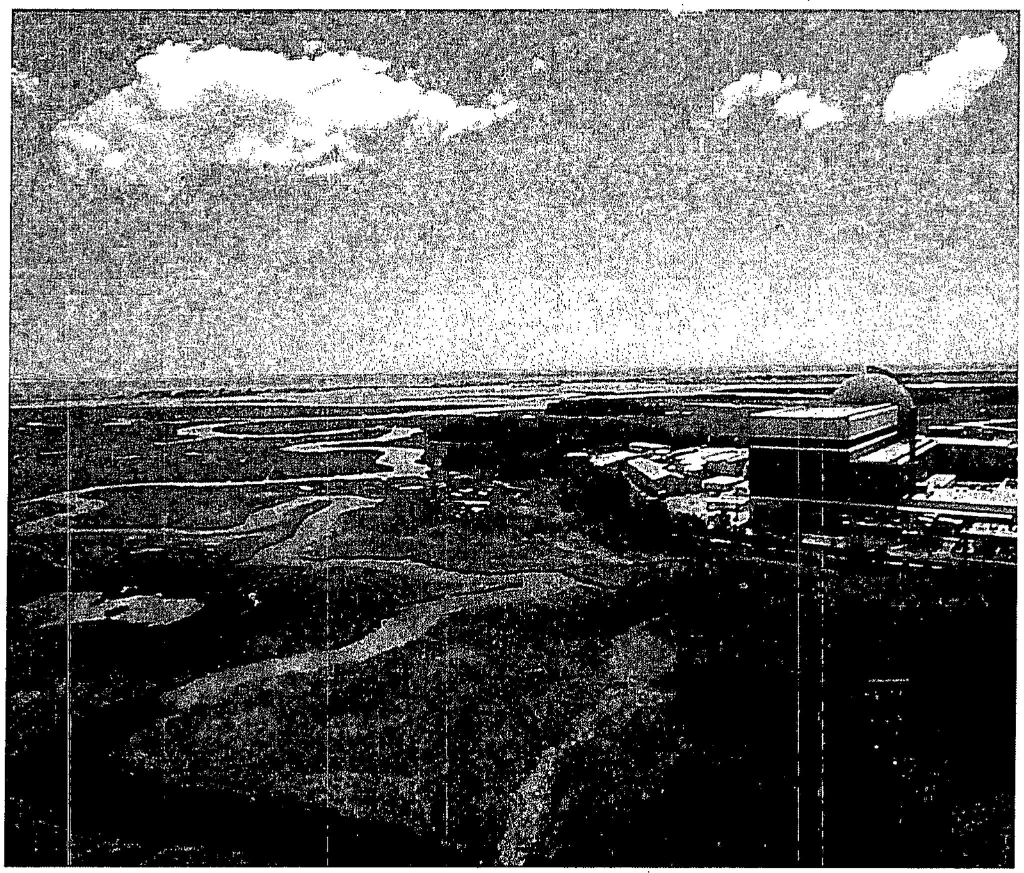
NEXTera ENERGY SEABROOK

# SBK-L-10185



## Attachment 2

## Vol. 5

August 30, 2010
NPDES Permit No. NH0020338
SBK-L-10152

Environmental Protection Agency
NPDES Program Operation Section
P.O. Box 8127
Boston, MA 02114

Seabrook Station
2009 Environmental Monitoring Report

NextEra Energy Seabrook LLC encloses the Seabrook Station 2009 Environmental Monitoring Report in accordance with NPDES Permit Section I.A.24.b.2.i. The report provides a comparison of 2009 environmental monitoring data to previous years and continues to demonstrate that Seabrook Station has not had an adverse effect upon the balanced indigenous populations in the Hampton-Seabrook area.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

If you have questions on this matter, please contact Mr. Allen Legendre, Principal Engineer, at (603) 773-7773.

Sincerely,

NextEra Energy Seabrook, LLC

Michael O'Keefe

Michael O'Keefe
Licensing Manager

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# Seabrook Station
# 2009 Environmental Monitoring in the Hampton - Seabrook Area

## *A Characterization of Environmental Conditions*

NEXTera ENERGY SEABROOK

# SEABROOK STATION
# 2009 ENVIRONMENTAL MONITORING
# IN THE HAMPTON-SEABROOK AREA
# A CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS

Prepared for


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August 2010


Cover Photo by Paul Geoghegan, Normandeau Associates
pictured Normandeau scientists Chris Baker (standing) and Eric Nestler
Hampton-Seabrook Harbor clam flat survey

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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 naturally-occurring variability: (1) that which occurs among different areas or stations, i.e., spatial, and (2) that which varies in time, from daily to weekly, monthly or annually, i.e., temporal. In the experimental design and analysis, the Seabrook Environmental 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

SEQUENCE OF EVENTS
FOR DETERMINING IF THERE ARE
ENVIRONMENTAL CHANGES
DUE TO OPERATION OF SEABROOK STATION

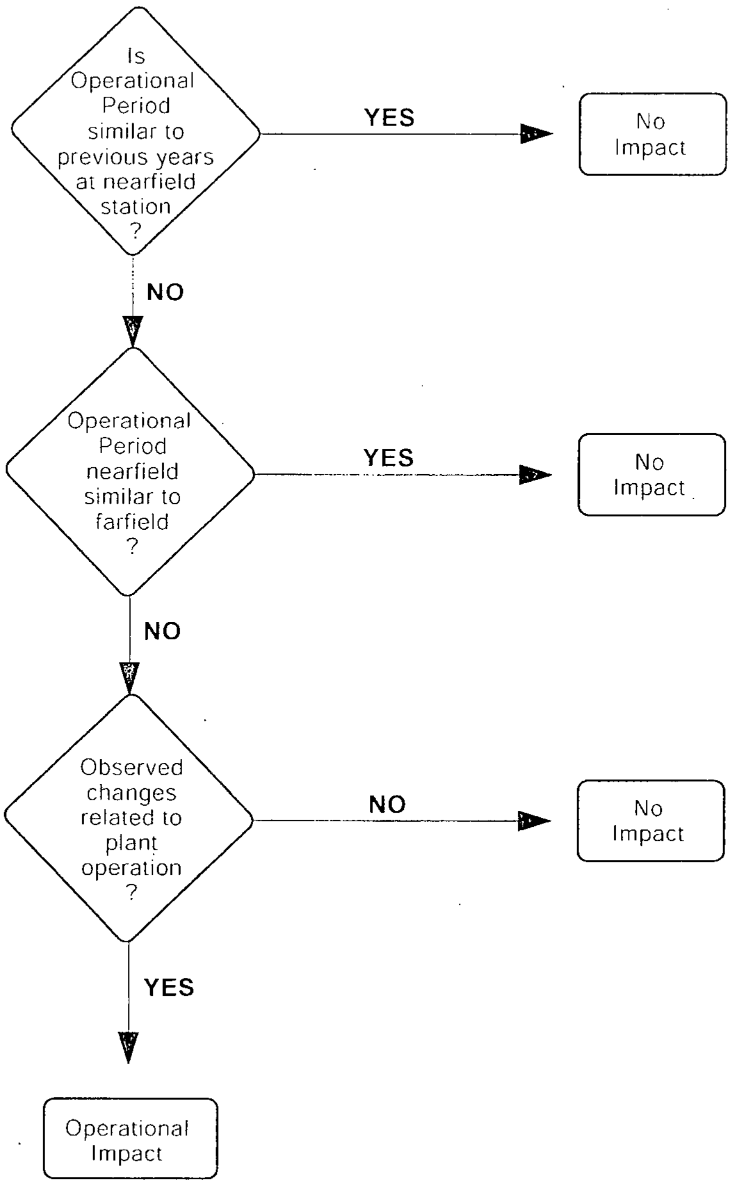


Figure 1-1. Sequence of events for determining if there are environmental changes due to the operation of Seabrook Station. Seabrook Operational Report, 2009.

**Table 1-1. Summary of Biological Communities and Taxa Monitored for Each Potential Impact Type. Seabrook Operational Report, 2009.**

| 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

community in the Seabrook study area should not be adversely influenced by loss of individuals due to entrapment in the Circulating Water System (CWS), exposure to the thermal plume, or exposure to increased particulate material (dead organisms) settling from the discharge. The current study continues to focus on the likely sources of potential influence from plant operation, and the sensitivity of a community or species 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 was restricted to only one of the areas (nearfield or farfield). The remaining terms, Year (Preop-Op) and Month (Year), were nested terms that explained some of the temporal variation in the data and improved the fit of the model. The error term included all the variation not explained by the model.

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

- 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. 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 NextEra 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 85.5 percent through December 2009 inclusive of refueling outages and other unscheduled outages. Although commercial operation began in August 1990, the cooling water system was in operation during hot functional testing that occurred in November 1985 for approximately two weeks. The NPDES Permit required Discharge Monitoring Report for November 1985 indicates that ocean Circulating Water Pumps and Service Water Pumps were in operation during the test with a maximum daily flow of 483 million gallons. A small amount of heat was rejected to the ocean during the test. A maximum temperature increase of 5°F across the condenser was reported in the Discharge Monitoring Report. Therefore the temperature rise at the ocean surface above the discharge diffuser nozzles was presumed to be minimal.

Table 1-2 supports the above statement regarding operation of the cooling water system prior to commercial operation. Data obtained from Discharge Monitoring Reports (DMR) submitted to EPA and NHDES indicate that the three Circulating Water System pumps were operated intermittently during the period prior to commercial operation (August 1990). The DMR data also indicates that the heat rejected to the cooling

**Table 1-2. Monthly Flow Characteristics of Seabrook Station Circulating Water System prior to Commercial Operation. Seabrook Operational Report, 2009.**

| Month/Year | No. of Days of CWS Operation | Average Flow in MGD | Maximum Flow in MGD | Average Temperature Increase (°F)[a] | Maximum Temperature Increase (°F)[a] |
|---|---|---|---|---|---|
| Jul90 | 31 | 582 | 611 | 24 | 37 |
| Jun 90 | 30 | 563 | 563 | 10 | 27 |
| May 90 | 31 | 562 | 563 | 2 | 8 |
| Apr 90 | 30 | 563 | 563 | 3 | 5 |
| Mar 90 | 31 | 563 | 563 | 1 | 5 |
| Feb 90 | 28 | 564 | 594 | 0 | 1 |
| Jan 90 | 31 | 324 | 563 | 0 | 0 |
| Dec 89 | 24 | 120 | 261 | 0 | 2 |
| Nov 89 | 20 | 24 | 37 | 0 | 1 |
| Oct 89 | 30 | 243 | 261 | 0 | 1 |
| Sept 89 | 14 | 264 | 279 | -0.3 | 0.25 |
| Aug 89 | 31 | 277 | 279 | 1 | 3 |
| Jul 89 | 31 | 365 | 577 | 0 | 4 |
| Jun 89 | 30 | 512 | 512 | 0 | 2 |
| May 89 | 31 | 278 | 512 | 0 | 1 |
| Apr 89 | 30 | 255 | 255 | 1 | 1 |
| Mar 89 | 31 | 92 | 255 | -1 | -2 |
| Feb 89 | 28 | 221 | 255 | 1 | 2 |
| Jan 89 | 31 | 254 | 255 | 2 | 2 |
| Dec 88 | 31 | 250 | 255 | 2 | 6 |
| Nov 88 | 30 | 255 | 255 | 0 | 9 |
| Oct 88 | 25 | 253 | 255 | 0 | 4 |
| Sept 88 | 25 | 252 | 255 | 0 | 1 |
| Aug 88 | 31 | 255 | 255 | -1 | 1 |
| Jul 88 | 31 | 255 | 255 | 0 | 3 |
| Jun 88 | 30 | 255 | 255 | 2 | 9 |
| May 88 | 25 | 187 | 255 | 1 | 4 |
| Apr 88 | 15 | 181 | 240 | 0 | 1 |
| Mar 88 | 19 | 22 | 30 | -2 | 1 |
| Feb 88 | 16 | 176 | 255 | 1 | 2 |
| Jan 88 | 11 | 19 | 30 | -2 | 1 |
| Nov 85 | | 483 | 483 | 4 | 5 |

[a] Temperature increase measured as the difference between water temperature at the intake transition structure and the discharge transition structure.

water was very low during the period before August 1990. Low power physics testing conducted in June 1989 also resulted in minimal heat rejection to the cooling water system as did Hot Functional Testing performed in November 1985. 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 81.0 percent during 2009, conducting a fall refueling outage (October 1 - November 12). An additional unplanned outage for turbine maintenance occurred in December (December 6 - December 24). Monthly flow rates of the Circulating Water System are provided for the period 1990-2009 in Table 1-3.

A review of the entire program in 1996 resulted in revision of a number of the program elements, which were approved by 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, (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 annual air temperature in the vicinity of coastal New Hampshire in 2009 was 0.4°C below normal and total precipitation was 2.6 cm above average. Monthly rainfall was the greatest in July (17.5 cm). The average 2009 surface water temperatures at the nearfield (P2: 9.8°C) and farfield stations (P7: 9.7°C) were higher than the preoperational means (nearfield 8.9°C; farfield 8.7°C) and the operational means (nearfield 9.5°C; farfield 9.3°C). Monthly patterns for surface water temperature in 2009 were similar to previous years. Annual mean bottom water temperatures in 2009 (nearfield 7.5°C; farfield 7.6°C) increased from the previous year and were warmer than the preoperational means (nearfield 7.0°C; farfield 6.8°C) and the operational means (nearfield 7.4°C; farfield 7.3°C). During the three-decade study period, the rise in annual mean surface temperature between the preoperational and operational periods has been 0.6°C at both stations. The bottom temperature rose 0.4°C at the nearfield station and 0.5°C at the farfield station. Average annual summer mean temperatures of surface water increased significantly throughout the study period at Stations P2 and P7. No

**Table 1-3. Monthly Flow Characteristics of Seabrook Station Circulating Water System for the Period 1990 Through 2009. Seabrook Operational Report, 2009.**

| Average Daily Flow (mgd) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | **90** | **91** | **92** | **93** | **94** | **95** | **96** | **97** | **98** | **99** | **00** | **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** |
| **Jan** | 324 | 584 | 585 | 587 | 566 | 576 | 570 | 578 | 635 | 569 | 591 | 288 | 591 | 568 | 567 | 565 | 640 | 637 | 605 | 606 |
| **Feb** | 564 | 580 | 578 | 587 | 589 | 572 | 507 | 565 | 566 | 567 | 566 | 576 | 574 | 568 | 575 | 572 | 633 | 608 | 603 | 604 |
| **Mar** | 563 | 580 | 581 | 580 | 573 | 572 | 573 | 571 | 571 | 529 | 588 | 461 | 590 | 567 | 569 | 568 | 616 | 607 | 612 | 614 |
| **Apr** | 563 | 581 | 576 | 579 | 352 | 573 | 577 | 572 | 580 | 116 | 645 | 574 | 603 | 590 | 572 | 178 | 650 | 615 | 192 | 623 |
| **May** | 562 | 581 | 581 | 582 | 188 | 625 | 637 | 345 | 689 | 522 | 668 | 587 | 281 | 647 | 620 | 638 | 663 | 643 | 628 | 644 |
| **Jun** | 563 | 578 | 593 | 582 | 171 | 662 | 686 | 235 | 417 | 665 | 677 | 679 | 675 | 683 | 656 | 671 | 665 | 668 | 653 | 659 |
| **Jul** | 582 | 535 | 593 | 578 | 331 | 685 | 689 | 662 | 572 | 679 | 681 | 673 | 691 | 684 | 671 | 671 | 664 | 669 | 661 | 661 |
| **Aug** | 588 | 253 | 583 | 579 | 681 | 687 | 691 | 674 | 678 | 682 | 682 | 683 | 692 | 687 | 676 | 672 | 660 | 669 | 664 | 660 |
| **Sep** | 583 | 257 | 314 | 574 | 696 | 686 | 691 | 672 | 682 | 682 | 679 | 681 | 691 | 688 | 679 | 670 | 656 | 668 | 663 | 658 |
| **Oct** | 590 | 552 | 159 | 574 | 690 | 685 | 678 | 673 | 682 | 680 | 524 | 679 | 658 | 321 | 677 | 669 | 151 | 645 | 663 | 135 |
| **Nov** | 590 | 590 | 566 | 612 | 692 | 287 | 647 | 666 | 568 | 656 | 60 | 675 | 682 | 655 | 650 | 670 | 539 | 663 | 664 | 520 |
| **Dec** | 589 | 591 | 563 | 608 | 628 | 486 | 599 | 668 | 602 | 612 | 231 | 675 | 608 | 603 | 606 | 667 | 669 | 626 | 634 | 570 |

significant trends in mean summer temperatures were found for bottom water at Stations P2 and P7.

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 and that warming during the operational period was regional.

Continuous temperature monitoring at the discharge (DS) station within 300 feet (90.9 m) of the discharge and the farfield (T7) station showed monthly mean temperature differences were consistent with previous years and within NPDES permit conditions. In 2009, the greatest difference (1.9°C) occurred in January. The discharge station was slightly cooler than the farfield station in July and August, due to entrainment of cooler bottom water by the jet-mixing system.

