flow of the EMCC into the WMCC (Pettigrew et al. 2005). In 1998, the average annual salinity at both stations was the second lowest of the time series at both stations, while 2000 was a year of near average salinity (Figure 2-8). Although the offshore water masses can influence the coastal waters containing runoff from rivers on the inner shelf of the western Gulf of Maine, these interactions are not completely understood.

There were few differences in temperature between the operational and preoperational periods. Average sea surface temperatures were higher (by 0.6°C at P2 and P7) in the operational period (Table 2-1), but the difference was not significant (Table 2-2). A comparison of monthly (Figure 2-3) and annual means (Figure 2-5) suggested that the differences occurred at both stations, indicating an area-wide trend. At nearfield station P2, monthly means in the operational period were higher than preoperational means each month (Figure 2-3). Similarly, monthly mean bottom temperatures from the operational period were higher than the means from the preoperational period each month except July. Annual mean surface temperatures in the nearfield and farfield areas in 2007 were above the preoperational averages, while bottom temperatures were above (Station P2) or equal to (Station P7) the preoperational averages (Table 2-1). Monthly mean bottom water temperatures in 2007 were above the 95% confidence limits of the preoperational mean in January and below them in May and September (Figure 2-3).

In both the nearfield and farfield areas, surface and bottom salinity averages were slightly lower during the operational period when compared to the preoperational period (Table 2-1). There were no significant differences between periods or for the interaction terms, confirming that these changes occurred at both nearfield and farfield stations. In 2007, the surface and bottom salinities at the nearfield and farfield stations were higher than the previous two years (Figure 2-8). The average annual surface salinity in 2007 was equal to the operational averages at both stations, while the bottom salinity was above the operational averages at both stations (Table 2-1). In 2007, near-drought conditions prevailed in late summer and fall, and may have contributed to the increased salinity. Although very high rainfall in spring 2006 temporarily flooded estuaries and nearshore waters with freshwater, salinities were higher than in 2005 when heavy spring runoff (after a total snowfall that was twice the average) and heavy rainfall in October, contributed to record low surface salinities.

There were few differences among annual mean dissolved oxygen values between the operational and preoperational periods at the nearfield and farfield stations (Table 2-1). At the surface at both the nearfield and farfield stations, the operational values were 0.1 ppm higher than the preoperational values. Bottom dissolved oxygen values were slightly higher during the preoperational period when compared to the operational period, but there were no significant differences between periods at either the surface or bottom (Table 2-2). Average surface monthly dissolved oxygen levels during the operational period at the nearfield station were within the confidence limits of the preoperational period in every month except September (Figure 2-9). Bottom values were also within the confidence limits of the preoperational period, except in May, June and September when they were below the lower confidence limits. In 2007, the lowest average monthly dissolved oxygen levels occurred in October at the surface (8.8

mg/l) and at the bottom (7.5 mg/l) (Figure 2-9). Bottom dissolved oxygen values did not approach values that may be a cause of concern for marine life.

Regional climatic conditions in 2007 indicate that the annual temperature was equal to the historical average and rainfall was 7.8 cm below normal, with near-drought conditions prevailing from August through November. Snowfall in 2007 (111.8 cm) was nearly normal (111.4 cm) (Boston Sunday Globe 2007). This is reflected in the water quality conditions observed during the year, especially for annual salinity which increased over the previous two years (Figure 2-7) and equaled the operational average (Table 2-1). The mean annual surface temperature was within the 95% confidence limits of the operational period; however, the bottom temperature was below the confidence limits at both stations.

Water quality collections were also used to assess potential plant impacts. Potential impacts include elevated temperature and the corresponding decrease in dissolved oxygen. The continuous temperature monitors indicated that the average monthly temperature in the discharge plume was typically less than 2°C warmer than the surrounding waters (Figure 2-11), which indicates compliance with the NPDES permit.

No effects from the operation of the Seabrook Station were detected in the nearshore environment (Table 2-6). The nearfield station was similar to the farfield station. There was no interaction between Period (Preop-Op) and station, which would be significant if a change had occurred due to plant operation. In addition, inspection of monthly and annual patterns did not reveal differences due to plant operation.

Table 2-6. Summary of Potential Effects of Seabrook Station on Ambient Water Quality. Seabrook Operational Report, 2007.

Parameter	Depth	Operational Period Similar to Preoperational Period?[a]	Spatial Trends Consistent with Previous Years?[b]
Temperature	Surface	Yes	Yes
	Bottom	Yes	Yes
Salinity	Surface	Yes	Yes
	Bottom	Yes	Yes
Dissolved Oxygen	Surface	Yes	Yes
	Bottom	Yes	Yes

[a] Based on BACI model ANOVA for 1982-2007, when both stations were sampled concurrently.
[b] Significant Preop-Op X Station term in BACI model ANOVA.

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Appendix Table 2-1. Monthly Mean Surface Temperatures (°C) and Temperature Differences (ΔT, °C) Between Discharge (DS) and Farfield (T7) Stations Collected from Continuously-Monitored Temperature Sensors, August 1990-December 2007. Seabrook Operational Report, 2007

Month	1990[a]			1991			1992			1993			1994		
	DS[b]	T7	ΔT[c]	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS[d]	T7	ΔT
JAN	--	--	--	6.47	4.71	1.76	6.02	4.32	1.70	5.69	3.80	1.89	4.12	2.57	1.55
FEB	--	--	--	5.38	4.17	1.21	4.74	2.92	1.82	3.52	1.38	2.14	2.23	1.32	0.91
MAR	--	--	--	5.11	3.78	1.33	4.94	3.16	1.78	3.26	1.63	1.63	2.69	1.73	0.96
APR	--	--	--	6.99	6.37	0.62	5.93	4.26	1.67	5.04	4.44	0.60	--	--	--
MAY	--	--	--	10.43	10.21	0.22	10.52	10.32	0.20	10.74	10.02	0.72	--	--	--
JUN	--	--	--	13.81	13.70	0.11	11.94	11.84	0.10	11.65	10.53	1.12	--	--	--
JUL	--	--	--	14.58	15.02	-0.44	13.81	14.16	-0.35	15.92	14.54	1.38	--	--	--
AUG	18.16	18.36	-0.20	16.86	17.06	-0.20	15.61	14.69	0.92	18.77	16.69	2.08	15.44	15.53	-0.09
SEP	16.31	16.09	0.22	15.66	15.69	-0.03	14.03	12.69	1.34	11.62	12.19	-0.57	16.33	15.47	0.86
OCT	13.04	12.11	0.93	11.87	11.68	0.19	--	--	--	10.13	11.27	-1.14	13.94	12.69	1.25
NOV	10.24	9.44	0.80	11.00	9.33	1.67	9.01	7.59	1.42	8.03	9.33	-1.30	11.77	10.37	1.40
DEC	8.91	7.32	1.59	8.45	6.81	1.64	7.32	5.61	1.71	5.64	7.55	-1.91	8.74	6.90	1.84

Month	1995			1996			1997			1998			1999		
	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT
JAN	6.37	4.66	1.71	4.08	2.40	1.68	6.57	4.91	1.66	4.64	3.89	0.75	5.72	3.97	1.76
FEB	5.41	3.54	1.87	3.21	2.07	1.14	5.47	3.37	2.10	4.21	2.75	1.46	4.19	2.56	1.63
MAR	4.67	3.23	1.44	4.20	2.69	1.51	5.71	4.03	1.68	4.29	3.31	0.98	3.92	2.84	1.08
APR	6.86	5.33	1.53	6.06	5.00	1.06	6.48	5.53	0.95	7.17	6.39	0.78	6.25	6.23	0.02
MAY	9.56	8.20	1.36	9.57	9.26	0.31	7.52	6.91	0.61	9.82	9.84	-0.02	10.46	10.61	-0.14
JUN	13.63	15.58	-1.95	13.40	13.72	-0.32	13.46	13.33	0.13	12.19	12.29	-0.10	13.41	13.99	-0.59
JUL	14.76	15.48	-0.72	13.29	13.68	-0.39	14.89	15.21	-0.32	14.39	15.19	-0.80	13.81	14.94	-1.13
AUG	17.40	17.71	-0.31	16.10	17.04	-0.94	16.60	17.01	-0.41	14.01	15.06	-1.05	15.81	16.21	-0.39
SEP	15.93	15.28	0.65	17.14	16.22	0.92	16.01	15.51	0.50	14.84	14.95	-0.11	16.71	16.82	-0.12
OCT	14.27	13.08	1.19	13.24	11.97	1.27	13.21	11.97	1.24	12.04	10.88	1.16	13.29	12.05	1.24
NOV	9.17	9.11	0.06	10.55	8.90	1.65	10.53	9.02	1.51	8.89	8.04	0.86	10.28	8.83	1.44
DEC	6.76	5.53	1.23	7.90	6.51	1.39	6.27	5.98	0.29	8.13	6.52	1.61	8.46	6.47	1.99

(continued)

Appendix Table 2-1. Continued

Month	2000			2001			2002			2003			2004		
	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT
JAN	5.72	4.17	1.55	3.49	3.34	0.15	7.33	5.32	2.01	4.96	3.12	1.84	4.99	3.39	1.60
FEB	4.75	2.74	2.01	5.23	3.48	1.75	6.56	4.53	2.03	3.23	1.28	1.94	4.28	2.24	2.04
MAR	5.32	3.89	1.42	3.69	3.27	0.42	6.62	4.76	1.86	3.82	2.02	1.80	4.71	2.79	1.92
APR	6.79	5.97	0.82	6.15	5.88	0.27	8.09	6.83	1.27	5.34	4.55	0.79	5.91	5.07	0.84
MAY	10.32	9.63	0.69	11.11	10.77	0.34	9.07	8.86	0.21	9.08	8.64	0.44	9.27	8.63	0.64
JUN	13.27	13.29	-0.02	13.41	13.66	-0.25	12.36	12.18	0.18	12.66	12.96	-0.29	12.41	12.33	0.08
JUL	15.71	15.93	-0.23	12.95	13.67	-0.72	14.79	15.61	-0.82	13.53	14.60	-1.07	15.47	16.21	-0.74
AUG	17.05	17.37	-0.32	15.38	16.46	-1.08	17.13	17.55	-0.42	14.32	16.09	-1.77	14.42	15.29	-0.87
SEP	15.89	15.31	0.58	14.07	14.17	-0.11	16.92	16.18	0.74	16.74	16.51	0.23	16.19	15.91	0.28
OCT	13.46	12.48	0.97	12.45	11.48	0.97	14.72	13.23	1.49	11.82	11.57	0.24	14.28	12.89	1.39
NOV	9.37	9.31	0.07	10.18	8.70	1.48	11.12	9.49	1.63	10.03	8.56	1.48	10.61	8.83	1.78
DEC	6.28	6.15	0.13	8.99	7.33	1.66	8.26	6.33	1.93	7.04	5.12	1.93	7.89	6.02	1.87

Month	2005			2006			2007		
	DS	T7	ΔT	DS	T7	ΔT	DS	T7	ΔT
JAN	5.29	3.07	2.22	6.07	4.71	1.36	8.07	6.52	1.56
FEB	3.63	1.62	2.01	5.66	4.08	1.57	5.36	3.49	1.87
MAR	3.57	2.16	1.41	5.71	3.83	1.87	4.69	3.19	1.51
APR	6.11	6.10	0.01	7.79	6.40	1.39	5.91	5.14	0.76
MAY	9.06	8.72	0.34	9.71	9.30	0.41	10.49	9.92	0.57
JUN	13.21	13.46	-0.25	14.48	14.74	-0.26	13.49	13.64	-0.14
JUL	16.21	15.96	0.25	14.56	15.18	-0.62	15.06	16.07	-1.01
AUG	16.94	16.94	0.00	15.88	16.21	-0.33	15.53	16.49	-0.96
SEP	14.51	14.99	-0.48	16.76	16.51	0.25	14.69	14.77	-0.07
OCT	11.78	11.22	0.56	12.53	12.48	0.05	14.61 [e]	13.83	0.78
NOV	10.44	9.37	1.07	10.01	9.06	0.94	10.76	9.06	1.70
DEC	8.32	6.69	1.54	9.95	8.44	1.51	7.24	5.46	1.79

[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.
[e] No data collected from October 21 – 29, 2007.

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3.0 SUMMARY

The zooplankton community was monitored by sampling bivalve larvae and macrozooplankton. For analytical purposes, the macrozooplankton were further divided into holoplankton, meroplankton and hyperbenthos assemblages.

Large-scale multi-year trends were observed in both the bivalve larvae and holoplankton assemblages. In general, annual abundances were low through the 1980s and increased substantially in the 1990s. Since 2003 annual abundances have been lower and are similar to levels observed in the 1980s. This same pattern was observed for both assemblages. In contrast to the large temporal trends, spatial differences were small. For both bivalve larvae and holoplankton, abundances in the nearfield and farfield areas followed almost identical trends.

Trends in the holoplankton assemblage in coastal New Hampshire are very similar to trends reported in the Gulf of Maine and on Georges Bank. The large increase in abundance in the 1990s of *Centropages typicus* and the dominance of the community by *Calanus finmarchicus* in the 1980s and recent years was observed at both the nearfield and farfield sites and throughout the Gulf of Maine. Factors affecting the holoplankton assemblage occur on a regional scale and there was no indication of a plant effect.

The meroplankton assemblage appears unaffected by plant operation and has remained relatively consistent through most of the study. This is attributed to the ubiquitous nature of most of the adult populations. Recent trends characterized by slightly lower abundances of the dominant species appear related to the reduction in replication that began in 1996 and do not suggest a plant effect.

Station differences have historically been observed for the hyperbenthos, probably the result of the tendency to sample Station P7 near dusk and considerably earlier than Station P2. The hyperbenthos assemblage from 1991 to 1995, the first 5 years of plant operation, was very similar to the assemblage observed in the preoperational period. Following method changes in 1996, densities of hyperbenthic taxa, especially the larger peracarid species have been dramatically reduced at Station P7, the control site. Since estimates of abundances observed since 1996 are probably influenced by a reduction in replication, and that operational period collections before the method change were similar to the preoperational period, a plant impact is unlikely.

Based on ANOVA results, there were no indications of plant impact on the larvae of the bivalve *Mytilus edulis*, the holoplanktonic *Calanus finmarchicus,* the meroplanktonic *Carcinus maenas* and *Crangon septemspinosa*, or the hyperbenthic *Neomysis americana*. Station differences were observed for the mysid shrimp *Neomysis americana*, attributed to the tendency to sample Station P7 earlier. Despite relatively large annual variation, multi-year trends were observed for each of the selected species. However, these trends occurred simultaneously at both the nearfield and control site and do not appear related to plant operation. In 2007, the seasonal patterns for *Crangon septemspinosa* and *Neomysis americana* were atypical of previous years.

The total number of bivalve larvae entrained in 2007 was $5,820 \times 10^9$, the fourth lowest when compared to all other years (411×10^9 to $67,415 \times 10^9$). *Anomia squamula* was the most commonly entrained bivalve in 2007, followed distantly by *Mytilus edulis* and *Hiatella* sp., the usual dominants. Unlike previous years, most larvae were entrained in October instead of June or July. This was attributed to very high abundances of *Anomia squamula* in the nearshore waters in mid-October. The density (no./m^3) of bivalve larvae in the entrainment samples is considerably greater than in the coastal waters during the summer months. This was attributed to the mid-water intake of the cooling system and seasonal changes of depth distribution of bivalve larvae.

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3.1 INTRODUCTION

Potential effects of the operation of coastal power plants on zooplankton include entrainment into the cooling water system and exposure to the thermal plume. Mortality due to entrainment varies among power plants and is dependent on site-specific features such as the degree of mechanical stress caused by pumping velocities, the magnitude of the temperature increase and the application of anti-fouling biocides such as chlorine (Capuzzo 1980). Entrainment can also alter respiration rates and lower egg production rates in entrained individuals. To investigate potential effects, the nearshore zooplankton community in the vicinity of Seabrook Station was monitored.

For purposes of monitoring, the zooplankton community is divided into four assemblages: holoplankton, meroplankton, hyperbenthos and bivalve larvae. Holoplankton species, represented mostly by copepods, cladocerans and euphausiids, are planktonic throughout their entire life cycle. Meroplankton includes species that spend a distinct portion of their life cycle in the plankton and is represented by the larvae of benthic invertebrates and medusoid forms of hydrozoans. The hyperbenthos (Mees and Jones 1997) includes benthic species that migrate into the water column on a regular basis and organisms that are spatially concentrated in the water immediately adjacent to the bottom. The hyperbenthic assemblage includes mysids, amphipods, cumaceans and some polychaetes. Holoplankton, meroplankton, and hyperbenthos are all components of the macrozooplankton. The bivalve larvae assemblage is a subset of both the meroplankton and microzooplankton. This assemblage represents most of the local species that produce planktotrophic larvae and includes several commercially and recreationally important species. Each of the four assemblages was analyzed separately because of differences in ecological function and abundances.

3.2 METHODS

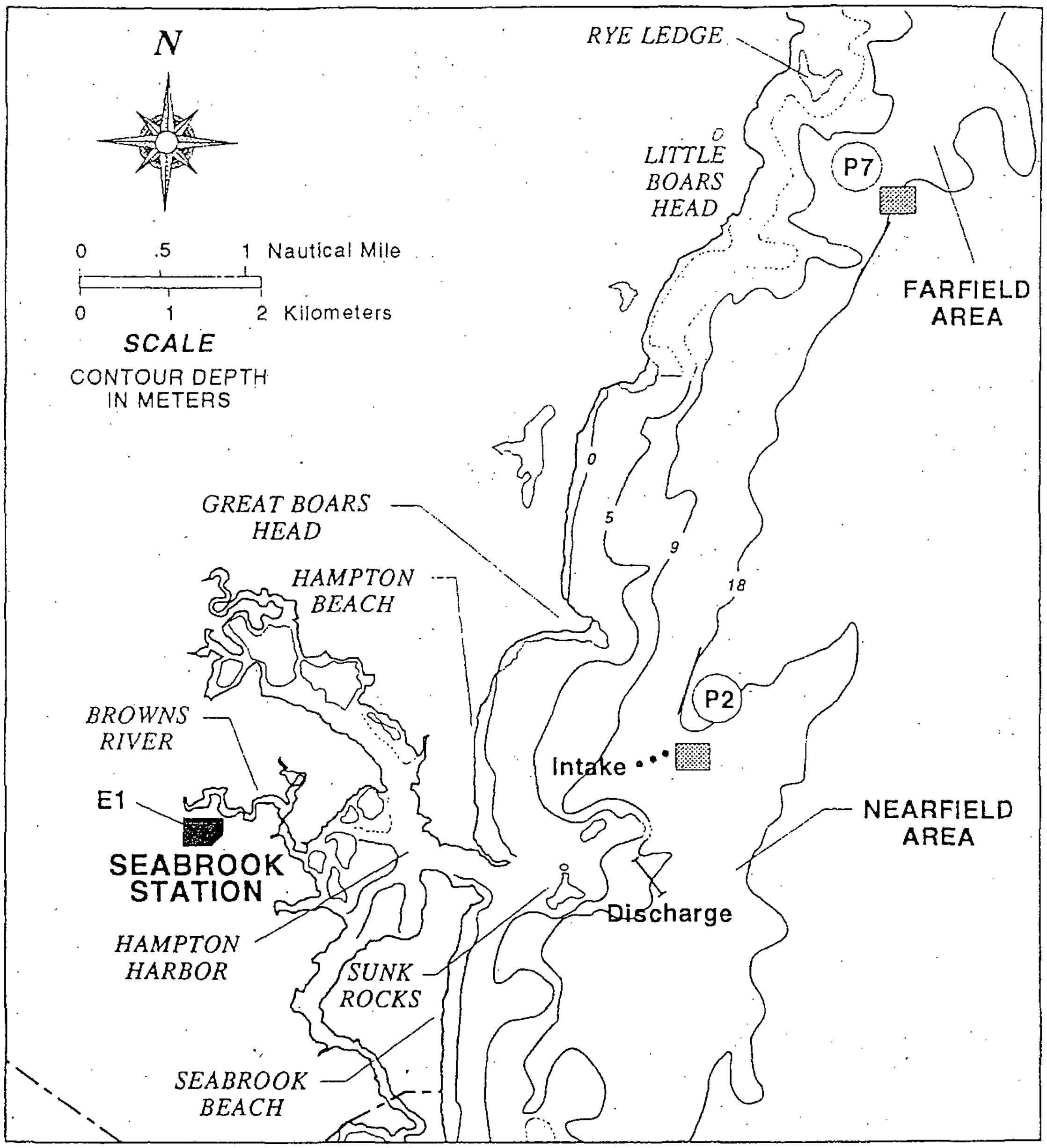
3.2.1 Field Methods

3.2.1.1 Bivalve Larvae

The spatial and temporal distributions of umbonate 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 Stations P2 and P7 during daylight (Figure 3-1). Sampling began at Nearfield Station P2 in July 1976. Farfield Station P7 was added to the program in 1982. Two simultaneous oblique tows were usually taken at each station. The volume of water filtered was recorded with a General Oceanics® flowmeter. In cases when nets clogged during oblique tows, vertical tows were taken. Nets were deemed clogged if the number of flowmeter revolutions for an oblique tow was less than 900. Volume filtered generally averaged 9 m^3 for oblique tows and 3 m^3 for vertical tows. Upon recovery, net contents were preserved with 1-2% borax buffered formalin (with sugar added to enhance color preservation) and refrigerated.

3.2.1.2 Bivalve Larvae Entrainment

Bivalve larvae entrainment sampling was conducted weekly during the day from the third week in April through October within the circulating water pump house (Station E1; Figure 3-1) at Seabrook Station from June 1990 to October 2007. Sampling dates coincided with offshore bivalve larvae sampling when possible. Samples were taken using a double barrel collection system. A 0.076-mm mesh plankton net was deployed in a 30-gallon drum that 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



LEGEND

——— = zooplankton stations

▒ = bivalve larvae stations

E1 = Seabrook Entrainment Station

Figure 3-1. Plankton and entrainment sampling stations. Seabrook Operational Report, 2007.

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.

3.2.1.3 Macrozooplankton

Macrozooplankton samples were collected at Stations P2 and P7 (Figure 3-1). Station P2 was sampled from January 1978 through December 1984, and from July 1986 through December 2007. Station P7 was sampled from January 1982 through December 1984 and from July 1986 through December 2007.

Macrozooplankton collections were made after sunset, twice per month concurrent with ichthyoplankton sampling. Prior to January 2006 sampling started 30 minutes after sunset. Starting January 2006 sampling began at nautical twilight which was generally at least 1 hour after sunset, based on U.S. Naval Observatory tables. On each date, paired oblique tows were made with 1-meter diameter 0.505-mm mesh nets at each station. Prior to 1998, two sets of paired oblique tows were made, generating four replicates. From 1998 through 2007, a single paired oblique tow was made. 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 meters off the bottom and to rise to the surface at least twice during the tow. When nets were clogged with plankton blooms, the nets were redeployed and the tow duration was shortened to 5 minutes. Nets were deemed clogged if the number of flowmeter revolutions for a 10 minute tow was less than 20,000. 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.

3.2.2 Laboratory Methods

3.2.2.1 Bivalve Larvae

Bivalve larvae samples from offshore and entrainment sampling were handled identically in the laboratory. Only umbonate larvae were counted. When the total number of larvae collected ranged from 1-600, the entire sample was processed. Samples were split when the total bivalve larvae count exceeded 600 specimens and two subsample fractions were examined. Umbonate larvae were identified and enumerated with a dissecting microscope from an established species list (Appendix Table 3-1). Specimens of other species were enumerated as Bivalvia. Samples collected in 1976 and 1977 were analyzed for *Mya arenaria* only. Samples collected in 1985 at Station P2 were analyzed for *Mytilus edulis* and *Mya arenaria* only; Station P7 samples were not processed in 1985. Species counts were converted to density by multiplying each 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. Bivalve larvae abundances for the community analysis and selected species were reported as no./1000 m^3.

3.2.2.2 Macrozooplankton

Prior to 1996, macrozooplankton were analyzed from three of the four replicates (randomly selected) at each station. From 1996 to 2007, only the first of the two replicates was analyzed. Species identified in the macrozooplankton samples follow an established list (Appendix Table 3-1). Copepods were analyzed by concentrating or diluting the sample to a known volume from which a 1-ml subsample of approximately 150 copepods could be obtained. The sample was agitated with a Hensen-Stempel pipette to distribute the contents homogeneously and a 1-ml aliquot was removed and

Table 3-1. Attributes of Data Used in Analysis of Zooplankton Communities and Selected Species. Seabrook Operational Report, 2007.

Analytical Method	Stations	Years	Data Characteristics
Community			
Cluster, MDS	P2	1978-1984 1987-2007[a]	Annual $\bar{x}$ of each taxon. Deleted all species occurring in <10%, family level taxa occurring in <20% and order level or higher taxa occurring in <50% of collections. Also deleted Bivalvia, *Macoma balthica*, *Teredo navalis*, Gastropoda, *Bougainvillia principis* and Polychaeta. Parasitic organisms were also deleted. Annual means computed from collection date means of log (x+1) transformed replicate data.
	P7	1982-1984 1987-2007[a]	
ANOSIM	P2, P7	1982-1984 1987-2007[a]	
Selected Species			
Geometric means (weekly, monthly or annual)	P2	1978-1984 1987-2007[a]	Collection date mean; all replicates log (x+1) transformed prior to average. Annual and monthly means were computed from collection date mean.
	P7	1982-1984 1987-2007[a]	
ANOVA	P2, P7	1982-1984 1987-2007[a]	*Mytilus edulis* = half-monthly mean. All others = monthly mean.

[a] Bivalve larvae were also sampled in 1986 and the data are included.

examined with a dissecting microscope. Subsampling continued until at least 30 of the numerically dominant species and a minimum of 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.

To enumerate less common 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 50X. Macrozooplankton counts were converted to density using the procedure described for bivalve larvae. Abundances were reported as no./1000 m^3.

3.2.3 Analytical Methods

3.2.3.1 Communities

Community structure was evaluated by non-parametric multivariate analyses as presented by Clarke and Warwick (1994). The data set was reduced by eliminating rarely occurring organisms and some higher order taxa (Table 3-1). To increase the relative importance of less common taxa in the analyses, abundance data from each replicate were log10 (x+1) transformed prior to use. Community analyses were performed separately for the three components of the macrozooplankton because of large differences in abundance (several orders of magnitude) among the groups. Replicate data were averaged to compute collection date, monthly and annual means. Annual means for each taxon were used to compute the Bray-Curtis Similarity Index

(Clifford and Stephenson 1975; Boesch 1977) between all combinations of station and year.

Using similarity indices, temporal and spatial patterns in the plankton communities were evaluated by hierarchical clustering and non-metric multi-dimensional scaling (MDS). The numerical classification presented a dendrogram with station and year combinations grouped by their similarity. Since the Bray-Curtis Similarity Index is affected by the degree of data transformation, all similarity values presented in the cluster were interpreted as relative rather than absolute. Relationships between years and stations were displayed as a two-dimensional plot using MDS. The relative position of the station and year combinations could then be used to interpret trends between stations and between the preoperational and operational years. For both displays, a potential plant impact would be indicated if all or most of the Station P2 collections from the operational years were grouped together and distinct from the other combinations.

Species abundances were determined to provide more detailed information on how community composition and individual species relate to plant operation. The mean and 95% confidence limits were determined for each of the dominant taxa from groups that were formed by numerical classification. Dominant taxa were defined as taxa that contributed more than 2% of the total geometric mean density in any group.

Spatial and temporal differences in the zooplankton community were also assessed by the analysis of similarities (ANOSIM) procedure (Clarke 1993). Tests for differences between treatment main effects, period and station, were provided by a two-way ANOSIM (Clarke and Warwick 1994). According to the before-after-control-impact (BACI) design (Stewart-Oaten et al. 1986), potential plant impacts would appear as an interaction between treatment main effects. The ANOSIM procedure cannot directly test for the interaction of main effects (Preop-Op, Station), but the interaction can be determined indirectly, provided there are no differences between stations in the preoperational period (Clarke 1993). Therefore, the interaction of main effects was tested using a two-stage procedure. First, the preoperational period was tested for station differences using a one-way ANOSIM. If there were no significant differences between stations in the preoperational period, then each station was tested for differences between periods using a one-way ANOSIM. If there were significant differences between periods for either station, the results were compared with the MDS and numerical classification for aid in interpretation and to account for accumulating Type I error. A 5% significance level for the test statistic was assumed to be ecologically meaningful. In cases where a significant interaction was indicated, the assemblage was further analyzed using SIMPER (Clarke and Warwick 1994) which computes a dissimilarity coefficient for each species and attempts to determine which species contributed greatest to the differences between stations in the operational period. Annual densities for each species were standardized prior to use by SIMPER. Species were ranked by their contribution to the overall dissimilarity and all species that accounted for 90% of the cumulative dissimilarity between stations were presented.

Weekly untransformed densities of bivalve larvae in entrainment samples were multiplied by the weekly volume of water pumped through the cooling water system of Seabrook Station to determine the number of larvae entrained. Weekly estimates were summed to produce monthly and annual estimates. In order to directly compare the nearshore station with the entrainment station, total larval density (no./m^3) was computed for each biweekly interval for both Stations P2 and E1. Biweekly densities from years when entrainment sampling was conducted throughout most of the sampling season were averaged and plotted.

3.2.3.2 Selected Species

Biologically important or numerically dominant taxa were selected for further investigation (Table 3-1). The operational and preoperational means, their 95% confidence interval and the 2007 geometric means (Sokal and Rohlf 1981) were tabulated. Monthly means for 2007 and the operational period were compared graphically to the preoperational period monthly means and 95% confidence intervals.

Period (preoperational vs. operational) and station (nearfield vs. farfield) differences in the density of selected species and the interaction between them were evaluated using a mixed linear model analysis. A before-after-control-impact (BACI) design was used to test for potential impacts of plant operation. A mixed model, based on a 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) 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 both stations were sampled concurrently (thus maintaining an equal number of years between stations within the preoperational period). The plant began to operate intermittently in 1990 and this transitional year was excluded from the analysis. Bi-weekly averages were used for *Mytilus edulis* and monthly averages were used for the four macrozooplankton species due to occasional missed collections that were generally caused by adverse weather. Because *Carcinus maenas* was rare or absent during the winter and early spring, data from January through April were excluded from the ANOVA. Similarly, *Mytilus edulis* was frequently absent in bivalve larvae samples from the beginning of collections in mid-April and early May and these sampling weeks were excluded from the tests of significance.

The inference test for Preop-Op, the fixed effect in the model, was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS Institute, Inc. 1999). The likelihood ratio test was used to test the significance for random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects.

3.3 RESULTS

3.3.1 Zooplankton Assemblages

Bivalve Larvae

The bivalve larvae assemblage monitored in this study includes the common local species that produce planktonic larvae and includes several commercially and recreationally-important species. Locally, spawning occurs in the warmer months in a rather predictable pattern from year to year.

Over the past 29 years, relatively large changes in abundance and a shift in the relative abundance of the dominant species of the bivalve larvae assemblage from *Mytilus edulis* and *Hiatella* sp. to *Anomia squamula* and *Mytilus edulis* has occurred. Groups formed by numerical classification had a high level of similarity (Figure 3-2) due in part to the relatively few species involved in the analysis and the numerical dominance of the assemblage by three species. A well-defined temporal pattern was observed, however. *Mytilus edulis* and *Hiatella* sp. dominated collections 1979 to 1984 (Group 1), the early preoperational years

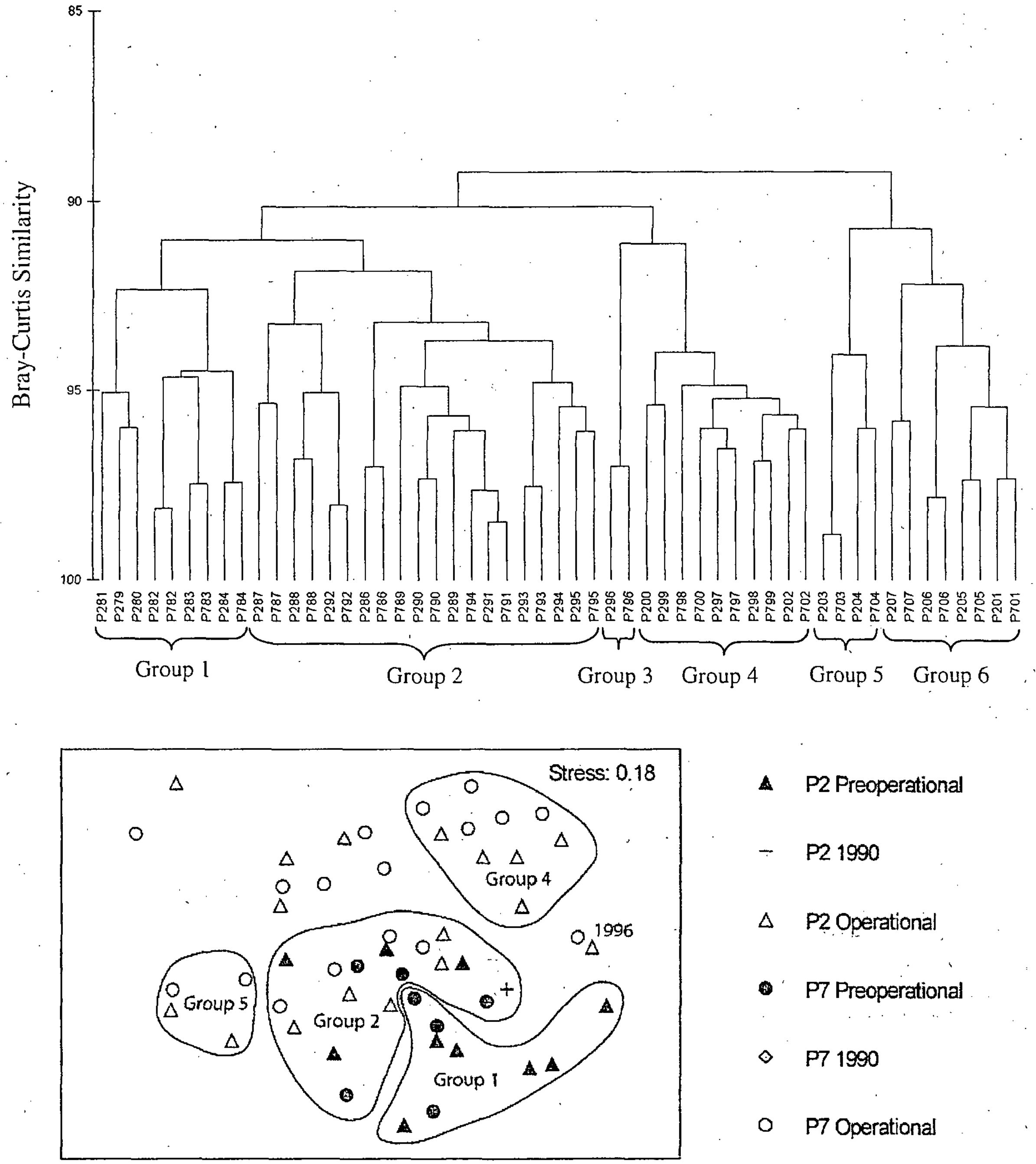


Figure 3-2. Cluster dendrogram and multi-dimensional scaling of the bivalve larvae community at Stations P2 and P7 from 1979 to 1984 and 1986 to 2007. Seabrook Operational Report, 2007.

(Figure 3-2; Table 3-2). From 1986 to 1995 (Group 2), *Anomia squamula* was also dominant, along with *Mytilus edulis* and *Hiatella* sp. High densities of all three dominant species were observed in 1996 (Group 3). *Mytilus edulis* and *Anomia squamula* persisted in large numbers from 1997 to 2002 (except for 2001) while *Hiatella* sp. densities decreased to pre-1996 levels (Group 4). Relatively low densities of bivalve larvae occurred in 2003 and 2004 (Group 5). Collections from recent years, 2005 to 2007, along with 2001 form Group 6 which differs from all other associations in the sole dominance of *Anomia squamula* while densities of the other two dominants were similar to or slightly below preoperational levels.

The MDS ordination and the cluster dendrogram demonstrated temporal trends that appear unrelated to plant operation. The MDS ordination separated the preoperational years from the operational years with a transitional period (Group 2) containing collections from both periods (Figure 3-2). Station P7 collections in the operational period did not form a separate group, but were intermingled with the Station P2 collections. In the dendrogram, yearly collections at Stations P2 and P7 were usually paired. Exceptions to the yearly pairing of stations included both preoperational (1989) and operational years (1994 and 1998 to 2000). The annual pairing of stations in numerical classification indicated that factors that vary annually

Table 3-2. Geometric Mean Density (no./1000 m^3) of Bivalve Larvae in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2007.

	Group 1			Group 2			Group 3		
Species	LCL[a]	MEAN	UCL[b]	LCL[a]	MEAN	UCL[b]	LCL[a]	MEAN	UCL[b]
Mytilus edulis	31,788	72,096	163,517	44,417	78,345	138,188	330,582	493,243	735,941
Anomia squamula	5,623	10,591	19,949	30,333	40,658	54,497	27,614	222,525	1.8x10^6
Hiatella sp.	40,071	77,699	150,660	22,501	34,008	51,400	1,565	210,964	28.4x10^6
Modiolus modiolus	1,202	3,657	11,118	1,480	2,663	4,790	664	6,959	72,843
Solenidae	2,191	4,041	7,456	1,864	2,386	3,054	51	3,458	231,235
Spisula solidissima	172	246	351	288	419	607	0	409	509,177
Mya arenaria	662	776	911	91	142	221	36	123	415
Mya truncata	19	43	95	24	38	62	21	448	9,300
Placopecten magellanicus	9	17	31	1	1	2	0	14	221

	Group 4			Group 5			Group 6		
Species	LCL[a]	MEAN	UCL[b]	LCL[a]	MEAN	UCL[b]	LCL[a]	MEAN	UCL[b]
Mytilus edulis	286,867	430,063	644,739	25,648	40,439	63,760	40,395	58,388	84,396
Anomia squamula	435,607	689,504	1.0x10^6	28,578	31,870	35,542	102,578	158,715	245,574
Hiatella sp.	13,469	22,848	38,760	12,041	46,896	182,637	8,737	17,630	35,576
Modiolus modiolus	1,179	2,353	4,693	89	184	379	33	158	737
Solenidae	5,732	10,707	19,999	1,064	2,144	4,320	2,754	4,798	8,356
Spisula solidissima	441	642	933	7	25	81	122	186	284
Mya arenaria	744	1,152	1,783	40	108	285	308	480	747
Mya truncata	14	24	41	7	23	71	3	8	16
Placopecten magellanicus	2	5	10	0	<1	1	0	<1	1

[a] LCL = Lower 95% confidence limit.
[b] UCL = Upper 95% confidence limit.

have a greater effect on the bivalve assemblage than any potential effects from the operation of the plant. No significant differences between the preoperational and operational periods was detected using the ANOSIM model (Table 3-3). Station differences were also not observed and there was no indication of a significant interaction.

Holoplankton

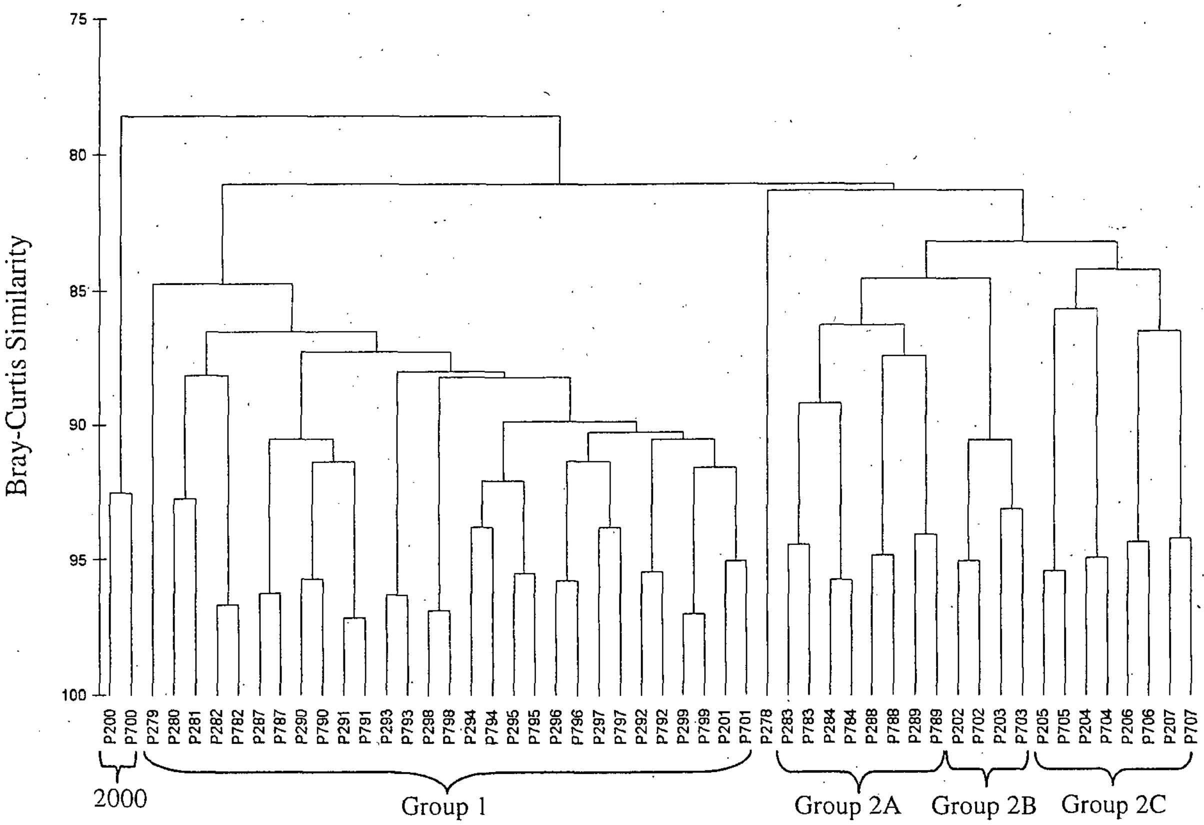
Holoplankton typically spend their entire lives in the plankton. The group is dominated both in numbers and biomass by copepods, although euphausids, larvaceans and a few other species also contribute significantly. The group is important as they are the primary consumers in the coastal open water environment, transferring energy into the higher trophic levels.

Annual changes in the density and relative abundance of the two dominant copepods, *Calanus finmarchicus* and *Centropages typicus*, have largely determined the temporal patterns observed in the holopankton assemblage during this study. Collections were divided into two major groups by numerical classification (Figure 3-3). *Centropages typicus* dominated Group 1 and also in 2000 (Table 3-4); Group 2 collections and 1978 were dominated by *Calanus finmarchicus*. No consistent patterns were observed in any of the other species within these groups. Collections composing Group 2 were further

Table 3-3. Analysis of Similarities (ANOSIM) Between Station and Period of Each Zooplankton Assemblage. Seabrook Operational Report, 2007.

Assemblage	Comparison	R	P[a]
Bivalve larvae	Period[b]	0.09	11.9 NS
	Station[b]	-0.04	90.7 NS
	Preop: P2 vs. P7[c]	-0.16	98.7 NS
	P2: Preop vs. Op[c]	0.02	38.9 NS
	P7: Preop vs. Op[c]	0.15	7.4 NS
	Interaction of Main Effects		Not Significant
Holoplankton	Period[b]	0.13	7.9 NS
	Station[b]	-0.06	99.6 NS
	Preop: P2 vs. P7[c]	-0.15	89.6 NS
	P2: Preop vs. Op[c]	0.17	7.5 NS
	P7: Preop vs. Op[c]	0.08	24.0 NS
	Interaction of Main Effects		Not Significant
Meroplankton	Period[b]	-0.10	84.6 NS
	Station[b]	0.01	39.0 NS
	Preop: P2 vs. P7[c]	0.05	29.2 NS
	P2: Preop vs. Op[c]	-0.10	77.8 NS
	P7: Preop vs. Op[c]	-0.10	77.3 NS
	Interaction of Main Effects		Not Significant
Hyperbenthos	Period[b]	0.06	21.1 NS
	Station[b]	0.68	0.1*
	Preop: P2 vs. P7[c]	0.81	0.2*
	P2: Preop vs. Op[c]	–	–
	P7: Preop vs. Op[c]	–	–
	Interaction of Main Effects		Not Testable

[a]p=significance level of test statistic R.
* indicates significant differences, p<5.0%
NS indicates no significant differences
[b]Two-way crossed ANOSIM
[c]One-way ANOSIM



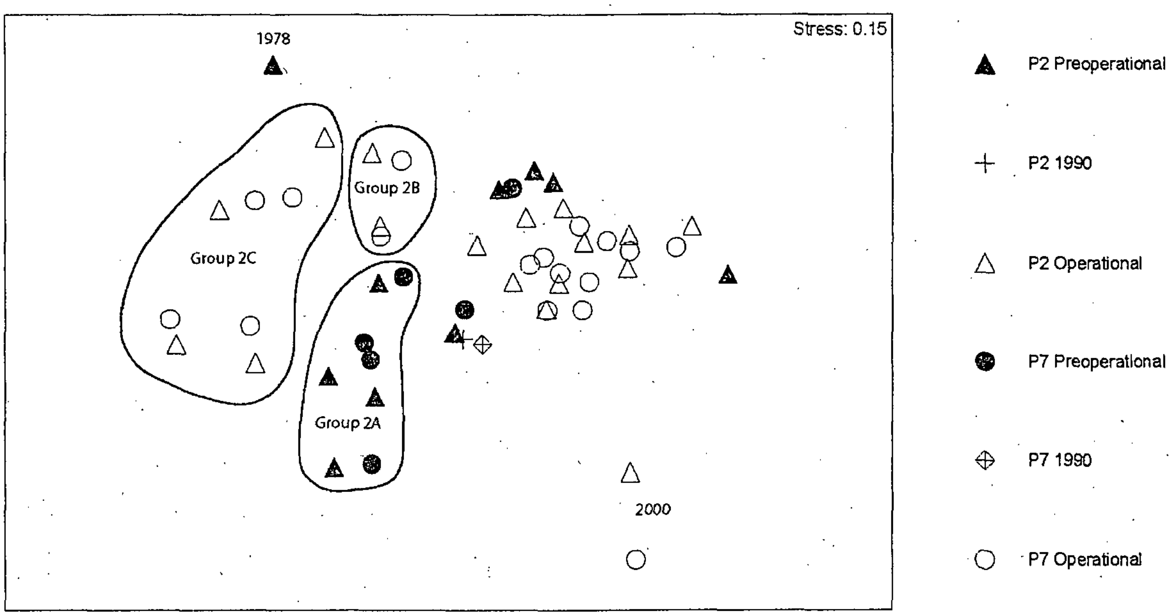


Figure 3-3. Cluster dendrogram and multi-dimensional scaling of the holoplankton community at Stations P2 and P7 from 1978 to 1984 and 1987 to 2007. Seabrook Operational Report, 2007.

Table 3-4. Geometric Mean Density (no./1000 m³) of Dominant[a] Holoplankton in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2007.

Species	Group 1			Group 2A			Group 2B		
	LCL[b]	MEAN	UCL[c]	LCL	MEAN	UCL	LCL	MEAN	UCL
Centropages typicus	6,147	8,926	12,962	559	1,637	4,793	412	1,803	7,882
Calanus finmarchicus	2,882	3,604	4,508	1,972	3,362	5,731	3,641	6,437	11,379
Temora longicornis	903	1,576	2,749	433	878	1,779	4,888	6,026	7,428
Tortanus discaudatus	574	925	1,492	24	65	170	725	2,725	10,228
Metridia sp.	260	400	615	14	28	55	23	132	733
Sagitta elegans	288	359	446	158	274	475	96	366	1,386
Pseudocalanus sp.	208	270	350	168	242	347	162	274	464
Centropages sp.	160	258	416	60	81	110	7	13	25
Centropages hamatus	43	61	85	49	144	418	41	901	19,299

Species	Group 2C			1978			2000		
	LCL	MEAN	UCL	LCL	MEAN	UCL	LCL	MEAN	UCL
Centropages typicus	87	235	632	–	327	–	5,557	81,397	1,191,986
Calanus finmarchicus	4,218	6,486	9,973	–	10,528	–	0	640	2.5x10E8
Temora longicornis	469	964	1,981	–	35	–	3	495	62,011
Tortanus discaudatus	338	1,145	3,869	–	249	–	18	393	8,214
Metridia sp.	31	62	124	–	139	–	9	20	44
Sagitta elegans	65	134	276	–	321	–	13	150	1,609
Pseudocalanus sp.	36	89	215	–	2,536	–	1	13	97
Centropages sp.	3	12	37	–	17	–	182	3,803	79,292
Centropages hamatus	34	69	138	–	27	–	8	61	416

[a] Taxa contributing >2% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

divided into three sub-groups, but the dendrogram shows the differences among the subgroups are relatively small compared to the within group similarity (Figure 3-3). The subgroups of Group 2 display temporal differences in the *Calanus finmarchicus* dominated assemblage. Sub-group 2A, which includes 1983 to 1984 and 1988 to 1989 had low densities of *Tortanus discaudatus* compared to Sub-groups 2B and 2C. Sub-group 2B, which includes 2002 and 2003, was distinguished from the other subgroups because of greater densities of *Temora longicornis*, *Tortanus discaudatus* and *Centropages hamatus*. Sub-group 2C, which includes 2004 to 2007, was distinguished by relatively low densities of *Centropages typicus*.

Several multi-year trends were indicated by numerical classification. Collections from consecutive years tended to group together within the dendrogram (Figure 3-3). *Centropages typicus* dominated the holoplankton from 1979 to 1982. *Calanus finmarchicus*-dominated assemblages were more common from 1983 to 1989. Thereafter, *Centropages typicus* dominated the holoplankton for a decade, from 1990 to 2001. Abundances then decreased, shifting dominance back to *Calanus finmarchicus*, whose abundances have been rather consistent throughout the study (with notably higher abundances in 1978 and lower abundances in 2000). The *Calanus finmarchicus* dominated assemblage has occurred since 2002. The multi-year trends observed in the holoplankton have occurred simultaneously at both stations. Collections from each year have always been paired indicating very small station differences relative to the multi-year variation. There were no significant differences between the two stations and the interaction term was not significant (Table 3-3).

Meroplankton

Meroplankton are the larvae or planktonic stages of benthic invertebrates, including crustaceans, mollusks and jellyfish. In general, the adult populations of the dominant species in the meroplankton assemblage are common in coastal areas from shallow to relatively deep water. Larvae of coastal species such as *Eualus pusiolus*, *Crangon septemspinosa*, and *Cancer* sp. are dominant, while estuarine species like *Hippolyte* sp. and *Palaemonetes* sp. are relatively rare. All of the adult populations also have wide geographic ranges extending both north and south of Cape Cod.

The rather ubiquitous nature of the dominant coastal species has resulted in a meroplankton assemblage that has been relatively consistent throughout the study period. Except for 2000, all collections from 1980 to 2003 (Group 1) were associated at a relatively high level of similarity by numerical classification (Figure 3-4). The 2007 collections were associated with Group 1. Several smaller groups representing early preoperational collections (Group 2) and later operational collections (Groups 3 and 2000) were also formed. In general the dendrogram displays a considerable degree of chaining and the differences among the groups were relatively small when compared to the overall similarity within a group, suggesting that actual differences among the groups were rather small. Groups were distinguished primarily by varying abundances of the dominant species, *Eualus pusiolus* and *Crangon septemspinosa* (Table 3-5). Low densities of the veligers of the snail *Lacuna vincta* in the early preoperational period (Group 2) and again in the later operational period (Group 3) helped distinguish those groups. In general however, abundances of most of the meroplankton taxa were similar among the groups formed by numerical classification.

Collections from several of the recent years, 2000 and 2004 to 2006 (Group 3), formed new groups, distinct from the meroplankton assemblage observed from 1980 to 1999 and 2001 to 2003 (Group 1) and suggest that a new trend may be developing. The abundances of most of the meroplankton species were slightly lower in these years (Table 3-5). However, collections from Stations P2 and P7 were paired in 2000 and from 2004 to 2006, suggesting that a similar trend is occurring at both the nearfield and farfield sites. Neither the dendrogram nor the MDS plot indicated any plant impacts. The MDS ordination displayed a weak trend from the preoperational to the operational period and the tight clustering of most sampling years. Except for 1996, 1997 and 2001, Stations P2 and P7 were always paired, indicating that trends in the meroplankton assemblage occur on a larger scale. Consistent with the results of numerical classification, significant differences were not detected between the preoperational and operational periods or between stations (Table 3-3). The indirect test for interaction was not significant. The formation of new groups in numerical classification or the disassociation of annual station pairs has been observed since 1996, coincidental with the reduction in number of replicates analyzed (see Discussion).

Hyperbenthos

The hyperbenthos assemblage in coastal New Hampshire waters is composed mostly of mysids and a few benthic amphipods and cumaceans that commonly occur and are widespread in the Gulf of Maine. Harpacticoids (mostly *Phyllo*

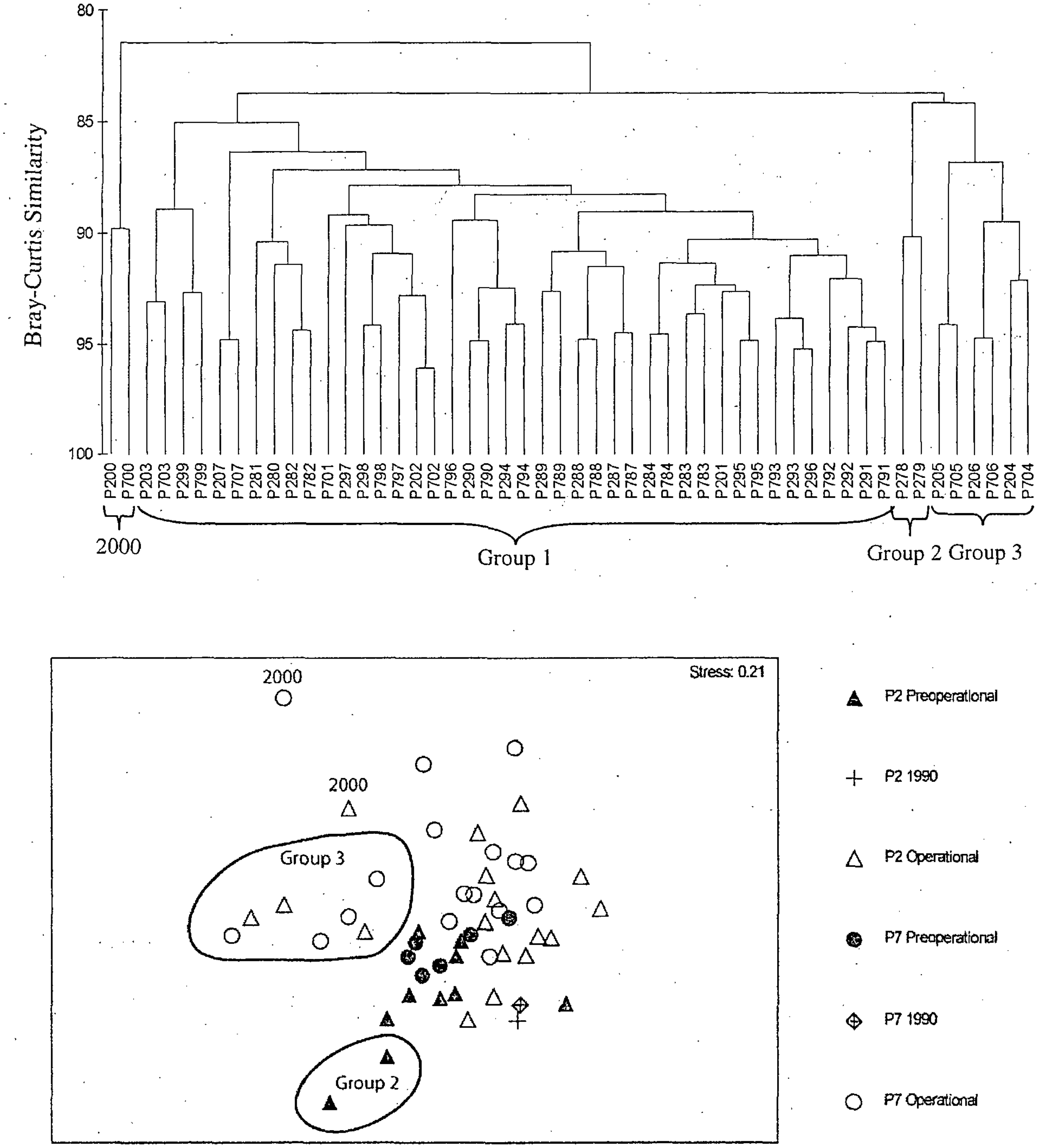


Figure 3-4. Cluster dendrogram and multi-dimensional scaling of the meroplankton community at Stations P2 and P7 from 1978 to 1984 and 1987 to 2007. Seabrook Operational Report, 2007.

Table 3-5. Geometric Mean Density (no./1000m^3) of Dominant[a] Meroplankton in Groups formed by Cluster Analysis. Seabrook Operational Report, 2007.

	Group 1			Group 2			Group 3			2000		
Species	LCL[b]	MEAN	UCL[c]	LCL	MEAN	UCL	LCL	MEAN	UCL	LCL	MEAN	UCL
Eualus pusiolus	565	675	807	1	150	9,950	267	385	557	156	282	507
Crangon septemspinosa	128	156	190	361	390	420	32	48	73	0	83	14,466
Cancer sp.	109	126	145	37	164	716	93	108	125	31	72	163
Carcinus maenas	34	40	47	0	23	401	14	19	26	4	58	766
Cirripedia	27	33	41	1	20	256	11	18	28	1	5	18
Lacuna vincta	23	32	43	0	2	123,025	1	6	20	0	11	2,324
Pagurus sp.	23	28	33	20	29	40	14	23	36	0	18	4,376

[a] Taxa contributing >2% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

thalestris and *Alteutha*) and swarming reproductive adults of some polychaetes are also present.

Large station differences have been observed throughout the study. Numerical classification defined three groups (Groups 2A, 2B and 2C) composed entirely of Station P7 collections (Figure 3-5). All Station P2 collections were included in a single group (Group 1) along with a few Station P7 collections: 1982, 1994, and 2004. Differences in species abundances between stations were large (Table 3-6). Average abundances of hyperbenthos at Station P2 (Group 1) have typically been an order of magnitude greater than Station P7 abundances (Group 2). Within-group similarities are fairly low relative to the other macrozooplankton assemblages (>80%; Figure 3-5), attributable to the low abundances and the seasonal and migratory behavior of the species making up this component of the macrozooplankton.

Multi-year temporal trends were not observed for the hyperbenthic assemblage in the vicinity of the cooling water intakes, Station P2. Species composition and abundances at Station P2 were similar in the preoperational and operational periods (Figure 3-5). All of the Station P2 annual collections were united within Group 1 and tightly grouped in the MDS ordination. In contrast, long-term trends were observed at the farfield station (P7). The hyperbenthos assemblage at the farfield site during the early years of plant operation (1990-1994 and 1996: 1994 included in Group 1) was similar to the assemblage observed in the preoperational period (Group 2B). Two additional groups have been defined that include all of the farfield collections since 1997 (Groups 2A and 2C), except for 2004. The wider scatter of P7 operational points in the MDS plot is attributed to collections from Groups 2B and 2C and suggests a considerable increase in sampling variability. Species abundances were low in these collections, which distinguishes them from the earlier operational collections at the farfield station (Table 3-6). The decrease was generally limited to the larger peracarid species including *Neomysis americana*, resulting in a change of the relative ranking of the dominant taxa. The decrease in the peracarids at Station P7 in the latter half of the operational period coincided with the reduction in the number of replicates from three to one in 1996 (see Discussion). Changes in the hyperbenthic assemblage that occurred during the operational period at only one station could be indicative of a plant impact; however, the ANOSIM model could not test the interaction of main effects because of station differences in the preoperational period (Table 3-3).

Stations P2 and P7 are generally similar in terms of hydrography and gross habitat. Both

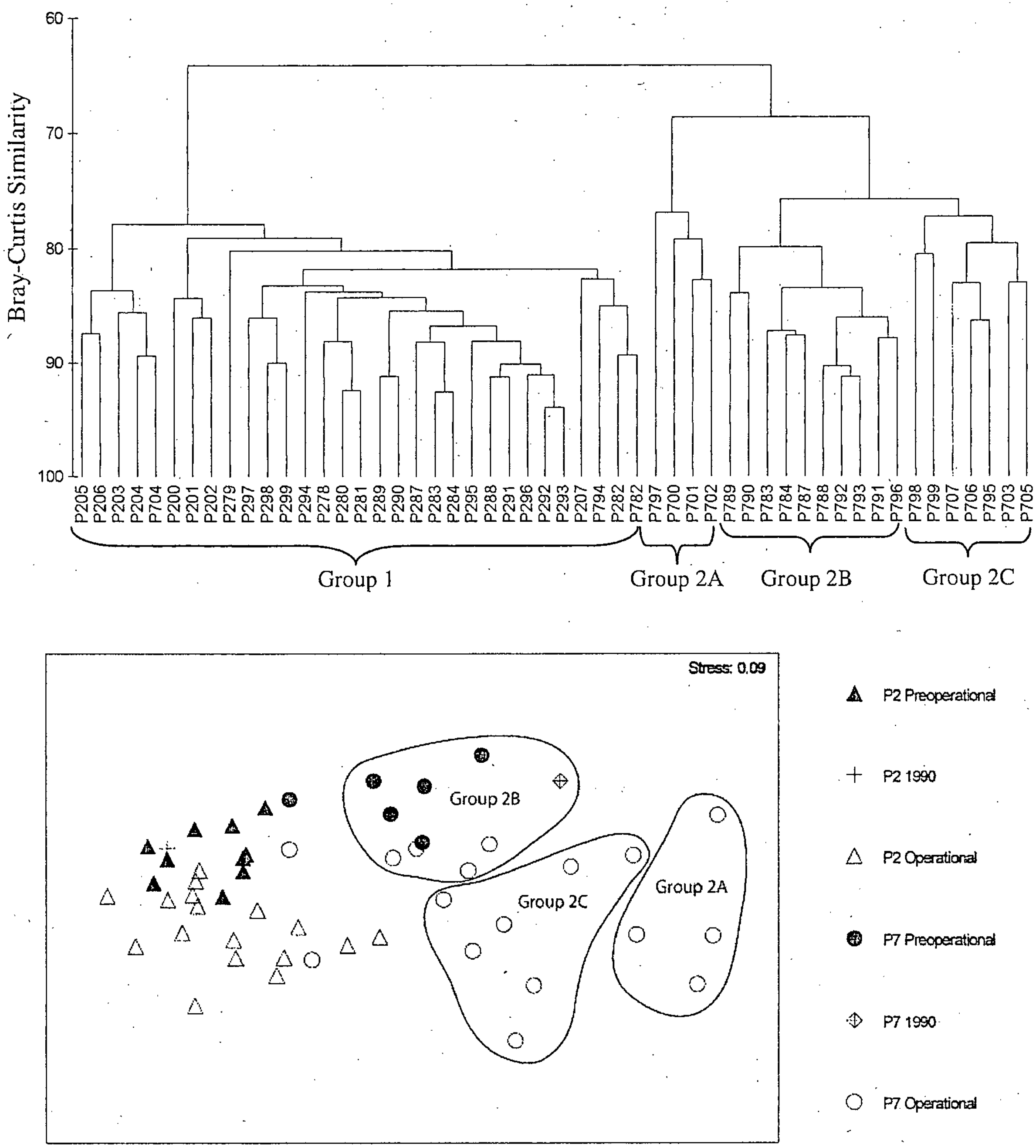


Figure 3-5. Cluster dendrogram and multi-dimensional scaling of the hyperbenthos assemblage at Stations P2 and P7 from 1978 to 1984 and 1987 to 2007. Seabrook Operational Report, 2007.

Table 3-6. Geometric Mean Density (no./1000m^3) of Dominant[a] Hyperbenthos in Groups formed by Cluster Analysis. Seabrook Operational Report, 2007.

Species	Group 1			Group 2A		
	LCL[b]	MEAN	UCL[c]	LCL	MEAN	UCL
Neomysis americana	84	125	187	5	10	17
Diastylis sp..	26	36	50	<0.5	1	3
Pontogeneia inermis	23	30	40	<0.5	<0.5	1
Harpacticoida	13	18	25	3	7	14
Oedicerotidae	11	14	18	<0.5	<0.5	1
Pseudoleptocuma minor	5	7	9	<0.5	1	3
Amphipoda	5	6	7	<0.5	1	2
Syllidae	4	5	7	2	7	16
Mysis mixta	3	3	4	<0.5	<0.5	<0.5
Gammarus lawrencianus	1	2	3	<0.5	<0.5	1
Calliopius laeviusculus	1	2	2	<0.5	1	2
Jassa marmorata	1	1	1	<0.5	1	1

Species	Group 2B			Group 2C		
	LCL	MEAN	UCL	LCL	MEAN	UCL
Neomysis Americana	16	25	40	3	8	19
Diastylis sp..	2	4	6	3	4	6
Pontogeneia inermis	3	6	10	2	2	3
Harpacticoida	3	6	10	7	10	14
Oedicerotidae	4	7	11	1	3	4
Pseudoleptocuma minor	1	1	2	1	2	4
Amphipoda	2	3	4	1	2	2
Syllidae	9	11	14	3	6	9
Mysis mixta	2	3	4	<0.5	1	1
Gammarus lawrencianus	<0.5	<0.5	<0.5	<0.5	1	3
Calliopius laeviusculus.	<0.5	<0.5	1	<0.5	<0.5	1
Jassa marmorata	<0.5	<0.5	<0.5	<0.5	<0.5	1

[a] Taxa contributing >2% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

have predominantly sandy bottoms in about 18 meters of water. Because station differences existed prior to plant operation, it is likely that factors other than plant operation are affecting the hyperbenthic assemblage. Abundances of the peracarid species are typically much greater at Station P2, which could be attributed to the earlier sampling times at Station P7 (see Discussion).

3.3.2 Selected Species

Five species were selected from the zooplankton program for further investigation due to either their abundance or commercial or ecological importance. Larvae of *Cancer* sp. (rock and Jonah crabs) and *Mya arenaria* (soft-shell clam) were enumerated in the zooplankton program, but results are presented in sections 6.0 and 7.0. The ANOVA model used only the preoperational and operational years when both stations were sampled concurrently. Calculation of geometric means for the preoperational and operational periods used all available years.

Mytilus edulis

The blue mussel, *Mytilus edulis* occurs from the Arctic to the Carolinas and is very common in New England (Abbott 1974). Locally, mytilids are the dominant organisms in the rocky intertidal zone. They are also common at all of the subtidal hard substrate benthic stations in the nearshore waters (Section 5.0). Read and Cumming (1967) suggested that the subtidal distribution of adult mussels south of Cape Hatteras was limited by temperatures in the range of 26.7 to 28.9°C. Temperatures in coastal New Hampshire waters and in the nearfield area never approach that level. However, temperature can influence other phases of mytilid biology. Fertilization occurs from 5-22°C (Bayne 1976). Growth occurs from 3-25°C with optimal growth occurring between 10 and 20°C (Seed 1976).

In coastal New Hampshire waters, *Mytilus edulis* veligers were abundant from late May through the end of sampling in October (Figure 3-6). The development of trochophore larvae does not occur at less than 8°C (Bayne 1976) and the observed increase in larval density is consistent with the rise in surface temperatures to above 8°C at Station P2 and Hampton Harbor in May (see Section 2.0). Weekly densities of larvae in mid-May were considerably greater during the operational period compared to the preoperational period, suggesting a seasonal shift of the initial appearance of the larvae. Previous reports show that this temporal shift occurred consistently from 1996 to 2002 (NAI 2001, 2002, 2003) and that larval densities were typically several orders of magnitude greater than during the preoperational and early operational years (1991 to 1995). In more recent years, 2003 to 2007, larvae have appeared in mid-May, but the magnitude of the densities has been lower than observed from 1996 to 2002. In 2007, veligers were absent from collections through the first week in May, with moderate numbers present in the second week of May and peak densities occurring June through mid-July. Peak period densities, mid-June to mid-July, in 2007 were similar to the preoperational and operational weekly means. Larval densities were much lower in August 2007 than has been historically observed.

At both stations in 2007, the geometric mean larval density was below the 95% confidence interval for the operational period, but within the confidence intervals for the preoperational mean (Table 3-7). The preoperational and operational means suggest a substantial increase in abundance in the operational period. However, a large portion of the increase can be accounted for by the seasonal shift. The preoperational and operational geometric means were nearly identical in 1995 (NAI 1996), before the seasonal shift was observed. Table 3-7 presents a partial-year mean for *Mytilus edulis* for a period that was established to monitor the soft-shell clam *Mya arenaria*. The geometric mean presented in Table 3-7 is not representative of total annual *Mytilus edulis* larval abundance, as larvae persist at relatively high numbers after the end of sampling in the fourth week of October (Figure 3-6). A small shift in the seasonal occurrence can dramatically change the annual mean values because fewer zero or near-zero values are not included in the mean. Weekly means (Figure 3-6) suggest that preoperational and operational period means are much more similar than indicated by the geometric means presented in Table 3-7.

Annual larval densities at Stations P2 and P7 have been almost identical in each year throughout the study. Densities have typically been less than 2 x 10^5 larvae per 1000 cubic meters, with periodic years of greater abundance (Figure 3-7). Higher densities, attributed in part to the seasonal shift (above), occurred from 1996 to 2000 and 2002. Larval densities in recent years were typically low, similar to the preoperational years 1982 to 1985. There were no significant differences between the preoperational and operational periods, or between stations (Table 3-8). The interaction of the main effects was also not significant.

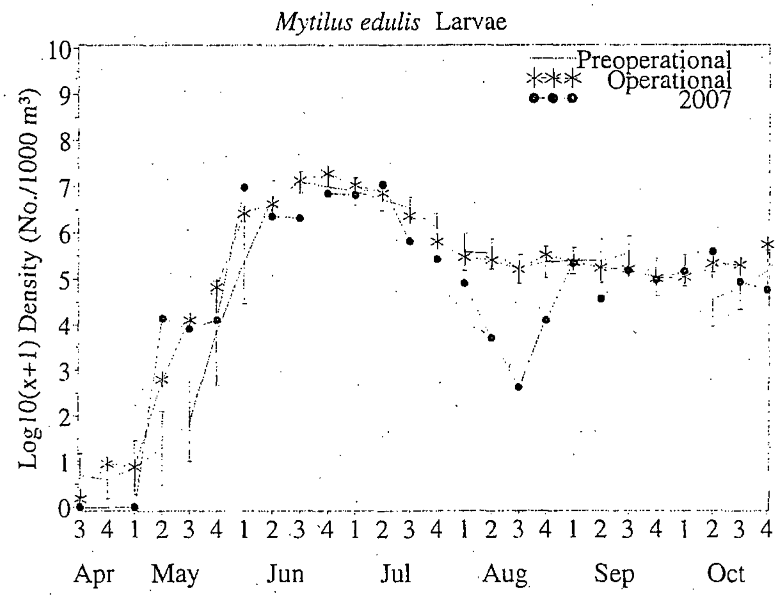


Figure 3-6. Weekly density of *Mytilus edulis* larvae at Station P2; preoperational period (1978-1984, 1986-1989) log (x+1) weekly means and 95% confidence intervals, and the operational period (1991-2007) and 2007 weekly means. Seabrook Operational Report, 2007.

Table 3-7. Annual Geometric Mean Density (no./1000 m³) and 95% Confidence Limits of Selected Zooplankton Species at Stations P2 and P7 During the Preoperational and Operational Periods and in 2007. Seabrook Operational Report, 2007.

Species/Lifestage	Station	Preoperational LCL[c]	Preoperational Mean	Preoperational UCL[d]	Operational LCL[c]	Operational Mean	Operational UCL[d]	2007 Mean
Mytilus edulis[a]	P2	26,666	65,181	159,327	66,783	126,864	240,995	39,609
	P7	23,885	64,444	173,877	65,674	124,704	236,792	44,609
Calanus finmarchicus[b]	P2	3,424	5,198	7,892	3,796	5,028	6,661	15,053
	P7	1,595	3,082	5,957	2,040	3,199	5,016	8,314
Carcinus maenas[b]	P2	22	28	36	32	46	67	23
	P7	23	32	46	28	36	48	35
Crangon septemspinosa[b]	P2	220	270	330	101	150	224	158
	P7	92	161	281	61	81	108	121
Neomysis americana[b]	P2	68	143	298	67	121	217	113
	P7	17	43	105	8	13	19	27

[a] Years sampled: Preoperational: P2=1978-1984, 1986-1989, P7=1982-1984, 1986-1989
Operational: P2 and P7=1991-2007
Mytilus edulis means are based on collections from mid-April through October

[b] Years sampled: Preoperational: P2=1978-1984, 1987-1989, P7=1982-1984, 1987-1989
Operational: P2 and P7=1991-2007

[c] LCL = 95% Lower confidence limit
[d] UCL = 95% Upper confidence limit

Table 3-8. Results of the Analysis of Variance Comparing Log (x+1) Transformed Abundances (no./1000m^3) of Selected Zooplankton Species from Stations P2 and P7 During the Preoperational and Operational Periods. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Mytilus edulis	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Apr-Oct)	Preop-Op[a]	1, 22	1.27	0.2717	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.0998	2.773	0.0479	
	Half Month(Year)[c]	1.5947	735.651	<0.0001*	
	Station[d]	0	0.000	0.5000	
	Preop-Op X Station[e]	<0.0001	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.4999	
	Error	0.5832			
Calanus finmarchicus	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Jan-Dec)	Preop-Op[a]	1, 36.3	0.17	0.6806	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0	0.000	0.4995	
	Month(Year)[c]	1.1008	477.397	<0.0001*	
	Station[d]	0.0113	0.673	0.2060	
	Preop-Op X Station[e]	0.0005	0.011	0.4587	
	Station X Year (Preop-Op)[f]	0	0.000	0.4990	
	Error	0.6803			
Carcinus maenas	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(May-Dec)		1, 84.9	0.07	0.7878	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0	0.000	0.4993	
	Month(Year)[c]	2.1317	661.707	<0.0001*	
	Station[d]	0.0032	0.109	0.3704	
	Preop-Op X Station[e]	0.0015	0.068	0.3970	
	Station X Year (Preop-Op)[f]	0	0.000	0.4998	
	Error	0.5023			
Crangon septemspinosa[c]	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Jan-Dec)	Preop-Op[a]	1, 243	3.09	0.0800	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0	0.000	0.4999	
	Month(Year)[c]	1.1819	702.753	<0.0001*	
	Station[d]	0.0296	2.008	0.0783	
	Preop-Op X Station[e]	<0.0001	0.000	0.4999	
	Station X Year (Preop-Op)[f]	0.0152	5.011	0.0126*	
	Error	0.4360			
Neomysis americana[c]	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Jan-Dec)	Preop-Op[a]	1, 5.24	5.69	0.0604	
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.0515	2.725	0.0494*	
	Month(Year)[c]	0.3540	145.867	<0.0001*	
	Station[d]	0.3804	2.767	0.0481*	P2 > P7
	Preop-Op X Station[e]	0.0036	0.073	0.3932	
	Station X Year (Preop-Op)[f]	0.0446	13.152	0.0001*	
	Error	0.6251			

[a] Preop-Op compares 1982-1989 to 1991-2007 regardless of station
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within year.
[d] Stations (Nearfield=P2, Farfield = P7) regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Station X Year within Preop-Op.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_0: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

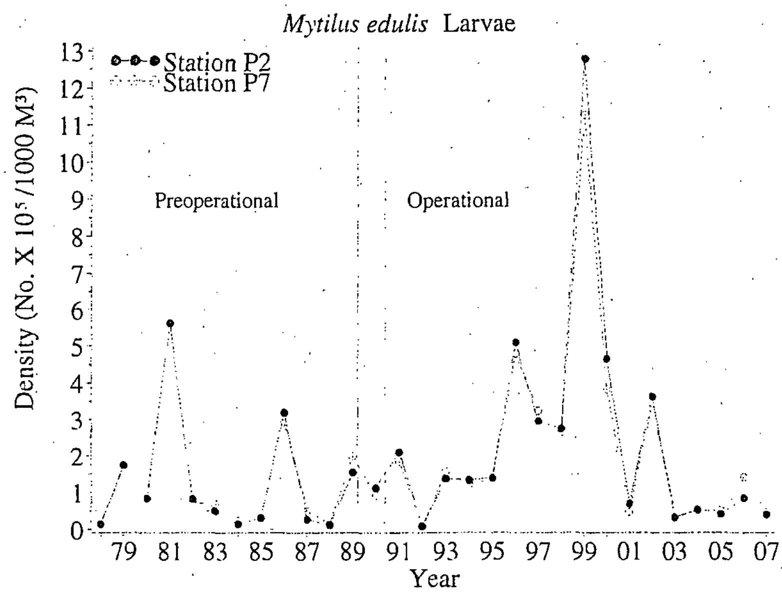


Figure 3-7. Annual geometric mean density of *Mytilus edulis* larvae at Stations P2 and P7 from 1978 to 2007. Seabrook Operational Report, 2007.

Calanus finmarchicus

The herbivorous *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. In the deeper waters of the Gulf of Maine, it is a known vertical migrant.

Densities of *Calanus finmarchicus* in 2007 were very high at both stations. The 2007 mean density at Station P2 (15,053 per 1000 m^3; Table 3-7) was the greatest ever observed in the 29 years of this study, exceeding the previous high of 10,835 in 1980 (Figure 3-8). The 2007 density at Station P7 (8,314/1000 m^3) was the second highest ever observed at that station, less than the record high of 10,172/ 1000 m^3 observed in 2001. *Calanus finmarchicus* is a vertical migrant; large portions of the population probably move toward the surface at night, but the timing and magnitude of the migration in the coastal waters is not known. The lower mean preoperational and operational abundances at Station P7 probably reflect the tendency to sample Station P7 first, shortly after sunset. In winter of 2006, sampling time was moved to nautical sunset, which is slightly later than what was previously sampled. Densities at Station P2 were higher than P7 in 2007, consistent with the pattern for most years.

In coastal New Hampshire waters, *Calanus finmarchicus* was most abundant in the summer, where it is usually among the dominant plankton species. At Station P2, densities increased through the mid-spring and were relatively consistent during the peak period from May to August, before densities declined in the fall (Figure 3-9). In general, the seasonal cycle in the operational period was similar to the preoperational period cycle. However, densities in the operational period declined more gradually in the fall from a maximum in July, in contrast to the preoperational period, resulting in greater operational period densities in October and November. At Station P2 in 2007, densities were above monthly preoperational and operational means in January and February, May, July and also in October and November. The higher abundances in the winter and fall

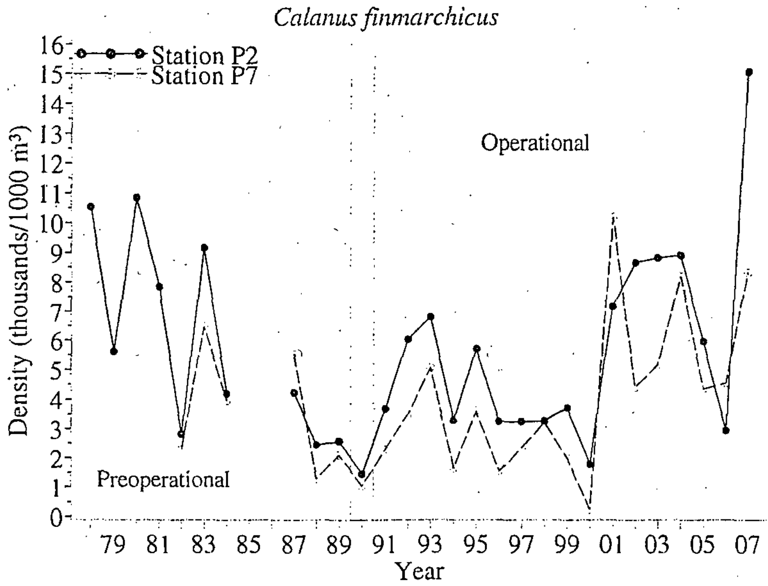


Figure 3-8. Annual geometric mean density of *Calanus finmarchicus* at Stations P2 and P7 from 1978 to 2007. Seabrook Operational Report, 2007.

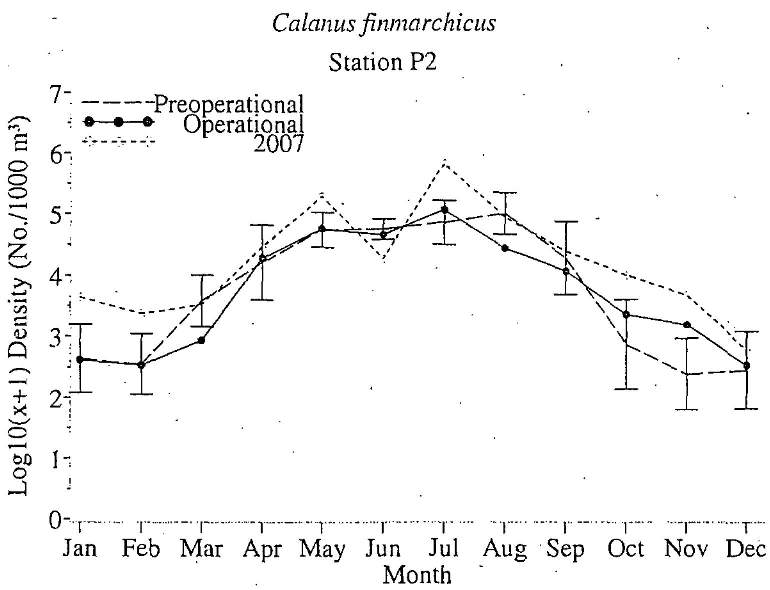


Figure 3-9. Monthly density of *Calanus finmarchicus* at Station P2; preoperational period (1978-1989, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2007) monthly means. Seabrook Operational Report, 2007.

likely contributed to the record high densities in 2007.

Annual densities of *Calanus finmarchicus* indicate several long-term trends. Although variation among years was great, abundances at both Stations P2 and P7 generally declined from 1978 to 1990. Relatively low densities occurred from 1991 to 2000, thereafter the densities have increased to levels observed in the early preoperational period. Although Station P7 densities were usually lower than Station P2, both stations followed similar trends (with a few exceptions: notably 2002 and 2003). Statistically significant differences were not observed between the preoperational and operational periods (Table 3-8). There were also no significant differences between stations and the interaction term was not significant.

Carcinus maenas

The green crab (*Carcinus maenas*) is an introduced species, found from Nova Scotia to Virginia in intertidal and shallow subtidal estuaries and coastal areas (Williams 1974). The adult crabs are strictly benthic, but the larval zoea and megalopa are common in the plankton. Adults are abundant and can be used as bait and they are important predators on soft-shell clams. Adults exhibit thermal stress at 31-35°C (Cuculescu et al. 1998).

At Station P2 in 2007, larval *Carcinus maenas* densities were similar to average densities observed in the preoperational period, but about half of the densities typical of the operational period (Table 3-7). At Station P7, larval densities in 2007 were similar to both preoperational and operational means. Annual mean density of *Carcinus maenas* larvae was generally similar at both stations (Figure 3-10). Density reached a peak at both station in 1997 through 2002 and subsequently declined to preoperational period levels in 2003 through 2007.

Larvae of *Carcinus maenas* have typically appeared in May, with densities increasing rapidly to a summer peak followed by a more gradual decrease in the fall. In 2007, larvae first appeared in June and the annual peak occurred in August (Figure 3-11). Densities were below the preoperational lower confidence limit in September, November and December. The seasonal pattern of *Carcinus maenas* was almost identical in the preoperational and operational periods except that May densities during the operational period were above the upper confidence limit of the preoperational period.

Differences between the preoperational and operational period means were not significant (Table 3-8). No station differences were detected and the interaction term was not significant.

Crangon septemspinosa

The sand shrimp *Crangon septemspinosa* is one of the most abundant coastal shrimps on the North American east coast (Haefner 1979), ranging from the Arctic to Florida in shallow subtidal areas (Williams 1974). The larval zoea and megalopa (first post-zoeal stage) are planktonic. Juveniles and adults are benthic, but are occasionally encountered in plankton tows. Adult *Crangon septemspinosa* can be important predators on post-settlement winter flounder (Taylor 2003).

Geometric mean *Crangon septemspinosa* densities in 2007 were similar to the operational period means at both stations, and less than the preoperational period means (Table 3-7). Average densities of this nighttime vertical migrant were generally lower at Station P7, possibly due to the tendency to sample Station P7 first. In 2006 and 2007, when sampling was delayed until the onset of nautical sunset, densities at Station P7 were only slightly less than Station P2 (Figure 3-12). Small station differences were also observed in 1999, 2002 and 2005. Annual *Crangon septemspinosa* densities have fluctuated widely among years (Figure 3-12), but appeared to remain fairly

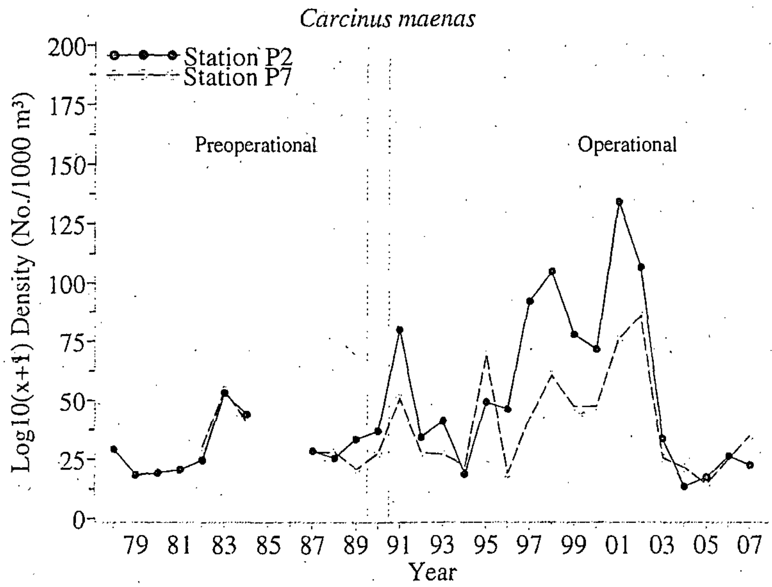


Figure 3-10. Annual geometric mean density of *Carcinus maenas* larvae at Stations P2 and P7 from 1978 to 2007. Seabrook Operational Report, 2007

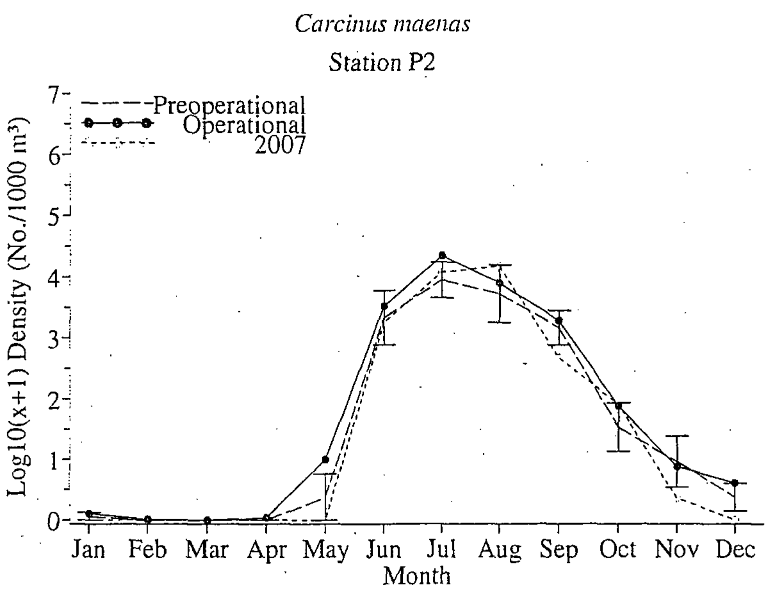


Figure 3-11. Monthly density of *Carcinus maenas* larvae at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2007) monthly means. Seabrook Operational Report, 2007.

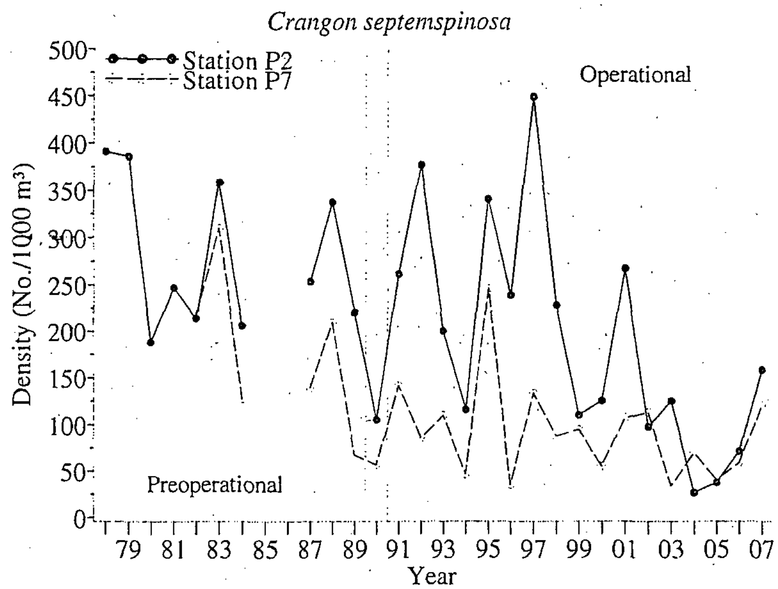


Figure 3-12. Annual geometric mean density of *Crangon septemspinosa* larvae at Stations P2 and P7 from 1978 to 2007. Seabrook Operational Report, 2007.

consistent from the beginning of sampling to about 1998. Larval abundances have been lower on average since 1998, especially at Station P2, coinciding with the reduction in the number of tows taken (see Discussion).

In Chesapeake Bay, larval *Crangon septemspinosa* were present all year, but were most abundant in the 10-14°C temperature range (Wehrtmann 1994). A similar pattern was observed in this study, with the annual peak typically occurring from June to September (Figure 3-13) when temperatures are in this range locally. Densities at the nearfield station (P2) generally remained high throughout the summer. Seasonally, there appeared to be a slight shift temporally, indicated by high abundances earlier in spring (although within the preoperational confidence limits), and low abundances from August through December during the operational period (Figure 3-13). Larval densities in 2007 were somewhat atypical of previous years. There were moderate densities in winter when larvae are usually scarce, and high abundances in April as well. In 2007, larval densities were well below the average in June, the usual annual peak, and below average throughout the late summer and fall. Larvae were absent in December.

For years when stations were sampled concurrently, no significant differences were detected between stations or the preoperational and operational periods, and the interaction term was not significant (Table 3-8).

Neomysis americana

Neomysis americana is the most abundant mysid in northeastern coastal waters, ranging from the Gulf of St. Lawrence to Virginia (Wigley and Burns 1971). It frequently moves up toward the surface 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). Mauchline (1980) described a two-generational annual cycle of *Neomysis americana*. Larvae spawned by the over-wintering generation in spring matured quickly and reproduced in summer. Larvae spawned in summer matured slowly and formed the over-wintering population. This pattern was observed by Wigley and Burns (1971) on

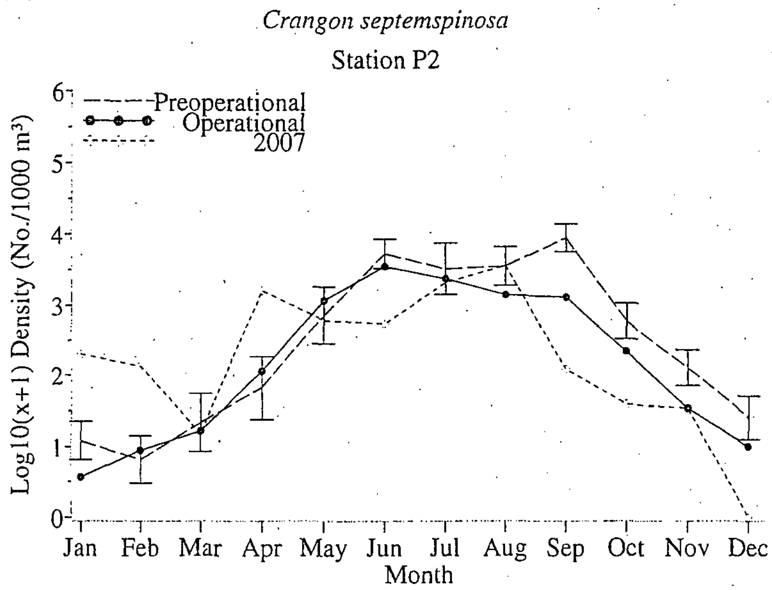


Figure 3-13. Monthly density of *Crangon septemspinosa* larvae at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2007) monthly means. Seabrook Operational Report, 2007.

Georges Bank and in this study (NAI 1995, 1996, 1998a).

Neomysis americana density at Station P2 in 2007 was similar to both the preoperational and operational means (Table 3-7). Density at Station P7 exceeded the operational average and was within the 95% confidence interval of the preoperational period. In 2007, *Neomysis americana* was more abundant at Station P2 than at Station P7, which was typical of previous years (Figure 3-14). This trend was possibly due to the tendency to sample Station P7 earlier in the evening, although in 2007 sampling started later in the night, at nautical sunset. At Station P2 from 1978 to 1997, annual average densities of *Neomysis americana* were typically between 100 and 400 individuals per 1000 cubic meters, with a few years of much greater abundance. With the exception of 2000, densities have typically been below 100 individuals per 1000 cubic meters since 1998, coincident with the reduction of field sampling (see Discussion).

Seasonally, *Neomysis americana* density has been highly variable as indicated by the large confidence intervals of the preoperational monthly means (Figure 3-15). Monthly densities in 2007 were atypical of previous years. Densities of the over-wintering generation were well below normal during the winter, but were above average in the spring. Despite high numbers of the summer generation (July), the fall population actually declined at the nearfield station, rather than increasing to the normal annual peak in November.

Annual geometric means indicate clear station differences. Densities at Station P2 were significantly greater than Station P7 (Table 3-8). However, there were no significant differences between operational periods and the interaction was not significant.

3.3.3 Bivalve Larvae 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

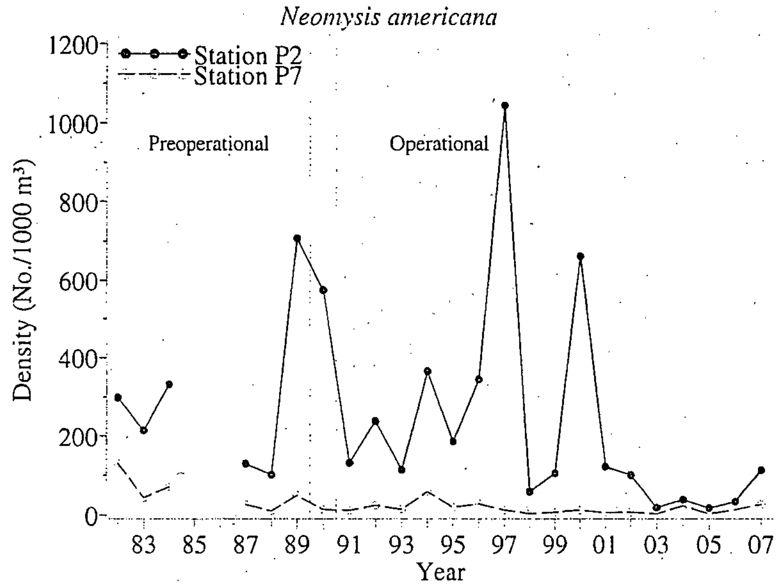


Figure 3-14. Annual geometric mean density of *Neomysis americana* at Stations P2 and P7 from 1978 to 2007. Seabrook Operational Report, 2007.

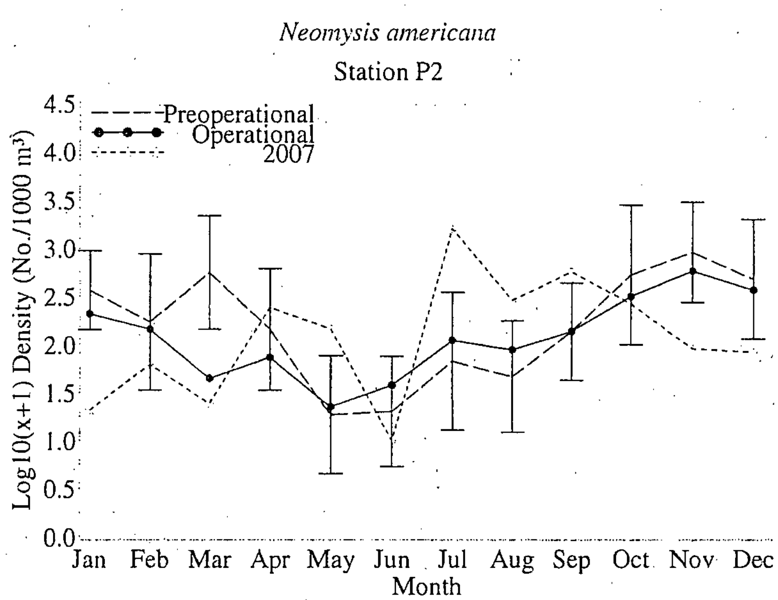


Figure 3-15. Monthly density of *Neomysis americana* at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2007) and 2007 monthly means. Seabrook Operational Report, 2007.

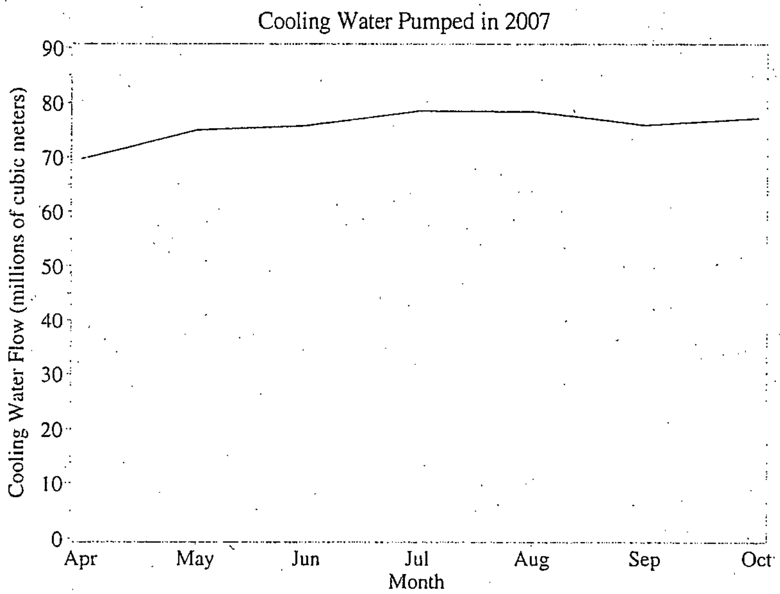
because these determine the number of larvae exposed to potentially lethal temperatures and physical shock.