Annual mean surface water salinities in 2009 (nearfield and farfield: 30.7 PSU) were lower than the preoperational (nearfield 31.6 PSU; farfield 31.5 PSU) means and the operational means (nearfield 31.2 PSU; and farfield 31.1 PSU). Bottom salinity levels in 2009 (nearfield 31.6 PSU; farfield 31.7 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 2009 was 2.6 cm above the average, and July was the wettest month. The decrease in annual mean surface salinity between the pre-operational and operational periods was 0.4 PSU at both stations, while the bottom salinity decreased 0.4 PSU at the nearfield station and 0.3 PSU at the farfield station. These differences were not significant 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 patterns for surface and bottom salinity in 2009 were similar to previous years.

Annual mean surface dissolved oxygen (DO) levels in 2009 (nearfield and farfield: 10.0 mg/l) were higher than the preoperational (nearfield and farfield 9.7 mg/l) and operational means (nearfield and farfield 9.8 mg/l). Bottom DO levels in 2009 (nearfield

9.0 mg/l; farfield 8.9 mg/l) were lower than the preoperational (nearfield 9.2 mg/l; farfield 9.1 mg/l) and operational means (nearfield 9.1 mg/l; farfield 9.0 mg/l). The decrease in annual mean surface and bottom DO between the preoperational and operational periods was 0.1 mg/l at both stations. 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 2009 exhibited a monthly pattern that was similar to previous years.

Water quality parameters showed a distinct monthly 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, bivalve larvae and macrozooplankton, were sampled to identify spatial and temporal trends at both the community and species level. Initial monitoring characterized preoperational variation 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 changes in abundance and community composition of the bivalve larvae assemblage were observed during this study. From 1979 to 1995, which includes the preoperational and early operational period, the bivalve larvae assemblage was dominated by *Mytilus edulis* and *Hiatella* sp. Larval bivalve densities increased greatly (by about a factor of seven) from 1996 to 2000 and 2002. Densities in recent years (2001 and 2003 to 2008) were similar to bivalve larvae densities observed in the preoperational and early operational period but community composition has changed and the assemblage was dominated by *Anomia squamula* and to a lesser extent, *Mytilus edulis*. Densities and community composition in 2009 were similar to the high abundance period of the late 1990s and early 2000s. The large changes were observed at both the nearfield and farfield stations simultaneously. Station differences were negligible. The absence of any significant station differences and the similarity of the temporal trends at both stations suggest that plant operation has had no effect on the bivalve larvae assemblage.

*Mytilus edulis* was the selected species of the bivalve larvae assemblage. Average densities of *Mytilus edulis* in 2009 (nearfield: 283,578/1,000 $m^3$, farfield: 424,930/1,000 $m^3$) exceeded the 95% confidence intervals for the preoperational and operational means at both stations and were among the highest densities observed in the study. A slight seasonal shift in the appearance of larvae was observed in the operational period. Large numbers of larvae have appeared in mid-May, rather than late May. The shift occurred consistently from 1996 to 2002 and has occurred intermittently since, a possible result of warmer surface water temperatures. In more recent years (2003-2008), larvae appeared in mid-May, but in lower densities than observed from 1996 to 2002. In 2009, densities were more similar to the 1996 to 2000 period. 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 the nearfield and farfield stations 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 operation. The total number of bivalve larvae entrained in 2009 ($35{,}983 \times 10^9$), was the third greatest annual entrainment among years when sampling was conducted from April through October. *Anomia squamula* ($27{,}733 \times 10^9$) was the most numerous species entrained, followed by *Mytilus edulis* ($3{,}974 \times 10^9$) and *Hiatella* sp. ($2{,}548 \times 10^9$). In 2009, entrainment was greatest in August, due mostly to large numbers of *Anomia squamula* larvae being entrained. 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; nearshore 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, but venture into the overlying water nightly or seasonally. Annual holoplankton abundances are generally greater 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 the operation of Seabrook Station.

Numerical classification defined two distinct holoplankton assemblages, one dominated by *Centropages typicus*, the other by *Calanus finmarchicus*. 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 elsewhere 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 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 2009 (nearfield: 7,755/1000 $m^3$, farfield: 8,318/ 1000 $m^3$) were above the confidence limits of the operational and preoperational periods, continuing a trend of higher than average densities that has been observed in recent years. Average annual densities of *Calanus finmarchicus* were very similar between the preoperational and operational periods.

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. All collections from 1980 to 2003, except for 2000, associated at a relatively high level of similarity, indicating the consistency of the assemblage over long temporal scales. 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. Collections from 2004, 2005, 2008 and 2009 differed from earlier years because of lower densities of each of the seven common meroplankton species. The reduced abundances in these later years was observed at both stations and suggests plant effects are not likely.

In 2009, average densities of larvae of the selected meroplankton species, *Crangon septemspinosa*, at the nearfield station (49/1000 $m^3$) and farfield station (45/1000 $m^3$), were lower than the confidence limits of the preoperational and operational periods, continuing a trend of lower than normal abundances that has been observed since about 2003. Significant differences were observed between the preoperational and operational periods; however, the lower operational period abundances were observed at both the nearfield and farfield stations. There were no significant differences between stations for the density of *Crangon septemspinosa*, and the interaction term was not significant. Average densities of *Carcinus maenas* (green crab) larvae in 2009 at the nearfield (35/1000 $m^3$) and farfield station (26/1000 $m^3$) were within the confidence limits of the preoperational and operational periods. 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 at the nearfield site. 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 collections (except for 2005) were tightly grouped in the MDS ordination. In contrast, collections at Station P7 were considerably more variable and distinct groups were formed by numerical classification. Some collections (1996, 2004, 2006, 2008 and 2009) were associated with the nearfield collections, but most collections formed groups distinct from the nearfield site. In general, species abundances were much lower at Station P7. Numerical classification defined a group composed exclusively of operational period (1997, 1998, 2000-2002) farfield collections and could suggest a plant effect. Farfield collections from 1997 to 2002, were characterized by extremely low densities, especially of the larger peracarid species, including *Neomysis americana*. Starting in 1996 the number of replicates collected was reduced, which effectively resulted in earlier sampling times at the farfield station. This methodological change likely caused the decrease in the larger peracarids and the presence of the farfield station group (1997-2002) in the operational period.

For the hyperbenthos, station differences were observed in the preoperational period. Station differences were maintained in the early operational period, until changes to the sampling method were initiated in 1996. Taking into consideration that the method change accounts for the reduced peracarid densities at the farfield station from 1997 to 2002, and that station differences which were observed in the preoperational period were maintained in the operational period, a plant effect on the hyperbenthos is not likely.

Average densities of the selected hyperbenthic species, *Neomysis americana*, at the nearfield station (34/1000 $m^3$) and the farfield station (21/1000 $m^3$) were less than the preoperational and operational period means. The nearfield station had significantly higher densities than the farfield station. Operational period densities were significantly lower than the preoperational period. The interaction of these main effects was not significant however.

**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 pump house. 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 often 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 1988-2009. However, ANOSIM detected no differences between stations. The difference between periods was primarily due to increases in the density of hake/fourbeard rockling eggs and decreases in Atlantic cod/haddock and fourbeard rockling eggs. The interaction of the main effects was not significant indicating no impact due to the operation of Seabrook Station.

Most 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 an earlier years (1983-1984, 1986-1988) and a later years (1990-1991, 1993-2005, 2007-2009) as a result of increases in cunner and silver hake, and decreases in witch flounder and winter flounder. ANOSIM detected significant differences in the fish larvae assemblage between the early and later years, 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 were no significant differences in larval abundance between periods or stations for hakes, pollock, cunner, American sand lance, Atlantic mackerel, and yellowtail flounder. Only Atlantic herring, Atlantic cod, 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 2009 decreased from the previous year to 25.0 and was within the range of previous operational years. CPUE of demersal fish has generally increased since a record low in 1995. Winter flounder, hakes, longhorn sculpin, yellowtail flounder, and skates dominated the catch in 2009. During the operational period, these same species predominated along with windowpane, compared with yellowtail flounder, longhorn sculpin, winter flounder, Atlantic cod and skates 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 9.4 in the preoperational period to 1.4 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) and has resulted in 11 out of 19 stocks being overfished (NEFSC 2008). The CPUE of winter flounder increased from 2.9 in the preoperational period to 3.3 in the operational period. The increase started in 1995 and this trend was consistent with the stock assessment data presented in NEFSC (2006) which showed that spawning stock biomass of winter flounder increased through 2001. However, the most recent management data collected (through 2007) from the Gulf of Maine indicates that winter flounder are overfished (NEFSC 2008).

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 other regional factors. 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 2009 decreased from the previous year to 6.2. The 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 2009, an estimated 9,283 fishes and 21 American lobsters were impinged on the traveling screens at Seabrook Station. This was a decrease from last year, and was less than the highest impingement estimate since reliable estimates were first made in 1994 (2003: 71,946). The months with the highest impingement estimates were November (1,669; 18%) and December (3,523: 38%). Hake sp. (1,427: 15%), cunner (837: 9%), American sand lance (796: 9%), rock gunnel (701: 8%), and northern pipefish (698: 8%) comprised 49% of the fish impinged in 2009. Most impinged fish were probably YOY and yearling 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 impact of Seabrook Station on the local fish assemblages. Entrainment of eggs in 2009 (2,072 million) was the third highest to date. The taxa with highest egg entrainment in 2009 were cunner/yellowtail flounder (1,448 million), silver hake (196 million), hake/fourbeard rockling (121 million), Atlantic mackerel (83 million), and hake sp. (72 million). Based on larval abundances, almost 100% of the cunner/yellowtail flounder eggs were cunner.

Entrainment of larvae in 2009 (523 million) was the third highest estimate to date. American sand lance (129 million), cunner (106 million), and rock gunnel (83 million) were the most abundant taxa entrained in 2009. Entrainment of larvae in 2009 was highest in June (134 million), when cunner (70 million) and Atlantic mackerel (25 million) were most abundant.

Equivalent Adult (EA) analyses of seven commercially-important fishes indicated that entrainment and impingement in 2009 resulted in the estimated loss ranging from six (yellowtail flounder) to 2,023 (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. Pre-operational 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 commercial operation of Seabrook Station began in August 1990. Possible impacts of greatest concern include increased temperature and increased turbidity and sedimentation. Temperature-related impacts would most likely occur in the shallow-subtidal zone, where the benthos could be exposed to the buoyant thermal plume. Thermal impacts would be unlikely at deeper stations; however, suspended solids and entrained organisms in the discharge plume could potentially increase turbidity and sedimentation, adversely affecting benthic organisms 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 (nearfield station B17, 4.9 m depth; farfield station B35, 4.6 m depth) 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 significantly lower during the operational period compared to the pre-operational 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 2009 collections from the nearfield and farfield stations were included in the main assemblages. Since the main assemblages include both stations from both preoperational and operational years, there is no evidence that the operation of Seabrook Station has altered macrobenthic assemblages, in contrast to other New England power plants. 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: 15.2 /100 $m^2$) compared to the farfield station (Preoperational: 155.8/100 $m^2$; Operational: 73.9/100 $m^2$). Since the decline began prior to the operation of Seabrook station at both nearfield and farfield stations, it is not likely to be related to station operation. The cause of this decline remains unclear. Since sporogenesis declines at temperatures above 17° C, the area-wide warming trend in surface water temperatures may play a role. At the nearfield station the annual mean number of days with surface temperature ≥ 18° C in the operational period (15.3) was almost twice the number in the preoperational period (7.8). Similarly at the farfield station the annual mean number of days with water temperatures ≥ 18° C in the operational period (12.5) was nearly five times the number in the preoperational period (2.8). Sea urchins, a potential grazer of *Laminaria digitata*, were eliminated as a possibility due to their low abundance at the shallow subtidal stations. Episodic removal by storms may contribute to the annual variation in the shallow subtidal zone. The lack of recovery at the nearfield station from the low abundance that began in 1996 remains unexplained.

A significant decline in the dominant kelp *Saccharina latissima* occurred at the nearfield station between the periods (Preoperational 415.1/100 $m^2$; Operational: 137.9/100 $m^2$), but there was no decline at the farfield station (Preoperational: 325.7/100 $m^2$; Operational: 326.0/100 $m^2$). In 2009, densities at both stations increased from the previous year. 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 kelp beds has been documented in the Gulf of Maine (Harris and Tyrrell 2001), off Nova Scotia (Scheibling and Hennigar 1997) and elsewhere in the western North Atlantic (Steneck et al. 2004), and causes such as overfishing, grazing by sea urchins, 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. Suspended sediment was monitored at the mid-depth stations and the nearfield shallow subtidal station in a special study conducted in March 2008. No significant difference was found for suspended sediment parameters (such as total suspended sediment, organic matter, carbon and nitrogen and chlorophyll *a*, phaeophytin and isotopes of carbon and nitrogen) between the shallow subtidal and mid-depth nearfield stations, the mid-depth farfield station and the Seabrook Station discharge; however, the station in Hampton Harbor was different (McDowell 2009). This study found no evidence to suggest that nearfield benthic stations and the discharge of Seabrook Station have significantly higher amounts of total suspended sediment or a different biochemical "fingerprint" than the farfield stations.

Macrofaunal density and number of taxa, as well as the algal biomass and the algal community structure in the mid-depth zone (9-12 m) have shown no changes between the preoperational and operational periods at the nearfield and farfield stations. The number of algal taxa increased significantly at the farfield station (Preoperational: 11.0/0.0625 $m^2$; Operational: 13.6/0.0625 $m^2$), but was not significantly different at the nearfield (discharge) station (Preoperational: 10.1/0.0625 $m^2$; Operational: 9.9/0.0625 $m^2$). Also, subtle changes in faunal community structure were identified through multivariate analyses. Numerical classification separated most samples from recent years into different groupings for nearfield and farfield stations as compared to collections prior to around 1995, which generally grouped together. Samples from the nearfield station were more similar to the preoperational period samples than those from the farfield station. In contrast, algal community structure as determined through numerical classification has typically been stable throughout the study period with collections divided by station into two major groups (nearfield=Group 1, farfield=Group 2). The 2009 collections joined their respective groups by station. Since there was a mix of preoperational and operational collections in each group, there is no indication that the operation of Seabrook Station affected community structure. At the species level, preoperational-operational relationships at the nearfield and farfield stations in the mid-depth zone remained stable over time for *Agarum clathratum* (kelp), *Saccharina latissima* (kelp), *Chondrus crispus* (red understory alga), *Phyllophora/Coccotylus* (red understory alga), *Ptilota serrata* (red understory alga), Mytilidae (mussel) spat, large and small *Strongylocentrotus droebachiensis* (urchins), and *Modiolus modiolus* (horse mussel). Only the kelps *Laminaria digitata* and *Alaria esculenta* and the amphipod *Pontogeneia inermis* showed nearfield-farfield differences that were not consistent between preoperational and operational periods. 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: 7.5/100 $m^2$) than the farfield (Preoperational: 500.2/100 $m^2$; Operational: 157.7/100 $m^2$). The cause of this regional decline remains unclear. An area-wide increase in the number of days with water temperature $\geq$ 18° C may be inhibiting reproduction of *L. digitata*. Nonetheless, many other factors provide plausible explanations for the decline. Grazing by the green sea urchin, *Strongylocentrotus droebachiensis* could have reduced the density of *L. digitata* during the years when urchins were most abundant. These two species had a statistically significant inverse relationship at the farfield station during years from 1993 through 1996 (when urchin density peaked at 8.5 urchins/$m^2$). Higher turbidity at the nearfield station (NAI 2001), 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* decreased at the farfield station between periods, but not at 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: 40.0/100 $m^2$), and remained low at the nearfield station (Preoperational: 2.4/100 $m^2$; Operational: 2.3/100 $m^2$). Similarly, the amphipod *Pontogeneia inermis* decreased significantly at the farfield station between periods (Preoperational: 404/0.0625 $m^2$; Operational: 173/0.0625 $m^2$), but not at the nearfield station (Preoperational: 604/0.0625 $m^2$; Operational: 461/0.0625 $m^2$). Since there were no significant changes in density at the nearfield station, and the decline in annual means of *A. esculenta* and *P. inermis* occurred only at the farfield station, this does not appear to be an effect of plant operation. For nearfield and farfield stations combined, *Saccharina latissima* showed a significant decrease between the preoperational and operational periods, while *Chondrus crispus* showed a significant increase. These trends are area-wide and not a local impact of Seabrook Station.

**Epibenthic Crustacea**

The objective of the epibenthic crustacean 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 2009 (0.6 to 0.9/1000 $m^2$) were similar to the previous year (0.6 to 1.0/1000$m^2$), but higher or equal to the corresponding preoperational means (0.4 to 0.6/1000$m^2$) at all three stations (intake, P2; discharge, P5; and farfield, P7). Operational means at the three sampling stations ranged from 0.8 to 1.1/1000$m^2$. Weekly patterns of mean lobster larval density in 2009 were different from preoperational and operational patterns with highest densities occurring in fourth week of June with secondary peaks in the second week of August and the first week of September. Larvae were absent by the second week in 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 2009 (nearfield: 116.8; farfield 130.4) increased from the previous year at both stations, and was greater than both the preoperational (nearfield: 65.5; farfield: 81.4) and operational (nearfield: 89.8; farfield: 103.7) means. $CPUE_2$ at the nearfield station was the second highest in the time series. Total $CPUE_2$ was significantly higher in the operational period and there were no significant differences between stations. The interaction between periods and stations was not significant.

$CPUE_2$ of legal-size lobsters was significantly lower in the operational period (nearfield: 3.8; farfield: 3.5) than in the preoperational period (nearfield and farfield: 5.6) at both stations, likely a result of increases in the legal size-limit, a prohibition in taking lobsters with carapace lengths of 127 mm (5 inches) and greater, and commercial exploitation. The average legal-size $CPUE_2$ in 2009 (nearfield 4.7; farfield: 4.1) 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 sublegal lobsters and mean June through November surface water temperatures lagged by six years at the nearfield ($r_s$=0.51) and farfield stations ($r_s$=0.55). This finding 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 2009, an estimated 21 lobsters were impinged in the Station's circulating water system. A total of 318 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 2009 (nearfield: 9,878/1000 $m^3$; farfield 8,565/1000 $m^3$) was lower than the operational means (nearfield: 10,671/1000 $m^3$; farfield 11,130/1000 $m^3$) and similar to the preoperational means (nearfield: 9,532; farfield: 8,426) at both stations. 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 2009 at the nearfield station (6.8) and the farfield station (2.9) was lower than the preoperational period means (nearfield: 12.2; farfield: 9.6) and the operational period means (nearfield: 14.1; farfield: 8.2). 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 generally followed similar trends among years.

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 2009 at the nearfield (1.9) and farfield stations (1.0) was less than the preoperational mean CPUE (nearfield: 2.6; farfield 1.5) and operational mean CPUE (nearfield 2.8; farfield: 4.4). 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. However, in recent years (2005-2009), CPUE at the farfield station has been similar to the nearfield station.

**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 2009, larvae were first observed in the first week of June and peak densities occurred in the first week of July. Geometric mean density of soft-shell clam larvae in 2009 (nearfield: 9.7/m$^3$; farfield: 14.9/m$^3$) was higher than the preoperational means (nearfield: 5.2/m$^3$; farfield: 5.5/m$^3$) and the operational means (nearfield: 6.0/m$^3$; farfield: 6.8/m$^3$). There were no significant differences in mean larval abundance between the preoperational and operational periods or between stations. An estimated 31.8 billion soft-shell clam larvae were entrained in 2009. This estimate was within the range of previous years.

Mean density of YOY clams (1-25 mm) in 2009 at all flats (75.5/m$^2$) was higher than the preoperational mean (52.8/m$^2$) and the operational mean (32.6/m$^2$), and was the second highest recorded at Flat 1. Density of yearling clams (26-50 mm) in 2009 (0.1/m$^2$) was lower than both the preoperational (3.9/m$^2$) and the operational (1.0/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 2009 (2.5/m$^2$) 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. Density of yearlings in the operational period was significantly lower than in the preoperational period.

In 2009, the mean density of seed clams (1-12 mm) in Hampton Harbor (136.8/m$^2$) decreased from 2008 but was above the preoperational and operational period means. Average density of seed clams in 2009 in the farfield Plum Island Sound area (33.1/m$^2$) was below the preoperational period mean and similar to the operational mean. 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 11% 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. At most, 17% of the variation in YOY clam density was explained by variation in green crab density. 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 generally increased from 2004 through 2006, possibly as a result of reductions in clamming days starting in 2003, but has been variable since then.

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 2009 had an average air temperature that was 0.4°C below normal and precipitation was 2.6 cm above normal. Total 2009 snowfall was 37.1 cm above normal, leading to above-average freshwater runoff in the spring.

Mean monthly surface water temperatures in 2009 at the intake (P2) were above the 95% confidence limits of preoperational years in February, June through September, November, and December. Monthly mean surface water temperatures in the operational period warmed earlier and stayed warm later than in the preoperational period. Bottom temperatures were above the 95% confidence limits of the preoperational period in February, June, September, November, and December. Annual mean surface water temperatures in 2009 (P2: 9.8°C and P7: 9.7°C) were above the preoperational period (P2: 8.9°C and P7: 8.7°C) and operational period averages (P2: 9.5°C and P7: 9.3 °C). Annual mean bottom water temperatures in 2009 (P2: 7.5°C and P7: 7.6 °C) were warmer than the operational averages (P2: 7.4°C and P7: 7.3 °C) and the preoperational averages (P2: 7.0°C and P7: 6.8°C). During the study period, surface temperature rose 0.6°C between the preoperational and operational periods at both stations, while the bottom temperature rose 0.4°C at Station P2 and 0.5°C at Station P7. Annual mean and summer mean surface water temperatures rose significantly at Stations P2 and P7 during the time series, but there were no significant trends in bottom water temperatures. There were no significant differences in water temperature 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. January had the highest monthly temperature difference (1.9°C) in 2009. Compliance with this permit requirement was again demonstrated in 2009.

In 2009, annual mean surface salinities (P2 and P7: 30.7) were below the averages for the operational period (P2: 31.2 and P7: 31.1 PSU), and the preoperational period (P2: 31.6 and P7: 31.5 PSU). The 2009 bottom salinities (P2: 31.6 and P7: 31.7 PSU) were below the averages for the operational period (P2: 31.8 and P7: 31.9 PSU) and the preoperational period (P2 and P7: 32.2 PSU). Mean monthly surface salinity at Station P2 in 2009 was below the preoperational means during every month except May. The average annual decrease in surface salinity between the preoperational and operational periods was 0.4 PSU at both stations, while the bottom salinity decreased 0.4 PSU at the nearfield station and 0.3 PSU at the farfield station. There were significant freshening trends in salinity for the entire time series at both stations and depths. 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.

In 2009, annual mean surface dissolved oxygen (DO) values (P2 and P7: 10.0 mg/l) 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 2009 bottom values (P2: 9.0, P7: 8.9 mg/l) were above the averages for the preoperational (P2: 9.2 and P7: 9.1 mg/l) and operational periods (P2: 9.1 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 dissolved oxygen levels. Monthly mean surface dissolved oxygen levels in 2009 at Station P2 were above the 95% confidence limits of the preoperational average in April, May, August, and October through December. Monthly mean bottom DO levels in 2009 were below the 95% confidence limits of the preoperational average in January, July and September. The lowest monthly average DO value in 2009 was 6.8 mg/l and occurred in September at the bottom at Station P2. In 2009, DO was within the range that would support local marine life all year.

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## 2.1 INTRODUCTION

Water quality data were collected to aid in interpreting information obtained from the biological monitoring program, and also 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. Heaed 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.

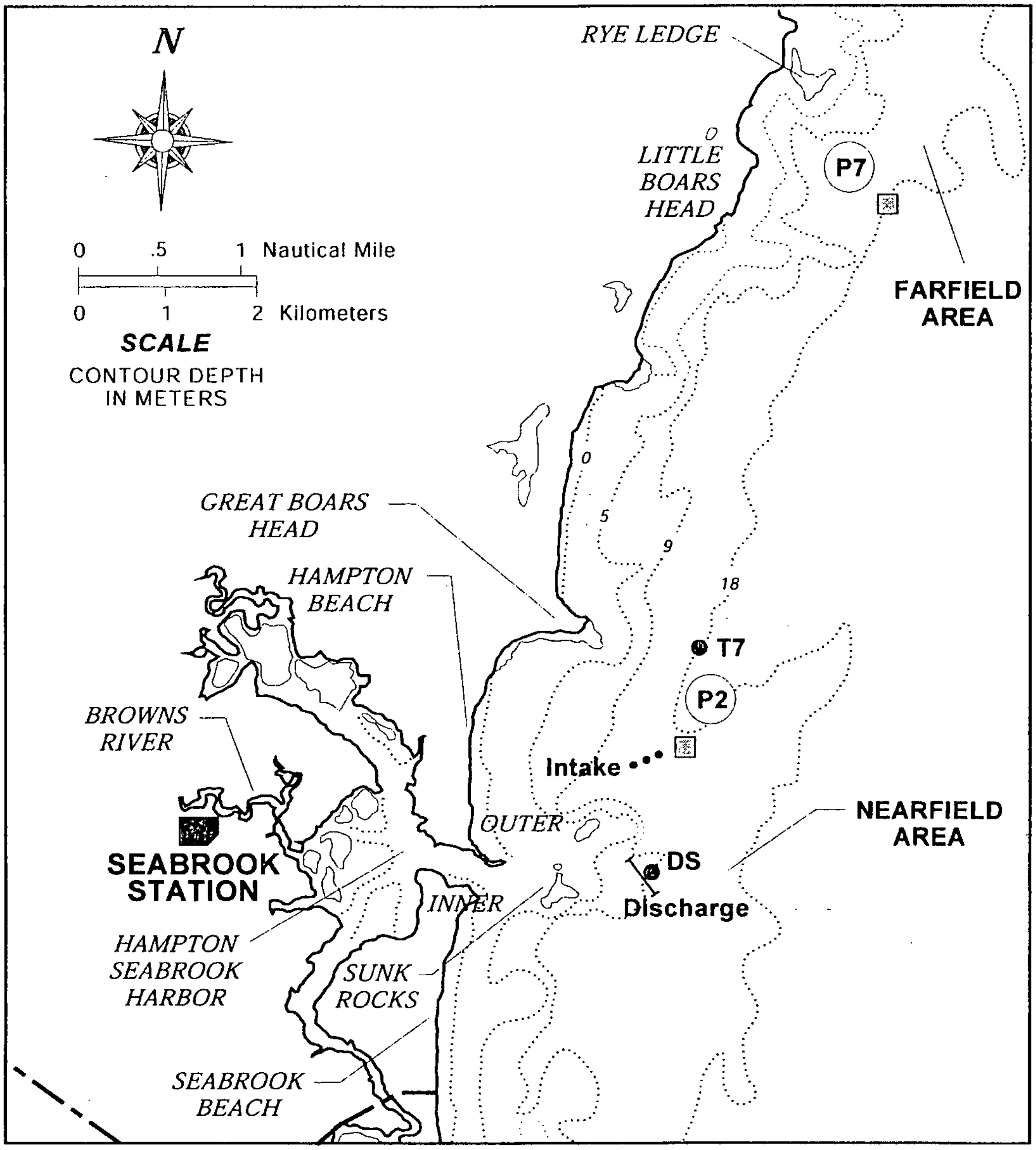
Seabrook Station uses continuous low-level chlorination in the circulating and service water systems to control biofouling. Application of chlorine to the cooling water systems is achieved through the controlled addition of a 15 % solution of sodium hypochlorite. Introduction of the chlorine into the cooling water systems can be made at one of four locations depending on the need for biofouling control. As part of Seabrook Station's NPDES permit compliance program, information was collected through the Chlorine Minimization Program. This program assessed the effectiveness of chlorine application in preventing biofouling while using the least amount of chlorine. Total Residual Oxidant (TRO) measurements are obtained from the cooling water system, just prior to entry into the discharge tunnel. The NPDES Permit limits for TRO are 0.2 ppm daily maximum and 0.15 ppm monthly average. In 2009, the daily maximum each month ranged from 0.00 ppm in January to 0.19 ppm in July. The monthly average TRO was 0.00 ppm in January through April and October through December, and it ranged from 0.05 to 0.07 ppm from May through September (FPL Energy Seabrook Station 2010a).

## 2.2 METHODS

### 2.2.1 Field Methods

Temperature, dissolved oxygen, and salinity measurements began in 1979 at the Intake Station P2 (depth=18 m) and in 1982 at the Farfield Station P7 (depth=20 m) (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 were 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




## LEGEND

▣ = water quality stations

● = continuous temperature monitoring stations

Figure 2-1. Water quality sampling stations. Seabrook Operational Report, 2009.

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). Salinity was measured in Practical Salinity Units (PSU), based upon electrical conductivity. 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) 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). The discharge station is located within the jet-mixing region, located within 300 feet of the submerged diffuser in the direction of the discharge (FPL Energy Seabrook 2010b). Divers retrieved monitors usually every two weeks and the data downloaded to a personal computer. Water temperatures were continually integrated and recorded over 15-minute intervals by Onset ocean temperature loggers. 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 2009 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 2009 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. A linear regression (PROC GLM procedure, SAS Institute, Inc. 1999) was used to test annual mean temperatures and salinities and summer mean temperatures for significant trends throughout the study period.

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. Continuous temperature monitors verified compliance with the NPDES permit conditions.

#### 2.3.1.1 Regional 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 water masses in the western Gulf of Maine. Based on records from Boston, the 2009 air temperature was 0.4°C below normal, and the only heat wave of the year occurred during a three-day period running from August 17 through 19 when air temperature reached a high of 35.0°C on two days (Boston Sunday Globe 2010). Annual precipitation was 2.6 cm above normal, and snowfall was 37.1 cm above normal.

Average air temperature in Boston in 2009 (10.5°C) was 0.4°C below the historical average of 10.9°C. Temperatures in June and July were 2.2°C and 1.9°C below normal, respectively. Average monthly air temperature ranged from 0.5°C in February to 23.1°C in August. The largest deviations from monthly normal occurred in June (2.2°C below normal) and November (2.2°C above normal). Total precipitation in 2009 was 111.1 cm, 2.6 cm above the historical average. January through June had below average precipitation, and July through December had above average precipitation. July was both cool and wet with precipitation 9.9 cm above normal. Total snowfall for 2009 was 143.5 cm, which is above normal (106.4 cm). Snowfall was highest in January (60.2 cm).

Additional climatic and oceanographic context for the 2009 Seabrook Station observations was provided by the Gulf of Maine Ocean Observing System (GoMOOS 2010). The GoMOOS project, started in 2001, is a national pilot program designed to collect and disseminate hourly oceanographic data. Data for 2001 – 2009 are available online (www.gomoos.org). Sea surface (1-m below the surface) temperature and salinity data along with air temperature data, were retrieved from Buoy B (Western Maine Shelf) located in the western Gulf of Maine roughly half-way between Hampton Harbor and Portland, Maine.

The average monthly air temperature at Buoy B ranged from –3.8°C in January to 19.2°C in August (Figure 2-2). Boston air temperatures in 2009 followed the same general trend, although Boston air temperatures were generally warmer than the offshore temperatures at Buoy B.

### 2.3.1.2 Temperature

Average monthly surface and bottom temperatures at Station P2 in 2009 generally followed a well-established pattern with the highest mean surface temperature (17.5°C) occurring in August, and the lowest (3.1°C) occurring in February and March (Figure 2-3). In 2009 the monthly surface temperatures were above the preoperational confidence limits and the operational means in February, June through September, and November and December. Surface temperatures during the operational period were higher than the preoperational confidence limits in June and from September through December, indicating that the operational period stayed warm later and began warming earlier than the preoperational period. In 2009 the highest mean monthly bottom water temperature (12.5°C) occurred in September, as it did during the preoperational and operational periods. The 2009 bottom water temperatures were above the preoperational confidence limits in February, June, September, November and December. Bottom temperatures during the operational period were higher than the preoperational confidence limits only in June and December.

In 2009 the monthly mean surface and bottom temperatures were similar at Stations P2 and P7 throughout the year (Figure 2-4). However, surface temperatures were slightly ($\leq$ 0.6°C) warmer at Station P2 in February, April, and June and, cooler in September. Surface temperatures at Stations P2 and P7 generally exhibited a similar pattern to those observed at the offshore GoMOOS Buoy B in 2009. Monthly mean bottom water temperatures at Stations P2 and P7 were similar

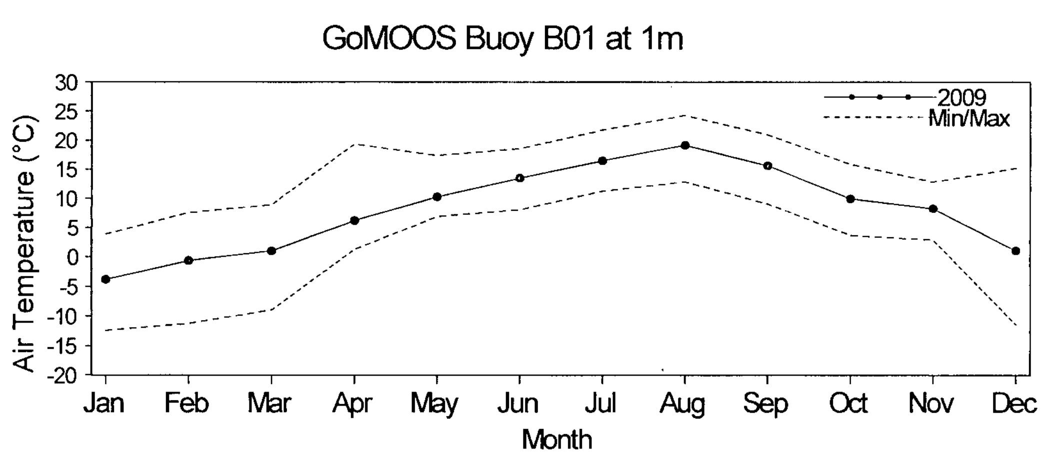



Figure 2-2. Monthly Average Air Temperatures (°C) and the Minima and Maxima Measured at GoMOOS Buoy B in the Western Gulf of Maine in 2009. Seabrook Operational Report, 2009.