The total number of bivalve larvae entrained from April through October in 2007 was 5,820 X 10^9 (Table 3-9). In years when entrainment has been measured throughout most of the sampling period (excluding 1991 and 1992), total entrainment has ranged from 2,909 X 10^9 to 67,415 X 10^9, which places 2007 as the second lowest year (Appendix Table 3-2). In 2007, as observed in previous years, *Anomia squamula* was the most common bivalve larva entrained (68%), followed by *Mytilus edulis* (14%) and *Hiatella* sp. (11%). Unlike previous years, most of the larvae were entrained in October (41% of total). Peak entrainment typically occurs in June and July, which in 2007 accounted for 22% and 23% of the total entrainment. In coastal New Hampshire waters, the seasonal maxima of the three numerically dominant taxa, *Mytilus edulis, Anomia squamula* and *Hiatella* sp., usually occurs in June and July (NAI 1990). Large numbers of *Hiatella* sp. appear first, followed by *Mytilus edulis* and finally *Anomia squamula.* That pattern is repeated in the entrainment collections (Figure 3-16). In 2007, large numbers of *Amonia squamula* appeared in the second and third weeks of October in the nearshore waters, contributing to the high entrainment values in October.

Recent reports have indicated that entrainment in Seabrook Station does not reflect densities in the nearshore waters (NAI, 2001, 2002, 2003, 2004, 2005, 2006). There are clear differences between mean biweekly entrainment and nearshore densities (Figure 3-17), even though the amount of cooling water used is relatively consistent. Nearshore densities peak in June, while peak entrainment densities are

Table 3-9. Estimated Number of Bivalve Larvae Entrained (X 10^9) by the Cooling Water System at Seabrook Station from the Fourth Week in April Through the Fourth Week of October, 2007 Seabrook Operational Report, 2007.

Species	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	%
Anomia squamula	0.01	0.27	75.10	807.14	174.72	541.23	2351.26	3949.75	67.86
Bivalvia	0.00	0.38	10.11	5.38	3.03	5.48	21.81	46.19	0.79
Hiatella sp.	0.73	48.63	544.14	44.80	1.76	1.21	9.43	650.69	11.18
Modiolus modiolus	0.00	0.00	17.44	149.09	3.95	1.85	0.17	172.51	2.96
Mya arenaria	0.00	0.01	3.44	0.46	0.11	0.48	0.19	4.69	0.08
Mya truncata	0.00	0.00	2.96	0.00	0.02	0.00	0.00	2.98	0.05
Mytilus edulis	0.01	3.03	474.31	311.28	13.64	18.24	13.87	834.38	14.34
Placopecten magellanicus	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05	0.00
Solenidae	0.01	2.45	145.90	2.96	0.30	0.67	3.75	156.05	2.68
Spisula solidissima	0.00	0.00	1.14	0.00	0.05	0.00	1.63	2.82	0.05
Total	0.76	54.76	1274.58	1321.12	197.60	569.17	2402.11	5820.11	100.00
% of Total	0.01	0.94	21.90	22.70	3.40	9.78	41.27	100.00	



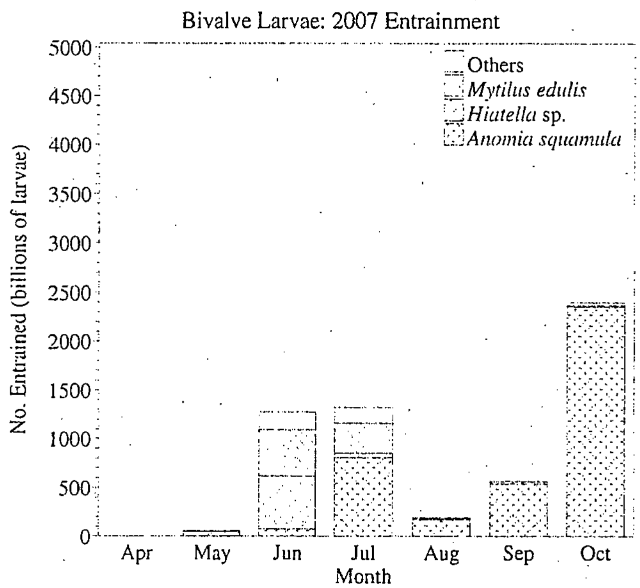


Figure 3-16. Volume of cooling water pumped during months of bivalve larvae sampling and total number of bivalve larvae (x 10^9) entrained by Seabrook Station in 2007. Seabrook Operational Report, 2007.

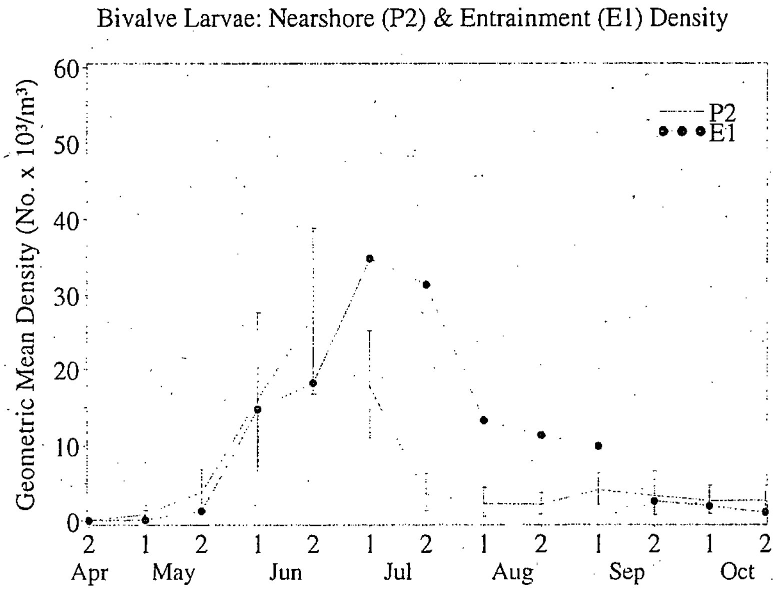


Figure 3-17. Geometric mean density of total bivalve larvae at Station E1 in 2007 and P2 (95% confidence levels for P2; 1993, 1995-2007). Seabrook Operational Report, 2007.

observed in July. Densities are similar from the beginning of sampling in late April through June. Over the summer, densities in entrainment samples are two to three times greater than the nearshore water. Differences disappear in late September and October. The data suggest that larvae maintain a different depth distribution during the summer months than in spring or fall. Entrainment samples are drawn through the intake structure primarily from the middle of the water column, whereas bivalve larvae samples are collected from the entire water column. Mann (1985) found seasonal changes in the depth distribution of bivalve larvae in shelf waters. Larvae were typically distributed deeper in the summer months and shallower in the fall; Mann (1985) attributed this to variations in the depth distribution of chlorophyll *a*. The distribution of phytoplankton may have been affected by thermal stratification and the depth of the thermocline.

The number of *Mya arenaria* entrained in 2007 was 4.7 X 10^9 larvae, on the lower end of the range of what has typically been observed since operation began in 1990 (Appendix Table 3-2). The predicted entrainment level was 41 X 10^9 larvae (NAI 1977). Annual estimates of the number of *Mya arenaria* entrained have ranged from 4 X 10^9 to 60 X 10^9 larvae among years when a complete set of entrainment samples were collected. Entrainment of *Mya arenaria* may have little effect on settlement of young-of-the-year-clams; a strong relationship does not exist between larval abundance and settlement (see Section 7.0). Entrainment of *Mytilus edulis* larvae in 2007 (834 X 10^9 larvae) was similar to the predicted entrainment of 900 X 10^9 (NAI 1977). Entrainment of *Mytilus edulis* has ranged from 922 X 10^9 to 22,374 X 10^9 larvae for years when sampling occurred throughout most of the study period, making 2007 the lowest year in the time series. Entrainment of *Mytilus edulis* has apparently not affected local populations of adults monitored in the marine macrobenthos program (Section 5.0).

3.4 DISCUSSION

Naylor (1965) suggested that nearshore marine organisms may be more susceptible to effects of heated effluents than estuarine organisms, but were less likely to be affected because the effluent would be discharged into an essentially open system, which would allow the heat to be efficiently dissipated. Capuzzo (1980) reviewed the results of several studies on power plant impacts to zooplankton and concluded that at sites where adequate dilution was provided, alterations in zooplankton productivity in the receiving waters were not observed.

A potential plant impact should appear as either consistent or episodic differences between stations (Underwood 1994) during plant operation. In the BACI model, an impact would appear as a significant interaction, whether tested indirectly by ANOSIM for the community analysis or by ANOVA for the selected species. In numerical classification, a potential impact would be implied if all or many of the Station P2 (impact site) collections from the operational period were grouped together and were distinct from the Station P7 (control site) collections, provided that a similar pattern did not exist in the preoperational period. Significant interactions, suggesting the possibility of plant impacts, were not observed for any assemblages by the ANOSIM model (Table 3-10). However, numerical classification results suggest a possible interaction in the hyperbenthos assemblage, although the ANOSIM model cannot be used because of spatial differences in the preoperational period. Changes in the hyperbenthos assemblage occur at the control site (Station P7) and appear to be related to changes in sampling method. Operation of Seabrook Station did not appear to have an effect on any of the selected species (Table 3-11).

Spatial differences of plankton communities are usually the result of the interaction of physical oceanographic processes, such as turbulent advection, and local bathymetry (Mackas et al. 1985, Parsons and Takahashi 1973). However, the bathymetric features associated with patchiness, such as prominent land masses or major river discharges capable of altering local currents, are largely absent in coastal New Hampshire waters (Figure 3-1) and the adjacent areas of Maine and Massachusetts. A study in the coastal waters of New Hampshire in 2002-2003 found no major differences in the zooplankton community along a horizontal gradient of about 10 kilometers at depths of between 50 and 100 meters (Manning and Bucklin, 2005). Except for periodic events of high freshwater discharge from either the Hampton or Piscataqua Rivers, there are no other environmental factors likely to cause spatial differences between stations P2 and P7.

There were two methodological changes that may have had unanticipated effects on the results. In 1996, the number of replicates analyzed was reduced from three to one and in 1998, the number of paired oblique tows was reduced from two to one. Since the beginning of the study in 1978, Station P7 has typically (but not always) been sampled first, often beginning about a half hour after sunset. The earlier sampling time at station P7 is believed to account for the lower abundance of many species at the reference station, such as the selected species *Calanus finmarchicus*, *Crangon septemspinosa* and *Neomysis americana*, observed in the preoperational and early operational periods. The reduction in replication is believed to have had a greater effect at Station P7 than at Station P2 because of the earlier sampling time at Station P7. Prior to 1996, three replicates (randomly selected from four) were analyzed from two pairs of oblique tows at each station on each sampling date. Even after considering Type I Error, there were clear differences between the two pairs of oblique tows at Station P7 (NAI 2005), where densities were typically greater in the second pair of collections (C and D replicates). Beginning in 1996, only the "A" replicate was analyzed. This effectively moved the average sampling time at Station P7 to a point closer to dusk and could have resulted in lower species densities in the samples. Prior to 1996, the lower-abundance A and B replicates from Station P7 were averaged

Table 3-10. Summary of Potential Effects, Based on Non-Parametric Multivariate Analyses of the Operation of Seabrook Station on the Zooplankton Community. Seabrook Operational Report, 2007.

Assemblage	Operational Period Similar to Preoperational Period?	Differences Between Operational and Preoperational Periods Consistent Among Stations?
Bivalve Larvae	No (numerical classification) Yes (ANOSIM)	Yes (numerical classification) Yes (ANOSIM)
Holoplankton	No (numerical classification) Yes (ANOSIM)	Yes (numerical classification) Yes (ANOSIM)
Meroplankton	Yes (numerical classification) Yes (ANOSIM)	Yes (numerical classification) Yes (ANOSIM)
Hyperbenthos	No (numerical classification) Yes (ANOSIM)	No (numerical classification) Not testable (ANOSIM)

Table 3-11. Summary of Potential Effects of the Operation of Seabrook Station on Abundances of Selected Zooplankton Species, Based on ANOVA Results. Seabrook Operational Report, 2007.

Plankton Selected Species and Lifestages	Operational Period Similar to Preoperational Period?	Differences Between Operational and Preoperational Periods Consistent among Stations?
Mytilus edulis larvae	Yes	Yes
Calanus finmarchicus	Yes	Yes
Crangon septemspinosa larvae	Yes	Yes
Carcinus maenas larvae	Yes	Yes
Neomysis americana	Yes	Yes

with the higher-abundance C and D replicates. Differences between the two sets of tows were generally not observed at Station P2, which was typically sampled later in the night. The elimination of the second set of oblique tows in 1998 had the effect of moving sampling time at Station P2 to an earlier time, as sampling at Station P7 was completed earlier. Most indications of an interaction, such as un-pairing of station collections from a year, or formation of new groups in numerical classification were observed after 1996.

The differences between the two sets of oblique tows at Station P7 was most noticeable among known vertical migrants and the hyperbenthos. Beginning in 1996, station differences were observed in the meroplankton assemblage and peracarid abundances in the hyperbenthos assemblage at Station P7 decreased. Most hyperbenthic species are on or very near the bottom during daylight, venturing into the overlying waters at night. The differences between the pairs of oblique tows at Station P7 suggest that a large portion of the population had not moved upward from the bottom meter of water when the A and B replicates were collected. By the time Station P2 was sampled, many more of the migrants had likely entered the water column and were susceptible to capture by the nets, resulting in a distribution of organisms among the pairs of replicates that was more uniform.

In 2006, the time for the start of sampling was moved to nautical twilight, which is later than the previously used time of 30 minutes after sunset. The intention was to start sampling at a time when the distribution of vertically migrating organisms was more uniform between the stations. In 2007, densities of *Neomysis americana* and *Crangon spetemspinosa* were still low, but were higher than the past few years. Stations P2 and P7 of the meroplankton assemblage were paired and grouped with the preoperational and early operational period years.

The reduction in the number of replicates analyzed appears to be at least partially mitigated by the later start in sampling times. The purpose of the zooplankton monitoring program is to determine if the operation of Seabrook Station has affected the zooplankton community. Despite the methodological changes that have occurred it is still possible to fulfill the purpose of the program by recognizing and taking into account the effects of these changes.

A four-decade study by NOAA found large interdecadal variation in the zooplankton community of the Gulf of Maine (Pershing et. al 2005). Their results show a sudden and large increase in *Centropages typicus*, *Metridia* spp. *Pseudocalanus* spp. and other species in the 1990s and a subsequent decline around 2002. *Calanus finmarchicus* dominated most years in the 1980s. They also noted an abrupt decline in zooplankton abundance observed in 1983 and 1984, as observed in this study and by other researchers (Meise-Munns et. al 1990, Jossi and Goulet 1993, Sherman et. al 1998). The pattern described by Pershing et. al (2005) is almost identical to the results of this study, indicating that zooplankton (holoplankton) abundances in coastal New Hampshire waters are determined by trends occurring throughout the Gulf of Maine. A similar trend was observed on Georges Bank (Kane 2007). Both Pershing et. al (2005) and Kane (2007) suggest that the increase in zooplankton in the 1990s may have been related to the "freshening" of the surface waters in the Gulf of Maine, caused by changes in the Scotian Shelf water inflow, which may have helped to stabilize the water column and promote algal growth, the primary food source of the zooplankton in the Gulf of Maine.

In general, abundances of the taxa responsible for the temporal differences in the zooplankton community observed in this study increased during the operational period. Food and temperature are considered important factors affecting populations. Kane (1999) found greater abundances of *Centropages typicus* along the eastern US coast in areas of greater phytoplankton abundance. He also suggested that low winter and spring abundances in the Gulf of Maine were probably due to reduced reproductive efficiency in the colder water. Egg production limited by food availability has been shown for several copepod species (Ban 1994, Sabatini and Kiørboe 1994, Peterson 1985). Temperature determines the range in which a species can reproduce and can also affect larval survival. For example, only 20% of *Cancer irroratus* larvae survived to the megalopa stage at 10°C compared to 83% at 24°C (Johns 1981). Ban (1994) and Schmidt et al. (1998) considered food availability to be a more important factor than temperature in controlling populations of *Eurytemora affinis* and *Acartia bifilosa*. Peterson (1985) determined that *Temora longicornis* populations in Long Island Sound were controlled by egg production that was limited by food availability. The macrozooplankton community in coastal New Hampshire waters and nearby waters of the Gulf of Maine has probably responded to factors such as food availability, temperature, and recruitment, rather than plant operation. There has been a slight warming of about 0.5°C in the operational period. Although no significant differences were detected, phytoplankton cell counts were greater in the operational period (through 1997) compared to the preoperational period (NAI 1998b).

Entrainment does not appear to have affected the bivalve larvae community. Bayne (1976) stated that larval loss to a population, either from over dispersal or mortality due to factors such as predation, settlement in unsuitable habitat, and exposure to extreme physical conditions, was high; possibly approaching 99%. In population studies, mortality at the settlement stage was also found to be enormous (Bayne 1976). The loss of veligers entrained by Seabrook Station is probably small in comparison to the natural mortality rate. As most of the settling stage larvae reside low in the water column, larvae at this stage are less likely to be entrained by the mid-water intake of Seabrook Station. Recruitment to adult populations should be unaffected. There was no evidence that entrainment of bivalve larvae resulted in decreased abundance of adult *Mya arenaria* (Section 7.0), *Mytilus edulis* or *Modiolus modiolus* (Section 5.0).

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Appendix Table 3-1. List of Zooplankton Taxa identified in Seabrook samples. Seabrook Operational Report, 2007.

Bivalve Larvae		
		Anomia squamula Linnaeus 1758
		Hiatella Bosc 1801
		Macoma baltica (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
Holoplankton		
	Cnidaria	*Aglantha digitale* (O.F. M(ller) 1776
	Mollusca	*Clione limacina* Phipps 1774
		Limacina retroversa Fleming 1823
	Annelida	*Tomopteris helgolandicus* Greeff 1879
	Arthropoda/Cladocera	*Evadne* Lovén 1835
		Podon Lilljeborg
	Arthropoda/Copepoda	*Acartia* Dana 1846
		Acartia hudsonica Pinhey 1926
		Acartia longiremis (Lilljeborg) 1853
		Acartia tonsa Dana 1849
		Aetideidae
		Anomalocera opalus Penell 1976
		Calanus finmarchicus (Gunnerus) 1765
		Caligus Müller 1785
		Candacia armata (Boeck) 1872
		Centropages hamatus (Lilljeborg) 1853
		Centropages Krøyer 1849
		Centropages typicus Krøyer 1849
		Euchaeta Philippi 1843
		Eurytemora herdmani Thompson and Scott 1897
		Metridia Boeck 1865
		Monstrillidae
		Pseudocalanus Boeck 1872
		Rhincalanus nasutus Giesbrecht 1892
		Temora longicornis (Müller) 1785
		Tortanus discaudatus (Thompson and Scott) 1897
	Arthropoda/Amphipoda	Hyperiidae Dana 1852
	Arthropoda/Euphaucea	*Meganyctiphanes norvegica* (M. Sars)
		Thysanoessa Brandt
	Chaetognatha	*Sagitta elegans* Verrill 1873
	Urochordata	Larvacea
Meroplankton		
	Cnidaria	Hydrozoa
		Bougainvillia principis (Steenstrup 1850)
		Melicertum octocostatum L. Agassiz 1862
		Obelia Péron and Lesueur 1809
		Phialidium Leuckart 1856
		Rathkea octopunctata (M. Sars) 1835
		Sarsia Lesson 1843
		Scyphozoa
		Tubulariidae

Appendix Table 3-1. (Continued)

Meroplankton (continued)

Mollusca	Cephalopoda Cuvier 1797
	Lacuna vincta Montagu 1803
Arthropoda/Cirripedia	Cirripedia
Arthropoda/Decapoda	*Axius serratus* Stimpson 1852
	Brachyura
	Cancer Linnaeus 1758
	Carcinus maenas (Linnaeus) 1758
	Caridion gordoni (Bate) 1858
	Crangon septemspinosa Say 1818
	Eualus pusiolus (Krøyer) 1841
	Hemigraspus sanguineus (de Haan) 1953
	Hippolytidae Dana 1852 (*Eualus* Thallwitz 1892, *Lebbeus* White 1847, *Spirontocaris* Bate 1888)
	Homarus americanus H. Milne Edwards 1837
	Hyas Linnaeus1758
	Pagurus Fabricius 1775
	Palaemonetes Heller 1869
	Pandalidae
Echinodermata	Echinodermata

Hyperbenthos

Polychaeta	Nereidae Johnston 1865
	Syllidae Grube 1850
Arthropoda/Copepoda	Harpacticoida G. O. Sars 1903
Arthropoda/Mysida	*Erythrops erythrophthalma* (G⊕es) 1864
	Mysis mixta (Lilljeborg) 1852
	Mysis stenolepis S. I. Smith 1873
	Neomysis americana (S.I. Smith) 1873
Arthropoda/Cumacea	*Diastylis* Say 1818
	Lamprops quadriplicata S.I. Smith 1879
	Leuconidae Sars 1878
	Mancocuma stellifera Zimmer 1943
	Petalosarsia declivis (Sars) 1865
	Pseudoleptocuma minor Calman 1912
Arthropoda/Isopoda	Isopoda
Arthropoda/Amphipoda	Amphipoda
	Calliopius laeviusculus (Krøyer) 1838
	Corophium Latrielle 1806
	Gammarus lawrencianus Bousfield 1956
	Ischyrocerus anguipes Krøyer 1838
	Jassa marmorata (Holmes 1903)
	Oedicerotidae Liljeborg 1865
	Photis pollex Walker 1895
	Podoceridae Leach 1814
	Pontogeneia inermis Krøyer 1842
	Unciola irrorata Say 1818

Appendix Table 3-2. Estimated Number of Bivalve Larvae Entrained ($X 10^9$) by the Cooling Water System at Seabrook Station 1990 through 1993, and 1995 through 2007[a]. Seabrook Operational Report, 2007.

Species	1990[b]	1991[c]	1992[d]	1993[e]	1995[e]	1996[e]	1997[e]	1998[e]	1999[e]	2000[e]	2001[e]	2002[e]	2003[e]	2004[e]	2005[f]	2006[g]	2007[e]
Anomia squamula	1691.4	250.8	6.9	3922.7	8905.9	23521.6	2883.3	3827.3	36495.2	7542.2	4128.7	8203.5	3218.1	2595.0	1217.4	3965.8	3949.8
Bivalvia	181.7	38.1	14.5	334.5	797.1	671.4	71.1	64.5	651.3	228.6	483.0	194.2	73.7	89.6	40.4	73.9	46.2
Hiatella sp.	876.6	421.3	189.8	2405.5	2598.2	4670.2	923.7	609.7	4416.5	1920.8	1575.2	567.3	1203.9	1024.2	352.9	604.6	650.7
Modiolus modiolus	909.7	160.2	0.3	1283.9	546.4	5144.8	614.7	241.7	2376.0	2520.7	251.6	776.4	240.8	843.2	292.9	715.1	172.5
Mya arenaria	8.1	0.6	0.2	22.5	4.3	33.2	53.7	11.4	45.7	23.9	26.4	60.2	5.1	15.1	9.2	11.1	4.7
Mya truncata	249.2	6.5	1.1	2.1	27.6	123.0	0.8	8.3	66.0	34.9	26.3	1.9	13.8	5.2	2.3	0.6	3.0
Mytilus edulis	3991.3	1687.5	121.9	10050.7	13231.0	17931.8	1744.5	1493.0	22374.0	10254.7	9621.3	3318.4	2199.0	1526.1	921.5	1351.4	834.4
Placopecten magellanicus	0.7	0.7	0.1	16.9	6.2	31.0	0.8	0.8	11.5	9.9	8.5	0.8	0.0	0.7	0.1	0.0	0.1
Solenidae	61.1	0.0	75.7	102.5	1092.3	241.9	49.5	20.9	773.2	150.4	922.9	150.8	85.5	113.4	57.9	65.2	156.1
Spisula solidissima	69.0	4.4	0.0	48.5	112.5	171.1	22.5	14.8	175.5	33.6	50.8	44.2	3.1	10.0	14.5	20.0	2.8
Teredo navalis	<0.1	15.9	0.0	0.0	4.8	7.4	1.7	0.8	29.9	1.5	0.3	2.3	0.1	0.6	0.3	0.8	0.0
Total	**8038.9**	**2586.0**	**410.5**	**18189.8**	**27326.5**	**52547.4**	**6366.3**	**6293.4**	**67414.9**	**22721.1**	**17094.8**	**13320.0**	**7043.1**	**6223.0**	**2909.3**	**6808.5**	**5820.1**

[a] No sampling occurred in 1994.
[b] Sampling occurred from June through October 1990.
[c] Sampling occurred from the last week in April through the first week in August 1991.
[d] Sampling occurred from the third week in April through the third week in June 1992.
[e] Sampling occurred from the third week in April through the fourth week in October.
[f] Sampling occurred from the fourth week in April through the fourth week in October.
[g] Sampling occurred from the fourth week in April through the fourth week in September

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4.0 SUMMARY

Fishes of the Hampton-Seabrook area have been sampled since 1975 to assess potential impacts associated with the operation of Seabrook Station. Potential intake impacts include the entrainment of fish eggs and larvae and the impingement of juvenile and adult fish at the offshore station intake. Potential discharge impacts include avoidance by larger fish and entrainment of fish eggs and larvae into the offshore thermal discharge.

Numerical classification was used to characterize the species composition of the ichthyoplankton in the preoperational and operational periods. A potential plant impact could be indicated if station pairs (nearfield and farfield) in the operational period were not grouped together based on similarity, as the plant operation potentially affected only the nearfield stations. However, in each year of the preoperational and operational periods, the nearfield and farfield stations were similar, indicating that the factors controlling the ichthyoplankton communities operated equally at both stations thus indicating no impact due to the operation of Seabrook Station. The larval assemblage in 2007 was similar to other operational years, but different from 2006. The 2007 larval assemblage was characterized by a high abundance of cunner, silver hake, fourbeard rockling and radiated shanny, and low abundance of American sand lance, Atlantic mackerel, Atlantic herring, and winter flounder.

There were no significant differences in larval density of five of the nine selected species between the preoperational and operational periods. Densities of larval Atlantic herring, Atlantic cod, pollock, and winter flounder were significantly higher in the preoperational period than in the operational period. Changes in larval fish density between periods for the selected species of larval fish were similar between stations, indicating no effect due to the operation of Seabrook Station.

CPUE (catch per ten-minute tow) of demersal fishes in 2007 decreased from the previous year to sixth highest in the operational period. CPUE in 2007 at all stations was dominated by winter flounder (7.8), longhorn sculpin (6.1), windowpane (3.1), and skates (3.1). CPUE of rainbow smelt, Atlantic cod, hakes, yellowtail flounder decreased between the preoperational and operational periods while winter flounder increased between periods. The magnitudes of the changes were not consistent between stations, resulting in a significant interaction term for each species. The reductions in demersal fish resources at both nearfield and farfield stations are probably due to commercial overfishing rather than plant operation.

Trend line analysis of all species combined captured in the trawl indicated that there was no significant trend in CPUE at the nearfield station (T2). However, there was a significant negative trend at the farfield station T1 from 1976 through 1995 and no significant tend after that. At Station T3 there was a significant negative trend from 1976 through 1993 and a significant subsequent positive trend. CPUE was generally significantly lower from 1976 through the late 1980s and mid 1990s at all stations for rainbow smelt, Atlantic cod, hakes, and yellowtail flounder. In contrast, CPUE was significantly higher from the mid 1990s through 2007 for winter flounder at two stations. The consistent negative trends in CPUE for many of the selected species from 1976 through the mid-1980s and 1990s are an indication that the current low levels are a result of processes that began prior to plant operation. The positive trends in CPUE of winter flounder are consistent with the recent

change of status of the Gulf of Maine stock to not overfished.

CPUE (catch per seine haul) for estuarine fishes in 2007 was 11.2, an increase from the previous year (8.3). The catch in 2007 at all stations was dominated by Atlantic silverside (5.6), killifishes (0.7), rainbow smelt (0.6), and winter flounder (0.6). CPUE was significantly higher in the preoperational period for rainbow smelt, Atlantic silverside, and winter flounder.

In 2007, an estimated 715 million eggs were entrained. This was a decrease from the 2006 estimate of 1,075 million. Cunner/yellowtail flounder (293 million), Atlantic mackerel (154 million), hake/fourbeard rockling (68 million), silver hake (61 million), American plaice (36 million), and windowpane (35 million) were the dominant eggs entrained. Based on the ratio of cunner to yellowtail flounder larvae, almost 97% of the cunner/ yellowtail flounder eggs were cunner.

An estimated 297 million fish larvae were entrained in 2007, the fourth highest estimate to date when sampling occurred in all 12 months. Cunner (98 million), rock gunnel (47 million), American sand lance (37 million), and Atlantic seasnail (34 million) were the most abundant larval taxa entrained in 2007. Entrainment of larvae in 2007 was highest in August when cunner (95 million) and fourbeard rockling (15 million) were most abundant.

An estimated 22,451 fish and 21 lobsters were impinged in 2007 at Seabrook Station based on impingement samples and cooling water flow. This estimate increased from last year but was less than the highest impingement estimate since reliable estimates were first made in 1994. Most fish were impinged in April (7,983: 36%). Winter flounder (3,949; 18%), rock gunnel (3,174: 14%), northern pipefish (2,374: 11%), American sand lance (2,073: 9%), and windowpane (1,502: 7%) comprised 59% of the fish impinged in 2007.

It appears that the majority of the fish impinged at Seabrook Station are YOY demersal fishes taken during the spring and fall. Many common inshore demersal fishes undergo a seasonal movement in the fall and winter as they move to deeper waters as inshore water temperatures decrease. Impingement of YOY demersal fishes in the fall and winter may be a result of these fishes moving past the station's offshore intakes as they complete their annual movements.

Equivalent adult (EA) analysis of seven species of commercially important fishes indicated that estimated average losses of adult fish due to entrainment ranged from 19 (Atlantic cod) to 2,055 (winter flounder). Losses due to impingement ranged from 4 (yellowtail flounder) to 1,318 (Atlantic herring). EA losses due to entrainment for most species were larger than impingement losses.

The operation of Seabrook Station did not affect the ichthyoplankton and fish communities of the Hampton-Seabrook area. Relatively few individuals were removed by station operation through entrainment. CPUE of demersal fishes decreased at all stations in the operational period. This was attributed to overfishing that has caused a general reduction in the abundance of commercially important species in the Gulf of Maine.

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4.1 INTRODUCTION

The 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. 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, the thermal plume could affect local distribution of fishes, and some eggs and larvae could be subjected to thermal shock due to plume entrainment following the offshore discharge of condenser cooling water from the diffuser system.

The following report presents general information on each finfish collection program and provides more detailed analyses of 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 2007 by various ichthyoplankton and adult finfish sampling programs is given in Appendix Table 4-1.

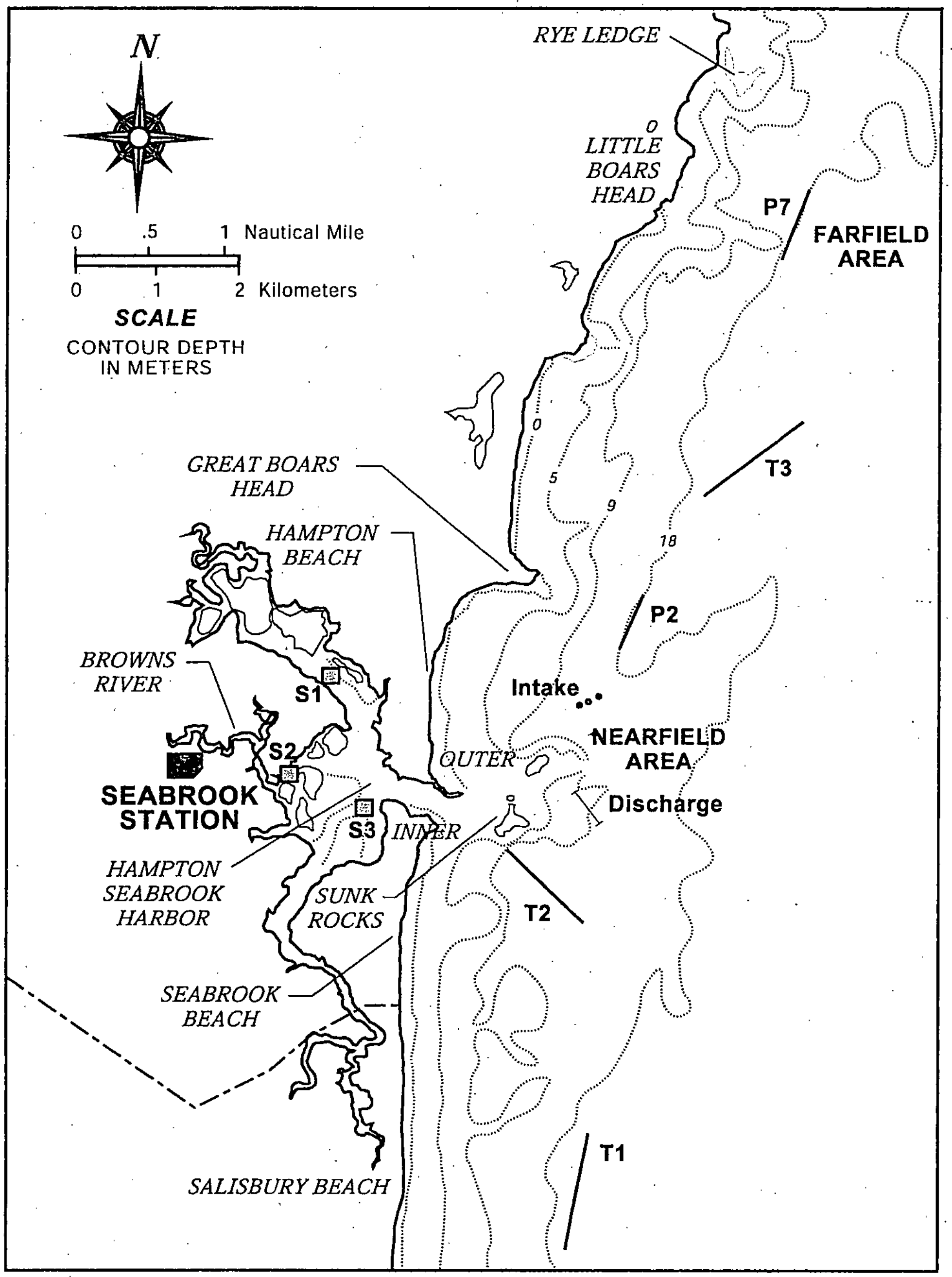
4.2 METHODS

4.2.1 Ichthyoplankton

4.2.1.1 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 4-1). Station P5 (nearfield site for the Seabrook discharge) was sampled from July 1975 through December 1981 and from July 1986 through December 1997, when sampling at this station ceased. Station P7 (farfield station located about 7 km north of the nearfield stations), representing a non-impacted or control site, was sampled from January 1982 through December 1984 and from January 1986 through December 2007. 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. Sampling occurred twice during all months from January 1979 to February 1983. Sample collection was increased to the current frequency of four times per month at each station sampled from March 1983 to December 2007.

Four samples were collected at night from July 1975 through December 1993 on each sampling date and at each station. Sampling began one half-hour after sunset until 2006 when sampling began at nautical sunset. Beginning in January 1994, two tows were collected on each of the four sampling periods each month.



LEGEND

P = Ichthyoplankton Tows

T = Otter Trawls

S = Seine Hauls

Figure 4-1. Ichthyoplankton and adult fish sampling stations. Seabrook Operational Report, 2007.

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.

4.2.1.2 Entrainment Sampling

Ichthyoplankton entrainment sampling was conducted four times per month by Seabrook Station personnel from July 1986 through June 1987, and June 1990 through December 1997. Three replicate samples were collected using 0.505-mm mesh nets suspended in double-barrel collection devices during the day on each sampling date. In each barrel, a 0.505-mm mesh net was suspended in a 30-gal drum 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 using an in-line flowmeter and averaged approximately 100 m^3 per replicate. The three simultaneous replicates were summed into one sample during analysis.

Beginning in January 1998, the sampling design changed to include 24-hour sampling, and evaluation of 0.505-mm and 0.333-mm mesh sizes. Sampling occurred four times each month, and four diel periods (2400-0600, 0600-1200, 1200-1800, 1800-2400 hours) were sampled on each sampling date. Flow was diverted from the cooling water system into four double-barrel samplers on each sampling date and diel period. Of the four samplers, two contained 0.333-mesh nets and two contained 0.505-mesh nets. The flow through each mesh size (two samplers) was about 0.265 m^3/min, resulting in a volume sampled of about 100 m^3 for each mesh size and each diel period. The total volume sampled for each mesh size on a sampling date (four diel periods) was about 400 m^3.

There were no significant differences in ichthyoplankton density between the 0.333-mm mesh nets and the 0.505-mm mesh nets (NAI 2000); therefore, the samples from the two mesh sizes were pooled resulting in a volume filtered on each sampling date of about 800 m^3. Starting in 1999, only 0.333-mm mesh was used for entrainment sampling.

Beginning in April of 2002, the entrainment sampling program was further modified. Sampling occurred four times per month as before, but diel periods were redefined to morning (0415-1015), day (1015-1615), evening (1615-2215), and night (2215-0415). These diel periods were adjusted for the time of transit between the intakes and the sampling locations in the plant, and standardized to Eastern Standard Time. The purpose of redefining the diel periods was to ensure that biologically significant time periods (sunset, dawn) were contained within the same diel period year round, thereby minimizing within period variability. Within each diel period, samples were collected during a two-hour period. Since only two of the possible six hours were sampled each week, the two-hour sampling period was scheduled systematically to insure different two-hour periods were sampled each week. The sample volume in each two-hour period was approximately 275 m^3.

4.2.1.3 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 4.2.1.1) 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 eggs were difficult to identify to species due to their stage of development. These eggs 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 Gadid/witch flounder; 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.

4.2.2 Adult Fish

4.2.2.1 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 4-1; Table 4-1). Four replicate tows were made at each station once per month. Beginning in

Table 4-1. Description of Finfish Sampling Stations. Seabrook Operational Report, 2007.

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
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)

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, particularly since 1983. In 2007, no samples were collected at Station T2 from July through October due to the presence of lobster gear. Fish collected were identified to their lowest practical taxon (usually species), and measured for total length to the nearest mm.

4.2.2.2 Estuarine Fishes

Seine samples were taken monthly from April through November at Stations S1, S2, and S3, beginning in July 1975 (Figure 4-1; Table 4-1). No samples were collected in 1985 or from April through June of 1986. Duplicate daytime hauls were taken into the tidal current at each station with a 30.5 m x 2.4 m bag seine. The nylon bag was 4.3 m x 2.4 m with 1.4-cm stretch mesh, and each wing was 13.1 m x 2.4 m with 2.5-cm stretch mesh. Fish collected were identified to their lowest practical taxon (usually species), and measured for total length to the nearest mm.

4.2.2.3 Impingement

Before 1998, Seabrook Station personnel collected fish impinged at Seabrook Station. Traveling screens were generally washed within the circulating water pumphouse at least once to twice each week and more frequently during storm conditions that could result in the impingement of more debris such as seaweed (R.Sher, FPL Seabrook, pers. comm.). Impinged material was sluiced into a collection basket, and fish were separated from debris, measured, and counted. Not all impingement collections were monitored, and the number of fish impinged in unmonitored collections was estimated based on the volume of debris in the unassessed screenwash, and the number of fish per volume of debris in the assessed screenwash nearest in time (NAI 1998).

Starting in 1998, commitment was made to improve the accuracy of the impingement estimates by monitoring every screenwash, and to investigate the possibility that fish were lost on the traveling screens during long duration samples. To accomplish this, from 1998 through April 2002, the traveling screens at Seabrook Station were washed at a minimum twice weekly, and Normandeau Associates staff enumerated screenwash debris. The first sample, usually collected on a Tuesday, had a sample duration of six days. The second sample, usually collected on a Wednesday, had a sample duration of one day. Collection of a sample of six-days duration every week was not possible because there were often intermediate washes within the six-day sample, and a priority of the program was to monitor every screenwash. The impingement estimate was derived from the sum of the fish impinged in the individual screenwashes.

Beginning in April 2002, the impingement sampling procedures were changed to two approximately 24-hour collections each week. Samples were usually collected on Monday and Thursday mornings and the sample duration was usually between 23 and 26 hours. Impingement estimates were made by standardizing individual collections to 24-hours. The two 24-hour samples each week were averaged and then multiplied by 7 to produce a weekly impingement estimate. Weekly impingement estimates were summed to produce monthly estimates and the monthly estimates were summed to produce the annual estimate.

The work-up of the impingement samples in 2007 was similar to the procedures used in prior years and complete details are available in Seabrook Station Procedure Number ZN1120.03, Rev. 00, Impingement Assessment Procedure. All fish were identified to the lowest taxon possible (generally species), and a maximum of 20 individuals per taxon were randomly selected for measurement of total length to the nearest mm.

4.2.3 Analytical Methods

Temporal and spatial changes in the ichthyoplankton egg and larval community structure were evaluated by cluster analysis (numerical classification) and non-metric multi-dimensional scaling (MDS) of the annual means (log (x+1)) of each taxon at each station. Both methods form relationships between samples (the station-year combinations were treated as samples in this study) based on a similarity index. In this study, the Bray-Curtis similarity (Clifford and Stephenson 1975; Boesch 1977) index was used. Values of the indices ranged from 0 for absolute dissimilarity to 1 for absolute similarity. Cluster analysis presented a dendrogram with station-year combinations grouped by their similarity. The Bray-Curtis similarities associated with the dendrogram provided a unit to measure the differences. MDS is a method of comparing samples where a "map" or configuration of samples is drawn in a specified number of dimensions which attempts to satisfy all the conditions imposed by the rank similarity matrix (Clarke and Warwick 1994). The MDS plot shows the relative relationships among samples, but provides no measure of the magnitude of the differences. The adequacy of the representation of the relationships among samples is measured by "stress." Clarke and Warwick (1994) provided rules of thumb for evaluating stress in MDS plots. Stress less than 0.1 corresponded to good ordination with no real prospect of a misleading interpretation. Stress less than 0.2 still provided a potentially useful two-dimensional picture. Conclusions drawn from MDS plots with stress levels near 0.2 should be verified with those from an alternate technique such as clustering. A potential plant impact would be indicated in both displays if all or most of the Station P2 collections from the operational years were grouped together and distinct from the preoperational collections or if station differences that were apparent in the preoperational period did not appear in the operational period.

Cluster analysis and MDS results were evaluated to determine if community trends were related to spatial or temporal differences. 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%). Spatial and temporal differences in the ichthyoplankton community were assessed using the analysis of similarity (ANOSIM) procedure (Clarke 1993). Tests for differences between treatment main effects, period and station, were provided by a two-way ANOSIM (Clarke and Warwick 1994). According to the before-after-control-impact (BACI) design (Stewart-Oaten et al. 1986), potential plant impacts would appear as an interaction between treatment main effects. The ANOSIM procedure cannot directly test for the interaction of main effects (Preop-Op X Station), but the interaction can be determined indirectly, provided there are no differences between stations in the preoperational period (Clarke 1993). Therefore, the interaction of main effects was tested using a two-stage procedure. First, the preoperational period was tested for station differences using a one-way ANOSIM. In the absence of no significant differences between stations in the preoperational period, then each station was tested for differences between periods using a one-way ANOSIM. Significant differences between periods for either station were compared with the MDS and cluster analysis for aid in interpretation and to account for accumulating Type I error. A 5% alpha level for the significance of the test statistic was assumed to be ecologically meaningful in this report.

If significant differences occurred between the preoperational and operational periods through ANOSIM, the Bray-Curtis dissimilarity (Clarke and Warwick 1994) was used to determine the contribution of each individual species to the overall dissimilarity between periods. Annual means for each station were used to compute individual and overall dissimilarity. Densities were not log transformed prior to performing the dissimilarity computation, but were standardized as recommended by Clarke and Warwick (1994). Taxa were ranked by their percent contribution to the overall dissimilarity and tabulated with preoperational and operational period means and standard deviations.

Total ichthyoplankton entrainment was estimated by calculating the arithmetic mean density in a sample for each sampling week, and multiplying by the weekly cooling water volume during the week the samples were taken. These weekly estimates were summed for a monthly estimate, and monthly estimates were summed for the annual estimate.

Eleven taxa were selected from the species collected over the years for detailed analyses of abundance and distribution and for an assessment of impact by Seabrook Station (Appendix Table 4-1, Table 4-2). 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 4-2 by sampling program, were individually evaluated for temporal and spatial changes in abundance between the

Table 4-2. Selected Finfishes and Sampling Programs That Contributed Abundance Data for Species-Specific Analyses. Seabrook Operational Report, 2007.

Selected Species	Predominant Sampling Programs
Atlantic herring	Ichthyoplankton
Rainbow smelt	Otter trawl, beach seine
Atlantic cod	Ichthyoplankton, otter trawl
Pollock	Ichthyoplankton
Hakes	Ichthyoplankton, otter trawl
Atlantic silverside	Beach seine
Cunner	Ichthyoplankton
American sand lance	Ichthyoplankton
Atlantic mackerel	Ichthyoplankton
Winter flounder	Ichthyoplankton, otter trawl, beach seine
Yellowtail flounder	Ichthyoplankton, otter trawl

preoperational and operational periods. Geometric means were compared among the preoperational, operational, and 2007 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) of juvenile and adult fish. The distribution of numerical count data for ichthyoplankton and fish was generally right skewed. The log transformation of these data tends to result in a more nearly symmetric distribution, which more closely fits the assumptions of conventional parametric statistical testing. CPUE was defined as number per 10-min tow for the trawl, and number per standard haul of the seine. A transformed mean was calculated for each year and for combined years (e.g., preoperational and operational periods). The 95% confidence intervals of the mean of annual means of the preoperational and operational periods (Sokal and Rohlf 1995) in the logarithmic scale were also computed. The annual and combined geometric means and confidence intervals are presented as back-transformed values. Some life stages are seasonal, so the data used to compute the geometric means of some species were restricted to periods of primary occurrence. When trimmed data were used, it is noted in the text, figure, or table.

Segmented regression analysis was performed on total catch of estuarine and demersal fishes as well as for those selected species collected by trawl that had a significant interaction term from the analysis of variance (ANOVA). Segmented regression was used to identify when there were significant changes or "breakpoints" in the time series of annual abundance. These breakpoints typically divided the time series into two periods. Significant differences in mean CPUE between the two periods were evaluated with a t-test. If a breakpoint was identified, linear regression was used within each period to describe trends of abundance.

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 (months) 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). Operational status (preoperational vs. operational) and station differences and the interaction between them were evaluated using a mixed linear model analysis using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. The preoperational period for each analysis was specified as the period during which both stations were sampled concurrently (thus maintaining an equal number of years between stations within the preoperational period). Collections from 1990, the year the plant began to operate intermittently, occurred during the transition from preoperational to operational periods and were excluded from the analysis. The inference test for Preop-Op was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS Institute, Inc. 1999). The likelihood ratio test was used to test the significance for random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects.

To assess 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 of estuarine fish in Hampton Harbor was slightly different from the model used for the otter trawl and ichthyoplankton 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 eliminated, 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 of a species, depending on seasonal pattern of occurrence of each species or times of sample collection (Appendix Table 4-2), and is noted as such on the ANOVA tables. Larval data were restricted to the period July 1986 through December 2006, and for selected taxa collected by trawl, and seine, the data used were from July 1975 through December 2006. Trawl data were excluded from the ANOVA in August through November because of reduced sampling effort at Station T2. The data used in the analyses of trawl and seine samples were $\log_{10}$ (CPUE + 1) transformed for each collection. In the case of larvae, the transformed mean density of replicate samples was used for data up through 1993 (only one replicate was analyzed in 1994 through 2007).

Adult Equivalency Methods

An adult equivalency analysis of selected species of entrained larvae was determined using the methods of Saila et al. (1997). This analysis estimates the number of adult fish that would have resulted if the larvae had not been entrained. Seven species were selected for this analysis, on the basis of their regional commercial importance, their recreational value, and their consistent occurrence among species entrained at Seabrook Station: Atlantic cod, Atlantic herring, Atlantic mackerel, pollock, red hake, winter flounder and yellowtail flounder. Although hake larvae have not been identified to the species level in the Seabrook program due to the similarity between red hake and white hake larvae, we follow Saila et al. (1997) in treating "hake" (*Urophycis* sp.) larvae as red hake. Impingement data from 1995 through 2006, and entrainment data from 1998 through 2006 were used in these analyses because these years were considered to have the most accurate impingement and entrainment estimates.

Adult equivalencies for eggs were estimated as follows:

$$N_a = 2\,N_i / f_a \qquad \text{(Equation 1)}$$

where

N_a = number of equivalent adults,

N_i = estimated number of eggs entrained, and

f_a = average lifetime egg production.

Larval 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:

$$S_e = 1 / \exp [Z_e + Z_L (i-h)] \quad \text{(Equation 2)}$$

where

S_e = probability of survival from egg to size entrained,

Z_e = egg mortality,

Z_L = larval mortality per millimeter,

i = length in millimeters when entrained, and

h = predominant size at hatching (millimeters).

Then the adult equivalent in each size class of entrained larvae was estimated as

$$N_a = 2 N_i / (S_e f_a) \quad \text{(Equation 3)}$$

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 potentially resulting from impingement of fish was estimated using the following expression:

$$N_R = N_0 e^{-m(t_R - t_0)} \quad \text{(Equation 4)}$$

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

Methods of estimation are presented in NAI 2001.

4.3 RESULTS AND DISCUSSION

4.3.1 Ichthyoplankton Assemblages

Analyses of the ichthyoplankton program focused on seasonal assemblages of both eggs and larvae, as well as on larvae of individual selected taxa (Table 4-2). Selected taxa are discussed in Section 4.3.3, 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.

4.3.1.1 Offshore Samples

Previous analyses of the fish egg and larval assemblages in the offshore Hampton-Seabrook area indicated that time of year was the only factor that corresponded with the cluster groups (NAI 1998). Furthermore, these groups appeared consistently at about the same time of year each year. No groups were defined solely by station, and there were no major seasonal groups that appeared only in the operational period. Based on this consistency, there was no evidence of an impact due to the operation of Seabrook Station.

Analysis of the 2007 ichthyoplankton data investigated the relationships between the ichthyoplankton assemblage among stations and years, because previous analyses demonstrated that the within-year seasonality of groups (clusters) was very consistent among years. A total of 50 collections were used in the cluster analysis, with each cluster representing an annual average of samples at either Station P2 or P7.

Both egg and larval assemblages were characterized by a high degree of similarity (>70%) among collections. Within the egg assemblage, two subgroups were apparent. Annual means for each station from 1983, 1984, 1986, and 1987 comprised the eight collections in Group 1 (Figure 4-2). Group 2 was composed of annual means for each station for the remaining years, with the exception of 1982, which was ungrouped. Stations in both preoperational and operational years were usually paired together indicating a higher degree of similarity in structure between stations than among years. In 10 of the 17 operational years (1991-2007), the egg assemblages at the nearfield and farfield stations were more similar to each other than to any other station/year combination. The greater similarity between stations than among years indicated that the factors that control the composition of the egg assemblage appeared to be operating equally in both the nearfield and farfield areas.

The MDS plot showed some separation between the preoperational and operational years, but agreed closely with the cluster analysis. Station pairs in the lower right quadrant of the MDS plot (1983, 1984, 1986, 1987) corresponded with Group 1 in the cluster analysis. Station pairs in the left half of the MDS plot were a combination of including preoperational and operational years, 2007, which was grouped with Group 2 in the cluster analysis. The station pair for 1982 was isolated in the upper right quadrant.

ANOSIM indicated that there were significant differences in the egg assemblage between the preoperational and operational periods, but there were no differences between stations (Table 4-3). Within the preoperational period, there were no significant differences between stations, which then allowed comparisons of the individual stations between periods. Significant differences between periods were evident at both Stations P2 and P7. These differences occurred at both the nearfield and farfield stations and cannot be attributed to plant operation.

Density of Atlantic mackerel, cunner/ yellowtail flounder, hake/fourbeard rockling, silver hake, and windowpane eggs was greater in Group 2 compared to Group 1 (Table 4-4). Density of hake, Atlantic cod/haddock and fourbeard rockling eggs was lower in Group 2. Low densities of hake/fourbeard rockling, fourbeard rockling, and windowpane eggs characterized the ungrouped year 1982.

The larval assemblage exhibited a similar degree of homogeneity among collections as the egg assemblage (Figure 4-3). Within larval samples, two subgroups were apparent. Group 1 consisted of collections at each station for all preoperational years sampled and operational year 1993. Group 2 consisted of collections at each station all operational years, except for the station pairs from 1992, 1993, and 2006. Stations from a given year in both the preoperational and operational periods were always clustered together with the exception of 1995. As with the egg assemblage, this indicated that there was a greater similarity in the larval assemblage between stations than among years. Densities of cunner, silver hake, fourbeard rockling and radiated shanny larvae were greater in Group 2 compared to Group 1 (Table 4-4). American sand lance, Atlantic mackerel, Atlantic herring, and winter flounder larval densities were lower in Group 2 compared to Group 1.

The years 1992 and 2006 were ungrouped as they were substantially different from all other years. In 2006, ichthyoplankton larval densities were generally lower than other years, with the exception of cunner larvae. In 1992, larval densities were substantially lower compared to Groups 1 and 2, and the most abundant larvae were American sand lance and rock gunnel.

The MDS plot generally supported the results of the cluster analysis. The station pairs for 1992 and 2006 were separated from the

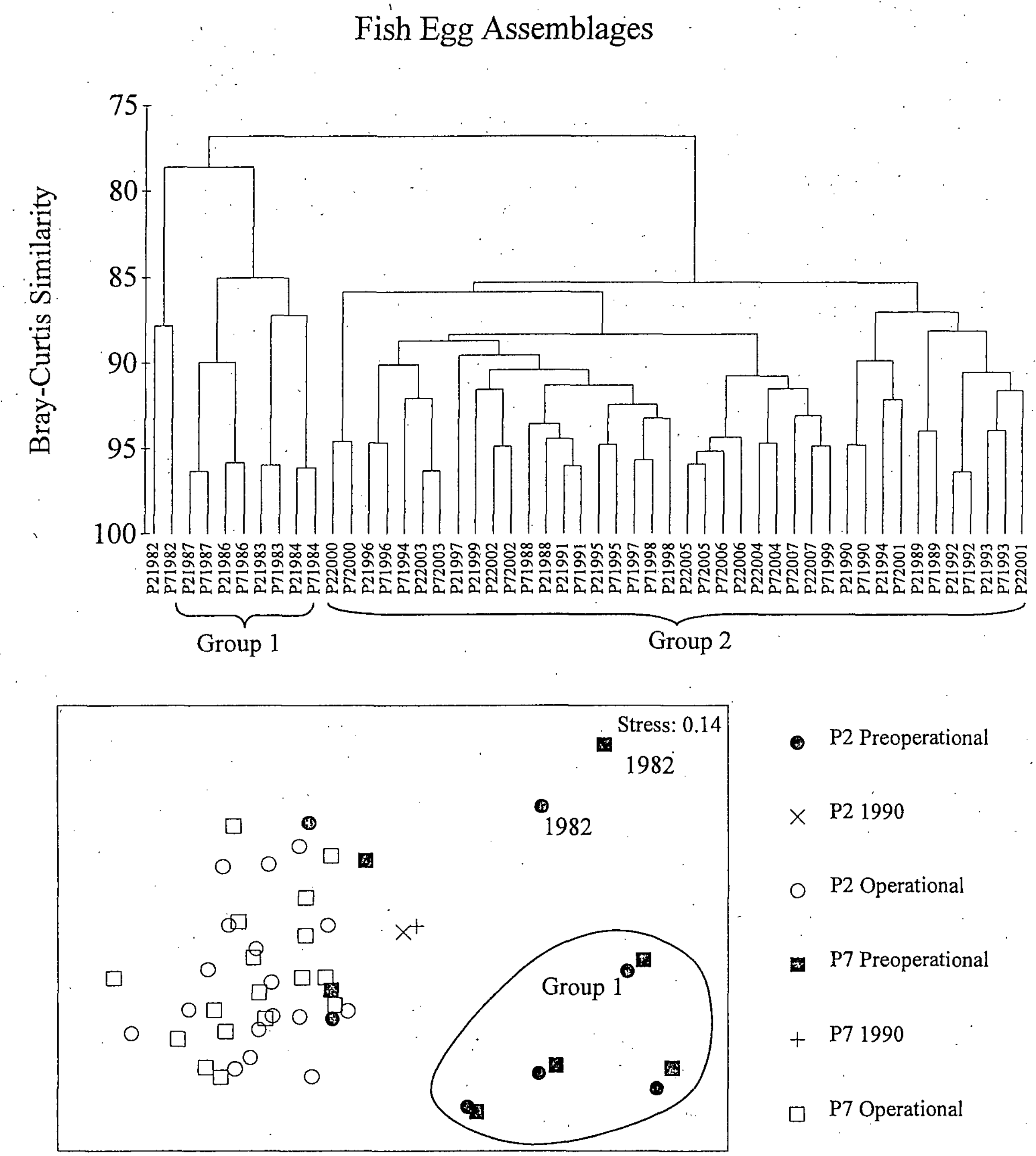


Figure 4-2. Dendrogram and temporal/spatial occurrence pattern of fish egg assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m^3) at Seabrook intake (P2) and farfield (P7) stations, 1982-1984, 1986-2007. Seabrook Operational Report, 2007.

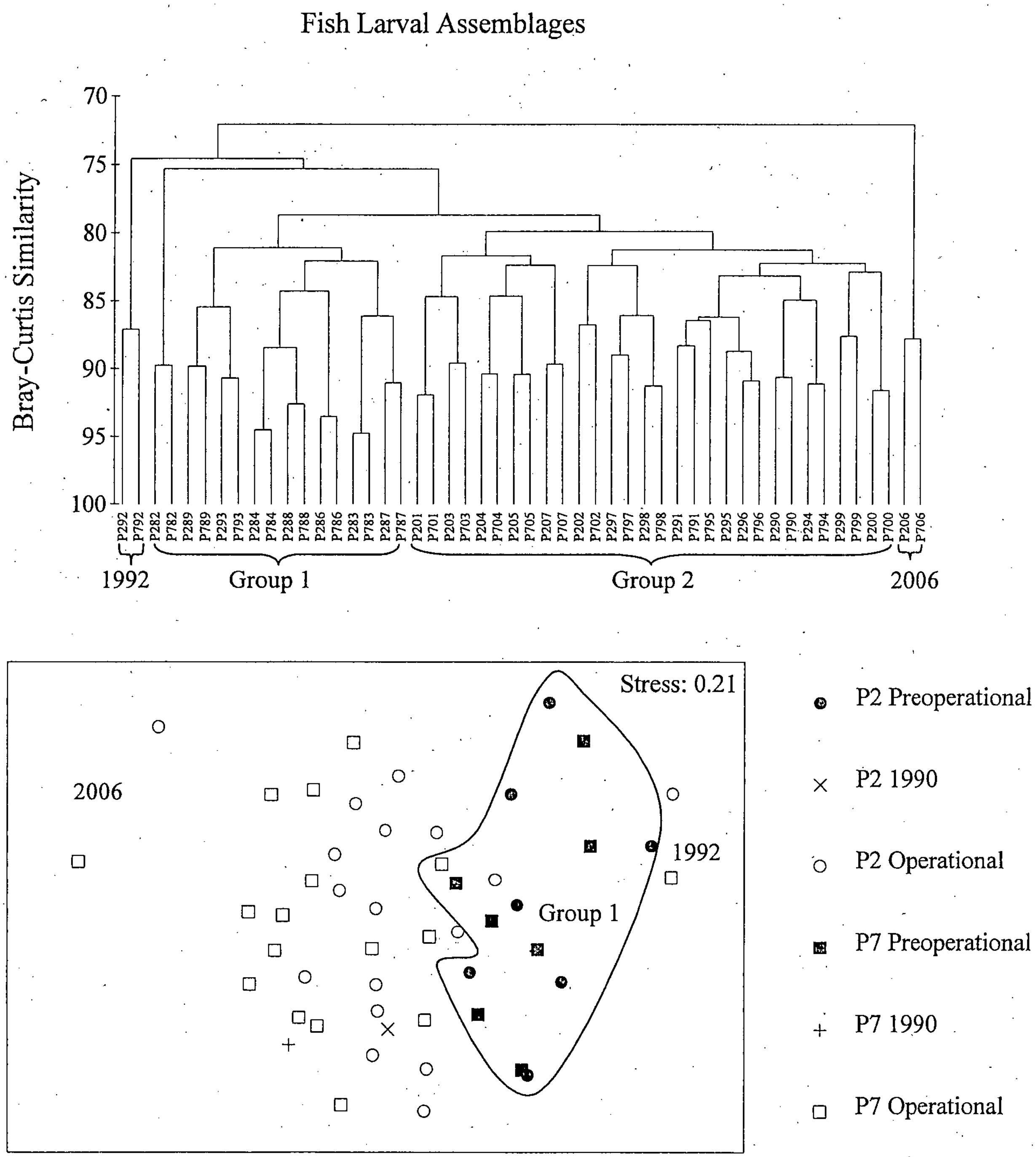


Figure 4-3. Dendrogram and temporal/spatial occurrence pattern of fish larvae assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m3) at Seabrook intake (P2), and farfield (P7) stations, 1982-1984, 1986- 2007. Seabrook Operational Report, 2007.

Table 4-3. Analysis of Similarities (ANOSIM) between Station and Period of the Fish Egg and Larvae Assemblages. Seabrook Operational Report, 2007.

Community	Comparison	R	P[a]
Egg	Period[b]	0.66	<0.01*
	Station[b]	0.02	0.23 NS
	Preop: P2 vs. P7[c]	-0.09	0.83 NS
	P2: Preop vs. Op[c]	0.67	<0.01*
	P7: Preop vs. Op[c]	0.65	<0.01*
	Interaction of Main Effects		NS
Larvae	Period[b]	0.32	<0.01*
	Station[b]	0.02	0.23 NS
	Preop: P2 vs. P7[c]	-0.11	0.88 NS
	P2: Preop vs. Op[c]	0.27	0.01*
	P7: Preop vs. Op[c]	0.37	<0.01*
	Interaction of Main Effects		NS

[a] p = significance level of test statistic R [b] Two-way crossed ANOSIM [c] One-way ANOSIM
* indicates significant differences, p<0.05
NS = no significant differences

Table 4-4. Mean density (no./1000 m^3) and Upper and Lower 95% Confidence Limits of Dominant Fish Eggs and Larvae in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2007.

	Group 1[a]			Group 2[b]		
TAXON	LCL[c]	Mean	UCL[d]	LCL	Mean	UCL
Eggs						
Atlantic mackerel	650	1,009	1,369	1321	1952	2583
Cunner/Yellowtail flounder	2,764	5,003	7,243	6318	7155	7993
Hakes	235	1,226	2,217	275	439	603
Hake/Fourbeard rockling	45	215	386	508	649	790
Atlantic cod/haddock	80	153	226	62	95	128
Windowpane	73	147	221	164	246	328
Fourbeard rockling	169	248	328	31	48	65
Silver hake	45	77	109	108	299	490
Larvae						
Cunner	239	418	597	1009	1731	2453
American sand lance	120	228	336	134	175	215
Atlantic mackerel	47	140	233	53	116	178
Fourbeard rockling	42	70	98	63	88	112
Atlantic herring	34	56	78	23	30	37
Rock gunnel	21	37	54	29	41	53
Winter flounder	16	33	50	7	10	13
Silver hake	9	16	24	38	82	125
Radiated shanny	18	25	32	0	31	64

[a] Years = 1983, 1984, 1986, 1987.
[b] Years = 1988-2007.
[c] LCL = Lower 95% confidence limit.
[d] UCL = Upper 95% confidence limit.
[e] Years = 1982-1984, 1986-1989, 1993.
[f] Years = 1989-1991, 1994-2007.

other years. Stations pairs on the right side of the MDS plot corresponded to Group 1, and the remainder of the stations composed Group 2. The stress level in the two-dimensional MDS plot was 0.21, indicating that the representation is still useful, especially when interpreted with the cluster analysis. A three-dimensional MDS plot would result in a lower stress level, but the visual presentation of these plots is more difficult to interpret.

ANOSIM indicated that there were significant differences in the larval assemblage between periods, but there were no significant differences between stations (Table 4-3). Within the preoperational period, there were no significant differences between stations. When the larval assemblage at each station was compared between periods, there were significant differences at both stations. Because these differences between period occurred at both the nearfield and farfield stations, they cannot be attributed to plant operation.

There was high degree of similarity among nearfield and farfield collections of offshore eggs and larvae of the Hampton-Seabrook area. Due to this high similarity, there is no evidence that the operation of Seabrook Station has affected the fish egg and larval assemblages. If the operation of Seabrook Station had affected the composition of the egg and larval assemblages, it would be expected that station pairs (nearfield and farfield) for the operational years would not cluster together, as plant operation would potentially affect only the nearfield station. However, in each year of the preoperational and operational periods, the assemblages at the nearfield and farfield stations were similar, indicating that the factors controlling the egg and larval assemblages operated equally at both stations.

ANOSIM results agreed with the cluster and MDS analyses. There were significant differences between periods, but these differences occurred at both stations, indicating that the changes were area-wide. There was no evidence of a change in either the egg or larval assemblages between the preoperational and operational periods that occurred at only one station.

4.3.1.2 Entrainment

Entrainment of fish eggs and larvae through the condenser cooling water system is one of the most direct potential impacts of Seabrook Station on the local fish assemblages. Eggs belonging to 17 taxa and larvae of 26 taxa (plus one group of unidentified larvae) were collected in entrainment samples in 2007 (Table 4-5). Total estimates of entrainment for 2007 were 715 million eggs and 297 million larvae. About 48% of the egg entrainment occurred in June and about 40% of larval entrainment occurred in August (Figure 4-4; Table 4-5).

Egg entrainment in previous years ranged from 5 million in 1994 (8 months of sampling) to 2,104 million in 2000 (Table 4-6). The egg entrainment estimate for 2007 (715 million) was within the range of previous years. Entrainment was greatest in June due to large numbers of entrained Atlantic mackerel and cunner/yellowtail flounder eggs (Figure 4-4). Cunner/yellowtail flounder (293 million), Atlantic mackerel (154 million), hake/four-beard rockling (68 million), silver hake (61 million), American plaice (36 million), and windowpane (35 million) were the most numerous fish eggs entrained in 2007 (Table 4-5). Atlantic mackerel and cunner/yellowtail eggs from June together made up about 38% of the total estimated annual egg entrainment.

The entrainment estimate for the most abundant egg taxon in 2007, cunner/ yellowtail flounder, decreased compared to 2006 (Table 4-6). Estimates in previous years ranged from 0 (1994: no sampling from

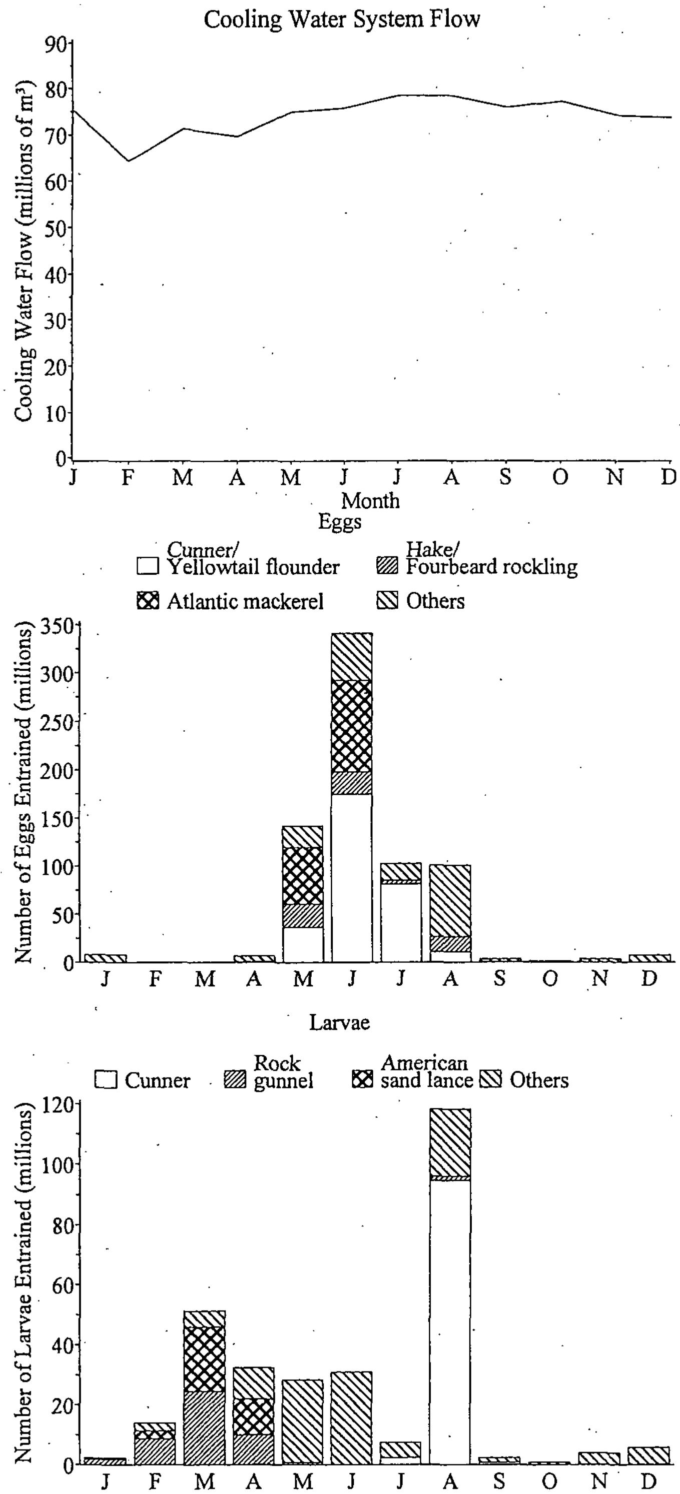


Figure 4-4. Total monthly cooling water system flow and estimated numbers of fish eggs and larvae entrained during 2007. Seabrook Operational Report, 2007.

Table 4-5. Monthly Estimated Numbers of Fish Eggs and Larvae (in millions) Entrained by the Cooling Water System at Seabrook Station During January Through December in 2007. Seabrook Operational Report, 2007.

Eggs

TAXON	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
American plaice	0.00	0.00	0.00	2.50	10.26	23.05	0.00	0.00	0.00	0.00	0.00	0.00	35.81
Atlantic cod	0.50	0.00	0.00	0.00	0.03	0.07	0.00	0.00	0.00	0.00	3.01	5.79	9.41
Atlantic cod/haddock	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Atlantic cod/witch flounder	0.00	0.00	0.07	2.25	1.81	4.59	1.99	0.20	0.00	0.00	0.00	0.00	10.92
Atlantic mackerel	0.00	0.00	0.00	0.00	58.94	94.29	0.35	0.00	0.00	0.00	0.00	0.00	153.58
Atlantic menhaden	0.00	0.00	0.00	0.00	0.00	3.08	0.00	0.00	0.00	0.00	0.00	0.00	3.08
Cunner	0.00	0.00	0.00	0.00	0.00	0.00	8.72	1.19	0.00	0.00	0.00	0.00	9.91
Cunner/yellowtail flounder	0.00	0.00	0.00	0.25	36.24	174.60	72.57	9.21	0.00	0.02	0.00	0.00	292.89
Cusk	0.00	0.00	0.00	0.00	0.00	0.15	0.07	0.15	0.00	0.00	0.00	0.00	0.36
Fourbeard rockling	0.00	0.00	0.00	0.00	5.61	3.28	1.00	0.42	0.00	0.07	0.00	0.00	10.38
Hake	0.00	0.00	0.00	0.00	0.00	0.00	2.69	12.70	0.16	0.07	0.00	0.00	15.61
Hake/fourbeard rockling	0.00	0.00	0.00	0.35	24.01	22.86	3.60	15.77	0.47	0.71	0.00	0.00	67.77
Lumpfish	0.00	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82
Pollock	7.29	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	1.18	8.50
Silver hake	0.00	0.00	0.00	0.00	0.00	2.08	4.34	52.47	1.68	0.23	0.00	0.00	60.80
Windowpane	0.00	0.00	0.00	0.00	4.73	13.08	7.47	8.58	0.72	0.07	0.00	0.00	34.65
Winter flounder	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Total	7.79	0.07	0.07	6.38	141.62	341.14	102.80	100.68	3.03	1.15	3.03	6.97	714.73

(continued)

Table 4-5. (Continued)

Larvae

TAXON	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Alligatorfish	0.00	0.00	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
American plaice	0.00	0.00	0.00	0.00	0.10	2.37	0.07	0.00	0.00	0.00	0.00	0.00	2.55
American sand lance	0.17	2.63	21.42	11.95	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.16	36.57
Atlantic cod	0.00	0.03	0.00	0.00	0.03	0.59	0.89	0.00	0.00	0.00	0.02	0.03	1.59
Atlantic herring	0.23	0.04	0.28	0.99	0.00	0.00	0.00	0.00	0.00	0.61	3.85	5.51	11.51
Atlantic seasnail	0.00	0.02	0.00	0.58	15.97	15.98	1.11	0.00	0.00	0.00	0.00	0.00	33.65
Butterfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	0.00	0.00	0.00	0.00	1.19
Cunner	0.00	0.00	0.00	0.00	0.00	0.00	2.34	94.53	0.77	0.00	0.03	0.00	97.67
Fourbeard rockling	0.00	0.00	0.00	0.00	0.00	0.00	0.67	14.62	0.99	0.08	0.00	0.00	16.36
Grubby	0.00	0.21	2.54	7.46	5.14	0.04	0.00	0.00	0.00	0.00	0.00	0.00	15.39
Gulf snailfish	0.02	0.00	0.14	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
Longhorn sculpin	0.10	1.64	1.78	0.43	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.99
Lumpfish	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Pollock	0.02	0.42	0.28	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77
Radiated shanny	0.00	0.00	0.00	0.00	1.42	0.95	0.43	0.65	0.00	0.00	0.00	0.00	3.44
Rainbow smelt	0.00	0.00	0.00	0.00	0.25	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.38
Rock gunnel	1.73	8.58	24.51	9.93	0.55	0.00	0.00	1.38	0.00	0.00	0.00	0.00	46.68
Sea raven	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Shorthorn sculpin	0.00	0.13	0.19	0.25	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
Snakeblenny	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Unidentified	0.00	0.05	0.08	0.21	0.28	0.43	0.29	0.00	0.00	0.07	0.00	0.00	1.41
Unidentified sculpin	0.00	0.08	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
Windowpane	0.00	0.00	0.00	0.00	0.00	0.00	0.28	1.93	0.39	0.02	0.00	0.00	2.62
Winter flounder	0.00	0.00	0.00	0.00	4.29	10.47	0.94	0.05	0.00	0.00	0.00	0.00	15.75
Witch flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.29	1.19	0.00	0.00	0.00	0.00	1.48
Yellowtail flounder	0.00	0.00	0.00	0.00	0.00	0.04	0.00	2.48	0.15	0.00	0.00	0.00	2.66
Total	2.26	13.89	51.26	32.43	28.36	30.99	7.31	118.02	2.29	0.78	3.90	5.70	297.20

Table 4-6. Annual Estimated Numbers of Fish Eggs and Larvae Entrained (in millions) by the Cooling Water System at Seabrook Station from June 1990 Through December 2007. Seabrook Operational Report, 2007.

Eggs

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[f]	1997[f]	1998[f]	1999[f]	2000[f]	2001[f]	2002[f]	2003[f]	2004[f]	2005[f]	2006[f]	2007[f]
American plaice	2.6	21.0	52.3	19.5	0.4	14.8	78.2	15.6	13.7	24.8	16.7	26.8	22.4	37.8	33.4	11.7	5.27	35.81
Atlantic cod	2.5	4.9	1.8	0.0	0.2	2.2	8.1	2.9	8.4	5.3	2.9	11.0	13.4	7.9	2.9	4.4	8.23	9.41
Atlantic cod/haddock		0.2	0.6	50.3	0.3	2.2	1.4	0.2	0.3	0.4	1.6	0.1	0.2	0.4	0.8	0.9	0.80	0.05
Gadid/witch flounder	26.2	69.4	37.1	0.0	0.5	32.6	47.2	8.9	77.3	47.2	59.0	21.0	67.4	11.2	14.5	12.8	11.10	10.92
Atlantic mackerel	518.8	673.1	456.3	112.9	0.0	74.5	305.1	23.1	39.3	44.6	266.9	330.4	56.7	26.4	70.1	37.7	475.60	153.58
Atlantic menhaden		0.5	1.4	0.1		0.2	0.1	0.2	0.1	0.2	0.1			<0.1				3.08
Butterfish							0.1			<0.1						0.4		
Cod family						0.2				<0.1								
Cunner		52.3						35.9	9.3	21.7	207.5	18.0	2.4	15.6	83.6	1.6	4.51	9.91
Cunner/yellowtail flounder	490.4	664.1	198.6	58.4		18.6	110.2	186.1	56.2	232.4	1001.9	229.7	1396.5	128.3	434.6	254.6	486.03	292.89
Cusk	0.1	0.5		0.1		0.2	1.8	0.2	0.1	<0.1	0.1	3.0	0.3		0.6	0.2	0.77	0.36
Fourbeard rockling	7.4	4.4	0.8	1.4	0.2	4.2	10.9	4.8	2.9	2.7	13.7	14.1	3.23	5.9	5.1	5.2	7.40	10.38
Goosefish									0.9		0.9				0.1	0.1	0.03	
Grubby										0.1								
Hake	37.3	2.6		0.2	0.6	25.1	184.0	68.6	7.4	6.1	114.0	4.4	79.6	5.0	5.2	2.8	7.23	15.61
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	33.0	58.3	38.4	33.6	63.6	30.08	67.77
Lumpfish				9.5	0.1	6.0	1.2	0.3						<0.1				0.82
Pollock		1.0	0.4	0.2	0.1	0.4	0.4	0.2	2.9	0.2	<0.1	0.3	0.6	1.0	0.9	1.0	4.13	8.5
Rainbow smelt							0.1											
Silver hake	11.4		0.1	0.4	0.4	22.5	73.6	271.1	18.6	139.9	90.4	48.9	341.4	235.6	19.8	30.7	9.39	60.8
Tautog		0.2					0.3	0.1	0.1			0.1	3.8		0.1	0.2		
Unidentified		2.1		0.8	0.2	6.4	0.8	0.1	0.1	0.1	2.0	0.6	<0.1		0.6	0.1	0.08	
Unidentified sculpin										<0.1			0.6	0.1				
Windowpane	36.4	19.9	22.5	29.1	0.1	17.4	44.2	28.5	17.9	43.2	95.1	33.4	39.1	15.5	18.2	26.2	24.71	34.65
Winter flounder											0.3			0.3				0.2
Witch flounder	0.4					0.7	0.1	0.9	0.1	0.1	0.2					0.2		
Yellowtail flounder						0.2	1.6				0.1	0.2	0.7				0.02	
TOTAL	1247.7	1551.3	822.6	315.6	4.8	255.9	926.4	692.7	286.7	593.9	2104.4	775.1	2086.8	529.4	723.7	454.4	1075.38	714.73

(Continued)

Table 4-6. Continued

Larvae

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[f]	1997[f]	1998[f]	1999[f]	2000[f]	2001[f]	2002[f]	2003[f]	2004[f]	2005[f]	2006[f]	2007[f]
Alligatorfish		0.1	0.2		0.2	0.3	0.1	0.1	0.2	0.1			<0.01	0.1	<0.1		0.03	0.12
American eel									<0.1	0.1							0.03	
American plaice	0.4	1	0.8	0.7		7.9	8.1	7	2.9	4.9	1.6	8.7	11.3	9.1	2.6	1.4	0.64	2.55
American sand lance		37.3	18.1	12	8.3	9.5	14	10.1	10.7	7:8	1.0	5.3	10.5	27.1	107.1	28.3	14.05	36.57
Atlantic cod	0.7	1.5	0.4	0.1		2.3	0.3	0.7	2.2	1.0	0.4	2.5	34.6	2.5	0.5	1.6	0.27	1.59
Atlantic herring	0.7	0.5	4.9	9.6	0.1	11.2	4.3	2.1	9.5	8.6	0.2	15.2	11.7	15.3	8.8	9.7	12.79	11.51
Atlantic mackerel	0.2	4.7					0.1	0.4	0.0	0.1	0.3	0.1	0.4		20.2	0.1	0.48	
Atlantic menhaden	0.1								0.1	0.1			0.1		<0.1		0.15	33.65
Atlantic seasnail	11.6	16	31.5	64.4		26.5	60.6	1.2	38.5	76.5	34.3	19.7	29.0	43.2	64.2	37.5	20.24	
Atlantic silverside														<0.1				
Bluefish								0.1										
Butterfish						0.3	0.1											1.19
Cunner	42.7	0.05		4.7	0.1	4.4	9.2	203.8	8.4	4.7	111.0	13.6	391.1	22.5	451.2	2.5	8.75	97.67
Cusk									<0.1			0.4	1.8	0.1	2.1		0.09	
Fourbeard rockling	37.9	0.5	0.1	2.2		3.9	11.7	22.4	13.1	21.0	8.2	19.6	176.4	19.3	61.4	2.0	4.93	16.36
Fourspot flounder	0.2							0.1	<0.1				<0.01					
Goosefish	0.1										2.0				0.1			
Gadidae																	0.04	
Grubby		22.4	18.9	13.8	4.9	17.4	18.6	12.8	17.3	6.4	2.2	12.4	6.6	27.5	51.8	7.8	9.32	15.39
Gulf snailfish	0.1	2.8	1.9	2.6	3.5	0.2	2.8	0.6	1.5	0.3	0.3	0.1	4.4	2.0	9.5	2.3	1.04	0.52
Haddock			0.1													0.1		
Hake	4.8			0.1		0.7	12.3	1.7	<0.1	0.1	29.8		0.3	0.1	1.0		0.15	
Herring family																0.5	0.04	
Liparis sp.																	0.16	
Longhorn sculpin		0.6	0.6	0.4	0.3	0.4	1.3	0.7	0.8	0.6	0.3	0.3	0.6	2.0	5.2	1.2	0.97	3.99
Lumpfish	0.6	0.1	0.1	0.2		0.6	0.1	0.2	0.5	0.1	0.3	0.6	0.1	0.1	0.3	0.2	0.50	0.07
Moustache sculpin		0.1	0.3	0.4	2.2		0.6	0.3	<0.1							<0.1		
Northern pipefish							0.1			0.1		0.1	0.1		0.1	<0.1	0.02	
Northern searobin																<0.1		

(Continued)

Table 4-6. Continued

TAXON	1990[a]	1991[b]	1992[c]	1993[d]	1994[e]	1995[f]	1996[f]	1997[f]	1998[f]	1999[f]	2000[f]	2001[f]	2002[f]	2003[f]	2004[f]	2005[f]	2006[f]	2007[f]
Ocean pout														<0.1				
Pleuronectidae							0.3											
Pollock	0.2		0.1						<0.1				<0.1	0.6	0.1	0.1	0.76	0.77
Radiated shanny	4.8	3.1	1.1	0.2		2.1	2	0.3	1.7	3.5	14.0	2.4	8.3	12.3	3.6	7.0	0.76	3.44
Rainbow smelt	0.2		0.1						0.2		0.3	0.1		0.5	<0.1	0.5	4.27	0.38
Redfish			0.4		0.05											<0.1		
Rock gunnel		51.1	45.3	5.7	11	15.6	33.8	25.1	16.9	18.2	3.5	4.6	12.3	56.0	109.0	54.2	30.31	46.68
Sea raven									<0.1	<0.1				<0.1	0.2	0.1	0.02	0.03
Shorthorn sculpin		0.2	0.6	0.2	0.1	0.5	0.1	1.1	2.1	1.0	0.1	0.5	0.2	3.9	11.6	2.1	0.16	0.6
Silver hake	7.7			0.1		0.9	16.9	69	0.2	0.4	33.2	0.6	5.9	0.5	0.2	<0.1	0.09	
Snailfish	0.1	0.3		0.2			0.4						<0.1			0.2		
Snakeblenny																	0.02	
Summer flounder									<0.1					<0.1				0.02
Tautog	0.3						0.2				0.1			0.1				
Unidentified	0.7	2.1	1.4	5.5	0.6	30.4	2.5	4.3	0.5	1.4	0.6	1.7	4.8	1.5	4.8	1.0	0.72	1.41
Unidentified sculpin			0.1				0.6	0.05		0.1			<0.1	0.5	4.4	1.2	0.42	0.16
Unidentified searobin							0.1				0.1							
Windowpane	3.8	0.05	0.1	0.1	0.05	2	2	5.6	1.4	3.7	2.3	1.3	6.5	0.5	0.4	0.5	0.52	2.62
Winter flounder	3.2	9.0	6.2	2.9		8	10.3	2.2	4.7	7.4	14.3	14.3	4.5	20.0	34.8	4.9	7.17	15.75
Witch flounder	0.3						0.8	1.2	<0.1	0.1	0.5		1.7	1.4	0.8	0.2	0.18	1.48
Wrymouth		0.1								<0.1					<0.1			
Yellowtail flounder	0.1	0.3	0.1			0.1	1.6	0.5	0.3	0.8	0.3	0.5	0.9		0.1	<0.1	0.02	2.66
TOTAL	**121.5**	**153.8**	**133.1**	**126.1**	**31.2**	**145.3**	**215.7**	**373.4**	**134.1**	**171.8**	**261.2**	**124.3**	**724.4**	**268.5**	**958.5**	**167.0**	**123.23**	**297.2**

[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.

April through August) to 1,397 million in 2002. The peak month for cunner/yellowtail flounder egg entrainment in 2007 was June when 60% of the annual cunner/yellowtail flounder estimate was entrained (Table 4-5). Almost all (about 97.3%) of the annual total of these eggs were probably cunner, because only an estimated 2.7 million yellowtail flounder larvae were entrained in 2007.

Atlantic mackerel egg entrainment ranked second (154 million) in abundance in 2007 and occurred only from May through July (Table 4-5). The 2007 estimate was within the range of previous years (Table 4-6). The relatively high entrainment of Atlantic mackerel eggs corresponds with the high stock abundance for this fish (Section 4.3.3.9).

Hake/fourbeard rockling egg entrainment ranked third in abundance in 2007 (68 million) with 69% of the annual estimate occurring in May-June (Table 4-5). Estimates in previous years ranged 1.7 million in 1994 (8 months of sampling) to 231 million eggs in 2000 (Table 4-6). Silver hake egg entrainment ranked fourth (61 million) in abundance in 2007 with 86% of the annual estimate occurring in August (Table 4-5). Estimates in previous years with samples collected all 12 months ranged from 18.6 million in 1998 to 341 million in 2002 (Table 4-6). In 2007, American plaice and windowpane egg entrainment ranked fifth and sixth in abundance at 36 million and 35 million, respectively (Table 4-6). Entrainment of American plaice eggs was the third highest recorded among years with samples collected from all 12 months and entrainment of windowpane eggs was within the range of previous years.

An estimated 297 million fish larvae were entrained in 2007, the fourth highest estimate to date when sampling occurred in all 12 months (Table 4-6). In previous years, larval entrainment estimates ranged from 31 million in 1994 (8 months of sampling) to 959 million in 2004. Entrainment of larvae in 2007 was highest in August, when cunner (95 million) and fourbeard rockling (15 million) were most abundant (Figure 4-4). Cunner (98 million), rock gunnel (47 million), American sand lance (37 million), and Atlantic seasnail (34 million) were the most abundant larval taxa entrained in 2007 (Table 4-5).

Cunner were the most abundant larvae entrained in 2007 and comprised 33% of the annual total (Table 4-5). Approximately 97% of the annual total entrainment of cunner occurred in August (Figure 4-4). The 2007 estimate of 98 million was fifth highest since 1995 when all months were sampled (Table 4-6).

Rock gunnel were the second most abundant larvae entrained in 2007 and comprised 16% of the annual total (Table 4-5). Approximately 52% of the annual total entrainment of rock gunnel occurred in March (Figure 4-4). The 2007 estimate of 47 million was within the range of previous years (Table 4-6).

American sand lance was the third-most common species entrained in 2007 (Table 4-5). Entrainment of this species was highest in March when 59% of the annual estimate of 37 million occurred. The 2007 estimate was within the range of previous years (Table 4-6). Atlantic seasnail ranked fourth in entrainment abundance in 2007, and the entrainment estimate was highest in May and June (Figure 4-4) when 95% of the annual estimate of 34 million occurred (Table 4-5). Atlantic seasnail are often among the most numerous larvae entrained and ranked first in entrainment in 1993, 1996, 1998, 1999, and 2001 (Table 4-6). The 2007 estimate was within the range of previous years (Table 4-6).

Consistent with the average entrainment estimates in 2007, there were few record estimates of entrainment for any individual species or species group. The 2007 entrainment estimates for pollock eggs (9 million) and larvae (1.0 million) and yellowtail flounder larvae (3 million) were the highest to date (Table 4-6).

Differences between entrainment estimates of larval and egg stages of the same taxon in the same year are due to varying susceptibility of the two developmental stages to entrainment. Some dominant larvae are species 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 of some taxa that have high egg entrainment. For instance, hake and fourbeard rockling larvae are surface oriented (Hermes 1985) and may not be as 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 may 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 4-7). Except for Atlantic cod, the upper end of the range of annual entrainment estimates for Seabrook Station were similar to, or less than, annual estimates at the other two power plants.

4.3.2 Adult Fish Assemblage

4.3.2.1 Demersal Fishes

A 9.8-meter trawl was used at three stations (Figure 4-1) to determine the abundance and distribution of demersal fishes. In 2007, the geometric mean CPUE (catch per 10-minute tow) of fish caught at all stations combined decreased from the previous year and was the sixth highest CPUE (37.3) in the operational period (Figure 4-5). Since a record low CPUE of 8.4 at Station T2 in 1995, CPUE has generally increased through 2007, although CPUE has been variable since 2000. The highest CPUE occurred in 1980 (78.9) and 1981 (78.1) primarily due to large catches of yellowtail flounder (see Section 4.3.3.11). In 2007, winter flounder, longhorn sculpin, windowpane, skates (Rajidae), hakes and yellowtail flounder dominated the catch (Table 4-8).

Differences in CPUE and species composition were apparent among the stations. The bottom at the nearfield station (T2), located in 15-17 m of water off mouth of Hampton-Seabrook Harbor was occasionally inundated with drift algae (Table 4-1). Stations T1 (20-28 m) and T3 (22-30 m) are in deeper water and have sandy bottoms. CPUE in the preoperational period was consistently lower at Station T2 than at Stations T1 and T3, which tended to have similar levels of CPUE (Figure 4-5). In the operational period, CPUE was highest at Station T3 followed by Stations T1 and T2. At Station T1, yellowtail flounder was the dominant fish in the preoperational period, while longhorn sculpin and winter flounder were dominant in the operational period. Winter flounder and yellowtail flounder were dominant at Station T2 in the preoperational period, and winter flounder remained dominant at Station T2 in the operational period. At Station T3, yellowtail flounder and longhorn sculpin dominated in the preoperational period. In the operational

Table 4-7. Comparison of Entrainment Estimates (in millions) of Selected Taxa at Selected New England Power Plants (nominal cooling water flow in m^3/sec) with Marine Intakes from 1990 Through 2007. Seabrook Operational Report, 2007.

Taxon	Seabrook[a] (31.5)	Pilgrim[b] (20.3)	Millstone[c] (34.6)
Cunner/yellowtail flounder eggs[d]	18.6-1,396.5	580-6,576	577-6,099
Atlantic cod larvae	<0.1-34.6	0.1-4.2	
Atlantic mackerel eggs	23.1-475.6	22-4,673	–
Atlantic herring larvae	<1-15.3	0.5-43.2	–
Cunner larvae	2.5-451.2	1.2-576.3	–
Grubby larvae[e]	2.2-51.8	–	11-178
Atlantic seasnail larvae[f]	1.2-76.5	–	–
Rock gunnel larvae	3.5-109.0	–	–
American sand lance larvae	1.0-107.1	–	3-176
Atlantic mackerel larvae	0-20.2	<1-320	–
Winter flounder larvae	2.2-34.8	3.5-86.8	29-492

a Restricted to 1995-2007, years when sampling occurred in all 12 months.
b Entergy Nuclear Generation Company (2006); Cape Cod Bay. Based on full load flow.
c Dominion Resources Services (2004); Long Island Sound.
d Seabrook-cunner/yellowtail flounder; Pilgrim-cunner; Millstone-cunner.
e Seabrook and Millstone-grubby; Pilgrim-grubby and other sculpins.
f Seabrook-Atlantic seasnail; Pilgrim-Atlantic seasnail and other snailfishes.

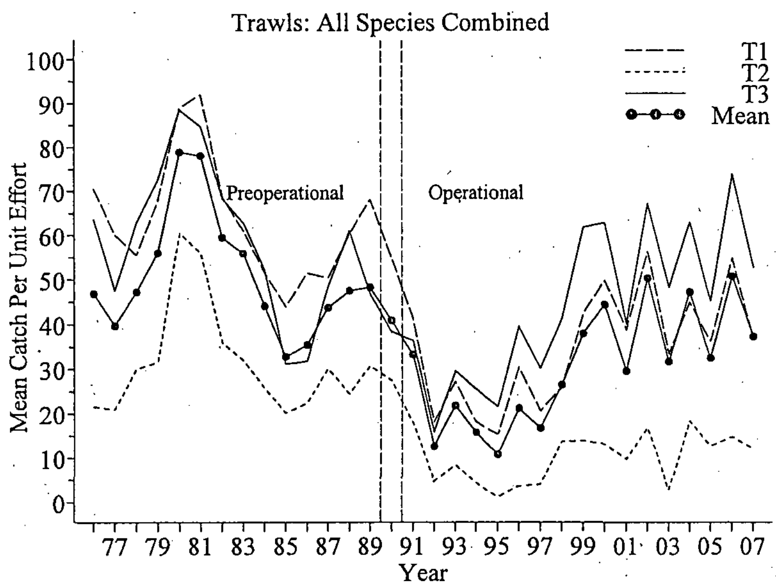


Figure 4-5. Annual geometric mean catch of all species combined per unit effort (number per 10-minute tow) in trawl samples by station and the mean of all stations, 1976-2007. Seabrook Operational Report, 2007.

Table 4-8. Geometric Mean Catch per Unit Effort (number per 10-minute tow) and Upper and Lower 95% Confidence Limits by Station (T1, T2, and T3) and All Stations Combined of Abundant Species Collected by Otter Trawl During the Preoperational and Operational Periods and the 2007 Mean. Seabrook Operational Report, 2007.

		Preoperational Period			2007	Operational Period		
		LCL	Mean	UCL	Mean	LCL	Mean	UCL
Yellowtail flounder	T1	15.9	20.0	25.2	3.3	2.7	3.5	4.5
	T2	2.0	2.7	3.5	0.1	0.1	0.1	0.2
	T3	7.6	10.2	13.6	3.2	1.7	2.6	3.7
	All Stations	7.5	9.3	11.6	2.5	1.6	2.1	2.7
Longhorn sculpin	T1	3.3	4.6	6.2	6.3	4.2	5.5	7.3
	T2	0.7	1.1	1.5	0.5	0.3	0.5	0.8
	T3	5.8	8.3	11.8	10.5	8.2	10.7	13.9
	All Stations	2.9	4.1	5.7	6.1	3.9	5.3	6.9
Winter flounder	T1	2.4	3.1	4.0	8.7	4.3	5.6	7.2
	T2	4.4	5.9	7.9	2.6	2.0	2.8	3.9
	T3	1.7	2.2	2.8	9.1	4.1	5.3	6.8
	All Stations	2.7	3.5	4.3	7.8	3.8	5.0	6.4
Hakes	T1	3.3	4.1	5.0	1.5	0.8	1.1	1.4
	T2	1.3	1.7	2.1	0.9	0.3	0.5	0.6
	T3	2.8	3.5	4.4	6.1	1.5	2.0	2.7
	All Stations	2.6	3.2	3.8	2.9	1.1	1.4	1.7
Atlantic cod	T1	1.4	2.0	2.8	0.2	0.2	0.3	0.6
	T2	0.4	0.7	1.0	0.3	0.1	0.2	0.4
	T3	2.0	3.2	4.8	0.5	0.5	0.9	1.3
	All Stations	1.2	1.8	2.6	0.3	0.3	0.5	0.7
Raja sp.	T1	0.9	1.7	2.7	2.2	3.1	4.1	5.4
	T2	0.4	0.6	0.7	0.9	0.5	0.8	1.1
	T3	2.9	3.7	4.6	5.3	4.2	5.5	7.1
	All Stations	1.3	1.9	2.6	3.1	2.8	3.7	4.7
Windowpane	T1	1.3	1.9	2.8	3.2	2.1	2.6	3.3
	T2	0.7	0.9	1.2	2.2	0.5	0.8	1.2
	T3	0.7	1.0	1.5	3.5	1.0	1.7	2.5
	All Stations	0.9	1.3	1.8	3.2	1.4	1.9	2.4
Rainbow smelt	T1	0.8	1.1	1.4	0.5	0.2	0.3	0.5
	T2	1.3	1.8	2.5	1.4	0.3	0.5	0.8
	T3	0.5	0.8	1.1	0.5	0.2	0.3	0.4
	All Stations	0.8	1.1	1.5	0.6	0.2	0.3	0.5
Ocean pout	T1	0.6	0.7	0.8	0.2	0.1	0.1	0.2
	T2	0.4	0.6	0.7	0.2	0.2	0.2	0.3
	T3	1.1	1.4	1.7	0.1	0.1	0.1	0.2
	All Stations	0.7	0.8	1.0	0.2	0.1	0.2	0.2
Silver hake	T1	0.5	0.9	1.3	1.9	0.7	1.0	1.3
	T2	0.1	0.2	0.3	0.0	0.0	0.1	0.1
	T3	0.5	0.8	1.2	1.1	0.4	0.6	0.9
	All Stations	0.4	0.7	0.9	1.2	0.5	0.7	0.9

(continued)

Table 4-8 (Continued)

		Preoperational Period			2007	Operational Period		
		LCL	Mean	UCL	Mean	LCL	Mean	UCL
Pollock	T1	0.2	0.3	0.5	0.0	0.0	0.2	0.3
	T2	0.3	0.7	1.1	0.0	0.1	0.2	0.4
	T3	0.1	0.2	0.3	0.0	0.1	0.1	0.2
	All Stations	0.2	0.4	0.5	0.0	0.1	0.2	0.3
Haddock	T1	0.0	0.2	0.3	0.0	0.0	0.0	0.0
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T3	0.2	0.5	0.8	0.0	0.0	0.1	0.2
	All Stations	0.1	0.2	0.4	0.0	0.0	0.1	0.1
Spiny dogfish	T1	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T3	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	All Stations	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Other species	T1	1.3	1.6	2.0	2.0	1.3	1.6	2.0
	T2	1.2	1.6	1.9	0.9	0.6	0.8	1.0
	T3	0.9	1.2	1.5	1.3	0.9	1.2	1.5
	All Stations	1.2	1.4	1.7	1.6	1.0	1.3	1.6

[a] Preoperational 1976-1989; geometric mean of annual means. [b] Geometric mean of the 2007 data. [c]Operational: 1991-2007; geometric mean of annual means. [d] LCL = Lower 95% confidence limit. [e] UCL = Upper 95% confidence limit. [f] May include red hake, white hake, or spotted hake.

period, longhorn sculpin, winter flounder, and skates were dominant (Table 4-8).