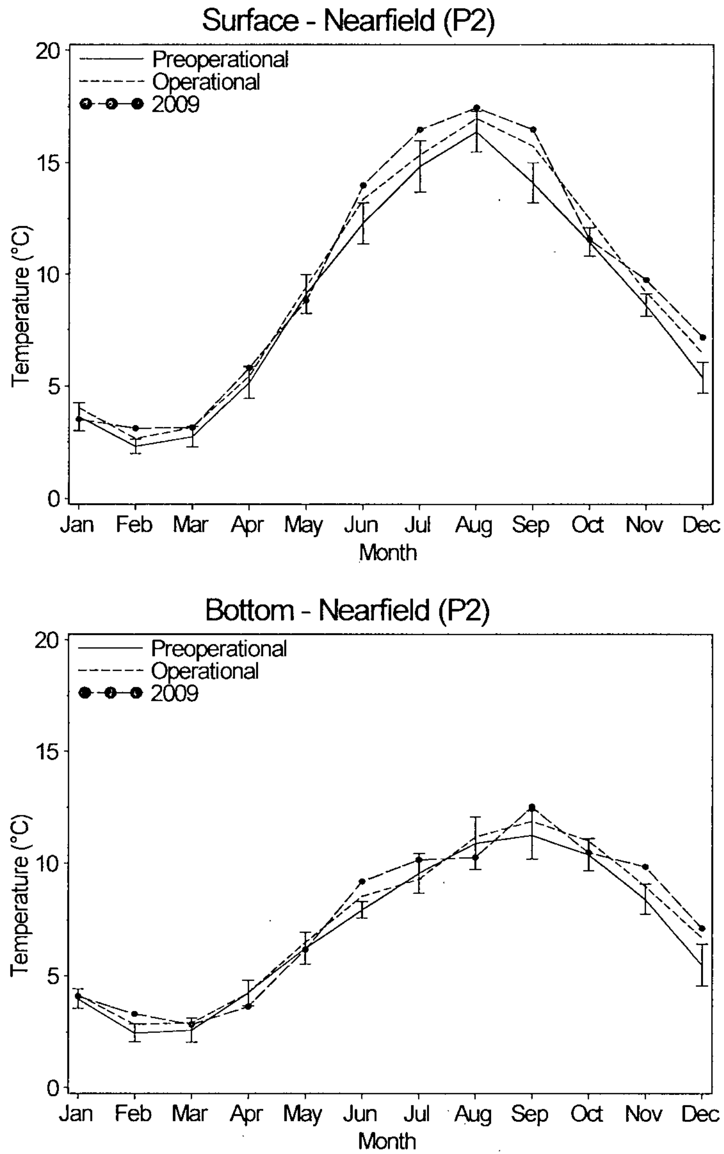



Figure 2-3. Surface and bottom temperature (°C) at nearfield Station P2, monthly means and 95% confidence intervals during the preoperational period (1979-1989) and operational period (1991-2009), and monthly means in 2009. Seabrook Operational Report, 2009.

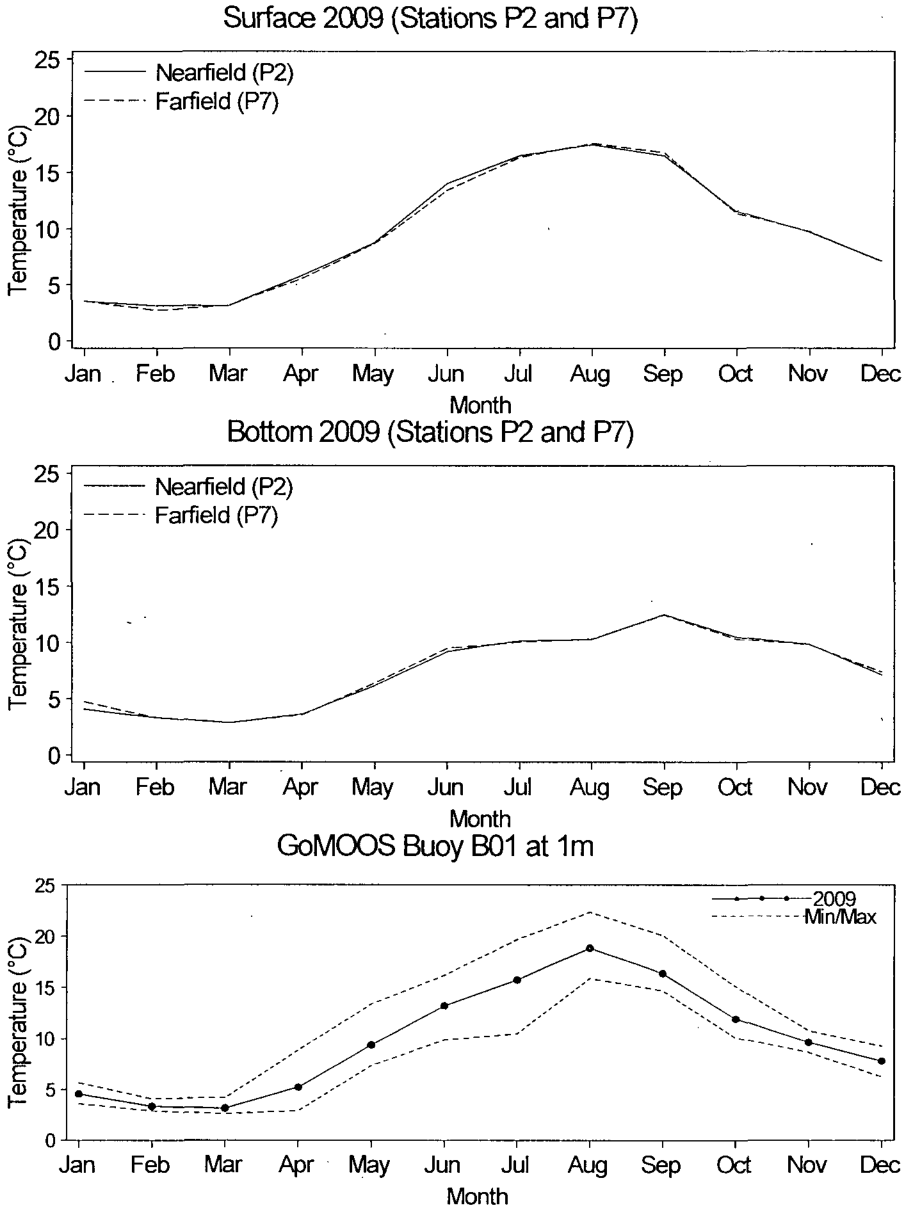



Figure 2-4. Monthly mean surface and bottom temperatures (°C) measured at Stations P2 and P7 in 2009, and monthly means, minima and maxima for sea surface temperatures measured at GoMOOS Buoy B in 2009. Seabrook Operational Report, 2009.

and were within 1°C of each other in every month.

Long-term patterns in summer (July–September) surface and bottom temperatures from 1979 through 2009 indicated that similar conditions and trends occurred at both stations (Figure 2-5). Average annual summer mean temperatures of surface water increased significantly throughout the study period at Stations P2 and P7 ( $p=0.02$ for both stations). No significant trends in mean summer temperatures were found for bottom water at Stations P2 and P7.

In the preoperational and operational periods the annual mean surface temperatures were 0.2°C higher at Station P2 compared to Station P7, and in 2009 there was 0.1°C difference between stations (Table 2-1). Annual mean bottom temperatures were 0.1°C warmer at Station P2 in the operational period and in 2009. The average surface and bottom temperatures at both stations in 2009 were warmer than the preoperational and operational period means at both stations (Table 2-1). Long-term patterns in annual surface and bottom temperature from 1979 through 2009 indicated that similar conditions and trends occurred at both stations (Figure 2-6).

During the study period, the rise in annual mean surface temperature between the preoperational and operational periods was 0.6°C at both stations, while the bottom temperature rose 0.4°C at Station P2 and 0.5°C at Station P7. There were significant positive increases for the entire time series in annual mean surface water temperature at Stations P2 and P7 (P2: R-Square=0.24, $p=0.01$; P7: R-Square=0.29, $p=0.01$). There were no significant trends in bottom water temperatures. There were no significant differences in surface or bottom water temperature for the main effects of Preop-Op (Period) and Station or for the interaction between the main effects (Table 2-2). Since the temperature increase during the time series 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, 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 2-7). Stratification in the operational and preoperational periods at Stations P2 and P7 was similar. In 2009, stratification occurred from April through October, and it was most pronounced in August at both stations. Monthly mean differences between surface and bottom water temperatures in 2009 were above the preoperational confidence limits April, August and September at both stations.

### 2.3.1.3 Salinity

Nearshore salinity is affected by runoff from nearby landmasses, 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). January through June had below average precipitation, and July through December had above average precipitation. July was both cool and wet with precipitation 9.9 cm above normal.

Mean monthly surface salinity at Station P2 in 2009 was lower than the preoperational means during every month except May and ranged from 29.3 PSU in July to 31.8 PSU in January (Figure 2-8). Precipitation in May 2009 was 1.4 cm lower than normal and may have contributed to the increase in salinity at

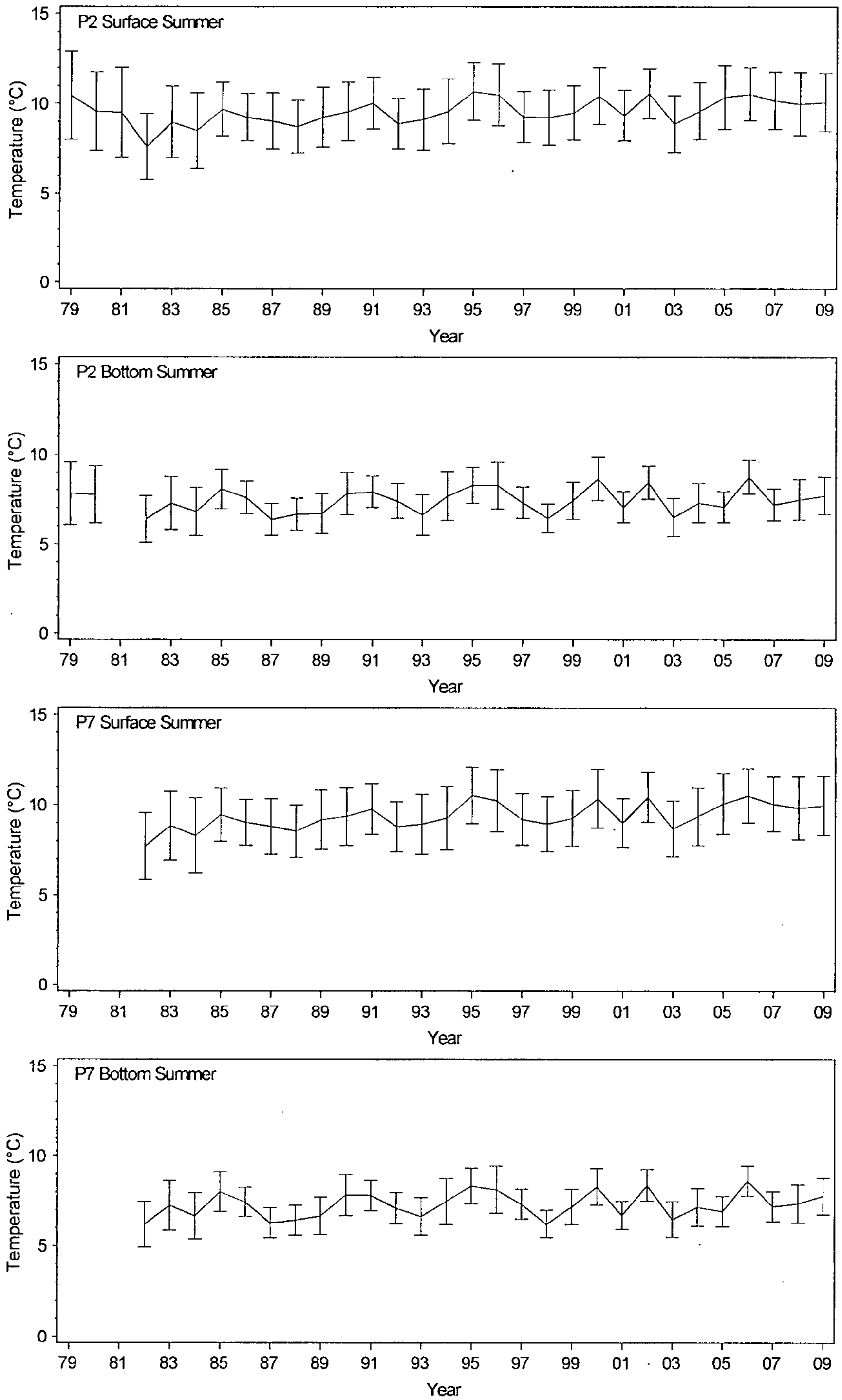



Figure 2-5. Time-series of summer (July-September) means and 95% confidence intervals of surface and bottom temperatures (°C) at Stations P2 and P7, 1979-2009. Seabrook Operational Report, 2009

**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 2009. Seabrook Operational Report, 2009.**

| | | PERIOD | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preoperational[a] | | | | | Operational Years[b] | | | | | 2009 | | |
| | | 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 | 9.8 | 2.3 | 19.4 |
| | **P7** | 8.4 | 8.7 | 9.0 | 0.1 | 19.3 | 9.2 | 9.3 | 9.6 | 0.2 | 21.0 | 9.7 | 2.1 | 18.9 |
| **Bottom** | **P2** | 6.6 | 7.0 | 7.4 | 0.0 | 16.7 | 7.1 | 7.4 | 7.7 | 0.1 | 17.7 | 7.5 | 2.5 | 15.9 |
| | **P7** | 6.3 | 6.8 | 7.3 | 0.4 | 16.4 | 7.0 | 7.3 | 7.6 | 0.2 | 18.5 | 7.6 | 2.3 | 15.2 |
| **Salinity (PSU)** | | | | | | | | | | | | | | |
| **Surface** | **P2** | 31.3 | 31.6 | 31.9 | 24.7 | 34.2 | 30.9 | 31.2 | 31.4 | 25.5 | 34.2 | 30.7 | 28.4 | 32.3 |
| | **P7** | 31.1 | 31.5 | 31.9 | 19.6 | 34.6 | 30.8 | 31.1 | 31.4 | 25.2 | 34.4 | 30.7 | 27.7. | 32.3 |
| **Bottom** | **P2** | 32.0 | 32.2 | 32.4 | 29.0 | 34.5 | 31.6 | 31.8 | 32.0 | 26.9 | 34.3 | 31.6 | 29.9 | 32.4 |
| | **P7** | 32.0 | 32.2 | 32.5 | 29.2 | 34.4 | 31.7 | 31.9 | 32.1 | 26.2 | 34.7 | 31.7 | 29.9 | 32.4 |
| **Dissolved Oxygen (mg/l)** | | | | | | | | | | | | | | |
| **Surface** | **P2** | 9.5 | 9.7 | 9.9 | 6.5 | 16.0 | 9.6 | 9.8 | 10.0 | 4.2 | 13.9 | 10.0 | 7.2 | 12.8 |
| | **P7** | 9.6 | 9.7 | 9.8 | 6.3 | 16.2 | 9.7 | 9.8 | 10.0 | 5.2 | 14.7 | 10.0 | 7.1 | 12.5 |
| **Bottom** | **P2** | 9.0 | 9.2 | 9.5 | 6.2 | 16.1 | 8.9 | 9.1 | 9.3 | 2.6 | 12.6 | 9.0 | 5.8 | 11.7 |
| | **P7** | 8.9 | 9.1 | 9.3 | 4.7 | 16.0 | 8.8 | 9.0 | 9.2 | 3.4 | 12.8 | 8.9 | 6.0 | 11.7 |

[a] Preoperational years: P2 = 1979–1989, P7 = 1982–1989
[b] Operational years: P2 and P7 = 1991–2009
[c] LCL = Lower 95% confidence limit
[d] Mean of annual means
[e] UCL = Upper 95% confidence limit

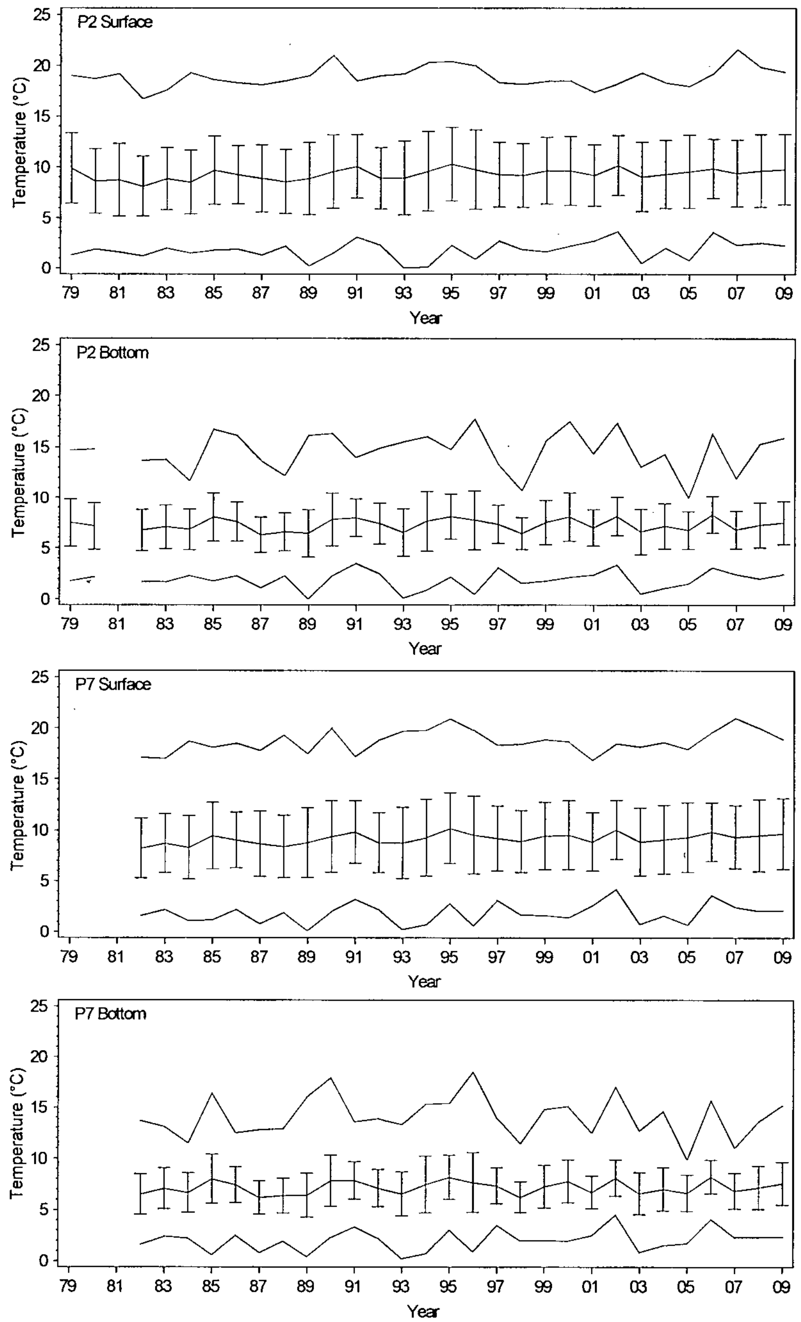



Figure 2-6. Time-series of annual means and 95% confidence intervals, and annual minima and maxima of surface and bottom temperatures (°C) at Stations P2 and P7, 1979-2009. Seabrook Operational Report, 2009.

**Table 2-2. Results of Analysis of Variance Comparing Water Quality Parameters Between Stations P2 and P7 During the Preoperational (1982-1989) and Operational (1991-2009) Periods. Seabrook Operational Report, 2009.**

| Parameter | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| Surface Temperature | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 323 | 1.30 | 0.2559 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **p** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.5000 | |
| | Month(Year)[c] | 24.35 | 4618.63 | <0.0001* | |
| | Station[d] | 0.01 | 1.42 | 0.1168 | |
| | Preop-Op X Station[e] | <0.00 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 1.88 | | | |
| Bottom Temperature | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 323 | 1.24 | 0.2662 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **p** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.4994 | |
| | Month(Year)[c] | 9.90 | 3537.21 | <0.0001* | |
| | Station[d] | 0.01 | 1.23 | 0.1338 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4995 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4995 | |
| | Error | 1.36 | | | |
| Surface Salinity | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 25.0 | 2.96 | 0.0976 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **P** | |
| | Year (Preop-Op)[b] | 0.19 | 19.02 | <0.0001* | |
| | Month(Year)[c] | 1.07 | 1430.11 | <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 | 0.4997 | |
| | Error | 0.55 | | | |
| Bottom Salinity | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 24.9 | 4.25 | 0.0498 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **P** | |
| | Year (Preop-Op)[b] | 0.12 | 40.32 | <0.0001* | |
| | Month(Year)[c] | 0.36 | 1355.22 | <0.0001* | |
| | Station[d] | <0.01 | 2.12 | 0.0734 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 0.22 | | | |
| Surface Dissolved Oxygen | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 323 | 0.79 | 0.3760 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **P** | |
| | Year (Preop-Op)[b] | 0 | 0 | 0.5000 | |
| | Month(Year)[c] | 1.02 | 2008.31 | 0.0000* | |
| | 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 | 0.35 | | | |
| Bottom Dissolved Oxygen | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 25.1 | 0.35 | 0.5578 | |
| | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **p** | |
| | Year (Preop-Op)[b] | <0.01 | 0.00 | 0.4906 | |
| | Month(Year)[c] | 1.80 | 2633.68 | 0.0000* | |
| | Station[d] | <0.01 | 1.59 | 0.1034 | |
| | Preop-Op X Station[e] | 0 | 0 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0 | 0 | 0.5000 | |
| | Error | 0.40 | | | |

**Table 2-2. (Continued)**

[a] Preop-Op compares 1978-1989 to 1991-2009 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 ≤ 0.05)

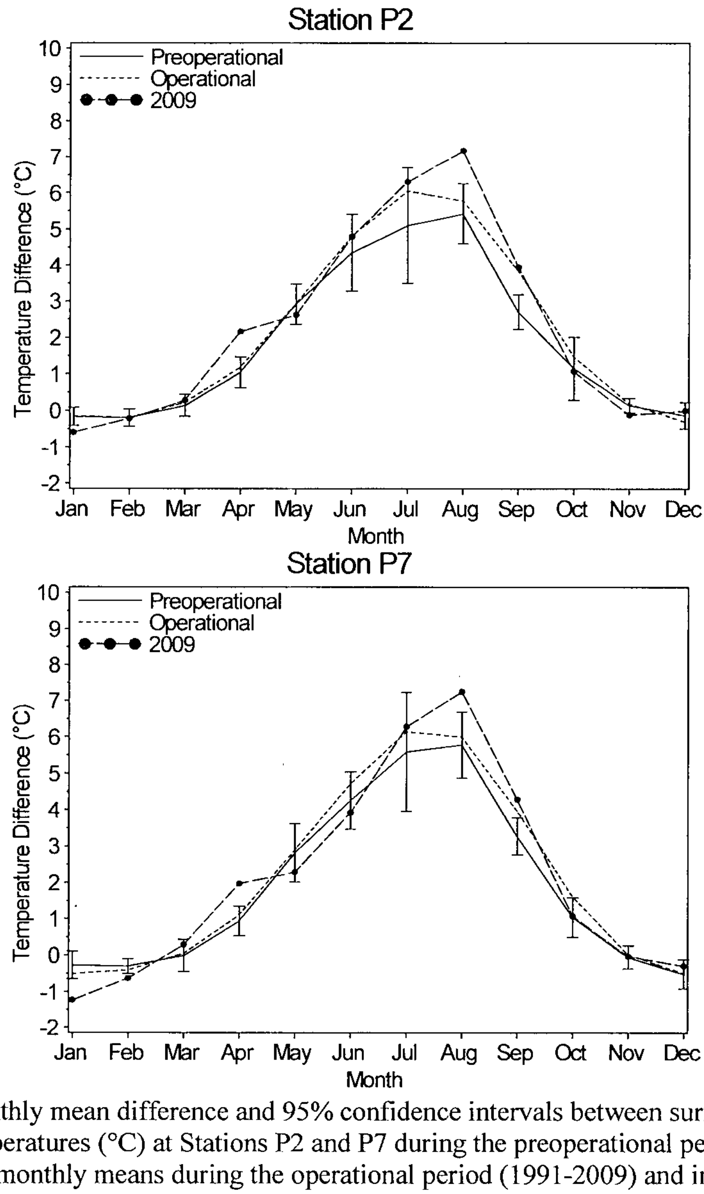



Figure 2-7. Monthly mean difference and 95% confidence intervals between surface and bottom temperatures (°C) at Stations P2 and P7 during the preoperational period (1979-1989) and monthly means during the operational period (1991-2009) and in 2009. Seabrook Operational Report, 2009.

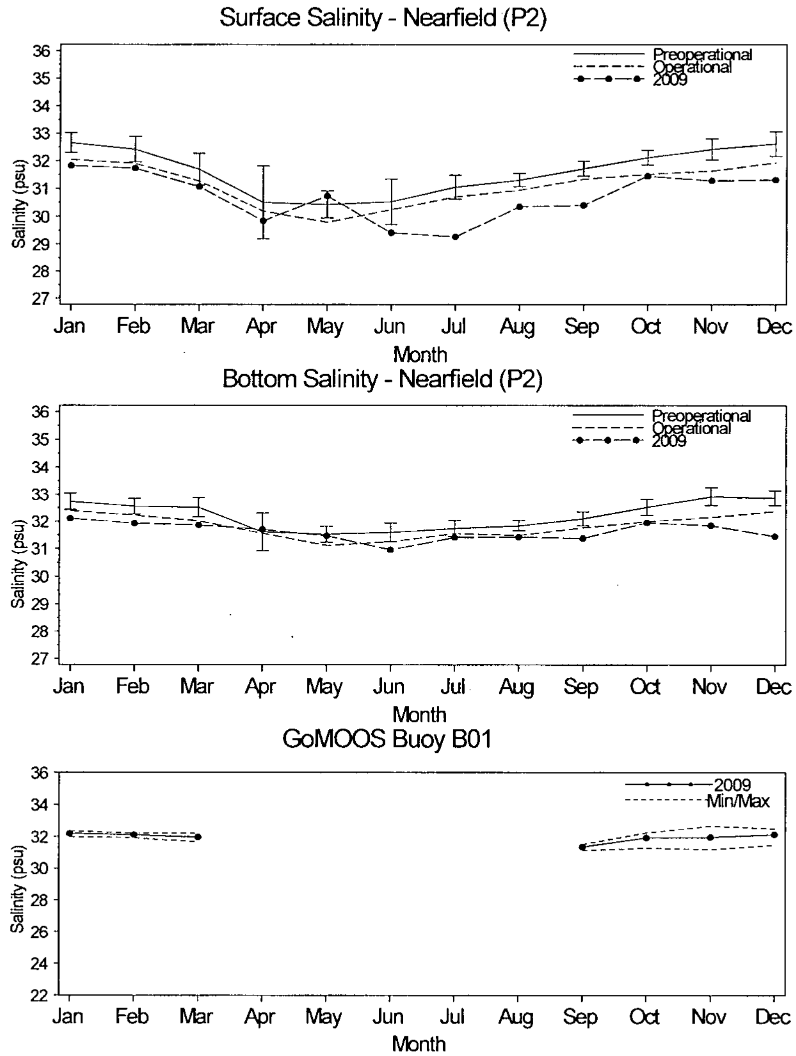



Figure 2-8. Surface and bottom monthly mean salinity and 95% confidence intervals measured during the preoperational and operational periods at Station P2, and monthly means, minima and maxima for surface salinities (PSU) measured at GoMOOS Buoy B. (GoMOOS salinity data not collected between April and August 2009). Seabrook Operational Report, 2009.

Station P2 in May. Surface salinities measured at GoMOOS Buoy B in 2009 were not taken from April through August (Figure 2-8). Therefore it is not possible to draw comparisons between salinities at Buoy B and Station P2. Average monthly surface salinity during the operational period was lower than the preoperational salinity in every month, an indication of a freshening trend in nearshore waters. Bottom salinity at Station P2 in 2009 was lower than the preoperational means in every month except April and ranged from 31.0 PSU in June to 32.1 PSU in January (Figure 2-8). Average monthly bottom salinity during the operational period was lower than the preoperational salinity in every month, and indication that bottom water is freshening.

Annual mean surface salinities in 2009 at Stations P2 (30.7 PSU) and P7 (30.7 PSU) were below the confidence limits of the pre-operational and operational periods (Table 2-1). Annual mean bottom salinity in 2009 at Station P2 (31.6 PSU) was below the confidence limit of the preoperational period. In 2009, surface salinities were below the operational confidence limits, in part because the precipitation was 2.6 cm above-normal. Long-term patterns in annual surface and bottom salinity from 1982 through 2009 indicated that similar conditions and trends occurred at both stations (Figure 2-9). 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 effect due to the operation of Seabrook 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 pre-operational period (Table 2-1), although the differences were not significant (Table 2-2). However, there were significant negative trends (decreases) in surface and bottom salinity during the entire time series at both stations (P2 surface: $p=0.003$; P2 bottom: $p=0.004$; P7 surface: $p=0.010$; P7 bottom: $p<0.001$

**2.3.1.4 Dissolved Oxygen**

Several factors affect dissolved oxygen in nearshore waters, including temperature, which affects the solubility of oxygen, salinity 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 2-10). Lower water temperature, phytoplankton blooms and reduced abundance of consumers can increase DO concentrations in the winter and spring. In 2009, the surface DO values exceeded the corresponding confidence limits of the preoperational average in April, May, August, and October through December. Monthly mean bottom DO values in 2009 were below the corresponding preoperational confidence limits in January, July and September. In 2009, the lowest average monthly dissolved oxygen levels occurred in September at the surface (8.8 mg/l) and at the bottom (6.8mg/l) (Figure 2-10). In December 2009, after the thermocline had dissipated, the monthly average oxygen at the bottom increased to 9.3 mg/l.

The 2009 annual mean surface DO concentrations at Stations P2 and P7 (Stations P2 and P7: 10.0 mg/l) were above the preoperational and operational means (Table 2-1). In 2009, the mean bottom dissolved oxygen levels were 9.0 mg/l and 8.9 mg/l at Stations P2 and P7, respectively, and were within the confidence limits for the operational period and equal to the lower confidence limits for the preoperational period (Table 2-1). Annual mean bottom dissolved oxygen in 2009 at Station P2 and P7 declined from the high values of the previous year (Figure 2-11). 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 has not affected dissolved oxygen (Table 2-2).

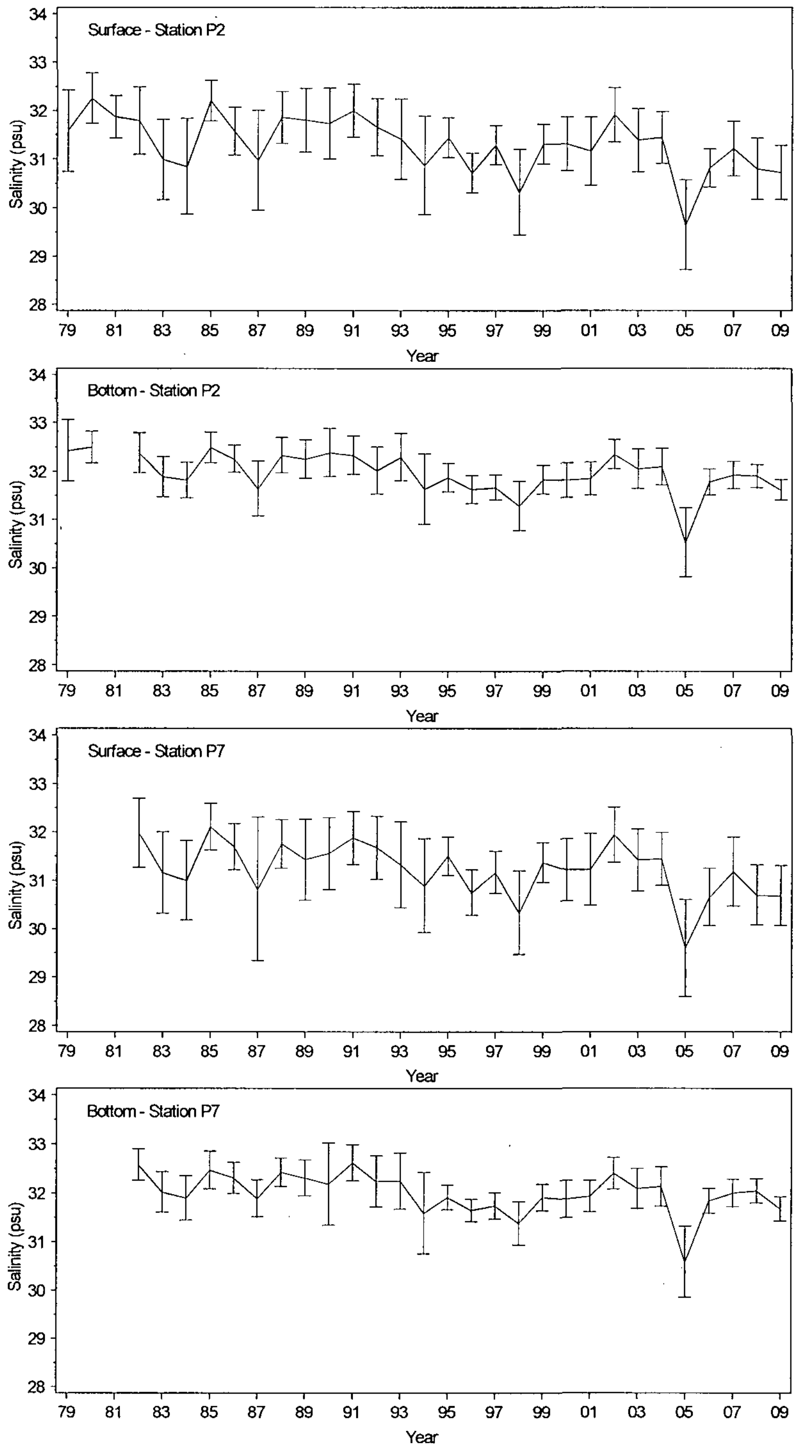



Figure 2-9. Time-series of annual means and 95% confidence intervals of surface and bottom salinity (PSU) at Stations P2 and P7, 1979-2009. Seabrook Operational Report, 2009.