Comparisons among stations are limited by the inability to collect trawl samples at Station T2 during many sampling trips from August through November when catches are often highest. Commercial lobster gear deployed near Station T2 prevents the collection of trawl samples during this period. Inter-station comparisons that use the entire database are potentially biased due to the lack of sampling at Station T2 during this period of high fish abundance. Because of this potential bias, data from the August through November period were not used in any of the ANOVAs for the selected species collected by trawl sampling (Section 4.3.3). In other months during the study period, a few collections were missed at Station T2, but overall trawl sampling effort at T2 was about 80% that of T1 or T3.

The total catch of demersal fishes caught by otter trawl showed periodic trends in annual geometric mean CPUE. From 1976 through 1993, total CPUE significantly declined at Station T3 and then significantly increased from 1994 through 2007 (Table 4-9). There were no significant differences in mean CPUE between these two time periods. Mean total CPUE at Station T1 declined significantly from 1976-1995, and there was no significant trend from 1996 through 2007. Mean CPUE was not significantly higher during the earlier period at Stations T1 (Table 4-9). No significant trends were detected at Station T2, although CPUE was significantly higher from 1976 through 1990 than from 1991 through 2007.

Groundfish abundance data from the Seabrook Station Monitoring Program is in general agreement with the data collected by the National Marine Fisheries Service (NMFS). The index of abundance for principal groundfish (Atlantic cod, haddock, pollock, silver hake, red hake, Acadian redfish) and flounders (yellowtail, summer, witch, and winter flounders, American plaice, windowpane, and Atlantic halibut) off the northeastern United States began to rise in the mid-1970s following the reduction in foreign fishing effort (NEFSC 2006). However,

Table 4-9. Results of Segmented Regression Analysis. Seabrook Operational Report, 2007.

Gear, Species, and Station	Comparison[a] Based on Break Points[b]	Period 1 Slope	Period 2 Slope
Beach Seine (No./haul)[c]			
Estuarine Fish Catch			
S1	1976-2005 > 2006-2007 NS	Negative**	NS
S2	1976-1997 > 1998-2007 **	Negative***	NS
S3	1976-1995 > 1996-2007 ***	Negative***	NS
Otter Trawl (No./10-min tow)[d]			
Demersal Fish Catch			
T1	1976-1995 > 1996-2007 *	Negative***	NS
T2	1976-1990 > 1991-2007 ***	NS	NS
T3	1976-1993 > 1994-2007 NS	Negative***	Positive*
Rainbow Smelt			
T1	1976-1990 > 1991-2007 ***	NS	NS
T2	1976-1990 > 1991-2007 ***	NS	NS
T3	1976-1987 > 1988-2007 NS	Negative **	Negative **
Atlantic Cod			
T1	1976-1994 > 1995-2007 **	Negative **	Positive*
T2	1976-1985 > 1986-2007 ***	NS	NS
T3	1976-1988 > 1989-2007***	NS	NS
Hakes			
T1	1976-1995 > 1996-2007***	Negative***	NS
T2	1976-1994 > 1995-2007 **	Negative*	NS
T3	1976-1993 > 1994-2007 NS	Negative***	Positive*
Winter Flounder			
T1	1976-1994 < 1995-2007 ***	NS	Positive **
T2	1976-1985 > 1986-2007 **	NS	NS
T3	1976-1993 < 1994-2007 ***	NS	Positive ***
Yellowtail Flounder			
T1	1976-1995 > 1996-2007 ***	Negative **	NS
T2	1976-1980 > 1981-2007*	NS	Negative ***
T3	1976-1991 > 1992-2007***	Negative **	NS

[a] Comparison of period means using a t-test.
[b] Periods separated by breakpoints as identified by segmented regression analysis.
[c] Beach seine, annual geometric mean; 1985 and 1986 were not sampled.
[d] Otter trawl, annual geometric mean log10 (x+ 1) transformed catch per 10-minute tows for months included in ANOVA for individual species and all months for total catch of demersal fishes.
N/A= Not Applicable
NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p>0.01$)
** = Highly significant ($0.01 \geq p>0.001$)
*** = Very Highly Significant ($p \leq 0.001$)

beginning in the late 1970s, the index began to decline. After a smaller peak in late 1970s for groundfish and early 1980s for flounders, both indices reached record lows in the early 1990s.

The principal groundfish index increased through 2005, but the flounder index peaked in the early 2000s and has declined through 2005.

Changes in the index have been directly attributed to changes in fishing mortality (NEFSC 2006). The increase in abundance in the 1970s was attributed to a decrease in fishing mortality caused by the reduction in effort of the foreign fishing fleet. Decreases in abundance began in the late 1970s and early 1980s when effort from the domestic fishing fleet began to increase. The record high levels of fishing effort in the late 1980s and early 1990s resulted in rapid reduction of new year classes before they were able to grow and reproduce (NEFSC 2006). As traditional target species such as Atlantic cod, haddock and yellowtail flounder became overfished, fishing effort switched to non-traditional species such as goosefish and spiny dogfish. Consequently, abundance of these nontraditional species decreased. The increase in abundance of groundfish since the mid-1990s was attributed to higher biomass of Georges Bank haddock and redfish (NEFSC 2006).

Atlantic cod, yellowtail flounder, winter flounder, white hake, haddock, American plaice, windowpane, ocean pout, thorny skate, and butterfish are all considered by NMFS to be overfished in some part of their range (NEFSC 2006). Atlantic herring, Atlantic mackerel, silver hake, pollock, witch flounder, the northern stocks of windowpane and red hake, and Gulf of Maine winter flounder are among the common commercial fishes captured in this monitoring program not considered overfished (NEFSC 2006). In the Seabrook Station monitoring program, CPUE of most fishes, especially commercially important fishes declined between the preoperational and operational periods (Table 4-8). Yellowtail flounder showed the largest decrease in CPUE from 9.3 in the preoperational period to 2.1 in the operational period. Similar large decreases in CPUE occurred for hakes, Atlantic cod, and ocean pout. In contrast with other commercial species, CPUE of winter flounder in the operational period was higher than that of the preoperational period. Winter flounder are no longer considered overfished in the Gulf of Maine (NEFSC 2006), which is in agreement with our comparisons of CPUE between the preoperational and operational periods. The northern stock of windowpane is also not considered overfished (NEFSC 2006) and CPUE in our study increased between periods. The abundance and species composition of groundfish in this monitoring program probably reflect larger trends that are occurring in the Gulf of Maine and Georges Bank that are driven by commercial fishing.

Reduction in abundance of groundfish may have resulted in a "competitive release" where small elasmobranchs such as skates and dogfishes have replaced gadids and flounders (Fogarty and Murawski 1998). CPUE of skates has increased between the preoperational and operational periods in our study area and five of the six species of commercially exploited skates are considered to be not overfished (NEFSC 2006). Furthermore, there is evidence that the current high stock levels of Atlantic herring and Atlantic mackerel may inhibit recruitment of some demersal fish, especially Atlantic cod, through predation on the early life stages of the demersal fish and competition for prey items (Swain and Sinclair 2000; Bundy and Fanning 2005).

4.3.2.2 Estuarine Fishes

Sampling of estuarine fishes was conducted at three stations within the estuary of Hampton-Seabrook Harbor (Figure 4-1) using a 30.5-m seine. Although geometric mean CPUE (catch per haul) of all fish caught at Station S2 decreased from the previous year, mean CPUE of all fish at all stations during 2007 increased to 11.2 from 8.3 in 2006 due to an increase at Station S1 and S3 (Figure 4-6). Atlantic silverside, killifishes, rainbow smelt, and winter flounder were the dominant fishes in the seine in 2007 (Table 4-10). CPUE in the seine was highest in 1979, and has generally declined since then. Overall, CPUE has been lower during 1987 through 2007 (2.7-24.1/haul) than 1976 through 1984 (22.7-59.1/haul); no seine sampling took place in 1985, or April through June of 1986.

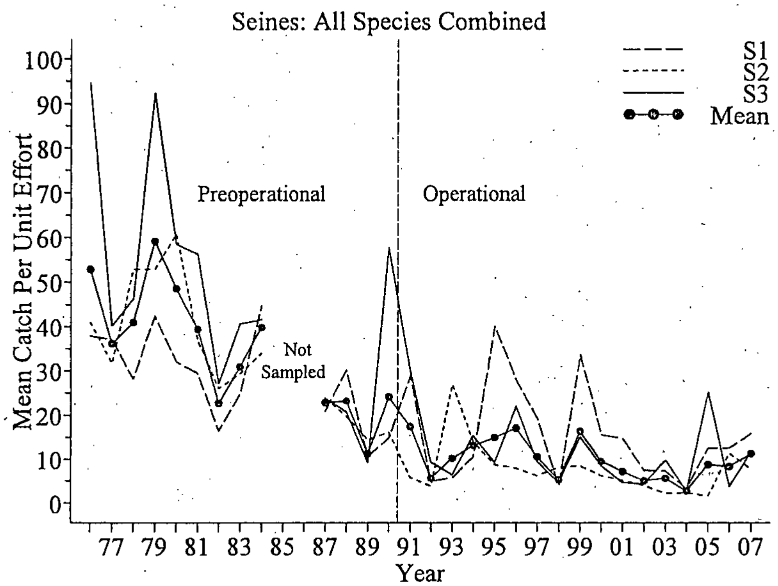


Figure 4-6. Annual geometric mean catch of all species combined per unit effort (number per haul) in seine samples by station and the mean of all stations, 1976-2007. Seabrook Operational Report, 2007.

The CPUE of most species declined from the preoperational to the operational period, although the species composition has remained similar (Table 4-10). Atlantic silverside dominated the catch in all years sampled with killifishes (mummichog and striped killifish), winter flounder, and ninespine stickleback also contributing frequently to the catch in both periods. CPUE of American sand lance has increased between periods.

CPUE by station varied considerably over the years (Figure 4-6). Station S1, located 200 m upriver from the mouth of the Browns River had the highest CPUE in 2007, which was higher than the previous year. In the preoperational period, CPUE at Station S1 was generally lower than the other stations, but in the operational period CPUE was highest at Station S1 in 1995-1997, 1999-2002, 2004, 2006, and 2007. In 2007, CPUE was second highest at Station S3, located near the mouth of the estuary (Figure 4-6, Table 4-1). CPUE was highest at this station in 1976, 1977, 1979, 1981, 1983, 1990, 2003, and 2005. CPUE in 2007 was lowest at Station S2, located in the Browns River, and decreased from the previous year. CPUE at this station was generally lower than the other stations in the operational period, and intermediate in the preoperational period.

There were significant negative trends in CPUE at Stations S1, S2 and S3 (Table 4-9). Significant breakpoints occurred between 2005 and 2006 (Station S1), 1997 and 1998 (Station S2), and 1995 and 1996 (Station S3). Peaks in CPUE were mostly due to fluctuations in the catch of Atlantic silverside, the most common species at all three stations (Table 4-10). Winter flounder were also common, especially at Station S3, and killifishes were most common at Station S1 and S2.

4.3.2.3 Impingement

An estimate of 22,451 fish and 21 lobsters (see Section 6.0) were impinged in 2007 at Seabrook Station (Table 4-11). This estimate

Table 4-10. Geometric Mean Catch per Unit Effort (number per standard haul) and Upper and Lower 95% Confidence limits by Station (S1, S2, and S3) and All Stations Combined for Abundant Species Collected by Seine During the Preoperational and Operational Periods and the 2007 Mean. Seabrook Operational Report, 2007.

Species	Station	Preoperational Period[a]			2007[b]	Operational Period[c]		
		LCL[d]	Mean	UCL[e]	Mean	LCL	Mean	UCL
Atlantic silverside	S1	5.1	7.2	10.2	6.3	3.4	4.6	6.3
	S2	5.1	6.8	9.1	3.3	2.4	3.3	4.4
	S3	4.0	6.7	10.7	5.6	2.1	3.0	4.2
	All Stations	4.8	6.9	9.7	5.6	2.9	3.6	4.5
Winter Flounder	S1	0.6	0.9	1.2	0.4	0.2	0.4	0.5
	S2	0.6	1.0	1.5	0.1	0.1	0.2	0.3
	S3	2.2	3.2	4.4	1.4	0.3	0.5	0.8
	All Stations	1.2	1.5	2.0	0.6	0.2	0.3	0.5
Killifishes	S1	0.8	1.1	1.5	1.8	0.5	0.8	1.3
	S2	0.6	1.2	2.0	0.0	<0.1	0.1	0.3
	S3	<0.1	<0.1	0.1	0.3	0.0	0.1	0.1
	All Stations	0.5	0.7	1.0	0.7	0.2	0.3	0.4
Ninespine stickleback	S1	0.4	0.7	1.2	0.4	0.1	0.2	0.4
	S2	0.3	0.8	1.6	0.0	<0.1	0.1	0.1
	S3	0.3	0.8	1.4	0.1	0.1	0.2	0.3
	All Stations	0.4	0.8	1.3	0.2	0.1	0.2	0.2
Rainbow smelt	S1	<0.1	0.1	0.2	0.2	<0.1	0.1	0.2
	S2	<0.1	0.2	0.3	0.4	0.1	0.1	0.2
	S3	0.3	0.7	1.2	1.4	0.1	0.2	0.4
	All Stations	0.2	0.3	0.4	0.6	0.1	0.2	0.3
American sand lance	S1	<0.1	0.1	0.2	0.2	0.1	0.2	0.3
	S2	0.0	0.2	0.5	0.1	0.0	0.1	0.2
	S3	<0.1	0.1	0.2	0.2	0.3	0.6	0.9
	All Stations	0.1	0.1	0.2	0.2	0.2	0.3	0.4
Pollock	S1	<0.1	0.1	0.2	0.0	0.0	<0.1	<0.1
	S2	<0.1	0.2	0.3	0.0	0.0	<0.1	<0.1
	S3	0.1	0.4	0.8	0.0	0.0	0.1	0.1
	All Stations	<0.1	0.2	0.4	0.0	<0.1	<0.1	0.1
Blueback herring	S1	0.1	0.2	0.3	0.2	0.1	0.3	0.5
	S2	<0.1	0.1	0.1	0.2	<0.1	0.1	0.1
	S3	<0.1	0.1	0.3	0.1	<0.1	<0.1	0.1
	All Stations	<0.1	0.1	0.2	0.2	0.1	0.1	0.2
Atlantic herring	S1	0.0	0.1	0.2	0.2	0.1	0.1	0.3
	S2	0.1	0.3	0.5	0.0	<0.1	<0.1	0.1
	S3	0.1	0.1	0.2	<0.1	<0.1	0.1	0.2
	All Stations	0.1	0.2	0.2	0.1	<0.1	0.1	0.1
Alewife	S1	<0.1	0.1	0.2	0.2	<0.1	0.2	0.4
	S2	0.0	0.1	0.2	0.1	0.0	<0.1	<0.1
	S3	<0.1	0.1	0.1	0.0	0.0	0.1	0.2
	All Stations	<0.1	0.1	0.1	0.1	<0.1	0.1	0.2
Other species	S1	0.5	0.8	1.2	0.9	0.3	0.4	0.6
	S2	0.9	1.1	1.4	0.2	0.2	0.4	0.5
	S3	1.0	1.5	2.1	0.7	0.4	0.6	0.8
	All Stations	0.8	1.1	1.5	0.8	0.3	0.5	0.6

[a] Preoperational: 1976-1989; geometric mean of annual means
[b] Geometric mean of the 2007 data.
[c] Operational; 1991-2007; geometric mean of annual means
[d] LCL = Lower 95% confidence limit.
[e] UCL = Upper 95% confidence limit.

Table 4-11. Species Composition and Total Number of Finfish and American Lobster Impinged at Seabrook Station by Month During 2007 Seabrook Operational Report, 2007.

Species	Month												Total	Percent
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Acadian redfish	0	0	3	0	0	0	0	0	0	0	0	9	12	0.05
Alewife	0	0	0	80	0	0	0	0	7	14	125	18	244	1.09
American lobster	0	0	0	3	7	4	0	0	0	3	4	0	21	0.09
American sand lance	0	228	54	266	9	0	0	0	0	3	8	1,505	2,073	9.22
American shad	0	0	0	7	0	0	0	0	0	18	34	129	188	0.84
Atlantic cod	0	18	4	25	4	4	39	3	35	7	8	31	178	0.79
Atlantic herring	0	17	7	111	100	0	4	0	0	0	18	3	260	1.16
Atlantic menhaden	0	0	0	0	0	0	0	0	128	10	13	9	160	0.71
Atlantic silverside	0	200	92	62	0	0	0	33	0	4	11	237	639	2.84
Black sea bass	0	0	0	4	7	7	0	0	4	0	0	0	22	0.10
Blueback herring	0	0	3	231	3	0	0	0	0	0	0	0	237	1.05
Butterfish	0	0	0	0	0	0	0	0	23	168	8	0	199	0.89
Cunner	0	3	14	90	315	80	75	46	82	73	137	7	922	4.10
Cusk	0	1	0	0	0	0	0	0	0	0	0	0	1	0.00
Empty sample	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Four-beard rockling	0	0	0	0	0	0	0	0	7	0	0	0	7	0.03
Fourspine stickleback	0	0	13	0	0	0	0	0	0	0	0	0	13	0.06
Fourspot flounder	0	0	0	0	3	0	0	0	0	0	0	0	3	0.01
Goosefish	0	1	0	6	0	0	0	0	0	0	4	0	11	0.05
Grubby	14	33	168	68	7	0	0	0	3	0	341	235	869	3.87
Haddock	0	0	0	0	0	0	10	0	11	0	4	0	25	0.11
Hake species	0	0	0	0	14	12	23	0	884	35	185	31	1,184	5.27
Longhorn sculpin	0	2	0	24	0	0	0	0	0	0	19	7	52	0.23
Lumpfish	0	33	61	319	0	0	0	0	0	0	0	7	420	1.87
Northern pipefish	0	11	269	1,745	37	0	0	7	67	35	196	7	2,374	10.56
Northern searobin	0	0	0	0	7	0	0	0	0	0	0	0	7	0.03
Ocean pout	0	0	0	3	0	0	0	0	0	0	0	0	3	0.01
Pollock	0	0	3	9	0	0	203	68	21	18	0	18	340	1.51
Radiated shanny	0	0	79	29	0	0	0	0	0	0	0	11	119	0.53
Rainbow smelt	0	74	102	289	0	0	4	3	18	3	0	79	572	2.55
Red hake	0	105	78	1,159	12	32	3	0	0	0	0	0	1,389	6.18
Rock gunnel	0	3	1,312	941	56	29	77	41	204	239	262	10	3,174	14.12
Scup	0	0	0	0	0	0	0	0	4	0	4	0	8	0.04
Sea Raven	0	10	24	51	4	3	17	7	14	4	26	4	164	0.73
Sea lamprey	0	0	0	71	0	0	0	0	0	0	0	0	71	0.32
Short bigeye	0	1	0	0	0	0	0	0	0	0	0	4	5	0.02
Shorthorn sculpin	4	13	143	48	45	0	0	0	7	4	0	201	465	2.07
Silver hake	0	0	0	3	0	0	0	0	18	0	0	0	21	0.09
Skate sp.	0	5	7	22	0	4	0	0	0	0	11	15	64	0.28
Snailfish sp.	0	7	28	0	0	0	0	0	0	3	0	38	76	0.34
Spiny dogfish	0	0	0	0	0	0	0	0	0	3	0	0	3	0.01
Striped Bass	0	0	0	0	0	0	0	0	0	4	0	0	4	0.02
Tautog	0	0	0	0	4	4	0	0	0	0	0	0	8	0.04
Threespine stickleback	0	18	99	67	0	0	0	0	0	0	0	9	193	0.86
Weitzman's pearlside	0	10	0	0	0	0	0	0	0	0	0	0	10	0.04
White hake	0	2	29	84	0	25	0	0	0	0	0	0	140	0.62
Windowpane	0	132	95	662	74	11	0	0	0	7	250	271	1,502	6.68
Winter flounder	0	556	1,293	1,467	18	0	0	0	0	0	106	509	3,949	17.57
Wrymouth	0	12	7	37	0	0	0	0	0	0	0	4	60	0.27
Yellowtail flounder	0	7	4	0	0	0	0	0	0	0	0	0	11	0.05
All	18	1,502	3,991	7,983	726	215	455	208	1,537	655	1,774	3,408	22,472	100.0
Average Daily Flow (MG)	637.1	608.0	607.1	614.6	643.0	667.6	668.5	668.7	668.1	644.5	663.1	626.4		
Impingement Rate (fish/10MG)	0.01	0.88	2.35	3.71	0.40	0.12	0.19	0.11	0.66	0.36	0.96	1.81		

was an increase from last year but substantially less than in 2003, which was the highest impingement estimate for the period 1994 through 2007 (Appendix Table 4-3). The month with the high impingement of fish was April (7,983; 36%). Cooling water was pumped at Seabrook Station throughout 2007. Daily average circulating water flow ranged from 607 million gallons per day (MGD) in March to 669 MGD in August (Table 4-11).

In 2007, winter flounder (3,949: 18%), rock gunnel (3,174: 14%), northern pipefish (2,374: 11%), American sand lance (2,073: 9%), and windowpane (1,502: 7%) comprised 59% of the fish impinged (Table 4-11). In 2007, short bigeye and Weitzman's pearlside were impinged for the first time.

Winter flounder were impinged from February through May and November-December with the highest estimate occurring in March and April (2,760: 70%). Winter flouner are a resident flatfish in the Gulf of Maine and spawn inshore on sandy bottom and algal mats during winter and early spring (Collette and Klein-MacPhee 2002). Most of the winter flounder impinged in 2007 were probably YOY (86%) and Age 1 and 2 (13%) based on their length frequency distribution (Figure 4-7). The 2007 estimate of impinged winter flounder was the second highest number of winter flounder impinged since 1994 (Appendix Table 4-3).

Rock gunnel were impinged primarily in March and April (2,253: 71%). Rock gunnel are year-round residents to the Gulf of Maine where they occur (Collette and Klein-MacPhee 2002), and rock gunnel impinged at Seabrook Station were of variety of ages, but mostly Age 2-3 based on length distributions (Figure 4-7). The 2007 impingement estimate for rock gunnel was the fourth highest annual impingement estimate since 1994 (Appendix Table 4-3).

Northern pipefish were impinged in all months except January, June and July and were primarily impinged in April (1,745: 74%). Northern pipefish range from Gulf of St. Lawrence south to Florida, and are commonly found among eelgrass and seaweeds. Although typically found in bays, salt marshes, creeks, river mouths, and harbors, northern pipefish have been known to make offshore migrations and stray into coastal surface waters among floating seaweeds (Collette and Klein-MacPhee 2002). The total length distribution of northern pipefish impinged by Seabrook Station was normal with a central mode of 130-139 mm (Figure 4-7).

American sand lance were impinged February through May and October through December with the highest estimate occurring in December(1,505: 73%). American sand lance are a common fish along sandy shores in the Gulf of Maine with peak spawning occurring in winter months (Collette and Klein-MacPhee 2002). Most of the American sand lance impinged in 2007 were probably mature based on their length frequency distributions (Figure 4-7). The 2007 estimate of impinged American sand lance was the second highest number of sand lance impinged since 1994 (Appendix Table 4-3).Windowpane were impinged in February through June, and October through December. The highest impingement estimate occurred in April when 662 (44%) were impinged. Based on length frequency, most windowpane impinged were probably YOY fish less than 119 mm in length (Figure 4-7).

Impingement in 2007 was more than in 2006 for most commercially important species, a reflection of the increase in total impingement. An estimated 178 Atlantic cod, 260 Atlantic herring, 2,713 hakes (red, white and hake sp.), and 3,949 winter flounder were impinged in 2007 (Table 4-11). Estimated impingement of haddock (25), Atlantic

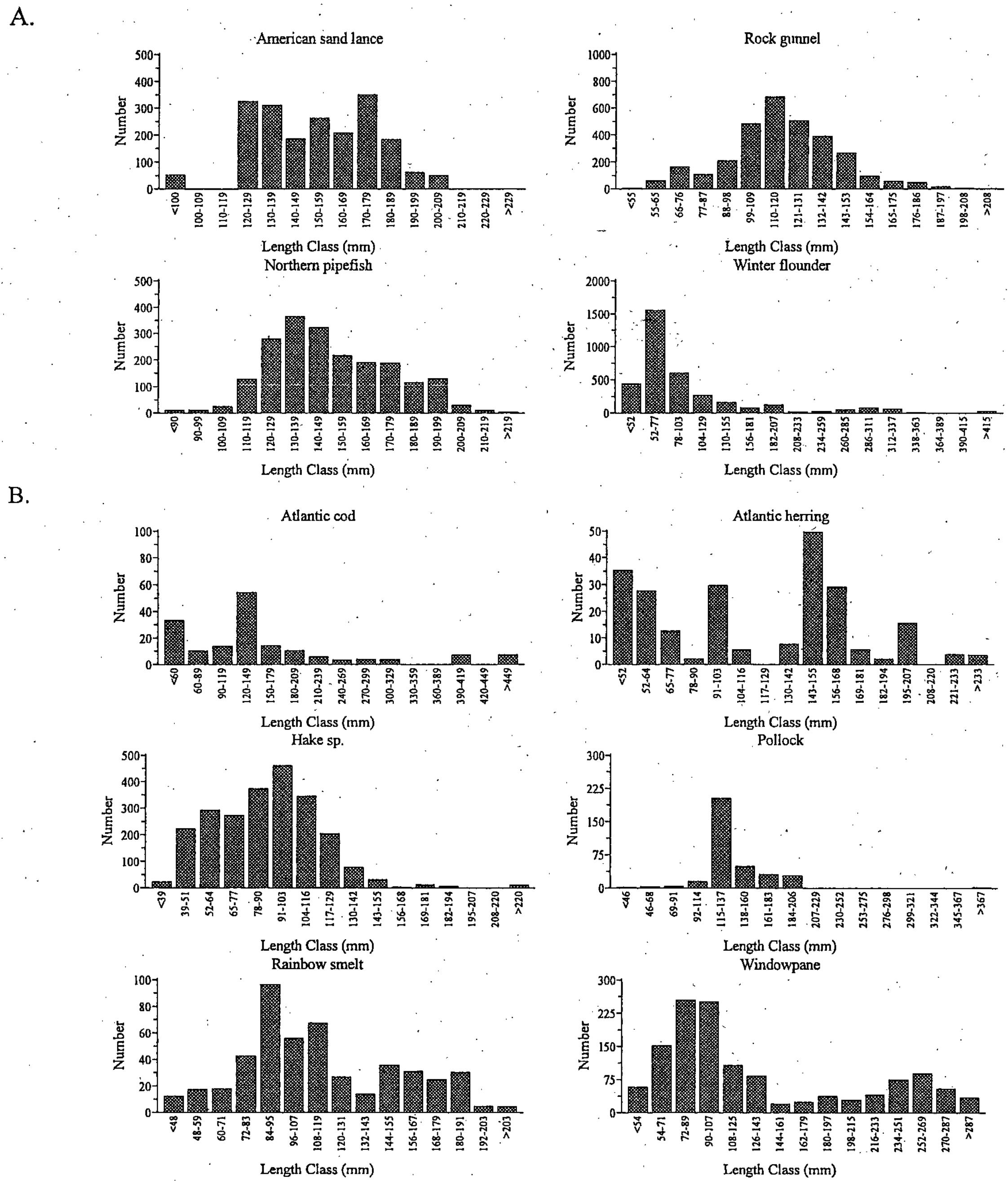


Figure 4-7. Length frequency distributions of A) the four most abundant impinged fish and B) commercially-important fish impinged at Seabrook Station in 2007. Seabrook Operational Report, 2007.

menhaden (160), butterfish (199), pollock (340), silver hake (21) and yellowtail flounder (11), was each less than 400 fish for the year. No American eel, or Atlantic mackerel were collected in impingement samples in 2007.

These losses represent a small fraction of the stock size of these commercial fishes. Based on impingement data from the end of 1994 through 2007, it appears that the majority of the fish impinged are YOY demersal fishes taken during the spring and fall. Many common inshore demersal fishes undergo a seasonal movement in the fall and winter as they move to deeper waters as water temperatures decrease inshore. The impingement of YOY demersal fishes in the fall and winter may be a result of these fishes moving past the intakes as they complete their annual movements.

Fish impingement at Seabrook Station is a direct impact to the fish community as it results in the removal of fish from the environment. However, impingement at Seabrook has generally been less than or similar to impingement at other plants with coastal intakes (Table 4-12). At Seabrook, mean annual impingement for 1994 through 2006 was 21,912 fish/year, and annual estimates ranged from 7,281 (2000) to 71,950 (2003; Table 4-12). Mean annual impingement estimates for other plants ranged from 44,755 fish/year at Pilgrim Station to 65,927 fish/year at Millstone 2.

During 2007, about 36% of the total annual estimate occurred in April. High impingement events at Seabrook Station and other plants were often associated with storm events. At Millstone Nuclear Power Station, large winter flounder impingement events were related to a combination of high sustained winds and low temperatures (NUSCO 1987). Storm events have also increased impingement at other estuarine (Thomas and Miller 1976) and freshwater (Lifton and Storr 1978) power plants. In 2007, a storm known as the Patriot's Day Storm occurred in mid-April (NCDC 2007) and brought greater than 30-ft waves and high winds to the region. Samples collected during the week of this storm accounted for 75% of the April total and 27% of the annual total.

Impingement at a power plant is dependent on many factors, including the fish abundance near the intakes, the susceptibility of the species or lifestage to impingement, 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; Turnpenny 1983). The offshore intakes at Seabrook Station are equipped with velocity caps that primarily withdraw cooling water from mid-water depths with a velocity of about 0.15 m/s (0.5 ft/s). This design has apparently been successful in reducing impingement of fish and lobsters. The majority of the fishes impinged have been demersal fishes, with the exceptions of Atlantic silverside, Atlantic menhaden and pollock, and rainbow smelt.

4.3.3 Selected Species

4.3.3.1 Atlantic Herring

The Atlantic herring (*Clupea harengus*) 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). 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). Atlantic herring have recovered from overfishing in the 1960s and 1970s and their distribution has been restored throughout western and central Gulf of Maine (Overholtz 2002). A major spawning area and source of larvae in the western Gulf of Maine is Jeffreys Ledge (Townsend 1992, Overholtz and Friedland 2002), although other banks and ledges in this area are also used (Boyar et al. 1971). The early life history of Atlantic herring is somewhat unique among other northern temperate fishes in that the larval

Table 4-12. **Comparison of Fish Impingement Estimates at Selected New England Power Plants with Marine or Estuarine Intakes. Seabrook Operational Report, 2007.**

Station	Source Water Body	Rated Capacity (Mwe)	Nominal Cooling Water Flow (m^3/sec)	Years of Study	Mean Annual Impingement	CV (%)	Range for Annual Estimates	Mean Number per Day	Reference
Seabrook	Gulf of Maine	1,150	31.5	1995-2006[a]	22,090[a]	79	7,281-71,950	61	–
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	1980-2006	44,755[c]	146	1,112-302,883[c]	123	Environmental Protection Group, Entergy Nuclear-Pilgrim Station (2006)
Brayton Point 1-3	Mount Hope Bay	1,150	39.0	1972-92	54,433	136	15,957-359,394	118	MRI (1993)
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] 65,927[e]	59 214	8,560-60,410[d] 8,560-511,387[e]	71 181	NUSCO (1988)

[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.

stage is up to eight months old before metamorphosis to a juvenile phase (Sinclair and Tremblay 1984). 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. The biomass of the Atlantic herring resource in the Gulf of Maine is presently near record highs and the resource is considered not overfished and overfishing is not occurring (NEFSC 2006). The 1994 and 1998 year classes were extremely large and recruitment for the 1999-2000 year classes has been weaker than average. The offshore spawning component of the Gulf of Maine-Georges Bank Atlantic herring stock complex is now fully recovered following stock collapse in the 1980s. However, Atlantic herring appear to be less available to the fixed-gear inshore fishery (NEFSC 2006).

Atlantic herring eggs have not been identified in any ichthyoplankton or entrainment collections for Seabrook Station studies, probably because they are demersal and adhesive. Larvae were present between October and May, and most common in the fall spawning season, October through December (NAI 1993). In 2007, average larval density was lower than the preoperational and operational mean at Station P2 (Table 4-13). At Station P7, the 2007 mean was lower than the preoperational mean and similar to the operational mean. Atlantic herring larval densities have been variable with major peaks in 1975-76, 1986, and 2001 (Figure 4-8). In 2007, larval density decreased at both stations compared to 2006. Density of Atlantic herring larvae in operational period was significantly lower than the preoperational period (Table 4-14). The interaction term was not significant, indicating that the decrease between periods occurred equally at all stations.

Entrainment and impingement of Atlantic herring appeared to have a small effect on local populations. An estimated 260 Atlantic herring were impinged in 2007 (Table 4-11) and length ranged from 50 to 235 mm. Atlantic herring accounted for about 4% of larvae entrained in 2007 (11.5 million, Table 4-5). 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. Annual entrainment estimates from 1995 through 2007 ranged from 200,000 in 2000 to 15.3 million in 2003 (Table 4-6). Entrainment of these larvae and impingement of adults resulted in the estimated average loss of 1,051 equivalent adults each year for the period 1998 through 2006. An estimated 495 equivalent adults were lost in 2007 due to entrainment and impingement.

4.3.3.2 Rainbow Smelt

The anadromous rainbow smelt (*Osmerus mordax*) 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. 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). In the Great Bay of New Hampshire, hatching of eggs occurs from April through June (Ganger 1999).

Rainbow smelt were most common in trawl samples from November through May (NAI 1993). In 2007, geometric mean CPUE for all trawl stations combined decreased compared to 2006 (Figure 4-9). CPUE was highest at Station T2, especially during 1978, 1981,

Table 4-13. Geometric Mean Catch per Unit Effort (number per 1000 m^3) with Upper and Lower 95% Confidence Limits by Station (P2 and P7) and All Stations Combined of Larvae of Selected Species Collected in Ichthyoplankton Samples During the Preoperational and Operational Periods and in 2007. Seabrook Operational Report, 2007.

		Preoperational Period[a]			2007[b]	Operational Period[c]		
		LCL[d]	Mean	UCL[e]	Mean	LCL[d]	Mean	UCL[e]
American sand lance	P2	106.9	159.6	238.1	179.5	90.0	122.3	165.9
	P7	56.0	106.0	199.9	56.6	72.9	96.5	127.7
	All Stations	95.4	144.2	217.6	101.0	83.4	108.6	141.5
Atlantic cod	P2	1.3	2.5	4.4	0.2	0.3	0.6	1.0
	P7	0.3	1.0	2.1	0.0	0.2	0.3	0.5
	All Stations	1.2	2.4	4.3	0.1	0.2	0.4	0.7
Atlantic herring	P2	14.8	29.0	55.9	8.1	7.7	11.4	16.6
	P7	15.8	33.2	68.5	12.1	8.5	12.3	17.8
	All Stations	15.5	29.7	55.9	9.9	8.2	11.8	16.9
Atlantic mackerel	P2	4.5	6.9	10.4	1.2	2.1	3.7	6.2
	P7	3.8	5.9	9.1	1.6	2.1	3.6	5.8
	All Stations	4.5	6.8	9.9	1.3	2.1	3.6	5.9
Cunner	P2	28.9	48.5	81.0	197.5	79.7	136.3	232.9
	P7	23.9	59.0	143.9	255.0	88.8	145.1	236.5
	All Stations	31.0	51.4	84.7	224.4	85.1	140.7	232.1
Hakes[f]	P2	2.4	3.9	6.2	1.0	1.7	4.2	9.1
	P7	1.4	3.9	9.0	0.6	2.0	4.6	9.5
	All Stations	2.5	4.1	6.3	0.8	1.9	4.4	9.1
Pollock[g]	P2	3.1	6.8	13.7	21.8	0.5	1.2	2.2
	P7	0.8	2.4	5.6	9.1	0.5	1.1	2.0
	All Stations	3.1	6.8	13.8	14.1	0.5	1.2	2.1
Winter flounder	P2	9.0	12.1	16.0	6.0	3.0	4.1	5.6
	P7	4.7	8.0	13.4	5.3	1.4	2.1	2.9
	All Stations	7.7	10.5	14.1	5.6	2.3	3.0	3.8
Yellowtail flounder	P2	1.9	3.4	5.8	0.0	0.7	1.3	2.0
	P7	1.2	2.9	5.7	0.0	0.5	1.1	1.8
	All Stations	2.1	3.7	6.1	0.0	0.6	1.2	1.9

[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 2007 data.
[c] Operational: August 1990-December 2007; geometric mean of annual means.
[d] LCL = Lower 95% confidence limit.
[e] UCL = Upper 95% confidence limit.
[f] May include red hake, white hake, spotted hake, or more than one of these species.
[g] Annual geometric mean for pollock in 2007 includes November through December 2006 and January through February 2007.

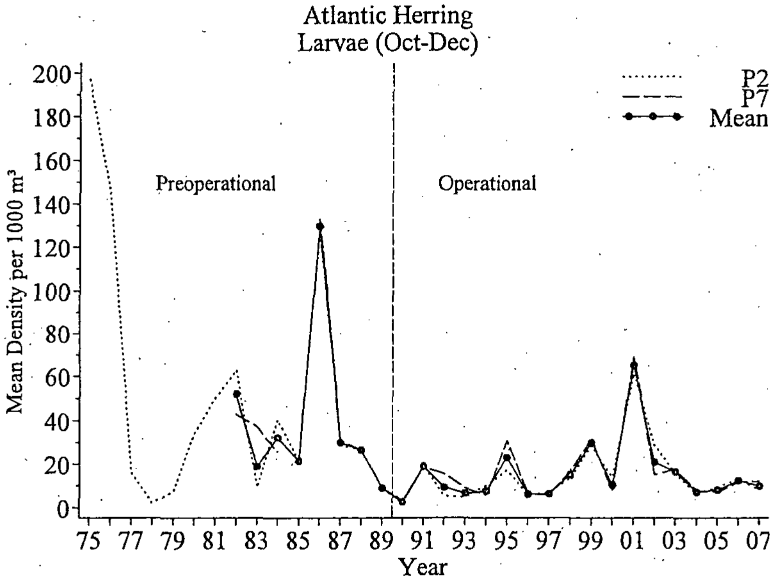


Figure 4-8. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of Atlantic herring in ichthyoplankton samples by station and the mean of all stations, 1975-2007. Seabrook Operational Report, 2007.

Table 4-14. Results of Analysis of Variance of Atlantic Herring Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton (Oct.-Dec.) (1982-2007)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 73.7	6.19	0.0159*	Op<Preop
	Random Effects	**Estimate[j]**	χ^2	p	
$Log_{10}(x+1)$	Year (Preop-Op)[b]	0	0.000	0.4999	
	Month(Year)[c]	0.3499	163.508	<0.0001	
	Station[d]	0	0.000	0.5000	
	Preop-Op X Station[e]	0	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.4326			

[a] Preop-Op compares 1982-1984, 1986-1989 to 1990-2007 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

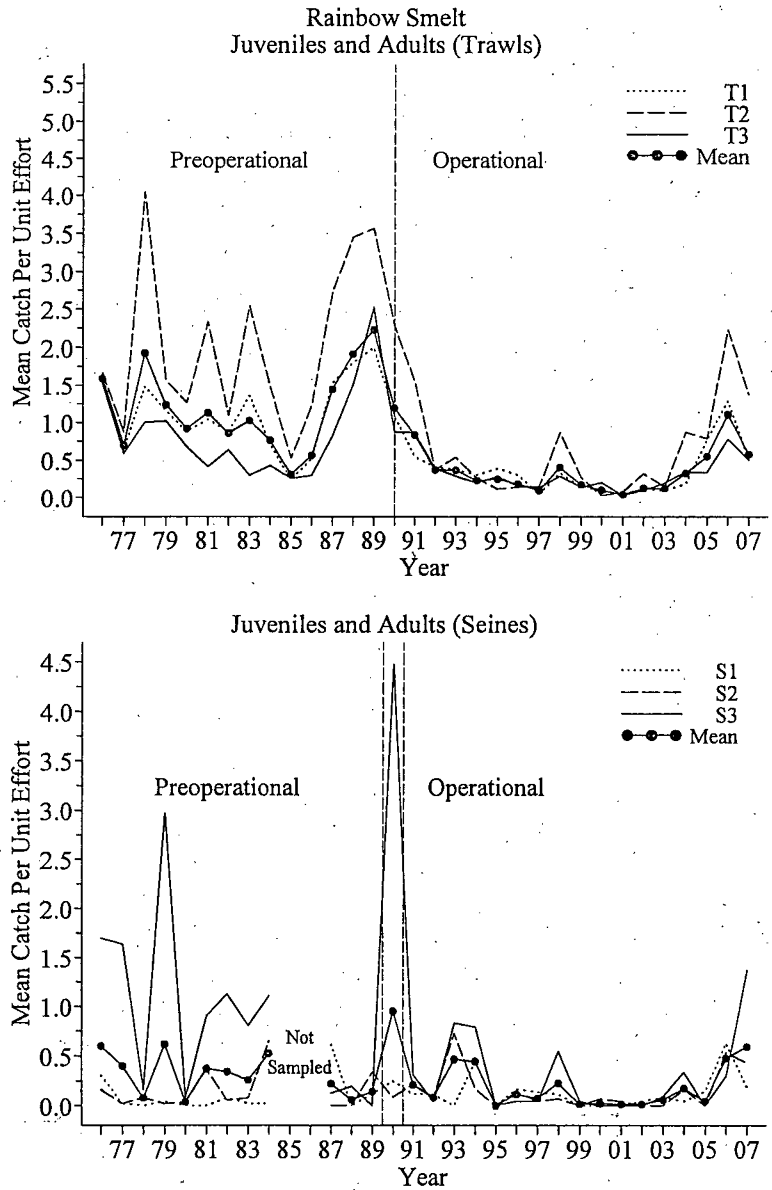


Figure 4-9. Annual geometric mean catch of rainbow smelt per unit effort in trawl (number per 10-minute tow) and seine (number per haul) samples by station and the mean of all stations, 1975-2007 (data between two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

1983, 1987-1989, 1998, 2006, and 2007 (Figure 4-9). At Stations T1 and T2, there were no significant trends, but CPUE was higher in the period 1976 though 1990 compared to 1991 through 2007 at Station T1, and higher during 1976-1990 compared to 1991-2007 at Station T2.

CPUE of rainbow smelt did not decrease equally at all stations as indicated by the significant interaction term (Table 4-15). CPUE decreased between the preoperational and operational periods to a greater degree at Station T2 (Figure 4-10). In the preoperational period there were significant differences in CPUE among stations, but there were no differences in the operational period, indicating that CPUE has declined to low levels at all stations. The general decline in CPUE began in 1990 at all stations, (Figure 4-9). The uniformly low CPUE at all stations in the operational period suggest a regional decline in rainbow smelt stocks.

Mean CPUE of rainbow smelt in seine samples in 2007 increased compared to 2006 (Figure 4-9). Seine CPUE was variable, especially at Station S3 during the pre-operational period. In 2007, CPUE at Station S3 was the highest observed in the operational period. Mean CPUE peaked in the pre-operational period in 1979 and 1990, one year after similar peaks occurred in trawl samples. Peaks in seine CPUE may have corresponded to increased numbers of age-1 fish resulting from larger than average adult spawning stocks the previous year. During the operational period, CPUE was less variable as CPUE among the three stations generally followed the same trends. CPUE was significantly greater at Station S3 than Stations S2 and S1 and there were no significant differences between the preoperational and operational periods (Table 4-15).

An estimated 572 rainbow smelt were impinged in 2007, with 50% of the annual estimate occurring in April (Table 4-11). Rainbow smelt impinged in April were on average 100 mm in total length (range= 42-184 mm) and were probably Age 2-3 fish based on length (Murawski and Cole 1978). An estimated total of 17,023 rainbow smelt have been impinged since 1994, resulting in an average of 1,216 impinged per year (Appendix Table 4-3). To put this loss in perspective, an estimated average of 98,000 rainbow smelt were taken by recreational anglers in the Great Bay ice fishery each year between 1994 and 2007 (no estimate was possible for 2002 and 2006; NHFG 2008).

The abundance of rainbow smelt is potentially influenced through impingement and entrainment. Rainbow smelt spawn in the estuary and the adhesive eggs remain there and are generally not subject to entrainment. Because of the behavior and specific life history of the rainbow smelt, no eggs and larvae (3.1% 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. Eggs or larvae have been collected in entrainment samples in 1990, 1992, 1996, 1998, 2000, 2001, and 2003 through 2007 accounting for a total entrainment estimate of about 6.7 million larvae since the beginning of plant operation (Table 4-6).

4.3.3.3 Atlantic Cod

The Atlantic cod (*Gadus morhua*), present in the Northwest Atlantic Ocean from southwest Greenland to Cape Hatteras, is one of the most important commercial and recreational fishes of the United States and eastern Canada. Many separate groups have been noted to spawn at different locations in the northwest Atlantic Ocean, but for

Table 4-15. Results of Analysis of Variance of Rainbow Smelt Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Seine (Apr.-Nov.) (1976-1984, 1987-2007	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 26.9	2.98	0.0957	(last year Op<Preop NS this year)
	Random Effects	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.0003	0.0474	0.4139	
$\text{Log}_{10}(x+1)$	Month(Year)[c]	0.0067	7.4644	0.0032*	
	Station[d]	0.0031	10.6622	0.0006*	S3> <u>S2 S1</u>
	Station X Year (Preop-Op)[f]	0.0040	6.3608	0.0058*	
	Error	0.0521			
Trawl (Dec-May) (1975-2007)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 12.7	20.52	0.0006*	Op<Preop
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0.0118	2.908	0.0441	
$\text{Log}_{10}(x+1)$	Month(Year)[c]	0.0994	182.581	<0.0001*	
	Station[d]	0	0	0.5000	
	Preop-Op X Station[e]	0.0052	12.259	0.0002*	2Pre 1Pre 3Pre <u>1Op 3Op 2Op</u>
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.0660			

[a] Preop-Op for seine compares 1976-1984 and 1987-1989 to 1991-2007 regardless of station. Preop-Op for trawl compares 1990-2007 to 1975-1990 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on *multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).*
* = significant ($p \leq 0.05$)

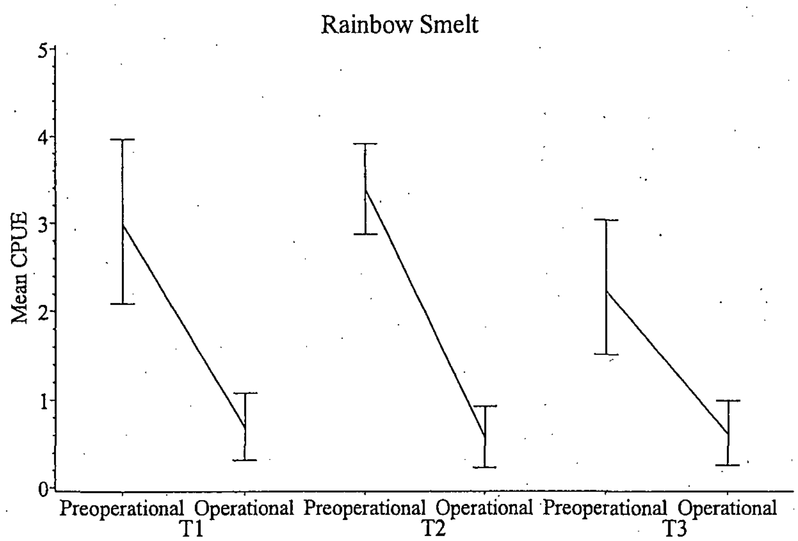


Figure 4-10. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of rainbow smelt caught by trawl during the preoperational (November 1975-May 1990) and operational (November 1990-May 2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-14). Seabrook Operational Report, 2007.

management purposes two stocks (Gulf of Maine, and Georges Bank and South) are recognized in U.S. waters (NEFSC 2006). Atlantic cod appear to return to the same areas to spawn (Robichaud and Rose 2001; Windle and Rose 2005). Local egg retention explains small-scale population structure (Knutsen et al. 2007), which may partly explain the slow re-colonization rates observed in North Atlantic stocks. Year class strength in Atlantic cod is dependent on many factors including large-scale meteorological systems and offshore winds (Koslow et al. 1987). On Georges Bank, growth rate of cod larvae increases with water temperature to 7 °C and then decreases (Buckley et al. 2004). Year class strength did not appear to be related to egg or larval abundance, but instead was determined by the abundance of pelagic and settled juveniles (Campana et al. 1989). In the Gulf of Maine, Atlantic cod has a broad diet that shifts from mostly small crustaceans at < 10 cm total length (TL) to a more piscivorous diet with herrings and silver hake as major diet components at > 50 cm TL (Link and Garrison 2002). However, Swain and Sinclair (2000) found a strong negative relationship between the biomass of the pelagic Atlantic herring and Atlantic mackerel and the recruitment rate of Atlantic cod. They suggested that these pelagic fishes prey on early life stages of Atlantic cod, reducing year class strength of Atlantic cod, and decreasing predation and competition for the young-of-the-year pelagic fishes. The current high stock levels of Atlantic herring and Atlantic mackerel may be inhibiting the recovery of Atlantic cod stocks (Swain and Sinclair 2000). Bundy and Fanning (2005) reported similar findings to Swain and Sinclair and suggested that the lack of recovery of Atlantic cod on the Scotian Shelf was due to high predation on small cod and competition between small cod and forage fish such as sand lance and capelin for food items.

The Gulf of Maine and Georges Bank Atlantic cod stocks are overfished and overfishing is occurring (NEFSC 2006). Year class strength has been low and relatively consistent since the exceptionally strong 1987 year class (Working Group etc. 2002). The strong 1987 year class is no longer predominant and was replaced by the less numerous year classes from the 1990s. The 1998, 2003, and 2004 year classes appear to be relatively strong and biomass indices from 2003-2005 suggest the population biomass remains slightly above the low levels of the early 1990s (NEFSC 2006). Fishing mortality must be substantially reduced and remain low to prevent further stock declines and promote rebuilding of the stocks (NEFSC 2006).

Atlantic cod eggs in ichthyoplankton collections were usually grouped as Atlantic cod/haddock because it was difficult to distinguish between the eggs of these two species; this aggregation also included witch flounder eggs. Eggs of these taxa have been numerically dominant in the winter and early spring (NAI 1998). Examination of larval data collected since 1982 indicated that the percent composition of these three species among all species collected was 0.47% for Atlantic cod, <0.01% for haddock, and 0.42% for witch flounder. Assuming a relatively similar hatching rate, it appears 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 (NAI 1998), before the spawning seasons of haddock and witch flounder.

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. Density of Atlantic cod larvae was highest from 1977 through 1982 with peaks in 1978 and 1981 when sampling only occurred at Station P2 (Figure 4-11). Since then density has declined to relatively low and stable levels. Density of Atlantic cod larvae was low in 2007 as they were only collected at Station P2. Density in 2007 was below the lower confidence limits for the preoperational and operational means at both stations (Table 4-13). Due to the recent low abundance of Atlantic cod larvae, density was significantly lower in the operational period. There were no significant differences between stations and the interaction between station and period (Preop-Op) was not significant (Table 4-16).

Atlantic cod were captured year-round in the trawl, but were most abundant from November through July (NAI 1993). Mean CPUE at all stations combined decreased from 0.7 in 2006 to 0.3 in 2007 (Figure 4-11) and was less than the preoperational and operational means (Table 4-8). Mean CPUE was highest for all stations from 1978 through 1983, 1987 through 1988, 1993, and 2003 through 2004 (Figure 4-11). Similar increases corresponding to increased recruitment of the 1977-1980, 1983 and 1985-1987 year classes one to two years later at ages 1 and 2 were observed in the NMFS recruitment index (Mayo and Terceiro 2005). The increase in CPUE observed in our trawl data in 2003 and 2004 may be a reflection of the strong 2003 year class. There was a significant negative trend in annual geometric mean CPUE during 1976-1994 at Station T1, but a positive trend from 1995 through 2007 (Table 4-9). Mean CPUE at Station T1 for the prior period was significantly higher compared to the period of the later years (Table 4-9). There were no significant trends at Stations T2 and T3, although mean CPUE was significantly higher from 1976 through 1985 compared to 1986-2007 at Station T2, and higher during 1976-1988 compared to 1989-2007 at Station T3.

CPUE decreased at all stations between the preoperational and operational periods, but the decrease was smaller at Station T2, resulting in a significant interaction term (Table 4-16; Figure 4-12). On a percentage basis, the decreases in CPUE were relatively similar. CPUE decreased 83% at Station T1, 76% at Station T2, and 69% at Station T3. CPUE has generally been highest at Station T3 followed by Stations T1 and T2, probably due to habitat preferences (Figure 4-11). The consistency in CPUE among stations, and the generalized decrease in CPUE to very low levels in recent years suggest a regional trend (NEFSC 2006).

An estimated 178 Atlantic cod were impinged in 2007 (Table 4-11). The lengths of impinged Atlantic cod were variable, and ranged from 32 to 475 mm with the majority in the 120-149 mm length class (Figure 4-7). Impingement (22%) was highest in July. Most of these fish appeared to be YOY (Collette and Klein-MacPhee 2002). Since 1994 an estimated 5,005 fish were impinged, a total not likely to affect Atlantic cod resources in the study area (Appendix Table 4-3).

Egg entrainment (9.4 million in 2007) has been relatively low (Tables 4-5 and 4-6), given the high fecundity of Atlantic cod in the Gulf of Maine. Entrainment of cod larvae in 2007 (1.6 million) was the sixth highest observed to date during years when sampling occurred in all 12 months. It is not likely that entrainment of cod eggs and larvae would affect recruitment to the juvenile stage because year class strength is not related to egg or larval abundance (Campana et al. 1989) and may be more strongly related to overfishing and climate change (Rose 2004), or predation and interspecific competition (Bundy and Fanning 2005).

Equivalent adult analysis was conducted to estimate the impacts of entrainment of eggs and larvae on the adult stock. Few haddock larvae have been collected in the study area so it was assumed that all the eggs in the Atlantic cod/haddock group were Atlantic cod. Witch

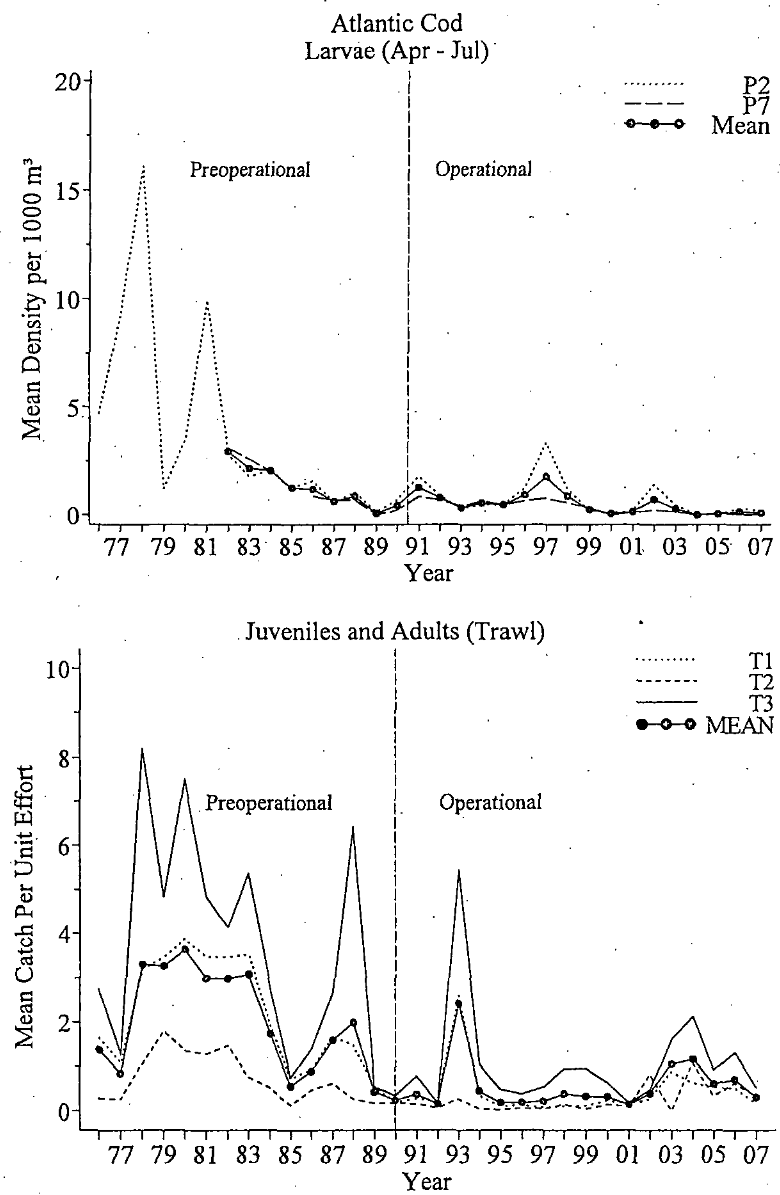


Figure 4-11. Annual geometric mean catch of Atlantic cod per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2007. Seabrook Operational Report, 2007.

Table 4-16. Results of Analysis of Variance of Atlantic Cod Densities by Sampling Program. Seabrook Operational Report, 2007

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Apr.-Jul.)	Preop-Op[a]	1, 22.8	5.90	0.0235*	Op<Preop
(1982-1984,					
1986-2007)	**Random Effects**	**Estimate[j]**	χ^2	**P**	
	Year (Preop-Op)[b]	0.0070	1.257	0.1311	
$Log_{10}(x+1)$	Month(Year)[c]	0.0392	42.373	<0.0001*	
	Station[d]	0.0019	0.612	0.2170	
	Preop-Op X Station[e]	0.0000	0.000	0.4998	
	Station X Year (Preop-Op)[f]	0.0000	0.000	0.4998	
	Error	0.1732			
Trawl	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Dec.-Jul.)	Preop-Op[a]	1, 5.56	10.48	0.0198*	Op<Preop
(1975-2007)	**Random Effects**	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0.0219	31.930	<0.0001*	
$Log_{10}(x+1)$	Month(Year)[c]	0.0304	89.092	<0.0001*	
	Station[d]	0.0243	1.868	0.0859	
	Preop-Op X Station[e]	0.0063	12.408	0.0002*	3Pre 1Pre 3Op 2Pre 1Op 2Op
	Station X Year (Preop-Op)[f]	0.0040	7.628	0.0029*	
	Error	0.0478			

[a] Preop-Op for ichthyoplankton compares 1991-2007 to 1982-1984 and 1986-1990 regardless of station. Preop-Op for trawl compares 1990-2007 to 1975-1990 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

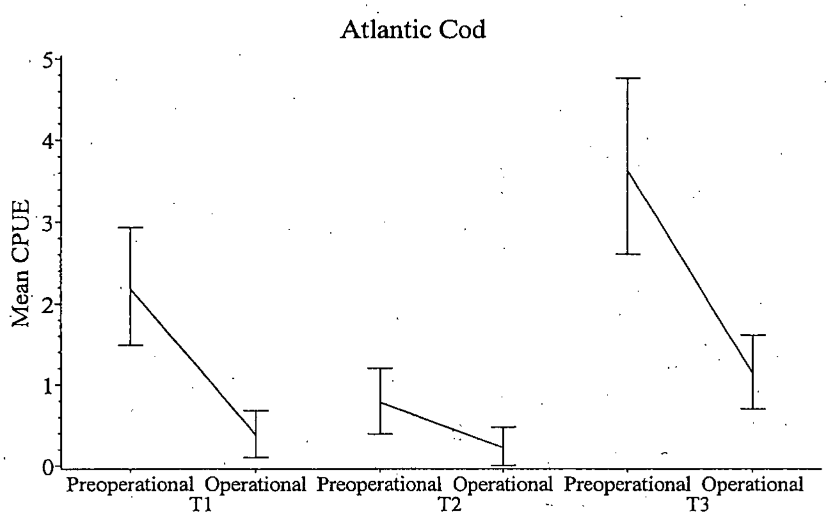


Figure 4-12. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of Atlantic cod caught by trawl during the preoperational (November 1975-July 1990) and operational November 1990-July 2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-15). Seabrook Operational Report, 2007.

flounder larvae are common, so the ratio of Atlantic cod to witch flounder larvae each year from 1998 through 2007 was used to estimate the number of Atlantic cod eggs in this group. Entrainment of cod eggs could potentially result in the loss of an average of 230 adult Atlantic cod/year for the period 1998 through 2007 with an estimate of 41 for 2007. Entrainment of cod larvae from 1998 to 2007 ranged from 0.4 million to 34.6 million. The mean annual estimated equivalent adult loss due to entrainment of larvae was 396 adults each year (1998-2007) with an estimate of 16 equivalent adults for 2007. An estimated 106 equivalent adult cod were also lost in 2007 due to impingement. These losses represent a small fraction of the stock of this commercial fish.

4.3.3.4 Pollock

The pollock (*Pollachius virens*) is one of the most pelagic gadids and is often found in large schools. Pollock are most abundant in the Gulf of Maine and Scotian Shelf (Collette and Klein-MacPhee 2002). 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). Commercial landings averaged 13,100 metric tons from 19986-1995, declined to a low of 4,500 metric tons in 1996, but have steadily increased to a recent high of 8,600 metric tons in 2005 (NEFSC 2006). Based on NEFSC trawl surveys, the stock biomass of pollock in the Gulf of Maine and on Georges Bank has decreased sharply during the 1980s and mid 1990s from a peak in the late 1970s. Since the mid 1990s the index has risen (NEFSC 2006). Relatively strong year classes occurred in 1999 and 2001. As of 2004, the stock was not overfished and overfishing was not occurring.

Larval pollock abundance generally peaked in November through February (NAI 1993). Large peaks in annual larval pollock density occurred in 1976, 1979, and 1984, with a smaller peak in 1987 and 2006 (Figure 4-13). In 2006 (November 2006 through February 2007), density of pollock larvae was above the preoperational and operational means and was the highest in the operational period (Table 4-13; Figure 4-13). Density of pollock larvae was significantly higher in the preoperational period than in the operational period, and there were no significant differences between stations (Table 4-17). The interaction term was not significant, indicating that changes in larval densities between the preoperational and operational periods were similar between stations. No changes in abundance or distribution can be attributed to power plant operation.

An estimated 340 pollock were impinged in 2007, primarily in June (60%; Table 4-11). Lengths of impinged pollock ranged from 34 to 372 and were primarily YOY and age 1 fish based on the length frequency distribution (Figure 4-7; Collette and Klein-MacPhee 2002).

An estimated 8.5 million pollock eggs and 770,000 larvae were entrained in 2007 (Table 4-5). The egg and larval entrainment estimates were the highest to date and an increase over the previous highest estimates in 2006 (Table 4-6). Pollock eggs were entrained most years and larvae were entrained only in 1990, 1992, 1998, and 2002 through 2007 (Table 4-6).

An estimated 435 equivalent adult pollock per year were lost due to impingement for the years 1998 through 2007 (NAI 2006). In 2007, an estimated 76 equivalent adults were lost due to impingement. Entrainment losses of pollock eggs and larvae at Seabrook Station in 1998 through 2007 were estimated to result in the annual loss of 31 equivalent adults annually, with an estimate of 89 equivalent adults for 2007.

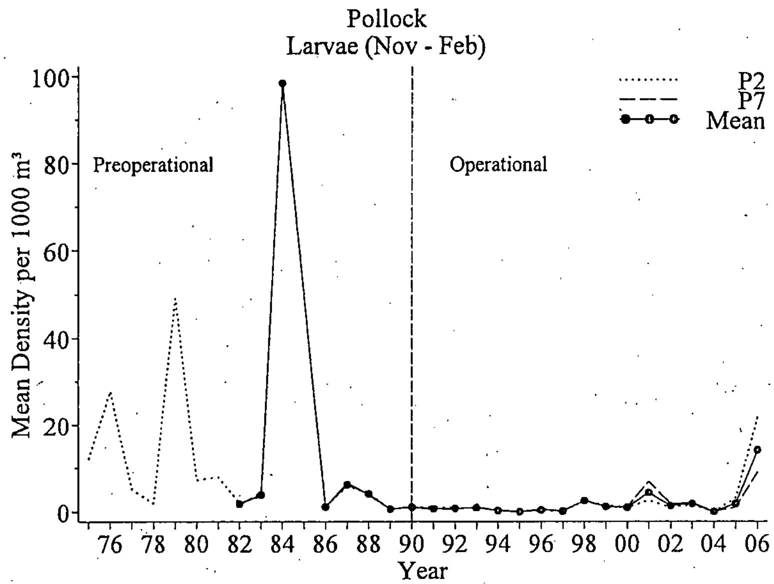


Figure 4-13. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of pollock in ichthyoplankton samples by station and the mean of all stations, 1975-2006. Note, 2006 includes November and December of 2006 and January and February of 2007. Seabrook Operational Report, 2007.

Table 4-17. Results of Analysis of Variance of Pollock Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton (Nov.-Feb.) (1982-1983, 1986-2006)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 20.6	2.68	0.1169 *	Op<Preop
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	0.0403	5.315	0.0106*	
	Month(Year)[c]	0.1075	106.558	<0.0001*	
	Station[d]	0	0.000	0.5000	
	Preop-Op X Station[e]	0	0.000	0.4999	
	Station X Year (Preop-Op)[f]	0	0.000	0.4996	
	Error	0.2043			

[a] Preop-Op for ichthyoplankton compares 1990-2006 to 1982-1983 and 1986-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Station and Year within Preop-Op.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_0: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

4.3.3.5 Hakes

Three species of hake (genus *Urophycis*) are found in the Gulf of Maine: red hake (*U. chuss*), white hake (*U. tenuis*), and spotted hake (*U. regia*). The spotted hake, however, is apparently quite rare in this area (Scott and Scott 1988; Collette and Klein MacPhee 2002) and is not important to the fisheries. For this reason, it will not be discussed further. 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). 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 fish, 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. 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.

Based on the depth distribution of the red and white hake, red hake is probably the most common hake in the study area. The NEFSC biomass index for red hake suggested a gradual increase in biomass from the 1970s through 2002, followed by a decline in 2005 to the lowest level since 1974 (NEFSC 2006). Despite the recent decrease, red hake are currently not overfished and overfishing is not occurring in the Gulf of Maine and northern Georges Bank (NEFSC 2006). In contrast, white hake are considered overfished and overfishing is occurring (NEFSC 2006). The NEFSC index of abundance was highest but very variable in the 1970s and 1980s, and began to decline in 1990, falling to a near record low in 1999 (NEFSC 2006). The biomass index increased in between 2000 and 2002, but has since declined.

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 (NAI 1998). Hake larvae generally peaked during July through September (NAI 1993). Density of hake larvae was relatively low and consistent in the preoperational period (Figure 4-14). There was a major peak in hake larval density in 1990, followed by a decrease to levels similar to the preoperational period. After 1993, densities have generally increased, with mean densities in 2000 the highest recorded (Figure 4-14). Mean density in 2000 was an order of magnitude higher than both the preoperational and operational period means at both stations (Figure 4-14). Mean density in 2007 decreased to levels below the preoperational and operational means (Table 4-13). Despite the increases in larval density from 1993 through 2000 and in 2003, there were no significant differences between the preoperational and operational periods (Table 4-18). The relation between stations was consistent between periods as indicated by the non-significant interaction term.

Hakes are taken year-round in trawl sampling, but peak catches were made from June through October, with a sharp decrease usually occurring in November (NAI 1993). Catches were generally lower at Station T2 each year, possibly a result of habitat preference (Figure 4-14). There was a

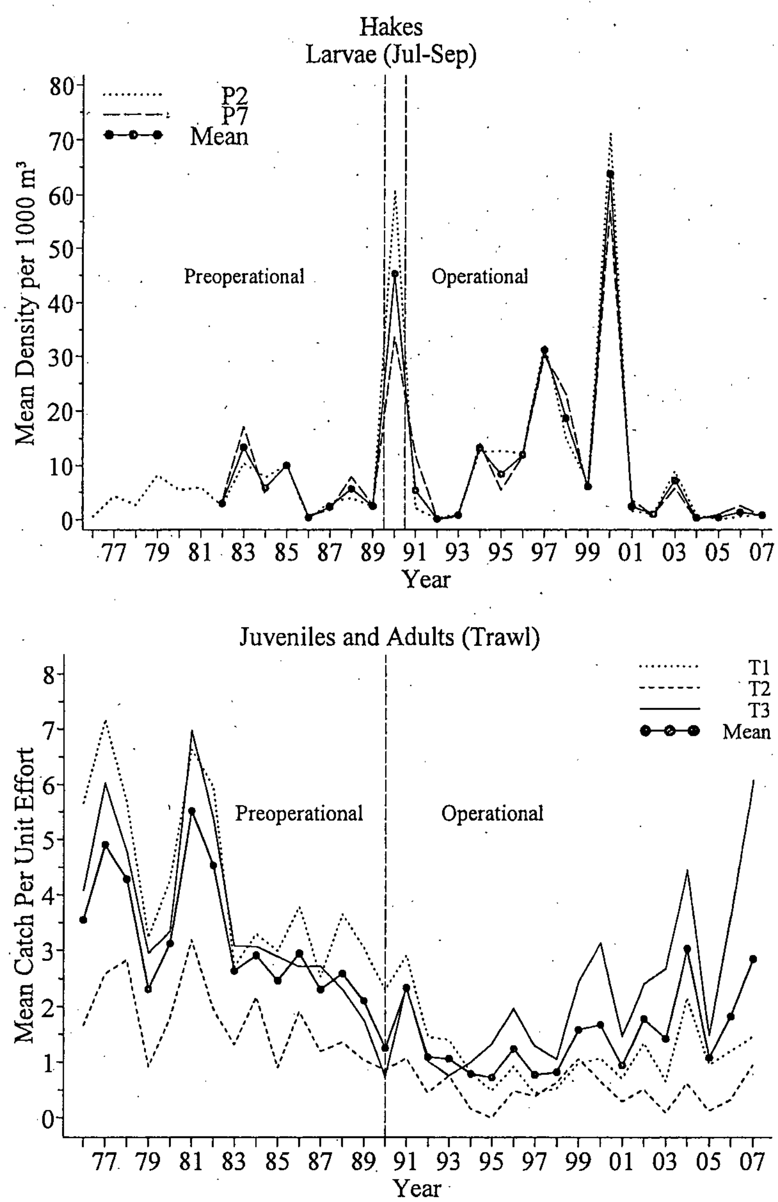


Figure 4-14. Annual geometric mean catch of hakes per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2007 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Table 4-18. Results of Analysis of Variance of Hake (red, white, and spotted hake) Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Jul.-Sep.)	Preop-Op[a]	1, 22.3	0.11	0.7406	
(1982-1984,					
1986-2007)	**Random Effects**	**Estimate[j]**	χ^2	p	
	Year (Preop-Op)[b]	0.1478	8.439	0.002*	
$Log_{10}(x+1)$	Month(Year)[c]	0.1742	40.940	<0.0001*	
	Station[d]	<0.0001	0.000	0.5000	
	Preop-Op X Station[e]	0	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.6033			
Trawl	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Dec.-Jul.)	Preop-Op[a]	1, 4.12	7.19	0.0534	
(1976-2007)	**Random Effects**	**Estimate[j]**	χ^2	p	
	Year (Preop-Op)[b]	0	0.000	0.4998	
$Log_{10}(x+1)$	Month(Year)[c]	0.1046	364.058	<0.0001*	
	Station[d]	0.0004	0.010	0.4599	
	Preop-Op X Station[e]	0.0053	17.792	<0.0001*	1Pre 3Pre 2Pre 3Op 1Op 2Op
	Station X Year (Preop-Op)[f]	0.0003	0.069	0.3961	
	Error	0.0456			

[a] Preop-Op for ichthyoplankton compares 1990-2007 to 1982-1984 and 1986-1989 regardless of station. Preop-Op for trawl compares 1990-2007 to 1976-1990 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \le 0.05$)

significant negative trend in geometric mean CPUE during 1976-1995 at Station T1, 1976-1994 at Station T2, and 1976-1993 at Station T3, but there were no trends in subsequent years except for a positive trend during 1994-2007 at Station T3 (Table 4-9). Stations T1 and T2 had a significantly higher mean CPUE in the early period than in the later period (Table 4-9). CPUE in 2007 at Stations T1 and T2 was lower than the preoperational mean and higher than the operational period mean (Table 4-8). CPUE in 2007 at Station T3 was higher than the preoperational and operational period means, and the second highest in the time series. CPUE decreased at all stations between the preoperational and operational periods, but the absolute decrease was greatest at Station T1, resulting in a significant interaction term (Table 4-18; Figure 4-15). On a percentage basis the decrease was 73% at Station 1, 59% at Station 2, and 37% at Station T3.

Entrainment and impingement losses due to plant operation did not appear to affect local populations. In 2007, an estimated 15.6 million hake eggs and 67.8 million hake/fourbeard rockling eggs were entrained but no hake larvae were collected in entrainment samples (Table 4-6). These estimates were within the range of previous years.

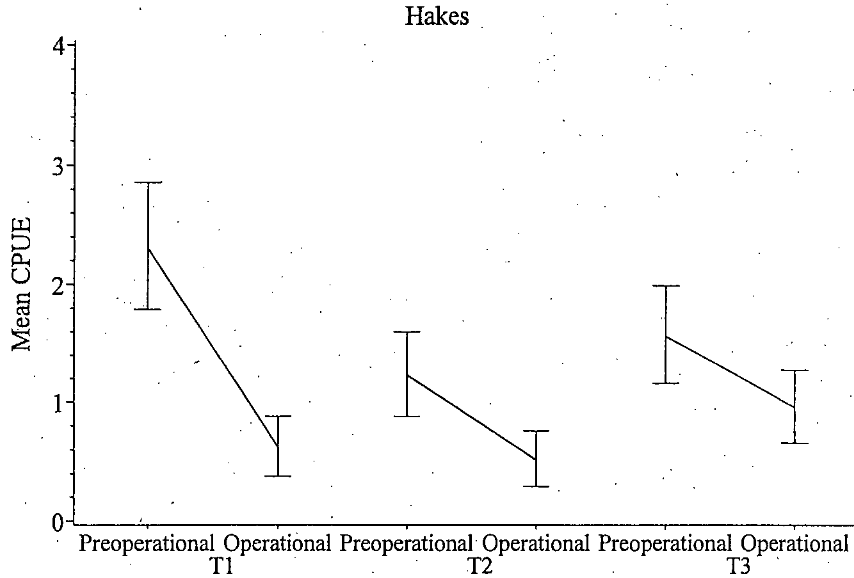


Figure 4-15. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of hakes caught by trawl during the preoperational (November 1976-July 1990) and operational (November 1990-July 2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-17). Seabrook Operational Report, 2007.

An estimated 2,713 hakes (red hake, white hake, and hake sp.) were impinged at Seabrook Station in 2007 (Table 4-11), which is within the range of previous years (Appendix Table 4-3). Assuming that all the hake sp. were red hake, an estimated 2,573 red hake were impinged and these fish ranged in length from 35 to 225 mm. The majority of impingement of red hake in 2007 occurred in April (1,159). Most of these fish were YOY based on their length frequency distribution (Figure 4-7; Collette and Klein-MacPhee 2002).

Equivalent adult losses of red hake due to egg and larval entrainment averaged 181/year for 1998 through 2007. In 2007, the estimate was 94 equivalent adults. Equivalent adult losses due to impingement averaged 231 per year for 1998 through 2007. In 2007, an estimated 1,318 equivalent adults were lost due to impingement. Saila et al. (1997) estimated that impingement of red hake in 1994 and 1995 resulted in the loss of 101 to 202 equivalent adult red hake.

4.3.3.6 Atlantic Silverside

The Atlantic silverside (*Menidia menidia*) 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). It is found in bays, salt marshes, and estuaries from the Gulf of St. Lawrence to northern Florida, with the Gulf of Maine 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. 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 migration that high (up to 99%) overwintering mortality typically occurs, with mostly fish larger than 80 mm able to survive the winter (Conover and Ross 1982; Conover 1992). There were geographic differences in the ability of this species to tolerate winter stresses, with high-latitude populations better able to withstand stresses associated with low temperatures (Schultz et al. 1998).

Atlantic silverside were common in the seine sampling program and were taken each month throughout the April through November sampling season (NAI 1993). Geometric mean CPUE was highest from 1976 through 1981, whereupon catch decreased (Figure 4-16). From 1982 through 1999 CPUE fluctuated around a lower and more consistent level. From 2000 through 2004 CPUE decreased steadily, but this trend was reversed with the relatively high CPUE in 2005 through 2007. In 2007, as in previous years, Atlantic silverside was the most numerous fish captured in the beach seine (Table 4-10). CPUE in 2007 at Stations S1 and S3 increased from 2006 but decreased at Station S2.

Mean CPUE was significantly higher in the preoperational period with no significant differences among stations (Table 4-19). The decrease in CPUE began after 1981, before the plant became operational in 1990 (Figure 4-16). After 1987, mean CPUE has been relatively consistent.

An estimated 639 Atlantic silverside were impinged in 2007, with about 68% impinged in February and December (Table 4-11). Most of these fish were less than 119 mm and were probably a mixture of YOY and yearling fish (Conover and Ross 1982) `probably impinged during their offshore winter migration (Conover and Murawski 1982). Impingement in 2007 was within the range of previous years (Appendix Table 4-3). An estimated average of 2,514 Atlantic silverside per year have been impinged since 1994. Removal this number of fish each year will not affect this common inshore resource.

4.3.3.7 Cunner

The cunner (*Tautogolabrus adspersus*), present from Newfoundland to Chesapeake Bay (Scott and Scott 1988), is one of the most common fishes in the Gulf of Maine (Collette and Klein-MacPhee 2002). A small fish residing in inshore waters, few cunner measure over 31 cm, although fish as large as 43 cm are occasionally taken in deeper waters (Collette and Klein-MacPhee 2002). Most cunner are closely associated with structural habitats, such as rocks, tidepools, shellfish beds, pilings, eelgrass, and macroalgae.

Cunner eggs and larvae were dominant in the ichthyoplankton program (Table 4-4). Cunner eggs were grouped with yellowtail flounder (cunner/yellowtail flounder) because it was difficult to distinguish between eggs of these two species. 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 (Collette and Klein-MacPhee 2002). Tautog have only accounted for 0.06% of all larvae collected since 1982. A comparison of cunner and yellowtail flounder larval abundance indicated that almost 100% of the eggs in the cunner/yellowtail flounder group in 2007 were likely cunner, assuming a similar hatching rate between the two species (Table 4-13). The density of cunner larvae varied with peaks occurring approximately every three years in 1977, 1980, 1983, 1987, 1990, 1993, 1995, 1999, 2001, and 2003 and 2007 with 2001 being the highest recorded (Figure 4-17). Mean larval density in 2007 was greater than the preoperational and operational period means (Table 4-13).

Despite the higher densities of cunner larvae in the operational period, there were no significant differences between periods (Table 4-20), probably due to the high variability within periods. Larval cunner densities were not significantly different between stations,

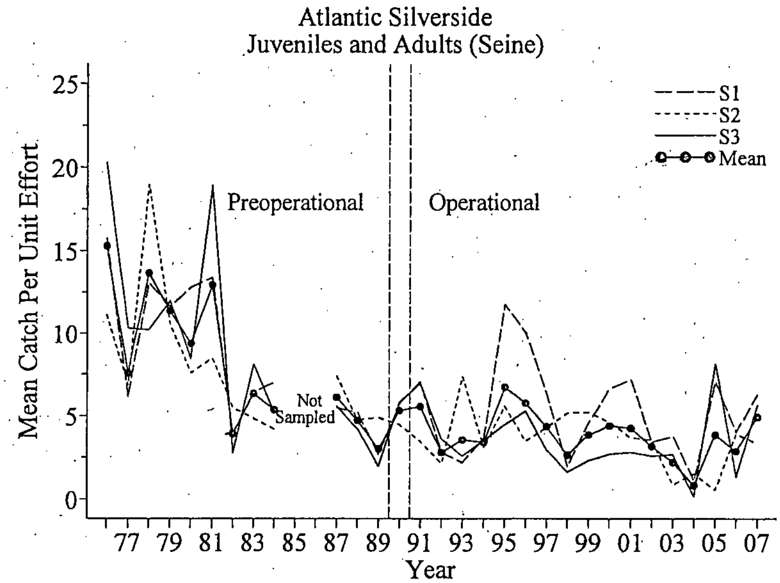


Figure 4-16. Annual geometric mean catch per unit effort of Atlantic silverside in seine samples (number per haul) by station and the mean of all stations, 1976-2007 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Table 4-19. Results of analysis of variance of Atlantic Silverside Densities by Sampling Program. Seabrook Operation Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Seine	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Apr.-Nov.)	Preop-Op[a]	1, 223	6.61	0.011*	Op<Preop
(1976-1984,	**Random Effects**	**Estimate[j]**	χ^2	**P**	
1987-2007)	Year (Preop-Op)[b]	0	0.000	0.5000	
	Month(Year)[c]	0.5257	435.649	<0.0001*	
$Log_{10}(x+1)$	Station[d]	0.0015	1.488	0.1113	
	Station X Year (Preop-Op)[f]	0.0023	0.296	0.2932	
	Error	0.1678			

[a] Preop-Op for seine compares 1991-2007 to 1976-1984 and 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \le 0.05$)

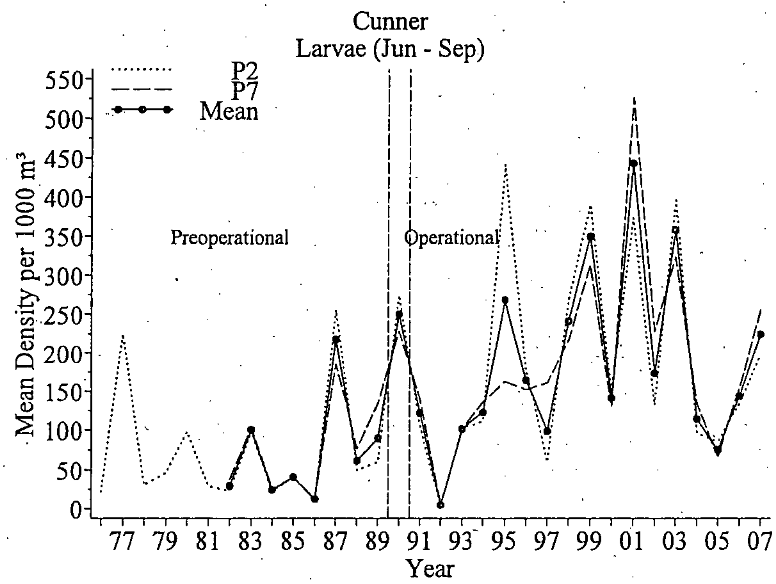


Figure 4-17. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of cunner in ichthyoplankton samples by station and the mean of all stations, 1976-2007 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Table 4-20. Results of Analysis of Variance of Cunner Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Jun.-Sep.)	Preop-Op[a]	1, 95	2.68	0.1048	
(1982-1984,	**Random Effects**	**Estimate[j]**	χ^2	p	
1986-2007)	Year (Preop-Op)[b]	0	0.000	0.4997	
	Month(Year)[c]	1.1562	387.004	<0.0001*	
	Station[d]	<0.0000	0.000	0.5000	
	Preop-Op X Station[e]	0	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.4996	
	Error	0.8466			

[a] Preop-Op for ichthyoplankton compares 1991-2007 to 1982-1984 and 1986-1989 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Station and Year within Preop-Op.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

and the relation between stations was consistent between periods.

Consistent with the high densities of cunner larvae observed in the ichthyoplankton program, cunner eggs and larvae are usually among the most common taxa entrained. In 2007, cunner/yellowtail flounder eggs (293 million) and cunner eggs (10 million) combined ranked first in entrainment abundance and accounted for about 42% of the total annual egg entrainment estimate (Table 4-5). This group has generally ranked first or second each year that entrainment sampling was conducted during the summer season of high abundance. Entrainment of cunner larvae in 2007 (98 million) was within the range of previous years (Table 4-6).

Relatively few cunner have been taken by otter trawl, 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 922 cunner were impinged in 2007 (Table 4-11). In previous years, impingement of cunner ranged from 32 (1994) to 1,121 (1996; Appendix Table 4-3). Impingement occurred in all months except January, with the majority taken in May (Table 4-11). Lengths of impinged cunner ranged from 32 to 241 mm, with the majority between 56 and 97 mm. Impingement of smaller cunner (about 40-60 mm) first occurred in abundance in April indicating recruitment of the 2005 year class approaching age 1 (Serchuk and Cole 1974).

4.3.3.8 American Sand Lance

Both the American sand lance (*Ammodytes americanus*) and the northern sand lance (*A. dubius*) occur 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 Seabrook Station studies are referred to as the American sand lance. This species is present from Labrador to Chesapeake Bay (Richards 1982; Nizinski et al. 1990). In the Gulf of Maine, the species occurs at depths of 6 to 20 m (Meyer et al. 1979). Sand lance are an important trophic link between zooplankton and larger fishes, birds, and marine mammals (Reay 1970; Meyer et al. 1979; Overholtz and Nicholas 1979; Payne et al. 1986; Gilman 1994; Furness 2002).

American sand lance larvae historically were dominant in the ichthyoplankton collections (Tables 4-4 and 4-13). 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 appear to have been greatest in the 1980s, and have been lower in the 1990s, and reached an all time low in 2006 (Figure 4-18). The decline since the 1980s was also apparent in other areas of the Northwest Atlantic Ocean. Larval densities in Long Island Sound over a 32-year period (1951-1983) were highest in 1965-1966 and 1978-1979, 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 (DNC 2002). Nizinski et al. (1990) also reported a peak in sand lance abundance throughout the Northwest Atlantic in 1981, with numbers declining since that time. 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). The increase in abundance of Atlantic mackerel and Atlantic herring in the 1990s may account for the recent decrease in larval abundance.

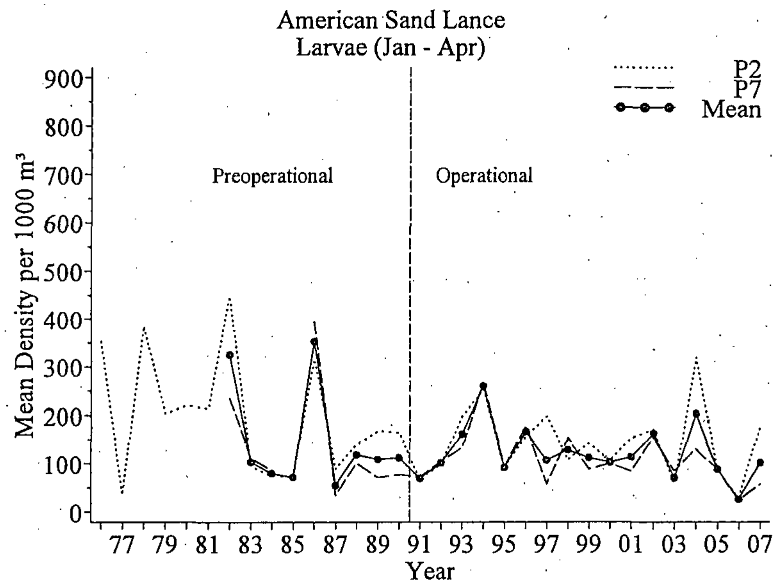


Figure 4-18. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of American sand lance in ichthyoplankton samples by station and the mean of all stations, 1976-2007 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Abundance of larval American sand lance in the Hampton-Seabrook area was higher at Station P2 in preoperational and operational periods (Table 4-13) and major peaks in density occurred at both stations in 1982, 1986, 1994 and 2004 (Figure 4-18). Mean density in 2007 increased from the low density of 2006 and was above the preoperational and operational means at Station P2, and below the preoperational and operational means at Station P7 (Table 4-13; Figure 4-18). There were no significant differences in larval sand lance density between periods or between stations (Table 4-21). The change in larval density between periods was similar between stations as indicated by the non-significant interaction term.

Impingement of American sand lance was estimated at 2,073 in 2007 and 73% of this estimate occurred in December (Table 4-11). Fish impinged were between 96 and 236 mm and the majority were age 2 and older fish (Figure 4-7; Westin et al. 1979). Impingement of sand lance in 2007 was the second highest to date (Appendix Table 4-3). Larval entrainment in 2007 (36.6 million) was within the range of previous years (Table 4-6). Sand lance eggs are demersal and adhesive (Fritzsche 1978), and none have been entrained since the plant became operational (Table 4-6).

Few American sand lance have been taken by Seabrook Station adult fish sampling programs (Appendix Table 4-1). 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 infrequent.

Table 4-21. Results of Analysis of Variance of American Sand Lance Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton (Jan.-Apr.) (1982-1984, 1986-2007)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 98.3	0.29	0.5921	
	Random Effects	**Estimate[j]**	χ^2	p	
	Year (Preop-Op)[b]	0	0.000	0.4999	
	Month(Year)[c]	0.2865	143.376	<0.0001*	
	Station[d]	0.0052	1.055	0.1522	
	Preop-Op X Station[e]	0	0.000	0.4997	
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.5072			

[a] Preop-Op for ichthyoplankton compares 1991-2007 to 1982-1984 and 1986-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Station and Year within Preop-Op.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

4.3.3.9 Atlantic Mackerel

The Atlantic mackerel (*Scomber scombrus*) is a schooling pelagic fish occurring from Labrador to Cape Lookout, NC that prefers a temperature range of 9 to 12°C (Scott and Scott 1988). Atlantic mackerel exhibit a distinct pattern of extensive annual movements; fish 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 move inshore in spring. Temperature is apparently a dominant factor 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). Although two spawning contingents exist, the species is managed as a single stock. Spawning biomass reached a record high in 2003-2004 and (NEFSC 2006). Large year classes were produced in 1982 and 1999, and the 2003 through 2004 year classes appear to be above average (NEFSC 2006). The stock is not considered overfished and overfishing is not occurring.

Atlantic mackerel was one of the dominant egg taxa collected in the ichthyoplankton program and entrainment samples (Tables 4-4 and 4-5). The larvae were abundant in ichthyoplankton collections, but were not dominant in entrainment samples (Tables 4-5 and 4-6). Larvae typically occurred from May through August (NAI 1993). Larval abundance in 2007 was lower than the preoperational and operational means (Table 4-13; Figure 4-19). Annual density of mackerel larvae fluctuated with peaks occurring in 1980-81 and 1991. In the operational period, peaks occurred in 1991, 1995, and 2001 (Figure 4-19). There were no significant differences between periods or stations, and the interaction of the main effects was not significant (Table 4-22).

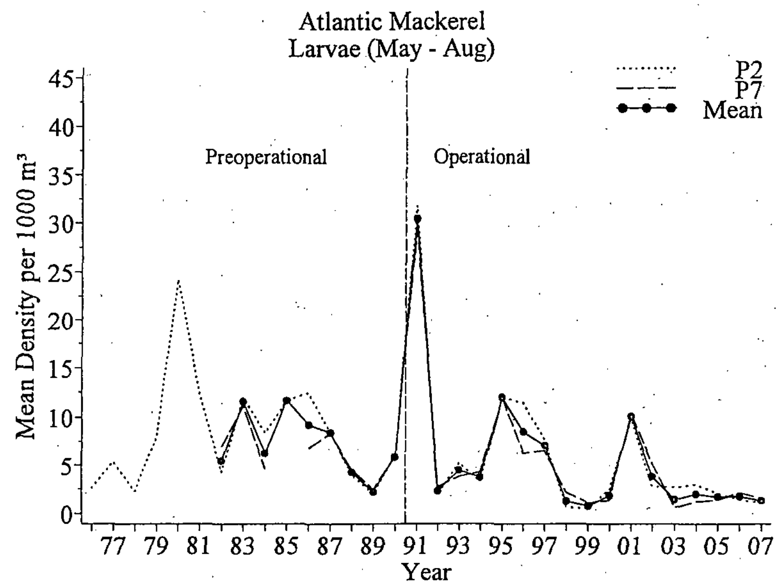


Figure 4-19. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of Atlantic mackerel in ichthyoplankton samples by station and the mean of all stations, 1976-2007. Seabrook Operational Report, 2007.

Table 4-22. Results of Analysis of Variance of Atlantic Mackerel Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(May.-Aug.)	Preop-Op[a]	1, 98.1	1.48	0.2270	
(1982-1984,	**Random Effects**	**Estimate[j]**	χ^2	p	
1986-2007)	Year (Preop-Op)[b]	0	0.000	0.5000	
	Month(Year)[c]	0.4748	190.183	<0.0001*	
$Log_{10}(x+1)$	Station[d]	<0.0001	-0.000	0.5000	
	Preop-Op X Station[e]	0	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.7319			

[a] Preop-Op for ichthyoplankton compares 1991-2007 to 1982-1984 and 1986-1990 regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year.
[d] Stations regardless of year or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Interaction of Station and Year within Preop-Op.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

No Atlantic mackerel were present in impingement samples in 2007; only ten have been impinged in previous years (Appendix Table 4-3). Entrainment of Atlantic mackerel eggs in 2007 (153.6 million; Table 4-5) was within the range of previous years (Table 4-6). No Atlantic mackerel larvae were collected in entrainment samples 2007 (Table 4-5), which also occurred in 1992-1995 and 2003 (Table 4-6). Entrainment of mackerel larvae has been relatively low compared with other species, possibly due to their rapid development, which results in larger larvae that can avoid the intake.

Equivalent adult losses of Atlantic mackerel due to egg and larvae entrainment from 1998 to 2007 averaged 178/year. In 2007, estimated equivalent adult losses due to entrainment were 469 fish and were due to the relatively large numbers of Atlantic mackerel eggs entrained. Losses due to impingement are negligible, as only ten Atlantic mackerel have been impinged since 1994.

4.3.3.10 Winter Flounder

The winter flounder (*Pseudopleuronectes americanus*) 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 1994). North of Cape Cod, movements of winter flounder are generally localized and confined to inshore waters (Howe and Coates 1975).

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 in males and 29.7 cm in females (O'Brien et al. 1993). Spawning habitat typically includes firm substrate and macroalgae (Crawford and Carey 1985). Because winter flounder spawn during periods of low water temperature, larval development is relatively slow and can take up to two months to complete.

However, climatic factors influence timing of spawning and larval development (Sogard et al. 2001). Spawning sites can occur in areas of estuaries where larvae would be minimally displaced by tidal movement (Crawford and Carey 1985). 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). Chant et al. (2000) and Curran and Able (2002) found that coves just inside of tidal inlets provided habitat for newly settled winter flounder. Young were common in inshore shallows of Waquoit Bay on the south shore of Cape Cod, where they remained until fall, undertaking little movement away from where they settled (Saucerman and Deegan 1991). Young winter flounder are vulnerable to a variety of predators including fish, birds, and decapods (Buckley 1989).

Larger green crabs (>20 mm carapace width) preyed most successfully on YOY winter flounder less than 21 mm (Fairchild and Howell 2000). Predation risk was greater in deeper waters, although YOY winter flounder were concentrated in very shallow (<1 m) water (Manderson et al. 2004). Sand shrimp (*Crangon septemspinosa*) are also a significant predator on newly settled winter flounder (Taylor 2005).

Habitat preference for YOY winter flounder appears to change as they grow, with fine sediment being an important habitat for newly settled individuals. Phelan et al. (2001) found that small (<40 mm SL) YOY winter flounder preferred fine-grained sediments (<0.5mm) while larger YOY winter flounder preferred coarser grained sediments. Winter flounder's ability to bury themselves in the substrate increased with body size. Mud/shelllitter habitat (Howell et al. 1999) and soft-substrate habitat (Meng and Powell 1999) were preferred habitat for juvenile winter flounder in Connecticut and Narragansett Bay. Juvenile winter flounder in the Great Bay estuary of New Hampshire were found in polyhaline open-water habitats, and few are found in the intertidal mud habitat (Armstrong 1997).

Biomass indices of winter flounder in the Gulf of Maine had been reduced substantially since 1982 to record lows in 1986 and 1994 (NEFSC 2006). The biomass index increased after 1996 and reached a record high in 2000. Since 2000 the biomass index has declined, however, record high recruitment (number of age-1 fish) was estimated for 2004 and 2005. The Gulf of Maine stock of winter flounder is not overfished and overfishing is not occurring (NEFSC 2006). Our CPUE data show a similar pattern, with mean CPUE peaking in 1981, and reaching a time-series low in 1995, and a general increase through 2004 to the highest levels in the time series (Figure 4-20). CPUE decreased in 2005 but has increased since then and remains higher than the preoperational years.

Larval winter flounder were collected in the ichthyoplankton program (Table 4-13), but eggs were absent because they are demersal and adhesive. Larvae typically occurred in the Hampton-Seabrook area during April through July (NAI 1993). Density of larval winter flounder has generally decreased since a period of high density from 1982 through 1988 (Figure 4-20). In the operational period, larval density was typically lower than the preoperational period. Mean density in 2007 was the highest since 1997 and was above the operational period means at both stations (Table 4-13). Larval density was significantly higher in the preoperational period and there were no significant differences among stations (Table 4-23). The interaction term was not significant.

Winter flounder were taken year-round by otter trawl at all stations, but most commonly from May through October (NAI 1993). Geometric mean CPUE peaked in 2004 with high catches at Stations T1 and T3 (Figure 4-20). Prior to 1986, CPUE was generally highest at Station T2 and lowest at T3. Starting in 1986, geometric mean CPUE was similar among the three stations until 1992. In contrast to the period prior to 1986, geometric mean CPUE after 1992 was lowest at Station T2 most years. Mean CPUE (all stations) in 2007 was higher than the upper confidence limits of both the preoperational and operational periods (Table 4-8; Figure 4-20).