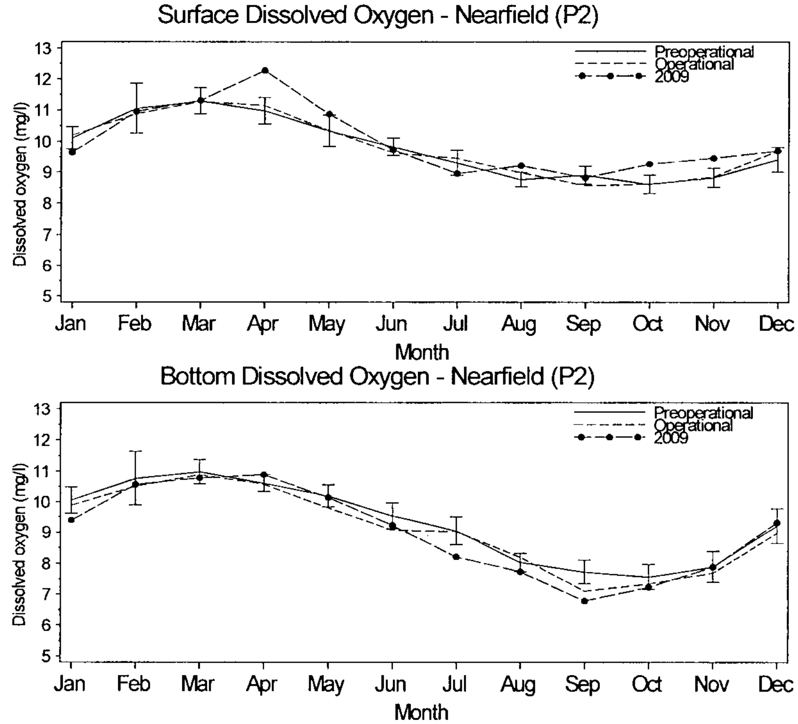



Figure 2-10. Surface and bottom dissolved oxygen (mg/l) at nearfield Station P2: monthly means and 95% confidence intervals during the preoperational and operational periods and in 2009. Seabrook Operational Report, 2009.

### 2.3.2 Continuous Temperature Monitoring

Surface temperatures in 2009 and most years at the discharge (DS) and farfield (T7) stations (Figure 2-12, Appendix Table 2-1) followed the seasonal pattern observed at Stations P2 and P7 (Figure 2-4). In 2009 the maximum monthly temperatures occurred in August at Station T7 (17.7°C) and in September at Station DS (17.4°C) (Figure 2-12). In 2009, the monthly mean differences in temperature between the discharge jet-mixing region (Station DS) and the farfield area (Station T7) were always less than 5°F (2.8°C), which is in compliance with the NPDES permit (Table 2-3). In 2009, the greatest difference (1.9°C) occurred in January. During every retrieval effort, divers observed Station DS to be within the thermal plume. The magnitude of temperature differences in 2009 between the nearfield and farfield areas was smallest in June. In July and August 2009, when the thermocline was most pronounced (Figure 2-7), the average temperature in the discharge area was cooler than the farfield area as indicated by the negative temperature difference. This was probably due to the entrainment of cooler bottom water by the jet mixing in discharge plume, which did not occur at the farfield station (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 (9.9°C) stations in 2009 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

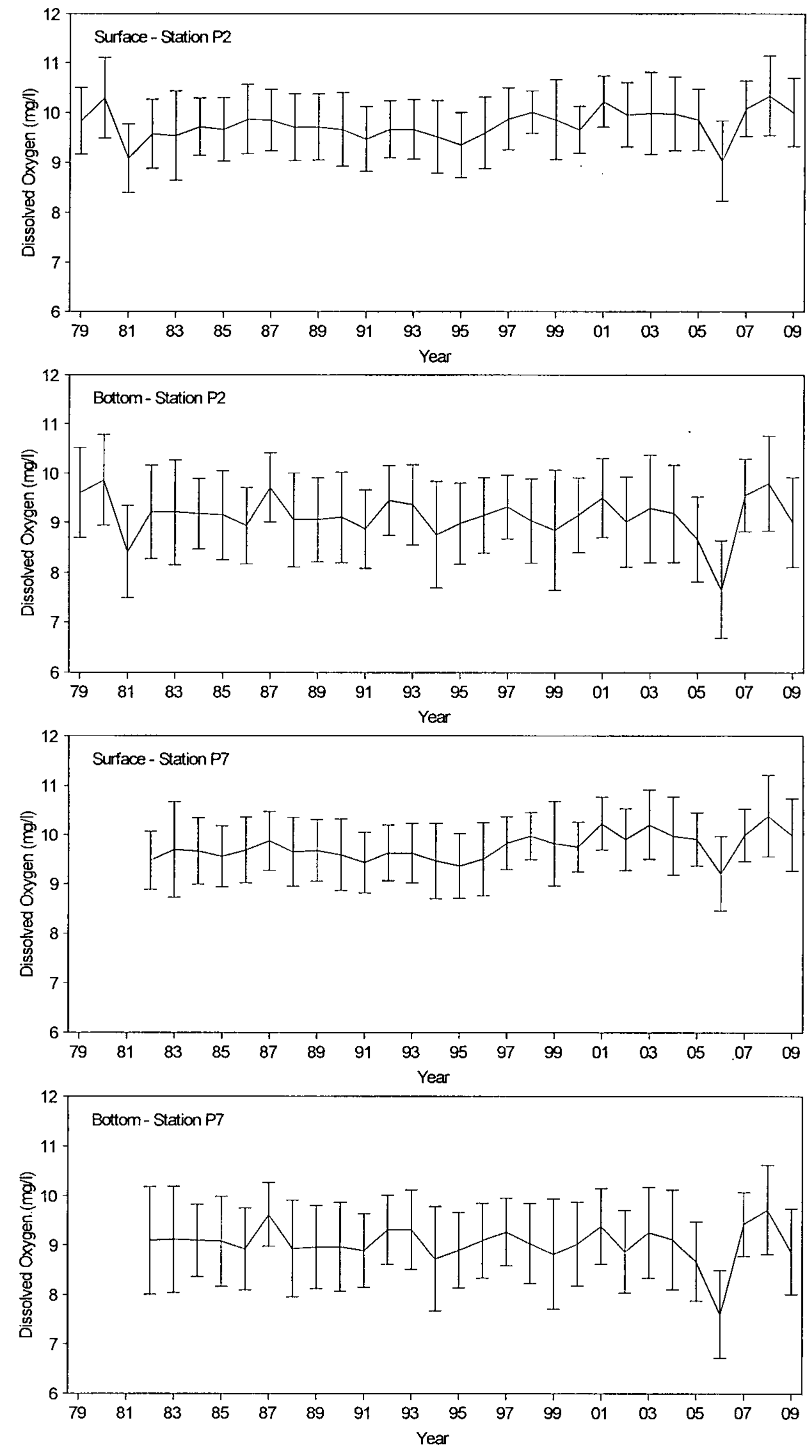



Figure 2-11. Time-series of annual means and 95% confidence intervals of surface and bottom dissolved oxygen (mg/l) at Stations P2 and P7, 1979-2009. Seabrook Operational Report, 2009.

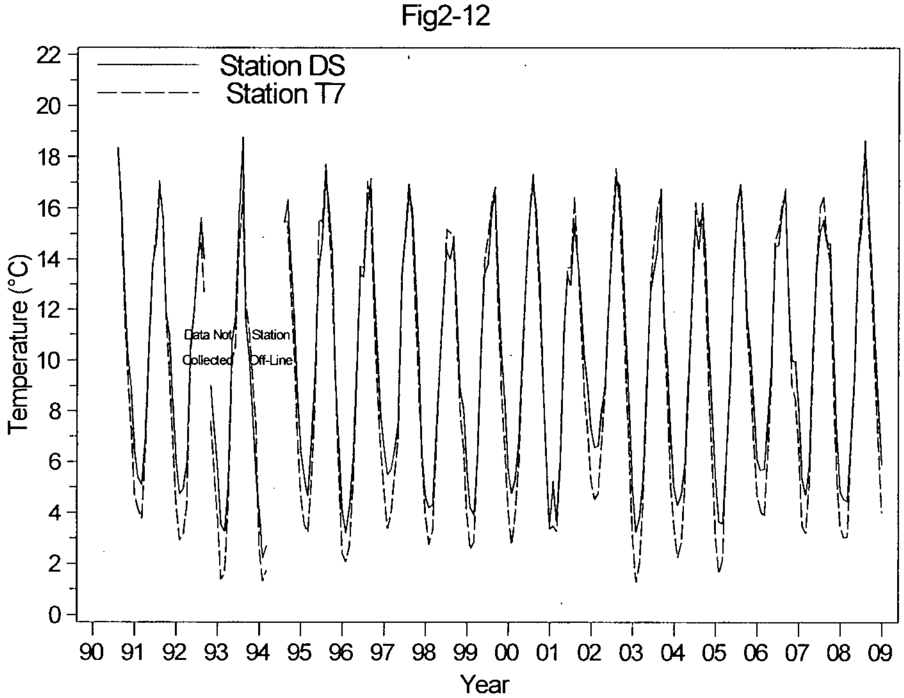



Figure 2-12. Comparison of monthly averaged continuous temperature (°C) data collected at the surface at discharge (DS) and farfield (T7) stations during commercial operation, August 1990-December 2009. Seabrook Operational Report, 2009.

**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 2009. Seabrook Operational Report, 2009.**

| | 2009 | | |
|---|---|---|---|
| Month | DS | T7 | ΔT |
| Jan | 5.89 | 4.01 | 1.88 |
| Feb | 4.88 | 3.13 | 1.75 |
| Mar | 4.53 | 3.27 | 1.26 |
| Apr | 6.61 | 5.66 | 0.95 |
| May | 9.72 | 9.34 | 0.38 |
| Jun | 14.45 | 14.33 | 0.12 |
| Jul | 15.96 | 16.20 | -0.24 |
| Aug | 17.15 | 17.71 | -0.56 |
| Sep | 17.41 | 16.67 | 0.74 |
| Oct | 11.55 | 11.49 | 0.06 |
| Nov | 10.55 | 9.73 | 0.82 |
| Dec | 7.61 | 7.13 | 0.48 |

**Table 2-4. Annual Mean Surface Continuous Temperatures (°C) and 95% Confidence Limits at Stations DS and T7 During Operational Monitoring. Seabrook Operational Report, 2009.**

| | STATION | | | | | |
|---|---|---|---|---|---|---|
| | DS | | | T7 | | |
| YEAR[a] | 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 |
| 2008 | 7.5 | 10.6 | 13.7 | 6.4 | 9.9 | 13.4 |
| 2009 | 7.5 | 10.5 | 13.6 | 6.5 | 9.9 | 13.3 |

13.3[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.

ocean thermal monitoring data from 2007 through 2009 indicated that Seabrook Station operated well within the NPDES Permit thermal limit.

### 2.3.3 Estuarine Water Quality

Monthly averages of surface water salinity and temperature taken at high and low slack tides in Hampton Harbor were used to examine seasonal and annual water quality patterns in the Hampton-Seabrook estuary. These data are directly applicable to sections on Estuarine Fish (Section 4.3.2.2) and Softshell Clam (Section 7.0).

#### 2.3.3.1 Temperature

Surface temperatures at high tide in 2009 followed the general pattern observed at the surface in the nearshore area, as would be expected considering the proximity of the estuarine station to the nearshore area. August was the warmest month at Station P2 offshore and at high tide in Hampton Harbor (Figure 2-3, Figure 2-13). Monthly mean temperatures in 2009 were above the long-term confidence limits in every month except January, May, June and October (Figure 2-13). The annual mean high tide temperature in 2009, 10.0°C, was above the average (9.4°C) for the study period and was the fifth highest for the study period (Table 2-5).

Low tide temperatures in 2009 followed a similar monthly pattern to that observed in previous years (Figure 2-13). Monthly mean temperatures in 2009 were above the long-term confidence limits in May, August and November. The 2009 annual mean low tide temperature of 10.2°C was equal to the long-term (Table 2-5). The minimum temperature recorded during 2009 was -0.4°C and occurred at low tide on January 13, while the maximum was 22.1°C and occurred on August 5 at low tide.

#### 2.3.3.2 Salinity

Monthly mean high tide salinities in 2009 were below the confidence limits of the long-term means in every month except for March through June (Figure 2-14). In general, the departures from the long-term averages were smaller than those noted for low-tide salinities. In 2009, the annual average high tide salinity was 30.4 PSU, below the long-term average of 30.9 PSU (Table 2-5).

The salinities at low tide in the estuary were affected by heavy rainfall in late July in 2009, and were below the confidence limits of the long-term averages in March, July, August, November and December (Figure 2-14). Annual mean salinity in 2009 at low tide was 26.6 PSU, 1.0 PSU below the long-term average of 27.6 PSU (Table 2-5). The annual minimum salinity (18.6 PSU) occurred at low tide on March 12, and the maximum salinity (31.9 PSU) occurred at high tide on March 23.

### 2.4 DISCUSSION

The nearshore water quality of coastal New Hampshire is affected by large-scale oceanographic processes such as the North Atlantic Oscillation (NAO), regional influences such as the Gulf of Maine Gyre, smaller scale influences such as the discharge from coastal rivers, and potentially by the operation of Seabrook Station. This monitoring program focused on detecting the influence of the operation of Seabrook Station, but larger scale processes have to be considered in the interpretation of data.

Large-scale oceanographic patterns have the potential to affect the nearshore water quality of the study area. The North Atlantic Oscillation (NAO), the natural fluctuation in atmospheric pressure differences observed in Lisbon, Portugal and Stykkisholmur, Iceland is a large scale pattern that affects weather on both sides of the North Atlantic (Hurrell 1995). Over the last 3 decades (1980-2009)

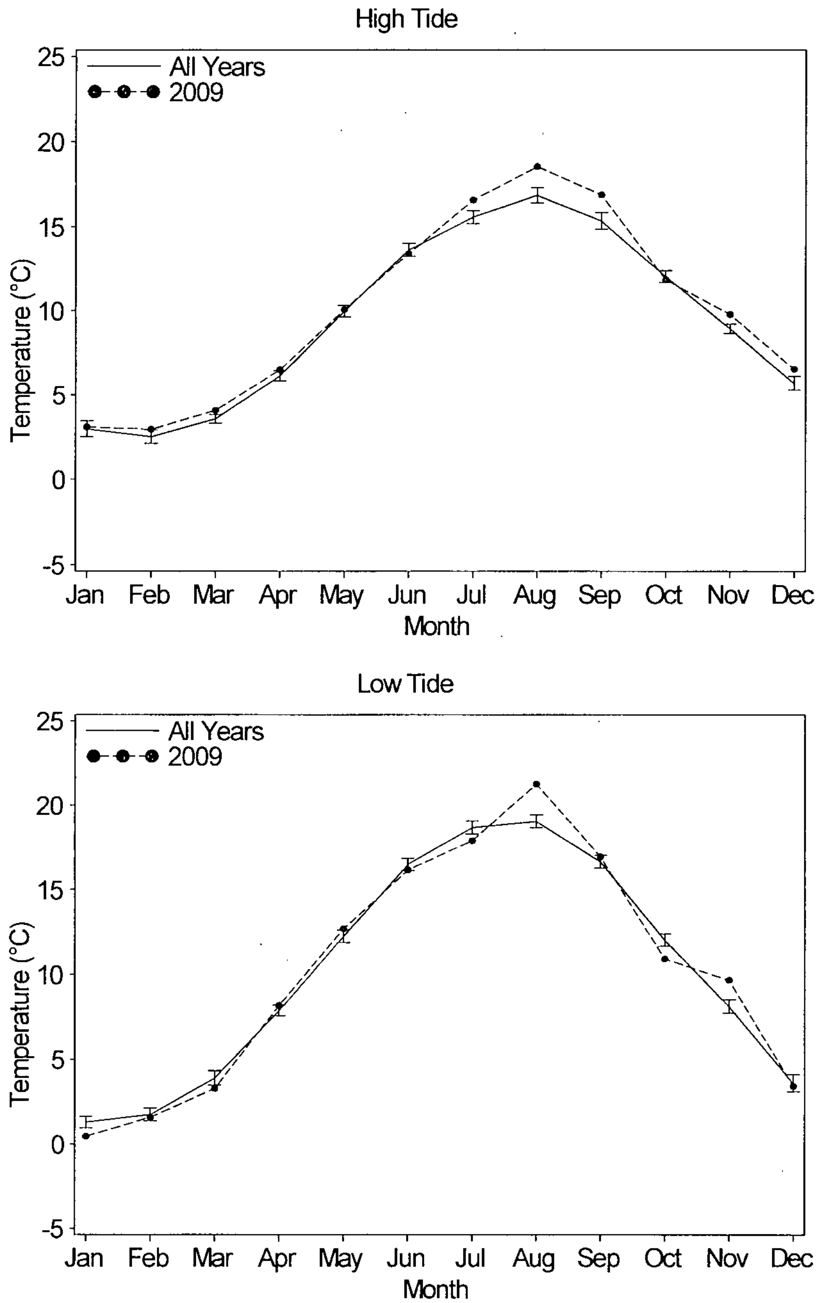



Figure 2-13. Monthly means and 95% confidence intervals of temperature (°C) measured at low and high slack tides in Hampton Harbor from May 1979 – December 2009, and monthly means in 2009. Seabrook Operational Report, 2009.

**Table 2-5. Annual Mean and 95% CL of Temperature (°C) and Salinity (PSU) Taken at Both High and Low Slack Tide in Hampton Harbor from 1980-2009. Seabrook Operational Report, 2009.**

| | High Tide | | | | Low Tide | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Temp[a] | CL[b] | SAL[a] | CL[b] | 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 |
| 2008 | 10.2 | 3.6 | 30.7 | 0.6 | 10.6 | 4.5 | 26.4 | 1.6 |
| 2009 | 10.0 | 3.5 | 30.4 | 0.5 | 10.2 | 4.4 | 26.6 | 1.1 |
| **Overall[c]** | **9.4** | **0.2** | **30.9** | **0.3** | **10.2** | **0.1** | **27.6** | **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.

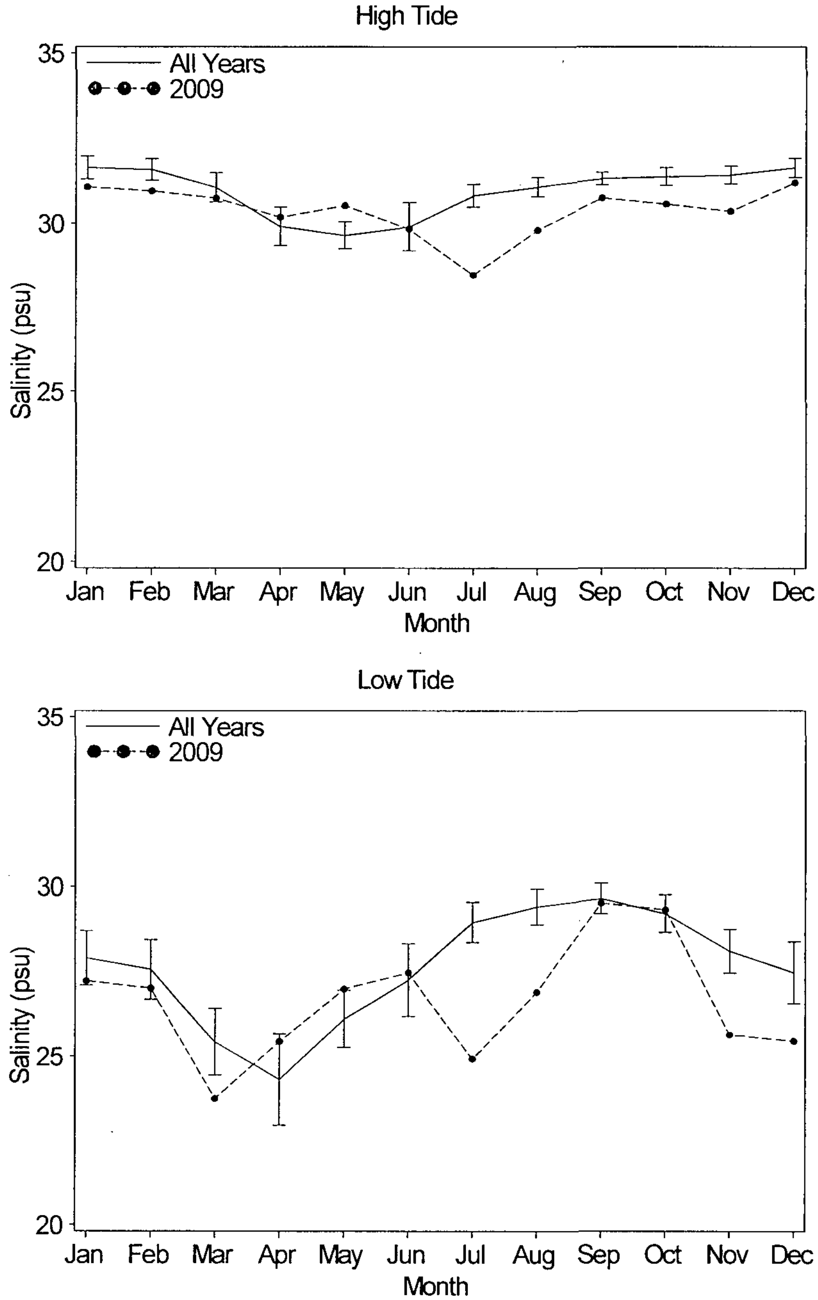



Figure 2-14. Monthly means and 95% confidence intervals of salinity (PSU) measured at low and high slack tides in Hampton Harbor from May 1979 – December 2009, and monthly means in 2009. Seabrook Operational Report, 2009.

the phase of the NAO has shifted 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 eastern US experiences mild and wet winter conditions. The predominately positive phase of the NAO may be reflected in the increasing annual mean surface water temperatures observed from 1978-2009 in this program.

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 gyre around the Gulf. This current diverges into the Eastern Maine Coastal Current (EMCC) and 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). The WMCC extends from Penobscot Bay in Maine to Massachusetts Bay (Pettigrew et al. 2005), and the study area is affected by it. The WMCC current flows primarily to the southwest at typical speeds of 0.10-0.20 m/s although the strength and direction of the current is affected by local tidal currents, wind conditions and freshwater input from the Kennebec and Penobscot Rivers (Geyer et al. 2004; Hetland and Signell 2005).

Through extensive hydrographic surveys from 1998 through 2001, Pettigrew et al. (2005) found that some years, 1998 for example, were unique because almost no leakage of the EMCC into the WMCC occurred. They 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 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 our study area, in 1998, the average annual salinity at both nearfield and farfield stations was the second lowest of the time series, suggesting that the study area was influenced by the less saline waters from the WMCC. In 2000 the study area had near average salinity (Figure 2-8), reflecting the mixing of the WMCC and the EMCC. Offshore water masses contribute to interannual variation of the coastal waters on the inner shelf of the western Gulf of Maine, and these interactions are variable and not completely understood.

The hydrography of the study area was studied intensively in the early years of the monitoring program and the results are summarized in NAI (1977). For the period 1973-1977, tidal currents comprised about 41% of the total flows and the annual range was from 32% to 48%. Steady state flows to the north or south made up the rest and ranged from 52% to 68% of the annual flows. The steady state flows were almost equally divided between flows to the south (29%) and flows to the north (31%).

There were major seasonal differences in the current flow (NAI 1977). In the fall, current flowed primarily to the north and northeast due to southwest winds and the breakdown of the Western Maine Coastal Current component of the Gulf of Maine gyre.

During the winter, flows were dominated by winds and storms, but were nearly equal divided between north and south flowing currents.

Temperature, salinity, and dissolved oxygen were monitored as part of the Seabrook Station water quality monitoring program. Average annual sea surface temperatures at the nearfield and farfield stations were higher (by 0.6°C at P2 and P7) in the operational period compared to the preoperational period. Bottom temperatures were also higher in the operational period (by 0.4°C at P2 and 0.5°C P7). For the entire time series, there were significant positive warming trends in annual and summer mean surface water temperatures at both nearfield and farfield stations. No significant warming trends were found for annual or summer mean bottom temperatures. At nearfield station P2, monthly mean surface water temperatures in the operational period warmed earlier and stayed warm later than in the preoperational period (Figure 2-3). Monthly mean bottom temperatures in the operational period were within the confidence limits of the preoperational period except in June and December. In 2009, annual mean surface and bottom temperatures in the nearfield and farfield areas were above the operational averages (Table 2-1). 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 temperatures became negligible.

In both the nearfield and farfield areas, surface and bottom salinity annual means were lower (0.3 to 0.4 PSU) 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 (Table 2-6), an indication of a regional trend, not a localized effect of plant operation. There were significant decreasing trends in surface and bottom salinities for the entire time series at both stations (P2 and P7). Surface waters in the northwest Atlantic were noticeably fresher during the 1990s when compared to previous years (Mountain 2004). The freshening of 1990s coincided with the first decade of the operation of Seabrook Station, and occurred throughout the region. Salinity data were taken

**Table 2-6. Summary of Potential Effects of Seabrook Station on Ambient Water Quality. Seabrook Operational Report, 2009.**

| 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 1982-2009, when both stations were sampled concurrently.
[b] Significant Preop-Op X Station term in BACI model ANOVA.

at the Maine Department of Marine Resources West Boothbay Harbor long-term environmental monitoring station from 1966 through 1997. 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 -1.7 m MLW) at the West Boothbay Harbor station ranged between 30 and 32 PSU (MDMR 1987), and then declined from 30.7 PSU in 1990 to 29.0 PSU in 1996, the last year that salinity was monitored (MDMR 1991, 1992, 1993, 1994, 1995, 1996, and 1997). Boothbay Harbor showed a slight long-term decrease in salinity, which also suggests a regional trend. The average annual surface and bottom salinities in 2009 at nearfield and farfield stations were below the operational averages, consistent with a long-term freshening trend (Table 2-1).

Only small (0.1 mg/l) differences among dissolved oxygen means occurred between the preoperational and operational periods at the nearfield and farfield stations (Table 2-1). A comparison of annual means at both stations showed that both nearfield and farfield stations typically followed a similar pattern, indicating the differences were regional (Figure 2-10). In 2009, the annual mean values of surface dissolved oxygen were above the means of both periods at both stations, and bottom values were 0.1 mg/l below the operational means at both stations.

The continuous temperature monitors are at a nearfield station (DS) located within the jet-mixing zone, 300 ft from the submerged diffuser in the direction of the discharge, and at farfield Station T7. The average monthly temperature in the discharge plume was typically less than 2°C warmer than the surrounding waters (Table 2-3, Figure 2-11), which indicates compliance with the NPDES permit.

In summary, no impacts to water quality due to the operation of Seabrook Station were detected in the nearshore environment. Potential impacts from the operation of Seabrook Station on water quality include elevated water temperature and the corresponding decrease in dissolved oxygen. No effects from the operation of the Seabrook Station were detected in the nearshore environment (Table 2-6). The surface and bottom temperature, salinity and dissolved oxygen at the nearfield station were not significantly different than the farfield station. There were no interactions between Period (Preop-Op) and station, which would be significant if a change had occurred due to plant operation. The operation of Seabrook Station is not having a local (nearfield) effect. In addition, inspection of monthly and annual patterns did not reveal differences between the preoperational and operational periods that were due to plant operation.

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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 2009. Seabrook Operational Report, 2009.**

| | 1990[a] | | | 1991 | | | 1992 | | | 1993 | | | 1994 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | **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 |

| | 1995 | | | 1996 | | | 1997 | | | 1998 | | | 1999 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | **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 | | | 2008 | | | 2009 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DS | T7 | ΔT | DS | T7 | ΔT | 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 | 4.81 | 3.48 | 1.33 | 5.89 | 4.01 | 1.88 |
| FEB | 3.63 | 1.62 | 2.01 | 5.66 | 4.08 | 1.57 | 5.36 | 3.49 | 1.87 | 4.54 | 3.03 | 1.51 | 4.88 | 3.13 | 1.75 |
| MAR | 3.57 | 2.16 | 1.41 | 5.71 | 3.83 | 1.87 | 4.69 | 3.19 | 1.51 | 4.45 | 3.05 | 1.40 | 4.53 | 3.27 | 1.26 |
| APR | 6.11 | 6.10 | 0.01 | 7.79 | 6.40 | 1.39 | 5.91 | 5.14 | 0.76 | 6.74 | 6.67 | 0.07 | 6.61 | 5.66 | 0.95 |
| MAY | 9.06 | 8.72 | 0.34 | 9.71 | 9.30 | 0.41 | 10.49 | 9.92 | 0.57 | 9.52 | 9.10 | 0.42 | 9.72 | 9.34 | 0.38 |
| JUN | 13.21 | 13.46 | -0.25 | 14.48 | 14.74 | -0.26 | 13.49 | 13.64 | -0.14 | 14.13 | 14.30 | -0.17 | 14.45 | 14.33 | 0.12 |
| JUL | 16.21 | 15.96 | 0.25 | 14.56 | 15.18 | -0.62 | 15.06 | 16.07 | -1.01 | 15.19 | 16.34 | -1.15 | 15.96 | 16.20 | -0.24 |
| AUG | 16.94 | 16.94 | 0.00 | 15.88 | 16.21 | -0.33 | 15.53 | 16.49 | -0.96 | 18.51 | 18.66 | -0.15 | 17.15 | 17.71 | -0.56 |
| SEP | 14.51 | 14.99 | -0.48 | 16.76 | 16.51 | 0.25 | 14.69 | 14.77 | -0.07 | 16.12 | 15.54 | 0.58 | 17.41 | 16.67 | 0.74 |
| OCT | 11.78 | 11.22 | 0.56 | 12.53 | 12.48 | 0.05 | 14.61 [e] | 13.83 | 0.78 | 13.81 | 12.84 | 0.97 | 11.55 | 11.49 | 0.06 |
| NOV | 10.44 | 9.37 | 1.07 | 10.01 | 9.06 | 0.94 | 10.76 | 9.06 | 1.70 | 10.92 | 9.45 | 1.47 | 10.55 | 9.73 | 0.82 |
| DEC | 8.23 | 6.69 | 1.54 | 9.95 | 8.44 | 1.51 | 7.24 | 5.46 | 1.79 | 8.22 | 6.63 | 1.59 | 7.61 | 7.13 | 0.48 |

[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.

Temporal trends were the major factor affecting the bivalve larvae assemblage. The densities of most of the species were much greater from about 1996 to 2002 (except 2001), compared to the other years. Community composition also changed as the community dominated originally by *Mytilus edulis* and *Hiatella* sp. changed to a community dominated by *Anomia squamula*, and to a lesser extent, *Mytilus edulis*. These changes occurred at both nearfield and farfield stations however and there was no indication of plant effects on the bivalve larvae assemblage. Collections from 2009 were similar to the high density period, 1996 to 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 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 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 occurred at both stations and suggest no plant effect on meroplankton.

Station differences have historically been observed for the hyperbenthos, probably the result of the tendency to sample Station P7, the farfield site, near dusk and considerably earlier than Station P2, the nearfield site. 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, the analysis of only the first of four replicates which resulted in a shift to a slightly earlier average sampling time at Station P7, densities of hyperbenthos, especially the larger peracarid species, have been reduced at Station P7. Community composition at the nearfield site, where a plant impact would be anticipated, has remained fairly similar throughout the study. Since estimates of abundances observed after 1996 at the farfield site are probably influenced by method changes, 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 impacts on any of the selected species. Abundances of the larvae of blue mussels, *Mytilus edulis,* and green crabs, *Carcinus maenas,* were generally greater during the late 1990s and early 2000s compared to earlier and later years, but the trend was observed at both stations. There was a slight seasonal shift in the density of blue mussel larvae, with greater numbers appearing in mid-April, rather than late April. The seasonal shift occurred consistently from 1996 to 2002, and has occurred intermittently since. The abundance of *Calanus finmarchicus*, a dominant holoplanktic copepod in the Gulf of Maine, appears to follow decadal trends with lower densities from the late 1980s through the 1990s, a trend that was observed at both stations. Annual abundances of the zoea of the sand shrimp, *Crangon septemspinosa*, have typically fluctuated considerably from year to year, but there appears to be a slight decrease in abundance since about 1998. The decrease was observed at both stations, however, and there is no indication of a significant plant effect. Densities of *Crangon septemspinosa* larvae have been lower in the late summer and fall in the operational period. The hyperbenthic *Neomysis* *americana* was the only species to display a significant difference between stations (P2 > P7), which was attributed to the tendency to sample Station P7 earlier than P2; however, the possibility of station differences cannot be ruled out. Preoperational period abundances were significantly greater than operational period abundances; however, differences between periods were consistent at both stations and the interaction was not significant indicating that the operation of Seabrook Station has not affected the population of *Neomysis americana*.