There was a significant positive trend in winter flounder CPUE during 1995-2007 at Station T1 and from 1994-2007 at Station T3 (Table 4-9). CPUE at both of these stations was significantly higher in the later period than earlier years. There were no significant trends at Station T2 and CPUE was significantly lower from 1986-2007 compared to earlier years.

CPUE decreased significantly between the preoperational and operational periods at Station T2. There were no significant differences at Station T1 and CPUE increased significantly at Station T3, resulting in a significant interaction term (Table 4-23; Figure 4-21). The months used in the ANOVA only included months when it was possible to sample at Station T2, therefore this analysis was not biased by missing samples. Although the rank order varied from year to year, CPUE at all three stations showed similar trends after 1986 (Figure 4-20). Starting in the mid 1990s through 2004, there has been a general increase in CPUE of winter flounder at all stations.

Younger winter flounder (juveniles through age 2; NAI 1993) were collected in the Hampton-Seabrook Harbor by seine throughout the April-November sampling

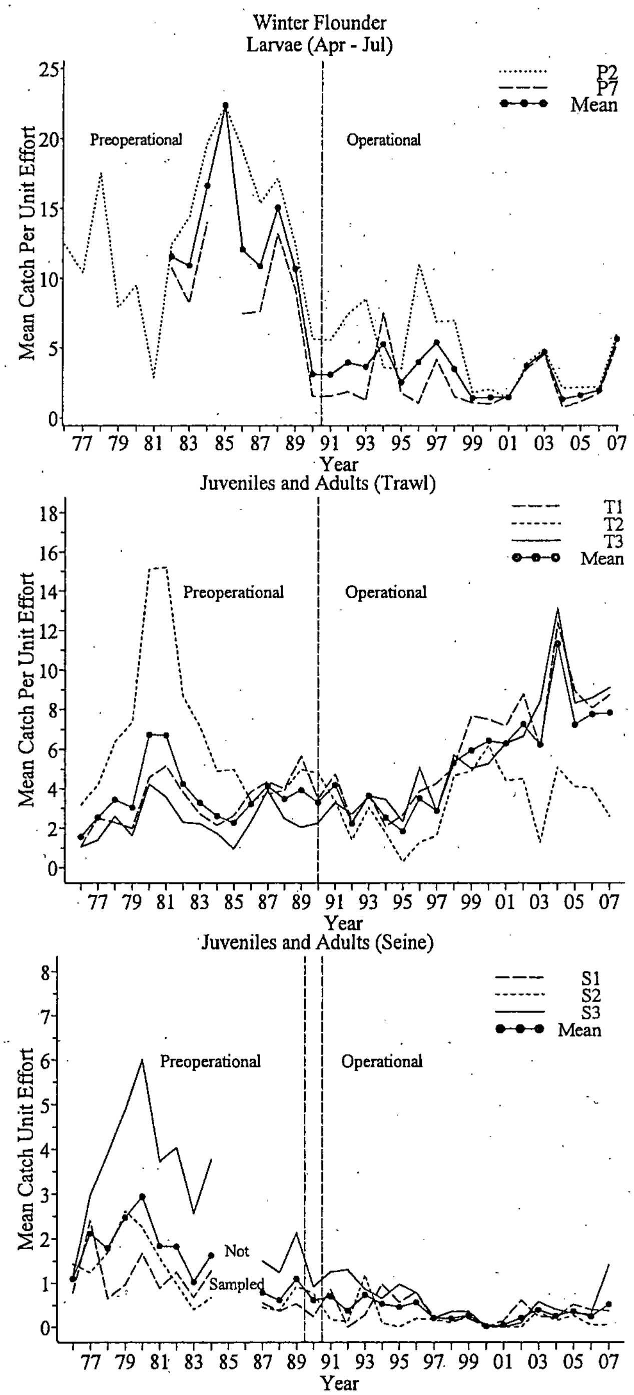


Figure 4-20. Annual geometric mean catch of winter flounder per unit effort in ichthyoplankton (number per 1000 cubic meters), trawl (number per 10-minute tow), and seine (number per haul), samples by station and the mean of all stations, 1975-2007 (data between the two vertical dashed lines were excluded from ANOVA model). Seabrook Operational Report, 2007.

Table 4-23. Results of Analysis of Variance of Winter Flounder Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Apr.-Jul.)	Preop-Op[a]	1, 98.2	15.34	0.0002*	Op<Preop
(1982-1984,	**Random Effects**	**Estimate[j]**	χ^2	p	
1986-2007)	Year (Preop-Op)[b]	0	0.000	0.4997	
	Month(Year)[c]	0.2326	157.084	<0.0001*	
$Log_{10}(x+1)$	Station[d]	0.0243	2.557	0.0549	
	Preop-Op X Station[e]	0	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.5000	
	Error	0.4275			
Trawl	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Dec-Jul.)	Preop-Op[a]	1, 5.60	0.17	0.6978	
	Random Effects	**Estimate[j]**	χ^2	p	
(1976-2007)	Year (Preop-Op)[b]	0.0146	7.995	0.0024*	
	Month(Year)[c]	0.0699	239.124	<0.0001*	
$Log_{10}(x+1)$	Station[d]	0	0.000	0.5000	
	Preop-Op X Station[e]	0.0224	42.359	<0.0001*	2Pre 1Op 3Op 1Pre 2Op 3Pre
	Station X Year (Preop-Op)[f]	0.0094	33.092	<0.0001*	
	Error	0.0441			
Seine	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(Apr.-Nov.)	Preop-Op[a]	1, 27	62.98	<0.0001*	Op<Preop
(1976-1984,	**Random Effects**	**Estimate[j]**	χ^2	p	
1987-1989,					
1991-2007)	Year (Preop-Op)[b]	0.0032	2.5596	0.0548	
	Month(Year)[c]	0.0081	17.4899	<0.0001*	
$Log_{10}(x+1)$	Station[d]	0.0089	25.1970	<0.0001*	S3>S1 S2
	Station X Year (Preop-Op)[f]	0.0077	29.5399	<0.0001*	
	Error	0.0374			

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1990 to 1991-2007 regardless of station. Preop-Op for trawl compares 1990-2007 to 1976-1990 regardless of station. Preop-Op for seine compares 1991-2007 to 1976-1984 and 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

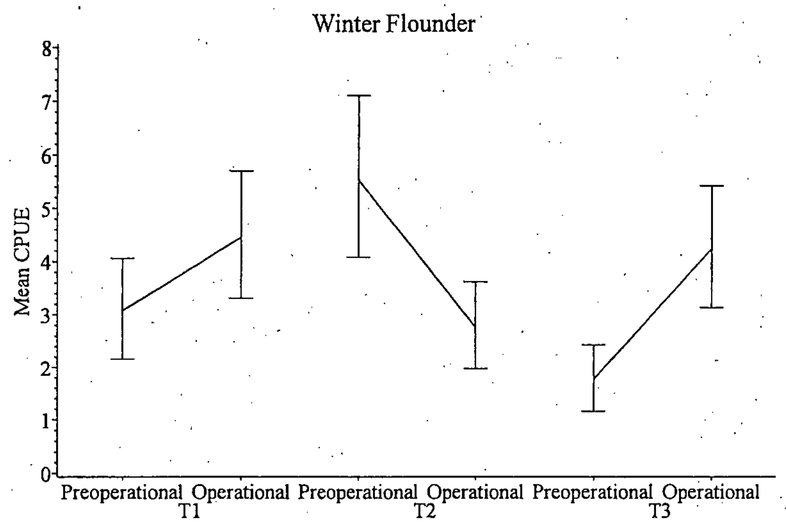


Figure 4-21. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of winter flounder caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-22). Seabrook Operational Report, 2007.

period. CPUE was generally higher in the period 1976 through 1984 than in 1987 through 2007 (Figure 4-20). CPUE was highest in 1980, one year prior to the peak in the trawl in 1981. Abundance began to decrease after 1980 and has been consistently low since 1987. Mean CPUE in 2007 increased sharply from 2006 at Station S3, and was similar at Stations S1 and S2 (Figure 4-20). Mean CPUE (all stations) in 2007 was lower than the preoperational mean and higher than the operational period mean (Table 4-10). CPUE of winter flounder in the seine samples was significantly higher in the preoperational period and was significantly higher at Station S3 (Table 4-23).

An estimated 15.8 million larvae were entrained in 2007 (Table 4-5) and this estimate was the third highest to date (Table 4-6). Despite their demersal and adhesive characteristics, 200,000 winter flounder eggs were collected in entrainment samples. In 2007, an estimated 3,949 winter flounder were impinged (Table 4-11), the second highest estimate to date (Appendix Table 4-3). Impingement of winter flounder in 2007 was highest (70%) in March and April. Lengths of impinged winter flounder ranged from 33 to 416 mm, but most of these were YOY fish based on the length frequency distribution (Figure 4-7; Collette and Klein-MacPhee 2002).

Equivalent adult losses of winter flounder due to entrainment averaged 1,322/year for 1998 through 2007. In 2007, the estimate of equivalent adult loss of winter flounder due to entrainment was 2,055 fish.

An annual mean of 2,049 winter flounder were lost each year due to impingement for 1994 through 2007 (Appendix Table 4-3). The equivalent adult loss estimate due to impingement for 1998-2007 ranged from 7 to 354 with an average loss of 87 equivalent adults/year. In 2007, an estimated 354 equivalent adult winter flounder were lost due to impingement.

4.3.3.11 Yellowtail Flounder

The yellowtail flounder (*Limanda ferruginea*) occurs 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 flounder 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 occur, with fish moving to shallower waters in spring and into deeper waters during fall and early winter. In Canadian waters, the range of yellowtail flounder has contracted to preferred habitat primarily as a function of low stock size (Brodie et al. 1998). Recruitment variability (year class strength) did not appear to be related to the presence of a larval food supply such as calanoid copepods during the time of first feeding (Johnson 2000).

The Cape Cod – Gulf of Maine stock of yellowtail flounder is considered overfished and overfishing is occurring (NEFSC 2006). The index of yellowtail flounder spawning stock biomass peaked in 1990-1991 and then again in 2000-2001 (NEFSC 2006). Since then spawning stock biomass has decreased steadily through 2004. Similarly, age-1 recruitment has decreased in recent years.

Yellowtail flounder eggs were grouped as cunner/yellowtail flounder because it was difficult to distinguish between the eggs of these two species. This egg group would also include tautog eggs, if present. The cunner/yellowtail flounder taxon was the dominant egg collected during the program (Table 4-4). Yellowtail flounder larvae were not collected in 2007, and it is likely that the egg group consisted of more than 99% cunner (Section 4.3.3.7). Mean density of yellowtail flounder larvae was highest from 1976 through 1979, and declined to a low in 1982 (Figure 4-22). Since then peaks in larval density have occurred in 1983, 1986-87, 1993 and 1997-98, and 2001 (Figure 4-22). Since 2003 density has been very low and was zero in 2006 and 2007 (Figure 4-22; Table 4-13). There were no significant differences between periods or between stations, and the interaction term was not significant (Table 4-24).

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 4-8). Recently, it has become most common only from May through October (NAI 1993). Yellowtail flounder CPUE peaked in 1980 and 1981 and subsequently declined to moderate, but stable levels in the mid and late 1980s (Figure 4-22). In 1989, a second peak in CPUE occurred, which was followed by a decline through 1997 to the lowest level in the time series. A third small peak in CPUE occurred in 1999, and a similar peak in CPUE occurred in 2006 (Figure 4-22). CPUE in 2007 was lower than the preoperational mean at all stations and higher than the operational period mean at Station T3 (Table 4-8). Annual geometric mean CPUE significantly declined during 1976-1995 at Station T1, 1981-2007 at Station T2 and 1976-1991 at Station T3 (Table 4-9). The mean for the early period at each station was significantly higher than the mean for the period of the subsequent years (Table 4-9).

CPUE in most years was higher at Station T1 followed by Station T3 and T2 (Table 4-8), probably due to a preference for coarse sand and gravel bottoms (Scott 1982b). Despite the preference by yellowtail flounder for Station T1, the decrease in CPUE was greater at Station T1 than at Stations T3 and T2 (Figure 4-23), with result of a significant interaction term (Table 4-24). However, on a percentage

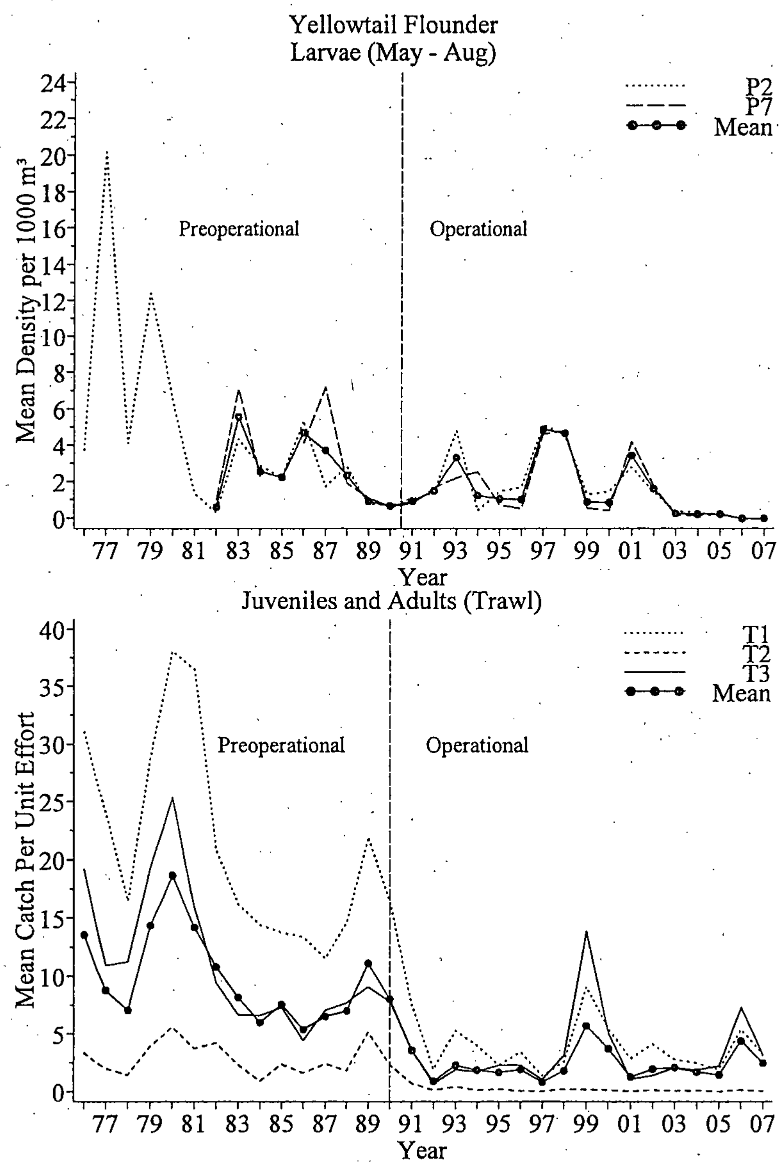


Figure 4-22. Annual geometric mean catch of yellowtail flounder per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2007. Seabrook Operational Report, 2007.

Table 4-24. Results of Analysis of Variance of Yellowtail Flounder Densities by Sampling Program. Seabrook Operational Report, 2007.

Program/ Months Used	Source of Variation	Test Statistics			Multiple Comparisons[k]
Ichthyoplankton (May-August.) (1982-1984, 1986-2007)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 23.3	3.35	0.0799	
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0.0212	2.021	0.0776	
	Month(Year)[c]	0.1099	72.236	<0.0001*	
	Station[d]	0	0.000	0.5000	
	Preop-Op X Station[e]	<0.0001	0.000	0.5000	
	Station X Year (Preop-Op)[f]	0	0.000	0.4999	
	Error	0.3199			
Trawl (Dec.-Jul.) (1976-2007)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 4.25	50.53	0.0016*	Op<Preop
	Random Effects	**Estimate[j]**	χ^2	**p**	
	Year (Preop-Op)[b]	0.0199	15.055	<0.0001*	
	Month(Year)[c]	0.0221	32.851	<0.0001*	
	Station[d]	0.0969	3.978	0.0231*	T1 T3>T2
	Preop-Op X Station[e]	0.0063	6.880	0.0044	1Pre 3Pre 2Pre 1Op 3Op 2Op
	Station X Year (Preop-Op)[f]	0.0083	13.488	0.0001	
	Error	0.0703			

[a] Preop-Op for ichthyoplankton compares 1991-2007 to 1982-1984 and 1986-1989 regardless of station. Preop-Op for trawl compares 1990-2007 to 1975-1990 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] *Underlined estimates were not significantly different based on multiple comparison tests of* H_o: *LSMEAN (i)= LSMEAN(j).*
* = significant ($p \leq 0.05$)

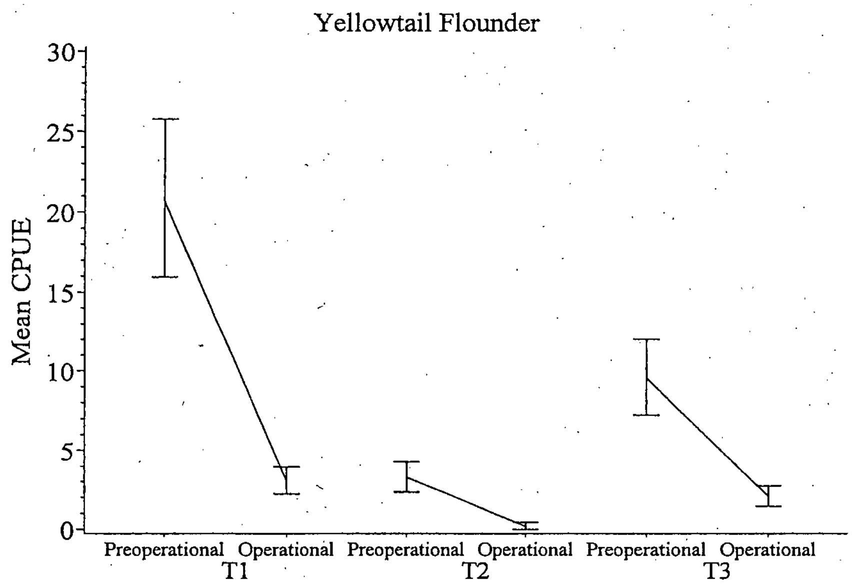


Figure 4-23. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of yellowtail flounder caught by trawl during the preoperational (November 1975-July 1990) and operational (November 1990-July 2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-23). Seabrook Operational Report, 2007.

basis, the decreases were similar. CPUE decreased 85% at Station T1, 95% at Station T2 and 74% at Station T3.

In 2007, 11 yellowtail flounder were collected in impingement samples (Table 4-11). With the exception of 1995 when 1,149 yellowtail flounder were impinged, impingement has been less than 100 fish each year (Appendix Table 4-3).

The cunner/yellowtail flounder group has ranked first or second among egg taxa entrained at Seabrook Station, with the exceptions of 1994 through 1996 (Table 4-6). The estimated entrainment of cunner/yellowtail flounder eggs in 2007 was 292.9 million, but it is likely that this group was almost 100% cunner eggs, based on the relative abundance of cunner and yellowtail flounder larvae. An estimated 2.7 million yellowtail founder larvae were entrained in 2007 which is the highest estimate to date (Table 4-6).

Equivalent adult losses of yellowtail flounder due to entrainment averaged 6/year for 1998 through 2007. The equivalent adult loss estimate for 2007 was 23 adult fish. Impingement of yellowtail flounder is less than 100 fish/year from 1998-2007 and is not considered significant.

4.4 EFFECTS OF SEABROOK STATION OPERATION

There has been no detectable effect of the operation of Seabrook Station on the ichthyoplankton or adult fish assemblages in the study area (Table 4-25). Cluster and MDS analyses of the fish egg and larvae assemblages indicated that there was no clear separation of years between the preoperational and operational periods. Within years, the fish egg and larvae assemblages at the nearfield and farfield stations were generally very similar. ANOSIM showed that although there were significant differences in the fish egg and

Table 4-25. Summary of Potential Effects of the Operation of Seabrook Station on the Ichthyoplankton Assemblages and Selected Fish Taxa. Seabrook Operational Report, 2007.

Species or Assemblage	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	No	yes		
Fish larvae assemblages	Ichthyoplankton	No	yes		
Atlantic herring	Ichthyoplankton	Op<Preop	yes	Slight decrease since 2000	Not overfished
Rainbow smelt	Trawl	–	no	Unknown	Unknown
	Seine	Op=Preop	–		
Atlantic cod	Ichthyoplankton	Op<Preop	yes		
	Trawl	–	no	Decrease since 2002	Overfished
Pollock	Ichthyoplankton	Op<Preop	yes	Increasing since 1995	Not overfished
Hakes	Ichthyoplankton	Op=Preop	yes		
	Trawl	–	no	Red hake: Decreasing since 2002 White hake: decreasing since 2002	Red Hake: Not overfished White hake: overfished
Atlantic silverside	Seine	Op<Preop	–	Unknown	Unexploited
Cunner	Ichthyoplankton	Op=Preop	yes	Unknown	Unexploited
American sand lance	Ichthyoplankton	Op=Preop	yes	2006 is low	Unexploited
Atlantic mackerel	Ichthyoplankton	Op=Preop	yes	Decline since 2001	Not overfished
Winter flounder	Ichthyoplankton	Op<Preop	yes		
	Trawl	–	no	Incline since 1996	Not overfished
	Seine	Op<Preop	–		
Yellowtail flounder	Ichthyoplankton	Op=Preop	yes		
	Trawl	–	no	Decreasing since 2000	Overfished

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 ANOVA for selected taxa, and numerical classification for assemblages.
c For commercial species, from NEFSC (2006)

larvae assemblages between periods, these differences occurred at both the nearfield and farfield stations, indicating a temporal trend. The close relationship of the assemblages between the nearfield and farfield areas indicated no evidence of a plant effect in the nearfield area. Factors that controlled characteristics of fish egg and larvae assemblages appeared to be unrelated to plant operation and were operating on a large scale that encompassed both the nearfield and farfield areas.

The egg and larval fish assemblages in 2007 were similar to most operational years. There was an overall low abundance of fish larvae in 2007, especially for Atlantic cod, Atlantic herring, Atlantic mackerel, hakes, and yellowtail flounder. However, relative abundance of American sand lance, cunner, pollock, and winter flounder increased from the previous year. The low abundance of larvae of commercially-important fishes in 2007 occurred at both stations and cannot be attributed to the operation of Seabrook Station.

Entrainment of fish eggs (715 million) in 2007 was within range of previous years when sampling occurred year-round. Cunner/yellowtail flounder (293 million), Atlantic mackerel (154 million) and hake/fourbeard rockling (68 million) were the most common eggs entrained. Based on the ratio of cunner to yellowtail flounder larvae, almost 100% of the cunner/yellowtail flounder eggs were cunner.

Larval entrainment (297 million) was the fourth highest estimate recorded among years when sampling occurred in all months. Cunner (98 million), rock gunnel (47 million), American sand lance (37 million), and Atlantic seasnail (34 million) were the most numerous larvae entrained. Entrainment of fish eggs and larvae appears to be similar to or less than entrainment at other New England power plants with marine intakes. Assuming 100% mortality of entrained larvae at all plants, the location and design of the offshore intakes have worked as expected in reducing entrainment impacts to fish populations.

Impingement at Seabrook Station in 2007 (22,472 fish and 21 lobsters) was the fourth-highest estimate since 1994. Winter flounder (3,949), rock gunnel (3,174), northern pipefish (2,374), American sand lance (2,073) and windowpane (1,502) were the most common fish impinged. Impingement in 2007 was highest in March-April (70% of annual estimate), possibly due to a strong storm. Annual impingement at Seabrook Station remains similar or lower than impingement observed at other New England power plants. The design of the intakes at Seabrook Station resulted in low approach velocities of about 0.15 m/s (0.5 ft/s). This design has minimized impingement of fishes and lobsters.

Equivalent Adult (EA) analysis was used to put entrainment and impingement losses in perspective. Saila et al. (1997) concluded that entrainment losses of winter flounder, pollock, and red hake at Seabrook Station from 1990 to 1995 had a negligible adverse ecological impact. This analysis was expanded to more species and used updated larval mortality data and entrainment estimates for the years when sampling occurred in all diel periods (1998 through 2000). With the additional data and expanded species list, the conclusions of Saila et al. (1997) that EA losses of fishes appear to be an ecologically insignificant fraction of any sustainable stock, were confirmed (NAI 2001). Entrainment and impingement of seven species of commercially-important fishes in 2007 resulted in the estimated loss of 23 (yellowtail flounder) to 2,409 (winter flounder) fish (Table 4-26). Losses due to entrainment were larger than impingement losses for most species evaluated.

Equivalent adult estimates are dependent on several factors including the number and age of fishes lost to entrainment and impingement, and other sources of mortality such as fishing mortality. In these analyses we have generally used the most recent estimates of fishing and natural mortality available from NMFS (Cadrin and King 2003; Mayo and Terceiro 2005, NEFSC 2006). However, estimates of fishing mortality have changed substantially in recent years. In 2003, the estimates of fishing mortality (F) for yellowtail flounder have changed from 2.17 to 0.75 (Cadrin and King 2003) to the present estimate of 0.87 (Mayo and Terceiro 2005). The estimate of F for winter flounder in the Gulf of Maine has varied since 1982 from as high as 2.1 (1995) to the current estimate of

Table 4-26. Annual Equivalent Adult Losses of Seven Commercially Important Species Impinged and Entrained at Seabrook Station in 2007. Seabrook Operational Report, 2007.

	Equivalent Adults		
Species	Impingement	Entrainment	Total
Atlantic Cod	106	57	163
Atlantic Herring	88	407	495
Atlantic Mackerel	0	469	469
Pollock	76	89	165
Hakes[a]	1,318	94	1,412
Winter Flounder	354	2,055	2,409
Yellowtail Flounder	4	19	23

[a] Includes red and white hake.

0.13 in 2004 (Mayo and Terceiro 2005). Estimates of the number of equivalent adults vary directly with F. A decrease in F will result in an increase in the lifetime fecundity estimate (f_a) as the probability of a fish spawning multiple times at older ages increases. This will result in a decrease in the number of equivalent adults as the parameter f_a is in the denominator for this calculation (see equation 3, Section 4.2.3). Therefore, changes in the equivalent adult estimates for selected species are driven by both changes in the entrainment and impingement estimates and changes in the estimates of life history parameters.

Equivalent adult estimates also assume that stocks are in equilibrium, meaning that that an adult female fish produces enough eggs during her lifetime to replace herself and one male (Goodyear 1978). The varying estimates of F may indicate that some stocks are not in equilibrium, thus violating one of the basic assumptions of equivalent adult analysis. On a larger scale, this assumption means that there are no significant changes in stock size during the average lifespan of the fish in question. Large changes in the estimates of F indicate that the stocks are not in equilibrium and the equivalent adult estimates for these fishes are suspect. The direction of the bias in equivalent adult estimates varies indirectly with the trends in stock size. A stock decreasing in size (overfished stocks such as yellowtail flounder and Atlantic cod) will have an overestimate of equivalent adults because the probability of a fish surviving to spawn repeatedly decreases. Similarly, underexploited stocks that are increasing in size such as pollock will have underestimates of equivalent adults because lifetime fecundity increases.

The estuarine fish community was apparently unaffected by the operation of Seabrook Station. After 17 complete years of monitoring in the operational period there is no apparent mechanism, with the possible exceptions of entrainment and impingement, by which the plant could be affecting estuarine fish populations. The thermal plume does not extend into Hampton Harbor and cannot affect estuarine fishes in that area. Estuarine fishes could only be exposed to impingement if they migrate past the offshore intakes. Eggs and larvae could be subject to entrainment if these lifestages are found in more offshore waters.

Entrainment and impingement of estuarine fishes do not appear to have affected the fish community. Atlantic silverside have been among the more numerous fish impinged each year (Appendix Table 4-3), but continued to be the dominant species caught by seine in the estuary in the operational period. Similarly, both winter flounder and rainbow smelt may be subject to impingement as they migrate past the offshore intakes. The decline in total CPUE of estuarine fishes caught by seine began in the preoperational period. The eggs of all three selected estuarine fish species, rainbow smelt, Atlantic silverside, and winter flounder are adhesive and not readily subject to entrainment. No Atlantic silverside and few rainbow smelt larvae have been entrained at Seabrook Station because these larvae tend to remain within the estuary and are not readily subject to entrainment at the offshore intakes. The continuous decline in CPUE starting in the preoperational period is an indication that factors other than plant operation are probably responsible for the decrease in fish resources in Hampton Harbor.

The largest single factor affecting the demersal fishes in the Gulf of Maine has been commercial overfishing. Stocks of several species were subject to gross overfishing in the 1990s (NEFSC 2006). The relative biomass index for principal groundfish developed by NEFSC (2006) is in close agreement with our annual geometric mean CPUE in the trawl (Figure 4-5). The NEFSC index peaked in 1977 and declined to low levels in 1987 and 1988. This was followed by a slight increase in 1989 and 1990 and a subsequent decrease to record low levels in 1992 through 1994. Since the mid-1990s the index has increased to levels slightly below that of the 1970s. These same trends occurred in our annual geometric mean CPUE in the trawl (Figure 4-5). The changes in the NEFSC index were attributed to increases in exploitation rates and subsequent restrictive management efforts. These same variations in commercial fishing pressure probably account for the similar trends seen in the NEFSC index and our CPUE of demersal fishes.

Winter flounder in the Gulf of Maine and Georges Bank, pollock, redfish, the northern stocks of windowpane, red hake, and silver hake, witch flounder, and six species of skate are no longer considered overfished (NEFSC 2006). Among pelagic species, Atlantic mackerel and Atlantic herring are not considered to be overfished. Despite these recent increases, stock sizes of most commercial fishes are still relatively low. The current low levels of commercially important groundfish may have resulted in the current relatively high levels of skates and longhorn sculpin. Any potential impact due to the operation of Seabrook Station either did not occur, or was not detectable in the face of overfishing.

The interaction term was significant for all of the selected groundfish species in the trawl. Our BACI design assumed that if there were no plant impacts, changes in abundance would occur equally at all stations. However, a significant interaction term could be caused by a large scale environmental change that reduced abundance to low levels at all stations, including stations where previously abundance had been high. A disturbance of this type would also result in a significant interaction term, and it would not be possible to detect a potential plant impact (Smith et al. 1993). It is probable that overfishing has reduced CPUE at all stations to lower levels than occurred previously and this has resulted in the significant interaction terms in the ANOVAs.

Trend line analysis for all species combined in the trawl and for the selected species indicated that although there often was a negative trend in CPUE in the preoperational period, trends in the operational period were either not significant or positive, with the exception of rainbow smelt and yellowtail flounder at one station. This pattern is an indication that the current low levels of demersal fishes are the result of processes that began prior to the plant starting operation in the preoperational period. Trends in winter flounder abundance in the operational periods at two of the three stations were positive, consistent with the recent reclassification of the Gulf of Maine stocks to "not overfished" (NEFSC 2006). However, there has been no evidence of an increase in the CPUE of young winter flounder in Hampton Harbor, or an increase in the density of winter flounder larvae. These conflicting trends are evidence that the current relatively high levels of adult winter flounder captured in the trawl may not originate from spawning nearshore or in Hampton Harbor.

The current low abundance of commercially important species and changes in the species composition in the demersal fish community in the study area are likely driven by commercial overexploitation and possibly by environmental factors and evolutionary factors. Reduction in the abundance of commercial species may have resulted in the competitive release of non-commercial and pelagic species (Fogarty and Murawski 1998). Furthermore, the current high abundance of pelagic fish such as Atlantic herring and Atlantic mackerel may be inhibiting the recovery of the demersal fish community, especially Atlantic cod (Swain and Sinclair 2000; Bundy and Fanning 2005). On the eastern Scotian Shelf, the ratio of pelagic feeders to demersal feeders has increased from 0.3 to 3.0 since the early 1990s (Bundy 2005). Furthermore Steneck et al. (2004) present evidence that a reduction in the abundance of apex vertebrate predators such as Atlantic cod has resulted in an increase in the abundance of macroinvertebrate predators such as crabs and lobsters. Link (2007) presents the "ugly fish" hypothesis where the removal of commercially valuable fish has resulted in an increase in underappreciated fish such as longhorn sculpin, resulting in a simplification of the ecosystem and a reduction in functional redundancy.

The shift to pelagic piscivorous feeders and macroinvertebrate predators may be inhibiting the recovery of demersal fishes and a similar situation could occur in the Gulf of Maine. Overexploitation of Atlantic cod stocks have also led to reductions in age and length at maturity. Potential for stock recovery is reduced due to the lower hatching rate and increased survival costs of reproduction among these smaller first time spawners (Hutchings 2005). Environmental factors such as the North Atlantic Oscillation (NAO) have been shown to significantly affect recruits per spawner relationships for 12 New England groundfish stocks (Brodziak and O'Brien 2005). A positive NAO index lagged forward by two years was shown to have the largest impact on recruits per spawner. Finally evolutionary factors may be inhibiting the recovery of northwest Atlantic demersal fish. Swain et al. (2007) presented evidence that the selective removal of large, fast-growing Atlantic cod by commercial fishing has resulted in a small size-at-age population that is genetically limited in growth potential, despite recent good growth conditions.

In conclusion, little impact to fishes can be attributed to Seabrook Station operation (Table 4-25). 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's offshore intakes and have egg or larval life stages that are largely maintained in inshore areas. Some fishes such Atlantic cod and yellowtail flounder continue to be overexploited by commercial fisheries and their stocks are presently declining. Other fishes, such as winter flounder and Atlantic mackerel, were overfished and are now either recovered or are recovering. Catch data 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 and gadids, flounders – elasmobranchs) 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 4-1. Finfish Species Composition by Life Stage and Gear, July 1975 - December 2007. Seabrook Operational Report, 2007[a].

		Ichthyoplankton Tows		Adult and Juvenile Finfish			
Scientific Name	Common Name	Eggs	Larvae	Trawls	Gill nets	Seines	Impingement
Myxine glutinosa	Atlantic hagfish						r
Acipenser oxyrhynchus	Atlantic sturgeon				r[b]		
Alosa aestivalis	Blueback herring		--	r	c	c	r
Alosa mediocris	Hickory shad		--		r		
Alosa pseudoharengus	Alewife		--	o	o	o	c
Alosa sapidissima	American shad		--	r	o	o	r
Alosa sp.	River herring		r	--	--	--	
Ammodytes americanus	American sand lance		a	o	r	o	c
Anarhichas lupus	Atlantic wolffish		r	r			r
Anchoa hepsetus	Striped anchovy					r	
Anguilla rostrata	American eel		c	r			r
Apeltes quadracus	Fourspine stickleback					r	
Archosargus probatocephalus	Sheepshead			r			r
Aspidophoroides monopterygius	Alligatorfish		c	o			
Balistes capriscus	Gray triggerfish						r
Brevoortia tyrannus	Atlantic menhaden	o	o	r	o	r	
Brosme brosme	Cusk	o	o				r
Caranx hippos	Crevalle jack					r	
Centropristis striata	Black sea bass			r	r		r
Conger oceanicus	Conger eel		r				
Clupea harengus	Atlantic herring		c	o	a	o	c
Clupeidae	Herrings	--	--	--	--	--	c
Cryptacanthodes maculatus	Wrymouth		o	r			c
Cyclopterus lumpus	Lumpfish		c	r	r	r	r
Dactylopterus volitans	Flying gurnard						r
Enchelyopus cimbrius	Fourbeard rockling	c	c	o			r
Fundulus sp.[c]	Killifish					c	r
Gadus morhua	Atlantic cod	--	c	c	o	r	r
Gadus/Melanogrammus	Atlantic cod/haddock/witch flounder	c	--	--	--	--	
Gasterosteus sp.[d]	Stickleback		r	r		c	r
Glyptocephalus cynoglossus	Witch flounder	c	c	o			
Hemitripterus americanus	Sea raven		o	c	o	r	c
Hippoglossoides platessoides	American plaice	c	c	o			
Hippoglossus hippoglossus	Atlantic halibut			r			
Labridae/*Limanda*	Cunner/yellowtail flounder[e]	a	--	--	--	--	
Limanda ferrugineus	Yellowtail flounder	--	c	a	r	r	c
Liparis atlanticus	Atlantic seasnail	r	c	--	--	--	

(continued)

Appendix Table 4-1. (Continued)

Scientific Name	Common Name	Ichthyoplankton Tows Eggs	Ichthyoplankton Tows Larvae	Adult and Juvenile Finfish Trawls	Adult and Juvenile Finfish Gill nets	Adult and Juvenile Finfish Seines	Impingement
Liparis coheni	Gulf snailfish		c	--	--	--	
Liparis sp[f]	Snailfish	r	--	o			c
Lophius americanus	Goosefish	r	o	o	r		r
Lumpenus lampretaeformis	Snakeblenny		o	r			r
Lumpenus maculatus	Daubed shanny		r	r			
Macrozoarces americanus	Ocean pout		o	c	r		r
Maurolicus weitzmani	Weitzman's pearlside						r
Melanogrammus aeglefinus	Haddock	--	o	c	r		r
Menidia menidia	Atlantic silverside		r	o	r	a	a
Menticirrhus saxatilis	Northern kingfish				r		r
Merluccius bilinearis	Silver hake	c	c	c	c	r	r
Microgadus tomcod	Atlantic tomcod		r	r		o	r
Monocanthus hispidus	Planehead filefish						r
Morone americana	White perch					r	r
Morone saxatilis	Striped bass				r	r	r
Mugil cephalus	Striped mullet					r	
Mustelus canis	Smooth dogfish				r		
Myoxocephalus aenaeus	Grubby		c	o	r	o	c
Myoxocephalus octodecemspinosus	Longhorn sculpin		c	a	o	r	r
Myoxocephalus scorpius	Shorthorn sculpin		c	o	r	r	r
Myxine glutinosa	Atlantic Hagfish						r
Odontaspis taurus	Sand tiger				r		r
Oncorhynchus kisutch	Coho salmon				r	r	
Oncorhynchus mykiss	Rainbow trout					r	
Ophidion margination	Striped cusk eel						r
Osmerus mordax	Rainbow smelt		o	c	o	c	c
Ostichthys trachypoma	Bigeye soldier fish	--	--	--	--	--	r
Paralichthys dentatus	Summer flounder		r	r			r
Paralichthys oblongus	Fourspot flounder	o	o	c	r		r
Peprilus triacanthus	Butterfish	o	o	r	o	r	r
Petromyzon marinus	Sea lamprey				r		r
Pholis gunnellus	Rock gunnel		c	o	r	r	c
Pleuronectes putnami	Smooth flounder		r	r		c	r
Pollachius virens	Pollock	c	c	c	c	o	c
Pomatomus saltatrix	Bluefish				o	o	r
Prionotus carolinus	Northern searobin	--	--	c	r		r
Prionotus evolans	Striped searobin	--	--	r			
Prionotus sp.	Searobin	o	r	--	--	--	
Pristigenys alta	Short bigeye						r
Pseudopleuronectes americanus	Winter flounder		c	c	o	c	c

(continued)

Appendix Table 4-1. (Continued)

Scientific Name	Common Name	Ichthyoplankton Tows: Eggs	Ichthyoplankton Tows: Larvae	Adult and Juvenile Finfish: Trawls	Adult and Juvenile Finfish: Gill nets	Adult and Juvenile Finfish: Seines	Impingement
Pungitius pungitius	Ninespine stickleback					c	
Raja sp[g]	Skate			c	r		c
Rhynchoconger gracilior	Whiptail conger						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	r
Scophthalmus aquosus	Windowpane	c	c	c	r	o	c
Sebastes sp[h]	Redfish		o				
Selene setapinnis	Atlantic moonfish						r
Selene vomer	Lookdown						r
Sphoeroides maculatus	Northern puffer			r		r	r
Squalus acanthias	Spiny dogfish			r	c		r
Stenotomus chrysops	Scup		r	o	r		r
Stichaeus punctatus	Arctic shanny		o				
Syngnathus fuscus	Northern pipefish		c	o	r	o	c
Tautoga onitis	Tautog	--	o		r		r
Tautogolabrus adspersus	Cunner	--	a		o	r	c
Torpedo nobiliana	Atlantic torpedo			r			r
Triglops murrayi	Moustache sculpin		o	r			
Ulvaria subbifurcata	Radiated shanny		c	o			r
Urophycis sp[i]	Hake	c	c	a	o	c	c

Footnotes:

a Names are according to Nelson et al. (2004). 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 of 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 4-2. Subsetting Criteria Used in Analyses of Variance of the Selected Finfish Species. Seabrook Operation Report, 2007.

Species	Gear	Season	Preoperational	Operational	Pooling	Deletions
Atlantic cod	Trawl	Dec-Jul	1975-1990	1990-2007	Dec with following year	Dec 2007
Atlantic cod	Ichthyo	Apr-Jul	1987-1990	1991-2007	None	None
Atlantic herring	Ichthyo	Oct-Dec	1986-1989	1990-2007	None	None
Atlantic silverside	Seine	Apr-Nov	1976-1984; 1987-1989	1991-2007	None	1990
Atlantic mackerel	Ichthyo	May-Aug	1987-1990	1991-2007	None	Aug 1990
American sand lance	Ichthyo	Jan-Apr	1987-1990	1991-2007	None	None
Cunner	Ichthyo	Jun-Sep	1987-1989	1991-2007	None	1990
Hakes	Trawl	Dec-Jul	1976-1990	1990-2007	Dec with following year	Dec 2007
Hakes	Ichthyo	Jul-Sep	1986-1989	1991-2007	None	1990
Pollock	Ichthyo	Nov-Feb	1986-1989	1990-2006	Jan-Feb with previous year	Nov-Dec 2007
Rainbow smelt	Trawl	Nov-May	1975-1990	1990-2007	Nov-Dec with following year	Nov-Dec 2007
Rainbow smelt	Seine	Apr-Nov	1976-1984;1987-1989	1991-2007	None	1990
Winter flounder	Trawl	Dec-Jul	1975-1990	1990-2005	Dec with following year	Dec 2007
Winter flounder	Seine	Apr-Nov	1976-1984; 1987-1989	1991-2007	None	1990
Winter flounder	Ichthyo	Apr-Jul	1987-1990	1991-2007	None	None
Yellowtail flounder	Trawl	Dec-Jul	1975-1990	1990-2007	Dec with following year	Dec 2007
Yellowtail flounder	Ichthyo	May-Aug	1987-1990	1991-2007	None	Aug 1990

Appendix Table 4-3. **Species Composition, Annual Totals, and Nine-Year Total of Finfish, and American Lobster Impinged at Seabrook Station From 1994 to 2007 [a]. Seabrook Operational Report, 2007.**

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Acadian redfish	0	0	0	0	0	0	0	0	0	0	0	3	0	12	15
Alewife	0	8	1,753	2,797	14	16	4	35	1	9	212	87	255	244	5,435
American lobster	31	16	31	20	4	6	0	1	23	19	0	77	5	21	254
American plaice	0	0	0	0	0	2	0	0	0	0	0	3	0	0	5
American shad	0	0	20	21	1	6	10	3	7	10	7	7	0	188	280
American sand lance	1,215	1,324	823	182	708	234	423	114	245	3,396	665	1,029	213	2,073	12,644
American eel	0	5	6	42	1	2	0	2	0	0	9	0	0	0	67
Atlantic menhaden	0	7	97	0	1	957	142	19	1,022	7	361	7,226	94	160	10,093
Atlantic hagfish	0	0	0	0	0	0	0	0	0	1,396	0	0	0	0	1,396
Atlantic torpedo	0	1	5	0	0	0	0	0	0	0	0	0	0	0	6
Atlantic silverside	5,348	1,621	1,119	210	834	1,335	31	282	1,410	20,507	877	2,717	788	639	37,718
Atlantic tomcod	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Atlantic wolffish	0	2	13	0	1	0	0	1	0	0	0	0	4	0	21
Atlantic cod	58	119	94	69	38	66	29	30	199	3,091	467	454	113	178	5,005
Atlantic mackerel	0	0	1	0	0	0	0	1	0	0	4	4	0	0	10
Atlantic herring	0	0	485	350	582	20	5	11	159	198	118	93	189	260	2,470
Atlantic moonfish	0	3	0	0	1	0	0	0	50	0	0	0	0	0	54
Bigeye soldierfish	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Blackspotted stickleback	0	0	0	0	2	28	0	0	0	107	12	0	3	0	152
Black sea bass	0	3	0	0	3	3	17	12	12	10	11	4	0	22	97
Blueback herring	13	0	111	323	7	53	1	59	475	50	380	130	138	237	1,977
Bluefish	0	0	0	0	0	0	0	0	7	0	0	0	0	0	7
Butterfish	3	14	3	223	9	5	1	28	1,170	4	35	54	44	199	1,792
Cunner	32	342	1,121	233	309	255	324	341	291	554	625	893	687	922	6,929
Cusk	0	0	19	0	0	0	0	0	0	0	0	0	0	1	20
Flounders	77	0	0	0	0	0	0	0	0	0	0	0	0	0	77
Flying gurnard	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Fourbeard rockling	0	6	0	0	3	1	1	1	0	0	7	3	0	7	29
Fourspine stickleback	0	0	0	0	23	24	0	6	3	0	0	0	0	13	69
Fourspot flounder	2	1	2	3	4	1	11	0	7	0	7	24	0	3	65
Goosefish	3	13	0	0	7	17	15	59	18	10	0	8	0	11	161
Gray triggerfish	0	0	0	0	0	0	0	1	0	0	0	1	3	0	5

(continued)

Appendix Table 4-3 (Continued)

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Grubby	2,678	2,415	1,457	430	3,269	3,953	1,174	549	1,089	2,523	676	531	235	869	21,848
Haddock	0	1	397	0	1	3	2	1	0	0	0	7	3	25	440
Hakes	2,822	2,188	156	122	4	68	113	523	1,813	166	35	11	6	1,184	9,211
Herrings	514	231	72	218	0	0	0	0	0	0	0	0	0	0	1,035
Killifishes	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Lefteye flounder	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
Longhorn sculpin	105	165	84	88	38	127	54	27	73	45	98	268	58	52	1,282
Lookdown	0	0	0	0	0	0	0	1	0	0	0	2	0	0	3
Lumpfish	182	190	51	62	137	344	85	158	84	370	68	61	176	420	2,388
Mummichog	0	0	47	24	0	0	0	0	0	0	0	4	0	0	75
Northern kingfish	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
Northern pipefish	188	579	1,200	243	268	748	370	714	936	2,716	1,413	1,724	1,288	2,374	14,761
Northern puffer	0	0	0	5	0	0	0	0	12	0	3	0	0	0	20
Northern searobin	0	0	0	11	1	2	0	1	2	564	0	11	0	7	599
Ocean pout	0	6	1	0	7	3	2	21	1	13	3	3	6	3	69
Planehead filefish	0	15	0	0	0	8	1	0	3	0	0	0	0	0	27
Pollock	1,681	899	1,835	379	536	11,392	534	405	719	499	80	218	73	340	19,590
Radiated shanny	0	92	40	2	39	108	11	53	4	158	18	49	44	119	737
Rainbow smelt	545	213	4,489	365	535	100	8	65	323	3,531	2,085	3,314	878	572	17,023
Red hake	1	16	1,478	371	903	1,120	112	155	52	271	892	821	546	1,389	8,127
Righteye flounder	0	3	4	0	0	0	0	0	0	0	0	0	0	0	7
Rock gunnel	494	1,298	1,122	459	2,929	2,308	1,514	2,251	2,066	6,274	4,137	1,752	3,782	3,174	33,560
Sand tiger shark	0	0	57	0	0	0	0	0	0	0	0	0	0	0	57
Sculpins	205	0	0	0	0	0	0	0	0	0	0	0	0	0	205
Scup	0	14	9	0	3	1	0	3	11	11	0	21	4	8	85
Sea raven	78	125	1,015	223	137	132	206	271	166	217	129	221	138	164	3,222
Sea lamprey	0	0	1	6	7	2	0	2	0	0	0	3	0	71	92
Sheepshead	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Short bigeye	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5
Shorthorn sculpin	14	156	282	123	190	296	923	621	642	7,450	876	2,214	1,258	465	15,510
Silver hake	0	49	58	108	13	100	41	5	1,177	22	212	306	31	21	2,143
Skates	190	157	225	177	41	41	42	17	299	145	60	170	33	64	1,661

(continued)

Appendix Table 4-3 (Continued)

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Smooth flounder	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
Snailfishes	180	165	1,013	351	856	2,356	690	334	616	451	185	442	330	76	8,045
Snakeblenny	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
Spotted hake	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Spiny dogfish	1	0	6	0	0	0	1	0	6	8	11	8	0	3	44
Striped bass	0	4	1	0	0	1	1	0	0	14	0	4	0	4	29
Striped cusk-eel	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3
Striped mullet	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Striped searobin	0	0	0	0	0	5	0	0	0	3	0	0	0	0	8
Summer flounder	3	0	0	0	0	0	0	0	0	0	0	0	4	0	7
Tautog	0	0	34	0	3	5	1	1	3	0	0	0	3	8	58
Threespine stickleback	67	155	320	174	773	506	10	280	34	1,549	130	307	139	193	4,637
Unidentified	6	40	88	49	0	15	0	0	0	0	0	0	0		198
Weitzman's pearlside	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10
Whiptail Conger	0	0	0	0	0	0	0	0	6	0	0	0	0		6
White hake	1	7	967	0	6	19	18	30	16	65	62	103	20	140	1,454
White perch	0	0	4	0	1	1	0	0	0	201	0	3	0		210
Windowpane	980	943	1,164	1,688	772	692	251	161	2,242	4,749	936	2,034	572	1,502	18,686
Winter flounder	1,435	1,171	3,231	468	1,143	3,642	102	777	897	10,491	783	1,875	767	3,949	30,731
Wrymouth	55	9	206	3	21	10	1	135	17	72	7	64	15	60	675
Yellowtail flounder	0	1,149	4	23	11	97	0	8	5	0	0	0	10	11	1,318
TOTAL	**19,212**	**15,940**	**26,825**	**10,648**	**15,198**	**31,241**	**7,281**	**8,577**	**18,413**	**71,946**	**16,696**	**29,368**	**12,955**	**22,472**	**306,772**

a Impingement data prior to October 1994 were underestimated.

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5.0 SUMMARY

Submerged rocky surfaces near Seabrook Station intake and discharge structures support rich and diverse communities of attached algae as well as mussel beds. An extensive monitoring program combining destructive and non-destructive sampling techniques was implemented in 1978 to assess the potential population and community level effects of Seabrook Station operation on the horizontal rocky-ledge habitat near the discharge of Seabrook Station (nearfield) and away from the influence of the discharge (farfield). 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 shallow subtidal communities (Stations B17, B35), and those associated with increased turbidity and sedimentation from transport of suspended solids and entrained organisms at the mid-depth communities (Stations B19, B31) near the discharge.

Shallow subtidal algal and faunal communities showed little change in community structure as determined through non-destructive and destructive sampling. Thermal impacts to macroalgae, such as shifts in abundance or occurrence of typically cold-water, warm-water or nuisance species were not evident. Although some typically warm-water taxa occurred for the first time during the operational period, some cold-water taxa were also collected more frequently and other warm-water taxa less frequently. Overall the algal community has been primarily composed of cold-temperate species throughout the study period. Macroalgal community structure was generally similar throughout the study as indicated by numerical classification and Multi-Dimensional Scaling (MDS) analysis.

At the shallow subtidal stations, changes in the macroalgal species richness (number of taxa) and macroalgal biomass were consistent between the preoperational and operational periods at the nearfield and farfield stations, indicating that if any changes occurred, they were area-wide. There were no significant differences in the number of macroalgal taxa (per 0.0625 m^2) between the preoperational (B17:11; B35:14) and operational periods (B17:11; B35:14) at both stations. In 2007 at the nearfield station, 11 algal taxa were collected, while at the farfield station there were 14 taxa. Similarly, there were no significant differences in mean algal biomass between the preoperational (B17:892 g/m^2; B35:891 g/m^2) and the operational (B17:878 g/m^2; B35:783 g/m^2) periods at both stations. In 2007, biomass at the nearfield (689 g/m^2) and farfield (609 g/m^2) stations was lower than the preoperational and operational period means.

Macrofaunal species richness has declined over time at both shallow subtidal stations. In 2007, the annual mean number of taxa at both stations (B17:28; B35:28) was lower than the previous year (B17:30; B35:38). A comparison of time periods suggests an area-wide decline between preoperational (B17:41; B35:42) and operational (B17:36; B35:35) periods. When both stations were combined, the number of taxa collected during the operational period was significantly lower than the preoperational period. Macrofaunal densities in 2007 at Station B17 (15,339) and Station B35 (16,875) were below the preoperational and operational averages. There were no significant differences in total faunal density between the preoperational (B17:22,835/m^2; B35:28,371/m^2) and operational (B17:19,926/m^2; B35:19,538/m^2) periods at both stations. Cluster analysis and MDS ordination identified only subtle differences in macrofaunal community structure. Changes in the species richness for macroalgae and macrofauna, biomass of macroalgae, and density of macrofauna reflect natural variation of dominant species, and do not indicate an

impact at the nearfield station after power plant operation began in 1990.

Selected taxa studies in the shallow subtidal zones revealed period differences that varied between nearfield and farfield stations for two species. The subdominant kelp *Laminaria digitata* and dominant kelp *Laminaria saccharina* are large, habitat-forming macrophytes that grow over the more abundant understory species such as *Chondrus crispus*. *L. digitata* densities declined significantly at both stations, but the decline was greater at the nearfield area (Preop: 213.9/100 m^2; Op: 16.7/100 m^2) than at the farfield area (Preop: 155.8/100 m^2, Op: 73.6/100 m^2). Likewise, density of the kelp *L. saccharina* declined significantly at the nearfield station (Preop: 415.1/m^2; Op: 151.8/m^2) although there was no significant difference at the farfield station (Preop: 325.7/m^2; Op: 336.6/m^2). In 2007 at the nearfield station, densities of *L. digitata* (3.2/m^2) and *L. saccharina* (9.5/m^2) were low relative to the operational means (16.7/m^2 and 151.8/m^2, respectively), as were the farfield densities of *L. digitata* (2007: 23.0/m^2; Op: 73.6/m^2) and *L. saccharina* (2007: 101.5/m^2; Op: 336.6/m^2). At present there is no clear causative factor for the decline between the preoperational and operational periods of *L. digitata* at both stations and *L. saccharina* at the nearfield station. Physical and/or biological factors (such as competition and predation) may play a role. Since the decline began prior to the operation of Seabrook station, it is not likely to be related to station operation. No significant changes between the preoperational and operational periods were observed for the abundant cold water-perennial algae *Chondrus crispus*, *Phyllophora/Coccotylus* and *Ptilota serrata* or for any of the selected species of macrofauna that occurred at the nearfield or the farfield stations.

In the mid-depth zone, 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 the nearfield area. Nearfield (B19) and farfield (B31) mid-depth stations were located at depths of 12.2 m and 9.4 m, respectively. Macroalgal and macrofaunal community structure was generally similar between the preoperational and operational periods at nearfield and farfield stations, as demonstrated by numerical classification and MDS analysis. Numerical classification (dendrograms and MDS) revealed that algal collections were generally separated into two major groups, defined spatially rather than temporally. Two exceptions were collections taken from Station B31 from 2001-2004 which formed Group 3 and the outlier, Station B19 in 2007. Collections from Group 3 were characterized by an overall low algal biomass, and the reduced relative abundance of the perennial algal complex *Phyllophora/Coccotylus* that occurred as a dominant in previous years. Instead, the cold-water perennial *Chondrus crispus*, the calcareous *Corallina officinalis,* and the annual *Polysiphonia stricta,* comprised most of the biomass. In 2007, algal collections from Station B31 were assigned to the group that contains the majority of preoperational and operational collections from Station B31. The outlier for algal collections (Station B19-2007) was characterized by the lowest overall biomass of any groups, and was dominated by the *Phyllophora/Coccotylus* complex with low biomass of *Phycodrys rubens* and *Corallina officinalis*. Recent (1995-2007) faunal collections from Station B31 also were assigned to a unique group by the cluster analysis and contained high numbers of *Lacuna vincta* and relatively low numbers of *Pontogeneia inermis.*

In the mid-depth zone, the spatial pattern of macroalgal species richness was not consistent between the preoperational and operational periods at the nearfield (Preop: 10; Op: 10) and farfield (Preop: 11; Op: 14) stations, and the interaction term of the ANOVA was significant. The number of taxa at both stations tracked each other closely during the early operational period, increasing until 1996 after which numbers of taxa at Station B19 decreased, reaching an historic low in 2000. In 2007, the numbers of algal taxa at both Stations B19 (10.9) and B31 (13.3) were within the 95% confidence limits of the operational means (B19:9.9; B31:13.6). In 2007 the algal biomass at Station B19 (81.0 g/m^2) and Station B31 (234.6 g/m^2) was below the preoperational and operational means. The algal biomass at Station B19 was at the low for the study period. The spatial pattern of algal biomass was consistent between the preoperational (B19: 277.3 g/m^2; B31: 419.1 g/m^2) and operational (B19: 239.3 g/m^2; B31: 337.6 g/m^2) periods, although there was significantly more algal biomass collected during the preopprational period when compared to the operational period at both stations combined.

Numbers of macrofaunal taxa in 2007 at the mid-depth farfield station (B31:30) were similar to the previous year and lower than most historical averages. In contrast, species richness at the nearfield station (B19:43) during 2007 was higher than the previous year and above the mean for the operational period. No significant differences in mean number of taxa at the mid-depth stations between the preoperational and operational periods were found using analysis of variance (ANOVA), and both stations have experienced similar trends in numbers of taxa over the duration of the study. At the nearfield mid-depth station (B19), mean faunal density in 2007 (B19:38,899 $/m^2$) was nearly three times as high as the previous year (B19:13,072 $/m^2$). This spike in density was largely due to high numbers of Mytilidae spat. Mean density at the farfield station (B31) in 2007 (B31:8,691 $/m^2$) was slightly higher than the previous year (B31: 7,271 $/m^2$) but lower than historical averages. Faunal density at Stations B19 and B31 was not significantly different between periods or stations and the interaction term was also not significant.

Recruitment patterns of the four selected species of fouling organisms from bottom panels in the mid-depth zone in 2007 were generally similar to the preoperational and operational periods. *Balanus* spp. barnacles settle the earliest, and were most abundant on panels harvested in April. Two sessile bivalves, *Hiatella* sp. and Mytilidae have historically been most common on panels harvested in August, but in 2007 Mytilidae set early at the nearfield station. The jingle shell *Anomia* sp. was most abundant on the December panels historically and in 2007.

Among the selected species, *Laminaria digitata* and *Alaria esculenta* were the only algal species at the mid-depth stations with a significant interaction term. No significant differences were found for the dominant kelps *Agarum clathratum* and *Laminaria saccharina* or for the understory algae *Phyllophora/ Coccotylus* or *Pilota serrata*. Density of *L. digitata* decreased significantly between periods at the mid-depth nearfield (Preop: 140 $/100\ m^2$; Op: 8 $/100\ m^2$) and farfield (Preop: 500 $/100\ m^2$; Op: 168 $/100\ m^2$) stations, but the decline was greater at the farfield station, resulting in a significant interaction term. In 2007, the density of *Laminaria digitata* at Station B19 was $4.0/100m^2$, while at Station B31 it was 122 $/100\ m^2$. The cause of this decline remains unclear. Grazing by the green sea urchin *Strongylocentrotus droebachiensis* has been cited as a major factor influencing kelp abundance. An inverse relationship between *S. droebachiensis* and *L. digitata* was found to be statistically significant in the far-field area when sea urchin abundance was high in 1993 and 1994. *L. digitata* is at its physiological limit with respect to water depth at the nearfield station (3 meters deeper than the farfield station), and competition with the dominant deep-water kelp *Agarum clathratum* may be affecting re-establishment of *L. digitata*. The density of *A. esculenta* decreased significantly between periods at the mid-depth farfield station (Preop: 75/100 m^2; Op: 45 /100 m^2) while there was no significant difference temporally at the nearfield (Preop: 2/100 m^2; Op: 2/100 m^2) stations. The decline was greater at the farfield station, in part because the preoperational density was was so low at the nearfield station. The decline in *A. esculenta* began in the early 1980s (before the operation of Seabrook Station), occurred at both stations, and appears to be part of a regional trend. Only very low densities have been reported at Station B19 (the deepest station) since 1981. Trends in abundance of the faunal selected species were consistent at the mid-depth stations between the pre-operational and operational periods. No significant differences were found between the time periods for any faunal selected species, except horse mussels. More horse mussels were collected in the preoperational period (B19:97/m^2; B31:89/m^2) compared to the operational period (B19:71/m^2; B31:52/m^2). Potential increases in the temperature or turbidity in the nearfield area due to plant operation do not appear to have caused responses in the macroalgal or macrofaunal communities or selected species in the study area.

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5.1 INTRODUCTION

The predominant benthic marine habitat near Seabrook Station's offshore intake and discharge structures is rocky substratum, primarily in the form of bedrock ledge and boulders. These rock surfaces support diverse communities of attached algae 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 algae 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 kelps inhabit subtidal areas (Sebens 1986; Witman 1987). Understory layers generally occur beneath or between these canopies and contain secondary levels of foliose and filamentous algae and upright attached macroinvertebrates over a layer of encrusting algal and faunal species, which occupy much of the remaining primary rock surfaces (Menge 1976; Sebens 1985; Ojeda and Dearborn 1989). Also, many niches created in and around this attached biota are occupied by mobile predator and herbivore species such as fish, snails, sea urchins, sea stars, 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 is well documented in the intertidal zone throughout the North Atlantic Ocean (Stephenson and Stephenson 1949; Lewis 1964; Chapman 1973; Lubchenco 1980; Mathieson et al. 1991), but is also present subtidally (Hiscock and Mitchell 1980; Sebens 1985; Mathieson et al. 1991). These patterns of community organization are the result of a variety of interacting physical (e.g., water movement, temperature, turbidity and light penetration) and biological (e.g., herbivory, predation, recruitment, inter- and intraspecific competition for space) mechanisms, which vary over spatial and temporal scales.

Coastal hard-bottom communities are ecologically important, well documented as effective integrators of environmental conditions, and potentially vulnerable to localized anthropogenic impacts. Studies of these communities have been and are an integral 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; NUSCO 1996; NUSCO 1998; DNC 2002; DNC 2005, Steinbeck et al. 2005). Similarly, Seabrook Station marine macrobenthic 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 (shallow subtidal zone). 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 algae and animal species occupying nearby 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 subtidal communities.

5.2 METHODS

5.2.1 Field Methods

Destructive (quantitative) macrofaunal and macroalgal samples were collected three times annually (May, August, November) at four benthic stations (Figure 5-1); nearfield-farfield station pairs were established at shallow subtidal (Stations B17 and B35; 5 and 6 m, respectively) and mid-depth (Stations B19 and B31; 12 and 9 m respectively) zones. The sampling program began in 1978 with three nearfield stations (B1, B17, and B19) and one farfield station (B31). Subsequently, two farfield stations were added in 1982 (B5 and B35). Intertidal stations (B1 and B5) were sampled through 2001 and this program was discontinued beginning in 2002. Station sampling histories are summarized in Appendix Table 5-1.

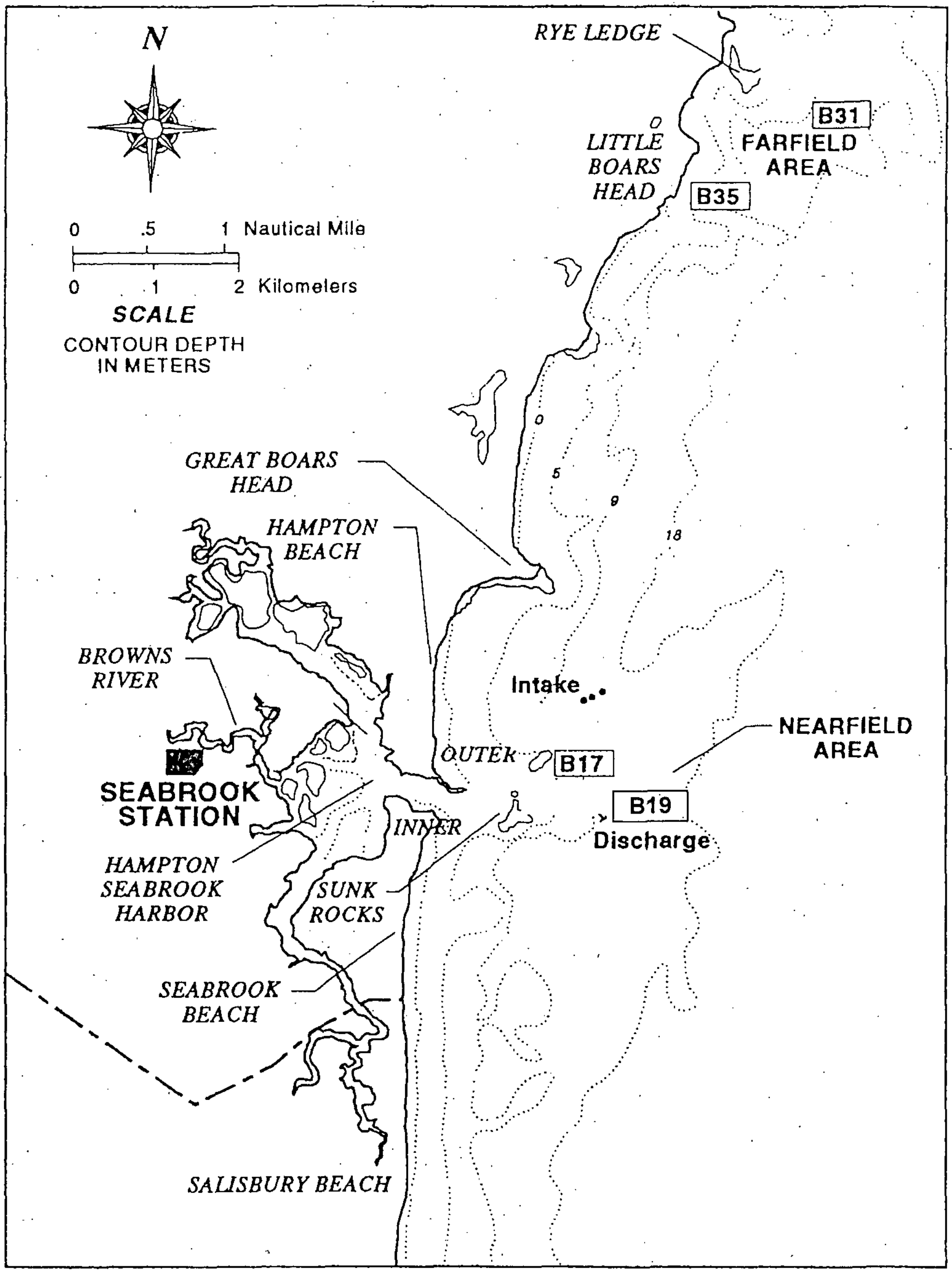
Destructive collections of macroflora and the associated macrofauna were removed from the substrate by scraping from five randomly selected 0.0625 m^2 areas on rock surfaces. Subtidal collections were drawn through a diver-operated airlift into a 0.79 mm mesh bag, placed in a labeled plastic bag, brought to the surface and sent to the laboratory for preservation and processing (NAI 1991). In conjunction with the five replicate samples, a comprehensive, qualitative collection of all visible algal species which included large and less common species not taken in the destructive collections was made at each station. These qualitative collections are referred to as the general algae collections.

Non-destructive subtidal transects were established to monitor larger macroinvertebrates and macroalgae that were not adequately represented in destructive samples or in the general algae collections. Six randomly-placed replicate 1 m x 7 m band-transects were surveyed at nearfield-farfield station pairs in the shallow subtidal (B17, B35) (Figure 5-1) and mid-depth (B19, B31) zones in April, July and October. Percent frequency of occurrence was estimated from counts of dominant understory macroalgae (*Chondrus crispus*, *Phyllophora/Coccotylus* and *Ptilota serrata*) under each of 20 marks on the transect line. Counts of *Strongylocentrotus droebachiensis* and the kelp species *Laminaria digitata, L. saccharina,* and *Alaria esculenta* were made at seven 1-m^2 quadrats per transect. However at Station B19 and B31, *Agarum clathratum* and *Modiolus modiolus* were counted in only two 1-m^2 quadrats per transect because they were so abundant. Additionally, estimates of percent cover per quadrat were made of *Laminaria digitata*.

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. Short-term bottom panels were exposed for four months during three exposure periods: January through April, May through August, and September through December. One panel was deployed at each station for each time period. The annual panel program, with an exposure period of 12 months, was discontinued after 1997. In addition, beginning in 1998, pine boards (2.5 x 10.1 x 25.4 cm) were deployed with the bottom panels to determine settlement of *Teredo* spp. (shipworms). Boards were x-rayed (250 kV, 5 mA, for 45 s), and no *Teredo* spp. have been found since the program began in 1998.

5.2.2 Laboratory Methods

All destructive samples were washed over a 1.0 mm sieve. Algal species from each sample were identified to the lowest identifiable 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



LEGEND

[ ] = benthic samples

Figure 5-1. Marine benthic sampling stations. Seabrook Operational Report, 2007.

community type in the study area, based on abundance, trophic level, and habitat specificity. All non-colonial faunal species collected in August were identified to the lowest identifiable taxonomic level and counted. The colonial taxa such as bryozoans were listed as present, and beginning in 1998, they were not identified.

Macroalgae from the general algae collections were identified to the lowest identifiable taxon. The complete macroalgal species list was compiled from triannual general and destructive collections and included crustose coralline algae that were sampled only in August.

A 50 cm x 50 cm frame was placed over each bottom panel and the area within the frame was divided into four quadrats for processing. The undisturbed bottom panel faces were analyzed for *Balanus* spp. (which includes *Semibalanus balanoides*) and Spirorbidae, and then scraped to remove sessile bivalves and solitary chordates for identification and enumeration.

5.2.3 Analytical Methods

5.2.3.1 Destructive Monitoring Program: Community Analyses

Statistical analyses, data summaries, and graphical presentation were used to evaluate the macrobenthic community at nearfield and farfield stations during the preoperational and operational periods. Data preparation and univariate analyses were run in SAS system software (version 9.1.3), while multivariate analyses were run in PRIMER (Plymouth Routines in Multivariate Ecological Research).

Several changes to protocols have been implemented during the history of the destructive macrofaunal program. Epizootic organisms (scraped from the surfaces of kelp fronds) were identified only during the first several years of the program. Colonial organisms, identified (as present or absent) until 1997, are no longer identified. Taxa in these groups must be excluded from the historical data prior to temporal analyses that include years following the change in protocol. Therefore, all colonial taxa and epizootic taxa have been excluded from community data analyses presented herein.

Macroalgal community analyses included analysis of variance (ANOVA) of community parameters such as the number of taxa and total abundance or biomass from triannual samples (collected three times per year). Macrofaunal ANOVAs for the number of taxa and total abundance and numerical classification of algal biomass or macrofaunal abundance used data from August collections (Table 5-1). Temporal (operational/preoperational) and spatial (nearfield/farfield) differences in total abundance or biomass and number of taxa were evaluated using a multiway 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. Period (preoperational vs. operational) and station (nearfield vs. farfield) differences and the interaction between them were evaluated using a mixed linear model analysis using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. A mixed model based on a 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) 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 both stations were sampled concurrently (thus maintaining an equal number of years between stations within the pre

Table 5-1. Selected Benthic Taxa and Parameters Used in ANOVAs. Seabrook Operational Report, 2007.

Community	Sample Type	Parameter	Station	Data Periods Used In Analysis	Data Characteristics[a]	Source of Variation In ANOVAs[b]
Benthic Macroalgae	Non-Dest.	**Kelp** *Laminaria saccharina, L. digitata, Alaria esculenta,* and	B17, B35	1982-1989, 1991-2007	Mean number per sample period and station, log (x+1) transformation	Preop-Op, Station, Year, Month
	Non-Dest.	*Laminaria saccharina, L. digitata, Agarum clathratum*	B19, B31	1978-1989, 1991-2007	Mean number per sample period and station, log (x+1) transformation	Preop-Op, Station, Year, Month
	Non-Dest.	**Understory Algae** *Chondrus crispus* and *Ptilota serrata*	B19, B31	1981-1989, 1991-2007	Mean % frequency per year, arcsin √Y transformation	Preop-Op, Station, Year, Month
	Non-Dest.	*Chondrus crispus* and *Ptilota serrata*	B17, B35	1982-1989, 1991-2007	Mean % frequency per year, arcsin √Y transformation	Preop-Op, Station, Year, Month
	Non-Dest.	*Phyllophora/Coccotylus*	B19, B31	1981-1989, 1991-2007	Mean % frequency per year, log (x+1) transformation	Preop-Op, Station, Year, Month
	Non-Dest.	*Phyllophora/Coccotylus*	B17, B35	1982-1989, 1991-2007	Mean % frequency per year, log (x+1) transformation	Preop-Op, Station, Year, Month
	Dest.	Number of taxa	B17, B35	1982-1989, 1991-2007	Number per station, year, month and replicate, no transformation	Preop-Op, Station, Year, Month
	Dest.	Total biomass	B19, B31	1980-1989, 1991-2007	Biomass per station, year, month and replicate, no transformation	Preop-Op, Station, Year, Month
	Dest.	*C. crispus* biomass	B17, B35	1982-1998, 1991-2007	Biomass per sample Square root transformation.	Preop-Op, Station, Year, Month, period and replicate.
Benthic Macrofauna	Non-Dest.	*Strongylocentrotus droebachiensis* > 10 mm	B17, B35	1985-1989, 1991-2007	Mean number per sample period and station, log (x+1) transformation	Preop-Op, Station, Year, Month
	Non-Dest.		B19, B31	1985-1989, 1991-2007	Mean number per sample period and station, log (x+1) transformation	Preop-Op, Station, Year, Month
	Non-Dest.	*Modiolus modiolus*	B19, B31	1980-1989, 1991-2007	Ranked densities; mean per sample period, no transformation.	Preop-Op, Station, Year, Month
	Dest.	*Jassa marmorata* and Mytilidae spat	B17, B35	1982-1989, 1991-2007	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Dest.	Asteriidae	B17, B35	1982-1989, 1991-2007	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Dest.	*Pontogeneia inermis* and Mytilidae spat 10 mm	B19, B31	1978-1989, 1991-2007	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Dest.	*Strongylocentrotus droebachiensis* <10 mm	B19, B31	1985-1989, 1991-2007	Abundance per replicate; 3 dates per year.	Preop-Op, Station, Year, Month
	Dest.	Total density, Number of Taxa	B17, B35; B19, B31	1982-2007 1978-2007	Amount or number per year in August only, station and replicate; no transformation for number of taxa.	Preop-Op, Station, Year

[a] Log_{10} (x+1) transformation except where noted.

[b] Preop-Op: preoperational period vs. operational period.

operational period). Collections of selected species from 1990, the year the plant began to operate intermittently, occurred during the transition from preoperational to operational periods and were excluded from the analysis. The inference test for Preop-Op was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS Institute, Inc. 1999). The likelihood ratio test was used to test the significance for random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects.

When an interaction between station and period (preoperational and operational) was significant, segmented regression analysis was used on the time series of annual means from each station to identify when there were changes or "breakpoints" in a time series. These breakpoints typically divided the time series into two segments. If a breakpoint was identified, linear regression was used to describe trends within each segment. Significant differences between the means for the two segments were evaluated with a t-test. The slope of each segment was tested for significance with a t-test.

A comparison of macroalgal and macrofaunal community composition during operational and preoperational periods was made using numerical classification methods (Boesch 1977). The analysis was made by grouping collections taken in August (peak-season) by depth zone: shallow subtidal (Stations B17 and B35); and mid-depth (Stations B19 and B31). Bray-Curtis similarity indices were computed for the annual August log-transformed average densities (macrofauna) and log transformed annual mean biomass (macroalgae). Macroalgal and macrofaunal species with less than 2% frequency of occurrence were excluded from the analysis. Macroalgal collections for which similarity indices were computed included 33 taxa from the shallow subtidal and 26 taxa from the mid-depth zone. Macrofaunal collections included 124 taxa from the shallow subtidal and 147 taxa from the mid-depth zones; the most abundant are listed in Appendix Table 5-2. The group average method (Boesch 1977) was used to classify the samples into groups or clusters. Computations were done with the computer program PRIMER (Clarke and Warwick 1994). The Multi-Dimensional Scaling (MDS) method was used to enhance interpretation of community analysis. MDS is a method of comparing samples where a "map" or configuration of samples is drawn in a specified number of dimensions that attempts to satisfy all the conditions imposed by the rank similarity matrix (Clarke and Warwick 1994). The adequacy of the representation of the relationships among samples is measured by the "stress" variable as defined in Clarke and Warwick (1994). Stress can be thought of as the difficulty in compressing the sample relationships into two (or a small number of) dimensions. In this study, the MDS plot used two dimensions for macroalgae and macrofauna. Clarke and Warwick (1994) provided guidelines for evaluating stress in MDS plots. Stress levels less than 0.05 gave excellent representation with no prospect of misinterpretation. Stress less than 0.1 corresponded to good ordination with no real prospect of a misleading interpretation. Stress less than 0.2 still provided a potentially useful two-dimensional picture. When stress was greater than 0.2, a three-dimensional plot with reduced stress was generated, unless the two-dimensional plot provided a better visual demonstration of the relationships among station-year combinations. The relative position of the station-year combinations could then be used to interpret trends among stations and between the preoperational and operational years. The units of the plot are dimension-less; therefore differences, which appear large on the MDS plot, may represent small percentage differences (Clarke and Warwick 1994).

Spatial and temporal differences were also assessed by the analysis of similarities (ANOSIM) procedure on log (x+1) transformed data (Clarke 1993). Tests for differences between treatment main effects, period and station, were provided by a two-way ANOSIM (Clarke and Warwick 1994). According to the before-after-control-impact (BACI) design (Stewart-Oaten et al. 1986), potential plant impacts would appear as an interaction between treatment main effects. Using ANOSIM to test for differences, an interaction between main effects could be determined indirectly by comparing the preoperational period to the operational period separately at each station using a one-way test, provided that there were no differences between stations in the preoperational period (Clarke 1993). Therefore, the interaction of the main effects was tested using a two-stage procedure. First, the preoperational period was tested for station differences using a one-way ANOSIM. If there were no significant differences between stations in the preoperational period, then each station was tested for differences between periods using one-way ANOSIM. If there were significant differences between periods for either station, these results were compared with the MDS and cluster analysis for aid in interpretation and to account for accumulating Type I error. A 5% significance level for the test statistic was assumed to be ecologically meaningful. In general a probability of 5% or less is commonly used as a criterion for rejection of the null hypothesis. The probability used as the criterion for rejection is called the significance level, which is denoted by the lower case Greek letter alpha.

5.2.3.2 Destructive Monitoring Program: Selected Species Analyses

Some algal and faunal taxa were selected for more detailed analysis due to their ecological or economic importance in the study area. ANOVAs were used to evaluate temporal and spatial differences in biomass (algae only) or density obtained from the destructive monitoring program. Segmented regression analysis was used on a time series of annual means for selected species to describe trends in the data.

5.2.3.3 Non-destructive Monitoring Program: Selected Species Analyses

Comparisons between preoperational and operational periods, stations, and the interaction between period and station were made with ANOVAs on several subtidal species (kelp, understory algae and the large macrofaunal species, *Strongylocentrotus droebachiensis* and *Modiolus modiolus*). The ANOVA models were structured similarly to those run on collections from the destructive monitoring program. Data were tested 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.

Annual means and confidence intervals are presented graphically for species that have a significant Station X Period (Preop-Op) interaction. If data were transformed for the ANOVA, then back-transformed values are presented. Significant interactions from the ANOVA model are presented graphically using the least squares means from the multiple comparison test. Segmented regression analysis was used on a time series of annual means for selected species to describe trends in the data.

5.3 RESULTS AND DISCUSSION

5.3.1 Marine Macroalgae

5.3.1.1 Horizontal Ledge Communities

Number of Taxa: Algae from Qualitative Samples taken in conjunction with Destructive Samples

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; DNC 2002, Steinbeck et al. 2005). To assess algal community diversity at Seabrook study sites, the number of algal taxa was determined in two ways. The destructive sampling program provided quantitative information on algal diversity (i.e., number of taxa per 0.0625 m^2); data that are amenable to statistical analysis. In addition, large and uncommon algal species, not usually taken in the 0.0625 m^2, destructive samples, were collected from a larger area at each station by SCUBA divers to augment the species list. These qualitative collections are termed general algae collections. A total of 160 taxa have been collected from the two programs during the study period. No additional species were collected in 2007 (Appendix Table 5-3).

Numbers of taxa collected in qualitative samples in the shallow subtidal zone in 2007 (Station B17- 35 taxa; Station B35- 33 taxa) were equal to the operational median at Station B17 and below the median at Station B35 (Figure 5-2). Numbers of taxa in 2007 at both stations were within the ranges for the preoperational and operational periods. Numbers of taxa collected in 2007 in the mid-depth zone (B19- 24 taxa; B31- 31 taxa) were also within the preoperational and operational period ranges (Figure 5-2). The number of taxa collected at Station B19 in 2007 was below the medians from the operational (25) and preoperational periods (29.5). At Station B31, the number of taxa collected in 2007 was similar to the operational (32) and preoperational period medians (32.5).

Patterns in the number of taxa collected among depth zones and stations were consistent between the preoperational and operational periods (Figure 5-2). The median number of taxa collected during both periods was generally higher in the shallow subtidal (B17 and B35) than the mid-depth (B19 and B31) zone. During both periods and in both depth zones, the median number of taxa at farfield stations was higher than the nearfield stations.

Number of Taxa: Destructive

In the shallow subtidal zone, the number of taxa collected in quantitative destructive samples at both stations in 2007 was below the preoperational and operational means (Table 5-2). The preoperational means were equal to, or very similar to, the operational means at each station. The ANOVA results indicated that there were no significant differences in number of taxa between the preoperational and operational periods, although Station B35 had significantly more taxa than Station B17 (Table 5-3). Figure 5-3 illustrates that the annual means at Station B17 were generally lower than the annual means at Station B35. The relationship between stations was consistent between the preoperational and operational periods as indicated by the non-significant interaction term; therefore there was no indication of a plant impact.

In the mid-depth zone, the number of taxa found at the nearfield station (B19) in 2007 was higher than both the preoperational and operational means (Table 5-2). At the farfield station (B31) the mean number of taxa in 2007 was similar to the operational period mean and higher than the preoperational mean. The relationship among stations changed between the preoperational and operational periods as indicated by the significant interaction term (Table 5-3; Figure 5-3). The mean number of taxa increased significantly between periods at

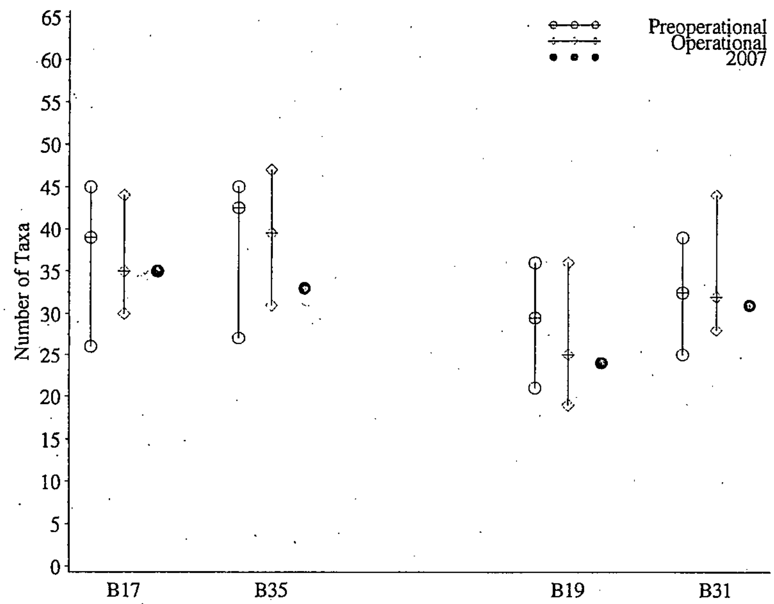


Figure 5-2. Number of macroalgal taxa in general algae collections from the subtidal zone. Median, minimum, and maximum numbers (calculated from annual totals) during the preoperational and operational periods, and the 2007 total. Seabrook Operational Report, 2007.

Table 5-2. Arithmetic Means and Confidence Limits of Biomass (g per m²) and Number of Macroalgal Taxa (per 0.0625 m²) from Destructive Samples during the Preoperational and Operational Periods. Seabrook Operational Report, 2007.

		Preoperational			2007	Operational		
Depth Zone	**Station**	**LCL[a]**	**Mean**	**UCL[b]**	**Mean**	**LCL**	**Mean**	**UCL**
Number of Taxa (per 0.0625 m²)								
Shallow subtidal	B17[c]	10.2	11.2	12.1	10.6	10.6	11.1	11.5
	B35[d]	12.8	14.2	15.5	13.8	13.5	14.2	15.0
Mid-depth	B19[c]	9.6	10.1	10.7	10.9	9.3	9.9	10.6
	B31[c]	10.2	11.0	11.8	13.3	12.6	13.6	14.6
Total Biomass (g/m²)								
Shallow subtidal	B17[c]	809.7	892.3	974.9	688.5	814.2	878.3	942.3
	B35[d]	774.2	891.4	1008.7	609.1	704.0	783.6	863.2
Mid-depth	B19[c]	232.1	277.3	322.6	81.0	194.2	239.3	284.4
	B31[c]	348.6	419.1	489.6	234.6	284.0	337.6	391.2

[a] LCL = Lower 95% confidence limit.
[b] UCL = Upper 95% confidence limit.
[c] Years = 1980-1989 (Preoperational); 1991-2007 (Operational)
[d] Years = 1982-1989 (Preoperational); 1991-2007 (Operational)

Table 5-3. Results of Analysis of Variance Comparing the Number of Macroalgal Taxa (per 0.0625 m^2) and Total Macroalgal Bimoass (g per m^2) from Destructive Samples at Shallow Subtidal and Mid-Depth Subtidal Stations During Preoperational and Operational years. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics (Data not transfomed)			Multiple Comparisons[k]
Number of Taxa	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 23.4	0.28	0.6001	
Shallow	**Random Effects**	**Estimate[j]**	χ^2	**p**	
Subtidal	Year (Preop-Op)[b]	0.19	0.28	0.2969	
(B17, B35)	Month(Year)[c]	1.41	71.97	<0.0001*	
	Station[d]	4.42	3.17	0.0374*	B35>B17
	Preop-Op X Station[e]	<0.01	0.00	0.4996	
	Station X Year (Preop-Op)[f]	0.65	21.74	<0.0001*	
	Error	4.25			
Number of Taxa	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 1.18	0.67	0.5462	
Mid-depth	**Random Effects**	**Estimate[j]**	χ^2	**p**	
(B19, B31)	Year (Preop-Op)[b]	0.82	4.74	0.0148*	
	Month(Year)[c]	0.73	51.84	<0.0001*	
	Station[d]	1.64	0.23	0.3144	
	Preop-Op X Station[e]	1.86	14.01	0.0001*	B31Op>B31Pre>B19Pre>B19Op
	Station X Year (Preop-Op)[f]	0.75	46.45	<0.0001*	
	Error	3.04			
Total Biomass	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 6.56	0.48	0.5136	
Shallow	**Random Effects**	**Estimate[j]**	χ^2	**p**	
Subtidal	Year (Preop-Op)[b]	0.00	0.00	0.4999	
(B17, B35)	Month(Year)[c]	16.47	249.52	<0.0001*	
	Station[d]	0.22	0.06	0.4030	
	Preop-Op X Station[e]	0.45	1.19	0.1382	
	Station X Year (Preop-Op)[f]	0.51	1.40	0.1185	
	Error	18.01			
Total Biomass	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 70.7	4.74	0.0328*	Pre>Op
Mid-depth	**Random Effects**	**Estimate[j]**	χ^2	**p**	
(B19, B31)	Year (Preop-Op)[b]	0.00	0.00	0.4992	
	Month(Year)[c]	3.62	41.95	<0.0001*	
	Station[d]	4.58	2.28	0.0655	
	Preop-Op X Station[e]	0.00	0.00	0.4992	
	Station X Year (Preop-Op)[f]	4.71	63.72	<0.0001*	
	Error	16.31			

[a] Compares Preop to Op, regardless of station; years included in each station grouping: Op years = 1991-2007, Preop years: B17, B35 = 1982-1989; B19, B31 = 1980-1989.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year. (Apr, Jul, Oct)
[d] Stations (Nearfield=P2, Farfield = P7) 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

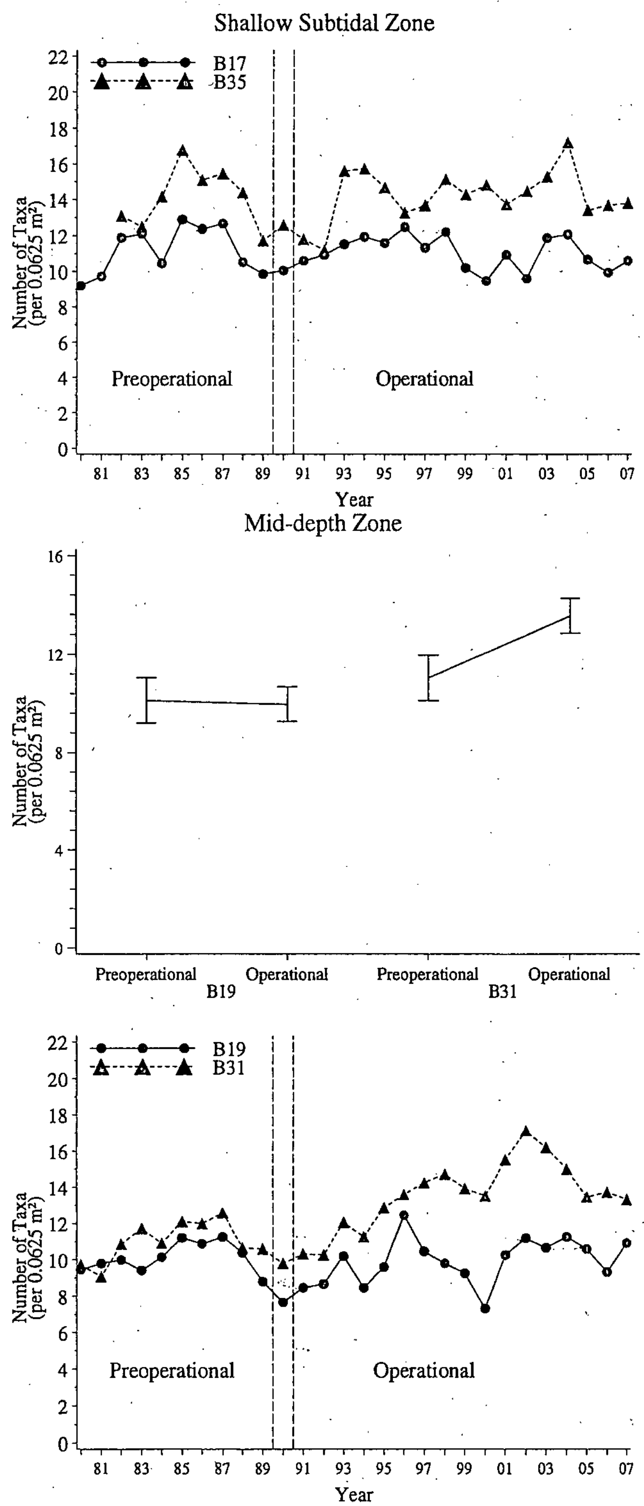


Figure 5-3. Annual mean number of macroalgal taxa (per 0.0625 m^2) each year in the shallow and mid-depth subtidal zones and the comparison between stations of number of taxa in the mid-depth subtidal zone during the preoperational (1980-1989) and operational (1991-2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model. Seabrook Operational Report, 2007.

Station B31, while there was no significant change at nearfield Station B19. ANOVA results are corroborated by the segmented regression analysis, which found that a significant increase in the number of taxa occurred at Station B31 after 1995, while no significant breakpoint occurred at Station B19 (Table 5-4). There has been a positive trend in number of algal taxa for both segments of the study period at Station B19. Overall the numbers of taxa at the two stations followed similar annual trends throughout most of the study (Figure 5-3). Numbers started to diverge after 1996, due to fluctuations in the occurrence of species not normally found in the mid-depth zone (Figure 5-3). For example, the peak number of taxa at Station B31 occurred in 2002 when *Ceramium rubrum, Polysiphonia flexicaulis, P. fucoides* and *P. nigra,* typically more common in the shallow subtidal zone, were also present at the mid-depth stations. In 2007, the number of taxa was higher at Station B19, and slightly lower at Station B31, as compared to the previous year.

No proliferation of warm-water species occurred at the mid-depth stations, and all taxa were within the geographical ranges as listed in Sears (2002). At Station B31, eighteen taxa occurred only during the operational period. Three taxa occurred exclusively during the preoperational period at Station B31. *Gloiosiphonia capillaris, Enteromorpha compressa, Elachista fucicola,* and *Rhizoclonium tortuosum* were found primarily in the operational period at Station B31 (Appendix Table 5-3). They are normally found in the shallow sublittoral zone (Sears 1998). Only three taxa occurred exclusively during the preoperational period at Station B31. At Station B19 fourteen taxa occurred only during the operational period, while six taxa occurred only during the preoperational period. Taxa found at Station B19 exclusively in the preoperational period include *Enteromorpha prolifera, Dumontia contorta, Sphacelaria radicans, Callithamnion tetragonum, Acrochaetium* sp. and *Ectocarpus fasciculatus.*

Total Biomass: Destructive Samples

Algal biomass generally decreased with increasing depth (Table 5-2, Figure 5-4). Depth ranged from 5 to 6 m at shallow subtidal stations (B17 and B35, respectively) and from 9 to 12 m at mid-depth stations (B31 and B19 respectively; Appendix Table 5-4). Mean biomass in 2007 at both shallow subtidal stations was lower than the preoperational and operational lower confidence limits (Table 5-2). At Station B35, the mean biomass in 2007 was the third lowest of the time series and at Station B17 it was the second lowest (Figure 5-4). There were no significant differences between stations or periods. The interaction term was not significant indicating that the relationship between stations was consistent between the preoperational and operational periods and there was no evidence of impact due to plant operation (Table 5-3).

At the mid-depth stations, mean biomass in 2007 was lower than both the preoperational and operational period lower confidence limits (Table 5-2). In 2007 biomass at Station B19 decreased from the previous year and was the lowest in the time series; at Station B31, biomass also decreased as compared to the previous year (Figure 5-4). ANOVA results indicate that biomass from the preoperational period was significantly greater than biomass from the operational periods. There were no differences between stations and the interaction term was not significant (Table 5-3). Biomass was generally higher at Station B31 in both periods; however, in 2001 through 2004 biomass was higher at Station B19 (Figure 5-4).

Macroalgal Community Analysis: Destructive Samples

Multivariate community analysis techniques were used to quantify similarity among

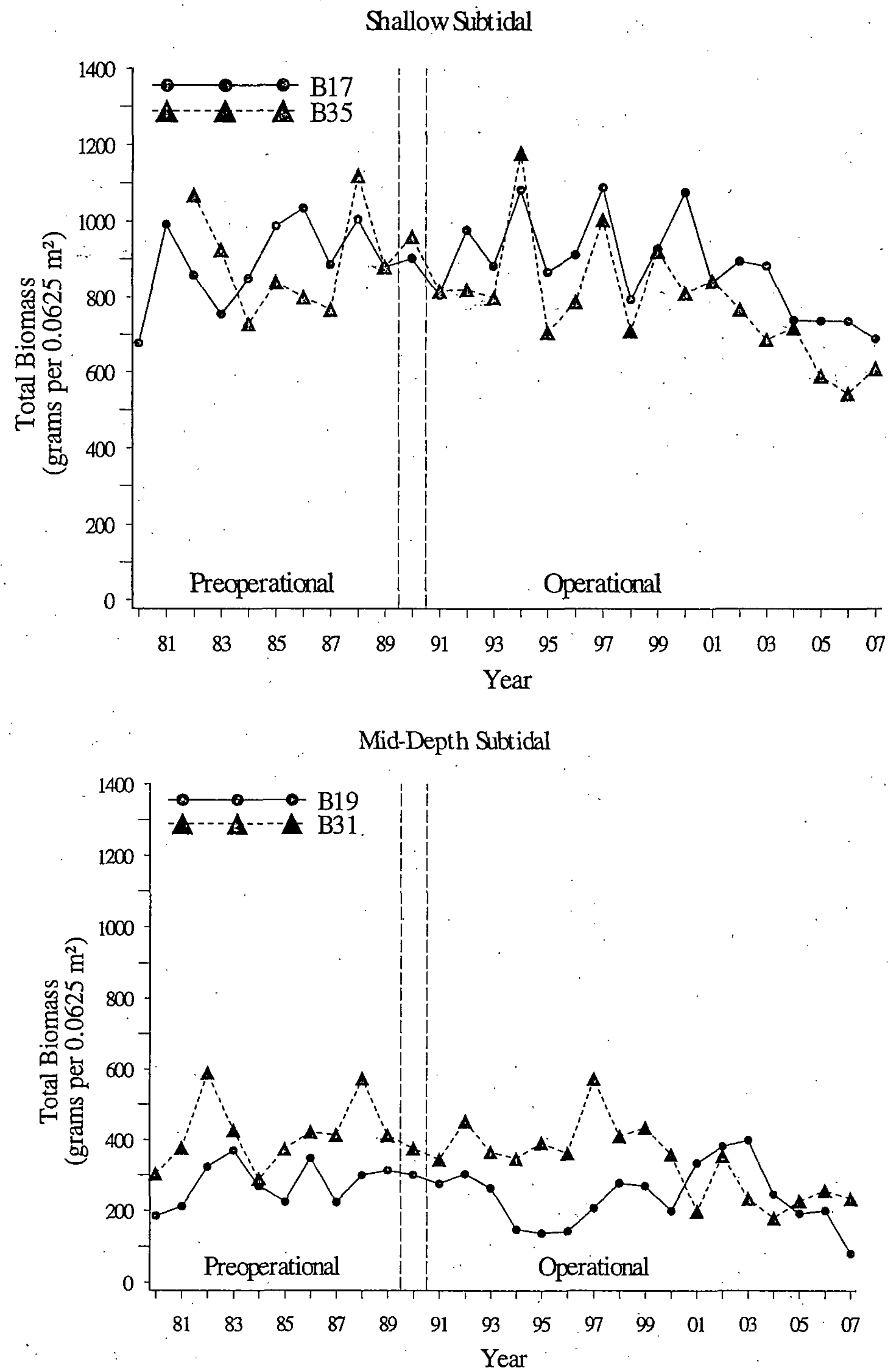


Figure 5-4. Annual mean biomass (g/m^2) from destructive samples collected triannually in the shallow subtidal and mid-depth subtidal zones during the preoperational and operational (1991-2007) periods. Seabrook Operational Report, 2007.

Table 5-4. Results of Segmented Regression Analysis on Number of Algal Taxa from Destructive Samples in the Mid-Depth Zones. Seabrook Operational Report, 2007.

Parameter	Station	Comparison Based on Breakpoints[a]	Period 1 Slope	Period 2 Slope
No. of taxa	B19	1980-1988 <1989-2007 NS	Positive*	Positive*
No. of taxa	B31	1980-1995 <1996-2007 ***	NS	NS

[a] As identified using segmented regression and tested for significance with a t-test.
NS = Not significant (p>0.05)
* = Significant (0.05≥p>0.01)
** = Highly Significant (0.01≥p>0.001)
*** = Very Highly Significant (0.001≥p)

all macroalgal collections made at the macrobenthic sampling stations in August since 1982. Communities were examined according to depth zone. For each group there were 52 station-year collections represented by 33 taxa in the shallow subtidal zone, and 26 taxa in the mid-depth subtidal zone. A power plant-induced impact to the macroalgal community could be inferred from the cluster analysis if the operational years' collections (1990-2007) were assigned to a separate group than the preoperational years' collections (1989 and earlier) at the nearfield stations only. Such a pattern was not seen in these results.

Collections from the two shallow subtidal stations (B17 and B35) did not show strong annual or spatial trends in the cluster analysis as evidenced by the high degree of similarity (77%) among all station-year combinations (Figure 5-5). Two groups encompassed most of the collections. Group 1 consisted primarily of collections from Station B17 from both the preoperational and operational periods, and Group 2 consisted of a mixture of collections from both stations and periods. This mixture of the preoperational and operational collections within a group is an indication that operation of Seabrook Station did not alter the existing community structure. Three collections from Station B35 taken in 2002, 2003 and 2005 were less closely allied with Groups 1 and 2 and were considered outliers. The MDS plot reinforces the results of the dendrogram and the three outliers from Station B35 in 2002, 2003 and 2005 are among the most distant from the groups. In 2007, Stations B17 and B35 were most similar to Group 2. No pattern of preoperational/operational differences or station differences occurred (Figure 5-5). Since the stations were significantly different during the preoperational period when tested with ANOSIM, it could not be utilized to test for the interaction of main effects (Table 5-5). Differences in the mean biomass of eight dominant taxa accounted for the major distinctions among the groups. Dominant taxa, comprising more that 1 g/m^2 of the biomass within a group, included *Chondrus crispus*, *Ceramium rubrum*, *Phyllophora/Coccotylus* complex, *Corallina officenalis*, *Cystoclonium purpureum v. cirrhosum*, *Phycodrys rubens*, and *Euthora cristata* (Table 5-6a). Group 1 was characterized by a higher total biomass, higher biomass of *Chondrus crispus,* and lower biomass of most other taxa compared to Group 2. *Chondrus crispus*, a perennial turf-forming red alga, ranked first in mean biomass in all groups; In Group 1, *Chondrus crispus* represented over 90% of the total biomass whereas it represented about 69% of the biomass in Group 2, 70% of the biomass in Station B35: 2002/2003, and only 32% of the total biomass at Station B35: 2005. *Cystoclonium purpureum v. cirrhosum* was a co-dominant with *Chondrus crispus* at Station B35: 2005, also representing about 32% of the total biomass. Biomass of *Phyllophora/Coccotylus* was 6 times higher in Group 2 when compared to Group 1, further contributing to

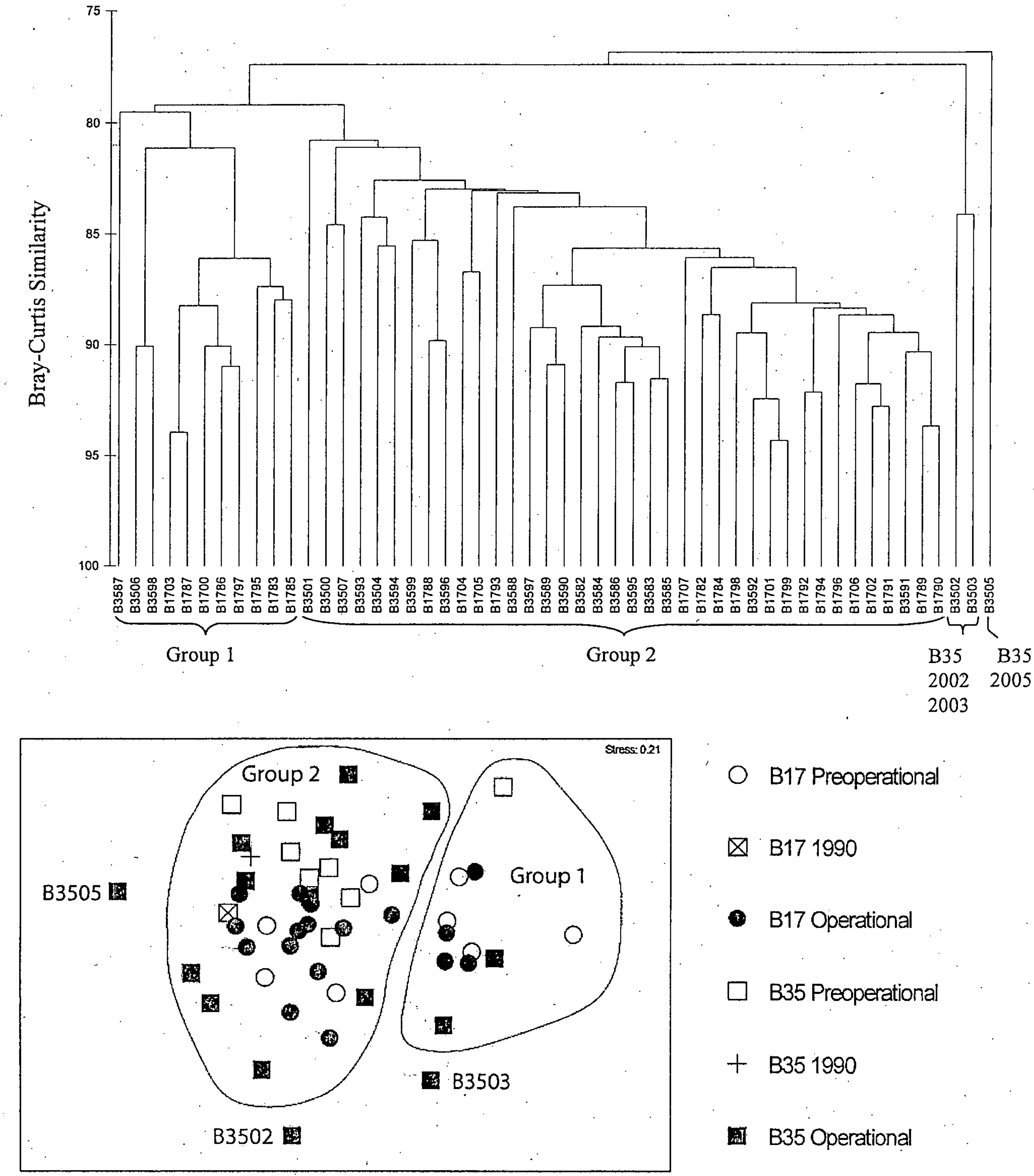


Figure 5-5. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August macroalgae collections from shallow subtidal Stations B17 and B35, 1982-2007. Seabrook Operational Report, 2007.

Table 5-5. Analysis of Similarities (ANOSIM) of Spatial and Temporal Differences between August Macroalgae Communities. Seabrook Operational Report, 2007.

Community	Comparison	R	p (%)[a]
Shallow Subtidal (B17, B35)	Period[b]	-0.01	50.5 NS
	Station[b]	0.25	0.1*
	B17 Pre vs. B35 Pre[c]	0.40	0.2*
	Interaction of Main Effects		Not testable
Mid-depth Subtidal (B19, B31)	Period[b]	-0.02	56.1 NS
	Station[b]	0.77	0.1*
	B19 Pre vs. B31 Pre[c]	0.94	0.1*
	Interaction of Main Effects		Not testable

[a] p=significance level of test statistic R.
* indicates significant differences, p<5.0%.
NS indicates no significant differences.
[b] Two-way crossed ANOSIM
[c] One-way ANOSIM

Table 5-6. Mean Biomass (g/m^2) and Upper and Lower 95% Confidence Limits of Dominant Algal Taxa from August Collections Taken Annually at Shallow Subtidal Stations B17 and B35 and the Mid-Depth Stations B19 and B31 in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2007.

A. Group Means of Macroalgae for Shallow Subtidal Zone

	Group 1			Group 2			B35:2002/2003			B35:2005
Taxon	LCL[a]	MEAN[b]	UCL	LCL	MEAN	UCL	LCL	MEAN	UCL	MEAN
Chondrus crispus	677.9	856.9	1083.0	473.3	544.3	625.9	0.0	356.2	194188	127.9
Ceramium rubrum	19.1	31.1	50.3	49.6	60.6	74.0	1.7	85.9	2768.3	14.4
Phyllophora/Coccotylus	11.6	19.7	32.9	95.9	118.2	145.6	0.0	36.2	11134	79.6
Corallina officinalis	12.0	16.8	23.5	8.2	11.5	15.9	0.0	2.7	102.5	1.5
Cystoclonium purpureum v. cirrhosum	3.5	6.5	11.4	18.8	26.0	35.7	0.0	4.6	130.0	127.4
Phycodrys rubens	3.0	4.0	5.4	11.0	13.3	16.1	0.0	6.5	117.2	21.0
Euthora cristata	2.0	3.2	4.8	6.8	8.5	10.5	0.0	5.2	252.1	21.0
Membranoptera alata	0.2	0.4	0.6	0.5	0.8	1.0	0.0	0.7	658.5	0.2
Chaetomorpha melagonium	0.0	0.3	0.5	0.2	0.3	0.4	0.0	0.0	0.5	0.1
Chaetomorpha picquotiana	0.0	0.2	0.7	0.1	0.3	0.5	0.0	5.1	76.1	0.8
Polysiphonia flexicaulis	0.0	0.2	0.4	0.0	0.1	0.3	0.5	0.6	0.7	0.0
Total biomass of taxa[c]		940.0			785.2			506.3		395.4

Table 5-6. (Continued)

B. Group Means of Macroalgae for Mid-depth Zone

Taxon	Group 1			Group 2			Group 3			B19:2007
	LCL	MEAN	UCL	LCL	MEAN	UCL	LCL	MEAN	UCL	MEAN
Phyllophora/Coccotylus	149.7	181.0	218.7	83.6	110.5	146.0	6.7	16.4	38.1	50.0
Phycodrys rubens	27.3	35.9	47.0	9.8	13.1	17.3	0.6	2.0	4.9	2.7
Euthora cristata	6.5	8.3	10.7	2.8	4.3	6.5	1.4	2.4	3.7	1.6
Ptilota serrata	4.3	5.8	7.7	1.3	2.1	3.1	0.0	0.1	0.3	1.2
Corallina officinalis	3.0	4.1	5.6	31.6	41.1	53.3	10.6	24.1	53.2	2.6
Membranoptera alata	2.0	2.9	3.9	1.9	3.0	4.5	0.4	1.2	2.4	1.3
Cystoclonium purpureum v. cirrhosum	1.7	2.5	3.5	0.8	1.6	2.8	0.0	0.8	4.6	0.1
Chondrus crispus	0.4	0.7	1.0	26.9	40.4	60.6	2.2	32.1	340.3	0.8
Polysiphonia stricta	0.1	0.2	0.4	0.6	1.3	2.3	9.3	23.9	59.3	0.0
Ceramium rubrum	0.0	0.1	0.2	0.3	0.5	0.8	0.2	3.9	19.8	0.0
Scagelia pylaisaei	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Desmarestia aculeata	0.0	0.0	0.0	0.0	0.5	1.2	0.0	0.4	1.2	0.0
Total biomass of taxa [c]		241.6			219.1			109.9		60.3

[a] LCL = Lower 95 % Confidence limit.
[b] UCL = Upper 95% Confidence limit.
[c] Sum of the biomass of all species used in the cluster analysis.

the differences between groups. Mean biomass of *Ceramium rubrum, Cystoclonium purpureum v. cirrhosum* and *Phycodrys rubens* was also higher in Group 2 than in Group 1. The *Phyllophora/ Coccotylus* complex and *Phycodrys rubens* are more common at the mid-depth stations, while *Ceramium rubrum* and *Cystoclonium perpureum v. cirrhosum* are aseasonal annuals found as epiphytes on perennial algae such as *Chondrus* or in the sublittoral fringe attached to rock. *Chaetomorpha picquotiana* is an unattached filamentous alga, often found unattached on the bottom or entangled with coarse algae (Sears 2002), and was most abundant at the outliers, B35:2002/2003.

The multivariate analysis of mid-depth subtidal collections (Stations B19 and B31) identified assemblages that separated by station (Group 1: Station B19; Groups 2 and 3: Station B31; Figure 5-6). Both the cluster analysis and the MDS plot showed clear spatial differences. No differences between the preoperational and operational periods were evident at Stations B19 and B31, although annual differences were apparent (Figure 5-6). ANOSIM indicated significant differences between stations, but could not be used to test for the interaction of main effects as the stations were significantly different in the preoperational period (Table 5-5). Differences in algal assemblages at these stations likely reflect differences in depth and bottom substrate. Station B31 was 9.1 m deep and the substrate was 48% ledge, 20% cobble and the remainder was a mixture (Appendix Table 5-4). Station B19 was 12.2 m deep with a substrate of 69% ledge, 6% cobble and 25% was a mixture. In 2007, Station B19 separated from other collections due to low biomass of all species and was an outlier in the

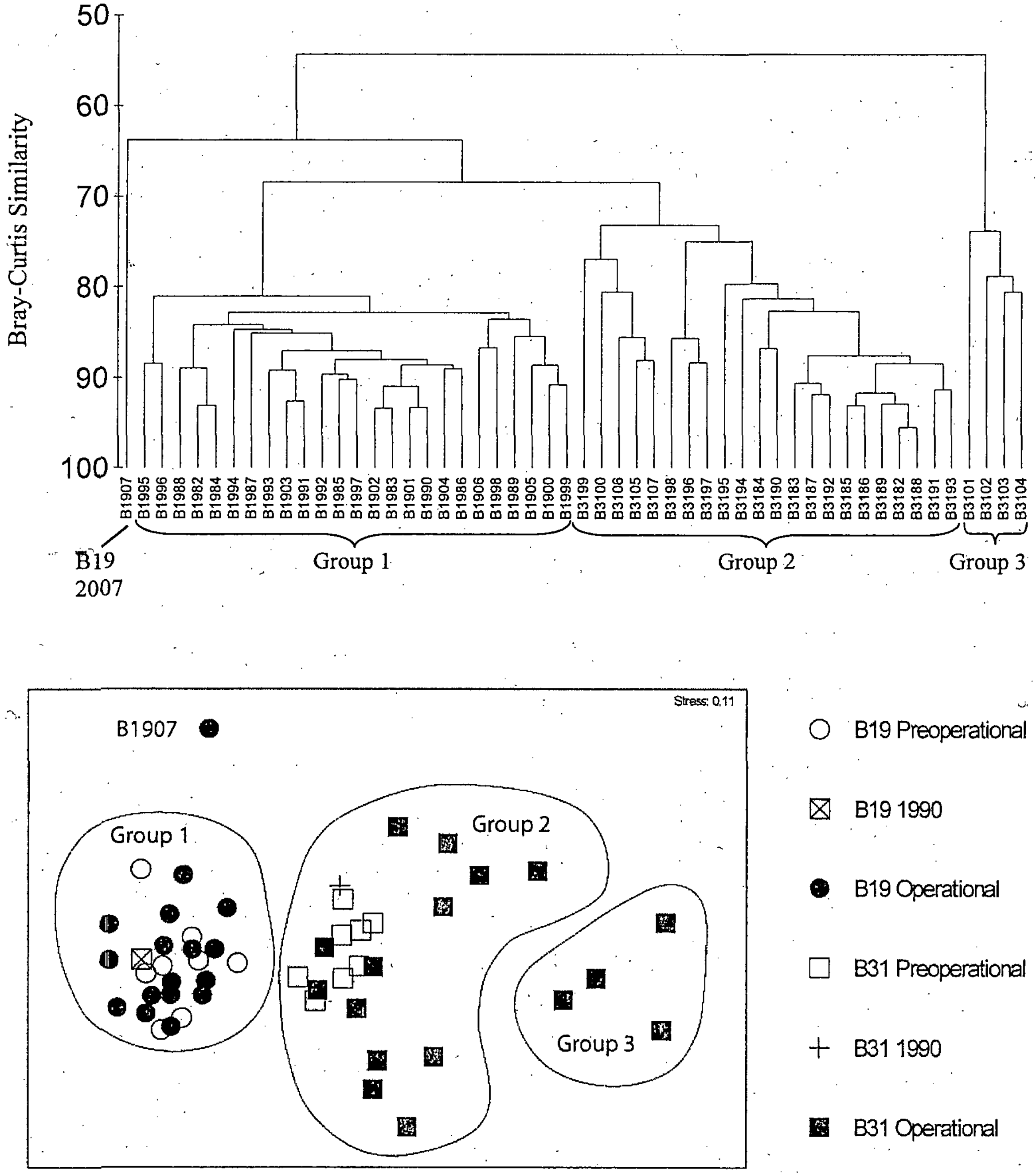


Figure 5-6. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August macroalgae collections from mid-depth subtidal Stations B19 and B31, 1982-2007. Seabrook Operational Report, 2007.

multivariate analysis (Figure 5-6). Since consistent differences between preoperational and operational collections have not been found at nearfield Station B19, these data suggest there is no impact from plant operation.

Taxa that accounted for distinctions between Groups 1 and 2 were primarily *Phyllophora/Coccotylus, Phycodrys rubens, Corallina officinalis* and *Chondrus crispus* (Table 5-6b). Total biomass was similar between Groups 1 and 2, but Group 1 (composed of collections from Station B19) was dominated by the deep-water species, *Phyllophora/Coccotylus* (Sears 2002), and *Phycodrys rubens*. In Group 2 (composed of collections from Station B31) *Phyllophora/Coccotylus* also ranked first, but at a lower biomass than Group 1, followed by species more typical of shallow water, *Corallina officinalis* and *Chondrus crispus*. Total biomass in Group 3 was lower by half compared to Groups 1 and 2 and was dominated by *Chondrus crispus, Corallina officinalis,* and *Polysiphonia stricta*. Biomass of *Phyllophora/Coccotylus* in Group 3 was much lower compared to Groups 1 and 2. The outlier, Station B19:2007, had the lowest overall biomass. *Phyllophora/Coccotylus* remained dominant, but at only one third of the biomass typical for Station B19.

Rarely-found taxa contribute little to the Bray-Curtis similarity indices due to the high biomass of dominant taxa in these samples. Those taxa comprising less than 2% of the total occurrences were not included in the multivariate analyses. Therefore, a comparison among time periods of frequency of occurrence was performed to examine trends in the occurrence of rarely encountered species (Table 5-7).

Ten taxa were found in both preoperational (1989 and earlier) and operational (1990-2007) periods. Seven of these taxa (*Fimbrifolium dichotomum, Ulva lactuca, Mastocarpus stellatus, Ectocarpus fasciculatus, Porphyra miniata, Palmaria palmata,* and *Polysiphonia* sp.) have decreased in frequency of occurrence in the operational period, while three species (*Polysiphonia lanosa, Porphyra umbilicalis,* and *Sphacelaria cirrosa*) have become more common in the operational period. Two taxa with cold-water affinities have declined in frequency during the operational period. *Porphyra miniata* is an ephemeral winter/spring annual only encountered sporadically in Seabrook collections. It is generally absent from local collections from July-September (Mathieson and Hehre 1986). *Fimbrifolium dichotomum*, a subtidal perennial, also decreased between periods. These two taxa are near the southern ends of their ranges, which extend from Cape Cod to Newfoundland (Sears 2002). *F. dichotomum* (as *Rhodophyllis dichotoma*) is near the end of its growing season during the August collections, which may explain possible fluctuations in its presence or absence. Additionally, records have shown that it was rarely found in the Hampton-Seabrook Estuary System during the pre-operational period (Mathieson and Hehre 1986, Bird and McLachlan 1992) suggesting that these decreases are probably not related to plant operation.

Six species were found in collections from preoperational years, but have not yet been collected in the operational period: *Enteromorpha prolifera, Dumontia contorta, Neosiphonia (=Polysiphonia) harveyi, Petalonia fascia, Ceramium deslongchampii,* and *Enteromorpha* sp. *Petalonia fascia* is a shallow water species associated with a cold water habitat, typically found in late winter to early spring (Sears 1998; Taylor 1957). *P. fascia* was not collected in the operational period, and it occurred very rarely in the preoperational period (Table 5-7). *Neosiphonia harveyi* is a summer annual and an introduced species from Japan (Carlton 2004). In 1995, one hundred percent cover of *Neosiphonia* (= *Polysiphonia*) *harveyi* was ob

Table 5-7. A Comparison of Percent Frequency of Occurrence of Rarely Found Species (overall Frequency of Occurrence < 4%) from Destructive Samples Collected In August During Preoperational (1978-1989) and Operational (1990-2007) Periods, and Over All Years (1978-2007). Seabrook Operational Report, 2007.

Species	Preoperational	Operational	All Years
Polysiphonia lanosa	2.4	2.8	2.6
Ectocarpus siliculosus	0.0	3.1	1.9
Porphyra umbilicalis	1.4	1.9	1.8
Fimbrifolium dichotomum	3.8	0.6	1.8
Ulva lactuca	1.9	1.1	1.4
Mastocarpus stellatus	1.9	0.8	1.2
Porphyra sp.	0.0	1.7	1.1
Ectocarpus fasciculatus	2.4	0.3	1.1
Porphyra miniata	1.9	0.3	0.9
Sphacelaria cirrosa	0.5	0.8	0.7
Palmaria palmata	0.9	0.3	0.5
Pterothamnion plumula	0.0	0.8	0.5
Enteromorpha prolifera	0.9	0.0	0.4
Sphacelaria plumosa	0.0	0.6	0.4
Dumontia contorta	0.9	0.0	0.4
Polysiphonia sp.	0.5	0.4	0.5
Neosiphonia (=Polysiphonia) harveyi	0.9	0.0	0.4
Enteromorpha sp.	0.5	0.0	0.2
Enteromorpha compressa	0.0	0.3	0.2
Enteromorpha intestinalis	0.0	0.3	0.2
Blidingia minima	0.0	0.3	0.2
Cladophora sericea	0.0	0.3	0.2
Sphacelaria radicans	0.0	0.3	0.2
Petalonia fascia	0.5	0.0	0.2
Ceramium deslongchampii	0.5	0.0	0.2
Polysiphonia elongata	0.0	0.3	0.2

served at an urchin barren site at White Island in the Isle of Shoals (Harris and Tyrrell 2001). It has not been observed in our study area since 1990. *E. prolifera* is most commonly found in estuaries, and *C. deslongchampii* is typically found in the mid- to lower intertidal, often under overhanging fronds of algae which provide shade (Sears 2002). *D. contorta* is a winter-late spring annual that occurs predominately in the mid- to lower intertidal or to 7 m in the shallow subtidal (Sears 2002). All species are within their range according to Sears (2002).

Ten species have been identified as occurring only during the operational period (1990-2007): *Ectocarpus siliculosus*, *Porphyra* sp., *Pterothamnion plumula*, *Sphacelaria plumosa*, *Enteromorpha compressa*, *Enteromorpha intestinalis*, *Blidingia minima*, *Cladophora sericea*, *Sphacelaria radicans*, and *Polysiphonia elongata*. None of these 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. Of the uncommon species that were collected in operational period, all were well within their geographical ranges. *Ectocarpus siliculosus* and *Pterothamnion plumula* range from just south of Cape Cod to Nova Scotia or further north (Sears 1998).

Other studies that monitor the effects associated with construction and operation of a nuclear power plant on attached macroalgal flora have documented that incursion of a thermal effluent to nearby rocky shore sites caused an alteration of the algal community at those sites (Vadas et al. 1976; Wilce et al. 1978; NUSCO 1994; NUSCO 1998). Specifically, there was an increased frequency of occurrence for species requiring or tolerant of warm water, and an absence or reduced frequency of occurrence for species with cold-water affinities. Power plant impact would be evident if similar trends were observed in the macroalgal community near Seabrook Station. All of the 26 rare species (Table 5-7) are within their geographical ranges as listed in Sears (2002). There is no indication of an increase in "southerly" species as would be expected with an overall warming of the bottom water of the Gulf of Maine or locally due to plant operation. In non-destructive collections *Codium fragile* spp. *tomentosoides*, the "southerly" invasive species that is moving in a northerly direction, was recorded only in 1990 and 1998, and has not become established at our sampling stations.

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, 1981b; Mathieson and Hehre 1986), and have maintained a high level of stability as reflected in the consistency of the dominant algal species in each depth zone. The warm-water species, *Codium fragile* subsp. *tomentosoides* (Asiatic green algae) is now the dominant canopy species to a depth of 8 m around much of the sheltered areas near Isles of Shoals, NH and is slowly spreading within New Hampshire and the southern Maine coastal zone (Harris and Mathieson 2000, Mathieson et al. 2003). It occurred within the Seabrook study area in 1998 and 1999, but did not occur at our sampling stations in other years. These factors taken together indicate that there has not been a community shift toward an assemblage dominated by warm-water species, and that there has been no measurable impact on the local macroalgal community as a result of Seabrook Station.

5.3.1.2 Selected Macroalgal Species: Destructive Samples

Chondrus crispus

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 dominate 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; Sears 1998). Although this species is reported to be common to depths of 20 m (Sears 2002), biomass has historically been substantially lower at the mid-depth stations (9 – 12 m) than the shallow subtidal stations (5 – 6 m) in the Seabrook study area. Owing to its predominance in the Seabrook shallow subtidal area, *C. crispus* was selected for further, more detailed analyses.

Historically, *Chondrus crispus* comprised over 50% of the total biomass at shallow subtidal stations, with the average biomass during the preoperational and operational periods exceeding 400 g/m^2 (Tables 5-8, 5-2).

Table 5-8. Arithmetic Means and 95% Confidence Limits of *Chondrus crispus* Biomass (g per m^2) Collected in Triannual (May, August, November), Destructive Samples During 2006 and During the Preoperational and Operational Periods. Seabrook Operational Report, 2007.

		Preoperational [a]			2007	Operational [b]		
		LCL [c]	Mean	UCL [d]	Mean	LCL	Mean	UCL
Shallow subtidal	B17	541.8	652.2	762.6	449.4	546.6	613.5	680.4
	B35	433.9	477.3	520.8	321.7	343.8	405.2	466.5

[a] Preoperational years are 1982-1989. The years are the same years used for the ANOVA.
[b] Operational years are 1991-2007. The years are the same years used for the ANOVA.
[c] LCL = Lower 95% confidence limit.
[d] UCL = Upper 95% confidence limit.

Biomass was usually lower at Station B35 than at Station B17 (Figure 5-7). In 2007, the biomass of *C. crispus* decreased at both stations. In 2007, mean biomass at Stations B17 and B35 was below the preoperational and operational lower confidence limits at both stations. Biomass was not significantly different between periods, but was significantly higher at Station B17 (Table 5-9). This relationship between stations was consistent across periods as indicated by the non-significant interaction term (Table 5-9).

5.3.1.3 Non-destructive Monitoring Program

Kelp Canopy

Extensive canopies of several kelp species cover subtidal zones (4-18 m) in the northwestern Atlantic, and can account for up to 80% of total algal biomass (Mann 1973). From the 1980s to the early 1990s, kelp forests reached an all-time low in their distribution and abundance throughout the Gulf of Maine (Steneck 1997). Steneck et al. (2002) surmised that kelp forests dominated the phytobenthos while predatory fish such as Atlantic cod were abundant at least through the 1930s. With the decline of predatory fish, sea urchins became abundant, and kelp declined. In 1987, fishing pressure caused a rapid decline in sea urchin distribution and abundance (Steneck 1997, Vavrinec 2003). In response, the kelp forests show recovery (Steneck et al. 2002). 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; Mathieson et al. 1991).

Laminaria spp. were found in both shallow (B17, B35) and mid-depth (B19, B31) zones during both periods (Table 5-10). In 2007 *Laminaria saccharina* was the dominant kelp species at shallow subtidal stations, while *Agarum clathratum* was the dominant at the mid-depth stations (Table 5-10). *Laminaria digitata* has been secondary in abundance at both the shallow subtidal and mid-depth stations throughout the study period. During the operational period, higher amounts of *L. digitata* were found at farfield stations in comparison to the nearfield stations in both depth zones.

Laminaria digitata

In the shallow subtidal zone, *Laminaria digitata* density in 2007 was below the preoperational and operational lower confidence limits at Stations B17 and B35 (Table 5-10). In 2007, density decreased at Station B35 and declined slightly at Station B17 (Figure 5-8).

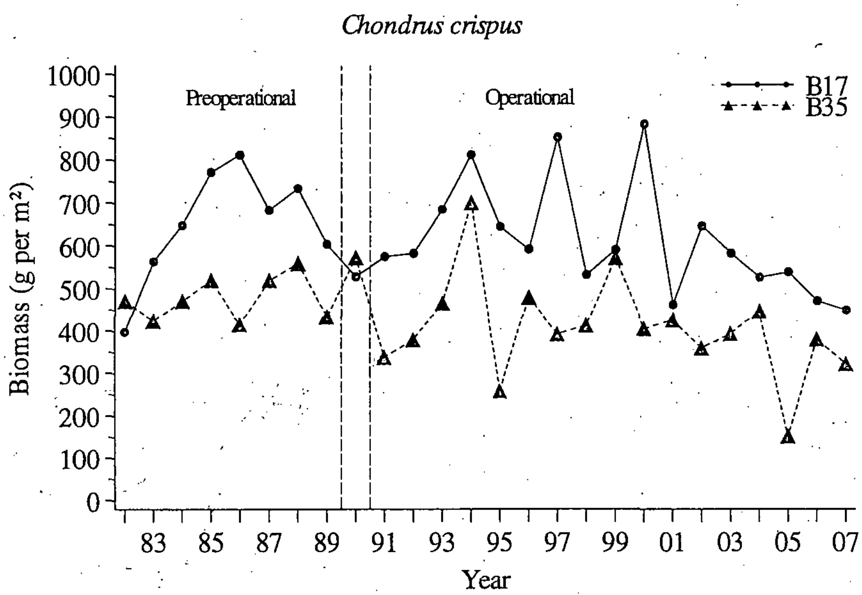


Figure 5-7. Annual mean density (grams per m²) of *Chondrus crispus* in destructive samples from the shallow subtidal zone (Stations B17 and B35), 1982-2007. . Seabrook Operational Report, 2007.

Table 5-9. Results of Analysis of Variance of *Chondrus crispus* Biomass (g per m²) Collected in Triannual (May, August, November) Destructive Samples During the Preoperational (1982-1989) and Operational (1991-2007) Periods. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics (Square root transformed)			Multiple Comparisons[k]
Chondrus crispus	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 71.5	1.08	0.1535	
Shallow Subtidal	**Random Effects**	**Estimate[j]**	**χ^2**	**p**	
(B17, B35)	Year (Preop-Op)[b]	0.00	0.00	0.4987	
(square root	Month(Year)[c]	12.25	71.03	<0.0001	
transformation)	Station[d]	10.86	2.86	0.0434*	B17>B35
	Preop-Op X Station[e]	<0.01	0.00	0.4988	
	Station X Year (Preop-Op)[f]	1.80	3.77	0.0261*	
	Error	42.17			

[a] Preop-Op compares preoperational period to operational period, regardless of station.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year. (Apr, Jul, Oct)
[d] Stations (Nearfield=P2, Farfield = P7) 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_0: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

Table 5-10. Preoperational and Operational Mean Densities of Kelp Species (no. per 100 m^2) and Percent Frequency of Occurrence of Understory Species from the Non-destructive Monitoring Program.[a] Seabrook Operational Report, 2007.

	Station	Preoperational[b]			2007	Operational[c]		
		LCL[d]	Mean	UCL[e]	Mean	LCL	Mean	UCL
Kelp (No. per 100 m^2)								
Laminaria digitata	B17	140.6	213.9	287.3	3.2	5.6	16.7	27.7
	B35	96.5	155.8	215.1	23.0	49.5	73.6	97.7
	B19	81.5	139.9	198.3	4.0	3.6	8.4	13.2
	B31	401.6	500.2	598.7	122.2	112.5	168.3	224.1
Laminaria saccharina	B17	270.7	415.1	559.4	9.5	73.8	151.8	229.7
	B35	210.9	325.7	440.5	101.5	252.8	336.6	420.4
	B19	2.0	59.1	116.3	0.0	1.7	11.3	20.9
	B31	59.6	95.5	131.3	6.3	34.2	54.3	74.4
Alaria esculenta	B19	0.0	2.4	7.2	0.0	0.4	2.5	4.6
	B31	19.9	75.2	130.5	0.0	23.7	44.6	65.5
Agarum clathratum	B19	613.5	786.6	959.6	766.4	776.2	959.3	1,142.3
	B31	280.2	366.4	452.6	444.3	389.4	497.4	605.3
Understory (% frequency)								
Chondrus crispus	B17	67.5	71.8	76.0	74.7	75.7	78.7	81.7
	B35	46.5	54.1	61.7	69.3	64.0	68.2	72.4
	B19	0.4	4.2	7.9	9.0	6.9	9.5	12.2
	B31	14.2	21.0	27.8	25.3	24.4	29.4	34.4
Phyllophora /Coccotylus	B17	14.6	20.3	26.0	24.7	19.6	22.9	26.2
	B35	11.2	19.9	28.7	22.0	15.7	20.0	24.3
	B19	28.5	34.0	39.6	38.7	33.3	39.8	46.2
	B31	25.5	31.8	38.0	43.0	21.6	26.3	31.1
Ptilota serrata	B17	0.0	0.8	1.6	0.7	0.2	1.9	3.6
	B35	0.0	0.6	1.1	6.0	0.9	3.5	6.2
	B19	28.6	35.6	42.5	35.0	33.6	38.9	44.2
	B31	9.3	13.1	16.8	9.0	8.0	12.9	17.7

[a] All taxa recorded along non-destructive subtidal transects in April, July, and October.
[b] Mean of annual means. Preop years for kelps - Stations B19, B31: 1978-1989; Station B17: 1982-1989; Station B35: 1982-1989; for understory species-Stations B19, B31: 1981-1989; Stations B17 and B35: 1982-1989.
[c] 1991-2007.
[d] LCL = Lower 95% confidence limit.
[e] UCL = Upper 95% confidence limit

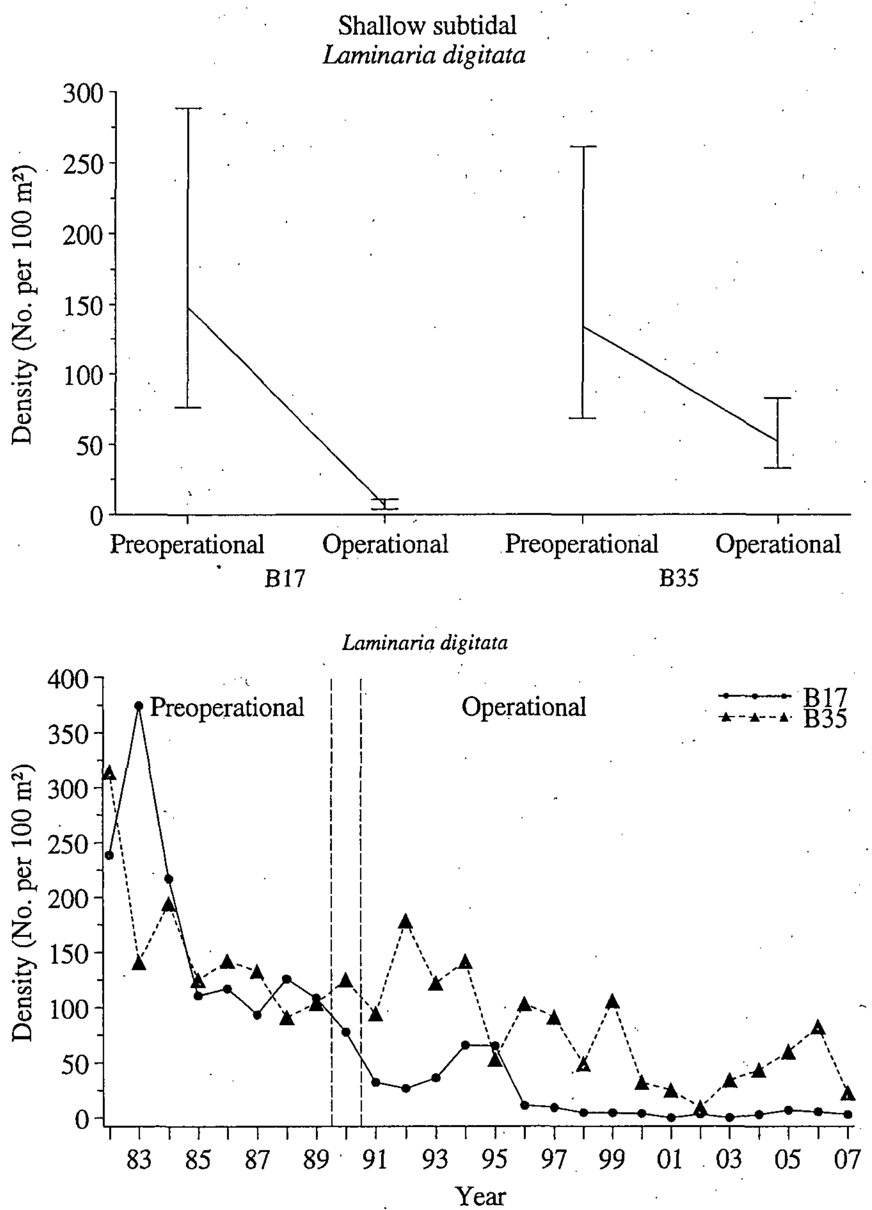


Figure 5-8. Comparison between stations of number of holdfasts/100 m^2 of *Laminaria digitata* in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density in the shallow subtidal. Seabrook Operational Report, 2007.

The decline that occurred between the preoperational period and the operational period at B17 (nearfield) was greater than the decline at B35 (farfield) (Figure 5-8) and resulted in a significant interaction term, which is consistent with a possible plant impact (Table 5-11). Further analysis indicated that at Station B17, mean density from 1982 through 1999 was significantly higher than the period after 2000, and a negative trend in density occurred during both periods (Table 5-12, Figure 5-8). This indicates that the decline started in the early 1980s before the plant became operational. In contrast, annual densities of *L. digitata* at Station B35 declined significantly between 1982 and 2001, and remained low from 2002 through 2007 (Table 5-12, Figure 5-8). Since the decline began during the preoperational period and occurred at both the nearfield and farfield stations, this is likely to be a regional occurrence, not a local effect from plant operation. Bertness et al. (2002) removed the seaweed (fucoid) community down to bare rock at a location in coastal Maine and found that it did not recover after three years in the presence of consumers (snails and crabs), although it did recover when consumers were excluded by cages. After the second year, a modest number of fucoid recruits were found in the non-caged section, but only in crevices that refuge from consumers. *L. digitata* at Station B17 has not rebounded after a decade of low density, and two years of 0.0 density in 2001 and 2003, although density of *Chondrus crispus* remains high (Figure 5-7).

Percent cover of *Laminaria digitata* is a reflection of the size of the thalli within each quadrat and was estimated by divers from the same quadrats used to determine density. In the shallow subtidal zone, the percent cover of *L. digitata*, on average, has been below 30% in the farfield area and below 15% in the nearfield area during all years of the study (Figure 5-9). These levels are relatively low compared to Cape Neddick, ME which had 100% cover in July 1989 (Lambert et. al. 1992).

Physical factors are generally favorable to *Laminaria digitata* in the shallow subtidal zone in that the substratum is composed of rock outcrop. Therefore some other physical or biological factor limits the distribution of *L. digitata* in the shallow subtidal zone. Seawater temperature is the physical factor that has the greatest potential to be influenced by station operation. To date there has been no significant change in bottom water temperatures attributed to Seabrook Station. In 2007, the mean temperature was 0.1°C higher than the mean temperature during the operational period at the nearfield station and equal at the farfield station (Table 2-1). Temperature did not appear to limit the distribution of laminarians in the Seabrook study area (Section 5.3.1.3 of NAI 2003). In 2007, the bottom water temperature at nearfield Station P2 (the temperature monitoring station closest to the nearfield benthic stations) ranged from 2.3 to 21.6°C (See Section 2.0, Table 2-1), within the tolerance of *L. digitata*. Another physical factor that could influence *Laminaria digitata* survival in this zone is periodic removal by storm events. Studies carried out along exposed coastlines have shown that episodic periods of large waves exert a critical role in determining abundance and relative species composition of assemblages of kelp (Dayton and Tegner 1984, Dayton et al. 1984, Seymour et al. 1989, Graham et al. 1997). Wave forces were important to the mortality and morphology of two species of understory kelp (*Agarum fimbriatum, Costaria costata*) in the San Juan Archipelago (Duggins et al. 2003). Storm-generated waves are also important to plant population dynamics in an provided inland island archipelago (San Juan Archipelago) at two stations with depths that ranged from 8 to 10 meters (Eckman et al. 2003). It is possible that the decrease in the annual mean at Station B17 between 1990 and

Table 5-11. Results of Analysis of Variance of the Number of Kelp per 100 m^2 and the % Frequency of Occurrence of Understory Species from the Non-Destructive Monitoring Program. Seabrook Operational Report, 2007.

Parameter	Depth Zone (Stations)	Source of Variation	Test Statistics			Multiple Comparisons[k]
Kelps (no./100 m^2)						
Laminaria digitata	**Shallow Subtidal (B17, B35)**	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
		Preop-Op[a]	1, 2.45	3.43	0.1816	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	0.10	12.08	0.0003*	
		Month(Year)[c]	<0.01	0.19	0.3312	
		Station[d]	<0.01	0.00	0.5000	
		Preop-Op X Station[e]	0.19	20.54	>0.0001*	B17Pre B35Pre>B35Op>B17Op
		Station X Year (Preop-Op)[f]	0.03	6.33	0.0059*	
		Error	0.07			
Laminaria digitata	**Mid-Depth (B19, B31)**	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
		Preop-Op[a]	1, 1.3	5.53	0.2319	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	0.07	7.69	0.0028*	
		Month(Year)[c]	0.03	5.83	0.0079*	
		Station[d]	0.47	0.74	0.1945	
		Preop-Op X Station[e]	0.18	19.62	<0.0001*	B31Pre>B31Op B19Pre>B19Op
		Station X Year (Preop-Op)[f]	0.05	16.78	<0.0001*	
		Error	0.06			
Laminaria saccharina	**Shallow Subtidal (B17,B35)**	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
		Preop-Op[a]	1, 1.28	0.95	0.4779	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	0.07	3.58	0.0292	
		Month(Year)[c]	0.03	2.71	0.0498	
		Station[d]	0.01	0.01	0.4566	
		Preop-Op X Station[e]	0.10	6.22	0.0063*	B35Pre B35Op B17Pre>B17Op
		Station X Year (Preop-Op)[f]	0.07	11.24	0.0004*	
		Error	0.09			
Laminaria saccharina	**Mid-Depth (B19, B31)**	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
		Preop-Op[a]	1, 2.43	8.89	0.0760	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	0.08	5.13	0.0118*	
		Month(Year)[c]	0.08	7.43	0.0032*	
		Station[d]	0.23	1.60	0.1030	
		Preop-Op X Station[e]	0.02	1.53	0.1079	
		Station X Year (Preop-Op)[f]	0.04	3.98	0.0231*	
		Error	0.14			

(continued)

Table 5-11. (Continued)

Parameter	Depth Zone (Stations)	Source of Variation	Test Statistics			Multiple Comparisons[k]
Alaria esculenta	Mid-Depth	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	(B19, B31)	Preop-Op[a]	1, 1.02	0.50	0.6073	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	<0.01	0.00	0.4727	
		Month(Year)[c]	0.01	0.15	0.3508	
		Station[d]	0.83	1.82	0.0890	
		Preop-Op X Station[e]	0.07	3.05	0.0404*	B31Pre>B31Op> B19Op B19Pre
		Station X Year (Preop-Op)[f]	0.12	18.03	<0.0001*	
		Error	0.16			
Agarum clathratum	Mid-Depth	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	(B19, B31)	Preop-Op[a]	1, 27	3.00	0.0945	
(#/100 m^2)		**Random Effects**	**Estimate[j]**	χ^2	p	
Data log (X+1) transformed		Year (Preop-Op)[b]	0.02	11.25	0.0004*	
		Month(Year)[c]	<0.01	0.75	0.1934	
		Station[d]	0.05	4.12	0.0212*	B19>B31
		Preop-Op X Station[e]	0.00	0.00	0.4999	
		Station X Year (Preop-Op)[f]	0.01	5.37	0.0103*	
		Error	0.02			
Understory (% frequency)	**Shallow Subtidal**	**Fixed Effects**	**DF[g]**	**F[h]**		
Chondrus crispus	(B17, B35)	Preop-Op[a]	1, 3.73	12.11	0.0283*	Op>Preop
Data		**Random Effects**	**Estimate[j]**	χ^2	p	
Arcsin √Y transformed		Year (Preop-Op)[b]	8.14	3.34	0.0339*	
		Month(Year)[c]	9.27	2.73	0.0492*	
		Station[d]	33.61	2.30	0.0649	
		Preop-Op X Station[e]	0.87	0.20	0.3258	
		Station X Year (Preop-Op)[f]	<0.01	<0.01	0.4998	
		Error	34.93			
Chondrus crispus	Mid-Depth)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
Data	(B19, B31	Preop-Op[a]	1, 24	6.59	0.0169*	Op>Preop
Arcsin √Y transformed		**Random Effects**	**Estimate[j]**	χ^2	p	
		Year (Preop-Op)[b]	20.48	7.95	0.0024*	
		Month(Year)[c]	9.20	1.59	0.1039	
		Station[d]	150.37	4.90	0.0134 *	B31>B19
		Preop-Op X Station[e]	<0.01	<0.01	0.5000	
		Station X Year (Preop-Op)[f]	<0.01	<0.01	0.5000	
		Error	49.29			
Phyllophora/Coccotylus	**Shallow**	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Subtidal	Preop-Op[a]	1, 23.1	0.01	0.9352	
Data log (X+1) transformed	**(B17,B35)**	**Random Effects**	**Estimate[j]**	χ^2	p	
		Year (Preop-Op)[b]	0.01	0.37	0.2712	
		Month(Year)[c]	0.01	0.77	0.1901	
		Station[d]	<0.01	0.38	0.2681	
		Preop-Op X Station[e]	<0.01	<0.01	0.5000	
		Station X Year (Preop-Op)[f]	0.02	2.93	0.0434*	
		Error	0.08			

(continued)

Table 5-11. (Continued)

Parameter	Depth Zone (Stations)	Source of Variation	Test Statistics			Multiple Comparisons[k]
Phyllophora/Coccotylus	Mid Depth	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	(B19, B31)	Preop-Op[a]	1, 1.38	0.32	0.6502	
Data log (X+1) transformed		**Random Effects**	**Estimate[j]**	χ^2	**p**	
		Year (Preop-Op)[b]	<0.01	0.27	0.3002	
		Month(Year)[c]	0.01	2.79	0.0475*	
		Station[d]	<0.01	0.18	0.3340	
		Preop-Op X Station[e]	<0.01	0.95	0.1643	
		Station X Year (Preop-Op)[f]	0.01	3.76	0.0263*	
		Error	0.03			
Ptilota serrata	Shallow	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
Data	Subtidal	Preop-Op[a]	1, 7.27	1.11	0.3259	
Arcsin √Y transformed	(B17,B35)	**Random Effects**	**Estimate[j]**	χ^2	**p**	
		Year (Preop-Op)[b]	10.99	4.64	0.0156*	
		Month(Year)[c]	<0.01	<0.01	0.4998	
		Station[d]	<0.01	<0.00	0.4998	
		Preop-Op X Station[e]	1.22	0.74	0.1955	
		Station X Year (Preop-Op)[f]	0.86	0.04	0.4284	
		Error	41.17			
Ptilota serrata	Mid-Depth	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
Data	(B19, B31)	Preop-Op[a]	1, 4.98	0.01	0.9130	
Arcsin √Y transformed		**Random Effects**	**Estimate[j]**	χ^2	**p**	
		Year (Preop-Op)[b]	19.36	6.07	0.0069*	
		Month(Year)[c]	14.07	3.82	0.0253*	
		Station[d]	159.62	3.31	0.0345*	B19>B31
		Preop-Op X Station[e]	1.52	0.33	0.2837	
		Station X Year (Preop-Op)[f]	3.49	0.47	0.2455	
		Error	39.11			

[a] Preop-Op compares preoperational period to operational period, regardless of station; preoperational years: all kelps (B17,B35): 1982-1989; all kelps (B19,B31) = 1978-1989; understory species (B17,B35) = 1982-1989; understory species (B19,B31) = 1981-1989; operational period for all species = 1991-2007. 1990 is excluded from data base since which use all three seasons since the plant became operational in 1990.
[b] Year nested within preoperational and operational periods regardless of station.
[c] Month nested within Year. (Apr, Jul, Oct)
[d] Stations (Nearfield=P2, Farfield = P7) 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

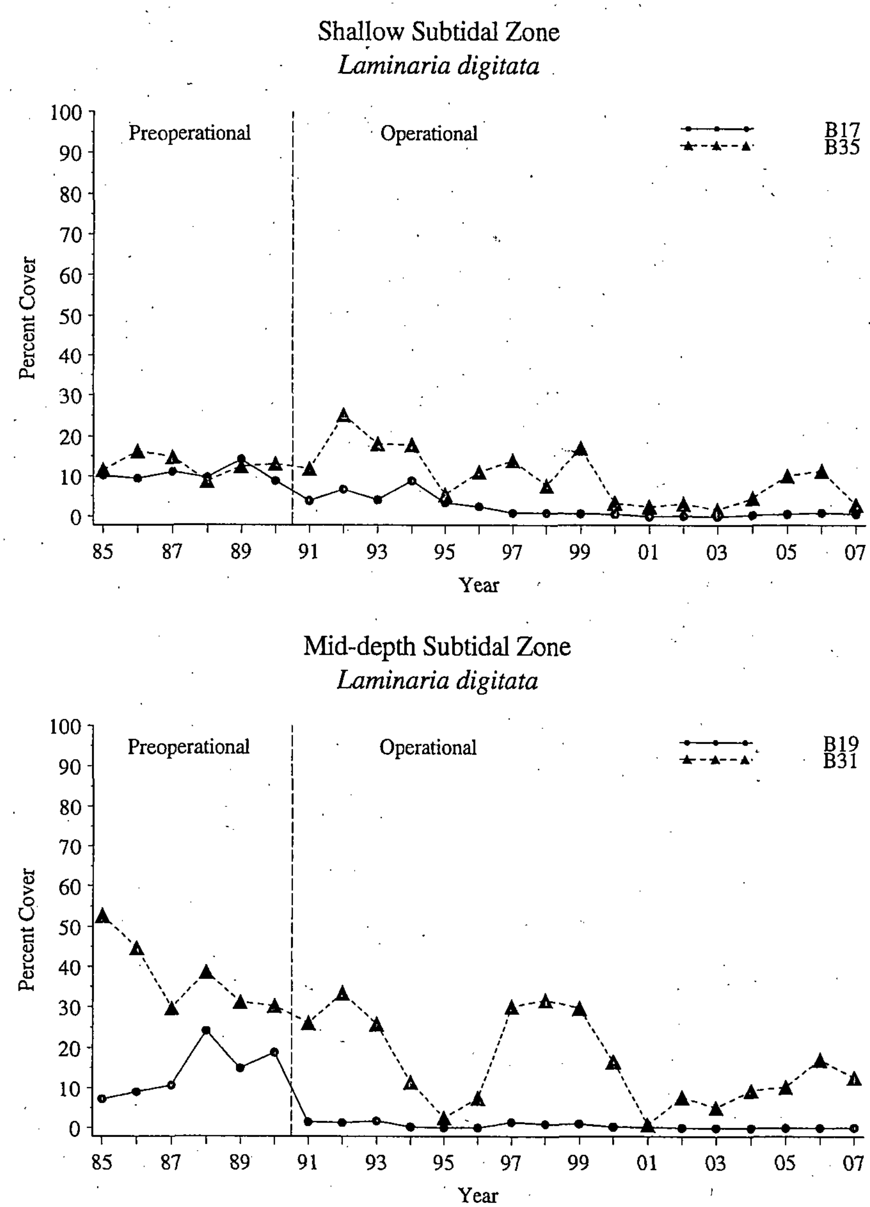


Figure 5-9. Annual mean percent cover of *Laminaria digitata* in the shallow and mid-depth subtidal zones, 1985-2007. Seabrook Operational Report, 2007.

Table 5-12. Results of Segmented Regression Analysis on the Density (no./100 m²) of Selected Algae with a significant ANOVA interaction term collected from Non-Destructive Transects in the Shallow Subtidal and Mid-Depth Zones. Seabrook Operational Report, 2007.

Parameter	Station	Comparisons Based on Breakpoints[a]	Period 1 Slope	Period 2 Slope
Kelp				
Laminaria digitata	B17	1982-1999>2000-2007***	Neg. **	Negative **
(no./100 m²)	B35	1982-2001>2002-2007**	Neg. **	NS
	B19	1978-1988>1989-2007**	NS	Negative **
	B31	1978-1994>1995-2007***	Neg.**	NS
Laminaria saccharina	B17	1982-1993>1994-2007***	NS	Neg. **
(no./100 m²)	B35	1982-2007 NS		NS
Alaria esculenta	B19	1978-1984>1985-2007 NS	NS	NS
(no./100 m²)	B31	1978-1980>1981-2007 NS	NS	Negative *

[a] As identified using segmented regression. Differences in mean between periods were tested for significance with a t-test.
NS = Not significant ($p>0.05$)
* = Significant ($0.05 \geq p > 0.01$)
** = Highly Significant ($0.01 \geq p > 0.001$)
*** = Very Highly Significant (($0.001 \geq p$)

1991 (Figure 5-9) was influenced by Hurricane Bob in August and the "Perfect Storm" in October, 1991.

A biological factor that affects *Laminaria digitata* densities is grazing by the green sea urchin *Strongylocentrotus droebachiensis*. There appeared to be an inverse relationship between the abundance of sea urchin and *L. digitata*, especially at the mid-depth stations. This relationship is examined in Section 5.3.2.2 of NAI 2001. However, sea urchins have not been abundant since their peak in 1994 (See Figure 5-26). Another biological factor reported to reduce the percent cover of *L. digitata* in southern Maine (Cape Neddick) between 1989 and 1990 is the three-fold increase of the percent cover per kelp blade (to 52%) of the European bryozoan *Membranipora membranacea*. This is thought to increase the susceptibility of kelp blades to storm damage by making them more brittle (Lambert et al. 1992). Outbreaks of *M. membranacea* in the Nova Scotian subtidal have negatively impacted kelp beds by reducing spore release from fertile blades (Saier and Chapman 2004). The presence of relatively small quantities of *M. membranacea* was noted in samples taken at all subtidal stations in August of 1998 (D. Weber, Normandeau Associates, pers. comm.), the last year that colonial taxa in macrofaunal samples were examined in the laboratory. It is not likely that these small quantities of *M. membranacea* could have contributed to the regional decline of *L. digitata*. To examine this question more closely, the percent coverage of *M. membranacea* on kelp blades from the general algae collections was estimated in the laboratory in 2007. The percent cover of *L. digitata* at Station B35 was 0% in May, 1% in August and 30% in November. At Station B17 *L. digitata* was not collected in May and August, but in November the percent cover was 50%. In the mid-depth zone at Stations B19 and B31 the highest percent cover of *L. digitata* occurred in November and was only 1%.

Percent cover of *Laminaria digitata* estimated by divers in the mid-depth zone exhibited a trend similar to the counts from quadrats. The annual mean percent cover of *L. digitata* at the nearfield station (B19) was generally low throughout the entire study, exceeding 20% only in 1988 (Figure 5-9).

Following a maximum in 1988, the annual mean percent cover declined to less than 5% by 1991, and has remained below 5% through 2007. Station B31 had a higher percent cover and peaks occurred in 1985, 1988, 1992 and 1997-1999. In 2001, it reached the low for the study period, then gradually increased above 15 % by 2006, with a slight decrease in 2007 (Figure 5-9).

In the mid-depth subtidal zone, densities of *Laminaria digitata* in 2007 at Stations B19 and B31 were below the preoperational means (Table 5-10, Figure 5-10). The decline at the farfield station (B31) between periods exceeded that at the nearfield station (B19), resulting in a significant interaction term that may reflect a possible plant impact (Table 5-11). However, the preoperational density at the nearfield station was about five times less than the farfield station, which limited the degree to which density could decline at the nearfield station (Figure 5-10). Segmented regression analysis at Station B19 indicated that density of *L. digitata* was significantly higher from 1978 through 1988 compared to 1989 through 2007 (Table 5-12). At Station B31 the breakpoint was between 1994 and 1995. Since the decline occurred at both stations it indicates a regional trend that has also been reported by Steneck (1997). The significant negative trend at Station B31 from 1978 through 1994 (Table 5-12) is further evidence of a regional decline not due to the operation of Seabrook Station. In 2007 densities at B31 decreased, while at Station 19 density increased from zero to 4.0 per 100 square meters (Figure 5-10).

In the mid-depth zone, *Laminaria digitata* may be near its physiological depth limit at Station B19 (12.2 m), as it typically occurs from the intertidal to a depth of 18 m in New England (Villalard-Bohnsack 1995). Light penetration is probably adequate in the shallower water at Station B31 (9.2 m; Luning 1980). Monitoring of turbidity in the study area found Station B19 to be significantly more turbid than Station B31, further diminishing the potential for light penetration at B19. This difference in turbidity was attributed to discharge from the Hampton-Seabrook estuary, not from Seabrook Station operation (NAI 1999a). Stress placed on *L. digitata* in the nearfield area due to lower light levels may make it more susceptible to disturbance by other physical or biological factors than the population in the farfield area. An investigation into the disappearance of *L. digitata* on the coasts of France (Cosson 1999) suggests that freshwater run-off, turbidity, and eutrophication are factors contributing to the local decline. The water temperatures observed locally and regionally (See Section 2.0) are not a likely contributing factor to the observed decline of *L. digitata* as they are still well below the lethal limit for both life stages (23 °C; Bolton and Lüning 1982).

Competition between *Laminaria digitata* and *Agarum clathratum* may also be contributing to the decline of *L. digitata* at Station B19. *A. clathratum* is generally the dominant kelp species below 12 m (Mathieson et al. 1991), where Station B19 is located. The significantly higher density of *A. clathratum* at Station B19 compared to Station B31 (Tables 5-10, 5-11) may be enough to affect *L. digitata* density. When the annual densities of the two species are examined (Figure 5-11), density of *A. clathratum* at Station B19 increased in the early preoperational period (1979-80) to become the dominant kelp through 2007 while density of *L. digitata* has declined. The dominance of *A. clathratum* at B19 placed this taxon in a better position to recover from disturbance and may have reduced *L. digitata* recruitment. At the shallower Station B31, both species suffered a decline beginning in the preoperational period in 1981, which lasted well into the operational period. In 1994, *A. clathratum* increased in density 3.5-fold over the previous year but by

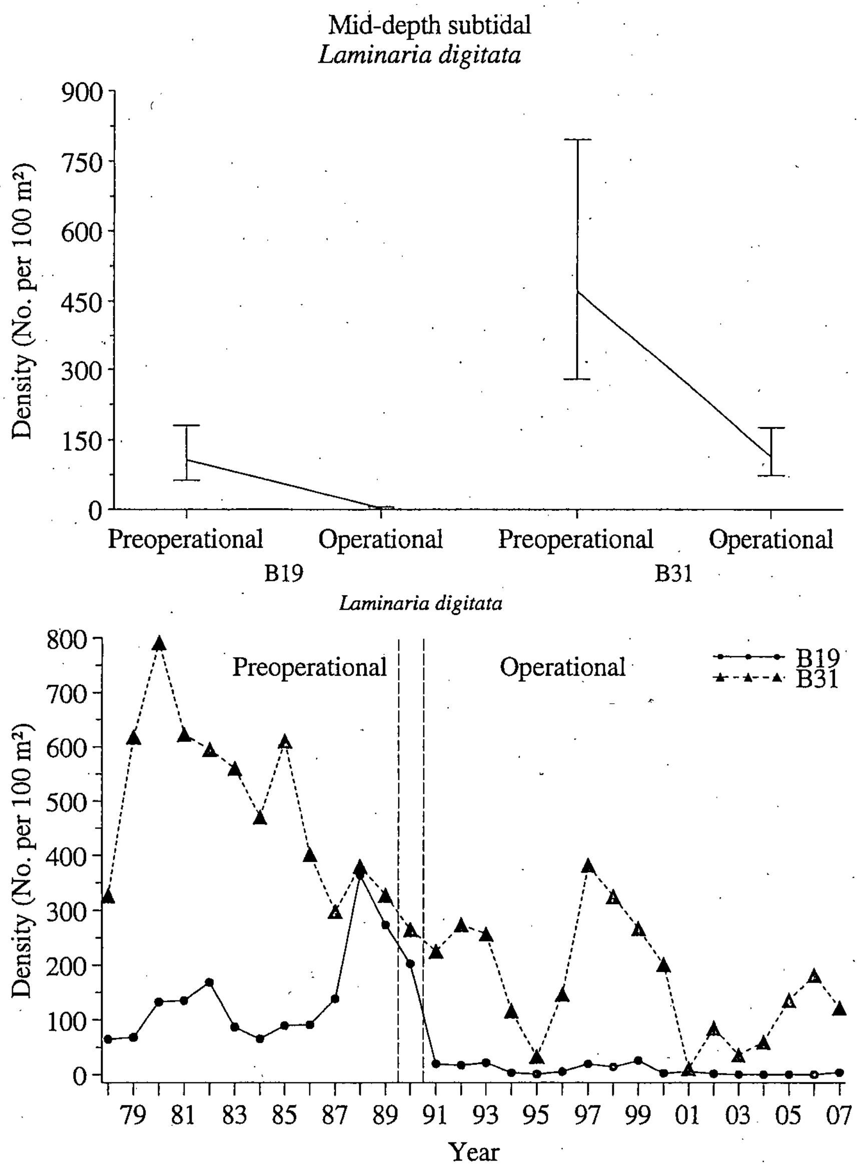


Figure 5-10. Comparison between stations of number of holdfasts/100 m^2 of the kelp *Laminaria digitata* in the mid-depth subtidal zone during the preoperational (1978-1989) and operational (1991-2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year. Seabrook Operational Report, 2007.

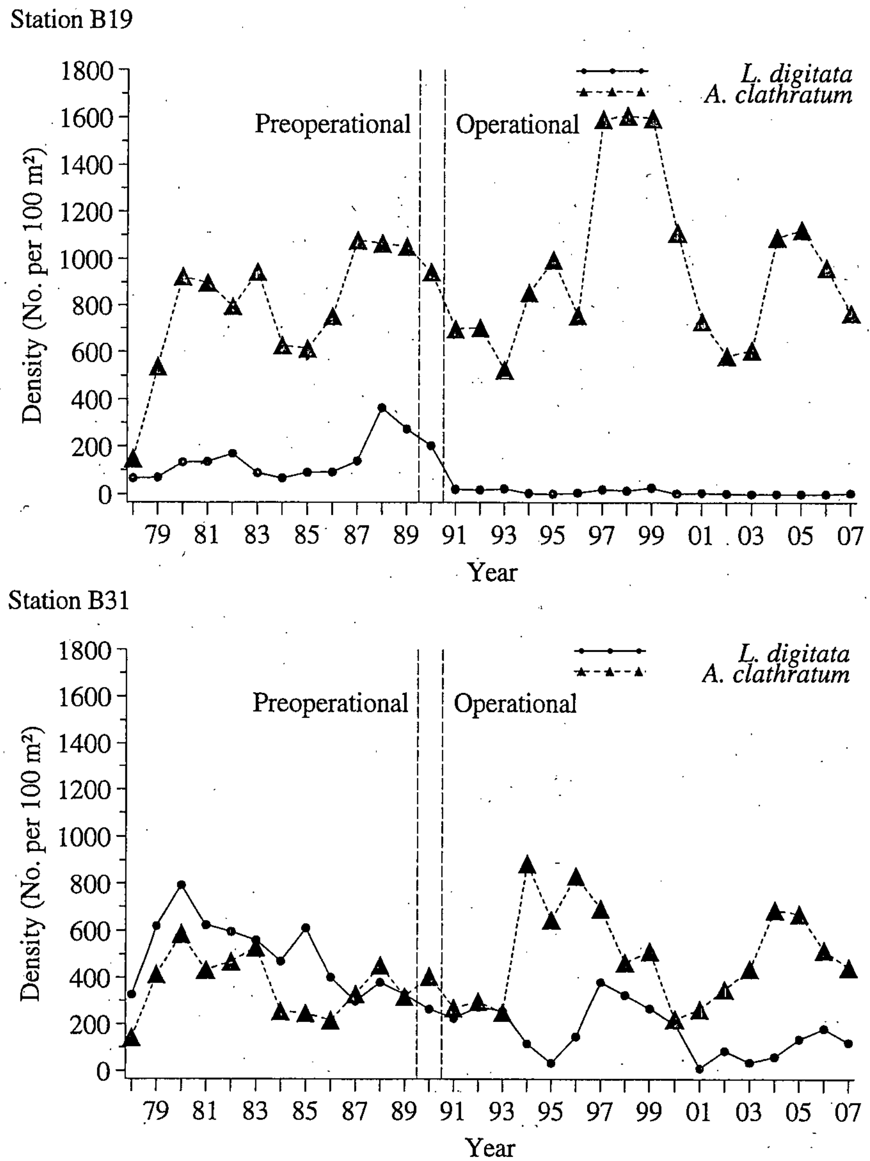


Figure 5-11. Annual mean densities (number per 100 m^2) of *Laminaria digitata* and *Agarum clathratum* in the mid-depth subtidal zone (Stations B19 and B31), 1978-2007. Seabrook Operational Report, 2007.

1996 had begun a gradual decline (Figure 5-11). In 2007 both species declined at Station B31.

During the operational period, densities of *Laminaria digitata* were lower than the preoperational densities, while densities of *Agarum clathratum* have been higher in the operational period (Table 5-10) at mid-depth stations. *A. clathratum* is competitively superior to *Laminaria* spp. on shores where urchins are present (Tremblay and Chapman 1980). The possible impact of grazing by sea urchins on *L. digitata* in this zone is examined in Section 5.3.2.2. Keats et al. (1982) observed sites where *A. clathratum* was persistent and abundant both with and without the presence of urchins and *Laminaria*, suggesting that competition between *A. clathratum* and laminarians has other undetermined factors. A similar situation may be occurring in France where *Sargassum muticum* appears to be thriving accompanied by the decline of *L. digitata* (Cosson 1999).

Stability of local patches of kelp populations has been observed to be highly variable (Dayton et al. 1984; Dayton et al. 1992; Dayton et al. 1998). Important factors contributing to these patterns are recruitment and survivorship, which in turn are influenced by disturbance, competition, spore dispersal, longshore currents, temperature, and light availability. Recruitment of *Laminaria* spp. may be particularly problematic 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, and 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 hyperborea*, a species more closely related to *L. digitata* than *Pterygophora*, has a dispersal range of at least 200 m (Fredriksen et al. 1995), but spore density decreased exponentially with distance from the source (Chapman 1986). Chapman (1981) demonstrated that substantial recruitment of *L. digitata* to areas barren of kelp was possible up to 600m away from reproductive thalli. With limited dispersal capability, the distance between an area that has experienced even a single severe disturbance (such as grazing by an urchin front or damage by a storm) and a healthy population is critical for recovery. If the distance between the disturbed area and reproducing kelp is several kilometers or more, recovery may depend on a period of high recruitment coinciding with winter storm currents to bring new kelp stock into the area. It is possible that physical disturbance caused by Hurricane Bob in August 1991 contributed to the reduction in density of *L. digitata* at Station B19 from 20/ 100 m^2 in July 1991 to 2/ 100 m^2 in October 1991 (NAI 1999a), and recruitment since then has been very low.

Laminaria saccharina

In the shallow subtidal zone, density of *Laminaria saccharina* in 2007 was below the preoperational and operational lower confidence limits at Stations B17 and B35 (Table 5-10). In 2007, density declined at both stations, and approached the lows of 2001 (Figure 5-12). Average density during the operational period in the shallow subtidal zone declined more at the nearfield station (B17) than at the farfield station (B35), resulting in a significant interaction (Figure 5-12, Table 5-11). Mean density at Station B17 for the years 1982 through 1993 was higher than 1994 through 2007 and there was a significant negative slope (decrease) from 1994 through 2007 (Table 5-12). At Station B35 there was not a significant breakpoint and no significant trends. Two factors indicate that the decline in *L. saccharina* density in the nearfield area was not due to plant operation. The highest density in the time series at Station B17 occurred in the operational period in 1993 (Figure 5-12). Segmented regression indicated a significant negative trend started in 1994, four years after the plant started operation. It is unlikely that both the highest density in the time series followed by a significant decline could be due to plant operation.

In the mid-depth subtidal zone, *Laminaria saccharina* annual densities were lower than the shallow subtidal stations (Table 5-10). Densities in 2007 were below both the preoperational and operational lower confidence limits at both stations, and at Station B19, no individuals were collected for the sixth consecutive year (Figure 5-12). The ANOVA indicated that there were no significant differences in the density of *L. saccharina* between the preoperational and operational periods, or among stations (Table 5-11). The relationship between stations was consistent between periods as indicated by the non-significant interaction term.

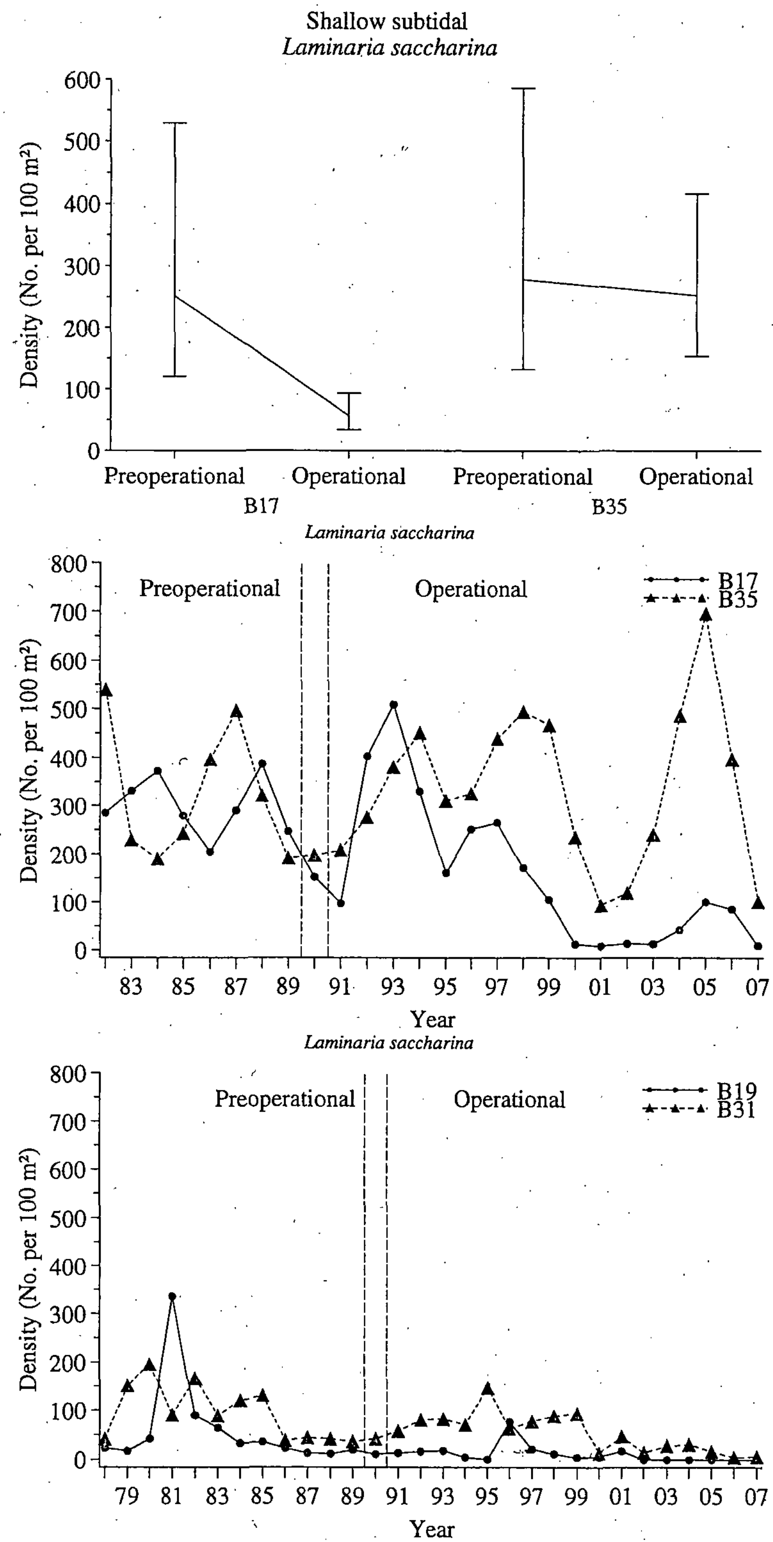


Figure 5-12. Comparison between stations of annual mean density of *Laminaria saccharina* in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year in the shallow and mid-depth zones. Seabrook Operational Report, 2007.

Alaria esculenta

Alaria esculenta annual mean densities were historically lower at nearfield Station B19 (12.2 m) than at farfield Station B31 (9.1 m) (Figure 5-13). In 2007, the density at the both stations was zero for the second consecutive year (Table 5-10). There were no significant differences between the preoperational and operational periods or stations although the interaction term was significant (Table 5-11). The decline at Station B31 was greater than at Station B19, which has historically had very low densities. *A. esculenta* is a kelp that prefers subtidal sites with a strong surge (Sears 2002), which may account for the larger amounts found at the shallower location, Station B31.

Agarum clathratum

Agarum clathratum was generally the numerically-dominant kelp at the mid-depth Stations B19 and B31 from 1988 through 2007 (Figure 5-11). Mean densities of *A. clathratum* increased between the preoperational and operational periods at nearfield Station B19 and at farfield Station B31 (Table 5-10). Densities observed in 2007 were below the operational period mean at Station B31and at Station B19. The density was significantly higher at the nearfield station, there were no significant differences between periods, and the interaction term was not significant (Table 5-11). *A. clathratum* is a kelp of deep water and northern distribution that extends deeper in the subtidal than most other kelps, at least in part due to its apparent adaptation to low light levels. Habitat range extends from tide pools and the shallow subtidal to 50m or more (Sears 2002).

Understory Algae

Patterns of distribution 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 beneath and adjacent to kelp canopies include the perennial foliose red algae *Chondrus crispus*, *Phyllophora/Coccotylus* and *Ptilota serrata*. These algae exhibit distinct patterns of distribution related to depth. Distribution of *Chondrus crispus* on fixed transects was similar to that observed from destructive collections (Tables 5-8, 5-10), with higher occurrences at the shallow subtidal stations (B17, B35) than at the mid-depth stations (B19, B31). Moderate cover of *Phyllophora/Coccotylus* occurred with the extensive turfs of *C. crispus* in the shallow subtidal, although frequency of occurrence of *Phyllophora/Coccotylus* was typically higher in the mid-depth subtidal zone (B19, B31). At mid-depth stations *Ptilota serrata* was dominant, joined by *Phyllophora/Coccotylus* at the nearfield station, and *Chondrus crispus* at the farfield station (Table 5-10).

Chondrus crispus

Overall, relationships in patterns of occurrence of understory taxa between depth zones and between nearfield-farfield stations remained remarkably consistent over the study period. *Chondrus crispus* was more abundant at the shallow subtidal stations than the mid-depth stations. In both depth zones, annual means at the nearfield stations were generally higher than the farfield stations and the annual means at both nearfield and farfield stations tracked each other fairly consistently (Figure 5-14). The percent frequency of occurrence of *Chondrus crispus* in 2007 in both the shallow subtidal and mid-depth zones was higher than the preoperational means at both stations and similar to the operational period means (Table 5-10). In both depth zones, there was a significantly higher frequency of occurrence during the operational period than the preoperational period, but differences between stations and the interactions between station and period were not significant (Table 5-11). The population has remained consistent before and during the operation of Seabrook Station.

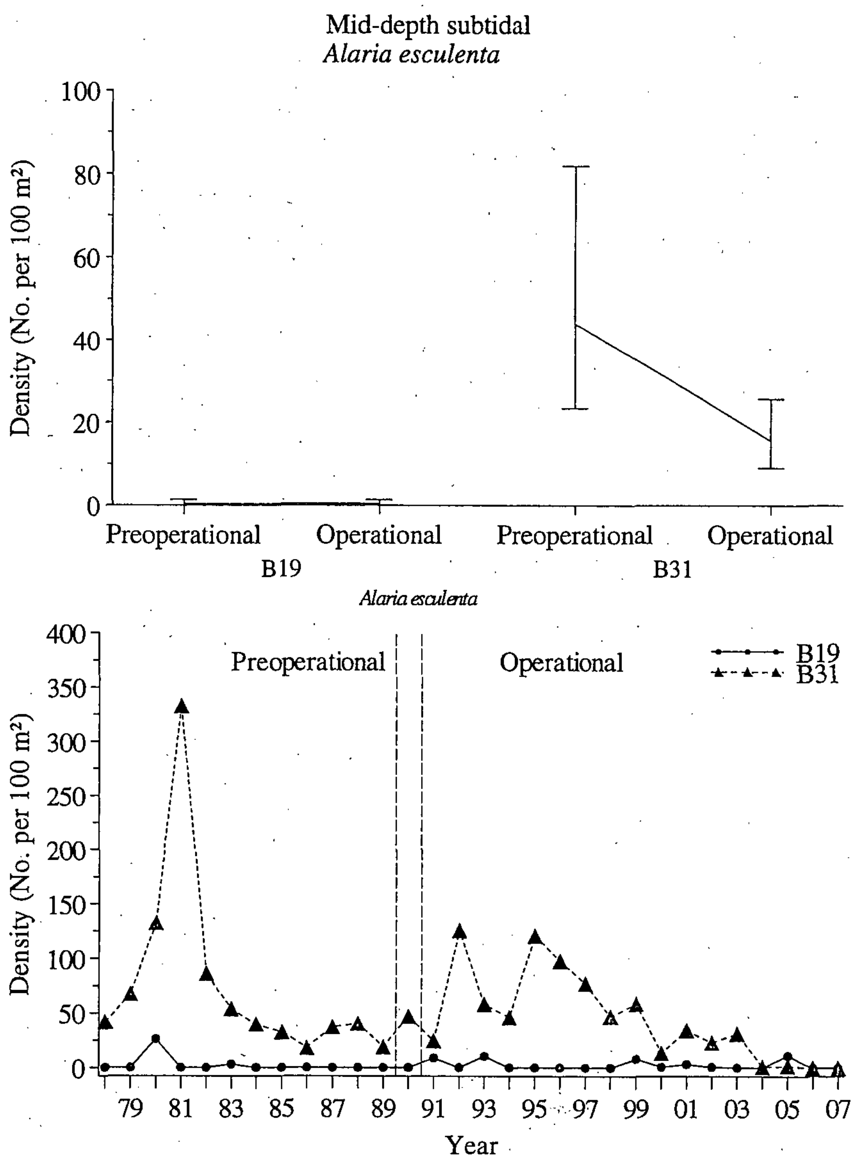
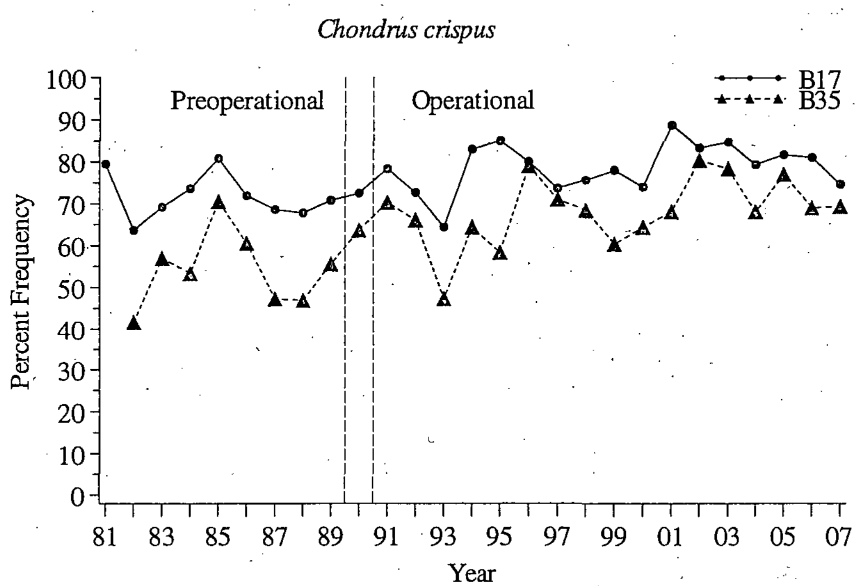


Figure 5-13. Comparison between stations of number of holdfasts/100 m^2 of *Alaria esculenta* in the mid-depth zone during the preoperational (1978-1989) and operational (1991-2007) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and the annual mean density in non-destructive transects in the mid-depth zone (Stations B19 and B31). Seabrook Operational Report, 2007.



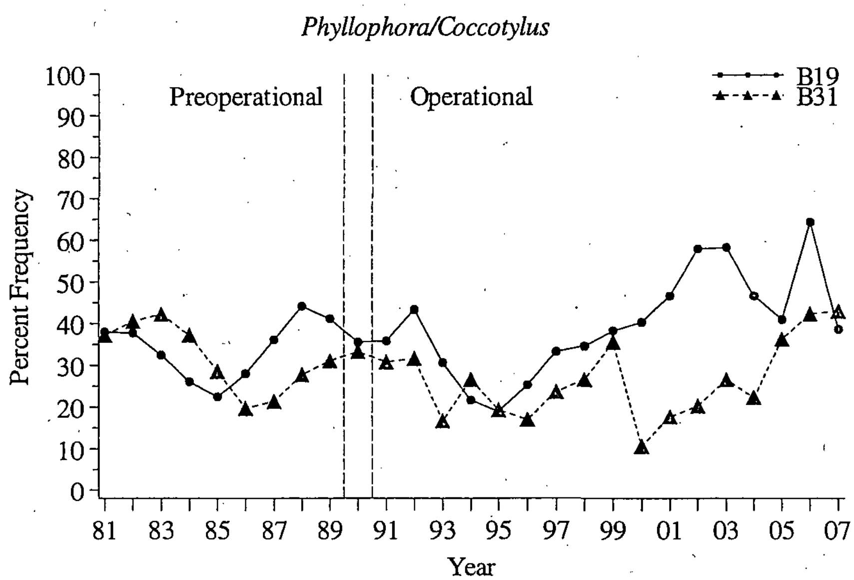


Figure 5-14. Annual mean percent frequency of *Chondrus crispus* observed at non-destructive transects in the shallow subtidal zone (Stations B17 and B35) and *Phyllophora/Coccotylus* in the mid-depth zone (Stations B19 and B31) from 1981-2007. Seabrook Operational Report, 2007.

Phyllophora/Coccotylus

The percent frequency of occurrence of *Phyllophora/Coccotylus* in 2007 was above the preoperational and operational means in the shallow subtidal zone, and was above the preoperational mean, and similar to the operational mean, in the mid-depth zone (Table 5-10). The *Phyllophora/Coccotylus* complex was abundant at both the shallow subtidal and mid-depth zones. At the mid-depth zone the annual means at both nearfield and farfield stations tracked each other fairly closely except for a sharp decrease in 2000, followed by relatively lower values through 2004, at Station B31 (Figure 5-14). The frequency of occurrence of *Phyllophora/ Coccotylus* in 2007 at Station B19 (39%) decreased from the high of the previous year while at Station B31 (43%) it was the highest in the time series (Figure 5-14). There were no significant differences between stations or periods observed in either the shallow subtidal or mid-depth zone for *Phyllophora/Coccotylus*, nor was the interaction between station and period significant (Table 5-11). *Phyllophora* is perennial and occurs in scattered or extensive beds on boulders within the sublittoral to 20 m (Sears 2002). *Coccotylus* is perennial and occurs in the sublittoral to 40 m on rock or other hard substrate (Sears 2002).

Ptilota serrata

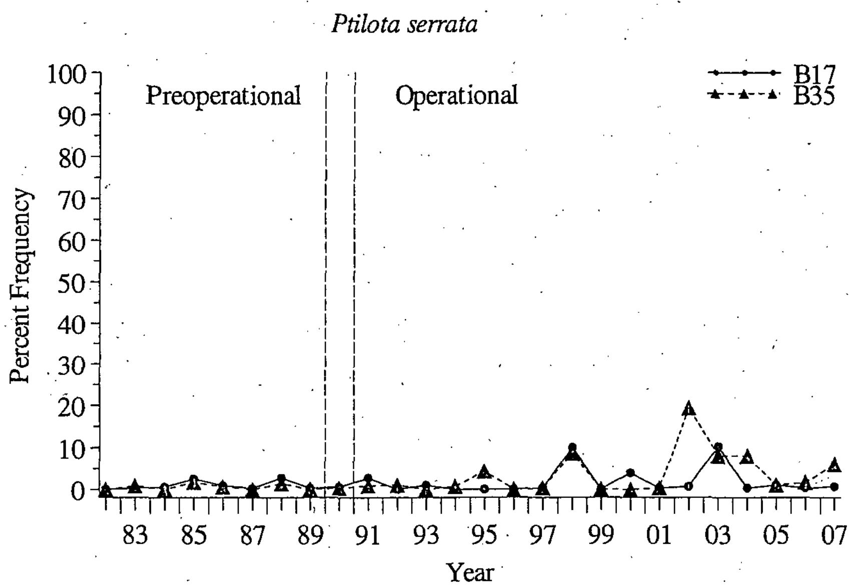
The frequency of occurrence of *Ptilota serrata* in the shallow subtidal zone was typically lower than the other common understory species (Table 5-10, Figure 5-15). In 2007, it was within the 95% confidence limits of both preoperational and operational means at Station B17, but was above the upper confidence limits for the preoperational period and near the upper confidence limits for the operational period at Station B35 (Table 5-10). No significant differences were found between stations, periods or their interaction (Table 5-11). In the mid-depth zone where *P. serrata* was more common, the annual means generally tracked each other closely. The nearfield station (deepest station at 12 m, Appendix Table 5-4) has always had a higher frequency of occurrence than the farfield station (Figure 5-15). The frequency of occurrence in 2007 at Stations B19 and B31 was within the confidence limits of the operational period (Table 5-10). Percent frequency of occurrence was significantly higher at Station B19 in the mid-depth zone (Table 5-11). There were no significant differences between periods observed in the mid-depth zone, nor was the interaction between station and period significant (Table 5-11). In the Gulf of Maine, *P. serrata* is perennial and a subdominant understory alga in the shallow sublittoral, but becomes dominant beyond 10m. It often forms monospecific turfs at the extinction depth of foliose algae to 43 m (Sears 2002).

5.3.2 Marine Macrofauna

5.3.2.1 Horizontal Ledge Communities

Number of Taxa and Total Density: Destructive Monitoring Program

Number of taxa and total density are two community parameters that have been used as monitoring tools in this program, and at other coastal nuclear power plants (Osman et al. 1981; NUSCO 1992, 1994; BECO 1994; DNC 2002). Number of taxa, also known as species richness, is an indicator of community stability (Pearson and Rosenberg 1978), while total density primarily reflects fluctuations of dominant organisms. During the preoperational period, the numbers of taxa were highest at the nearfield mid-depth station (B19) (Table 5-13). The shallow subtidal nearfield station (B17), the shallow subtidal farfield station (B35) and the farfield mid-depth station (B31) had comparable numbers of taxa. During the operational period the trend was similar with marginally higher species richness at B19 in comparison to other stations. Mean numbers of taxa at all stations have been slightly lower during the past decade as compared to historical levels.



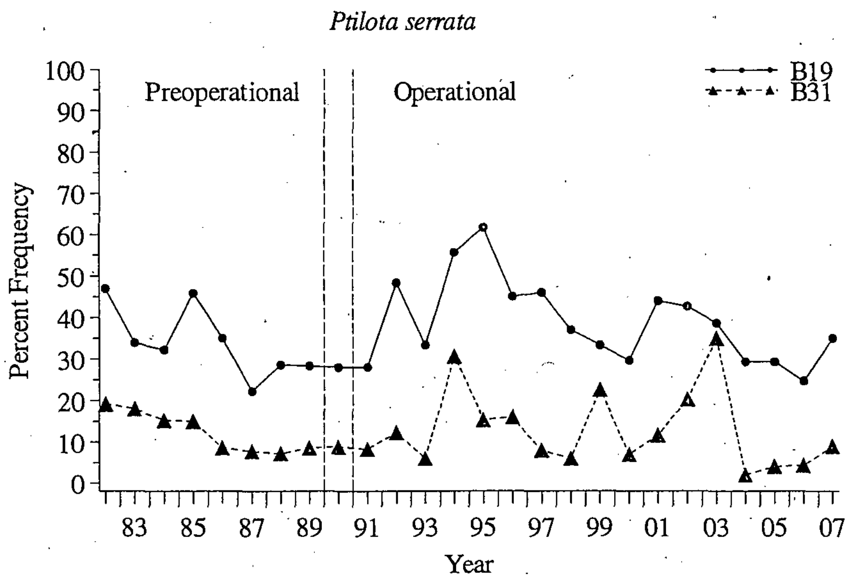


Figure 5-15. Annual mean percent frequency of *Ptilota serrata* observed at non-destructive transects in the shallow and mid-depth zones. Seabrook Operational Report, 2007.

Table 5-13. Number of Taxa and Total Density for Non-Colonial Macrofaunal Taxa Collected in August at Shallow Subtidal and Mid-Depth Stations. Preoperational and Operational Means and 95% Confidence Limits, along with 2007 Means. Seabrook Operational Report, 2007.

Depth Zone	Station	Preoperational[a] LCL[c]	Preoperational[a] Mean	Preoperational[a] UCL[d]	2007 Mean	Operational[b] LCL	Operational[b] Mean	Operational[b] UCL
No. of Taxa[e] (per 0.0625 m²)								
Shallow subtidal	B17	38	41	45	28	32	36	39
	B35	39	42	46	28	32	35	38
Mid-depth	B19	42	48	54	43	34	39	44
	B31	35	40	45	30	32	36	40
Total Faunal Density[f] (no. per m²)								
Shallow subtidal	B17	16,955	22,835	30,754	15,339	15,555	19,926	25,525
	B35	19,173	28,371	41,981	16,875	14,333	19,538	26,631
Mid-depth	B19	8,343	12,562	18,914	38,899	7,973	10,944	15,021
	B31	7,764	15,846	32,344	8,691	9,193	11,561	14,538

[a] Preoperational period extends through 1989 (Stations B17, B19, B31: 1978-1989; Stations B35: 1982-1989).
[b] Operational period: 1990-2007.
[c] LCL = Lower 95% confidence limit.
[d] UCL = Upper 95% confidence limit.
[e] Arithmetic mean
[f] Geometric mean

In 2007, the annual mean number of macrofaunal taxa at both shallow subtidal stations (B17/B35) was lower than the previous year (Figure 5-16). Values in 2007 were below the lower confidence limits of the average number of taxa during the preoperational and operational periods (Table 5-13). When the shallow subtidal stations were examined together using analysis of variance (ANOVA), the mean number of taxa was significantly higher during the preoperational period (Table 5-14). Nonetheless, there were no significant differences between stations and the interaction term was not significant, indicating that changes between periods were consistent at the nearfield and farfield stations. The decline in the number of taxa appears to be area-wide in the shallow subtidal zone.

The numbers of macrofaunal taxa at the mid-depth farfield station (B31) during 2007 were comparable to the previous year (Figure 5-16) and below the lower confidence limits of the average number of taxa during the preoperational and operational periods (Table 5-13). In contrast, species richness at the nearfield station (B19) during 2007 was higher than the previous year (Figure 5-16) and above the mean for the operational period (Table 5-13). When the mid-depth stations were examined together using analysis of variance (ANOVA), there were no significant differences in mean number of taxa between the preoperational and operational periods (Table 5-14). There also were no significant differences between stations and the interaction term was not significant. Overall, annual trends in numbers of macrofaunal taxa have been similar at Stations B19 and B31 throughout the program history (Figure 5-16).

Total macrofaunal density at both shallow subtidal stations in 2007 was slightly higher than the previous year, but still below the means for both the preoperational and operational periods (Table 5-13; Figure 5-17). Analysis of variance found no significant differences between periods or stations and the interaction term was also not significant (Table 5-14). These results indicate that any

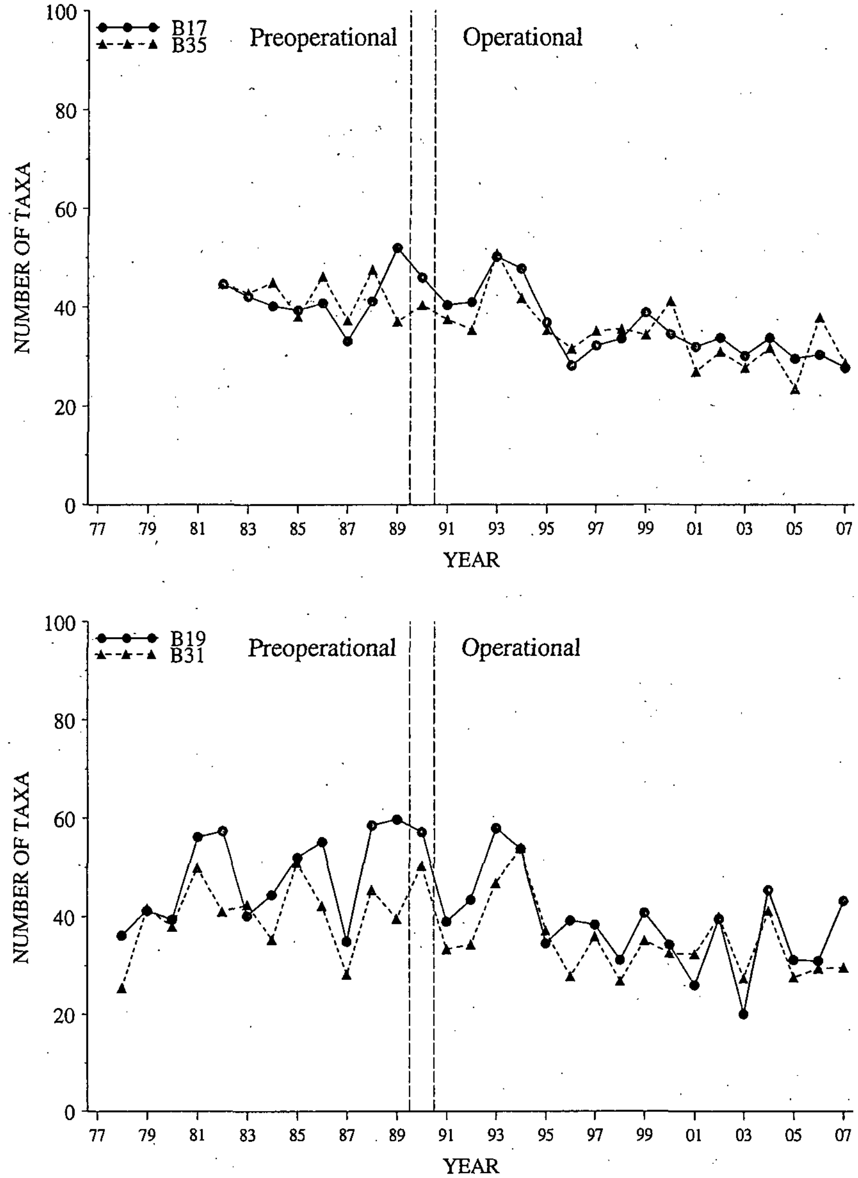
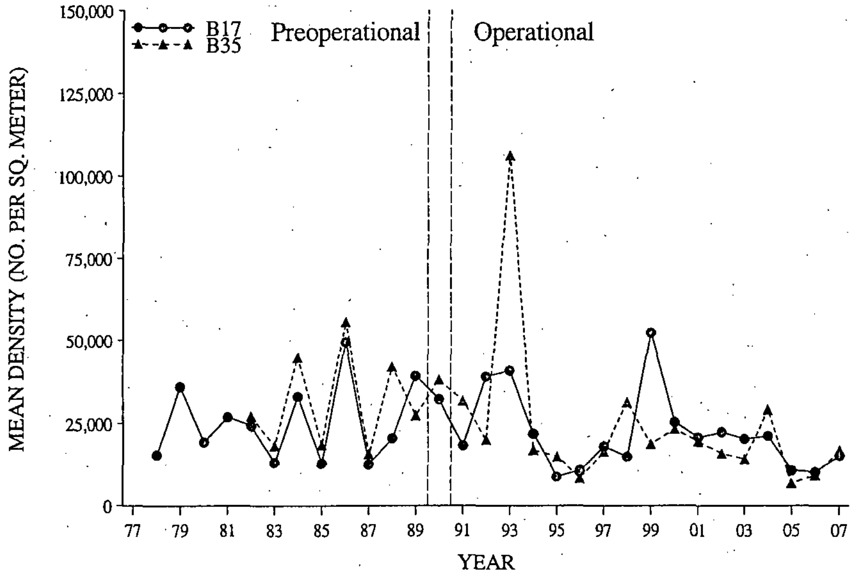


Figure 5-16. Annual arithmetic mean number of macrofaunal taxa (per 0.0625 m^2) in the shallow subtidal (B17, B35) and mid-depth (B19, B31) stations during the preoperational and operational (1991-2007) periods, and the comparison between stations of mean number of macrofaunal taxa in the mid-depth zone during the preoperational and operational periods. Seabrook Operational Report, 2007.

Table 5-14. Results of Analysis of Variance Comparing the Number of Macrofaunal Taxa (per 0.0625 m^2) and Total Macrofaunal Density (per m^2) from Destructive Samples Collected in August at Shallow (1982-2007) and Mid-Depth (1978-2007) Stations. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Number of Taxa	**Fixed Effects**	**DF**[g]	**F**[h]	**p**[i]	
	Preop-Op[a]	1, 24.2	7.97	0.0094*	Preop>Op
Shallow	**Random Effects**	**Estimate**[j]	χ^2	**P**	
Subtidal	Year (Preop-Op)[b]	25.02	14.20	0.0001*	
(B17, B35)	Station[d]	0.00	0.00	0.5000	
(Data not	Preop-Op X Station[e]	0.00	0.00	0.5000	
transformed)	Station X Year (Preop-Op)[f]	6.03	5.00	0.0127*	
	Error	35.83			
Number of Taxa	**Fixed Effects**	**DF**[g]	**F**[h]	**p**[i]	
	Preop-Op[a]	1, 6.6	3.18	0.1207	
Mid-depth	**Random Effects**	**Estimate**[j]	χ^2	**P**	
(B19, B31)	Year (Preop-Op)[b]	59.93	23.32	<0.0001*	
(Data not	Station[d]	13.66	0.82	0.1819	
transformed)	Preop-Op X Station[e]	3.39	1.11	0.1461	
	Station X Year (Preop-Op)[f]	7.27	2.99	0.0420	
	Error	60.53			
Total Density	**Fixed Effects**	**DF**[g]	**F**[h]	**p**[i]	
	Preop-Op[a]	1, 24.1	1.44	0.2418	
Shallow	**Random Effects**	**Estimate**[j]	χ^2	**p**	
Subtidal	Year (Preop-Op)[b]	0.04	14.36	0.0001*	
(B17, B35)	Station[d]	0.00	0.00	0.5000	
(Data log (X+1)	Preop-Op X Station[e]	0.00	0.00	0.5000	
transformed)	Station X Year (Preop-Op)[f]	0.01	7.36	0.0033*	
	Error	0.05			
Total Density	**Fixed Effects**	**DF**[g]	**F**[h]	**p**[i]	
	Preop-Op[a]	1, 27.5	1.13	0.2980	
Mid-depth	**Random Effects**	**Estimate**[j]	χ^2	**p**	
(B19, B31)	Year (Preop-Op)[b]	0.02	1.91	0.0838	
(Data log (X+1)	Station[d]	<0.01	0.00	0.5000	
transformed)	Preop-Op X Station[e]	0.00	0.00	0.4998	
	Station X Year (Preop-Op)[f]	0.05	40.32	<0.0001*	
	Error	0.07			

[a] Compares Preop to Op, regardless of station; years included in each station grouping: Op years = 1990-2007 Preop years: B17, B35 = 1982-1989; B19, B31 = 1978-1989.
[b] Year nested within preoperational and operational periods regardless of station.
[d] Stations (Nearfield=P2, Farfield = P7) 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] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value: * = significant ($p \leq 0.05$)
[j] Estimate of the variance component of random effect
[k] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).



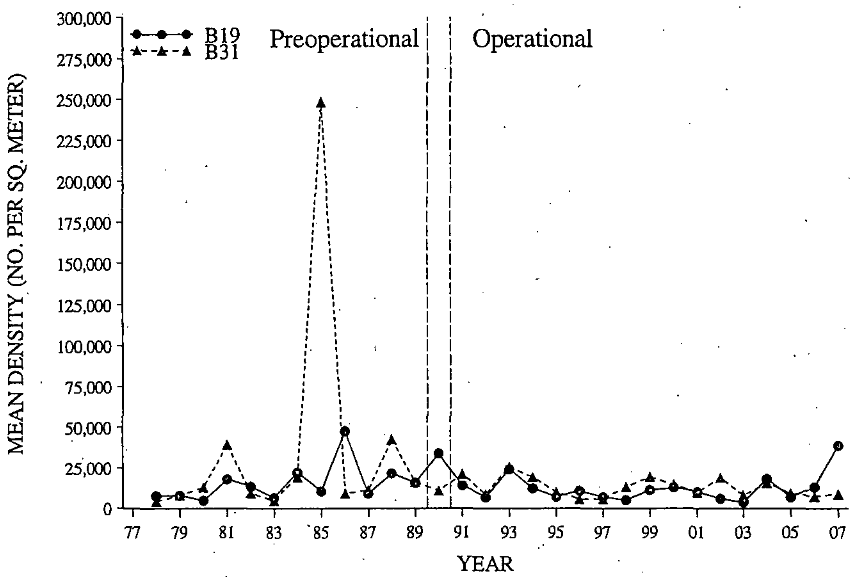


Figure 5-17. Annual geometric mean total density of macrofauna (no./m^2) in the shallow subtidal (B17, B35) and mid-depth (B19, B31) stations during the preoperational and operational (1991-2007) periods. Seabrook Operational Report, 2007.

changes in faunal density in the operational period as compared to the preoperational period have been consistent between the nearfield and farfield stations.

At the nearfield mid-depth station (B19), mean density in 2007 was higher than the previous year and above the upper confidence limits for both the preoperational and operational periods (Figure 5-17, Table 5-13). This spike in density is largely due to a single taxon, Mytilidae, which accounted for over 80% of the total density at B19 during 2007. At the farfield station (B31), mean density in 2007 was comparable to the previous year and below the means for both the preoperational and operational periods. Analysis of variance indicated that faunal density at Stations B19 and B31 was not significantly different beween periods or stations and the interaction term was also not significant. These results suggest that there is no indication of an effect from the plant on macrofaunal densities at mid-depth stations (Table 5-14).

Macrofaunal Community Analysis: Destructive Monitoring Program

The noncolonial macrofaunal community in the vicinity of Seabrook Station is a diverse assemblage, composed of both sessile and motile invertebrates, and dominated by molluscs, crustaceans, echinoderms, and annelids (Appendix Table 5-2). A total of 334 noncolonial taxa have been collected since 1978. Community analyses focus on spatial and temporal patterns in the horizontal ledge community at shallow subtidal (B17 4.9 m; B35 4.6 m deep), and mid-depth zones (B19 12.2 m; B31 9.4 m deep), at nearfield stations in the vicinity of the discharge, and at farfield stations further north. The results of multivariate analyses would be consistent with a power plant-induced impact to the macrofaunal community if the operational years' collections (1990-2007) were distinct from collections during the preoperational years at the nearfield stations, while similar patterns were not apparent at the farfield stations. This pattern is not evident in the present data.

Cluster analysis of the shallow subtidal stations (B17, B35) throughout the 26-year study period discriminated between four highly similar assemblages (Figure 5-18). The average similarity between the main groupings was over 70%. An MDS ordination provided an alternate presentation of the relative similarities among the station-year entities (Figure 5-18). Although the stress level was relatively high at 0.18, the two-dimensional plot provided useful information, revealing a gradual continuum of subtle differences between assemblages identified by the cluster analysis. Nontheless, the main patterns in the dendrogram were also apparent in the plot, supporting the choice of groupings to examine change in the faunal assemblages over space and time.

Most collections from both shallow stations (B17, B35) since 1996 were classified into Group 1 (Figure 5-18). The herbivorous gastropod *Lacuna vincta* was the most abundant species, followed by the isopod *Idotea phosphorea*, Mytilidae spat, and the amphipod *Jassa marmorata* (Table 5-15). Group 2 contained most collections from both stations prior to 1995. *Lacuna vincta* was again the numerical dominant, followed by Mytilidae spat and the isopod *Idotea phosphorea* (Table 5-15). The group was distinguished by having higher than average densities of the amphipod *Pontogeneia inermis* and no records of the gastropod *Mitrella lunata*. Also, mean numbers of Mytilidae spat were higher in Group 2 samples than in Group 1. Although stations were mixed within the main cluster groupings, some separation of the nearfield and farfield stations was apparent in the MDS plot. Nevertheless, this pattern represents only subtle differences among the samples. High similarity values indicate the high level of consistency in the faunal community over time and at both the nearfield and farfield stations. In addition to the main groupings, two outlier groups were identified by the cluster analysis (Figure 5-18). The collections from both stations during 1987 were distinguished by the highest abundance of Asteriidae, a relatively low abundance of *L. vincta*, and the absence of *Mitrella lunata* and the barnacle *Balanus crenatus*. The 2005 collection at the farfield station (B35) differed from all other samples in having low numbers of dominant taxa such as *L. vincta*, Mytilidae, *I. phosphorea*, and *J. marmorata*. Also in contrast, the caprellid amphipod *Caprella septentrionalis* was relatively abundant in this assemblage.

Results of the multivariate analyses provide no evidence of plant impact at the nearfield shallow station (B17). The main assemblages identified by these analyses were found at both stations (B17 and B35) and

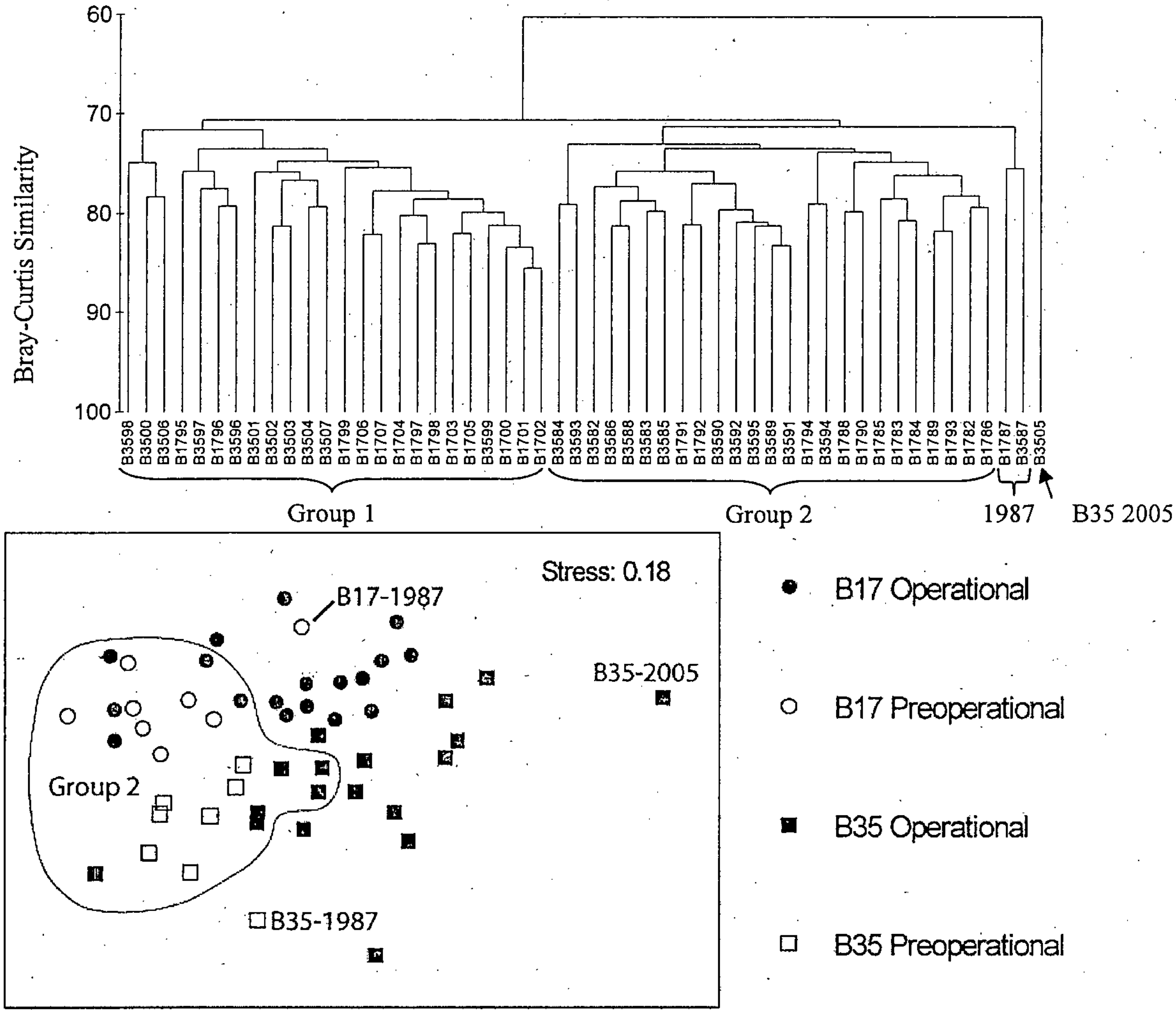


Figure 5-18. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August benthic macrofauna collections from shallow subtidal Stations (B17 and B35), 1982-2007. Seabrook Operational Report, 2007.

Table 5-15. Geometric Mean Density (no./m^2) of Dominant Macrofaunal Taxa[a] in Groups formed by Cluster Analysis. Seabrook Operational Report, 2007.

Shallow Subtidal Zone (Stations B17, B35) Taxa[a]	Group							
	Group 1			Group 2			B17/B35 1987	B35 2005
	LCL[b]	Mean	UCL[c]	LCL	Mean	UCL	Mean	Mean
Lacuna vincta	4,483	5,572	6,926	4,617	6,253	8,467	3,457	1,528
Mytilidae	883	1,308	1,939	1,965	3,219	5,272	3,121	587
Idotea phosphorea	1,050	1,432	1,953	1,589	1,860	2,178	845	299
Pontogeneia inermis	397	588	870	1,189	1,525	1,957	224	249
Jassa marmorata	654	1,041	1,655	686	1,090	1,730	843	53
Idotea balthica	223	365	596	375	608	983	173	16
Calliopius laeviusculus	176	278	439	380	515	698	101	81
Caprella septentrionalis	189	259	355	382	514	692	260	633
Asteriidae	208	323	502	302	483	773	1,008	34
Ischyrocerus anguipes	93	145	228	273	421	648	59	52
Caprella sp.	56	74	100	118	162	223	210	165
Ampithoe rubricata	133	195	286	49	90	163	16	113
Gammarellus angulosus	26	33	41	53	75	106	37	152
Balanus crenatus	19	56	158	20	36	64	-	297
Mitrella lunata	131	207	325	-	-	-	-	302

Mid-Depth Zone (Stations B19, B31) Taxa[a]	Group							
	Group 1			Group 2			B19/B31 1978	B19 01/03
	LCL[b]	Mean	UCL[c]	LCL	Mean	UCL	Mean	Mean
Mytilidae	1,856	2,955	4,704	1,030	2,216	4,763	244	201
Pontogeneia inermis	725	942	1,225	145	271	504	1,391	1,075
Caprella septentrionalis	496	633	809	281	464	767	238	1,496
Anomia sp.	431	599	832	439	612	853	195	86
Hiatella sp.	220	312	441	354	463	607	65	38
Lacuna vincta	237	303	387	719	1,150	1,839	217	307
Asteriidae	132	180	245	34	64	120	212	166
Molgula sp.	95	139	203	53	97	177	107	32
Caprella sp.	88	116	154	35	64	117	37	120
Cancer sp.	44	55	69	22	35	55	143	38
Mitrella lunata	30	55	99	34	59	103	-	151
Erichthonius rubricornis	35	44	55	19	27	38	16	165
Calliopius laeviusculus	29	35	42	29	38	50	125	100

[a] Taxa contributing more than 2% of total group abundance.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

differed only slightly in their species composition. Differentiation among the assemblages is mostly based on relative abundances of dominant taxa. These minor differences may be partially accounted for by the patchy distribution of the epifaunal species-groups and slight variations in substrate between the stations (Appendix Table 5-4). The dominant species in all groups was the mollusc *Lacuna vincta,* which contributed to the relatively high similarity among groups. Mytilidae spat were also common in all of the collections, as were several motile crustaceans such as *Pontogenia inermis, Idotea phosphorea, Idotea balthica, Jassa marmorata,* and *Ampithoe rubricata.* The macrofaunal community at the shallow nearfield and farfield stations during the preoperational period was significantly different; therefore ANOSIM could not be used to test for the interaction of main effects for a plant impact (Table 5-16).

Cluster analysis of the mid-depth stations (Stations B19, B31) during the past 30 years identified four groupings at a similarity level just over 60% (Figure 5-19). Distinctions between these assemblages were also apparent in an MDS ordination plot. Group 1 contained most collections, including both nearfield and farfield stations in the preoperational and operational periods. It was distinguished by the highest abundance of Mytilidae spat and relatively high numbers of Asteriidae and *Molgula* sp. (Table 5-15). Group 2 was composed of farfield collections taken from 1995 through 2007. Like Group 1, it was dominated by Mytilidae spat, although density was slightly lower. Group 2 was distinguished from the other groups by the high abundance of the herbivorous gastropod, *Lacuna vincta,* which is associated with algal holdfasts (Gosner 1978). Also, the amphipod *Pontogeneia inermis* was least abundant as compared to the other groups. Macrofaunal assemblages from both stations in 1978 differed from the majority of the collections and were characterized by elevated densities of *Pontogeneia inermis* and reduced densities of other taxa, including the subdominants Mytilidae and *L. vincta.* The 2001 and 2003 collections from B19 were distinguished by high densities of *Caprella septentrionalis* and *Pontogeneia inermis*, and low Mytilidae density.

The MDS plot illustrates the relatively high level of similarity among all collections at the mid-depth stations. The distinction of late operational period collections at Station B31 (Group 2) may relate to differences in algal biomass between the stations and over time (See Table 5-2). In addition, the differences in algal and faunal communities likely reflect the shallower depth and differences in substrate compared to Station B19 (Appendix Table 5-4). Group 2 was distinguished primarily by the high abundance of the gastropod *Lacuna vincta*, which is the numerical dominant at the shallow subtidal stations (Table 5-15). Neither the cluster diagram nor the MDS plot suggest an impact from the plant since Group 1 contained the majority of samples from both stations during both periods, and the similarity between all groups was high. Stations were found to be significantly different during the preoperational period; therefore, ANOSIM could not be used to test for the interaction of main effects to determine a possible plant impact (Table 5-16). Since the cluster analysis indicates that assemblages from the nearfield station during the operational years are distinct from those that occurred during preoperational years, these results are not consistent with a pattern of impact on the macrofaunal community due to plant operation.

Subtidal Fouling Community (Bottom Panel Monitoring Program)

Recruitment patterns of sessile, solitary (non-colonial) macroinvertebrates in the subtidal zone were monitored through the bottom panel program. Recruitment is influenced by several factors including substrate, time of year, length of exposure, and absence of

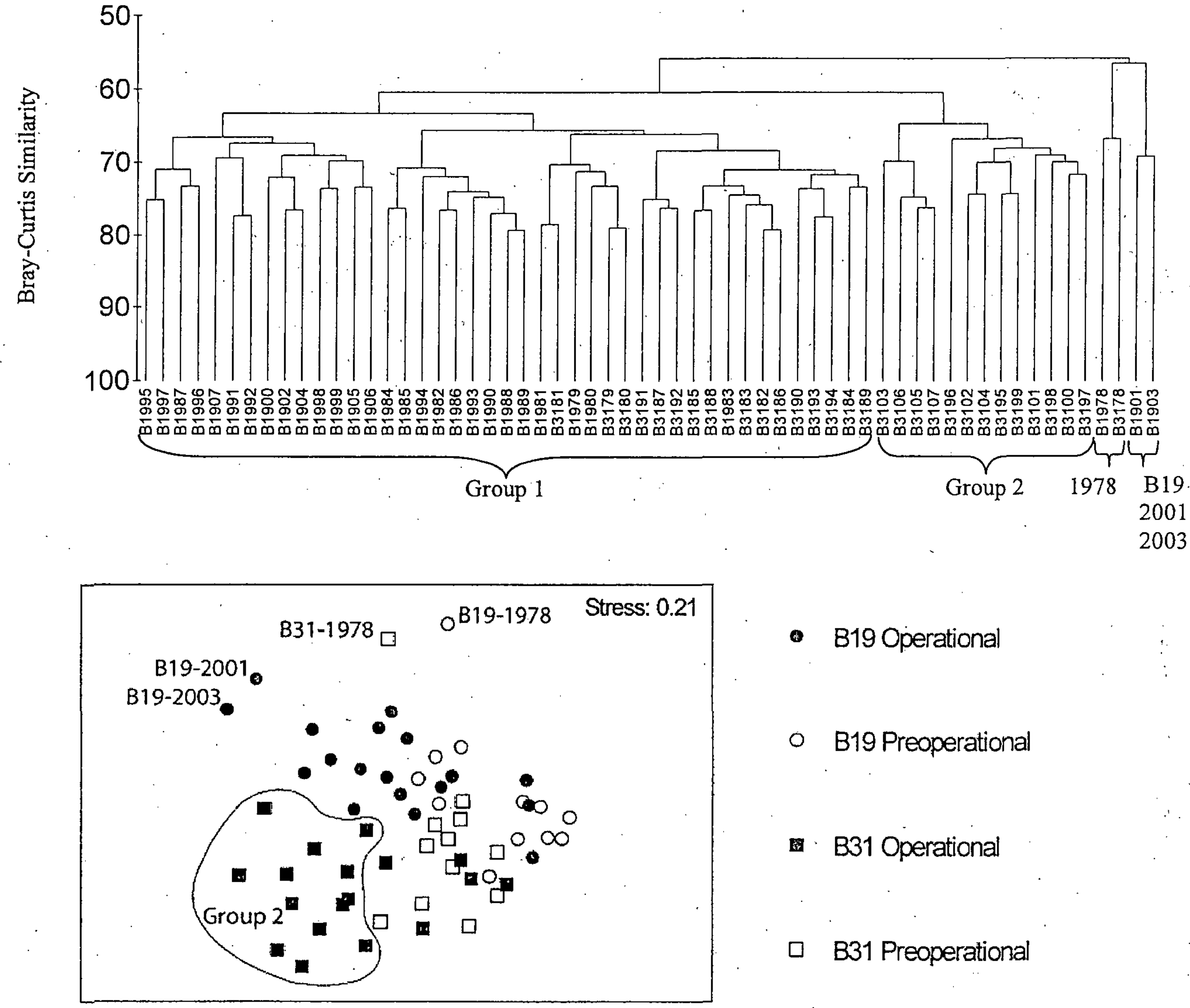


Figure 5-19. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August benthic macrofauna collections from mid-depth Stations (B19 and B31), 1978-2007. Seabrook Operational Report, 2007.

Table 5-16. Significance Test of Spatial and Temporal Differences of Macrofaunal Communities. Seabrook Operational Report, 2007

Community	Comparison	R	p (%) [a]
Shallow Subtidal (B17, B35)	Period[b]	0.31	0.1*
	Station[b]	0.28	0.1*
	B17 Pre vs. B35 Pre[c]	0.50	0.1*
	Interaction of Main Effects		Not testable
Mid-depth Subtidal (B19, B31)	Period[b]	0.31	0.1*
	Station[b]	0.44	0.1*
	B19 Pre vs. B31 Pre[c]	0.33	0.1*
	Interaction of Main Effects		Not testable

[a]p=significance level of test statistic R.
[b]Two-way ANOSIM
[c]One-way ANOSIM
* indicates significant differences, p<5.0%.
NS indicates no significant differences.

consumers such as crabs and snails (Zobell and Allen 1935; Schoener 1974; Osman 1977; Sutherland and Karlson 1977; Bertness et al. 2002). Variation was minimized in this program by using a standard substrate and controlling exposure times. Bluestone plates were suspended over the bottom for fixed periods in the mid-depth zone at Stations B19 and B31. Fixed duration sampling periods (January through April, May through August, and September through December) provided an adequate interval for larval settlement and development. Four marine taxa (identified to family or genus level) that are representative of fouling community organisms were selected as indicators of potential power plant effects.

The most common subtidal fouling organisms were the barnacles *Balanus* spp., which were primarily juvenile *Balanus crenatus*, but may include some *Balanus balanus*. Seasonal patterns of settlement of *Balanus* spp. have generally been consistent for the preoperational and operational periods, with heaviest recruitment on panels collected in April and substantially lower recruitment in subsequent exposure periods (Table 5-17). When averaged across all seasons, the operational density at Station B19 was higher than the preoperational density, while at Station B31 the operational density was lower than the preoperational density. The average density across all seasons in 2007 was lower than the preoperational and operational means, indicating a year of below-average recruitment at both stations.

The jingle shell, *Anomia* sp., was also commonly found on the bottom panels with the heaviest settlement on the December panels and lowest on the April panels at both stations during the preoperational and operational periods (Table 5-17). Larvae were typically most abundant in the water column from July through September during the preoperational period (NAI 1990). Operational means were higher than the preoperational means at both stations. The 2007 all-season mean density was below the preoperational and operational means at Stations B19 and B31.

A second dominant bivalve on the bottom panels was the Arctic saxicave, *Hiatella* sp. This species had heaviest settlement in the summer period, May through August, at both stations (Table 5-17). The greatest number of larvae in the water column occurred from May

Table 5-17. Estimated Density (per 0.25 m²) and 95% Confidence Limits of Selected Sessile Taxa on Hard-Substrate Bottom Panels Exposed during Four Months at Stations B19 and B31 Sampled Triannually (April, August, December) from 1981-2007 (except April 1985 through August 1986). Seabrook Operational Report, 2007.

Taxon, Station and Period	April			August			December			All Seasons		
	LCL[e]	Mean	UCL[f]	LCL	Mean	UCL	LCL	Mean	UCL	LCL	Mean	UCL
***Balanus* sp.**												
Nearfield (B19)												
Preop[a]	4,724	17,053	29,393	1,958	6,403	10,849	0	9	19	2,911	7,822	12,733
Op[b]	14,857	22,718	30,579	5,588	9,039	12,490	0	852	2,281	7,152	10,870	14,587
2007[c]		13,080			1,609			0		0	4,896	22,615
Farfield (B31)												
Preop	18,374	40,962	63,551	1,757	7,917	14,076	0	14	30	5,284	16,298	27,312
Op	18,188	27,688	37,188	4,539	7,658	10,776	0	630	1,742	7,487	11,992	16,497
2007		18,105			1,246			0		0	6,450	
***Anomia* sp.**												
Nearfield (B19)												
Preop	0	<1	1	0	31	92	306	1,232	2,158	21	431	842
Op	1	104	206	29	123	218	1,158	2,935	4,711	385	1,054	1,722
2007		110			174			936		0	407	1,548
Farfield (B31)												
Preop	0	0	0	0	36	78	0	993	2,170	0	373	815
Op	8	19	31	21	141	262	692	1,428	2,164	236	530	823
2007		21			4			124		0	50	211
Hiatella sp.												
Nearfield (B19)												
Preop	0	1	3	982	3,966	6,950	0	27	58	26	1,333	2,639
Op	2	9	17	1,587	3,436	5,285	1	9	16	418	1,151	1,885
2007		14			2,266			0		0	760	4,000
Farfield (B31)												
Preop	0	<1	1	0	11,659	23,840	0	16	37	0	3,891	8,306
Op	5	13	21	4,153	7,635	11,118	17	73	130	1,092	2,574	4,055
2007		7			4,240			20		0	1,422	7,484
Mytilidae												
Nearfield (B19)												
Preop	0	2	5	83	367	651	2	58	115	15	134	254
Op	59	207	356	91	1,761	3,431	34	67	100	116	678	1,241
2007		302			52			1		0	124	550
Farfield (B31)												
Preop	0	8	20	0	5,035	16,595	0	36	71	698	1,690	2,682
Op	33	138	242	1,421	2,773	4,126	49	185	322	484	1,032	1,580
2007		35			273			3		0	104	470

[a] Preop 1981-1984 and 1987-1989 (*Balanus* and *Anomia*, B19); 1982-1984 and 1987-1989 (*Balanus* and *Anomia*, B31); 1983-1984 and 1987-1989 (*Hiatella* and Mytilidae, B19 and B31).
[b] Op = 1991-2007
[c] 2007 monthly values = sum of four quadrants from single panel; all seasons = mean of monthly totals.
[d] All Seasons = mean of annual monthly values excluding 1996.
[e] LCL = Lower 95% confidence limit.
[f] UCL = Upper 95% confidence limit.

to July (NAI 1990), consistent with the high densities observed on the August panels. Mean densities have historically been higher at the farfield station, and the trend continued in 2007. In 2007, the all-season mean density was below the preoperational and operational means at both stations.

Mytilidae spat (primarily juvenile blue mussels) were most abundant in the August collections in the preoperational and operational periods as the larvae settled from the plankton (Table 5-17). Densities were typically higher at the farfield station, and the trend continued in 2007. This may be due, in part, to the habitat differences that are noted in Appendix Table 5-4 or prevailing currents. Destructive macrofaunal samples also indicate that densities of mytilids were generally higher at the farfield station (Table 5-18). In 2007, the operational mean over all seasons at the nearfield station was within the preoperational and operational confidence limits (Table 5-17). However, at the farfield station the all-season operational average was below the preoperational and operational confidence limits.

Shipworms (*Teredo* spp.) were absent during 2007 from the pine boards that were deployed beside the bottom panels at both nearfield and farfield stations. No shipworms have been found since pine boards were first deployed in 1998.

5.3.2.2 Selected Macrofaunal Species

Mytilidae: Destructive Monitoring Program

Bivalves from the mussel family, Mytilidae (mytilids), are common in the North Atlantic and typically are found attached by strong byssal threads to intertidal and shallow subtidal rocky substrata (or other hard surfaces) and occasionally are recorded from deeper water (Seed 1976). *Mytilus edulis* is the most abundant species of Mytilidae in the Gulf of Maine; however, a northern species, *M. trossulus*, has been reported in Maine from the Damariscotta River north to Cobscook Bay (Rawson et al. 2001). Mytilids are important prey items of marine predators such as starfish, lobsters, crabs, and fish in the subtidal zone (Menge 1979; Witman 1985; Ojeda and Dearborn 1991), and the Atlantic dogwinkle, *Nucella lapillus,* in the intertidal zone (Menge 1991; Petraitis 1987; Hunt and Scheibling 1995). Mytilids exhibit several defense mechanisms against predation. In response to both drilling (*N. lapillus*) and crushing (*Carcinus maenas*) predators, juvenile (9-13 mm shell length) *Mytilus edulis* produced thicker shells, effectively increasing the effort required by the predator to feed (Smith and Jennings 2000). Petraitis (1987) observed that mussels are capable of immobilizing *N. lapillus* by attaching byssal threads to the snail's body whorls and flipping it over. Within a mussel bed, several mussels near the drill may all attach byssi. This behavior can be effective because it can take *N. lapillus* from one to four days to drill through and consume an individual mussel (Petraitis 1990; Smith and Jennings 2000). Laboratory exposure to lobster effluent stimulated mussels to form clumps rapidly (Cote and Jelniker 1999), although this behavior is more pronounced in sparse populations than dense beds. Clumping or bed formation in itself, as occurs in the Seabrook hard substrate study areas, is also an effective protection against predation. Mortality caused by predation is higher at the edges of the mussel bed than in the center (Okamura 1986). Frandsen and Dolmer (2002) found, however, that increased intraspecific competition for food on complex substrate (including clumps and mussel beds) resulted in significantly lower growth rates for mussels.

Dense beds of mussels alter the uncolonized substratum and provide habitat for algae, other mussels and other faunal species on the shell surfaces and in the interstitial spaces (Dayton 1971; Seed 1976). Extensive mussel beds and bars can form on

Table 5-18. Geometric Mean Densities (no./m²) and 95% Confidence Limits of Selected Benthic Macrofauna Species Collected During Preoperational and Operational Periods and During 2007. Seabrook Operational Report, 2007

Taxon and Station[a]	Preoperational[b] LCL[g]	Preoperational[b] Mean	Preoperational[b] UCL[h]	2007 Mean	Operational[c] LCL	Operational[c] Mean	Operational[c] UCL
Mytilidae spat <25mm							
B17	1,508	2,580	4,413	2,195	1,038	1,568	2,368
B35	2,241	4,449	8,832	2,284	2,068	3,426	5,676
B19	901	1,947	4,205	17,287	592	1,315	2,918
B31	2,735	6,196	14,034	913	1,756	3,110	5,508
Asteriidae							
B17	409	590	849	96	355	502	710
B35	90	184	378	13	66	125	236
Pontogenia inermis							
B19	488	604	748	580	335	458	626
B31	294	404	556	319	145	186	239
Jassa marmorata							
B17	661	1,045	1,653	658	760	1,186	1,852
B35	1,028	1,888	3,467	1,518	958	1,535	2,461
***Strongylocentrotus droebachiensis*[d] <10 mm**							
B19	36	66	123	79	15	33	69
B31	16	31	58	8	12	20	35
***S. droebachiensis*[e] >10 mm**							
B17	0.00	0.14	0.52	0.00	0.00	0.03	0.06
B35	0.00	0.03	0.07	0.00	0.00	0.06	0.17
B19	0.02	0.09	0.17	0.00	0.00	0.24	0.62
B31	0.00	0.04	0.16	0.00	0.00	0.44	1.08
***Modiolus modiolus*[f]**							
B19	86	97	108	49	64	71	78
B31	71	89	106	23	38	52	66

[a] Nearfield = B17, B19; Farfield = B35, B31.
[b] Preoperational = mean of annual means, 1978-1989 (B17, B19, B31) or 1982-1989 (B35).
[c] Operational mean = mean of annual means, 1991-2007, for all stations.
[d] Juveniles<10mm in diameter from the destructive sampling program.
[e] Urchins > 10mm in diameter from subtidal transect program; preoperational years=1985-1989, operational years=1991-2007.
[f] Arithmetic means for *M. modiolus* from subtidal transect program; preoperational years=1980-1989, operational years=1991-2007
[g] LCL = Lower 95% confidence limit.
[h] UCL = Upper 95% confidence limit.

soft as well as hard substrates (Dolmer et al. 1994). A single mussel can attach to a small anchoring rock or sediment particle as small as 0.85 mm in diameter (Young 1983) and subsequently create hard substrate habitat where it previously did not exist. In this study, the mean shell lengths were <25 mm at all stations and indicate that mytilids do not persist in large numbers (NAI 1999b). Each year, the mussel population is made up primarily of recently settled spat. Various factors contribute to the local loss of mytilids from the hard substrate. Subtidal mytilids may be dislodged by wave action in exposed areas. In sheltered areas, algae can out-compete mussels for space. In addition, there are numerous predators of mytilids that preferentially occupy different depth zones.

Mytilidae spat were among the dominant taxa at shallow subtidal Stations B17 and B35 (Tables 5-15 and 5-18), and exhibited high year-to-year variability (Figure 5-20). In 2007, abundance was within the confidence limits of the preoperational and operational period means at Stations B17 and B35 (Table 5-18). Throughout most of the 26-year study period, Station B35 has had slightly higher abundance with an occasional peak (1993) that represents an extremely abundant set of juvenile mytilids (Figure 5-20). Nevertheless, differences in abundance were not significant between the two shallow subtidal stations or between preoperational and operational periods and the interaction between period and station was not significant (Table 5-19).

Mytilid spat have typically been the numerical dominant at mid-depth stations (Tables 5-15 and 5-18). In 2007, mean annual abundance at Station B19 was the highest reported at this station during the three-decade study period (Table 5-18; Figure 5-21). In contrast, mytilidae abundance at Station B31 during 2007 was lower than the preoperational and operational means, and comparable to the previous year's low numbers (Table 5-18 Figure 5-21). Abundances at both stations have varied throughout the study period, although the bigger sets occurred most often at the farfield station, particularly in 1985 (Figure 5-21). There were no significant differences between the preoperational and operational periods, or in the Preop-Op X Station interaction term (Table 5-19).

Asteriidae: Destructive Monitoring Program

Sea stars (Asteriidae) are predators of mollusks and are most abundant in the shallow subtidal zone (Table 5-15). *Asterias forbesii* and *A. vulgaris* are the most common asteriids collected in this study, but the genera *Leptasterias*, *Henricia*, and *Solaster* are also known to occur in the Gulf of Maine (Gosner 1971). Harris (1996) found that over the period from 1975 through 1995, the numerically dominant northern sea star, *Asterias vulgaris*, has declined in relative abundance compared to the southern sea star, *A. forbesii,* in southern Maine and at the Isles of Shoals, New Hampshire. Predation by *Asterias* spp. on mussels can be locally intense, and this feeding activity is believed to have considerable influence on both subtidal and intertidal community structure (Menge 1979; Sebens 1985).

Abundances of Asteriidae decreased at both stations in 2007 over the previous three years, reaching historical lows (Figure 5-22). The mean abundances in 2007 were well below the preoperational and operational lower confidence limits at both stations (Table 5-18). There were no significant differences in abundances between stations or the preoperational and operational periods, and the interaction term was not significant (Table 5-19). Since changes in abundance between periods were consistent at the nearfield and farfield stations there is no evidence of an impact from the plant.

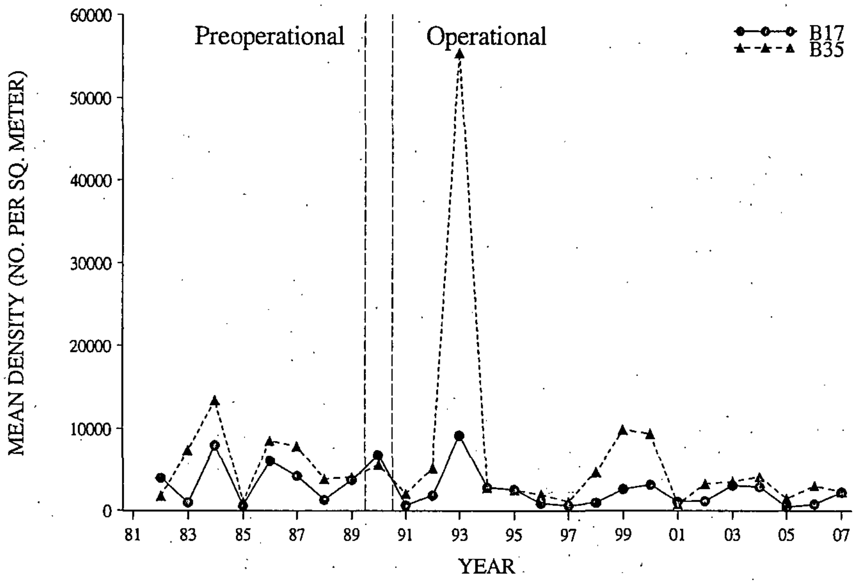


Figure 5-20. Annual geometric mean density (no./m^2) of Mytilidae at the shallow subtidal Stations B17 and B35, 1982-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

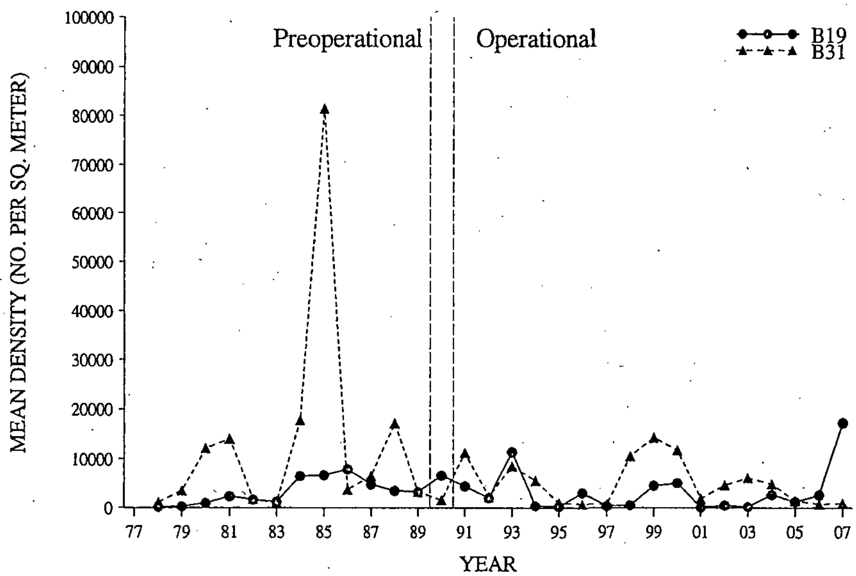


Figure 5-21. Annual geometric mean density (no./m^2) of Mytilidae at the mid-depth Stations B19 and B31, 1978-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Table 5-19. Results of Analysis of Variance Comparing Densities [Log_{10} (#/m^2+1)] of Selected Macrofaunal Taxa Collected in May, August and November at Nearfield-Farfield Station Pairs During the Preoperational (1982-1989) and Operational (1991-2007) Periods. Seabrook Operational Report, 2007.

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Mytilidae	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(spat<25 mm)	Preop-Op[a]	1, 23.2	1.14	0.2976	
Shallow	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
subtidal	Year (Preop-Op)[b]	0.03	0.59	0.2209	
(B17,B35)	Month(Year)[c]	0.23	232.55	0.0000 *	
	Station[d]	0.05	1.92	0.0828	
(destructive)	Preop-Op X Station[e]	<0.01	0.00	0.5000	
	Station X Year (Preop-Op)[f]	0.03	14.07	0.0001 *	
	Error	0.23			
Mytilidae	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
(spat<25 mm)	Preop-Op[a]	1, 27	1.81	0.1892	
Mid-Depth	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
(B19/B31)	Year (Preop-Op)[b]	0.05	0.68	0.2042	
	Month(Year)[c]	0.14	131.89	0.0000 *	
(destructive)	Station[d]	0.08	1.92	0.0830	
	Preop-Op X Station[e]	0.00	0.00	0.4998	
	Station X Year (Preop-Op)[f]	0.20	166.94	0.0000 *	
	Error	0.30			
Asteriidae	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
Shallow	Preop-Op[a]	1, 10.1	0.26	0.6241	
subtidal	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
(B17,B35)	Year (Preop-Op)[b]	0.09	9.28	0.0012 *	
	Month(Year)[c]	0.08	117.67	0.0000 *	
(destructive)	Station[d]	0.14	2.33	0.0633	
	Preop-Op X Station[e]	<0.01	0.15	0.3501	
	Station X Year (Preop-Op)[f]	0.03	34.03	0.0000 *	
	Error	0.16			
Pontogeneia	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
inermis	Preop-Op[a]	1, 2.32	3.40	0.1885	
Mid-Depth	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
(B19/B31)	Year (Preop-Op)[b]	0.00	0.00	0.5000	
	Month(Year)[c]	0.11	125.28	0.0000 *	
(destructive)	Station[d]	0.04	0.97	0.1623	
	Preop-Op X Station[e]	0.01	2.30	0.0646	
	Station X Year (Preop-Op)[f]	0.01	1.75	0.0932	
	Error	0.28			
Jassa	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
marmorata	Preop-Op[a]	1, 9.92	0.00	0.9692	
Shallow	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
subtidal	Year (Preop-Op)[b]	0.05	3.03	0.0408 *	
(B17,B35)	Month(Year)[c]	0.12	97.52	0.0000 *	
	Station[d]	0.01	0.83	0.1816	
(destructive)	Preop-Op X Station[e]	<0.01	<0.01	0.4812	
	Station X Year (Preop-Op)[f]	0.03	10.50	0.0006 *	
	Error	0.27			
Strongylocentrotus	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
droebachiensis	Preop-Op[a]	1, 27.5	2.01	0.1671	
juveniles<10mm	**Random Effects**	**Estimate[j]**	χ^2	**p[i]**	
Mid-Depth	Year (Preop-Op)[b]	0.10	5.30	0.0107 *	
(B19/B31)	Month(Year)[c]	0.15	65.90	0.0000 *	
	Station[d]	0.03	1.44	0.1151	
(destructive)	Preop-Op X Station[e]	0.00	0.00	0.4996	
	Station X Year (Preop-Op)[f]	0.05	12.89	0.0002 *	
	Error	0.53			

(continued)

Table 5-19. (Continued)

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Strongylocentrotus droebachiensis[1] >10mm Shallow subtidal (B17,B35) (non-destructive transects)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 20	0.41	0.5304	
	Random Effects	**Estimate[j]**	χ^2	**p[i]**	
	Year (Preop-Op)[b]	<0.01	0.02	0.4495	
	Month(Year)[c]	<0.01	5.59	0.0090 *	
	Station[d]	0	0.00	0.4999	
	Preop-Op X Station[e]	<0.01	0.00	0.4998	
	Station X Year (Preop-Op)[f]	<0.01	0.74	0.1942	
	Error	0.01			
Strongylocentrotus droebachiensis[1] >10mm Mid-Depth (B19,B31) (non-destructive transects)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 19.9	0.65	0.4293	
	Random Effects	**Estimate[j]**	χ^2	**p[i]**	
	Year (Preop-Op)[b]	0.05	22.37	0.0000 *	
	Month(Year)[c]	0.01	8.10	0.0022 *	
	Station[d]	0	0.00	0.4999	
	Preop-Op X Station[e]	<0.01	0.40	0.2648	
	Station X Year (Preop-Op)[f]	<0.01	15.42	<0.0001 *	
	Error	<0.01			
Modiolus modiolus (adults)[m] Mid-Depth (B19,B31) (non-destructive transects)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 59	25.87	<0.0001 *	Op<Preop
	Random Effects	**Estimate[j]**	χ^2	**p[i]**	
	Year (Preop-Op)[b]	0	0.00	0.4992	
	Month(Year)[c]	102.32	23.05	0.0000 *	
	Station[d]	100.70	0.77	0.1897	
	Preop-Op X Station[e]	<0.01	0.00	0.4988	
	Station X Year (Preop-Op)[f]	357.13	111.70	0.0000 *	
	Error	1950.53			

[a] Preop-Op compares 1982-1989 to 1991-2007 regardless of station for B17/B35.
Preop-Op compares 1978-1989 to 1991-2007 regardless of station for B19/B31.
Preop-Op compares 1980-1989 to 1991-2007 regardless of station for *M. modiolus.*

[b] Year nested within Preoperational and Operational periods regardless of Station.

[c] Month nested within Year regardless of Station or Period.

[d] Station pairs nested within a depth zone: Shallow subtidal = nearfield (B17), farfield (B35); Mid-depth = nearfield (B19), farfield (B31); regardless of Year, Station or Period.

[e] Interaction of the two main effects, Preop-Op and Station.

[f] Interaction of Station and Year nested within Preop-Op.

[g] Numerator degrees of freedom , denominator degrees of freedom

[h] F-statistic

[i] Probability value: * = significant ($p \leq 0.05$)

[j] Estimate of the variance component of random effect.

[k] Underlined estimates were not significantly different based on multiple comparison tests of H_0: LSMEAN (i)= LSMEAN(j).

[l] Density ($\log_{10}$ (#/m²+1)) of adult urchins from subtidal transect program; preoperational years = 1985-1989, operational years = 1991-2007.

[m] Analyses for *M. modiolus* adults were performed on untransformed density (#/m²) data.

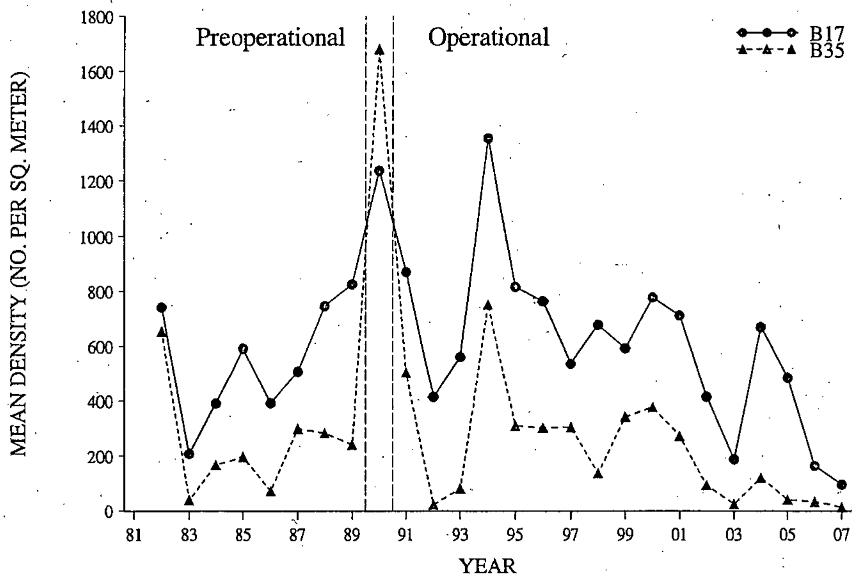


Figure 5-22. Annual geometric mean density (no./m^2) of Asteriidae at the shallow subtidal Stations B17 and B35, 1982-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

Pontogeneia inermis: Destructive Monitoring Program

The amphipod *Pontogeneia inermis* is an abundant subtidal macrofaunal species associated with macroalgae in the Gulf of Maine. It typically clings to submerged algae in the intertidal and subtidal zones to depths greater than 10 m, but it is also a powerful swimmer, occurring frequently in the water column (Bousfield 1973). *P. inermis* has occurred in the macrozooplankton collections in the Seabrook study area throughout the year (See Section 3.0) and has frequently been one of the dominant hyperbenthic species. Its semi-planktonic habits provide a mechanism for wide dispersal.

Pontogeneia inermis is an abundant species at all subtidal stations in the Seabrook study area (Table 5-15). Although total abundances were typically higher in the shallow subtidal zone, *P. inermis* represents a larger proportion of the macrobenthic assemblage at the mid-depth locations (Table 5-15). In 2007, the abundance at both mid-depth stations was higher than the previous year (Figure 5-23); the annual average at both stations was above the operational period means (Table 5-18). Density has typically been higher at Station B19, and that pattern continued in 2007 (Figure 5-23). Mean abundances between the preoperational and operational periods were not significantly different (Table 5-19). There were no significant differences in abundance between stations and the interaction term was not significant. Since differences between the preoperational and operational periods were consistent at both the nearfield and farfield stations, there is no evidence of an effect due to the operation of Seabrook Station.

Jassa marmorata: Destructive Monitoring Program

Jassa marmorata is a tube-building amphipod and a common member of the hard substratum community in the Gulf of Maine. Populations of this species can dominate primary space on hard surfaces, often outcompeting encrusting species by forming a complex mat composed of numerous tubes

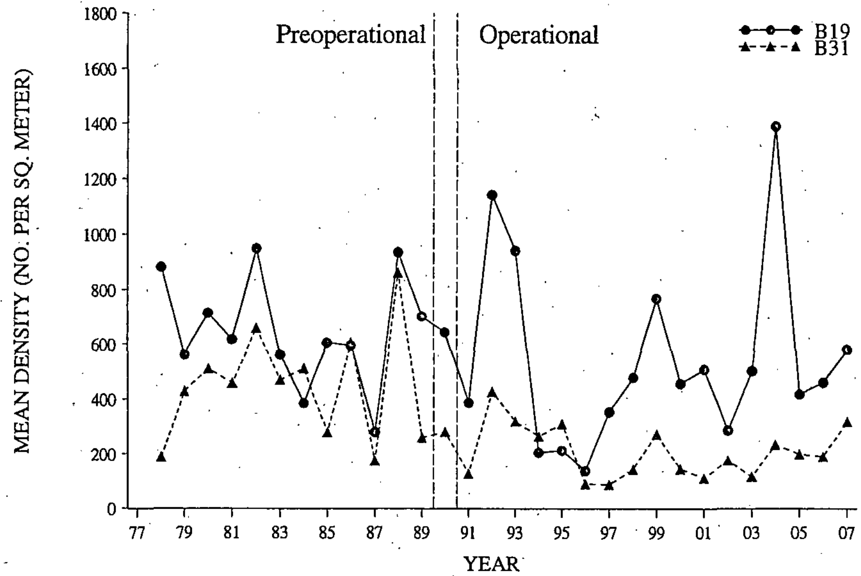


Figure 5-23. Annual geometric mean density (no./m^2) of *Pontogeneia inermis* at the mid-depth Stations B19 and B31, 1978-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

made from sediment and detritus (Sebens 1985). Franz and Mohamed (1989) found that production of multiple cohorts in a single season enabled *J. marmorata* to take advantage of seasonal changes in the encrusting community. Intraspecific competition was reduced by migration of new recruits over short distances to uncolonized substrate. Life span varied among the cohorts, with an inverse relationship to water temperature (Franz 1989). *J. marmorata* is primarily a suspension feeder (Nair and Anger 1979) and also a predator of small crustaceans such as ostracods (Bousfield 1973). Duffy (1990) found that *J. marmorata* benefited the brown alga *Sargassum* sp. by consuming epiphytes from the surface of the alga.

Jassa marmorata occurs most abundantly in the shallow subtidal zone in the Seabrook study area (Table 5-15 and Table 5-18) where it is among the dominant taxa. Following a major peak in abundance in 2000, annual mean abundances have remained relatively low at both stations (Figure 5-24). The 2007 mean was below the preoperational and operational lower confidence limits at Station B17, and below the period means at Station B31 (Table 5-18). There were no significant differences in the abundances of *J. marmorata* between the preoperational and operational periods or between stations, and there was no significant difference in the Preop-X Station interaction term (Table 5-19), an indication that there is no effect from the operation of Seabrook Station.

Strongylocentrotus droebachiensis: Destructive Monitoring Program

Grazing by locally-dense aggregates of the green sea urchin *Strongylocentrotus droebachiensis* in the subtidal zone preferentially eliminates populations of foliose algae (Breen and Mann 1976; Witman 1985), such as the kelp *Laminaria saccharina* and *L. longicruris* (Larson et al. 1980; Mann et al. 1984). Likewise, grazing by urchins also affects macroalgal cover in the low intertidal, exerting a major influence on the community structure of these zones (Lubchenco 1980; Witman 1985; Novaczek and McLachlan 1986; Johnson and Mann 1988). Dense aggregates of

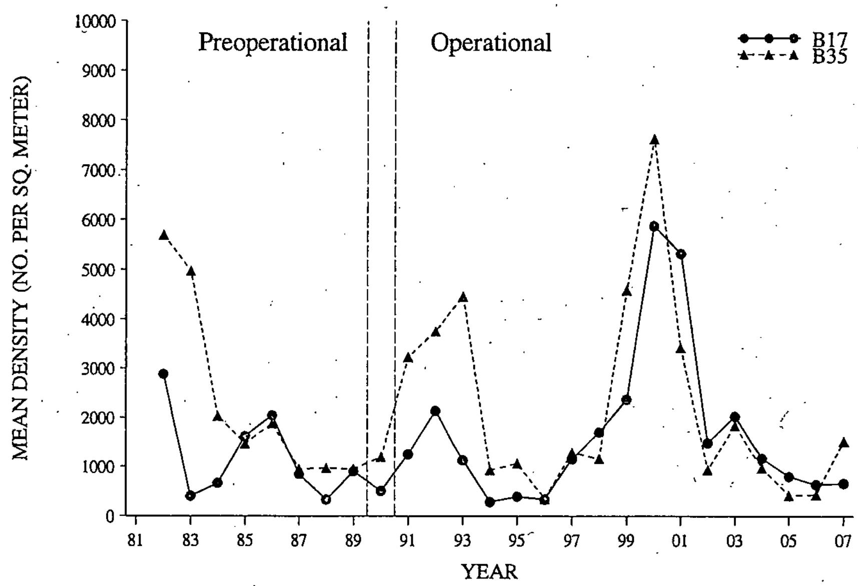


Figure 5-24. Annual geometric mean density (no./m^2) of *Jassa marmorata* at the shallow subtidal Stations B17 and B35, 1982-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

S. droebachiensis can reduce a kelp bed to a barren ground consisting primarily of crustose coralline algae. Fishing pressure or disease can reduce *S. droebachiensis* to levels that allow recolonization of denuded areas by foliose algae (Steneck et al. 1994). Rowley (1989, 1990) found that newly metamorphosed *S. purpuratus* (purple sea urchin) juveniles can settle in either barren grounds or kelp beds. In fact, Balch et al. (1998) found that settlement of *S. droebachiensis* was higher in barren grounds than kelp beds in Nova Scotia and the Gulf of Maine. During the first couple of months of benthic existence, juvenile urchins feed by surface scraping and are not capable of eating fleshy algae. When they reach the threshold of 0.8 to 1.2 mm in diameter, they become capable of feeding on kelp or algal turf if available (Rowley 1990). Juveniles settling in the barren grounds of kelp beds exhibited differential mortality and growth rates. Initially, mortality was lower and growth slightly higher in the barrens, perhaps because of the presence of a more suitable food source (Rowley 1989). Once juveniles reached the size at which they could consume algae, however, the growth rate in habitat structured by algae was six to seven times the rate on barren grounds (Rowley 1990; Meidel and Scheibling 1996). Urchins found along the edges of kelp beds and within the kelp bed achieve a higher gonad index than those in barren grounds, possibly a result of the quality of food available (Meidel and Scheibling 1998). Harris and Tyrrell (2001) proposed a model detailing the mechanism of transition of traditional kelp bed and urchin barren communities (primarily in the vicinity of the Isles of Shoals, NH) to other communities such as blue mussel beds and *Codium* beds.

Past measurements of urchins collected in the destructive samples from our project area indicate that they are predominantly <10 mm in diameter. Meidel and Scheibling (1999) estimated that *Strongylocentrotus droebachiensis* ranging in diameter from 13-17 mm were about 2-3 years old, suggesting that the urchins from destructive samples in our study area are likely to be from less than 1 to 2 years in age. *S. droebachiensis* can achieve sexual maturity at about 18-25 mm in diameter. Under optimum habitat conditions (i.e. availability of a mixed diet of macroalgae and mussels, such as occurs in the Seabrook study area), urchins can achieve a growth rate as high as 16-18 mm/year. However, various studies cited by Russell et al. (1998) indicate that growth to 50 mm (2 inches), the legal harvest size in Maine, may take from 2 to 16 years. Growth curves constructed by Russell et al. (1998) state that growth rate was fastest until the 50 mm size was reached, averaging 2.6-5.5 mm/year, and then became asymptotic.

Small urchins (predominately < 10 mm) monitored in the destructive sampling program, therefore, are neither immediately vulnerable to harvesting pressure, nor are they immediately likely to contribute to population increase because they are at least a year from sexual maturity. However, they may be viewed as an indicator of overall Gulf of Maine reproductive success, representing the previous year's urchin spawn. Hence, a change in abundance from year to year may be an indirect reflection of harvesting pressure or other external forces (including operation of Seabrook Station, natural population fluctuations, predation pressure, and the vagaries of settlement of planktonic larvae). Harvesting pressure has been intense in the Gulf of Maine since the late 1980s (prior to operation of Seabrook Station), to the extent that adult urchin abundances have decreased noticeably and macroalgal coverage (especially kelp) have increased in some areas (Wahle and Peckham 1999). Sea urchin landings have been recorded in Maine since 1964 but they represented an underutilized resource until the late 1980s. Landings peaked in 1993 at 19,115 mt (42 million pounds), but have steadily decreased to 1,533 mt (3.4 million pounds) in 2006 landings (Maine Department of Marine Resources Commercial Landing Statistics (http://www.maine.gov/dmr/comfish.htm)).
The Maine Department of Marine Resources initiated severe cutbacks (30-50 %, depending on the geographical zone) for the sea urchin fishery starting in fall 2003.

Juvenile sea urchins < 10 mm in diameter: Destructive Monitoring Program

Although present in all depth zones studied, juvenile sea urchins (collected from destructive samples) have been more abundant in the mid-depth zone than in the shallow subtidal during the operational period, although they have not been among the dominant taxa at any station (Table 5-15). Mean densities from the nearfield (Station B19) were about double those in the farfield (Station B31) during the preoperational period; although the operational period means were more similar, nearfield means continued to exceed the farfield (Table 5-18; Figure 5-25). In 2007, densities increased compared to the previous year at both stations (Figure 5-25). However, nearfield means were the highest recorded in a decade, while farfield means increased only slightly, remaining below the lower confidence limits for both periods (Table 5-18; Figure 5-25). Differences in abundance between stations and between periods were not significant, and the interaction term was not significant (Table 5-19).

Sea urchins > 10 mm in diameter: Non-destructive Monitoring Program

Sea urchin (generally 10 mm in diameter or greater) density (no./m^2) along transects was estimated at shallow subtidal (B17, B35) and mid-depth (B19, B31) stations. In 2007, no sea urchins were observed at any of the four stations (Table 5-18). Mean annual densities at the mid-depth stations were usually near zero except for a population increase that started in 1992 and reached peak abundances of about 7 or 8/m^2 in 1994 at both stations (Figure 5-26). By 1997, densities declined to near zero at both stations and the low densities have continued through 2007. There were no significant differences between periods or stations and the interaction between period and station was not significant for both

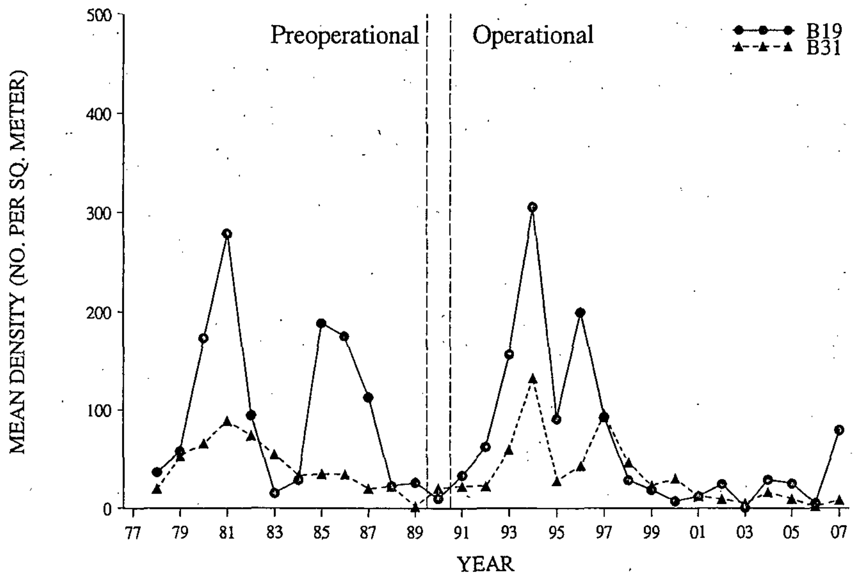


Figure 5-25. Annual geometric mean density (no./m^2) of juvenile *Strongylocentrotus droebachiensis* collected from destructive samples at the mid-depth Stations B19 and B31, 1978-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

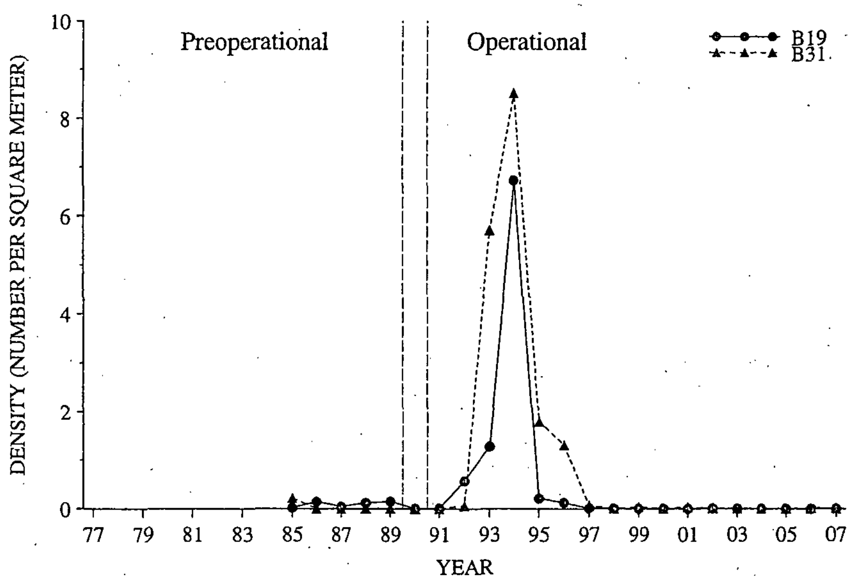


Figure 5-26. Annual geometric mean density of adult *Strongylocentrotus droebachiensis* (no./m^2) in the mid-depth subtidal zone, 1978-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

depth zones (Table 5-19). Urchins are often considered a keystone species because of their ability to graze-down laminarians and other algae. A significant negative relationship between high densities of urchins and low densities of *Laminaria digitata* was found at Station B31 only, indicating that urchin grazing may have reduced kelp densities from 1993 through 1996 (NAI 2001, Figure 5-9).

Modiolus modiolus: Non-destructive Monitoring Program

The boreal horse mussel *Modiolus modiolus* forms subtidal beds (Hiscock et al. 2004) that are often extensive in the Gulf of Maine, providing hard substratum habitat for benthic algae attachment (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 echinoderm, the green sea urchin, *Strongylocentrotus droebachiensis*, will sometimes also consume *M. modiolus* (Briscoe and Sebens 1988). Urchin activity may actually enhance horse mussel abundance by grazing the attached kelp from the mussels, thereby decreasing the risk of mussel dislodgement during storms (Witman 1987). Populations of *M. modiolus* have declined in recent years in the Irish Sea (Magorrian et al. 1995), and warming may prevent recovery (Hiscock et al. 2004).

Mean densities of *Modiolus modiolus* in 2007 were lower than the preoperational and operational lower confidence limits at both stations (Table 5-18). In 2007, both stations exhibited a decline in density from the previous year, and Station B31 reached a low for the study period (Figure 5-27). The time series of annual mean densities in the mid-depth zone indicates a gradual decline since the early 1980s, with the exception of 1994, when density was unusually high at the farfield station (Figure 5-27). When both stations were examined using analysis of variance, preoperational period densities were significantly higher than operational period densities, but no significant differences were detected between stations or in the Preop-Op X Station interaction term (Table 5-19), indicating that the relationship between stations was consistent between the preoperational and operational periods.

5.4 CONCLUSIONS

5.4.1 Introduction

Operation of Seabrook Station may expose the non-motile, hard substrate macrobenthic community to several types of environmental impacts. The buoyant character of the thermal plume potentially allows it to affect shallow subtidal communities, but not to contact the bottom at mid-depth habitats. Potential impacts include those related to direct contact with the thermal plume such as changes in the temperature regime and the corresponding changes in dissolved oxygen. Also possible are impacts associated with detrital loading (due to the discharge of organisms that were entrained in Seabrook Station) in the water column and the corresponding reduction in light transmission, potential increase in nutrients due to decomposition of entrained organisms, entrainment of nutrient-enriched bottom waters with discharge into surface waters, and exposure to chemicals used to reduce fouling within the cooling water system. Discharge effects that could extend beyond the physical boundary of the thermal plume are related to the increase in detrital loading (entrained organisms discharged) with the associated reduction in light transmission, and increased deposition of detritus. The potential exposure and response to each of these types of impacts is likely to vary in relation to water depth.

Other monitoring studies for generating stations have documented changes in community structure (species composition) by either reductions of cold-water species or

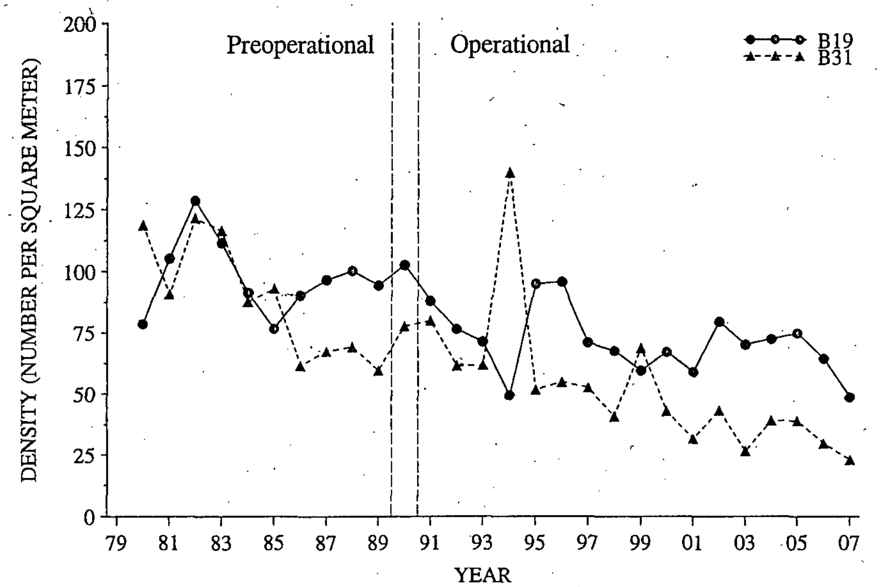


Figure 5-27. Annual arithmetic mean density (no./m^2) of *Modiolus modiolus* at the mid-depth Stations B19 and B31, 1980-2007 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2007.

increases in warm-water species (Vadas et al. 1976; Wilce et al. 1978; BECO 1994; NUSCO 1994, 1996; DNC 2005). Temperature-related impacts with corresponding decreases in dissolved oxygen are likely to be restricted to the shallow subtidal habitat as well. Effects of the continuous low-level chlorination (sodium hypochlorite) used by the plant to control fouling are also likely to affect only habitats directly exposed to the plume. Entrainment of nutrient-rich bottom water and discharge into near-surface waters could affect algal species composition and growth patterns. Jahn et al. (1998) found that kelp near the San Onofre Nuclear Generating Station (California) had higher than average nitrogen content with a pattern of decreasing enrichment related to increased distance from the diffuser plume. Because of the dispersal characteristics of the plume from the Seabrook discharge, these effects are likely to occur only in the shallow subtidal area where the potential for the plume to contact the bottom exists. Detritus-related impacts could be experienced in deeper waters. The intake removes water from approximately 5.2 m off the bottom, passes it through the circulating water system and discharges it approximately 2-3 m off the bottom where it rapidly rises to the surface. It is assumed that entrained organisms do not survive passage through the plant, and are therefore converted to detritus. Increased detritus could reduce light transmission and increase the level of suspended materials including nutrients. Detritus could also settle to the bottom, and adversely affect benthic organisms, whose sessile habits prevent relocation. These effects could be observed as a change in community structure (species composition), i.e. elimination of species sensitive to reduced light or increased sedimentation, increased abundance of more tolerant species, as well as changes in total biomass or density and number of taxa. Sedimentation is potentially one of the most pervasive factors affecting colonization and survival of early life stages of marine algae (Airoldi 2003). Devinny and Volse (1978) found that sediment concentrations of only 10 mg/ cm² could prevent giant kelp spores from settling and developing successfully, probably because they settled on unstable sediment grains. Fine sediments reduced fucoid attachment by > 90% relative to controls, and there can be species-specific differences in the ability to attach to primary substrata in the presence of fine sediments (Schiel et al. 2006). On a large scale, it is likely that the massive loss of giant kelp forests along the southern California coast in the late 1950s and 1960s was caused in part by increased sedimentation associated with sewer outfalls (Grigg and Kiwala 1970). Changes in the sedimentation rate due to potential detrital increases from the discharge would be more likely to occur in mid-depth habitats that are more quiescent and therefore likely to be more susceptible to the accumulation of detritus.

5.4.2 Evaluation of Potential Thermal Plume Effects on the Shallow Subtidal Benthic Communities

Shallow subtidal habitats (5-6 m) were included in the monitoring program because of the potential for exposure to the thermal plume, particularly at the Outer Sunk Rocks. Hydrodynamic modeling was used to predict the extent and level of temperature increase expected in the nearfield area (Teyssandier et al. 1974). Field validation of the modeling results confirms a small temperature increase (<1°F) in a limited (<32 acre) area near the shallow subtidal stations (Padmanabhan and Hecker 1991). Water temperatures at the shallow subtidal stations were measured from 1998–2000. Although continuously recorded monthly mean temperatures in 2000 were significantly different between the nearfield and farfield stations, the mean differences between the stations averaged 0.01°C and were not consistent between stations. The nearfield station was cooler than the farfield station from March through August (NAI 2001). There is no evidence that the thermal plume is affecting the bottom temperature at shallow subtidal stations.

Macroalgal and macrofaunal community structure in the shallow subtidal zone has been consistent throughout the study (Table 5-20, Figures 5-5 and 5-18). Relationships between stations for numbers of macroalgal taxa, total macroalgal biomass, numbers of macrofaunal taxa, and total macrofaunal density were consistent between periods in this zone (Table 5-20). This clearly supports the premise that the operation of Seabrook Station has not changed the structure of the benthic community. The decrease in macrofaunal taxa at both stations between the preoperational and operational periods indicates an area-wide decrease. Numbers of macroalgal taxa (per 0.0625 m^2) have been consistent between the preoperational and operational periods with only modest annual variation. The density of most selected species from destructive samples, including *Chondrus crispus, Phyllophora/Coccotylus*, *Ptilota serrata*, Mytilidae, Asteriidae and *Jassa marmorata* were consistent between periods (Table 5-21).

Large macroalgae were sampled non-destructively (no. of holdfasts per 100 m^2). Density of *Laminaria saccharina*, the dominant kelp in the shallow subtidal zone, decreased between periods at at the nearfield station, but was equal at the farfield station, resulting in a significant interaction term (Table 5-21; Figure 5-12). The breakpoint in the annual time series at the nearfield station occurred between 1993 and 1994, after the plant became operational (Table 5-12). Generally, both stations tracked each other from 1989 through the operational period (Figure 5-12). These observations indicate that the decline between the preoperational and operational periods at the nearfield is not likely due to the operation of Seabrook Station.

Density of the subdominant kelp *Laminaria digitata* also showed a statistically significant decline between periods at both the nearfield (B17), and farfield (B35) stations, but to a greater degree at the nearfield station (Figure 5-8). The breakpoint in the annual time series at the nearfield station occurred

Table 5-20. Summary of Evaluation of Potential Thermal Plume Effects on Benthic Communities in the Shallow Subtidal Zone (B17, B35) in the Vicinity of Seabrook Station. Seabrook Operational Report, 2007.

Community	Area/Depth Zone	Parameter[a]	Operational Period Similar to Previous Years?[b]	Nearfield-Farfield Differences Consistent with Previous Years?[c]
Macroalgae	Shallow Subtidal	No. of taxa	Yes	Yes
		Total biomass	Yes	Yes
		Community structure	Yes	Yes
Macrofauna	Shallow Subtidal	No. of taxa	Op < Preop	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 and MDS.
[b] Conclusions derived from ANOVA, main effect term: Preop-Op, when the interaction term was not significant.
[c] Conclusions derived from ANOVA, interaction term: Preop-Op X Station. Operational period = 1990-2007 (August only for fauna).

Table 5-21. Summary of Evaluation of Potential Thermal Plume Effects on Representative Important Benthic Taxa in the Shallow Subtidal Zone (B17, B35) in the Vicinity of Seabrook Station. Seabrook Operational Report, 2007.

Community	Area/Depth Zone	Selected Taxon	Operational Period Similar to Previous Years?[a]	Nearfield-Farfield Differences Consistent with Previous Years?[b]
Macroalgae	Shallow Subtidal	*Chondrus crispus*	Yes	Yes
		(biomass)	Op>Pre	Yes
		Chondrus crispus (% frequency)		NF: Op<Preop
		Laminaria digitata	—	FF: Op<Preop
		Laminaria saccharina	—	NF: Op<Preop FF: Op=Preop
		Phyllophora/Coccotylus	Yes	Yes
		Ptilota serrata	Yes	Yes
Macrofauna	Shallow Subtidal	Mytilidae	Yes	Yes
		Asteriidae	Yes	Yes
		Jassa marmorata	Yes	Yes

[a] Conclusions derived from ANOVA, main effect term: Preop-Op, when the interaction term was not significant.
[b] Conclusions derived from ANOVA, interaction term: Preop-Op X Station. Operational period = 1990-2007 (August only for fauna); NF = nearfield, FF = farfield.

between 1999 and 2000, although the decline began in 1984, well before the plant became operational. Since the decline was significant at both stations, and began during the preoperational period, it is not likely to be due to plant operation. Physical and biological factors may be contributing to the decline. Comparison of annual mean densities of *L. digitata* and *Strongylocentrotus droebachiensis* shows that increases in urchin density coincide with decreases in kelps, although the relationship was not statistically significant (NAI 2001). Kelp density has remained low at the nearfield station since 1996, although urchin abundance has also been low. Cosson (1999) reported a decline in *L. digitata* in the shallow sublittoral zone off the coast of France, coincident with an increase in *Sargassum multicum,* turbidity, and coastal eutrophication, although a definite relationship among these factors was not clear. It is unclear whether the increase in *S. multicum* is simply a result of available habitat or somehow contributing to the decline in *L. digitata*. The nearfield station is closest to the Hampton Harbor Inlet, and may be the station most likely to receive nutrients from Hampton Harbor. Also, episodic periods of large waves can exert a critical role in determining abundance and relative species composition of kelp (Dayton and Tegner 1984, Dayton et al. 1984, Seymour et al. 1989, Graham et al. 1997). Two storms in 1991 (Hurricane Bob and the "Perfect Storm") may have contributed to the drop in annual mean abundance noted at both stations between 1990 and 1991 (Figure 5-8). In 2007, the population at the nearfield station has remained low since 1996, while at the farfield station it was the second lowest of the time series (Figure 5-8). In our study area, the relatively low abundance of *Laminaria digitata* in the shallow subtidal zone during all years of the study suggests that the habitat conditions are marginal, making *L. digitata* is susceptible to even minor regional changes in physical or biological factors, which could have been sufficient to cause the observed decline.

Regional changes in the Gulf of Maine benthic community have been reported. In the shallow subtidal waters of New Hampshire and southern Maine, Harris and Tyrrell (2001) noted long-term changes in the climax community. Prior to the 1970s the climax community was composed of *Laminaria* spp. kelp beds with an understory of arborescent red algae. In the 1980s a population explosion of green sea urchins, *Strongylocentrotus droebachiensis* created *Corallina* dominated urchin barrens. A transition was observed from the urchin barrens and former kelp beds to an assemblage composed of the introduced species: *Codium fragile* subsp. *tomentosoides* (green alga), *Membranipora membranacea* (bryozoan), *Diplosoma listerianum* (tunicate) and *Bonnemaisonia hamifera* (red alga) and the opportunistic species *Mytilus edulis* (mussel) and *Desmarestia aculeata* (brown alga). More recently Harris and Jones (in press) have reported that the *Codium fragile* subsp. *tomentosoides* populations at the Isles of Shoals are successfully recruiting to locations in the shallow subtidal zone at depths less than 8 m and have become a new climax community at those locations. Factors that may slow the expansion to other nearshore sites include temperature instability due to a variety of factors including localized, wind-driven upwelling (Harris and Jones in press). Mathieson et al. (2003) located 26 *Codium fragile* subsp. *tomentosoides* populations ranging from southern Maine to New Hampshire, but found that outer estuarine and nearshore open coastal populations had more limited densities and biomass than those found at warmer offshore insular sites like the Isles of Shoals (Star Island). A similar decadal cycle has occurred in the rocky subtidal of Nova Scotia which alternates between kelp beds and coralline urchin barrens (Scheibling and Hennigar 1997, Scheibling et al. 1999).

Steneck et al. (2004) used archaeological, historical, ecological, and fisheries data to identify three phases in the trophic structure of the western North Atlantic kelp forest ecosystem. These phases resulted directly or indirectly from fisheries-induced "trophic-level dysfunction," in which populations of important species at higher trophic levels fell below the densities necessary to limit prey populations. Phase 1 was characterized by vertebrate apex predators such as Atlantic cod and other fish and persisted for more that 4,000 years. Phase 2 was characterized by herbivorous sea urchins and lasted from 1970s to the 1990s. Phase 3 developed since 1995 and is dominated by invertebrate predators such as large crabs. These findings as well as the studies by Harris and Tyrell (2001), and Mathieson et al. (2003) indicate that the trophic structure of benthic communities of the western Gulf of Maine is very dynamic and has been influenced by the introduction of non-native species and the removal of apex predators. The magnitude and scale of these larger regional influences complicates the task of detecting the relatively subtle and localized impacts potentially associated with power plant operation.

5.4.3 Evaluation of Potential Turbidity Effects on the Mid-Depth Benthic Communities

The nearfield mid-depth study site represents the macrobenthic community in closest proximity to the Seabrook Station discharge. Temperature effects at this site are unlikely, since the discharge is at midway between the surface and the bottom, and the thermal plume is buoyant, and not likely to reach the bottom (12 m). However, there is a potential for higher sedimentation rates resulting from increased levels of suspended particles in discharge waters relative to the surrounding waters, which could affect nearfield benthic communities. Higher sedimenttation 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 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 from the middle of the water column, 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.

In May and October 1998, turbidity was monitored at the mid-depth stations and in Hampton Harbor (October only). Turbidity was significantly higher at the nearfield station, and this was attributed to the proximity of the station to the outflow from Hampton Harbor (NAI 1999a). Turbidity in the discharge plume was less than that observed in Hampton Harbor, or at the nearfield station. Therefore, outflow from Hampton Harbor is more likely the source for turbidity at the nearfield station than the discharge plume.

The total algal biomass, total macrofaunal density, and number of macrofaunal taxa remained consistent between periods in the mid-depth zone (Table 5-22). The average number of algal taxa showed a significant increase at Station B31 between preoperational and operational periods, and no significant difference at the nearfield station (Table 5-22), resulting in a significant interaction term in the ANOVA model. The annual mean numbers of algal taxa at these stations were generally similar until 1989, when numbers of taxa became consistently higher at the farfield station (Figure 5-3). The two stations tracked

Table 5-22. Summary of Evaluation of Potential Turbidity Effects on Benthic Communities in the Mid-Depth Subtidal Zone (B19, B31) in the Vicinity of Seabrook Station. Seabrook Operational Report, 2007.

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	—	NF: Op=Pre FF: Op>Pre
		Total biomass	Op<Preop	Yes
		Community structure Yes		Yes
Macrofauna	Mid-depth	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 and MDS
[b] Conclusions derived from ANOVA, main effect term: Preop-Op, when the interaction term was not significant.
[c] Conclusions derived from ANOVA, interaction term: Preop-Op X Station. Operational period = 1990-2007 (August only for fauna); NF = nearfield, FF = farfield.

each other closely during the early operational period, increasing through 1996, after which numbers of taxa started declining at the nearfield station (until a rebound began in 2001) while the farfield station remained higher than the nearfield station. The difference in number of taxa is related to fluctuations in species that are typically found in shallower water and appear to be part of a long-term cycle. Also, numerical classification revealed the formation of a small group of recent collections (2001 to 2004) from the farfield station which had a relatively low similarity (54%) to the other groups (Figure 5-6). This group is characterized by low overall biomass, and *Phyllophora/Coccotylus* (the dominant in the other major groups) is replaced by *Chondrus crispus*, *Corallina officinalis* and the aseasonal annual, *Polysiphonia stricta* (Table 5-6). In 2007, Station B19 was an outlier and was characterized by low biomass of all taxa, particularly the dominant *Phyllophora/ Coccotylus*. Since preoperational and operational collections were mixed in the major groups, there is no indication of a local effect from the operation of Seabrook Station. Habitat differences between the nearfield and farfield stations, particularly depth, are greater than for the shallow subtidal stations (Appendix Table 5-4), which accounts for the somewhat decreased similarity in the macrofaunal assemblages.

At mid-depth stations, density of the dominant kelps, *Agarum clathratum* and *Laminaria saccharina,* the understory red algae *Phyllophora/Coccotylus and Pilot serrata,* and the selected macrofaunal taxa including Mytilidae spat, *Pontogeneia inermis* and *Strongylocentrotus droebachiensis* (>10 mm and <10 mm) were consistent among periods (Table 5-23). However, the densities of the subdominant kelp, *Laminaria digitata* declined significantly at both the nearfield (Station B19) and farfield (B31) areas, and the decline was greater at the farfield area (Figure 5-10). Annual mean densities of *L. digitata* showed a decline beginning at both stations prior to the startup of Seabrook Station. Since the declines occurred at both stations and began prior to the operation of Seabrook Station, they are probably not due to plant operation, but more likely are an area-wide occurrence that has also been described by

Table 5-23. Summary of Evaluation of Potential Turbidity Effects on Representative Important Benthic Taxa in the Mid-Depth Subtidal Zone (B19, B31) in the Vicinity of Seabrook Station. Seabrook Operational Report, 2007.

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
		Agarum clathratum	Yes	Yes
		Alaria esculenta	Yes	NF: Op=Preop FF: Op<Preop
		Laminaria saccharina	Yes	Yes
		Phyllophora/Coccotylus	Yes	Yes
		Ptilota serrata	Yes	Yes
Macrofauna	Mid-depth	Mytilidae spat	Yes	Yes
		Pontogeneia inermis	Yes	Yes
		Strongylocentrotus droebachiensis < 10 mm	Yes	Yes
		S. droebachiensis > 10 mm	Yes	Yes
		Modiolus modiolus	Op<Preop	Yes

[a] Conclusions derived from ANOVA, main effect term: Preop-Op, when the interaction term was not significant.
[b] Conclusions derived from ANOVA, interaction term: Preop-Op X Station. Operational period = 1990-2007 (August only for fauna); NF = nearfield, FF = farfield.

Harris and Tyrrell (2001) and Steneck et al. (2004). Density of a subdominant kelp, *Alaria esculenta* declined significantly only at the farfield station and remained very low, but nearly unchanged at the nearfield station, therefore the decline can not be related to plant operation. Mean density of *Modiolus modiolus* was significantly greater in the preoperational period at both stations. Since the declines occurred a both stations, they represent a regional occurrence, and are not a localized effect of plant operation.

5.4.4 Overall Effect of Seabrook Operation on the Local Marine Macrobenthos

Monitoring studies document that balanced indigenous macrobenthic communities continue to occupy subtidal rocky habitats in the vicinity of the Seabrook discharge with little change beyond that expected from annual and decadal 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 a historical trend that began prior to commercial operation of Seabrook Station.

The influence of the regional temperature increase of surface and bottom water (Section 2.0) between the preoperational and operational periods (on the order of 0.5° C) on the benthic community is unclear. A decline in *Laminaria digitata* at all stations in both the shallow and mid-depth subtidal zones occurred predominantly during the operational period. The population of *L. digitata*, a subdominant throughout the study period, has been reduced by a combination of physical and biological factors. An increase in sea urchin densities may have contributed to the observed decreases in *L. digitata* in the mid-depth subtidal zone. The regional decline in *Laminaria* spp. beds has been documented in the Gulf of Maine (Harris and Tyrrell 2001) and in the western North Atlantic (Steneck et al. 2004), and causes such as overfishing, climate change and invasive species have been suggested. It is likely that the decreases in *L. digitata* and *L. saccharina* from their peaks in the 1980s are part of the regional decline. Breemen (1990) suggests that far-reaching effects of temperature rise will cause marked northward shifts of the southern boundaries of kelps *L digitata* and *L saccharina* in France, the southern parts of Britain and Ireland, and southern Norway, which would cause major changes in ecosystem functioning except where replaced by the southern kelp *L. ochroleuca*. The horse mussel *Modiolus modiolus* is a northern species that is also expected to decline with an increase in temperature (Hiscock et al. 2004), and we have observed significant decreases in *M. modiolus* between periods at both stations. In European waters, beds of long-lived horse mussels are being adversely affected by trawling and possibly other human influences, such as nutrient run-off. Warmer sea temperatures may prevent recovery of damaged beds, and a decline in the occurrence of beds can be expected at least in the southern part of their range (Hiscock et al. 2004). It is unlikely, however that Seabrook Station is responsible for the observed declines in *M. modiolus* because the decrease was consistent at both the nearfield and farfield stations. Plant influence appears to be unlikely, as it cannot be demonstrated that there are local increases in bottom water temperature and turbidity in the vicinity of the plant discharge (nearfield stations).

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Appendix Table 5-1. Marine Macrobenthos Sampling History. Seabrook Operational Report, 2007

Stations		Sampling Method	Months	Years
Farfield	**Stations**			
Intertidal: B5MLW		Destructive	May, August, November	1982-2001
B5MSL		Non-destructive	April, July, November	1983-2001
Subtidal: B35	(shallow)	Destructive	May, August, November	1982-2007
		Non-destructive	April, July, October	1982-2007
B31	(mid-depth)	Destructive	May, August, November	1978-2007
		Non-destructive	April, July, October	1978-2007
		Panel Studies	Short Term	1982-2007
		Panel Studies	Long Term[a]	1982-1997
B34 (deep)		Destructive	August	1979-1997
		Panel Studies	Short Term, Long Term[a]	1986-1997
Nearfield	**Stations**			
Intertidal: B1MLW		Destructive	May, August, November	1978-2001
B1MSL		Non-destructive	April, July, November	1983-2001
Subtidal: B17	(shallow)	Destructive	May, August, November	1978-2007
		Non-destructive	April, July, October	1979-2007
B16	(mid-depth)	Destructive	August	1980-1984, 1985-1997
B19	(mid-depth)	Destructive	May, August, November	1978-2007
		Non-destructive	April, July, October	1978-2007
B04	(deep)	Destructive	August	1978-1997
		Panel Studies	Short Term, Long Term	1982-1997
B13 (deep)		Destructive	August	1978-1997
		Panel Studies	Short Term, Long Term	1986-1997
				1978-1997

[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 5-2. Nomenclatural Authorities and Common Names of Macrofaunal Taxa Cited in the Marine Macrobenthos Section. Seabrook Operational Report, 2007.

Scientific Name	Common Name[a]
Mollusca	
Polyplacophora	chitons
Gastropoda	snails
Acmea testudinalis (Müller 1776)	tortoiseshell limpet
Alvania castanea (Moller 1842)	alvania
Lacuna vincta (Montagu 1803)	Atlantic chink shell
Littorina littorea (Linnaeus 1758)	common periwinkle
Littorina obtusata (Linnaeus 1758)	smooth periwinkle
Littorina saxatilis (Olivi 1792)	rough periwinkle
Mitrella lunata (Say 1826)	lunar dove-shell
Nucella lapillus (Linnaeus 1758)	dogwinkle
Onchidoris sp.	rough-mantled nudibranch
Bivalvia	bivalves
Mytilidae	mussel family, primarily blue mussel
Modiolus modiolus (Linnaeus 1758)	horse mussel
Anomia sp.	jingle shell
Turtonia minuta (Fabricius 1780)	minute turton clam
Hiatella sp.	Arctic saxicave
Annelida	segmented worms
Oligochaeta	aquatic earthworms
Polychaeta	marine worms
Harmothoe imbricata (Linneaus 1767)	fifteen-scaled worm
Pectinaria granulata (Linnaeus 1767)	polychaete
Polycarpa fibrosa (Stimpson 1852)	polychaete
Dipolydora websteri (Hartman 1943)	polychaete
Arthropoda	jointed-leg animals
Pantopoda	sea spiders
Achelia spinosa (Stimpson 1853)	
Crustacea	crustaceans
Balanus sp.	barnacles
Balanus crenatus (Bruguiere 1789)	crenate barnacle
Idotea balthica (Pallas 1772)	isopod
Idotea phosphorea (Harger 1873)	isopod
Jaera marina (Fabricius 1780)	little shore isopod
Caprella septentrionalis (Kroyer 1838)	skeleton shrimp
Ampithoe rubricata (Montagu 1808)	amphipod
Calliopius laeviusculus (Kroyer 1838)	planktonic amphipod
Erichthonius rubricornis (Smith 1873)	amphipod
Gammarellus angulosus (Rathke 1843)	amphipod
Gammarus oceanicus (Segerstråle 1947)	scud
Ischyrocerus anguipes (Kroyer 1838)	amphipod
Jassa marmorata (Holme 1903)	amphipod
Pontogeneia inermis (Krøyer 1842)	hyperbenthic amphipod
Echinodermata	spiny-skinned animals
Echiniodea	sea urchins
Strongylocentrotus droebachiensis (Müller 1776)	green sea urchin
Stelleriodea	
Asteriidae	sea stars

[a] primarily from Gosner 1971, Barnes 1987, and Abbott 1974.

Appendix Table 5-3. **The Occurrence of Macroalgae from General Collections and Destructive Samples at all Intertidal and Subtidal Stations Sampled between 1978 and 2007 (Intertidal Collections have not been made since the end of 2001). Seabrook Operational Report, 2007.**

CHLOROPHYTA	**Year**																													
Species and Citation	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Blidingia minima (Naegeli ex Kutz.) Kylin	x		x	x	x	x	x	x	x										x											
Bryopsis plumosa (Huds.) C.Agardh							x								x	x														
Chaetomorpha aerea (Dillwyn) Kutz.					x																									
Chaetomorpha brachygona Harv.	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Chaetomorpha linum (O.F.Mull.) Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chaetomorpha melagonium (F.Weber et D.Mohr) Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chaetomorpha picquotiana Mont. ex Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Chaetomorpha sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x											
Cladophora albida (Nees) Kutz.																				x										
Cladophora sericea (Huds.) Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Cladophora sp.																		x												
Codiolum petrocelidis Kuck.	x	x																												
Codium fragile ssp. (Suringar) Har. ssp. tomentosoides																					x	x								
Enteromorpha compressa (L.) Nees													x						x											
Enteromorpha flexuosa (Wulf. ex Roth) J. Agardh ssp. paradoxa																				x										
Enteromorpha intestinalis (L.) Nees		x		x	x	x		x					x					x		x				x						
Enteromorpha linza (L.) J.Agardh	x	x		x	x	x	x	x									x	x				x	x							
Enteromorpha prolifera (O.F.Mull.) J.Agardh		x	x		x	x	x	x		x		x																		
Enteromorpha sp.				x			x		x	x	x							x												
Monostroma grevillei (Thuret) Witt.	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x						
Monostroma oxyspermum Kutz.	x	x	x		x					x									x					x						
Monostroma sp.																x	x	x												
Protomonostroma undulatum (Wittrock) K.L.Vinogr.	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x								
Pseudendoclonium submarinum Wille					x																									
Rhizoclonium tortuosum (Dillwyn) Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spongomorpha aeruginosa (L.) C. Hoek																					x		x							
Spongomorpha arcta (Dillwyn) Kutz.	x	x		x	x	x	x		x			x		x	x			x	x	x		x	x	x			x			
Spongomorpha sp.	x																		x											
Spongomorpha spinescens Kutz.	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x		x						
Ulothrix flacca (Dillwyn) Thuret				x							x																			
Ulothrix sp.																x														
Ulva lactuca L.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ulvaria obscura (Kutz.) Gayral V. blyttii (Aresch.) Bliding	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x
Urospora penicilliformis (Roth) Aresch.						x	x			x				x		x		x		x			x							
All	**18**	**17**	**13**	**16**	**20**	**18**	**19**	**16**	**15**	**15**	**14**	**14**	**14**	**14**	**13**	**16**	**13**	**19**	**17**	**16**	**11**	**14**	**13**	**13**	**7**	**6**	**8**	**6**	**6**	**6**

(continued)

Appendix Table 5-3. (Continued)

PHAEOPHYTA	Year																													
Species and Citation	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
Agarum clathratum Dumort.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Alaria esculenta (L.) Grev.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	
Ascophyllum nodosum (L.) Le Jolis	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Chorda filum (l.) Stackh.																		x												
Chordaria flagelliformis (O.F.Mull.) C.Agardh	x	x	x	x	x	x				x	x	x		x	x	x	x		x	x	x	x	x	x		x				
Desmarestia aculeata (L.) J.V.lamour.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Desmarestia viridis (O.F.Mull.) J.V.lamour.	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	
Dictyosiphon foeniculaceus (Huds.) Grev.																			x											
Ectocarpus fasciculatus Harv.					x	x	x	x	x	x	x			x	x	x	x	x	x		x	x		x			x			x
Ectocarpus siliculosus (Dillwyn) Lyngb.	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Ectocarpus sp.												x	x																	
Elachista chondrii Aresch.																				x	x									
Elachista fucicola (Velley) Aresch.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Elachista stellaris (Aresch.) Kuck.																					x			x						
Fucus distichus ssp. Distichus Powell	x	x	x				x					x	x	x	x	x	x	x												
Fucus distichus ssp. edentatus (Bach.Pyl.) Powell	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Fucus distichus ssp. Evanescens (C.Agardh) Powell			x		x	x	x	x	x	x		x	x	x		x		x			x	x	x	x						
Fucus sp.	x	x		x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Fucus vesiculosus L.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Fucus vesiculosus var. spiralis Farl.						x							x						x		x	x								
Halosiphon tomentosus (Lyngb.) Jaasund																			x		x					x				
Halothrix lumbricalis (Kutz.) Reinke																					x									
Hincksia granulosa (J.E.Smith) P.C.Silva in P.C.Silva						x	x																							
Isthmoplea sphaerophora (Carmich. Ex Harv. in Hook.) Kjellm.												x	x				x				x									
Laminaria digitata (Huds.) J.V.lamour.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Laminaria saccharina (L.) J.V.lamour.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Laminaria sp.			x		x		x		x		x							x	x		x	x		x			x			x
Laminariocolax tomentosoides (Farl.) Kylin															x			x												
Leathesia difformis (L.) Aresch.	x	x		x	x	x	x	x	x		x	x	x	x			x	x	x		x		x	x						
Leptonematella fasciculata (Reinke) P. C. Silva																								x						
Petalonia fascia (O.F.Mull.) Kuntze	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Petalonia zosterifolia (Reinke) Kuntze									x										x					x						
Petroderma maculiforme (Wollny) Kuck.							x																							
Pilayella littoralis (L.) Kjellm.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x						
Protectocarpus speciosus (Borgesen) Kuck. in Kornmann																				x	x									
Pseudolithoderma extensum (P.Crouan et H.Crouan) S.Lund										x																				
Punctaria latifolia Grev.																						x								
Punctaria plantaginea (Roth) Grev.																		x			x									
Ralfsia verrucosa (Aresch.) J. Agardh							x	x		x									x											
Saccorhiza dermatodea (Bach.Pyl.) J.Agardh	x			x															x	x										
Scytosiphon simplicissimus (Clemente) Cremades	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x							

(continued)

Appendix Table 5-3. (Continued)

PHAEOPHYTA (Continued)	Year																													
Species and Citation	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Sorapion kjellmanni (Wille) Rosenv.								x																						
Sphacelaria cirrosa (Roth) C.Agardh		x		x	x	x	x	x	x		x		x				x	x	x											
Sphacelaria plumosa Lyngb.							x	x		x		x						x	x	x			x				x			
Sphacelaria radicans (Dillwyn) C.Agardh						x	x	x											x							x				
Spongonema tomentosum (Huds.) Kutz.			x	x		x	x	x	x	x		x	x	x	x	x	x		x											
All	**19**	**18**	**16**	**20**	**19**	**24**	**26**	**22**	**22**	**22**	**20**	**23**	**23**	**21**	**20**	**20**	**21**	**25**	**29**	**20**	**27**	**21**	**19**	**22**	**6**	**9**	**9**	**4**	**6**	**6**

(continued)

Appendix Table 5-3. (Continued)

RHODOPHYTA	Year																													
Species and Citation	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
Acrochaetium flexuosum Vickers					x	x	x																							
Acrochaetium sp.	x	x		x																										
Ahnfeltia plicata (Huds.) Fries	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Antithamnionella floccosa (O.F.Mull.) Whittick	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Audouinella bonnemaisoniae (Batters) P.S. Dixon	x	x	x																											
Audouinella daviesii (Dillwyn) Woelk.														x			x													
Audouinella membranacea (Magnus) Papenf.															x	x														
*Audouinella pur*purea (Lightf.) Woelk.							x		x	x		x																		
Audouinella sp.												x					x	x	x	x			x				x			
Bangia atropurpurea (Roth) C.Agardh						x	x									x														
Bonnemaisonia hamifera Har.	x	x			x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Callithamnion sp.			x																											
Callithamnion tetragonum (With.) S.F.Gray		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x
Ceramium deslongchampii Chauv. ex Duby					x	x																								
Ceramium rubrum (Huds) C. Ag.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ceratocolax hartzii Rosenv.	x	x	x	x	x	x	x	x	x																	x				
Chondria baileyana (Mont.) Harv.	x																													
Chondrus crispus Stackh.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Choreocolax polysiphoniae Reinsch					x	x	x		x	x	x	x	x		x		x	x	x											
Clathromorphum circumscriptum (Stromf.) Fosl.	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Clathromorphum compactum (Kjellm.) Fosl.				x								x			x		x													
Coccotylus truncatus (Pallas) M.J.Wynne et Heine	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Corallina officinalis L.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cystoclonium purpureum (Huds.) Batters var. cirrhosum Harv.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Devaleraea ramentacea (L.) Guiry						x	x	x		x		x																		
Dumontia contorta (S.G.Gmelin) Rupr.				x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Erythrotrichia carnea (Dillwyn) J.Agardh	x	x			x	x												x												
Euthora cristata (Linnaeus ex Turner) J. Agardh	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fimbrifolium dichotomum (Lepechkin) G.I.Hansen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x						
Fosliella farinosa (Lamour.) Howe	x																													
Gloiosiphonia capillaris (Huds.) Carmich. ex Berk.						x	x														x									
Gymnogongrus crenulatus (Turn.) J.Agardh	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hildenbrandia rubra (Sommerf.) Menegh.			x			x	x		x	x	x							x	x						x	x	x	x	x	x
Leptophytum foecundum (Kjellm.) Adey																								x						
Lithophyllum corallinae (Crouan) Heydr.	x					x																								
Lithothamnion glaciale Kjellm.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mastocarpus stellatus (Stackh. in With.) Guiry in Guiry et al.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Melobesia membranacea (Esper) J.V. Lamour.																				x										
Membranoptera alata (Huds.) Stackh.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Palmaria palmata (L.) Kuntze	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Peyssonnelia rosenvingii F.Schmitz in Rosenv.	x	x	x	x	x	x	x	x	x	x	x	x			x		x	x			x				x	x				

(continued)

Appendix Table 5-3. (Continued)

RHODOPHYTA	Year																													
Species and Citation	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Phycodrys rubens (L.) Batters	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phyllophora pseudoceranoides (Gmelin) Newr. et A.Taylor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phyllophora traillii Holmes								x	x																					
Phyllophora/coccotylus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phymatolithan lamii (Me. Lemoine) Y. M. Chamb.																								x						
Phymatolithon foecundum (Kjell.) Duwelet Wegeberg	x	x		x	x	x	x		x	x		x	x	x	x		x	x					x							
Phymatolithon laevigatum (Foslie) Foslie			x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
Phymatolithon lenormandii (Aresch. in J.Agardh) Adey	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x			x	x							
Phymatolithon rugulosum Adey		x		x	x		x	x				x	x	x	x	x	x		x		x									
Phymatolithon sp.														x																
Phymatolithon tenue (Rosenv.) Duwel et Wegeberg	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x			x
Plumaria plumosa (Huds.) Kuntze			x		x	x	x	x	x	x		x							x	x	x									
Pneophyllum fragile Kutz.	x	x	x	x	x	x	x	x	x	x		x																		
Polyides rotundus (Huds.) Grev.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Polysiphonia denudata (Dillwyn) Grev. ex Harv. in Hook.										x																				
Polysiphonia elongata (Huds.) Spreng.																			x											
Polysiphonia fibrillosa (Dillwyn) Spreng.																					x			x	x					
Polysiphonia flexicaulis (Harv.) Collins	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x
Polysiphonia fucoides (Huds.) Grev.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Polysiphonia harveyi Bailey						x	x	x	x	x	x	x		x				x	x	x	x	x	x	x						
Polysiphonia lanosa (L.) Tandy	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x	x
Polysiphonia nigra (Huds.) Batters			x		x	x	x		x		x			x		x	x	x	x	x	x	x	x		x	x	x	x	x	x
Polysiphonia sp.			x															x		x										
Polysiphonia stricta (Dillwyn) Grev.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Porphyra leucosticta Thur. in Le Jolis	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Porphyra linearis Grev.														x			x													
Porphyra miniata (C.Agardh) C.Agardh	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x							
Porphyra sp.												x	x	x	x	x	x	x	x					x						
Porphyra umbilicalis (L.) J.Agardh	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Pterothamnion plumula (J.Ellis) Nageli																		x	x											
Ptilota serrata Kutz.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rhodomela confervoides (Huds.) P.C.Silva	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rhodophysema elegans (P.Crouan et H.Crouan ex J.Agardh) P.S.Dixon		x			x		x	x		x	x								x											
Scagelia pylaisaei (Mont.) M.J.Wynne	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spermothamnion repens (Dillwyn) Rosenv.																			x											
Titanoderma pustulatum (J.V.Lamour.) Woelk., Y.M. Chamb.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x		x			x
Turnerella pennyi (Harv.) F.Schmitz		x		x																										
All	**43**	**40**	**42**	**42**	**47**	**51**	**51**	**44**	**47**	**47**	**42**	**47**	**40**	**44**	**43**	**41**	**44**	**46**	**47**	**41**	**41**	**35**	**38**	**37**	**31**	**33**	**32**	**28**	**28**	**31**

(continued)

Appendix Table 5-3. (Continued)

OVERALL TOTAL	
Species and Citation	Year
	All Years
Total Taxa Over All Years	160
All	160

TOTAL TAXA BY YEARS																														
Species and Citation	Year																													
	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0	1	2	3	4	5	6	7
Total Taxa BY Year	80	75	71	78	86	94	96	82	84	84	76	84	77	80	76	78	79	91	93	77	79	70	71	72	44	48	49	38	40	43
All	80	75	71	78	86	94	96	82	84	84	76	84	77	80	76	78	79	91	93	77	79	70	71	72	44	48	49	38	40	43

Appendix Table 5-4. Description of Benthic Stations sampled in 2007. Seabrook Operational Report, 2007.

		Depth[a]			Substrate		
Location	**Station**	**Zone**	**Feet**	**Meters**	**Ledge**	**Cobble**	**Other[b]**
Nearfield	**B17**	**shallow**	16	4.9	99	1	<1
	B19	**mid-depth**	40	12.2	69	6	25
Farfield	**B35**	**shallow**	15	4.6	83	12	5
	B31	**mid-depth**	31	9.4	48	20	32

[a] bottom depth at mean low water

[b] gravel and sand, which may be over rock

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6.0 SUMMARY

American lobster (*Homarus americanus*), Jonah crab (*Cancer borealis*), and rock crab (*Cancer irroratus*) are important invertebrate resources in the Seabrook Station study area. The local lobster population supports a substantial commercial fishery. Both larval and adult stages of these epibenthic crustaceans are subject to potential impacts due to operation of Seabrook Station. Larval stages of lobsters and *Cancer* spp. are susceptible to entrainment into the buoyant discharge plume. Larval stages of lobsters and *Cancer* spp. may also be entrained into the cooling water system of the plant. Benthic stages of lobsters and *Cancer* crabs could be susceptible to impingement or discharge effects.

Mean density of lobster larvae at each of three sampling locations in 2007 (1.3 - 2.0/ 1000m^2) was higher than both the pre-operational mean (0.4 - 0.6/m^2) and operational mean (0.9 - 1.1/1000m^2). The lobster larval density in 2007 increased from the previous year and was above the upper 95% confidence limit of the operational mean density at all three stations. Larval densities in the operational period were significantly higher than the preoperational period and there was no significant interaction between periods and stations. Since increases between the preoperational and operational periods were consistent at both the nearfield and farfield stations, there is no evidence of an effect from the operation of Seabrook Station. In 2007, weekly densities of lobster larvae at Station P2 were not present until the third week of June, followed by an absence during the fourth week of June and a presence of larvae from the first week of July through the third week of August with peak abundance during the fourth week of July. No larvae were collected during the fourth week of August, but followed with the highest peak during the second week of September. In the preoperational and operational periods, density began to gradually increase in the first week of June and larvae were absent by the second or third week of October.

Catch of lobsters (total and legal) in 15 experimental lobster traps retrieved three times per week was adjusted to a standard soak time of two days (CPUE$_2$). Total CPUE$_2$ in 2007 decreased from the previous year at the nearfield station (95.3) and farfield station (115.5). Total CPUE$_2$ at both stations was greater than both the preoperational (nearfield: 65.4; farfield: 81.2) and operational (nearfield: 87.8; farfield: 100.6) means. Total CPUE$_2$ was significantly higher in the operational period than the preoperational period, but was there were no significant differences in CPUE$_2$ of total lobsters between stations. The interaction was not significant, an indication that there was no impact from the operation of Seabrook Station. CPUE$_2$ of legal-size lobsters in 2007 (nearfield: 4.0; farfield: 3.9) was higher than the operational means (nearfield: 3.7; farfield: 3.4) and lower than the preoperational means (nearfield: 5.5, farfield: 5.6). CPUE$_2$ of legal-size lobsters was significantly higher in the preoperational period (reflecting regulatory changes in the legal size definition), but the interaction term was not significant. Since differences between the preoperational and operational periods were consistent at both the nearfield and farfield stations, there is no evidence of impacts from Seabrook Station.

A nonparametric Spearman coefficient (r_S) was used for a robust correlation between surface water temperature and CPUE$_2$ of lobsters. CPUE$_2$ of sublegal lobsters at both stations was significantly correlated (nearfield: r_S=0.62; farfield: r_S=0.49) with June through November mean surface water temperature lagged by six years. The correlation between CPUE$_2$ of sublegal lobsters and June through November surface water temperature lagged by one year was also significant at the

nearfield station (r_S=0.55). There was also a significant correlation between $CPUE_2$ of legal-size lobsters and June through November surface water temperatures lagged by six years at the nearfield (r_S=0.50) and farfield station (r_S=0.50). These correlations suggest that recruitment from the larval stage is enhanced by warm water temperatures during the larval period.

An estimated 21 lobsters were impinged in 2007. The 18-year average of lobster impingement was 16.3/year. In previous years, lobster impingement ranged from 0 in 2000 to 77 in 2005.

Mean densities of *Cancer* spp. (*Cancer borealis* and *Cancer irroratus*) larvae in 2007 (4,742/1000 m^3 and 9,017/1000 m^3) were lower than the operational means at both stations and lower than the preoperational mean at the nearfield station. There were no significant differences between periods, stations, or the interaction of these main effects, indicating that trends between periods were consistent at both stations.

Jonah crab $CPUE_2$ in 2007 at the nearfield station (12.2) and the farfield station (6.7) was lower than the operational period means (nearfield: 14.7; farfield: 8.7) and the preoperational period mean at the farfield station (9.6). $CPUE_2$ at the nearfield station in 2007 was identical to the preoperational mean. There were no significant differences between periods or stations, and the interaction was not significant, an indication that there was no effect from the operation of Seabrook Station on Jonah crab. Annual $CPUE_2$ at each station has followed similar trends among years, except in 2007 the $CPUE_2$ continued to decrease at the nearfield station but increased from last year at the farfield station.

Rock crab CPUE in 2007 at the nearfield (2.4) and farfield stations (1.8) was less than the operational mean (nearfield: 2.9; farfield: 4.8) and, at the nearfield station was less than the preoperational mean (2.6). CPUE in 2007 at the farfield station (1.5) was greater than the preoperational mean. CPUE increased significantly between periods at the farfield station but there was no significant difference at the nearfield station. The CPUE of rock crab at the farfield station significantly increased from 1982 though 2000 but decreased from 2001 through 2007. Since the change in trend in rock crab CPUE occurred after the plant began operation began, it is not due to the operation of Seabrook Station.

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6.1 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) of 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 and lobster larvae may potentially be affected by mechanical damage or temperature increase associated with entrainment within the cooling system of the plant. Lobster larvae may also 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.

6.2 METHODS

6.2.1 Field Methods

Lobster Larvae (Neuston)

Distribution of American lobster larvae was monitored with neuston samples that were collected once a week from single tows made during the daylight hours from May through October. Each tow was taken along a horseshoe-shaped course approximately 800-m long on a side A tow was centered at each of three stations: the intake (P2), discharge (P5), and farfield (P7) stations (Figure 6-1). 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 3,732 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 two times per month from January through December. On each date, two replicate (two paired-sequential) oblique tows were made at night with 1-m diameter, 0.505-mm mesh nets at the intake (P2) and farfield (P7) stations (Figure 6-1). Collections began in 1978 at Station P2 and in 1982 at Station P7. Nets with depressors were set off the stern and towed for 10 minutes while varying 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 6-1). 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 (CL) were recorded in the field to the nearest one-eighth inch. Beginning in 1990, lobsters measuring 3-1/4 inches CL (83 mm CL) or greater were classified as legal. Jonah and rock crab carapace widths (CW) were recorded to the nearest mm. The total numbers

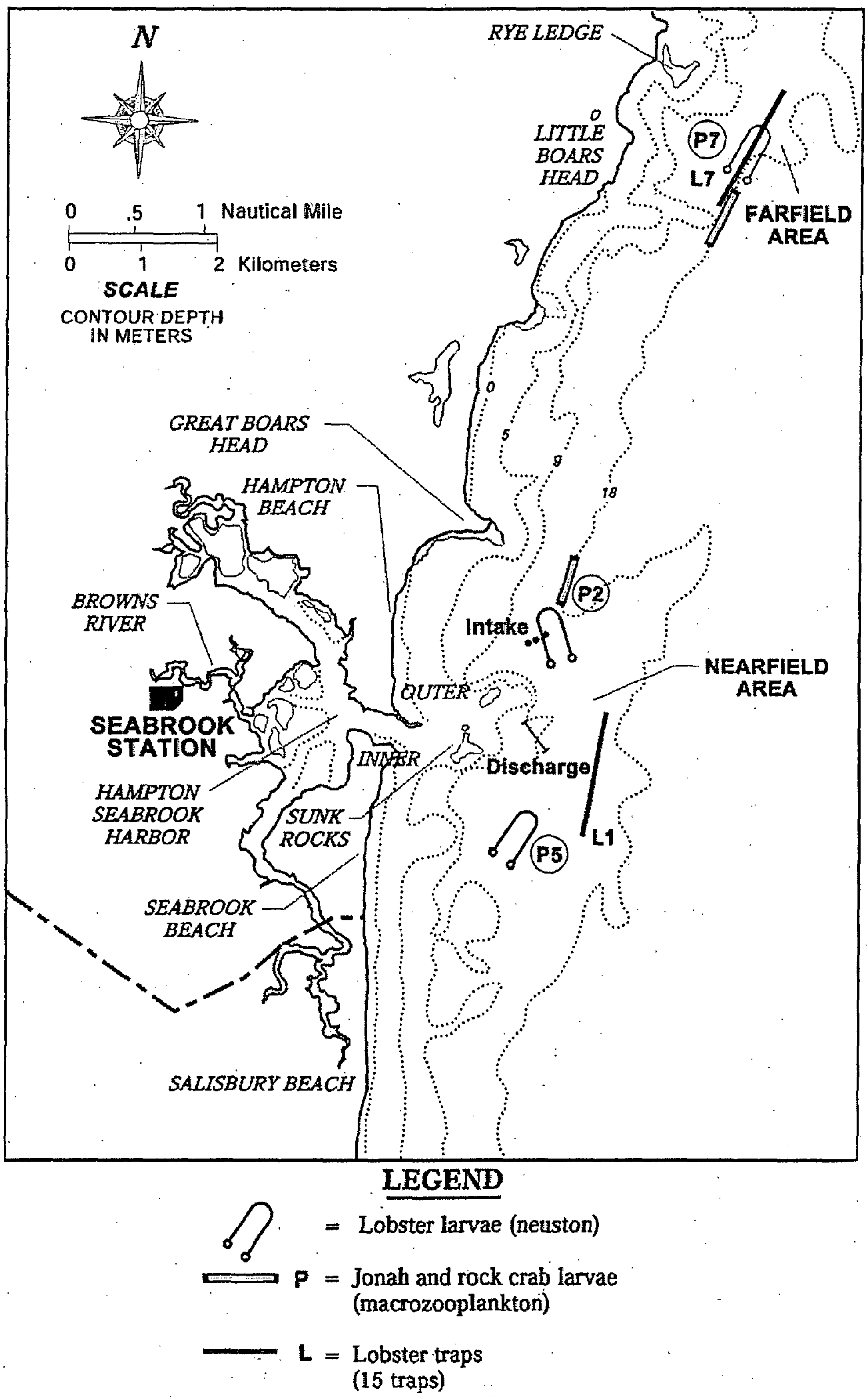


Figure 6-1. Epibenthic crustacea (American lobsters, Jonah and rock crabs) sampling stations. Seabrook Operational Report, 2007.

of males, females, and egg-bearing females for all three species were also recorded.

Impingement Collections

See Section 4.2.2.4 for a description of impingement collection procedures.

6.2.2 Laboratory Methods

Lobster larvae (neuston) samples were rinsed through a 1-mm mesh sieve and sorted live in the laboratory. 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).

Prior to 1996, *Cancer* spp. larvae from macrozooplankton samples were analyzed from three of the four replicates (randomly selected) at each station for two of the four sampling periods each month (usually the first and third weeks). Starting in 1996, only one replicate was analyzed from each of two sampling periods per month. 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 ¼ of the original sample volume, was analyzed. *Cancer* spp. larvae were identified to developmental stage and enumerated (NAI 1991).

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.

6.2.3 Analytical Methods

Period (preoperational vs. operational, Preop-Op) and station differences and the interaction between them (Preop-Op X Station) were evaluated using a mixed linear model analysis using a before-after-control-impact (BACI) design to test for potential impacts of plant operation. A mixed model based on a 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). Other random effects were nested temporal effects of years within period (Year(Preop-Op)), months or weeks within year (Month or Week(Year)) and the interaction of Station and Year within Preop-Op (Station X Year(Preop-Op)). The pre-operational period for each analysis was specified as the period during which both stations were sampled concurrently (thus maintaining an equal number of years between stations within the preoperational period). Collections from 1990, the year the plant began to operate intermittently, occurred during the transition from preoperational to operational periods and were excluded from the analysis. The inference test for Preop-Op was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS 1999). The likelihood ratio test was used to test the significance of random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects. A significant Preop-Op X Station interaction term would imply power plant effect (Thomas 1977, Green 1979, Stewart-Oaten et al. 1986) because the abundance indices were not consistent in the nearfield and farfield areas between the preoperational and operational periods. 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 mixed model used $\log_{10}$ (x+1) transformed densities of lobster and *Cancer* spp. larvae to determine differences between the average abundances for the operational (1991-2006) and preoperational (lobster larvae: 1988-1989; *Cancer* spp. larvae: 1982-1984, 1986-1989) periods at the discharge (P5), intake (P2), and farfield (P7) stations (intake and farfield only for *Cancer* spp. larvae). 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.

CPUE of lobsters increased significantly with soak time (the duration that lobster traps are fished) up to a soak time of five days. Beyond five days soak time, catch generally declined, was highly variable, and did not appear to be dependent on soak time. Decreases in catch at longer soak times can occur when escape exceeds entry as the bait loses its attractiveness (Miller 1990).

Lobster traps were scheduled to be fished three times per week from June through November resulting in a modal soak time of two days. Longer soak times, particularly more than five days, were often the result of unusual circumstances such as extended bad weather or equipment breakdowns. Therefore, catch was adjusted to two days, and samples with soak times of more than five days were excluded from the analysis, which resulted in the elimination of approximately 4% of the samples collected.

Soak time is an important factor affecting the catch in trap fisheries. In general, catch in a trap fishery is proportional to the soak time (Skud 1979), but this relationship is not linear (Austin 1977). Catch generally increases with soak time toward a maximum and then decreases (Saila et al. 2002a). Correction factors were developed by Estrella and McKiernan (1989) to standardize various soak times in the lobster fishery off Cape Ann, Massachusetts, to three days. We used a similar empirical approach for our data to standardize lobster catch to a soak time of two days. Mean unadjusted CPUE (catch per 15 traps) was plotted against soak time to define the relationship between catch and soak time (Figure 6-2). Adjusted lobster CPUE was calculated as catch per 15 traps adjusted to two days soak time ($CPUE_2$) using the adjustment factors in Table 6-1. These adjustment factors were calculated as:

Adjustment factor = $1-(C_s-C_2)/C_s$

where:

C_s = Mean catch (number per 15 traps) for all samples with soak time s

C_2 = Mean catch of samples with soak time of 2 days (87.9 lobsters and 11.5 Jonah crabs per 15 traps).

$CPUE_2$ (CPUE adjusted for fishing a duration of two days) was calculated for each sample based on the adjustment factor and the soak time. Arithmetic means of $CPUE_2$ were used for legal and sublegal lobsters during the preoperational (1982-1989) and operational (1991-2007) periods.

A similar approach was taken with Jonah and rock crabs. Mean catch of both species generally increased to a maximum at three days, but then began to decline (Figure 6-3). Behavioral interactions between lobsters and crabs can result in crabs either leaving the traps or being excluded (Richards et al. 1983). The regression of catch on soak time for Jonah crab was significant ($p = 0.04$) for soak times up to three days, but was not significant for rock crab. Therefore, CPUE of Jonah crab was

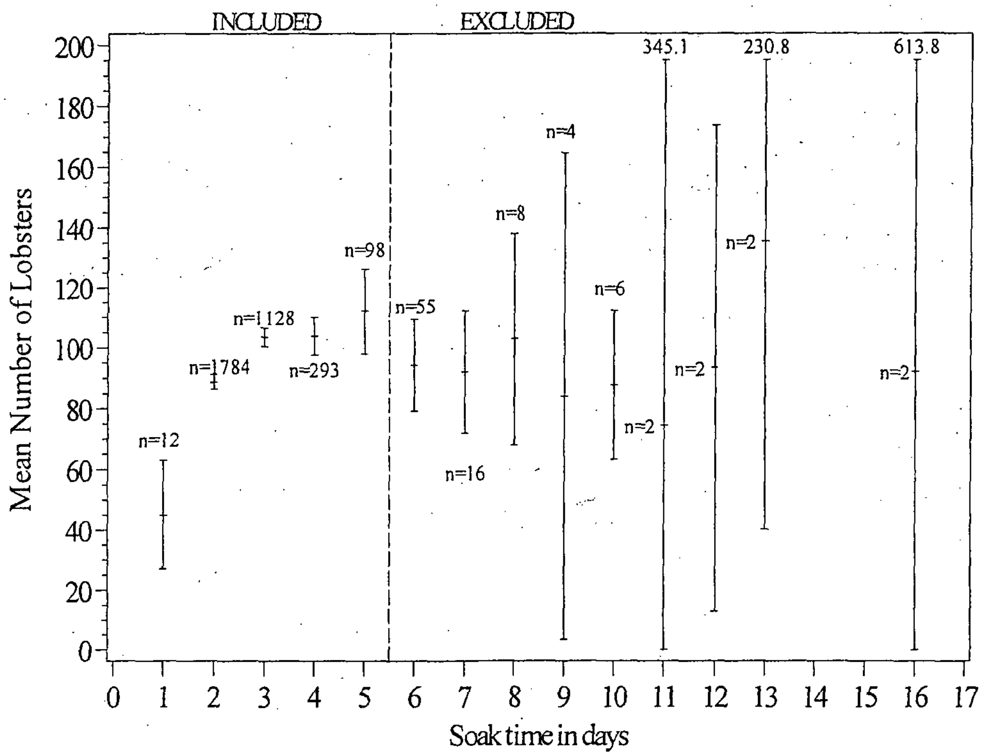


Figure 6-2. The relationship between soak time (number of days submerged) and mean catch of lobsters (per 15 traps) with 95% confidence intervals (C.I.), 1982-2007 at Stations L1 and L7. Seabrook Operational Report, 2007.

Table 6-1. Mean Catch and Adjustment Factors of American lobster and Jonah crab at Soak Times from 1 to 5 Days. Seabrook Operational Report, 2007.

Soak Time (days)	Mean Lobster Catch (lobsters/15 traps)	Adjustment Factor for Lobster Catch	Mean Jonah Crab Catch (crabs/15 traps)	Adjustment Factor for Jonah Crab Catch
1	45.0	1.969	9.0	1.278
2	88.6	1.000	11.5	1.000
3	103.4	0.857	13.5	0.852
4	103.8	0.853	n/a	n/a
5	112.1	0.790	n/a	n/a

a.

b.

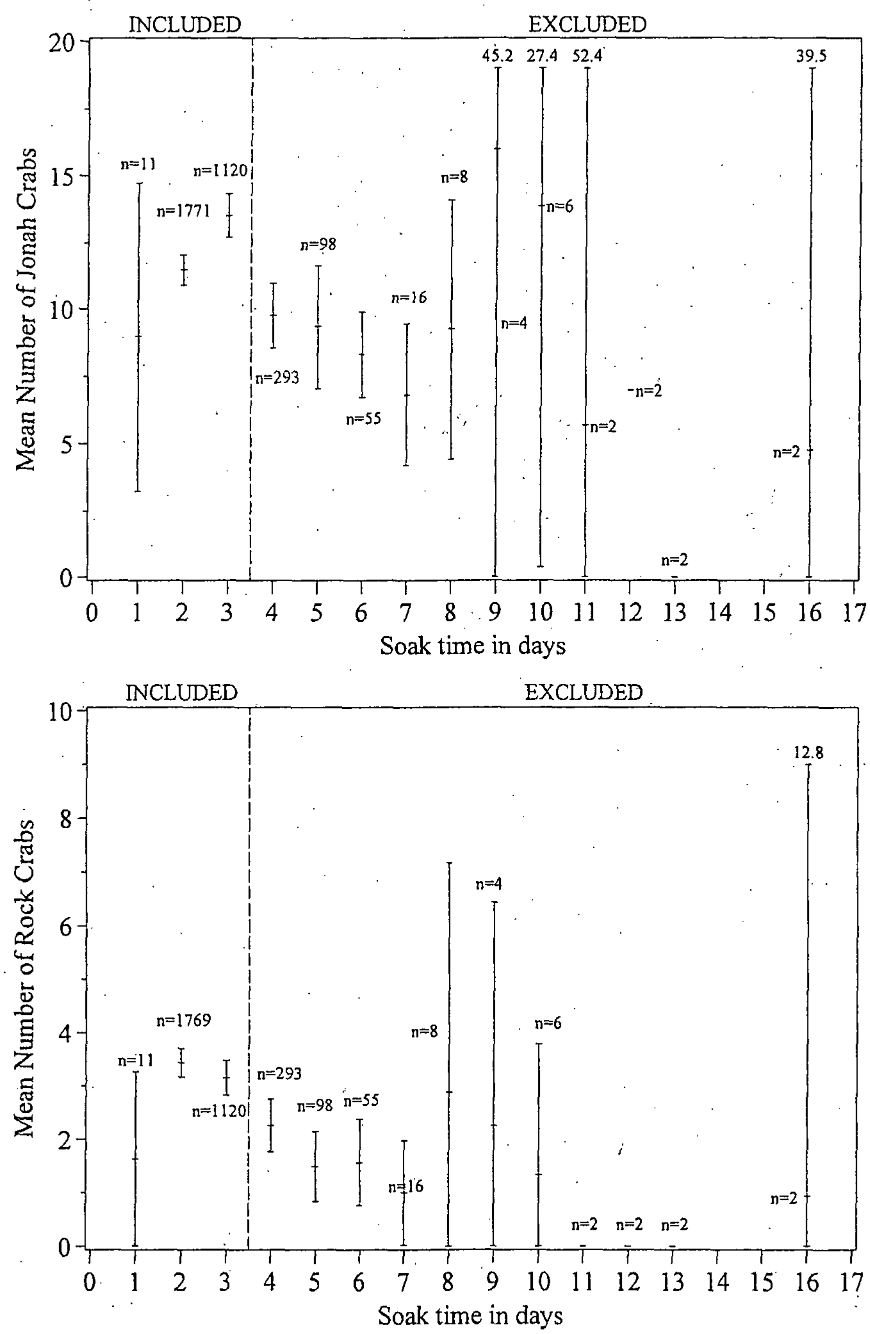


Figure 6-3. The relationship between soak time (number of days submerged) and mean catch of a) Jonah crab and b) rock crab (per 15 traps) with 95% confidence intervals (C.I.), 1982-2007 at Stations L1 and L7. Seabrook Operational Report, 2007.

expressed as catch per 15 traps adjusted to a soak time of two days ($CPUE_2$). No adjustment was necessary for rock crab and CPUE was expressed as catch per 15 traps. Samples with soak times longer than three days were deleted for both species, because catches declined after three days indicating escape from the traps. This resulted in the exclusion of approximately 12% of the samples.

Segmented regression analysis was performed on annual mean catch of crustaceans that had a significant interaction term from the mixed model analysis. Segmented regression was used to identify when there were significant changes or "breakpoints" in the time series of abundance. These breakpoints typically divided the time series into two periods. Significant differences in the annual means between the two periods were evaluated with a t-test. If a breakpoint was identified, linear regression was used within each period to describe annual trends of the parameter.

A correlation analysis was performed between lobster $CPUE_2$ and surface water temperature to further investigate the relationships between environmental variables and lobster catch. Spearman's non-parametric correlation statistic (r_S) was used because it requires no assumptions regarding normality or serial dependence (autocorrelation) of the data. Lobster larvae are found near the surface, and surface water temperature may affect their survival. Water temperature data are not collected as part of the lobster monitoring program; therefore, surface temperatures measured at Stations P2 and P7 were used as representative of surface water temperatures at Stations L1 and L7, respectively. Stations P2 and P7 are located within 500 m of Stations L1 and L7, and provide the best available estimates of surface water temperature at the lobster monitoring stations. The analysis was performed between lobster catch (June through November) in a given year and mean surface water temperatures in that year for the same months. A lag function was used to determine if surface water temperature in a given year affected lobster catch in following years.

Environmental variables such as water temperature during the larval stages may also affect $CPUE_2$ of Jonah crabs and CPUE of rock crabs in subsequent years. To investigate this possible relationship, Spearman's non-parametric correlation statistic was used to investigate the correlation between annual mean Jonah crab $CPUE_2$ and rock crab CPUE, and mean bottom water temperature during the May through November period of high larval *Cancer* spp. abundance in previous years.

6.3 RESULTS

6.3.1 American Lobster

Lobster Larvae

Geometric mean density of lobster larvae in 2007 was higher than preoperational and operational means at all stations (Table 6-2). Density at Station P7 was higher than Stations P2 and P5 in both the preoperational and operational periods. In 2007, density at Station P2 and P7 was similar (2.0/1000 m^2) and higher than at Station P5 (1.3/1000 m^2) (Table 6-2). The larval densities in 2007 increased from larval densities in 2006, and were the highest in the time series at Stations P2 and P5 (Figure 6-4). Larval densities in the operational period were significantly higher than the preoperational period, but there were no significant differences among stations (Table 6-3). The increase in larval density in the operational period occurred at all stations as indicated by the non-significant interaction term (Table 6-3). Since differences in lobster larval densities were consistently higher between the preoperational and operational periods at both the nearfield and farfield

Table 6-2. Geometric Mean Abundance (Larvae: Lobster = No./1000 m^2; *Cancer* spp. = No./1000 m^3) or Mean Catch per Unit Effort (Lobster and Jonah Crab = $CPUE_2$; Rock Crabs = CPUE = No./15 traps) and the Upper and Lower 95% Confidence Limits of Epibenthic Crustacea at Nearfield (P2, P5, L1) and Farfield (P7, L7) Stations During the Preoperational and Operational Periods and in 2007. Seabrook Operational Report, 2007.

Species (period sampled)	Station	Preoperational[a] LCL[d]	Preoperational[a] Mean	Preoperational[a] UCL[e]	2007[b] Mean	Operational[c] LCL[d]	Operational[c] Mean	Operational[c] UCL[e]
Lobster larvae (May-Oct)	P2	0.4	0.4	0.5	2.0	0.8	0.9	1.1
	P5	0.0	0.4	3.2	1.3	0.7	0.8	0.9
	P7	0.4	0.6	0.8	2.0	1.0	1.1	1.4
Lobster, total (Jun-Nov)	L1	54.4	65.4	76.5	95.3	76.4	87.8	99.3
	L7	69.4	81.2	92.9	115.5	85.4	100.6	117.7
Lobster, legal (Jun-Nov)	L1	4.1	5.5	7.0	4.0	3.1	3.7	4.4
	L7	3.8	5.6	7.3	3.9	2.7	3.4	4.1
Lobster, female (Jun-Nov)	L1	30.3	36.2	42.0	50.3	41.0	47.0	52.9
	L7	37.6	44.0	50.5	61.2	46.2	54.9	63.6
Lobster, egg-bearing (Jun-Nov)	L1	0.4	0.5	0.6	1.7	0.8	1.3	1.7
	L7	0.4	0.5	0.7	2.8	1.2	1.7	2.2
***Cancer* spp. larvae** (May-Sep)[f]	P2	6,791	9,532	13,380	4,742	7,197	11,492	18,351
	P7	4,926	8,426	14,414	9,017	8,737	12,068	16,669
Jonah crab, total (Jun-Nov)	L1	7.3	12.2	17.0	12.2	12.2	14.7	17.2
	L7	7.0	9.6	12.2	6.7	5.7	8.7	11.8
Jonah crab, female (Jun-Nov)	L1	5.8	9.4	13.1	7.1	8.7	10.3	11.9
	L7	5.1	6.9	8.7	3.3	3.4	5.1	6.9
Rock crab, total (Jun-Nov)	L1	0.9	2.6	4.2	2.4	2.0	2.9	3.7
	L7	0.0	1.5	3.1	1.8	3.3	4.8	6.2
Rock crab, female (Jun-Nov)	L1	0.0	0.5	1.0	0.5	0.1	0.4	0.7
	L7	0.0	0.3	0.6	0.3	0.3	0.7	1.0

[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. P7 1982-84 + 1986-89; all others 1982-89.
[b]2007 mean; mean of the total number of samples collected during the period sampled.
[c]Operational: 1991-2007, mean of annual means.
[d]UCL = Upper 95% confidence limit.
[e]LCL = Lower 95% confidence limit.
[f]Sampled year-round but abundance computed for peak period (May - September).

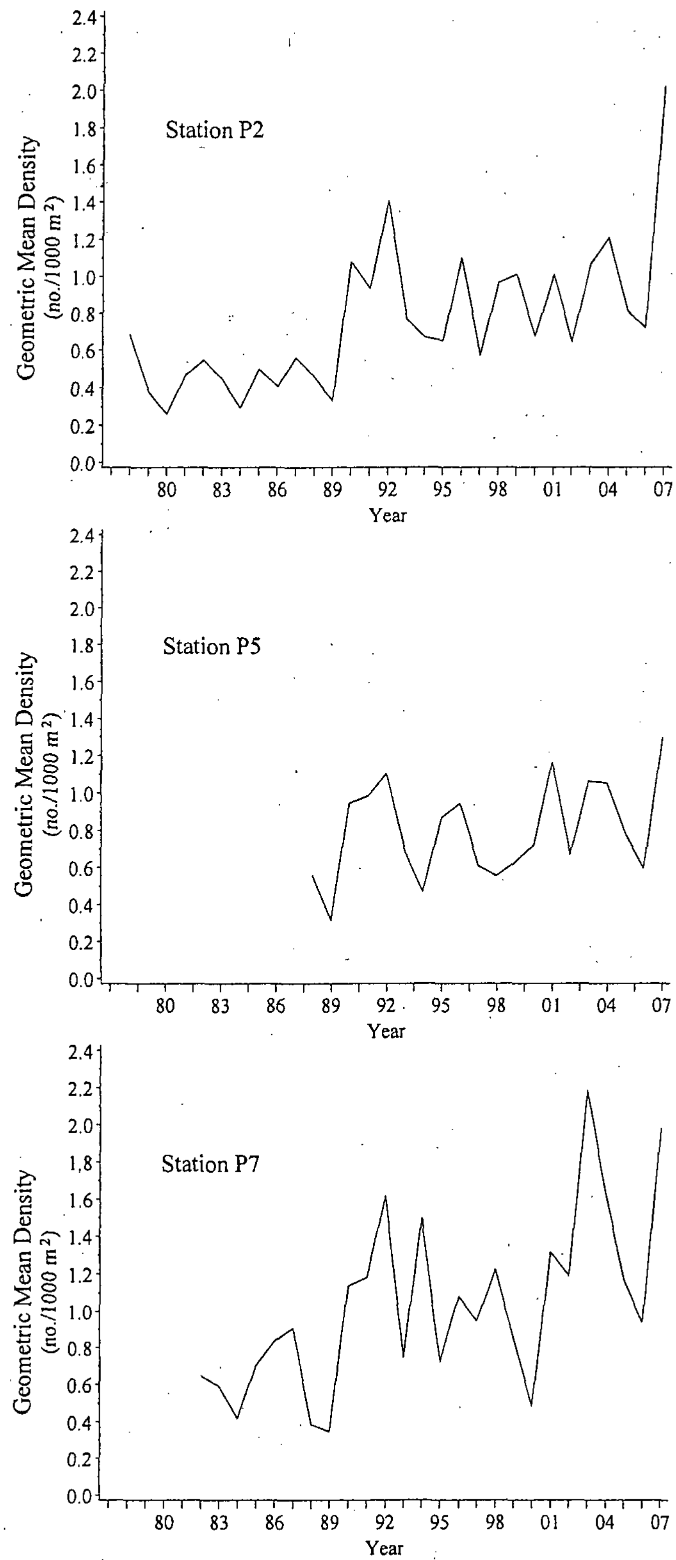


Figure 6-4. Geometric mean density (no./1000 m^2) of lobster larvae at Stations P2 (1978-2007), P5 (1988-2007) and P7 (1982-2007). Seabrook Operational Report, 2007.

Table 6-3. Results of Mixed Model 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, 2007.

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Lobster larvae (May-Oct)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 69.5	6.93	0.0104*	Op >Preop
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	0	0	0.5000	
	Week(Year)[c]	0.083	520.57	<0.0001*	
	Station[d]	0	0	0.4989	
	Preop-Op X Station[e]	<0.001	2.375	0.0616	
	Station X Year (Preop-Op)[f]	0	0	0.5000	
	Error	0.048			
Lobster (total catch)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 22.3	5.35	0.0303*	Op >Preop
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	228.70	4.26	0.0195*	
	Month(Year)[c]	1,311.88	2491.73	<0.0001*	
	Station[d]	102.06	2.86	0.0453	
	Preop-Op X Station[e]	0	0	0.5000	
	Station X Year (Preop-Op)[f]	75.51	101.49	<0.0001*	
	Error	733.25			
Lobster (legal size)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 23.7	9.25	0.0057*	Preop > Op
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	1.639	23.098	<0.0001*	
	Month(Year)[c]	2.956	790.35	<0.0001*	
	Station[d]	0	0	0.5000	
	Preop-Op X Station[e]	0.020	0.65	0.2102	
	Station X Year (Preop-Op)[f]	0.064	3.91	0.0240*	
	Error	6.03			
Cancer spp. Larvae	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 110	0.22	0.636	
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	0.0	0	0.5000	
	Month(Year)[c]	0.821	142.149	<0.0001*	
	Station[d]	0	0	0.5000	
	Preop-Op X Station[e]	0	0	0.5000	
	Station X Year (Preop-Op)[f]	0	0	0.5000	
	Error	0.711			
Jonah Crab (Jun-Nov)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 3.51	0.15	0.7244	
	Random Effects	**Estimate[j]**	**χ^2**	**p**	
	Year (Preop-Op)[b]	8.166	2.78	0.0477	
	Month(Year)[c]	46.352	897.64	<0.0001*	
	Station[d]	8.246	0.69	0.2028	
	Preop-Op X Station[e]	2.402	1.50	0.1105	
	Station X Year (Preop-Op)[f]	7.235	83.18	<0.0001*	
	Error	74.490			

(continued)

Table 6-3. (Continued)

Parameter	Source of Variation	Test Statistics			Multiple Comparisons[k]
Rock Crab (Jun-Nov)	**Fixed Effects**	**DF[g]**	**F[h]**	**p[i]**	
	Preop-Op[a]	1, 3.15	1.69	0.2811	
	Random Effects	**Estimate[j]**	χ^2	p	
	Year (Preop-Op)[b]	0	0	0.4974	
	Month(Year)[c]	8.208	595.62	<0.0001*	
	Station[d]	0	0	0.4974	
	Preop-Op X Station[e]	0.984	3.74	0.0266*	OpL7>OpL1>PreL1>PreL7
	Station X Year (Preop-Op)[f]	3.021	145.29	<0.0001*	
	Error	19.636			

[a]Preop-Op = Preoperational period (Lobster larvae, all stations: 1988, 1989; *Cancer* spp. larvae all stations: 1982-84, 1986-89. Adult lobster and crabs: 1982-1989); Operational period: 1991-2007 regardless of station or month.
[b]Year (Preop-Op) = Year nested within preoperational and operational periods regardless of year, month or station.
[c]Week (Preop-Op X Year) or Month (Preop-Op X Year) = Week or month nested within interaction of Preop-Op and Year.
[d]Station = Station differences (Lobster larvae: P2, P5, P7; *Cancer* spp. larvae P2, P7; all others: Discharge (L1) and Rye Ledge (L7)) regardless of year, month or period.
[e] Interaction of the two main effects, Preop-Op and Station.
[f] Station X Year(Preop-Op) = Interaction of station and year nested within preoperational and operational period.
[g] Numerator degrees of freedom , denominator degrees of freedom
[h] F-statistic
[i] Probability value
[j] Estimate of the variance component of random effect
[k]Underlining signifies no significant differences ($\alpha = 0.05$) among least squares means with a paired t-test.
* = Significant (p<0.05)

stations, there is no evidence of an effect due to the operation of Seabrook station.

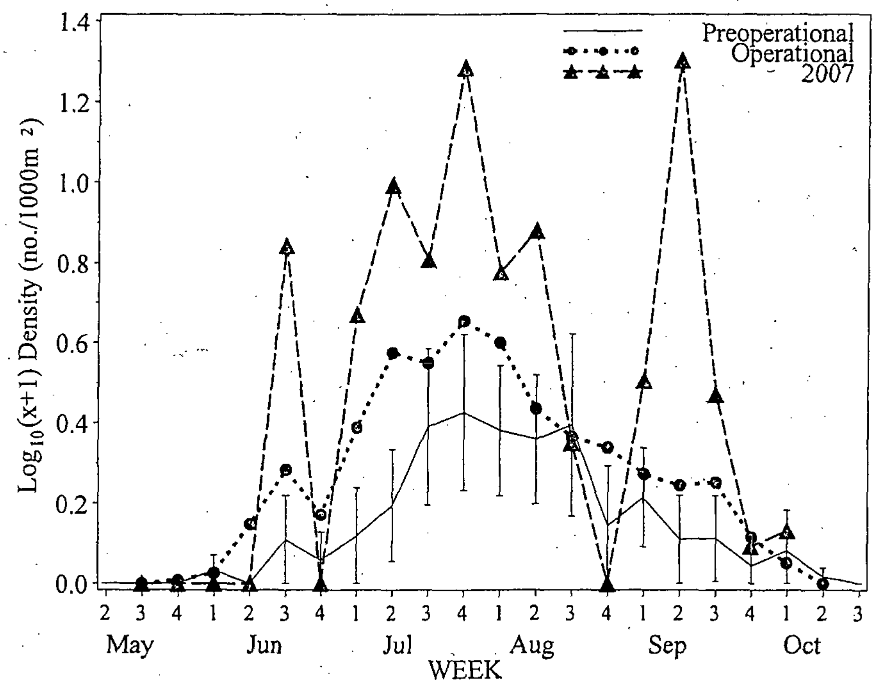
Weekly patterns of lobster larvae densities at Station P2 in 2007 differed from the preoperational and operational patterns (Figure 6-5a). In 2007, larvae at Station P2 were not present until the third week of June, followed by an absence during the fourth week of June and a peak in abundance during the second week of July through the second week of August. No larvae were collected during the fourth week of August, but the highest peak in abundance occurred during the second week of September. In the preoperational and operational periods, density began to gradually increase in the first week of June and larvae were absent by the second or third week of October. In 2007, lobster larval density at Station P2 exceeded the preoperational upper 95% confidence limits during the third week of June, first week of July through second week of August, and first three weeks of September. Stage IV larvae were the most abundant life stage in 2007 at Station P2, which is typical for most preoperational and operational years (Figure 6-5b). Mean density of both Stage I, III, and IV larvae in 2007 was higher than the preoperational and operational means. Mean density of Stage II larvae in 2007 were within the 95% confidence limits for the preoperational and operational periods and mean density of Stage III and IV larvae was above the confidence limits the pre-operational period (Figure 6-5b).

Total Catch: Legal- and Sublegal-Size

Annual mean $CPUE_2$ of total lobster in 2007 was higher than the preoperational and operational means at both stations (Table 6-2). Sublegal lobsters were the primary component of total lobsters (Figure 6-6a). The catch of sublegal lobsters at Station L1 began to increase in 1995, reached peaks in 1997 and 2005. In 2007 $CPUE_2$ decreased from 2005 and 2006.

Annual mean $CPUE_2$ of total lobster was generally higher at Station L7 compared to L1 (Figure 6-7). Annual $CPUE_2$ at Station L7 has

a.



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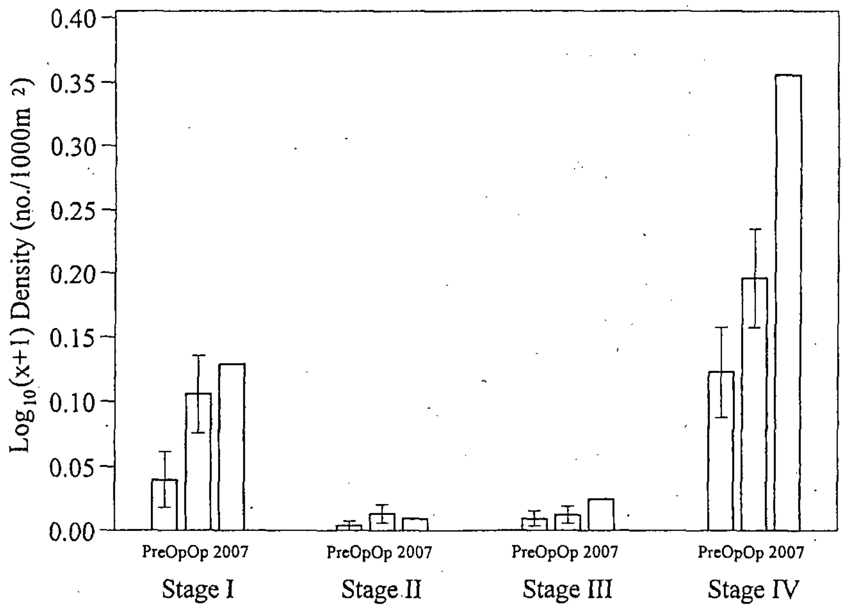


Figure 6-5. Preoperational and operational means with 95% confidence limits and 2007 means of a) weekly density (no./1000 m^2) of lobster larvae at Station P2, b) lobster larvae density by lifestage at P2. Seabrook Operational Report, 2007.

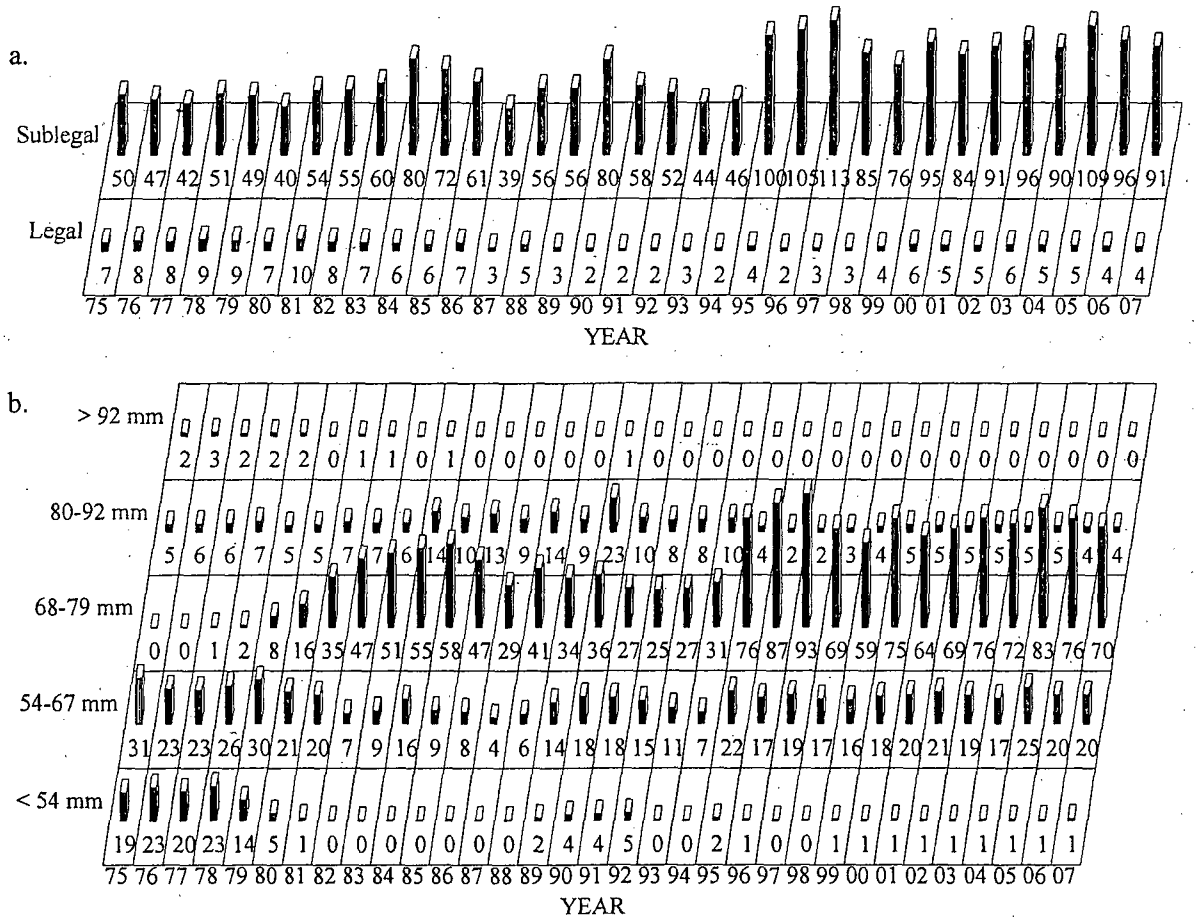


Figure 6-6. a) $CPUE_2$ of sublegal- and legal-size lobster at Station L1 and b) size class distribution at Station L1 from 1975-2007. Seabrook Operational Report, 2007.

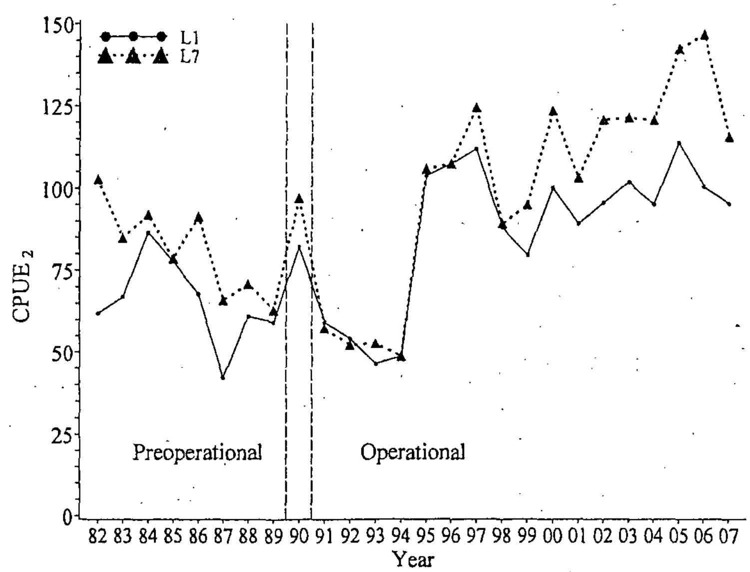


Figure 6-7. Annual mean $CPUE_2$ of total lobster, 1982-2007 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2007.

been higher than the Station L1 every year except 1991 and 1992. $CPUE_2$ was almost identical between the stations in 1994, 1996, and 1998, and reverted to the preoperational pattern of higher catches at Station L7 in 1997 and 1999 through 2007 (Figure 6-7). Annual mean $CPUE_2$ in 2007 at both stations decreased from the previous year. Mean $CPUE_2$ at both stations followed a similar trend in the operational period except in 2006 (Figure 6-7).

Monthly mean $CPUE_2$ of total lobster at Station L1 in 2007 showed a similar pattern to the operational period, except $CPUE_2$ in June was higher than in July during 2007 (Figure 6-8a). Monthly mean $CPUE_2$ in 2007 was higher than the preoperational and operational monthly means every month sampled except for the operational period mean in September (Figure 6-8a). Monthly mean $CPUE_2$ in 2007 was higher than the preoperational monthly mean's upper 95% confidence limits every month. On average in the preoperational period, the peak in $CPUE_2$ occurred one month earlier, in September, compared to the operational period. Mean $CPUE_2$ in the operational period was significantly greater than in the preoperational period, but there were no significant differences between stations (Table 6-3). The interaction term was not significant, indicating consistency in $CPUE_2$ of total lobsters between stations.

Water temperature in previous years may have affected sublegal lobster $CPUE_2$. Mean $CPUE_2$ of sublegal lobsters was significantly correlated with mean surface water temperature during the warm season (June through November) lagged by one (r_S=0.55) and six years (r_S=0.62) at Station L1, and lagged at six years (r_S=0.49) at Station L7 (Table 6-4; Figure 6-9).

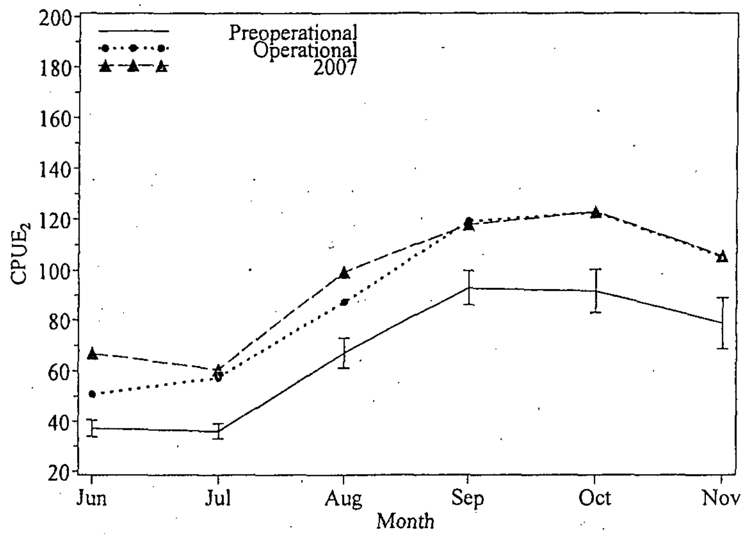
Legal-size Lobster

The definition of a legal-size lobster has changed several times during the course of this study. In 1984, the legal-size limit (carapace length) increased from 3 1/8 inches (79 mm) to 3 3/16 inches (81 mm) followed by a second increase in 1989 to 3 7/32 inches (82 mm). The legal-size limit was increased again in 1990 to 3 1/4 inches or greater (83 mm) and has not changed. In 2007, $CPUE_2$ of legal-size lobsters at the nearfield and farfield stations was greater than the operational mean, but less than the preoperational mean (Table 6-2). Annual mean $CPUE_2$ of legal-size lobsters decreased in 2007 from 4.1 to 4.0 lobsters per 15 traps at Station L1 and decreased from 4.1 to 3.9 lobsters per 15 traps at Station L17 (NAI 2007; Table 6-2). The monthly pattern of mean $CPUE_2$ at Station L1 in 2007 was slightly different from the preoperational and operational periods (Figure 6-8b). $CPUE_2$ of legal-size lobsters at Station L1 in 2007 was highest in October in contrast to pre-operational and operations periods, when the peak was in August. Mean $CPUE_2$ of legal-size lobsters in 2007 was lower than the lower 95% confidence limit for the preoperational period from August through November (Figure 6-8b).

During the preoperational period, legal-size lobsters were 8% of the total $CPUE_2$ at the nearfield station and 7% of the catch at the farfield station (Table 6-2). The $CPUE_2$ declined in the operational period to approximately 3-4% at both stations, probably due to increasing legal minimum size limits and the large increase in $CPUE_2$ of sublegal lobsters that began in 1995. In 2007, legal-size lobsters were 3-4% of the total $CPUE_2$.

$CPUE_2$ of legal-size lobsters was significantly higher in the preoperational period, but there were no significant differences between stations (Table 6-3). The difference between stations was similar between the preoperational and operational periods as indicated by the non-significant interaction term.

a.



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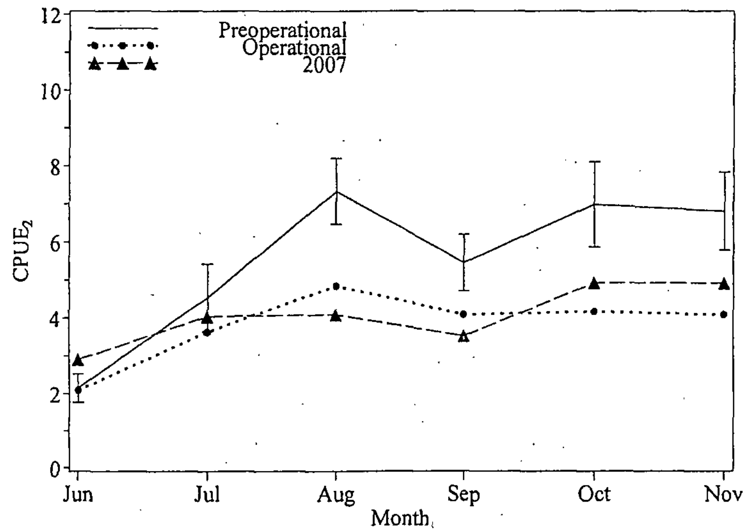


Figure 6-8 Preoperational and operational means with 95% confidence limits and 2007 means of a) monthly CPUE2 of total (legal and sublegal) lobster at Station L1, and b) monthly CPUE2 of legal-size lobster at Station L1. Seabrook Operational Report, 2007.

Table 6-4. Spearman's Correlation Coefficients Between $CPUE_2$ of Legal and Sublegal-size Lobsters and Mean Surface Water Temperature from June through November in previous years. Seabrook Operational Report, 2007.

Correlation Coefficients/Lag (Years)

	Station	
Size Class	**L1**	**L7**
Legal	0.50* /(1) 0.50*/(6)	0.35 NS/(1) 0.50*/(6)
Sublegal	0.55**/(1) 0.62**/(6)	0.29 NS/(1) 0.49**/(6)

(n) = lag time in years
NS = Not Significant (p > 0.05)
* Significant (0.05≥p>0.01)

** Highly Significant
(0.01≥p>0.001)

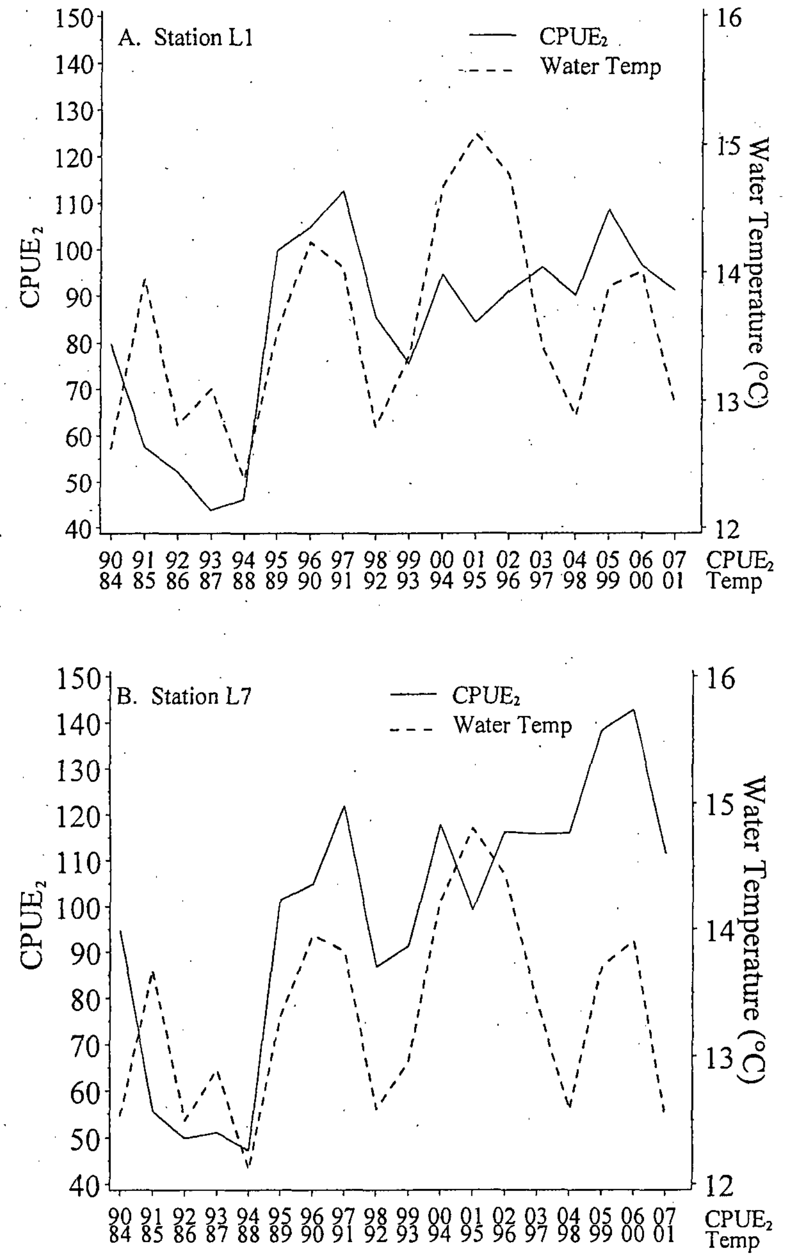


Figure 6-9. Relationship between sublegal-size lobster $CPUE_2$ from 1990 through 2007 and mean June through November surface water temperature lagged by six years at Stations: a. L1 (nearfield) and b. L7 (farfield). Seabrook Operational Report, 2007.

There was a significant positive correlation (r_S =0.50) between legal-size lobster $CPUE_2$ and mean surface water temperature during the warm season (June through November) lagged by one and six years at the nearfield station (Table 6-4; Figure 6-10). At the farfield station, the correlation was significant at a lag of six years (r_s = 0.49).

Size Class and Sex Distribution

Most lobsters collected in 2007 were in the 68-79 mm (2 5/8-3 1/8 in.) carapace length size class (Figure 6-6b). This size class has been most numerous every year since 1981. $CPUE_2$ in this size class in 2007 was within the range of recent years, but decreased from the previous year (Figure 6-6b). $CPUE_2$ of female lobsters in 2007 decreased from 2006 at both stations (NAI 2007) and was above the preoperational and operational period mean at each station (Table 6-2). Females comprised a relatively constant percentage of the total catch throughout the study period. In 2007, females were 53% of the total catch at the nearfield station and 53% at the farfield station, similar to that in the operational (54% nearfield; 55% farfield) and preoperational periods (55% nearfield; 54% farfield).

Mean $CPUE_2$ of ovigerous females for 2007 at both stations was higher than the mean $CPUE_2$ for the preoperational and operational periods, but less than the mean for 2006 at the nearfield station (Table 6-2; NAI 2007). In 2006, ovigerous females were 1.8% of the total catch at the nearfield station and 2.4% at the farfield station. In the preoperational period, ovigerous females comprised about 0.8% (nearfield) and 0.6% (farfield) of the total catch. In the operational period, ovigerous females comprised about 1.5% (nearfield) and 1.7% (farfield) of the catch.

Impingement

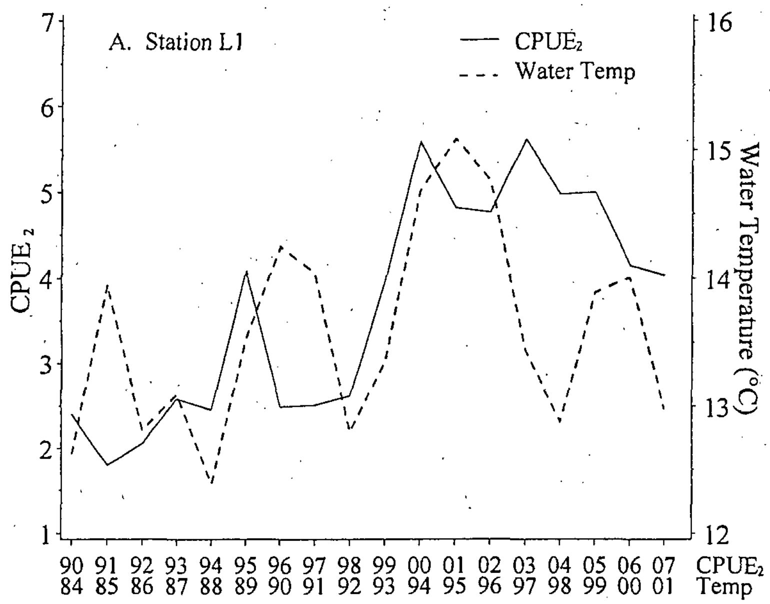
An estimated 21 lobsters were impinged in 2007, which was an increase from the 2006 estimate (Table 6-5). The 18-year average of lobster impingement was 16.3/year. In previous years, lobster impingement ranged from 0 in 2000 to 77 in 2005.

6.3.2 Jonah and Rock Crabs

Larvae

Density of *Cancer* spp. (*Cancer borealis* and *C. irroratus*) larvae in 2007 was lower than the operational means at both stations and lower than the preoperational mean at the nearfield station (Table 6-2). There were no significant differences between the preoperational and operational periods or between stations (Table 6-3). The interaction of these main effects was not significant, indicating that trends between periods were consistent at both stations. Annual geometric mean density of *Cancer* spp. larvae has followed similar trends at both stations (Figure 6-11). Mean density was highest in 1999 at both stations, and has generally decreased since then at both stations.

The seasonal abundance of *Cancer* spp. larvae in 2007 was similar to the preoperational and operational periods. In the preoperational and operational periods density was low until May, increased through August, and then decreased through December. Monthly mean density of *Cancer* spp. larvae in 2007 exceeded the preoperational upper 95% confidence limit in February, October, and November, but was below the preoperational lower 95% confidence limit in June, September, and December (Figure 6-12a).



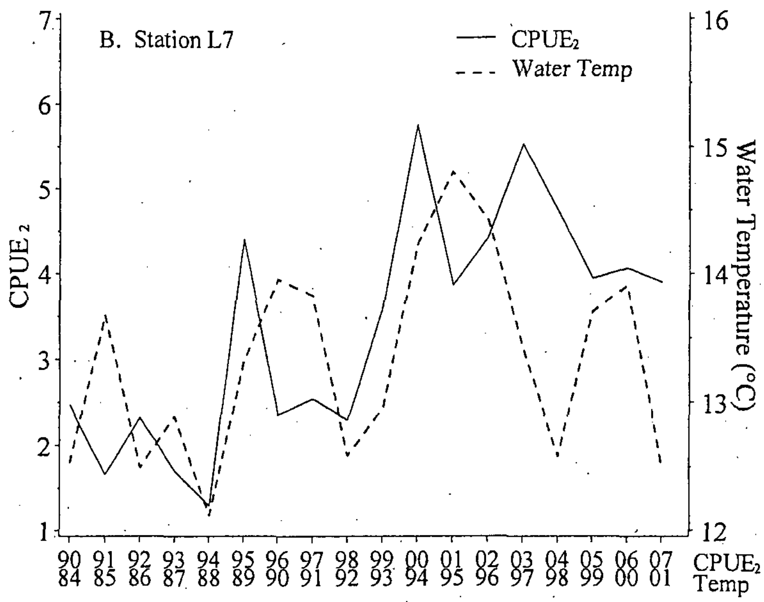


Figure 6-10. Relationship between legal-size lobster $CPUE_2$ from 1990 through 2007 and mean June through November surface water temperature lagged by six years (a) at Station L1 (nearfield) and (b) at Station L7 (farfield). Seabrook Operational Report, 2007.

Table 6-5. **Estimated Number of Lobsters Impinged in the Cooling Water System of Seabrook Station During 1990 Through 2007. Seabrook Operational Report, 2007.**

Year	Number of Lobsters Impinged
2007	21
2006	5
2005	77
2004	0
2003	19
2002	23
2001	1
2000	0
1999	6
1998	4
1997	20
1996	31
1995	16
1994	31
1993	1
1992	6
1991	29
1990	4
Total	**294**

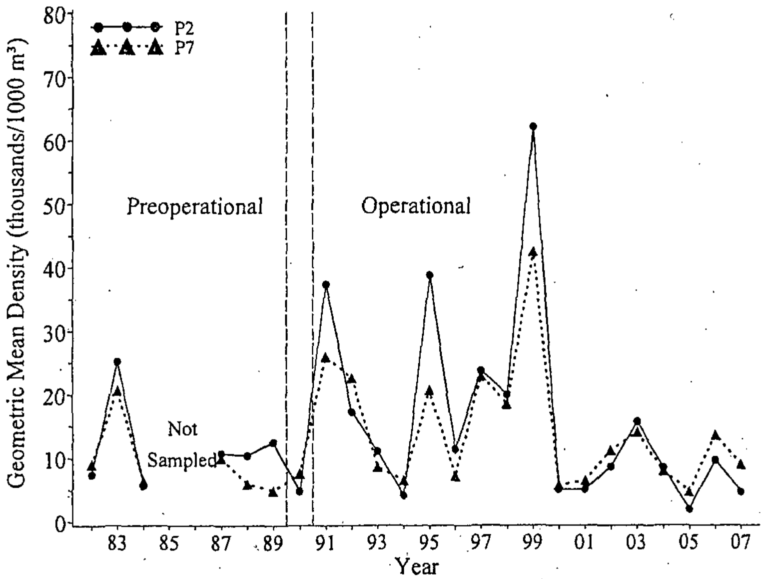


Figure 6-11. Annual geometric mean density (thousands/1000 m^3) of *Cancer* spp. larvae from 1982-2007 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2007.

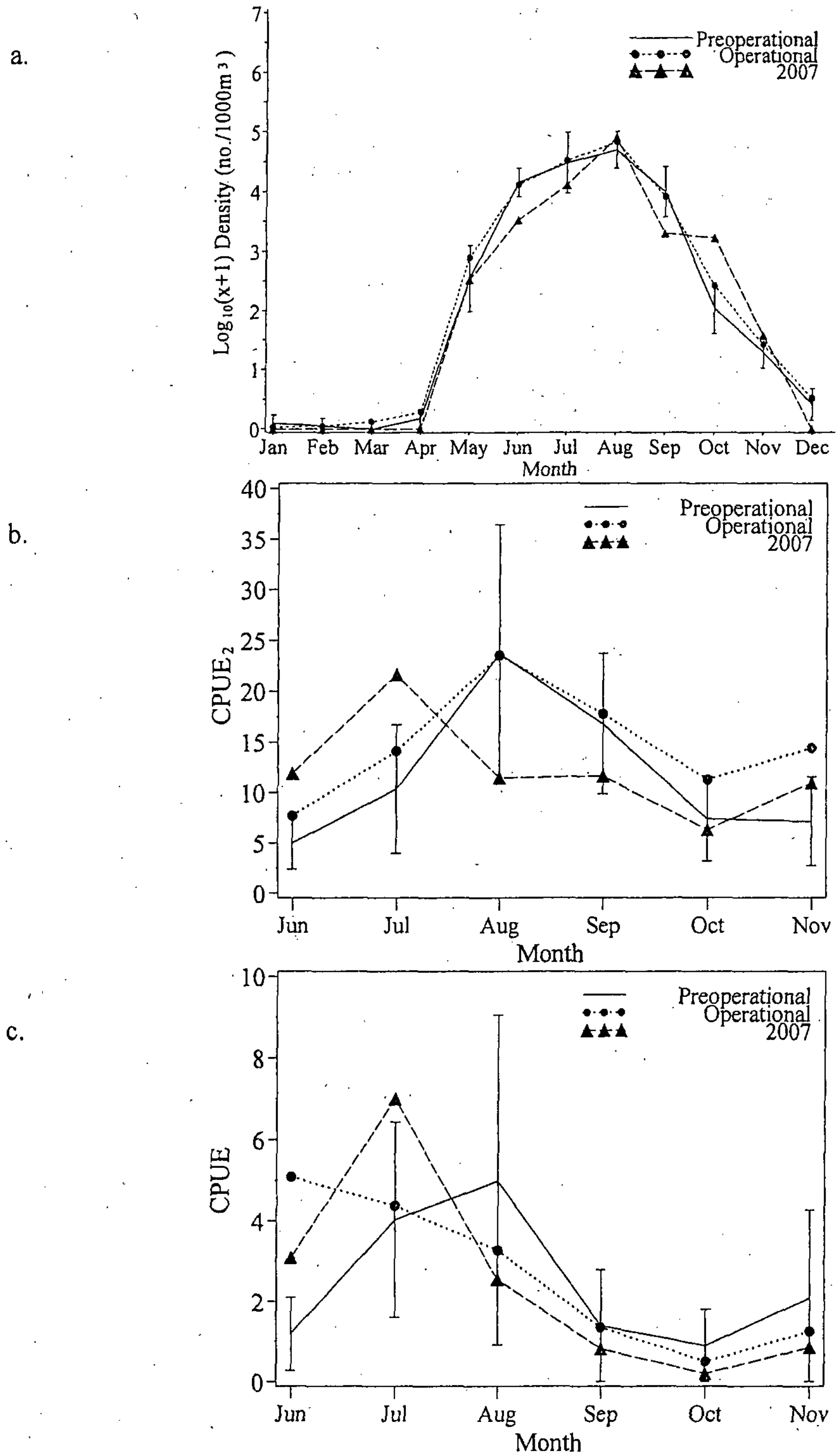


Figure 6-12. Monthly means and 95% confidence intervals of $\log_{10}(x+1)$ density (no./1000m^3) of a) *Cancer* spp. larvae at Station P2, and monthly mean catch per unit effort (15 traps) of b) Jonah and c) rock crabs at Station L1 during the preoperational period (1978-1984, 1986-1989: larvae; 1982-1989: adults) and monthly means during the operational period (1991-2007) and in 2007. Seabrook Operational Report, 2007.

Total Catch: Juveniles and Adults

In 2007, the $CPUE_2$ for Jonah crabs was equivalent to the preoperational mean and lower than the operational mean at the nearfield station, but was lower than the preoperational and operational means at the farfield station (Table 6-2). $CPUE_2$ in 2007 was the lowest since 1996 at the nearfield station and was similar to those of the operational years prior to 2000 at the farfield station (Figure 6-13). Annual $CPUE_2$ at both stations has generally followed the same trends, with $CPUE_2$ at the farfield station lower than the nearfield station, with the exception of 1983 through 1985. Since 1996, $CPUE_2$ at both stations has increased, peaked in 2004 and decreased through 2006 but with a slight increase in 2007 at the farfield station (Figure 6-13). There were no significant differences between periods or stations in Jonah crab $CPUE_2$ and the interaction term was not significant (Table 6-3).

The monthly pattern of Jonah crab $CPUE_2$ in 2007 at Station L1 was similar to the preoperational and operational patterns but with peak $CPUE_2$ in July instead of the average peak in August (Figure 6-12b). Consistent with the pattern in the operational period, $CPUE_2$ in 2007 increased from October to November (Figure 6-12b). In 2007, $CPUE_2$ was higher than the 95% confidence limit of the preoperational mean in June and July. Female Jonah crabs were more abundant than male crabs, and were 72% (L7) to 77% (L1) of the catch in the preoperational period, and 58% (L7) to 70% (L1) in the operational period (Table 6-2). Percentage of females in 2007 at Station L1 (58%) and L7 (49%) was lower than the preoperational proportion. The proportion of females has always been higher at Station L1.

Rock crabs were less abundant than Jonah crabs in the study area (Table 6-2), probably due to their habitat preference for a sandy substrate (Jeffries 1966) as opposed to the rock-cobble habitat most common in the study area. Rock crab CPUE in 2007 was lower than the preoperational and operational

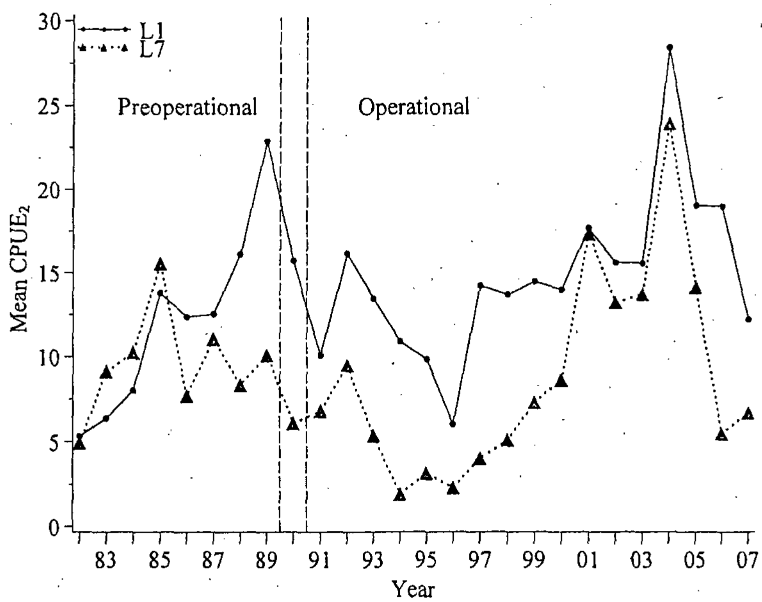


Figure 6-13. Annual mean $CPUE_2$ of Jonah crab, 1982-2007 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2007.

means at the nearfield station, and lower than the operational mean at the farfield station (Table 6-2). CPUE at both stations continued to decrease from 2003 means, except for an increase in 2007 at Station L7 (Figure 6-14). CPUE of rock crab increased significantly between periods only at Station L7, resulting in a significant interaction term (Table 6-3; Figure 6-15).

Rock crab CPUE at both stations has been variable among years. The increase in CPUE at Station L7 between periods was explained by relatively low CPUE in 1985 through 1988 followed by a period of high CPUE in 1997 through 2004. CPUE at Station L1 was generally greater than at Station L7 in the preoperational period but generally lower between 1994 and 2004. Rock crab CPUE at Station L1 significantly increased from 1982 through 1992 but did not significantly increase from 1993 through 2007 (Table 6-6). There was no significant difference in mean CPUE at Station L1 between periods of 1982-1992 and 1993-2007. Mean CPUE for rock crab at Station L7 significantly increased during the period 1982 through 2000 and significantly decreased from 2001 through 2007 (Table 6-6).

The monthly pattern of rock crab CPUE at Station L1 was similar to the preoperational and operational periods, except CPUE was higher in July (Figure 6-12c). In the preoperational period, CPUE was low in June, increased to a peak in August, and subsequently declined through October and increased slightly in November. In the operational period CPUE was highest in June, and declined steadily through October, and increased in November. In 2007, CPUE for rock crab increased from June to the highest in July and generally decreased through October, and increased slightly in November. Monthly CPUE in 2007 was within the 95% confidence intervals for the preoperational period in every month except June and July.

Percentage of females in the preoperational period was 19-20%, while in the operational period females made up 14%. In 2007, percentage of females was 21% at the nearfield station and 17% at the farfield station.

Jonah crab $CPUE_2$ and rock crab CPUE were not significantly correlated with mean bottom water temperature during the warm season (May through November) in any previous year. A correlation with water temperature lagged by seven years was previously significant (NAI 2005).

The majority of the Jonah and rock crabs captured in this program were between 100 and 119 mm CW (Figure 6-16). Although the total number of crabs varied each year, the distribution among length groups was relatively constant. Few Jonah and rock crabs less than 80 mm CW were captured. In 2007, $CPUE_2$ of Jonah crabs in the 100-119 mm and >119 mm size class decreased from levels in 2006. The larger sized rock crabs (> 119 mm) taken in 2007 increased from levels in 2005.

6.4 DISCUSSION

Both larval and adult stages of epibenthic crustacea in the study area are subject to potential impacts due to the operation of Seabrook Station. Larval stages of lobsters and *Cancer* spp. are susceptible to entrainment into the buoyant discharge plume. *Cancer* spp. may also be entrained into the cooling water system of the plant. Because larval lobsters are found predominantly at the surface and above the 12 °C isotherm (Harding et al. 1987; Boudreau et al. 1991, Annis 2005); they are

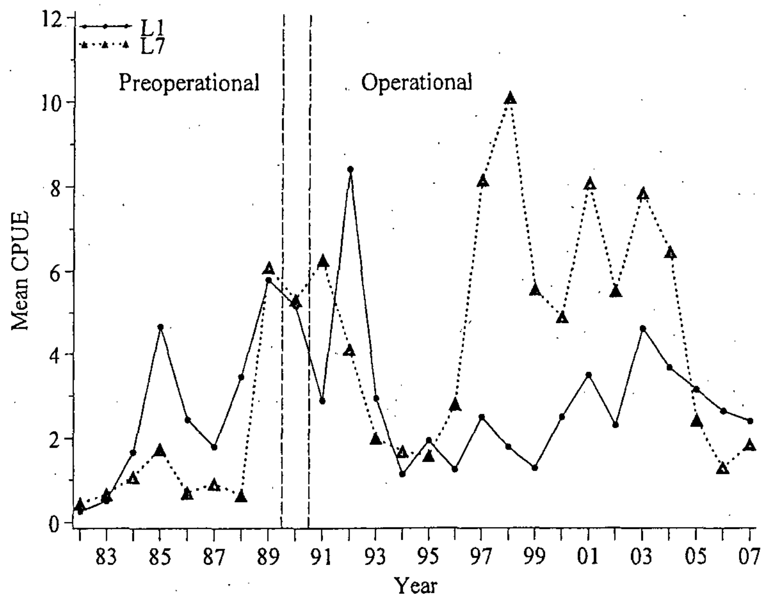


Figure 6-14. Annual mean CPUE of rock crab, 1982-2007 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2007.

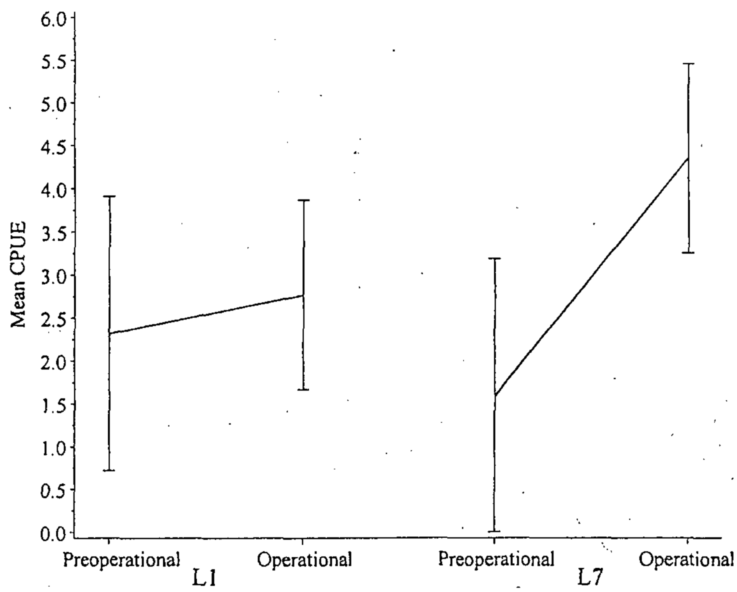


Figure 6-15. A comparison of mean CPUE with 95% confidence intervals of rock crab by station during the preoperational (1982-84; 1986-89) and operational (1991-2007) periods when the interaction term (Preop-Op X Station) of the ANOVA model was significant (Table 6-3). Seabrook Operational Report, 2007.

Table 6-6. Results of Segmented Regression Analysis of Annual CPUE of Rock Crabs. Seabrook Operational Report, 2007.

Species and Station	Mean Comparison Based on Break Points[a]	Period 1 Slope	Period 2 Slope
L1	1982-1992 > 1993-2007 NS	Positive*	NS
L7	1982-2000 < 2001-2007 NS	Positive*	Negative*

[a] As identified using segmented regression analysis.
NS = Not significant (p>0.05)
* Significant p<0.05)

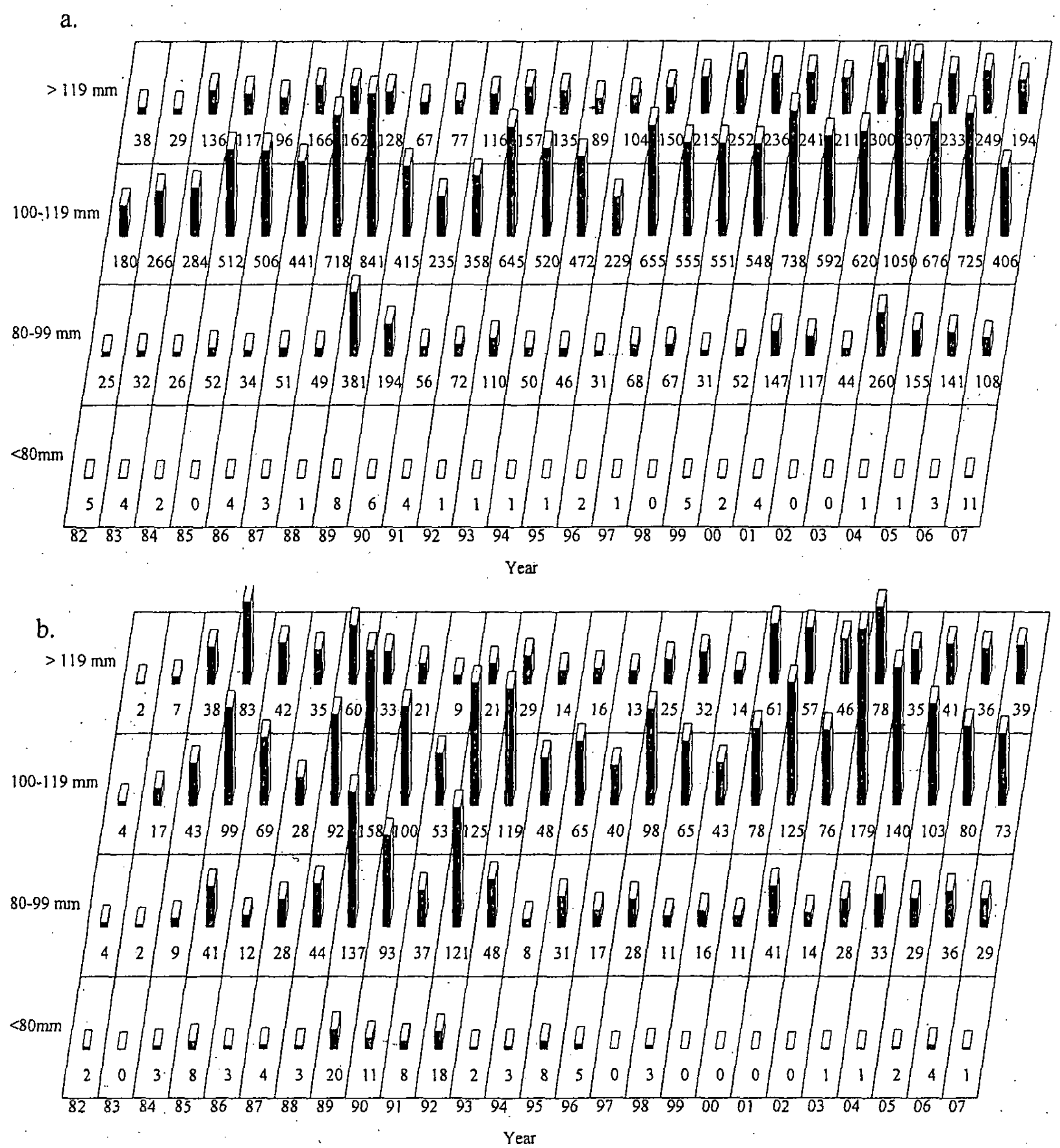


Figure 6-16. CPUE$_2$ of Jonah crab (a) and CPUE of rock crab (b) at Station L1 by size class from 1982 –2007. Seabrook Operational, Report 2007.

not as susceptible to entrainment at the mid-depth intake as other larvae, although entrainment may occur. Benthic stages of lobsters and *Cancer* crabs could be susceptible to impingement or discharge effects.

6.4.1 Lobster Larvae

Density of larval lobsters can be an important factor in determining benthic recruitment (Incze et al. 1997; Incze et al. 2000a; Wahle and Incze 1997). Seasonal integrated abundance of postlarval (stage IV larvae in this study) lobsters from the Seabrook monitoring program were remarkably similar to that at Johns Bay (Maine) for the period 1989 through 1995, but were different from the southern coast of Atlantic Nova Scotia (Incze et al. 2000b). Postlarval abundance from Seabrook monitoring program and mid-coast Maine settlement densities are positively correlated with trends associated with coastal circulation (Incze et al. 2006). Xue et al. (2008) used a coupled biophysical individual based model to simulate lobster populations from early life stages to recruitment to the fishery. The results of the model emphasized the importance of the timing and strength of southwesterly winds in the Gulf of Maine in determining the population of potential settlers. This indicates that the physical or biological processes controlling postlarval abundance in the Seabrook monitoring area may be similar to those processes elsewhere in the western Gulf of Maine but different from those in Atlantic Nova Scotia.

The geographic patterns in settlement of lobster larvae were mirrored in patterns of distribution of older life stages (Steneck and Wilson 2001). Locations of "hot spots" of larval settlement along the Maine coast were also locations of relatively high density of later stage adolescent (40-90 mm CL) lobsters. Larvae that settled on the mid-coast of Maine are apparently transported by currents from areas further to the east (Incze and Naimie 2000). Lobsters prefer to settle on cobble beds, probably to avoid predation, as opposed to rock crabs that are less selective in their settlement habitat (Palma et al. 1998; Castro et al. 2001). The selective habitat-seeking behavior and lower post-settlement mortality of lobsters are consistent with their lower fecundity and later onset of reproductive maturity, compared with rock crabs. Because there is a positive relationship between larval density and settlement, any process that affects the density of larval lobsters available for settlement may result in a change in the density of benthic stages. The density of lobsters from new recruits to sexually mature females can be predicted based on larval mortality rates, postlarval abundance, and available habitat for settlement (Incze et al. 2003).

Density of larval lobsters was significantly higher in the operational period than the preoperational period. This trend occurred at all stations and cannot be attributed to plant operation. Furthermore there is evidence that this trend is occurring elsewhere in the western Gulf of Maine (Incze et al. 2000b). The increase in lobster larval density in the operational period has come primarily from increases in Stage I and IV larvae. The reasons for these increases are not known but may be linked to recent increases in water temperature. Fogarty (1988) presents evidence that higher water temperature increases the probability of successful completion of the larval stage. The warmer surface water temperatures in the operational period may have contributed to the increased density of larval stages throughout the study area (see Section 2.0).

The monthly patterns of lobster larval abundance at Station P2 have not changed greatly since the plant became operational. Station P2 is located in the nearfield area, and any plant impacts due to entrainment into the thermal plume might be observed at this location. The monthly periodicity of larvae at P2 has been variable, but has generally shown the same pattern in the preoperational and operational periods. The variability in the monthly densities within a season may be partly explained by shifts in vertical distribution, thus variable vulnerability to surface sampling. Annis (2005) showed that the proportion of time spent near the surface (0-0.5 m) was inversely correlated with increasing depth of the 12°C isotherm. Proportion of larvae at the surface generally decreases over the season so peak abundance of larvae in later months might be underestimated by surface sampling. Also, the proportion of larvae at the surface is lowest midday and greatest in the morning and late afternoon (Annis 2005). Vertical distribution of different larval stages might also be explained by a shift in phototaxis from positive to negative with larval development (Annis 2005). The monthly periodicity at Station P2 is also similar to patterns observed elsewhere in the Gulf of Maine. In coastal Maine, Incze and Wahle (1991) found that densities of lobster postlarvae (Stage IV) increased rapidly in early August and then gradually declined. Fogarty and Lawton (1983) found that peak abundance of lobster larvae occurred between July and August. In 2007, peak abundance of lobster larvae at Station P2 occurred in the last week of July and second week of September.

Incze et al. (2000b) found general agreement between monthly patterns of postlarval abundance in the Seabrook Station study area and Johns Bay, Maine. The beginning and end of the postlarval seasons were similar between the two areas. In some years (1989, 1991 and 1992) there was an earlier start and abrupt increase in postlarval abundance at Seabrook compared to Johns Bay. The temporal patterns in 1993 and 1995 were very similar between the two areas and were characterized by early declines in abundance. However, in some years (1989 and 1990) the temporal patterns differed. In 1989, densities at Seabrook were high early in the season (>20/1000 m^2) and then declined to low levels for the rest of the season, in contrast to Johns Bay. In 1990, a period of very high density (>70/1000 m^2) occurred at Seabrook but did not occur at Johns Bay.

The operation of Seabrook Station does not appear to have affected lobster larval density in the study area. The density of lobster larvae in 2007 was higher than the preoperational and operational averages at all three stations. Lobster larvae density in the operational period was also significantly higher than in the preoperational period at both nearfield and farfield stations. Densities were also consistent between the Hampton-Seabrook study area and another area in the western Gulf of Maine. The monthly periodicity of lobster larvae abundance was similar to other areas in the region and does not appear to have changed in the operational period.

6.4.2 *Cancer* spp. Larvae

The density of *Cancer* spp. larvae in 2007 was lower than the operational means at both stations and lower than preoperational mean at the nearfield station. Despite the relatively high densities of *Cancer* spp. larvae in the operational years, there was no significant difference between the preoperational and operational periods. Mean densities observed in this study (4-62/m^3) are higher than the mean density observed in Narragansett Bay (2.9/m^3: Bigford 1979).

The seasonal occurrence for *Cancer* spp. larvae was from June through September in Canada, May through August in Massachusetts south of Cape Cod, and April through late October in Narragansett Bay (Bigford 1979). The seasonality in this study, with peak occurrence between May and October, is in general agreement with the published literature.

Rock crab larvae were found to be *eurythermal* but *stenohaline* during development (Johns 1981). Survival of larvae was highest at salinities of 30 and 35 ppt, and complete development occurred at temperatures between 10° and 24° C at a salinity of 30 ppt. Daily variation in catch of crab megalopae is correlated with tidal range (Shanks 2006). The peak spawning season for rock crab was centered around the portion of the year when environmental conditions (salinity and temperatures) were most favorable for recruitment to the benthic stage.

There is no evidence that the operation of Seabrook Station has affected development of *Cancer* spp. larvae through a change in environmental conditions. Seasonal occurrence of the larvae has not changed between the preoperational and operational periods (Figure 6-12a), indicating that critical environmental conditions (salinity and temperature) are similar between periods. The high densities of larvae in some of the operational years (1991, 1995, and 1999) at both stations, and consistency in annual trends between stations are evidence that there has been no measurable effect of the operation of Seabrook Station on *Cancer* spp. larvae.

6.4.3 Adult Lobsters

The fishery for American lobster is the most valuable fishery in the northeastern United States (NOAA 2001; Steneck and Wilson 2001). This fishery supported record landings in recent years due to increased fishing effort as expressed by an increase in the number of traps fished per fisherman. The resource in the Gulf of Maine is currently considered not overfished or depleted based on estimates of mortality and abundance indicators (ASMFC 2006). However, the high level of fishing effort is considered a negative indicator of health of the resource. In the Gulf of Maine, relative abundance of legal-size lobsters is at or near all-time highs (Selberg et al. 2003); however, the estimate of lobster abundance decreased sharply between 2002 and 2003 (ASMFC 2006; latest year available). An estimated 60% of the fishable stock are new entrants, raising concerns for the dependence of the fishery on new recruits (ASMFC 2006). Commercial landings have increased since the early 1970s, primarily due to increased fishing effort. In addition to commercial landings, the NMFS index of stock abundance has also risen since 1992, and increased in 2002 to the highest level in the time series (ASMFC 2006). In the Gulf of Maine, majority of the lobsters harvested are recent recruits to the legal-size limit, meaning that the fishery is supported by a few age classes, and any environmental disturbance that delays molting, increases mortality, or reduces spawning would have serious consequences to the fishery (NOAA 2001).

Current management strategies focus on trap limits and setting a minimum carapace length that allow lobsters to spawn at least once before they are recruited to the fishery. However, season length and area closures have been suggested to reduce exploitation rates based on recent models that account for temporal and spatial variation in fishing mortality as a result of catchability, lobster behavior, and fishing behavior (Gendron and Brêthes 2002). There are indications that the population dynamics and life history of the lobster make it resilient to overfishing. If a large proportion of the eggs are produced by undersized females, then lobster stocks can sustain exploitation rates as high as 95% (Ennis and Fogarty 1997). However, this situation may not occur in the Gulf of Maine, where a significant portion of the female lobsters caught in inshore areas are not sexually mature and the fishery is dominated by lobsters that have just molted into the legal size (NOAA 2001). The reasons why lobster populations continue to grow in the face of high fishing pressure remains unresolved (Wahle 1997). The lobster trap is not an efficient capture device as up to 94% of the lobsters entering traps escape (Jury et al. 2001). Furthermore, the bait in traps may provide a substantial contribution to lobster production (Saila et al. 2002b) or contribute to disease and mortality due to long-term effects of a diet heavily dependent on fish bait (Tlusty et al. 2008). The inherent inefficiency of the lobster trap as a capture device coupled with the food and shelter provided to lobsters may be factors that contribute to the continuing high abundance of lobsters.

Steneck and Wilson (2001) proposed that the recent increase in abundance of legal and sublegal size lobsters in the Gulf of Maine and southern New England was due to a causal mechanism that was very large and relatively long-term. Post-settlement mortality is thought to be very low, therefore the present distribution and demography of juvenile and adult lobsters appears to be driven by variations in the space and time of settlement of larvae (Steneck and Wilson 2001). The authors observed an increase in juvenile and adult lobster abundance that began in 1986 and may have started to decline around 1997. Their observation agrees with catch data from this study where $CPUE_2$ of total lobsters also reached a peak in 1997 and has subsequently declined. Zhang and Chen (2007) used American lobsters to demonstrate a shift from a groundfish-dominated ecosystem in the 1980s to a crustacean-dominated ecosystem in the 1990s. Because these trends in lobster demography are so wide-spread and have a period of at least a decade, Steneck and Wilson (2001) suggested that they may be related to large-scale oceanographic patterns including the North Atlantic Oscillation. The pattern of the most recent North Atlantic Oscillation, which may have ended around 1995, was coincident with the temporal patterns observed in abundance of lobsters.

On a smaller scale, the increase in $CPUE_2$ in the study area between periods may be related to a higher level of commercial lobster fishing activity in the area in the operational period. Presence of physical shelter is an important factor in the life of small lobsters as they use it to escape predation (Spanier et al. 1998, Castro et al. 2001). Lack of shelter causes lobsters to modify their behavior and places them at a greater risk of predation. Intraspecific shelter competition may drive declines of preharvestable-sized lobsters in shallow coastal zones and increase their abundance in offshore and deep waters (Steneck 2006). At small scale experiment-tation, Steneck (2006) has shown large lobsters leave or avoid areas of high popula-tion density and intense competition for low populated areas with less shelter competition. In a recent study by Bowlby et al. (2007), telemetry of 119 lobsters in the Gulf of St. Lawrence showed two movement behaviors: residents and dispersers. While resident lob-sters generally remain within the release area, dispersers typically make rapid movements away from release sites in autumn and a slow return in the spring (Bowlby et al. 2007). Bowlby et al. (2007) explains such dispersal behavior in lobsters as a result of seasonal limitations in hard-substrate habitat. Lobster abundance and survival also appear to be influenced by habitat type adjacent to hard-substrate such as cobble patch reefs (Selgrath et al. 2007). Selgrath et al. (2007) showed lobsters in Narragansett Bay, Rhode Island to benefit from seagrass edges compared to unvegetated edges along cobble patches. The presence of numerous commercial and re-creational lobster traps in the study area may provide shelter and food for small lobsters, thus contributing to an increase in $CPUE_2$ (Saila et al. 2002b).

Total $CPUE_2$ of lobsters was significantly higher in the operational period. The large increase in lobster abundance observed in our study beginning in 1995 is partially corroborated by other lobster monitoring programs in the area. Lobster monitoring conducted by New Hampshire Fish and Game (NHFG 2008) also indicated that total CPUE was highest in 1995, but in contrast to our findings, CPUE in the NHFG study has generally decreased through 2007. However, the NHFG sampling uses commercial traps with escape vents while this study uses ventless traps and it is likely that more sublegal lobsters are retained in our sampling. Total commercial lobster landings in the Gulf of Maine waters of Massachusetts was highest in 1989, peaked again in 1999, and has generally decreased from 2000 through 2004 (Glenn et al. 2007). The Massachusetts index of sublegal lobster abundance in the Gulf of Maine waters was highest in 1991, but in contrast with our findings, has decreased steadily through 2004 (Glenn et al. 2007).

Changes in water temperature affect lobster catches. Increases in lobster catch have been correlated with increasing water temperature (Fogarty 1988; Campbell et al. 1991). Higher water temperature increased the activity level of lobsters, making them more likely to enter traps. Catch rates were shown to increase within increasing bottom water temperatures and decrease with declining water temperatures 24 hours prior to traps being hauled (Drinkwater et al. 2006). Bottom water temperature increased between the preoperational and operational periods at both the nearfield and farfield areas, but the increase was not significant and was not attributed to plant operation (see Section 2.0).

There were significant correlations between $CPUE_2$ of sublegal and legal-size lobsters and mean surface water temperatures in June through November lagged by six years for sublegal lobsters at both stations and lagged by six years for legal lobsters at the farfield station. Correlations between lobster $CPUE_2$ and water temperature in previous years have been reported before. Huntsman (1923: cited in Harding et al. 1983) hypothesized that warm summer surface water stimulates rapid growth of planktonic larvae so that the larval stages are completed and settlement occurs before the onset of cooler temperatures halts development. Sheehy and Bannister (2002) showed year class size of European lobster, *Homarus gammarus*, was correlated with surface sea temperature based on neurolipofuscin analysis of microtagged lobsters. Increased settlement of young lobsters may result in increased catches when these lobsters reach legal size. Flowers and Saila (1972) found that lobster landings correlated well with coastal bottom water temperatures lagged by 5 to 8 years. Dow (1977) also found significant correlations between sea surface temperature and lobster catches four to seven years later. A similar relationship was found between water temperature and lobster catch in Maine six years later (Fogarty 1988), and in Nova Scotia four years (Campbell et al. 1991) and six to eight years later (Koeller 1998).

Our results are in general agreement with this well-established pattern as $CPUE_2$ of both sublegal and legal sized lobsters were significantly correlated with surface water temperature six years earlier. The majority of sublegal and legal lobsters are in the 68-79 mm and 80-92 mm size classes and probably are members of the year class spawned six years earlier. The correlation between $CPUE_2$ of sublegal-size lobsters at the nearfield station and surface water temperature of the proceeding year was statistically significant, but may not have any biological significance. Warmer June through November mean water temperatures may have promoted larval survival by accelerating development. The increased larval survival was reflected in increased $CPUE_2$ six years later.

The significant relationship between water temperature lagged by six years and $CPUE_2$ of sublegal and legal lobster occurred at both stations throughout the preoperational and operational periods. This is an indication that the thermal discharge from Seabrook Station has not disrupted any temperature-dependent processes that may affect recruitment from the larval to benthic stages.

$CPUE_2$ of legal-size lobsters was significantly lower in the operational period. This difference occurred equally at both stations and cannot be attributed to plant operation. The index for legal-size lobster CPUE in Massachusetts (Dean et al. 2007) has decreased since 1999, while our data indicate relatively stable but variable $CPUE_2$ (Figure 6-10). Overall catch per unit effort of legal-size lobsters in the Gulf of Maine has shown an increasing trend in the mid-1990's with some variation (NOAA 2001; ASMFC 2006) and our data are consistent with this trend for the 1990s. Potential changes in the temporal distribution of lobster $CPUE_2$ due to plant operation would be expected to occur at the nearfield station (L1). The pattern of monthly mean $CPUE_2$ at Station L1 was similar between the preoperational and operational periods for both total lobsters and legal-size lobsters. The size distribution at the nearfield station (L1) can only represent inshore populations because offshore lobster populations have a larger size structure compared to inshore populations in the Gulf of Maine (Chen et al. 2006).

Impingement of lobsters in the cooling water system of Seabrook Station is low due to the mid-water location of the intakes. During 2007, 22 lobsters were impinged, bringing the total for the operational period (1990-2007) to 295 lobsters. This level of impingement does not pose a threat to local lobster populations.

Annual $CPUE_2$ of egg-bearing lobsters and the percentage of egg-bearing lobsters was greater in the operational period than in the preoperational period. An increase in the percentage of egg-bearing lobsters over two decades (1980s and 1990s) was also observed in eastern Long Island Sound (Landers et al. 2001). The increase in percentage of egg-bearing females in eastern Long Island Sound may have been related to changes in environmental conditions (increased water temperature), intense fishing pressure selecting for lobster that mature at a sublegal size, or a combination of both factors. The size at which 50 percent of lobsters were mature was 91.9 mm (±0.6 95%C.I.) from Georges Bank and offshore Gulf of Maine compared to smaller size at maturity in warmer regions (Little and Watson 2005). Size at maturity decreases as the number of degree-days above 8°C increases (Little and Watson 2005). Similar processes may be working in our study area. Although ovigerous lobsters smaller and larger than the median size of maturity have been shown to experience similar number of degree days above 3.4°C, large egg-bearing lobsters experience less extreme temperature exposure and less variation in thermal regime due their movements (Cowan et al. 2007). Significant production of eggs by sublegal-size lobsters may be a factor in the continuing high $CPUE_2$ of lobsters in the face of intense fishing pressure.

There is no evidence that the operation of Seabrook Station has affected the lobster resources in the study area (Table 6-7). The distribution of lobster larvae and legal-size lobsters was consistent at the nearfield and farfield stations between the preoperational and operational periods. Recent trends in total differences lobster and legal-size lobster $CPUE_2$ were consistent with larger trends in the Gulf of Maine.

Table 6-7. Summary of Potential Plant Effects on Abundance of Epibenthic Crustacea. Seabrook Operational Report, 2007.

Parameter Measured	Operational Period Similar to Preoperational Period[a]	Differences Between Preoperational and Operational Periods Consistent Among Stations[b]
Lobster: Larvae	Op>Preop	Yes
Lobster: Total Catch	Op>Pre	Yes
Lobster: Legal-Sized Catch	Op<Preop	Yes
Cancer spp.: Larvae	Yes	Yes
Jonah Crab: Total Catch	Yes	Yes
Rock Crab: Total Catch	—	Nearfield: Op=Preop Farfield: Op>Preop

[a] based on Preop-Op term of ANOVA model (Table 6-3)
[b] based on the interaction term (Preop-Op X Station) of the ANOVA model and multiple comparison test at $\alpha = 0.05$ (Table 6-3)

6.4.4 Jonah and Rock Crabs

Jonah and rock crabs are captured incidentally in lobster traps and could be subject to the same potential plant impacts. There is no evidence of plant operations affecting either *Cancer* spp. larval or adult stages of Jonah or rock crabs. There were no significant differences between periods and differences between periods and stations were consistent for *Cancer* spp. larvae and adult Jonah crab. However, abundance of rock crabs increased between the preoperational and operational periods at the farfield station, but there was no significant increase at the nearfield station. The increase at the farfield station began after 1996, after the plant began operation. In 2007, annual CPUE of rock crabs at the farfield station was lower than the CPUE at the nearfield station indicating a potential converging trend in CPUE between the stations. Steneck et al. (2004) found that in kelp forests of the western North Atlantic invertebrate predators such as large crabs (especially Jonah crabs) have dominated the food chain since 1995, since predatory fish and sea urchins have been removed by fishing. McKay and Heck (2008) showed the presence of Jonah crabs could alter the foraging behavior of green sea urchins and subsequently reduce their grazing rates on kelp. The recent increase in abundance of Jonah and rock crabs observed in this study may be a result of the restructuring of the food web observed by Steneck et al. (2004) and modeled by Zhang and Chen (2007).

In previous years, $CPUE_2$ of Jonah crab and CPUE of rock crab were significantly correlated with bottom water temperature lagged by seven years. In 2007, this relationship was no longer significant. Warm water temperatures during the larval season may increase survival of larvae, resulting in increased settlement and recruitment to the adult stage similar to lobsters. However, previous significant correlations were weakened with the addition of 2007 data and do not support this hypothesis.

Behavioral interactions between lobsters and the two species of crabs can affect crab CPUE data. Richards et al. (1983) found that the presence of lobsters in a trap reduced entry by Jonah and rock crabs. Rock crab is a preferred prey item for lobster (Gendron et al. 2001), and an increase in lobster CPUE could cause a decrease CPUE of rock crabs. However, Salierno et al. (2003) found that foraging behavior of rock crabs was not affected by the presence of Jonah crabs, which suggests that entry of baited traps by rock crabs should also be unaffected by Jonah crabs. Addison and Bannister (1998), working with the closely related European lobster (*Homarus gammarus*) and crab (*Cancer pagurus*), found results similar to Richards et al. (1983), where the presence of a lobster in a trap inhibited entry to the trap by crabs, but the presence of crabs did not affect lobsters.

$CPUE_2$ of Jonah crabs and CPUE of rock crabs was lower than that of lobsters. In addition, the greatest catches of both crabs occurred at a soak time of three days, compared with a soak time of five days for lobsters. The occurrence of a maximum catch of crabs at an earlier soak time, and the lower apparent abundance of crabs compared with lobsters may be partially due to behavioral interactions and predation within a trap. If the presence of lobsters in a trap deters entrance by crabs, and if the presence of crabs does not affect lobster entry to a trap, then it might be expected that the presence of lobsters in a trap will depress the index of crab abundance as soak time increases. Crabs can burrow rapidly into the substrate to escape predation and therefore have a lower cost of not obtaining shelter than lobsters (Richards and Cobb 1986), which may partially explain why they do not compete with lobsters for shelter.

The relationship in $CPUE_2$ of Jonah crabs between stations has been relatively consistent. In the preoperational period, $CPUE_2$ was either similar between stations, or higher at Station L1. In the operational period, $CPUE_2$ was always higher at Station L1, but was almost identical to Station L7 in 2001. The means for the preoperational and operational periods were not significantly different (Table 6-7). The consistency in $CPUE_2$ between stations in the preoperational and operational periods as shown by the non-significant interaction term indicates there has been no impact from plant operation.

Mean CPUE of rock crabs at the farfield station was significantly higher in the operational period compared to the preoperational period, but the CPUE at the nearfield station was not significantly different between periods, resulting in a significant interaction (Figure 6-15). CPUE of rock crabs was exceptionally high at the farfield station in 1997 through 2004, resulting in the higher CPUE at the farfield station in the operational period. However, from 2005 through 2007, CPUE of rock crab at the farfield station was lower than the nearfield station, a pattern more consistent with the preoperational and early operational periods. Segmented regression indicated that CPUE of rock crabs at the farfield station was significantly increasing from 1982 through 2000 and decreasing from 2001 through 2007. The trend in annual CPUE at the farfield station changed for the period after 2000, well after the operational year of 1990, which suggests any changes in abundance might be better explained by behavioral or other biological interactions rather than an impact from plant operation.

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7.0 SUMMARY

There was no evidence that in 2007 the operation of Seabrook Station affected the density of softshell clam larvae, young-of-the-year (YOY), yearlings or adults in Hampton Harbor. There were no statistically significant differences in density of larvae, YOY, yearlings or adults between the preoperational and operational periods.

Geometric mean density of clam larvae in 2007 at the nearfield Station P2 (5.8/m^3) was below the preoperational period mean and equal to the operational mean. At the farfield Station P7 mean density in 2007 (3.4/m^3) was below the preoperational and operational period means. Annual means were generally similar at both stations except for 1999, 2000 and 2002 when more larvae occurred at Station P7. Density of YOY clams (1-25 mm) at all flats combined in 2007 (17.0/m^2) increased compared to 2006, but was lower than the preoperational and operational means. YOY density at Flat 1 (17.9/m^2), Flat 2 (25.1/m^2), and Flat 4 (9.7/m^2) in 2007 increased from 2006 at Flats 1 and 4 but were lower than the preoperational and operational means. There were no significant differences in YOY clam density between the preoperational and operational periods or among flats.

Density in 2007 of yearling clams (26-50 mm) at all flats combined (0.5/m2) decreased compared to 2006 and continued the pattern of poor recruitment into this size class. The 2007 mean density of yearling clams was lower than the preoperational and operational means. Mean densities in 2007 at Flat 1 (0.6/m^2), Flat 2 (0.1/m^2), and Flat 4 (1.0/m^2) were below the preoperational and operational period means. Density of yearling clams was significantly higher in the preoperational period. Yearling clam density differed significantly among flats being higher at Flat 4, followed by Flat 1 then Flat 2. Density of yearling clams is presently lower than adult clams, suggesting a potential for decreased adult recruitment in the future.

Mean density of adult clams (>50 mm) in 2007 at all flats combined (3.1/m^2) decreased from 2006, and was higher than the preoperational mean. Mean density at Flat 1 (4.0/m^2), was above the preoperational and operational period means, and mean density at Flat 2 (1.3/m^2) was below both means. At Flat 4 mean density (5.6/m^2) was above the preoperational mean. Mean density in 2007, compared to 2006, increased only at Flat 4.

Recruitment and survival of softshell clams in Hampton Harbor appeared to be highly variable and controlled by a variety of abiotic and biotic factors. Current transport probably affects larval density at the sampling stations. YOY and yearling densities appear to be controlled by post-settlement processes including bedload transport and predation by green crabs and other predators. Yearling and adult density appears to be affected primarily by disease and digging pressure.

Direct relationships between densities of earlier and later lifestages were not apparent. Larval density was not strongly related to recruitment of YOY or density of adult clams. Furthermore, density of YOY did not appear related to density of older lifestages in later years. Therefore, the predicted impacts of larval entrainment on benthic recruitment, which assumed a direct relationship between larval density and settlement, greatly overestimated the potential reduction in adult clams.

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7.1 INTRODUCTION

The objectives of the softshell clam (*Mya arenaria* Linnaeus 1758) monitoring programs are to determine the spatial and temporal patterns of abundance of various life stages of softshell 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 3.3.2). Larval entrainment might result in a reduction in benthic stages (after settlement to the bottom) if a significant relationship exists between larval supply and recruitment. Excursions of the thermal plume into Hampton Harbor were originally thought to have the potential to affect the benthic life stages of the softshell clam. However, after 17 years of monitoring of plant operation it is clear that such excursions do not occur. Factors unrelated to Seabrook Station that may affect clam density also considered were predation, disease, and recreational clamming. 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 by the operation of Seabrook Station.

7.2 METHODS

7.2.1 Bivalve Larvae

The spatial and temporal distributions of 12 species of umboned bivalve larvae, including softshell 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), and farfield (P7) stations (Figure 7-1). Sampling began at Station P2 in July 1976, at Station P7 in July 1982, and at Station P1 in July 1986. 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).

7.2.2 Hampton Harbor Population Survey

The five largest flats in the Hampton-Seabrook estuary (Figure 7-2) were surveyed in late October or early November from 1974-2007 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. Surveys for both adults (>25 mm) and young-of the year (1-25 mm) were conducted at Flats 1 (Common Island), 2 (Confluence), and 4 (Middle Ground). Adults were not collected at Flats 3 (Browns River) and 5 (The Willows), because the density has historically been extremely low.

Clams were grouped into the following size classes based on examination of clam length frequencies (measured to the nearest mm) starting in 1974 (NAI 1990, 1991, 1992, 1993, 1994, 1995) and the life table in Brousseau (1978):

Young-of-the-year (YOY) (seed clam 1-12 mm)	1-25 mm
Yearling	26-50 mm
Adult	>50 mm

A sample of YOY (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,

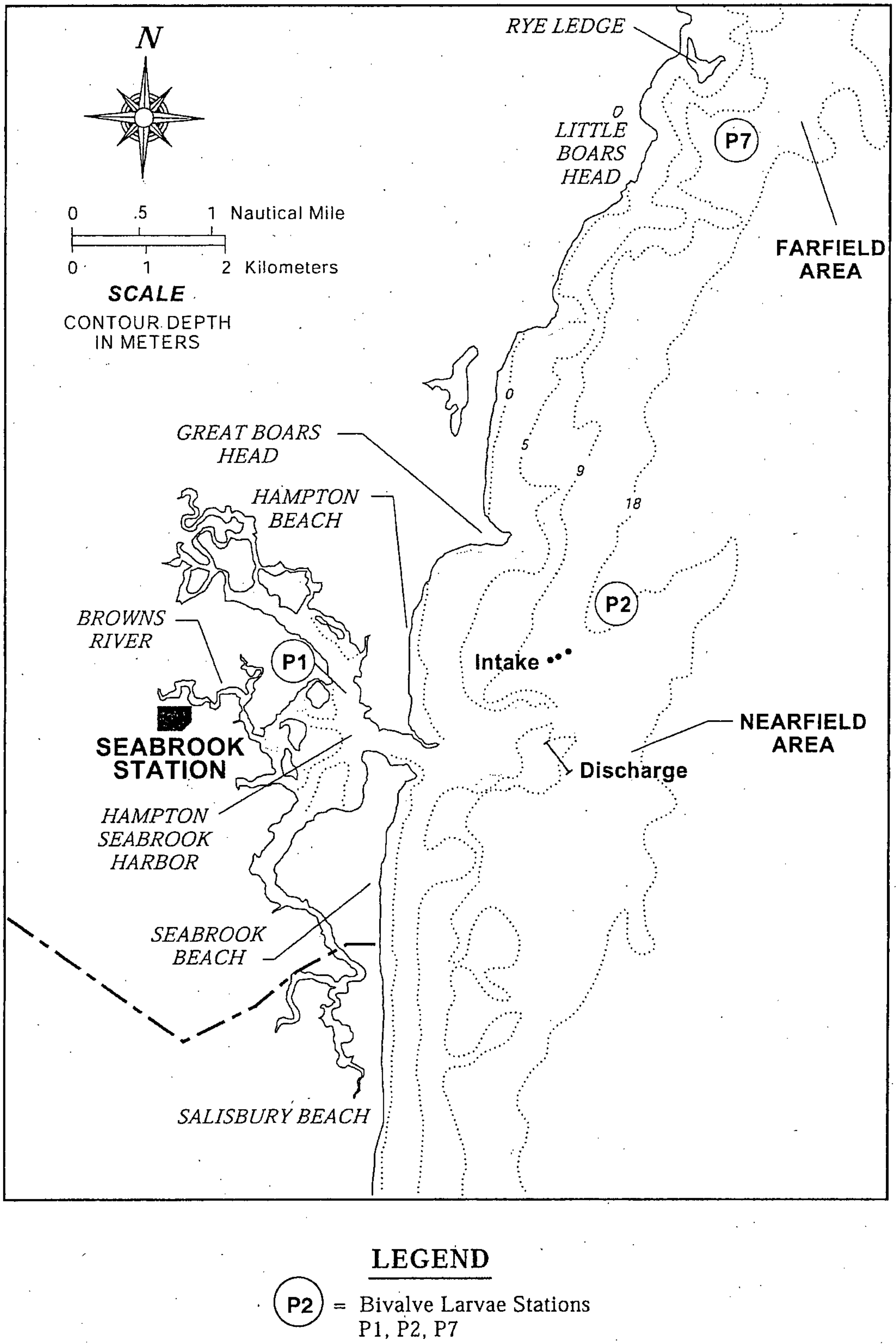

Figure 7-1. Bivalve larvae (including *Mya arenaria*) sampling stations.

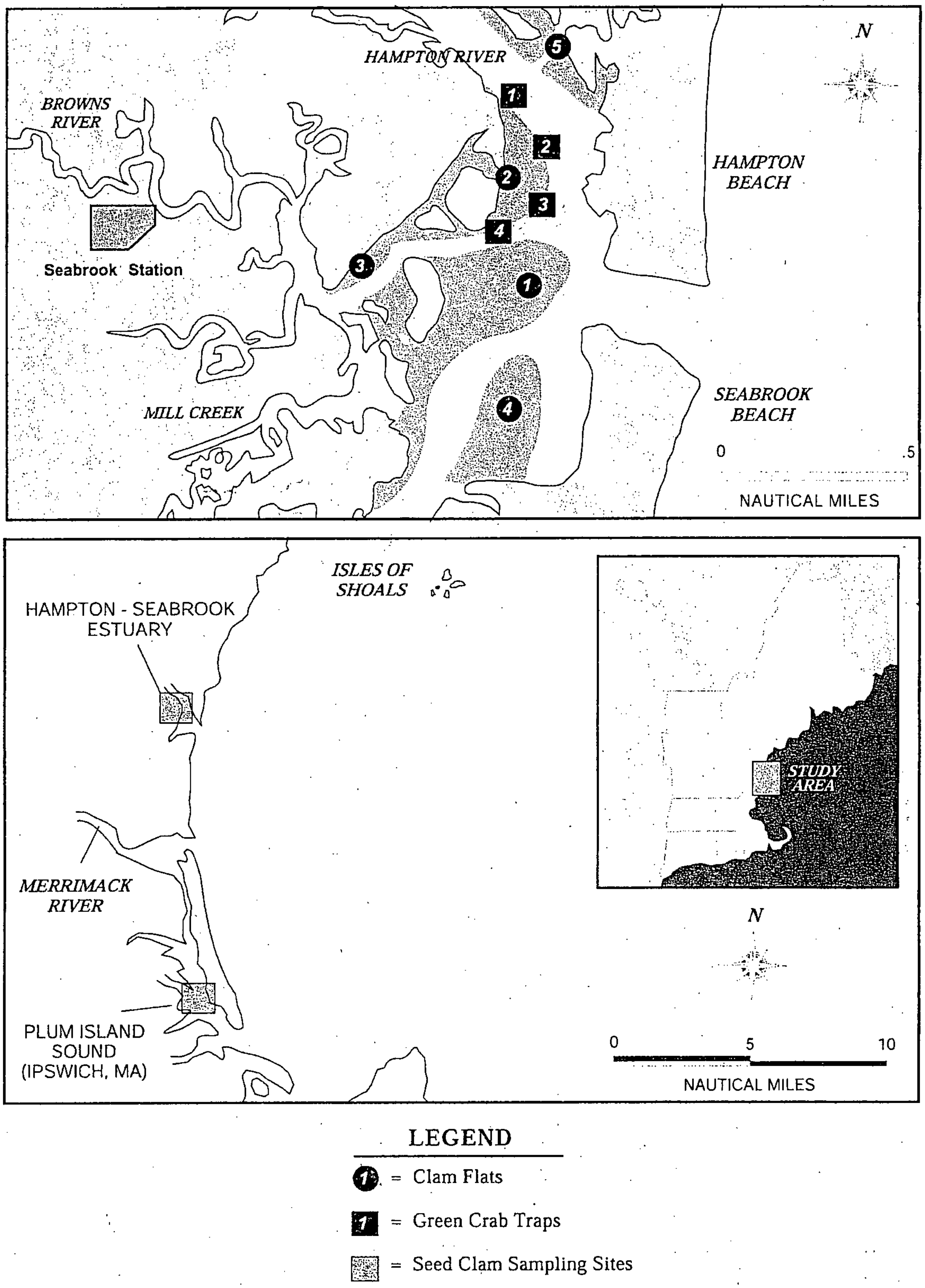

Figure 7-2. Hampton-Seabrook estuary and Plum Island Sound softshell clam (*Mya arenaria*) and green crab (*Carcinus maenas*) sampling areas.

and clams were enumerated, measured, and released. A sample of 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.

7.2.3 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 softshell clams (<1.0 mm). Sampling sites were at fixed locations within the two areas shown in Figure 7-2. Hampton-Seabrook estuary and Plum Island Sound softshell clam sampling areas were located where the abundance of clams has been high historically.

7.2.4 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 7-2). 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).

7.2.5 Analytical Methods

Annual geometric mean clam density (no./m^2) 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 the number of samples varying among years. Means were plotted graphically and examined for trends.

Clam populations in Hampton Harbor could possibly be affected through entrainment of larval clams (See Section 3.0) into the cooling water system of Seabrook Station. Potential impacts were investigated using a mixed effects analysis of variance (ANOVA) model 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 model for larvae used weekly mean of log(x+1) density collected from 1982 through 1984, and 1986 through 2007 when Stations P2 and P7 were sampled concurrently. Previous reports (NAI 1998) used a preoperational period of 1988 through 1989 when Stations P2, P5 and P7 were sampled concurrently.

The ANOVA model for benthic stages used log (x+1) densities from the total number of samples taken from 1974-2007 in the Hampton Harbor survey, and from 1987-2007 for the nearfield/farfield survey. The nearfield/farfield and bivalve larvae monitoring programs were based on 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 potentially affected (nearfield) locations (Green 1979). Period (preoperational vs. operational) and station differences and the interaction between them were evaluated using a mixed linear model analysis using a BACI design to test for potential impacts of plant operation. A mixed model based on reviews of the BACI model by Underwood (1994) and Stewart-Oaten *et al.* (1986) was used with all effects considered random, except operational status (Preop-Op). Time (months) 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 both stations were sampled concurrently (thus maintaining an equal number of years between stations within the preoperational period). Collections from 1990, the year the plant began to operate intermittently, occurred during the transition from preoperational to operational periods and were excluded from the softshell clam larvae analysis. The inference test for Preop-Op was made using a Type III F-test of fixed effects from the mixed model analysis (PROC MIXED, SAS Institute, Inc. 1999). The likelihood ratio test was used to test the significance for random effects by comparing the difference between the -2 residual log likelihood values of the full and reduced model (without the random effect of interest) to the chi-square distribution (Littell et al. 1996). Post-hoc multiple comparison tests were made for significant main effects using t-tests of least square means for fixed effects and predicted estimates for random effects.

The Hampton Harbor Monitoring Program of adult clams was not based on a BACI study design as all stations were located in a single farfield area (Hampton Harbor). The same ANOVA model was used for the Hampton Harbor Monitoring Program as the bivalve larvae and the nearfield farfield study, except the Preop x Station interaction term was dropped because sampling only occurred in the farfield. The putative plant effect, reduction of benthic stages due to entrainment of larvae, might be detected through a significant temporal term (Preop-Op), 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 number of clam licenses sold was plotted against year for Flat 1, where historically the majority of digging effort in Hampton Harbor occurred. The annual number of licenses sold was obtained from New Hampshire Fish and Game (B. Smith pers. comm. 2008) for the period 1990 through 2007. All flats were closed to digging due to coliform pollution from the fall of 1989 through 1993, and Flats 1 and 3 were reopened intermittently beginning in 1994. In 1995, Flat 2 was reopened, and Flat 4 was reopened in 1998. Flat 5 remains closed. In recent years the clam flats have been opened on Fridays and Saturdays from 1 November through 31 May, except when closed by the New Hampshire Department of Environmental Services due to coliform pollution. The number of licenses sold was used as an index of digging effort. In previous years, the number of diggers observed on the flats on Fridays was used to estimate digging effort. However, starting on 1 January 2003, the clam flats were only open on Saturday and it was not possible to continue the Friday clammer count index. Historically, the majority of the digging effort has been concentrated on Flat 1 (NAI 2002), therefore the relationship between digging effort and clam density was investigated at this flat. However, since 2004 clamming effort has increased on Flat 4 and this flat now receives the majority of the effort.

Defining the relationship between early and later lifestages of softshell clam is important to identify the lifestage that is critical in determining the abundance of adult softshell clams. If a significant relationship exists, then conservation or habitat enhancement efforts targeted to the critical lifestage may result in increased densities of adult clams. If no significant relationships exist between early and older lifestages, then recruitment of adults may be dependent on environmental or physical factors and predation, rather than the abundance of an earlier lifestage.

Initial concerns regarding the operation of Seabrook Station were that entrainment of larvae through the intakes could reduce the number of larvae available for settlement, and thus the number of adults available for harvesting. To evaluate this concern quantitatively, regression analysis was used to determine if a significant relationship existed between annual geometric mean densities of earlier and later lifestages. Regressions were calculated for annual geometric mean density of YOY clams (1-25 mm) on annual geometric mean density of larvae, with the line forced through the origin of the axes. This option was used because logically if no larvae were present in Hampton Harbor during the spring through fall, there would be no YOY present on the flats during the annual survey. Regressions were also calculated for the annual geometric mean density of adult clams (>50 mm) on annual geometric mean density of larvae, and for adults on YOY. In this case the line was not forced through the origin. Regressions were calculated for Flats 1, 2, and 4 and Flats 1, 2, and 4 combined. Larval data from Station P1 in Hampton Harbor were used in all larval regressions. The coefficient of determination (r^2) was used to describe the strength of the relationship between larval density and YOY and adult density. This statistic is a ratio that expresses the variability in YOY and adult density explained by the variability in larval density. A Bonferroni correction was applied to the p levels of the regressions to control Type I error because the same larval data set was used in the regressions and multiple comparisons were made (LeBlanc and Miron 2006).

7.3 RESULTS

7.3.1 Larvae

Softshell clam larvae were first observed in the third week of May in the preoperational period, and the fourth week of April in the operational period. Larvae were present through the end of October (the end of sampling) in both the preoperational and operational periods. Peaks in larval abundance occurred in late June and in August through September in both periods (Figure 7-3). In 2007, softshell clam larvae were first present in the fourth week of May through the last week of October at the end of the sampling period. Highest densities for the year occurred during the first week of June.

Geometric mean density of softshell clam larvae in 2007 was similar to the preoperational and operational means at the nearfield station (P2) and below the operational and preoperational period means at the farfield station (P7; Table 7-1). Mean density of softshell clam larvae began to increase at both stations 1996 and reached record levels at Station P2 in 1997 and at Station P7 in 2000 and 2002. Density in 2007 at Stations P2 and P7 was within the range of previous years (Figure 7-4).

Despite the high densities of softshell clam larvae in 1996 through 2002, there were no significant differences in mean larval density between periods or between stations (Table 7-2). Trends at each station were consistent between the preoperational and operational periods as indicated by the non-significant Preop-Op X Station interaction term.

7.3.2 Hampton Harbor Survey

Young-of-the-Year (1-25 mm)

This size class (1-25 mm) primarily contains clams that were spawned and recruited in 2007. Mean density of YOY

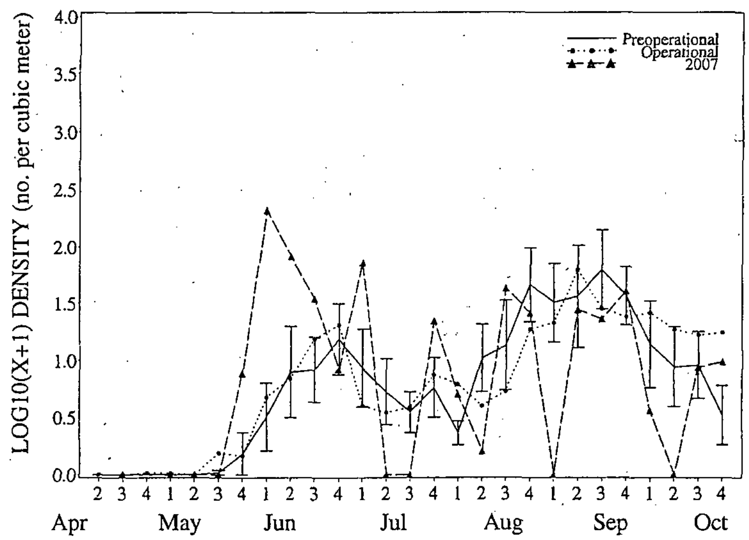

Figure 7-3. Weekly mean and 95% confidence interval of log10(x+1) density (number per cubic meter) of *Mya arenaria* larvae at Station P2 during preoperational (1977-84, 1986-89) and operational (1991-2007) periods and in 2007. Seabrook Operational Report, 2007.

Table 7-1. Geometric Mean Density and 95% Confidence Limits of *Mya arenaria* (number of larvae/m^3; number of juveniles or adults/m^2) collected during Preoperational and Operational Years and in 2007. Seabrook Operational Report, 2007.

		Preoperational[a]			2007	Operational[a]		
Lifestage	Station or Flat	LCL[b]	Mean[c]	UCL[d]	Mean[c]	LCL	Mean[c]	UCL[d]
Larvae	P2	4.1	5.2	6.6	5.8	4.2	5.8	7.7
	P7	4.0	5.5	7.5	3.4	4.4	6.4	9.0
1-25 mm	HH-1	10.6	24.1	53.2	13.8	17.9	30.9	52.8
(young-of-the-	HH-2	21.6	62.7	178.5	11.5	25.1	41.9	69.4
year)	HH-4	60.7	142.9	334.6	5.7	9.7	18.9	36.0
	All	22.1	52.8	124.3	9.7	17.0	27.8	45.2
26-50 mm	HH-1	1.6	5.1	13.3	0.5	0.6	1.3	2.3
(yearlings)	HH-2	0.4	1.2	2.4	0.1	0.1	0.5	1.1
	HH-4	2.4	7.0	17.7	0.7	1.0	2.1	3.7
	All	1.5	3.9	8.4	0.4	0.5	1.1	1.9
>50 mm	HH-1	1.3	2.6	4.4	4.0	2.2	3.5	5.3
(adults)	HH-2	0.8	1.6	2.9	1.3	1.4	2.3	3.6
	HH-4	1.3	2.5	4.4	5.6	4.4	6.8	10.4
	All	1.2	2.2	3.8	3.1	2.4	3.4	4.9
1-12 mm	Hampton Harbor	15.5	36.8	85.7	0.6	26.9	39.5	57.9
(seed clams)	Plum Island Sound	35.9	107.0	315.4	26.3	19.1	28.5	42.4

[a] Larvae PREOP = 1982-1984, 1986-1989. OP = 1991-2006. Hampton Harbor (HH) PREOP = 1974-1989; OP = 1990-2007 Hampton Harbor-Plum Is. PREOP = 1987-1989; OP = 1990-2007.
[b] LCL = Lower 95% confidence limit.
[c] PREOP and OP means = mean of annual means. 2007 mean = mean of the number of samples.
[d] UCL = Upper 95 % confidence limit.

Table 7-2. Results of Analysis of Variance Comparing *Mya arenaria* Larval, Young-of-the-Year, Juvenile and Adult Densities During Preoperational and Operational Periods. Seabrook Operational Report, 2007.

Mya arenaria Lifestage	Station/Flat	Source of Variation	Test Statistics			Multiple Comparisons[n]
Larvae[a]	Nearfield (P2) Farfield (P7)	**Fixed Effects**	**DF[j]**	**F[k]**	**p[l]**	
		Preop-Op[c,d]	1, 280	0.23	0.6353	
		Random Effects	**Estimate[m]**	**χ^2**	**P**	
		Year (Preop-Op)[e]	0	<0.001	0.4998	
		Week (Preop-Op X Year)[f]	0.48	356.31	<0.0001*	
		Station[g]	<0.01	0.07	0.3959	
		Preop-Op X Station[h]	0	<0.001	0.4999	
		Station X Year (Preop-Op)[i]	<0.01	0.292	0.2946	
		Error	0.10			
1-25mm[b] Young-of-the-Year	Hampton Harbor 1, 2, 4	**Fixed Effects**	**DF[j]**	**F[k]**	**p[l]**	
		Preop-Op	1, 31.5	2.80	0.1042	
		Random Effects	**Estimate[m]**	**χ^2**	**P**	
		Year (Preop-Op)	0.23	30.75	<0.0001*	
		Flat	0.02	3.73	0.0267*	2 4>1
		Flat X Year(Preop-Op)	0.13	130.27	<0.0001*	
		Error	1.11			
26-50 mm[b] Yearlings	1, 2, 4	**Fixed Effects**	**DF[j]**	**F[k]**	**p[l]**	
		Preop-Op	1, 31.9	5.04	0.0318*	Pre>Op
		Random Effects	**Estimate[m]**	**χ^2**	**P**	
		Year (Preop-Op)	0.17	57.38	<0.0001*	
		Flat	0.04	32.16	<0.0001*	4>1>2
		Flat X Year(Preop-Op)	0.05	130.27	<0.0001*	
		Error	0.35			
>50 mm[b] Adult	1, 2, 4	**Fixed Effects**	**DF[j]**	**F[k]**	**p[l]**	
		Preop-Op	1, 31.9	3.68	0.0641	
		Random Effects	**Estimate[m]**	**χ^2**	**P**	
		Year (Preop-Op)	0.06	33.09	<0.0001*	
		Flat	0.02	15.56	<0.0001*	4>1>2
		Flat X Year(Preop-Op)	0.03	172.97	<0.0001*	
		Error	0.33			
1-12 mm[b] Seed	Nearfield/ Farfield Hampton Harbor Plum Island Sound	**Fixed Effects**	**DF[j]**	**F[k]**	**p[l]**	
		Preop-Op	1, 40	1.21	0.2777	
		Random Effects	**Estimate[m]**	**χ^2**	**P**	
		Year (Preop-Op)	0	0.00	0.4998	
		Area	0	0.00	0.4997	
		Preop-Op X Area	0	0.00	0.4998	
		Area X Year (Preop-Op)	0.19	15.78	<0.0001*	
		Error	1.01			

[a] Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1982-84, 1986-89 and op = 1991-2007.

[b] For Hampton Harbor Survey preop = 1974-89 and op = 1990-2007. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-2007.

[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] Numerator degrees of freedom , denominator degrees of freedom

[k] F-statistic

[l] Probability value

[m] Estimate of the variance component of random effect

[n] Underlined estimates were not significantly different based on multiple comparison tests of H_o: LSMEAN (i)= LSMEAN(j).

* = significant ($p \leq 0.05$)

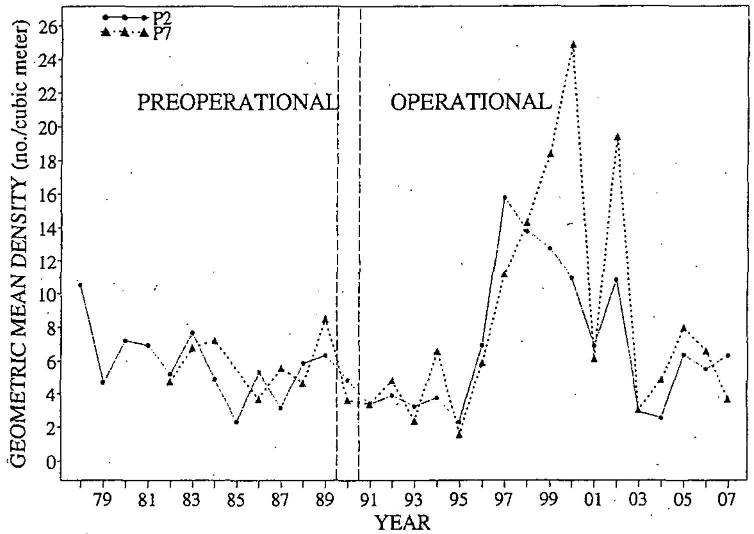

Figure 7-4. Annual geometric mean density (number per cubic meter) of larval *Mya arenaria*, 1978-2007. Seabrook Operational Report, 2007.

clams at each flat, and at all flats combined in 2007 was lower than the preoperational and operational means (Table 7-1). Annual mean density increased in 2007 compared to 2006 at Flats 1 and 4, and decreased at Flat 2 (Figure 7-5 and NAI 2007). Density was significantly higher at Flats 2 and 4 compared to Flat 1 (Table 7-2).

Yearling (26-50 mm)

This size class (26-50 mm) contains clams that are primarily yearlings. Geometric mean density of yearling clams in 2007 at Flats 1, 4, 2, and all flats combined decreased compared to 2006 (Figure 7-6 and NAI 2007). Density in 2007 was lower than the preoperational and operational means at each flat and for all flats combined (Table 7-1). The mean densities of yearlings observed in 2007 ended a generally increasing trend that started in 2002 (Figure 7-6). For the first time, density of yearlings in the operational period was significantly lower than the preoperational period (Table 7-2). Density of yearling clams has followed similar trends at all flats, with peaks occurring in 1980-81, 1990-91, and 1994-96 (Figure 7-6). Density differed significantly among flats, being highest at Flat 4, followed by Flat 1, then Flat 2 (Table 7-2).

Adults (>50 mm)

Clams measuring more than 50 mm are generally at least 2 years of age (Brousseau 1978). In 2007, geometric mean density of adult clams decreased at Flats 1, 2, and all flats combined, but increased at Flat 4 (Figure 7-7 and NAI 2007). Density in 2007 was higher than the preoperational and operational means at Flat 1, lower than the preoperational and operational means at Flat 2 and higher than the preoperational mean at Flat 4 and all flats combined (Table 7-1).

Density of adult clams has generally has increased since 2004 (Figure 7-7), but results from 2007 interrupted that trend at Flats 1 and 2. Trends in density of adult clams were generally similar among the three flats. Densities decreased from 1974 to a low in 1977 and then reached a broad peak at all flats from 1980 through 1985. Density decreased to a low in 1987, and then increased, especially

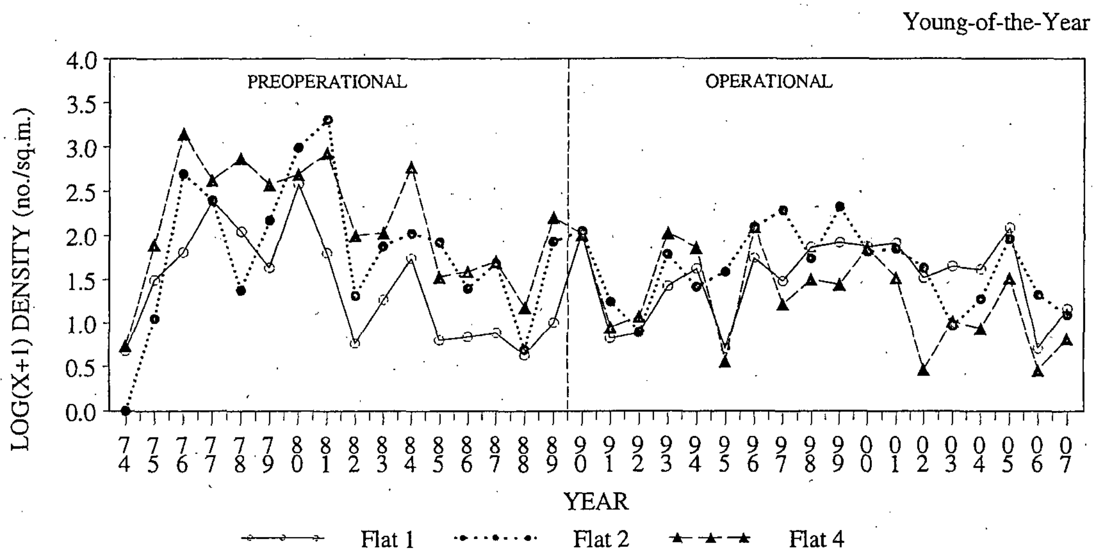

Figure 7-5. Annual mean log10(x+1) density (number per square meter) of young-of-the-year clams (1-25 mm), 1974-2007. Seabrook Operational Report, 2007.

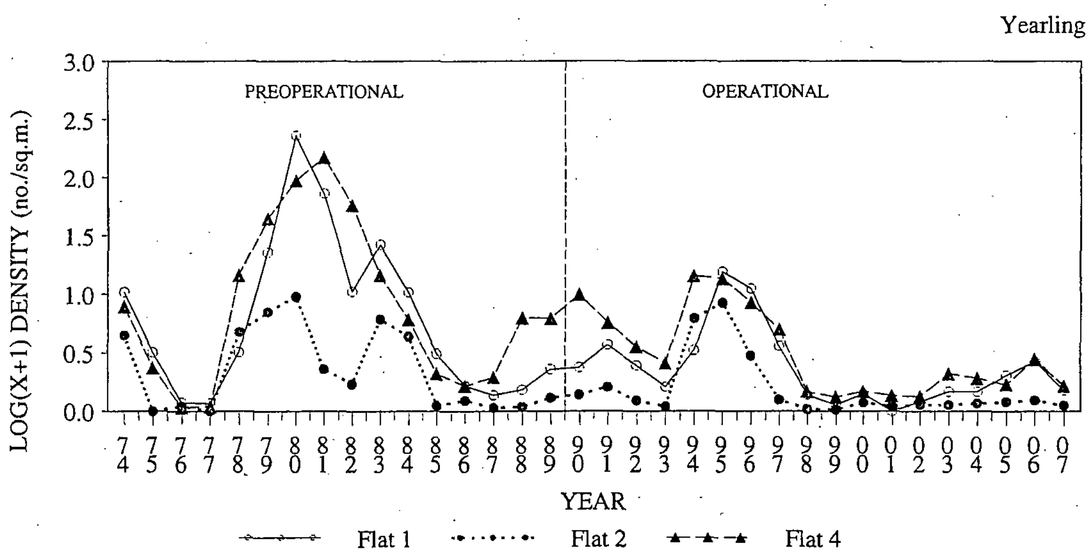

Figure 7-6. Annual mean log10(x+1) density (number per square meter) of yearling clams (26-50 mm), 1974-2007. Seabrook Operational Report, 2007.

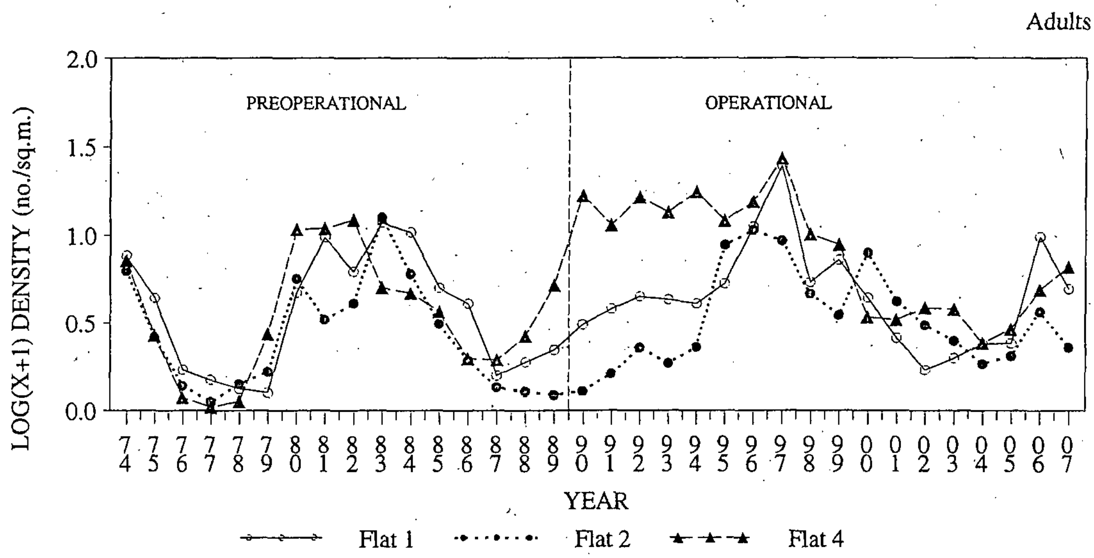

Figure 7-7. Annual mean log10(x+1) density (number per square meter) of adult clams (>50 mm), 1974-2007. Seabrook Operational Report, 2007.

at Flats 1 and 4, to record highs in 1997. Since 1997, density of adult clams generally decreased at all flats until about 2001 through 2004 and has increased since then.

There were no significant differences in density of adult clams between the preoperational and operational periods (Table 7-2). Density was significantly higher at Flat 4, followed by Flat 1, then Flat 2.

7.3.3 Nearfield/Farfield Study

In 2007, density of seed clams (1-12 mm) in Hampton Harbor and Plum Island Sounder was lower than both the preoperational and operational means (Table 7-1). Density of seed clams in 2007 in Hampton Harbor was the lowest observed in the time series (Figure 7-8). There were no significant differences in mean density between the preoperational and operational periods, and there were no differences between areas (Table 7-2). Trends between area and periods were similar as indicated by the non-significant Preop-Op X Area interaction term (Table 7-2).

7.3.4 Effects of Predation

Recreational clam digging and green crabs are two major sources of predation on clams in Hampton Harbor. Clam digging pressure, as estimated by licenses sold has varied considerably since 1980. From 1980 through April 1989, all flats (1 through 5) were open to digging. All flats were closed to digging in 1989 due to coliform pollution and remained closed until September 1994 when Flats 1 and 3 were reopened. In 1995, Flat 2 was reopened, and Flat 4 was reopened in 1998; Flat 5 remains closed (NAI 2003). Prior to 2003, the flats were potentially opened on Fridays and Saturdays from 1 January through 31 May, and then reopened again on Fridays and Saturdays the day after Labor Day. Starting in 2003, the flats were opened only on Saturdays. This general schedule can be modified by closures due to coliform pollution and paralytic shellfish poisoning. In recent years the flats have not reopened until 1 November.

Clam diggers reduce the population of clams by harvesting (direct mortality) and

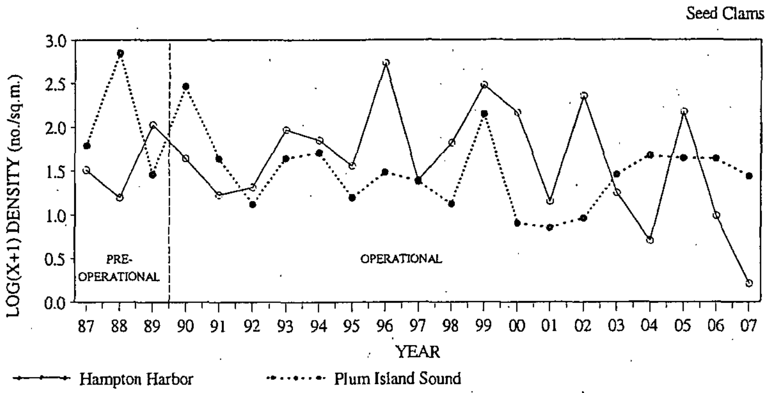

Figure 7-8. Annual mean log10(x+1) density (number per square meter) of seed clams (1-12 mm), in Hampton Harbor and Plum Island Sound 1974-2007. Seabrook Operational Report, 2007.

increased mortality of clams left behind (incidental mortality). Incidental mortality occurs through predation by gulls if the clams are at the surface, breakage if they come in contact with the clam forks, or desiccation or smothering if the clams are not able to rebury or right themselves. Estimates of incidental mortality due to harvesting ranged from 2% to 48% with a mean mortality of 17% (Robinson and Rowell 1990). The highest mortality occurred in muddy substrates where clams had difficulty reburying themselves. In a similar study Medcof and MacPhail (1964) estimated incidental mortality to be 50%. Mortality in Hampton Harbor could be at the high end of the published ranges due to high gull predation (B. Smith NHFG pers. comm.).

The number of licenses issued (digging effort) was relatively low from 1990 through 1993, and then increased in 1994 when Flat 1 reopened (Figure 7-9). The number of licenses sold declined through 1996 and then increased to the two highest numbers sold in 1999 and 2000. Since then the number of licenses has generally decreased through 2005 and increased slightly in 2006 and 2007.

It is difficult to determine the effect of digging effort on clam density because it is not clear if there is a cause and effect relationship especially for yearling and adult lifestages. Digging effort could cause a decrease in density of adult clams as diggers remove them from the flat. Alternatively, a decrease in density of adult clams due to increased natural mortality (or incidental mortality of younger clams) could cause a decrease in digging effort as unsuccessful clammers choose not to return to the flats.

In 1994 through 2002 there was no significant relationship between digger counts and density of YOY clams (NAI 2003). The number of licenses issued and the density of YOY clams generally appeared to follow parallel trends between 1990 and 2004; however, in 2005 there was a large set of YOY clams following a decreasing trend of license sales (Figure 7-9). In 2006, density of YOY clams decreased sharply while the number of licenses sold increased slightly. In 2007 density of YOY clams and number of licenses sold both increased slightly. There does not appear to be a strong relationship between number of license sold and density of YOY clams.

There was no strong evidence of a consistent relationship between licenses issued

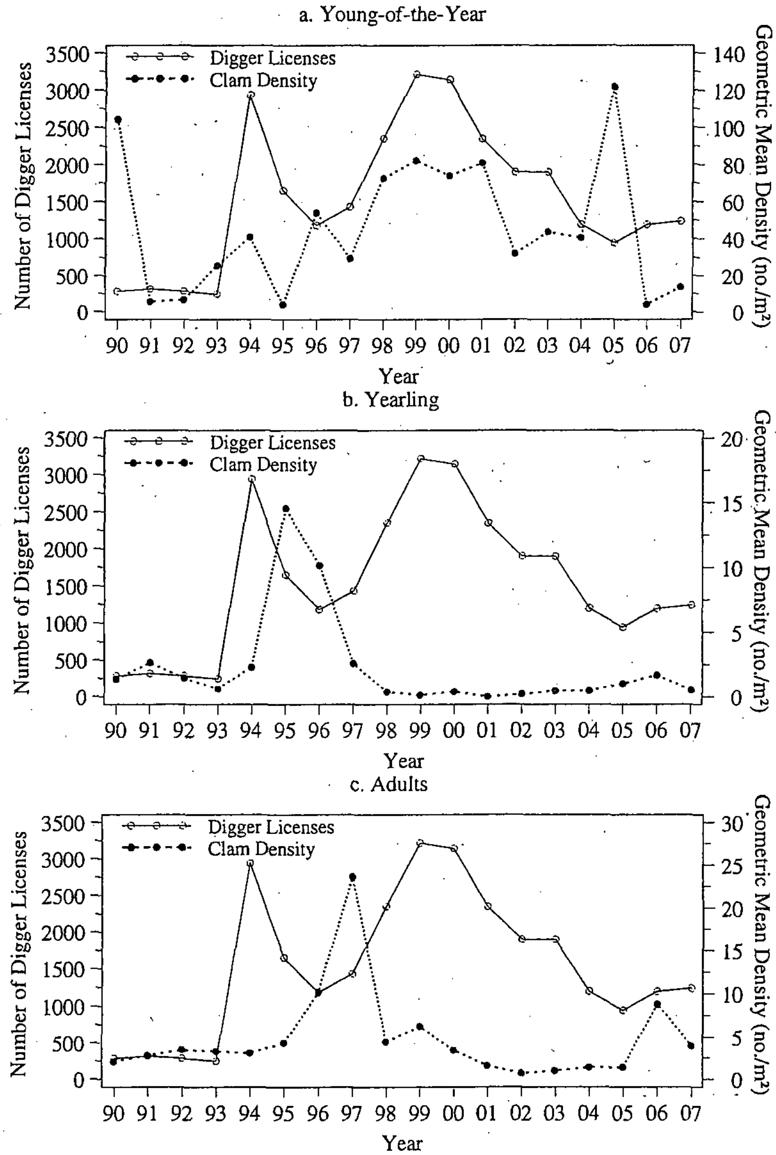

Figure 7-9. The relationship between digging effort (number of licenses) and density of (a) young-of-the-year (1-25 mm), (b) yearling (26-50 mm), and (c) adult (>50 mm) clams on Flat 1 in Hampton Harbor from 1990 through 2007. Seabrook Operational Report, 2007.

yearling clam density on Flat 1 (Figure 7-9). It would be expected that density of yearling clams would increase when the flats are not heavily fished, and decrease in the face of high digging pressure. However, density of yearlings on Flat 1 was relatively low from 1990 through 1993 when the flats were closed, and increased in 1995 one year after the flats reopened. From 1999 through 2004, density of yearling clams was very low and stable while the number of licenses issued was high but decreasing. However, starting in 2004, coincident with a shift in clamming effort away from Flat 1 to Flat 4, there has been a slight increase in density of yearling clams, although this trend did not continue in 2007. The occurrence of both high density of yearling clams (1995) and low density of yearling clams (1998-2001) during periods of relatively high number of licenses issued indicates that there is not a clear relationship between digging pressure and density of yearling clams.

There is more compelling evidence for a negative relationship between digging effort and density of adult clams. The highest density of adult clams occurred in 1997 during a period of relatively low license sales. License sales were high but decreasing in 1999 through 2004 and density of adult clams was low. After 2004, clamming effort began to shift away from Flat 1 and the density of adult clams increased sharply in 2006, but decreased in 2007.

Green crabs are also a major source of softshell clam predation (Glude 1955; Ropes 1969). This introduced species first appeared in the western North Atlantic in New York and New Jersey in the 19th century and has extended its range as far north as the Gulf of St. Lawrence (Audet et al. 2003). Abundance of clams appeared to decrease in New England in 1949 through 1954 as green crabs became more abundant (Glude 1955). Green crabs usually reach their maximum abundance in the late fall (Figure 7-10). Monthly mean abundance of green crabs in 2007 was below the preoperational period 95% confidence limits, and below the operational period monthly means for July and September through December.

Low winter water temperature limits green crab abundance the following spring and summer as the crabs are apparently killed by the cold temperatures. Welch (1969) and Dow (1972) found that green crab abundance increased following relatively warm winters. Flach (2003) found that juvenile green crabs appeared later in the season and were less abundant following cold winters. Our data generally support these findings, as green crab abundance often increased following relatively warm winters. From 1978 through 1996 green crab abundance and minimum water temperature followed similar trends (Figure 7-11). Starting in 1997 the relationship was less clear. During the years 1997, 2000, 2002, and 2005 green crab abundance and minimum water temperature followed opposite trends. However, in 2003 and 2006-2007 minimum water temperature and green crab abundance followed similar trends. Despite the apparent correspondence between minimum water temperature and green crab CPUE during some years, the Kendall tau association between these two variables (0.17) was not significant (p=0.20). Minimum water temperature is probably one of the many factors controlling the abundance of green crabs. Green crabs are voracious predators of young clams, and their abundance is probably an important factor affecting density of YOY and yearling clams.

7.3.5 Relationship between Larval Densities and Older Lifestages

Regressions of annual geometric mean density of YOY clams on annual geometric mean density of larval clams in Hampton Harbor were significant at Flats 1, 2, and 4,

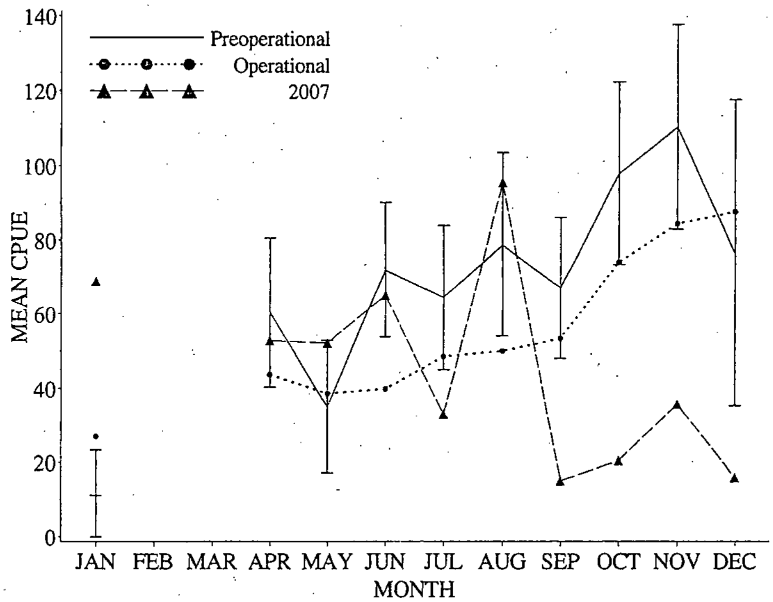

Figure 7-10. Mean monthly catch per unit effort and 95% confidence intervals of green crabs (*Carcinus maenas*) collected during preoperational years (1983-1989), operational years (1991-2007), and 2007. Seabrook Operational Report, 2007.

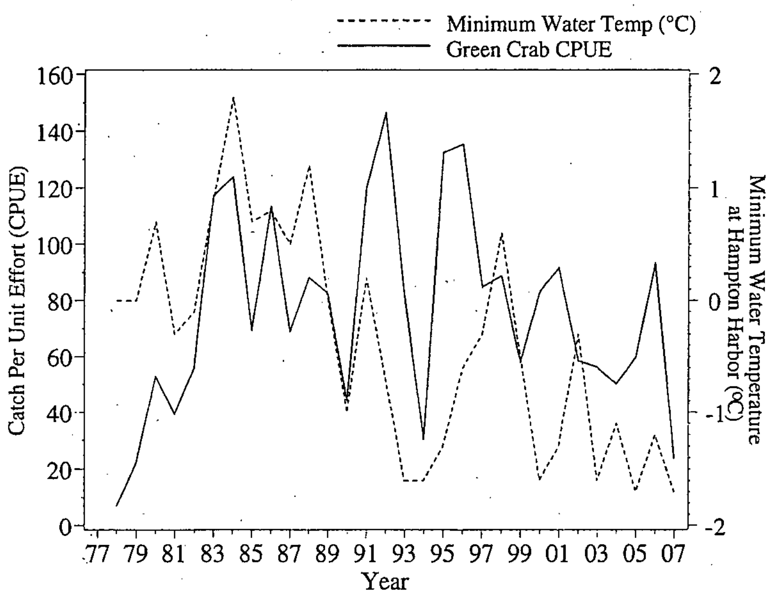

Figure 7-11. Mean fall (October-December) catch per unit effort of green crabs in Hampton-Seabrook Harbor and its relationship to minimum winter water temperature, 1977-2007. Seabrook Operational Report, 2007.

and all flats combined (Table 7-3). Although all regressions were significant, at most half the variation in YOY density was explained by variation in larval density as measured by the coefficient of determination (r^2). The r^2 was highest at Flat 2 where 50% of the variation in YOY density was explained by larval density (Table 7-3). The strengths of the relationships were weaker at Flats 1 and 4 where 13% and 6% of the variation in YOY density was explained by larval density. At Flats 1, 2, and 4 combined, 22% of the variation in YOY density was explained by larval density.

The relationship between larval density and YOY density was not consistent among flats. Since the larval data set comes from one station in Hampton Harbor (P1), the inconsistency in the relationship is due to variable recruitment on the different flats. At Flat 1, the highest YOY density occurred in 1990 and 2005 (Figure 7-12). However, larval densities for these years (1990: 7.1/m^3; 2005: 8.9/m^3) ranked ninth and eleventh out of the 19 year time series.

The relationship between larval density and YOY was strongest at Flat 2. Years of high recruitment (1999 and 1997) occurred during years of high larval density (1999: 18.0/m^3; 1997: 15.4/m^3). Flat 2 also tended to have the highest recruitment of YOY and may be better habitat for YOY clams. Both larval density (3.8/m^3) and YOY recruitment (11.5/m^2) in 2007 were low and the year was below the regression line.

The pattern at Flat 4 was similar to Flat 1 as the relationship between larval density and YOY recruitment was not strong. The two years with the highest larval density (1999; 18.0/m^3: 1997: 15.4/m^3) were among the lowest in YOY recruitment. The year 2007 was low in larval density (3.8/m^3) and YOY recruitment (5.7/m^2; Figure 7-12).

When data from all flats were combined, only 22% of the variation in YOY recruitment was explained by variation in larval density (Table 7-3). Variability in recruitment of YOY clams among flats, coupled with the relatively low coefficients of determination is an indication that larval density is not the only factor controlling recruitment.

A similar analysis was conducted to determine the relationship between larval abundance and adult clams (>50 mm). Clams greater than 50 mm are assumed to be at least two years old and the regression was performed on density of adult clams (y axis) on density of clam larvae lagged by two years (x axis). This is important to determine if the conservation of larval clam resources has an effect on the density of adults, presumably the preferred size for harvesting, two years later. The regressions were not significant at Flats 1, 2, and at all flats combined, and larval density explained between 5% (Flat 2) and 18% (all flats) of the variation in adult density (Table 7-4; Figure 7-13). At Flat 4 the regression was significant with a negative slope, implying that high densities of larval clams result in lower densities of adult clams two years later. As this does not make biological sense, it is assumed that there is no apparent relationship between density of clam larvae and adult clams.

To further explore the relationship between early and later lifestages of clams, density of adult clams (> 50 mm) was regressed on YOY clams (x axis) lagged by two years. A significant positive relationship would indicate that year class strength was set once YOY settled to the bottom. A significant negative relationship might indicate that intraspecific competition among YOY clams results in increased mortality of YOY and decreased abundance of adults. However, there were no significant relationships between density of YOY clams and density of adults two year later (Table 7-5; Figure 7-14). This lack of a significant relationship indicates

Table 7-3. Regression Statistics for the Regression of Annual Geometric Mean Young-of-the-Year *Mya arenaria* Density (No./m^2) on Annual Geometric Mean Larval *Mya arenaria* Density (No./m^3) during the Years 1987 through 2007. Seabrook Operational Report, 2007.

Flat	Regression Equation	Pr > F[a]	r^2
1	y=4.22 x	<0.0001 *	0.13
2	y=7.29 x	<0.0001 *	0.50
4	y=4.26 x	0.0004 *	0.06
Flats 1, 2, 4 Combined	y=3.97 x	<0.0001 *	0.22

[a] probability of achieving a higher F value; * = significant.

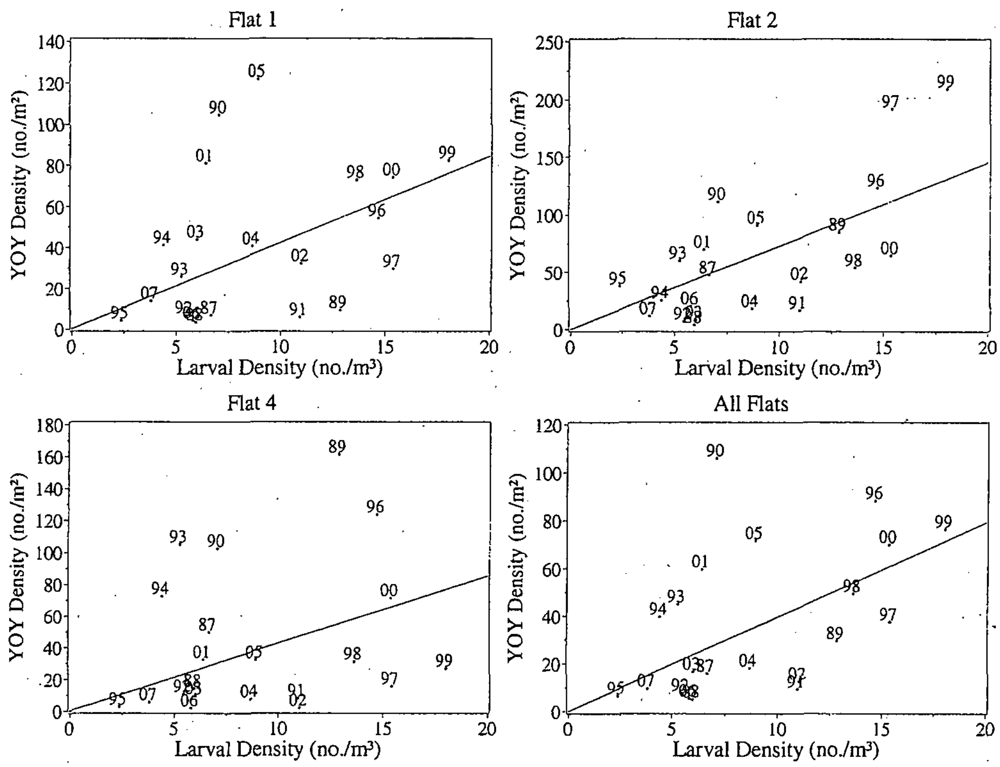

Figure 7-12. Relationship between larval density (no./cubic meter) and recruitment of young-of-the-year (YOY) softshell clam (no./square meter) in Hampton Harbor. Seabrook Operational Report, 2007.

Table 7-4. Regression Statistics for the Regression of Annual (1989-2007) Geometric Mean Adult (>50 mm) *Mya arenaria* Density (No./m^2) on Annual (1987-2005) Geometric Mean Larval *Mya arenaria* Density (No./m^3) Lagged by Two Years. Seabrook Operational Report, 2007.

Flat	Regression Equation	Pr > F[a]	r^2
1	y= 9.11-0.48 x	0.0821 NS	0.17
2	y= 4.32-0.15 x	0.3674 NS	0.05
4	y= 16.42-0.81 x	0.0169 *	0.29
Flats 1, 2, 4 Combined	y= 7.40-0.35 x	0.0733 NS	0.18

[a] probability of achieving a higher F value; * = significant.

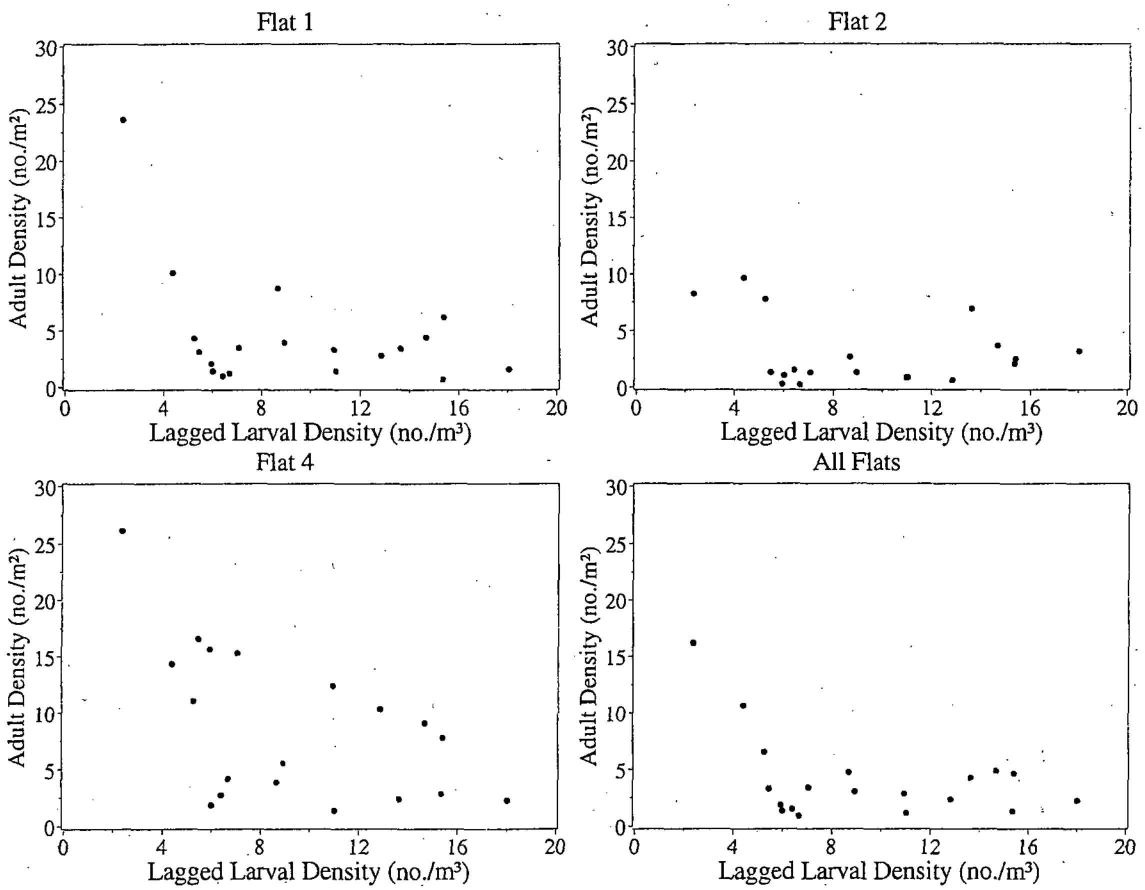

Figure 7-13. Relationship between larval density (no./cubic meter) and density of adult (>50 mm) softshell clam (no./square meter) two years later in Hampton Harbor. Seabrook Operational Report, 2007.

Table 7-5. Regression Statistics for the Regression of Annual (1989-2007) Geometric Mean Adult (>50 mm) Mya arenaria Density (No./m2) on Annual (1987-2005) Geometric Mean Young-of-the-Year Mya arenaria Density (No./m2) Lagged by Two Years. Seabrook Operational Report, 2007.

Flat	Regression Equation	Pr > F[a]	r^2
1	y= 6.23-0.04 x	0.2853 NS	0.07
2	y= 3.01-0.0009 x	0.9385 NS	<0.01
4	y= 8.23-0.01 x	0.7471 NS	0.01
Flats 1, 2, 4 Combined	y= 4.72-0.02 x	0.5963 NS	0.02

[a] probability of achieving a higher F value; * = significant.

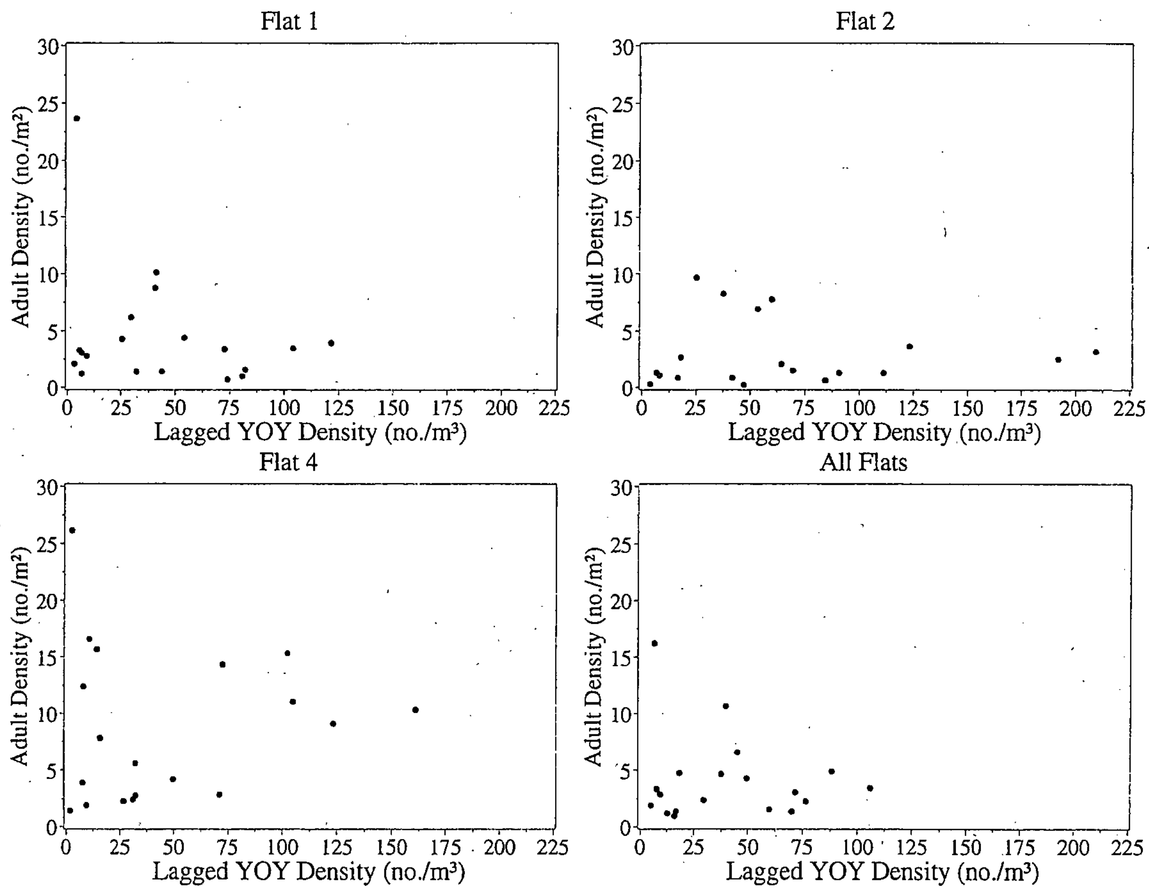

Figure 7-14. Relationship between density of young-of-the-year (no./square meter) and density of adult (>50 mm) softshell clam (no./square meter) two years later in Hampton Harbor. Seabrook Operational Report, 2007.

that year class strength is set some time after YOY clams settle to the bottom.

7.3.6 Effects of Disease

Neoplasia is a generally lethal form of leukemia in softshell clams. Neoplasia was first identified in clams at Flats 1 and 3 in 1986 (NAI 1999). By 1989, 80% of the clams examined from Flat 2 were infected to some degree. Additional testing in 1996 and 1997 indicated that the disease was present in clams from Flats 1, 2, and 4 (NAI 1998). In 1999, softshell clams with 100% neoplastic cells occurred at all flats with the highest percentages (7%) found in Flat 1 (NAI 2000). A. Boettger of the University of New Hampshire repeated a study of the prevalence of neoplasia in the softshell clams of Hampton Harbor in 2002 through 2007. In 2007, the incidence of neoplasia in clams ranged from 29% (Flat 1) to 67% (Flat 4; Table 7-6). At each flat incidence of neoplasia was highest in 2002 and has been lower and variable since then (Figure 7-15). There was a substantial decrease in incidence of neoplasia at Flat 1 in 2007. There was no clear pattern among years as to which flat had the highest incidence of neoplasia. In 2002 and 2005 incidence of neoplasia was highest at Flat 5. In 2003 and 2007 it was highest at Flat 4. In 2004 and 2006 it was highest at Flat 2.

7.4 DISCUSSION

The original concerns regarding the impacts of the operation of Seabrook Station on the softshell clam resource of Hampton Harbor were that entrainment of pelagic larvae would result in a decrease in settlement of benthic stages (EPA 1978). After 18 years of monitoring for the potential impacts of the plant, there is no evidence that the operation of Seabrook Station has affected either the larval or benthic stages of the softshell clam resources of Hampton Harbor (Table 7-7). Larval densities during part of the operational period (1996-2002) were the highest in the time series at both stations. The high larval density in the operational period indicates that entrainment has not affected larval densities. The density of YOY clams has varied over the years, but there were no significant differences between the preoperational and operational periods. There were also no significant differences in density of adult clams, although yearling clams were significantly more abundant in the preoperational period. Density of yearling clams generally decreased from 1996 through 2003, increased slightly in through 2006, but decreased at all flats in 2007. The current low levels of yearling clams indicate a lack of recruitment from the YOY to yearling stages, and a potential demographic bottleneck in the growth of softshell clam populations.

Despite the historically high densities of adult clams in Hampton Harbor from 1990 through 1997, there were no significant differences in density between the preoperational and operational periods. This period of high density has been countered by a recent decline in density from 1997 through 2004, possibly related to the cumulative impacts of up to nine years of digging effort and reduced recruitment from yearlings. In 2005 and 2006, density of adult clams generally increased at all flats, and in 2007 increased at Flat 4, possibly a result of recent closing of the flats to digging on Fridays.

Larval stages of softshell clam are potentially affected by entrainment into the cooling water system of the plant. Testimony during the licensing of the plant focused on estimating the number of softshell clam larvae that might be entrained into the plant. Implicit in the conclusions of Clark (1973) were the assumptions that a reduction in clam larvae would result in a reduction in recruitment, and the number of adult clams was dependent on the number of YOY. More recent studies indicate that recruitment can fluctuate greatly

Table 7-6. Percentage (number collected) of clams with neoplastic cells in Hampton Harbor during 2007. Seabrook Operational Report 2007.

Flat	Clams with Percent Occurrence of Neoplastic Cells						
	0%	1-25%	26-50%	51-75%	76-100%	Neoplastic (1-100%)	Total Collected
1	71 (42)	19 (11)	3 (2)	2 (1)	5 (3)	29 (17)	(59)
2	48 (13)	19 (5)	15 (4)	4 (1)	19 (5)	56 (15)	(27)
3	48 (27)	43 (24)	5 (3)	2 (1)	2 (1)	52 (29)	(56)
4	41 (24)	52 (30)	12 (7)	2 (1)	2 (1)	67 (39)	(58)
5	38 (20)	40 (21)	10 (5)	8 (4)	4 (2)	62 (32)	(52)

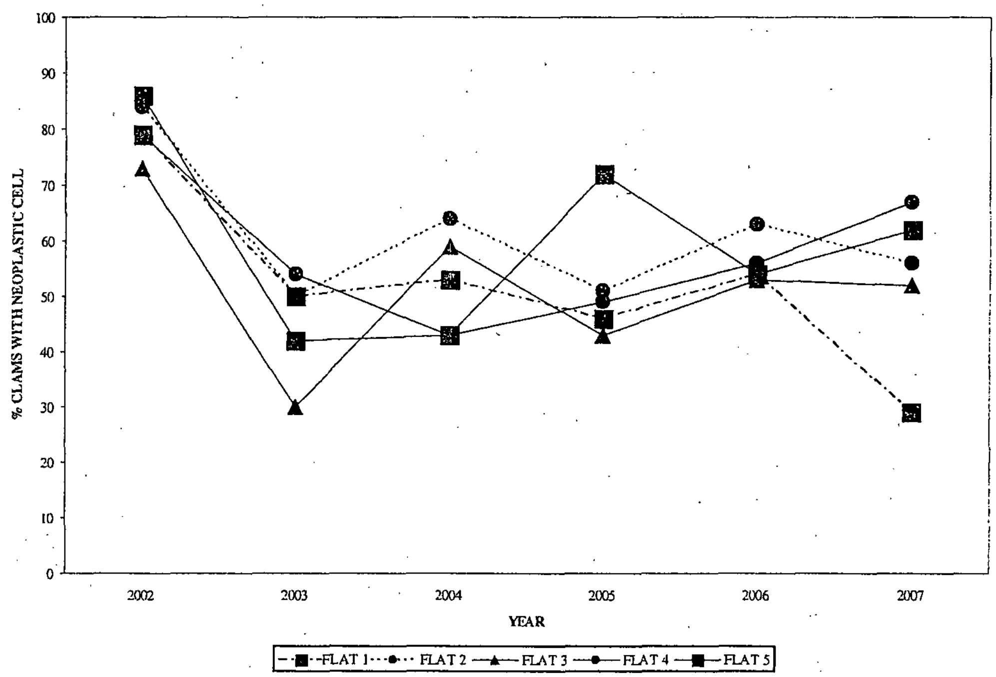

Figure 7-15. Percentage of softshell clams with neoplastic cells in Hampton Harbor, 2002 through 2007. Seabrook Operational Report, 2007.

Table 7-7. Summary of Evaluation of Effects of Operation of Seabrook Station on *Mya arenaria*. Seabrook Operational Report, 2007.

Location	Lifestage	Operational Period Similar to Preoperational Period[a]	Spatial Differences Consistent Between Operational and Preoperational Periods[b]
Nearfield (p2)/ Farfield (p7)	Larvae	Yes	Yes
Hampton Harbor	Young-of-year (1-25 mm)	Yes	N/A[c]
	Yearling (26-50 mm)	Op>Preop	N/A[c]
	Adult (>50 mm)	Yes	N/A[c]
Hampton Harbor/ Plum Island Sound	Young-of-year (1-12 mm)	Yes	Yes

[a] Operational period for larvae = 1991-2007; 1->50 mm size classes = 1990-2007; preoperational period for larvae = 1982-84, 1986-89;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.

from year to year as a result of differential mortality during three critical phases: (1) fertilization, (2) the free swimming planktonic phase, and (3) the early post-settlement larval attachment phase (Brousseau 2005). Regression analysis was used to evaluate the second of these factors. A functional regression between the annual entrainment estimate of softshell clam larvae and recruitment of YOY in Hampton Harbor was not significant (NAI 2002). Recruitment of larvae to YOY is not well understood, but apparently is related to more than just larval abundance. Larval density in Hampton Harbor (Station P1) explained 22% or less of the variability in YOY density at Flats 1, 4, and Flats 1, 2, and 4 combined. However, at Flat 2, 50% of the variability in YOY density was explained by larval density. Recruitment of YOY clams has historically been highest at Flat 2. The increased strength of the relationship between larval density and recruitment may be a reflection of the better habitat for YOY clams at Flat 2.

A weaker relationship was present for larval clams, YOY clams, and adults two years later. There was no significant relationship between larvae and adults, and YOY clams and adults. These findings are similar to those of LeBlanc and Miron (2006) who found no significant relationships between the number of planktonic larvae and newly settled clams, between newly settled and juveniles clams, or between juvenile and adult clams.

Density of adult clams does not appear to be strongly related to recruitment of YOY. It appears that the 1997 through 2002 year classes underwent significant mortality between the YOY and yearling stages. Beal et al. (2001) determined that predation rather than density dependent competition was the most important factor controlling the survival and growth of juvenile (YOY) softshell clam in Maine, consistent with his findings from Hampton Harbor (Beal 2002, 2006).

As there does not appear to be a direct relationship between density of settled softshell clams and larval density, Clark's (1973) projections most likely overestimated the effects of larval entrainment on densities of adult clams. Furthermore, peaks in the annual density of each lifestage during the operational period are further evidence of a lack of plant impact. Density of each lifestage of softshell clam (larvae, YOY, yearling, and adult) exhibited a major peak in density after the plant began operation. Nearfield larval densities were highest in 1997 through 2000, and 2002 (Figure 7-4). Peaks in the density of YOY occurred in 1993 and 1996-1999 (Figure 7-5). Densities of both yearling and adult clams are presently low or decreasing, but peaks occurred in 1995 for yearlings, and 1997 for adults (Figures 7-6 and 7-7).

The lack of consistency in the relationship between larval density and recruitment of YOY among flats is an indication that many factors may combine to control recruitment. Some minimum supply of larvae is obviously necessary to ensure recruitment of YOY, but catastrophic post-settlement mortalities of newly settled YOY clams are not unusual (Brousseau 2005). It appears that post-settlement processes such as predation, competition, biological or physical disturbance (Hunt 2004a, Hunt and Scheibling 1997; Strasser et al. 1999, Flach 2003), sediment dynamics and hydrodynamics (Emerson 1990; Emerson and Grant 1991; Young et al. 1998), affect recruitment of marine benthic invertebrates (Hunt 2004b, Hunt and Scheibling 1997; Hunt et al. 2008). Norkko et al. (2001) found that juvenile bivalves can disperse over a scale of meters during a tidal cycle (tidal range=2.0-3.4 m). The approximate 3-m tides of Hampton Harbor could cause significant bedload transport on the tidal flats, potentially transporting newly settled clams to unfavorable environments, or importing young clams from other flats. It is apparent that larval supply is only one of many physical and biological factors that interact to control recruitment of softshell clams in Hampton Harbor.

Hunt et al. (2003) studied the post-settlement patterns of newly recruited softshell clams in Barnstable Harbor, Massachusetts. They found that during the early post-settlement period there were large losses of newly settled softshell clams, and the spatial patterns in abundance of softshell clams changed substantially. High mortality rates of newly settled softshell clams resulted in some cohorts contributing little to the total population. Hunt (2004a) found that when clams reached 4.9 mm they may have achieved an apparent size refuge from erosion by "high-flow" shear velocities <1.6 cm per second. Hunt and Mullineaux (2002) found that changes in the distribution of softshell clams <2 mm were influenced by predation and postlarval transport due to currents. Once clams reached 2 mm, their distribution was more strongly influenced by predation.

Flach (2003) investigated the combined effects of predation and the presence of macro-infauna on the recruitment success of softshell clams and other bivalves on the Swedish coast. He found that the presence of macro-infauna (*Arenicola marina* and *Cerastoderma edule*) and predators (*Crangon crangon* and green crab) reduced recruitment success for softshell clams by about 80%. Macro-infauna may have reduced recruitment success by the biological reworking of large amounts of sediment and the resultant bioturbidity. Exclusion of predators from cages resulted in higher levels of recruitment success. Hunt (2004b) found that in addition to direct mortality, the predatory sand shrimp (*Crangon septemspinosa*) and juvenile green crab affected clams by causing transport of sediment and associated small invertebrates including recently settled clams when in the presence of a current. Shrimp actively changed the bottom topography and erosion threshold of the sediment, while juvenile green crabs caused fewer disturbances. Gut content analysis indicated that both juvenile green crab and sand shrimp fed on recently settled clams, although sand shrimp only ingested clams less than 3 mm in length.

Beal (2002) investigated the factors contributing to the apparent decrease in abundance of juvenile softshell clams at Flats 1, 2, and 4. Through a series of manipulative field experiments he found that clam losses due to physical scouring of the sediments and predation were important factors affecting survival. Scouring of the sediments resulted in the transport of softshell clams out of experimental units. However, the ultimate fate of juveniles transported by strong currents could not be determined. They may have been transported to other locations on the flat, or preyed upon before they had a chance to rebury (Hunt and Mullineaux 2002). It was determined that density of juveniles, winter kill, and neoplasia were not important factors in mortality of juveniles.

In a follow-up to these earlier studies, Beal (2006) investigated the role of predator exclusion on survival of juvenile softshell clams in the Hampton-Seabrook estuary. Clam survival was nearly 90% in plots protected with 6.4 mm mesh netting and there was almost complete mortality of clams in unprotected plots. Beal (2006) concluded that clam populations in the Hampton-Seabrook estuary were exposed to intense predation primarily due to green crabs and bottom feeding fish such as winter flounder and mummichogs. The results of this study indicated that predation accounts for most of the losses of small clams in the estuary.

Predation by green crabs, fish, clam diggers and other predators such as *Limulus polyphemus*, *Nereis virens*, and nemerteans (*Cerebratulus lacteus*) may be controlling factors in the abundance of YOY, yearling and adult clams. Bourque et al. (2001) found that mortality of softshell clams reached 100% in the presence of the *Cerebratulus lacteus* and there was no preference for softshell clam size. The predator-prey relationship between green crabs and clams is more complex than was previously realized. However, yearling clams (26-50 mm) may be a preferred size range for predation. Only yearling clams had the expected negative relationship between green crab CPUE and clam density (NAI 1998). Glude (1955) attributed the extensive reduction in population size of clams between 26 and 50 mm in Maine to green crab predation. Green crabs of all sizes preferred blue mussels with lengths between 10 and 20 mm (Elner 1980), and there may be a preferred size range for clams. Flach (2003) suggested that there was a size-related predator-prey relationship between green crabs and softshell clams. When the fall clam flat survey takes place in Hampton Harbor, most YOY clams are less than 6 mm (NAI 1996) and while these clams may be too small to be preferred by green crabs, there is evidence that green crabs will prey heavily on YOY clams (Jensen and Jensen 1985), potentially as small as 2 mm (Hunt and Mullineaux 2002). Cohen et al. (1995) found that green crabs select clams less than 20 mm and Floyd and Williams (2004) found negligible predation on large clams (mean length = 54.7 mm). Therefore, it is likely that green crabs can be significant predators on softshell clams from 2 to about 20 mm, which would include YOY and smaller yearling clams. Adult clams (>50 mm) may be in both a size and habitat refuge from predation. Zaklan and Ydenberg (1997) found that larger softshell clams were buried deeper into the substrate than smaller clams, and this provided a refuge from their major predator, the red crab *Cancer productus*. Seitz et al. (2001) concluded that thin-shelled clams such as the adult softshell clams respond to heavy predation by burrowing deep into the substrate to inhabit "noncoexistance refugia."

Low winter water temperatures have been proposed as a controlling factor for softshell clam predators, especially green crabs (Strasser 2002). Our data (Figure 7-11) imply a possible relationship between green crab CPUE and minimum winter water temperatures; however the relationship was not statistically significant. Despite the lack of statistical significance, Figure 7-11 indicates that green crab CPUE was often higher following relatively mild winters. Green crab abundance is also affected by density dependent intra-specific mechanisms. Both cannibalism on smaller individuals (Moksnes 2004a) and competition for habitat by newly settled juveniles (Moksnes 2004b) were important factors controlling population size. It is likely that factors in addition to minimum water temperature affects green crab population size and subsequent predation on softshell clams.

Digging effort did not appear to affect the density of YOY or yearling clams, but may have affected adult clams. Digging effort is represented by the number of licenses sold, and this may not be a precise measure of digging effort as not every license holder expends the same amount of time on the flats or removes the same number of clams. Furthermore, digging effort is affected by closures due to coliform pollution and paralytic shellfish poisoning (PSP) outbreaks. Trowbridge (2005; Figure 20) compared standing stock and number of licenses sold in Hampton Harbor for the period 1976 through 2004. There appeared to be a reasonable correlation for the period 1976 through 1989 prior to the closure of the flats due to coliform pollution. After some of the flats were intermittently reopened starting in 1994, the relationship did not appear to be as clear, although both standing crop and license sales have dropped steadily since 2000. In 2005, an extensive bloom of *Alexandrium fundyense* caused the flats to be closed to digging during the last two weeks of May due to PSP. Publicity about this bloom may have caused diggers to curtail their fishing effort, even though the flats were reopened for digging in November. Therefore, licenses sold probably represent only a crude measure of digging effort.

The resumption of digging in 1994 through 1998 did not result in a major change in YOY density (Figure 7-9). However, the Hampton Harbor clam flats may not provide the best data necessary to assess the relationship between digging effort and recruitment of YOY. The Hampton Harbor flats are closed to digging (usually 1 June through 1 November) during part of the peak season for softshell clam settlement.

Resumption of digging in 1994 through 1998 may have resulted in the present decrease in adult clams at all flats that began in 1998 (Figure 7-9). Diminished numbers may be related to both removal of adult clams and mortality to non-harvested clams. Ambrose et al. (1998) found that digging for baitworms negatively affected the survival of softshell clams by directly damaging the shells, or exposing the clams to increased risk of predation (incidental mortality). Beal and Vencile (2001) found that commercial harvesting of softshell clams and bait worms both reduced the density of softshell clams, but the decreases were greater due to commercial clamming because of the larger volume of substrate excavated. Robinson and Rowell (1990) estimated that incidental fishing mortality for clams ranged from 2-48% with an average mortality of 17%. They did not find a clear relationship between clam size and incidental mortality. An earlier study by Medcof and MacPhail (1964) estimated that incidental fishing mortality was as high as 50%. It is reasonable to expect that the total mortality for adult clams is higher than other size classes because they are subject to both fishing mortality (removal by diggers) and incidental mortality. The reductions in the density of adult clams in Hampton Harbor may be due to exploitation by diggers. However, the recent conservation measures instituted by New Hampshire Fish and Game may be resulting in an increase in density of adult clams. Starting in 2003, the flats were only open to digging on Saturdays. Density of adult clams increased at all flats in 2005 and 2006, and at Flat 4 in 2007, possibly as a result of reduced fishing pressure.

Disease is an additional factor that may contribute to a decrease in the current levels of yearling and adult softshell clams found in Hampton Harbor. The percentage of clams with 100% neoplastic cells in July 1999 ranged from 2.4% to 7.0% at Flats 1, 2, 3, and 5 (NAI 2000). This range of percent infection is narrower than that observed in 2002 through 2007 when between 0% and 19% of the clams collected on Flats 1 through 5 had between 76% and 100% neoplastic cells. However, the disease is usually fatal to clams (Farley et al. 1986) with only 16% of lightly infected clams achieving complete remission (Brousseau and Baglivo 1991). Therefore any evidence of neoplastic cells is an indicator that the clam will likely die. The percentage of clams with neoplastic cells has generally decreased in 2003 through 2007 compared to 2002 with the possible exception of Flat 5 in 2005 where 72% of clams had neoplastic cells (Figure 7-15). In contrast to our findings, Beal (2002), sampling clams less than 20 mm, found no evidence of neoplasia in Hampton Harbor. Our sampling did not include any clams less than 25 mm so it is possible that the discrepancy is due to the differing size classes. It is reasonable that smaller clams would have a lower incidence of neoplasia because they have not had time to develop the disease. It is likely that neoplasia will be a significant source of mortality to softshell clams in Hampton Harbor because in 2007 between 29% and 67% of the clams exhibited some degree of this usually fatal disease.

Decreased recruitment of adult clams from the yearling age class coupled with natural mortality and harvesting may cause a reduction in adult clams. In 1996 through 2007, density of yearling clams was less than adults, indicating that there are fewer yearling clams available for recruitment into the adult age class than in previous years (Figures 7-6, 7-7). The adult size class comprises more than one age class so densities are buffered from reduced recruitment of a single year class (yearlings). In previous years, periods of low yearling densities were usually followed by periods of low adult densities. In 1975 through 1977, density of yearling clams was low at all flats (Figure 7-6), followed in 1976 through 1979 by a period of reduced density of adult clams (Figure 7-7). Again in 1985 through 1987, density of yearlings was low, followed in 1987 and 1988 by a period of low adult density. Continued decreases in the density of adult clams may be expected if recreational digging continues and there is limited recruitment of yearlings.

The recent work by Flach (2003), Hunt (2004a and b), Hunt et al. (2003; 2008), Hunt and Mullineaux (2002), Beal (2002, 2006), and Beal et al. (2001) provide a strong indication that post-settlement processes such as transport by currents and predation are the major factors affecting the survival of newly settled softshell clams. Since neither of these factors can be affected by plant operation, there is no reasonable mechanism by which plant operation can affect the density of settled softshell clams in Hampton Harbor. The lack of a significant relationship between softshell clam larval entrainment and recruitment of YOY clams is further evidence that plant operation does not affect the softshell clam resources of Hampton Harbor. Predation and transport of small clams by currents appeared to be major factors affecting the density of softshell clams. There is no evidence that the operation of Seabrook Station has affected the abundance of any of the lifestages of the softshell clam.

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