The total number of bivalve larvae entrained in 2009 was 35,983 x $10^9$, which was the third highest recorded (of 17 years with complete sampling). Annual entrainment estimates have ranged from 2,909 x $10^9$ to 67,415 x $10^9$ larvae. *Anomia squamula* (77 %) was the most commonly entrained bivalve in 2009, followed distantly by *Mytilus edulis* (11%) and *Hiatella* sp. (7 %). Most larvae (73%) were entrained in August during 2009, corresponding to unusually high numbers of *Anomia squamula* larvae in the nearshore waters. The density 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, represented mostly by copepods, cladocerans and euphausiids, are planktic 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 (generally 20-200 microns in length). 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

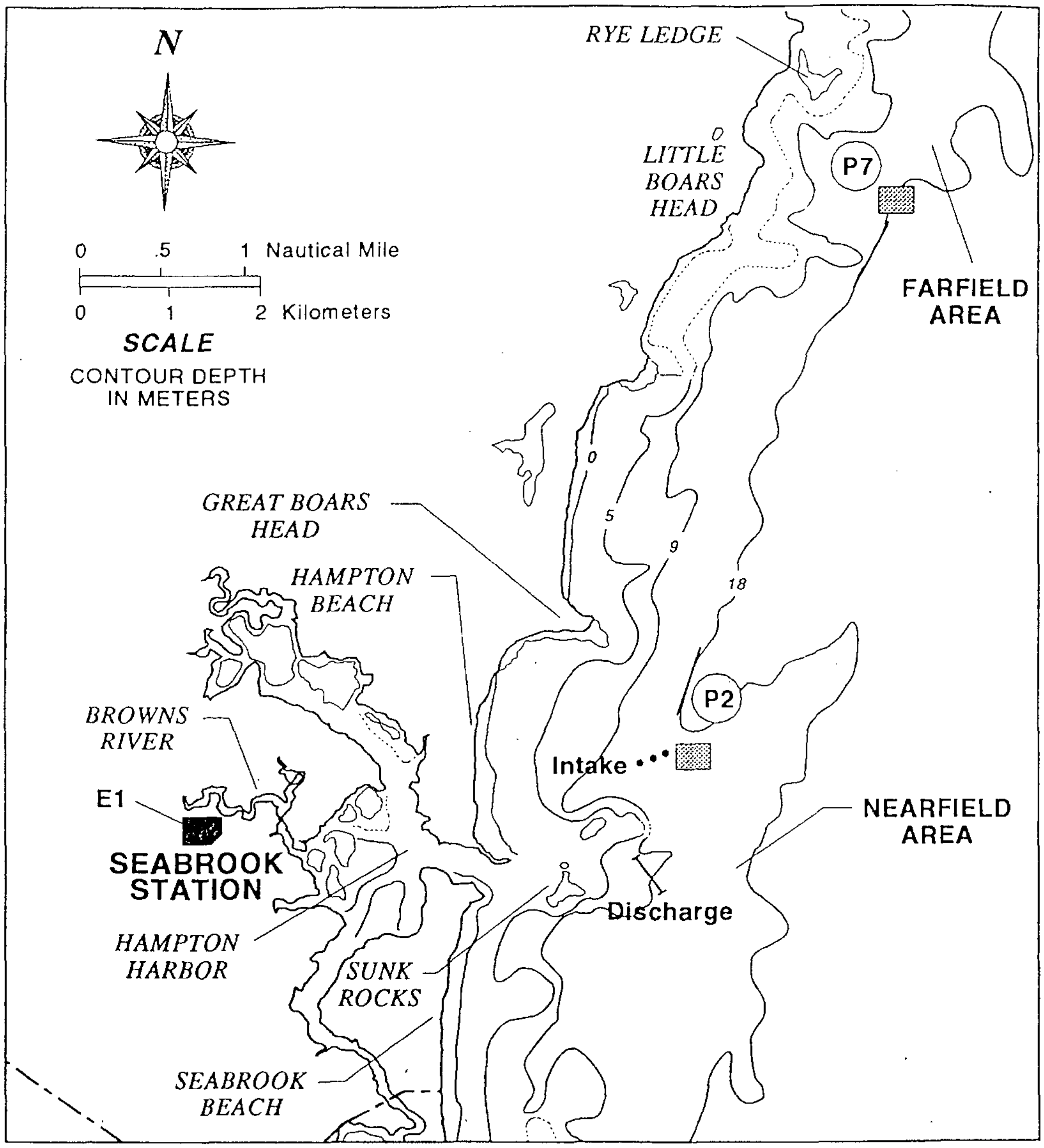
### 3.2.1 Field Methods

#### 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 plankton 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. Duplicate oblique tows were taken at both stations by varying boat speed and allowing the nets to sink to within a meter or two of the bottom, sampling both on the descent and the ascent. The duplicate tows were usually taken simultaneously. 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. Tow duration was about two minutes for an oblique tow and about 1 minute for a vertical tow. 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 2009. 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-




**LEGEND**

——— = zooplankton stations

▒ = bivalve larvae stations

E1 = Seabrook Entrainment Station

Figure 3-1. Plankton and entrainment sampling stations. Seabrook Operational Report, 2009.

gallon drum from the bottom and overflowed the 30-gallon drum into the plankton net. After passing through the net, the water discharged through the bottom of both drums. The water supply was adjusted to maintain three to six inches of water above the plankton net at all times. After the water was drained from the system, the sample contents were consolidated and preserved with 1% buffered formalin. Pumping times depended on flow rate but typically averaged 5 to 6 minutes. 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 2009. Station P7 was sampled from January 1982 through December 1984 and from July 1986 through December 2009.

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, oblique tows were made with 1-meter diameter 0.505-mm mesh bongo nets at each station. Prior to 1998, two sets of paired oblique tows were made, generating four replicates. From 1998 through 2009, 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 re-deployed 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 stations were handled identically in the laboratory. Only umbonate larvae were counted, defined as those in which the umbo was sufficiently developed to partially or totally obscure the hinge-line. 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. In 1996 and 1997, only the first of the four replicates was analyzed. From 1998 to 2009, only the first of the two replicates was analyzed. Species identified in the macrozooplankton samples follow an established list (Appendix Table 3-1) and effort has been made to maintain identification and enumeration technique consistently throughout the project and consistent with the taxonomy of the original species list. Copepods were analyzed by concentrating or diluting the sample to a known volume from which a subsample of approximately 150 copepods could be obtained. The sample was agitated with a Hensen-Stempel pipette to distribute the contents homogeneously and an aliquot was removed and 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 means. Monthly and annual means were computed from the collection date 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.

**Table 3-1. Attributes of Data Used in Analysis of Zooplankton Communities and Selected Species. Seabrook Operational Report, 2009.**

| Analytical Method | Stations | Years | Data Characteristics |
|---|---|---|---|
| **Community** | | | Annual mean of each taxon. Deleted all species |
| Cluster, MDS | P2 | 1978-1984 | occurring in <10%, family level taxa occurring in |
| | | 1987-2009[a] | <20% and order level or higher taxa occurring in |
| | P7 | 1982-1984 | <50% of collections. Also deleted Bivalvia, *Macoma* |
| | | 1987-2009[a] | *balthica*, *Teredo navalis*, Gastropoda, and Polychaeta. Parasitic organisms were also deleted. |
| ANOSIM | P2, P7 | 1982-1984 1987-2009[a] | Annual means computed from collection date means of log (x+1) transformed replicate data. |
| **Selected Species** | | | |
| Geometric means | P2 | 1978-1984 | Collection date mean; all replicates log (x+1) |
| (weekly, monthly or | | 1987-2009[a] | transformed prior to average. Annual and monthly |
| annual) | P7 | 1982-1984 | means were computed from collection date mean. |
| | | 1987-2009[a] | |
| ANOVA | P2, P7 | 1982-1984 | *Mytilus edulis* = half-monthly mean. |
| | | 1987-2009[a] | All others = monthly mean. |

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

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 1% 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: (1) the preoperational period was tested for station differences using a one-way ANOSIM, and (2), 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.

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. A summary of analytical methods for selected species is presented in Table 3-1. The operational and preoperational means, their 95% confidence interval and the 2009 geometric means (Sokal and Rohlf 1981) were tabulated. Monthly means for 2009 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 planktic 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 30 years, relatively large changes in abundance have occurred and the assemblage, originally dominated by *Mytilus edulis* and *Hiatella* sp., has shifted to one dominated by *Anomia squamula* and *Mytilus edulis*. Groups formed by numerical classification indicated a well-defined temporal pattern (Figure 3-2). All preoperational collections were associated with the early operational period to form Group 1, encompassing the years 1979 to 1995. Collections from 1996 to 2000 were grouped with 2002 and 2009 collections (Group 2). Group 3 included most of the recent collections, 2001 and 2003 to 2008. This effectively divided the timeline into three

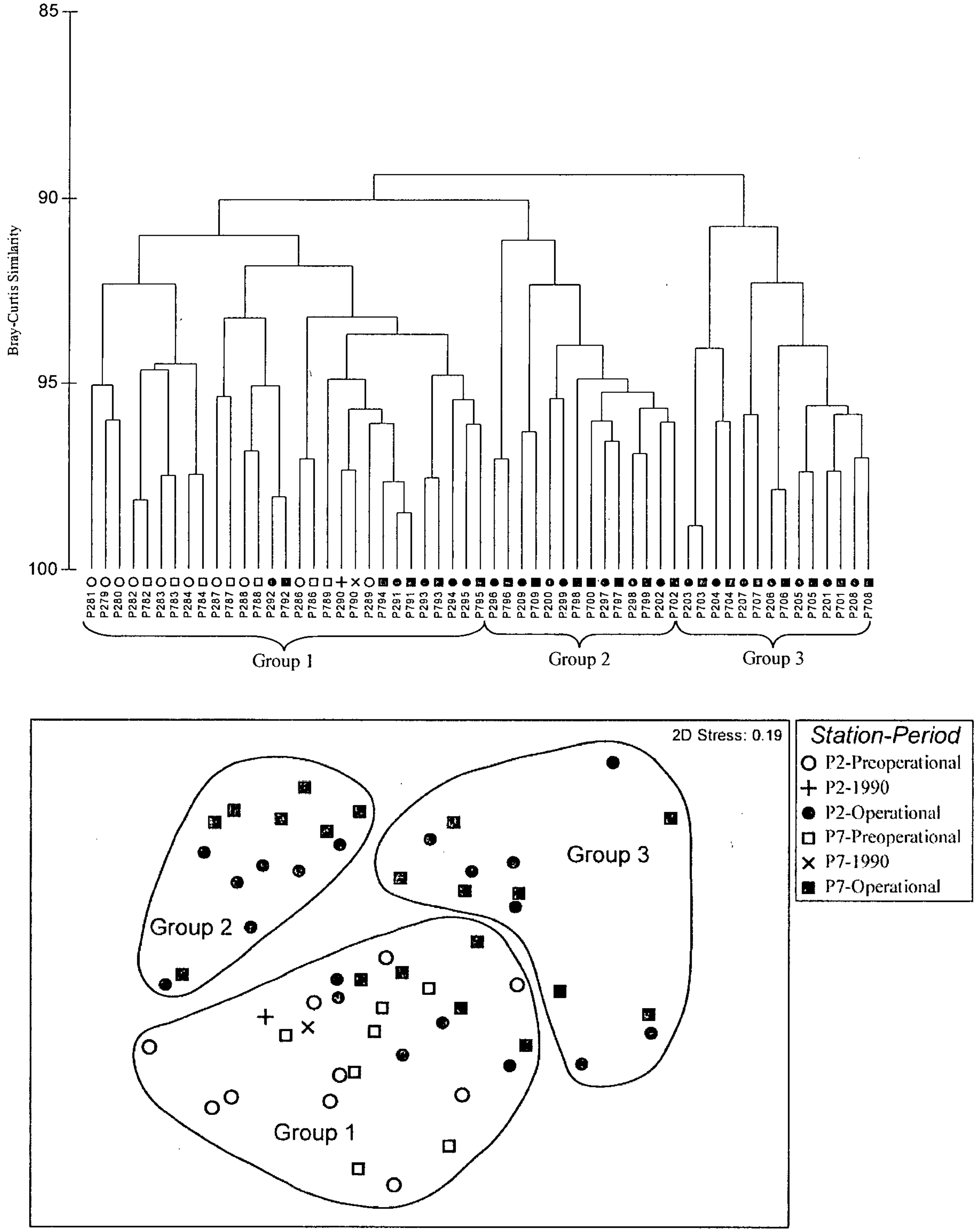



Figure 3-2. Cluster dendrogram and multi-dimensional scaling of the bivalve larvae community at Stations P2 and P7 from 1979 to 1984 and 1986 to 2009. Seabrook Operational Report, 2009.

periods with transition periods around 1995 and again around 2001-2002. The inclusion of the 2009 collections with Group 2 may indicate the beginning of a new trend. Collections from 2009 were associated with Group 2 because of very high densities of both *Mytilus edulis* and *Anomia squamula* (Section 3.3.2; Normandeau 2010). Long term temporal change was the main factor affecting the bivalve larvae assemblage. Station differences were minor in comparison to the temporal changes. Collections from Stations P2 and P7 from an individual year were usually paired and always occurred in the same group.

Average abundances of larval bivalves increased in the late 1990s and early 2000s (Group 2) compared to earlier collections (Group 1). The densities of all species except for *Hiatella* sp. and *Mya truncata* increased during this period and species like *Mytilus edulis* and *Anomia squamula* increased exponentially (Table 3-2). Total larval density was about seven times greater in Group 2 compared to Group 1 collections. In recent years, 2001 and 2003 to 2008 (Group 3), total larval densities returned to levels similar to Group 1, but the community composition differs between Groups 1 and 3. Collections from 1979 to 1995 (Group 1) were dominated by *Mytilus edulis* and *Hiatella* sp.; the recent collections (Group 3) were dominated by *Anomia squamula*.

The observed trends in bivalve larvae abundance and community composition appear unrelated to plant operation. The increase of bivalve larvae density in the mid-1990s to early 2000s, the subsequent decline and the change in dominants occurred at both stations (Figure 3-2; Table 3-2). The MDS plot displayed a trend between the preoperational and operational periods but no indication of any station differences (Figure 3-2). The MDS plot displayed all collections as a coherent group without any group of collections isolated from the others. As station differences were not observed and both stations followed a similar pattern throughout the study, a plant impact is unlikely. Significant differences between stations and the two operational periods were not detected using the ANOSIM model and there was no indication of a significant interaction (Table 3-3).

**Holoplankton**

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

Annual changes in the density and relative abundance of the two dominant copepods, *Centropages typicus* and *Calanus finmarchicus* have largely determined the patterns observed in the holopankton assemblage during this study. Collections were divided into two major groups by numerical classification (Figure 3-3). The main difference between Groups 1 and 2 was the abundance of *Centropages typicus* which was much less common in Group 2 (Table 3-4). Species that are typically found more offshore, such as *Metridia* sp. and Appendicularia were also more common when *Centropages typicus* dominated the holoplankton assemblage. *Calanus finmarchicus* was more abundant in the Group 2 collections when compared to Group 1 collections, but the increase was not as great as the difference in *Centropages typicus* densities between the two groups. Exceptionally large numbers of *Calanus finmarchicus* in 1978 and *Centropages typicus* in 2000 resulted in the separation of two unique groups by numerical classification.

Several multi-year trends were indicated by numerical classification. *Centropages typicus* dominated the holoplankton from 1979 to 1982 and then again from 1990 to 2001 (Figure 3-3; Table 3-4). *Calanus finmarchicus*-dominated

**Table 3-2. Geometric Mean Density (no./1000 $m^3$) of Bivalve Larvae in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2009.**

| | Group 1 | | | Group 2 | | | Group 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | LCL[a] | MEAN | UCL[b] | LCL[a] | MEAN | UCL[b] | LCL[a] | MEAN | UCL[b] |
| *Mytilus edulis* | 49,290 | 76,350 | 118,266 | 320,919 | 425,349 | 563,761 | 43,667 | 57,584 | 75,936 |
| *Hiatella* sp. | 30,685 | 43,948 | 62,944 | 21,156 | 41,933 | 83,114 | 15,978 | 26,795 | 44,936 |
| *Anomia squamula* | 18,818 | 26,782 | 38,117 | 395,424 | 586,442 | 869,735 | 63,674 | 108,253 | 183,177 |
| *Modiolus modiolus* | 1,792 | 2,938 | 4,817 | 1,886 | 3,376 | 6,044 | 73 | 163 | 362 |
| Solenidae | 2,188 | 2,810 | 3,607 | 3,399 | 6,563 | 12,673 | 2,593 | 3,795 | 5,556 |
| *Spisula solidissima* | 267 | 355 | 471 | 431 | 591 | 811 | 59 | 120 | 242 |
| *Mya arenaria* | 157 | 241 | 368 | 462 | 806 | 1,405 | 190 | 311 | 508 |
| *Mya truncata* | 27 | 40 | 58 | 12 | 29 | 68 | 6 | 11 | 18 |
| *Placopecten magellanicus* | 2 | 3 | 6 | 2 | 4 | 9 | <1 | <1 | 1 |

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

**Table 3-3. Analysis of Similarities (ANOSIM) Between Station and Period of Each Zooplankton Assemblage. Seabrook Operational Report, 2009.**

| Assemblage | Comparison | R | P[a] |
|---|---|---|---|
| Bivalve larvae | Period[b] | 0.11 | 5.7 NS |
| | Station[b] | -0.04 | 90.4 NS |
| | Preop: P2 vs. P7[c] | -0.17 | 97.9 NS |
| | P2: Preop vs. Op[c] | 0.07 | 21.4 NS |
| | P7: Preop vs. Op[c] | 0.16 | 7.5 NS |
| | Interaction of Main Effects | | Not Significant |
| Holoplankton | Period[b] | 0.10 | 10.8 NS |
| | Station[b] | -0.05 | 99.4 NS |
| | Preop: P2 vs. P7[c] | -0.15 | 90.5 NS |
| | P2: Preop vs. Op[c] | 0.15 | 10.7 NS |
| | P7: Preop vs. Op[c] | 0.05 | 30.9 NS |
| | Interaction of Main Effects | | Not Significant |
| Meroplankton | Period[b] | -0.13 | 95.9 NS |
| | Station[b] | 0.00 | 38.9 NS |
| | Preop: P2 vs. P7[c] | 0.05 | 29.2 NS |
| | P2: Preop vs. Op[c] | -0.14 | 89.6 NS |
| | P7: Preop vs. Op[c] | -0.12 | 81.7 NS |
| | Interaction of Main Effects | | Not Significant |
| Hyperbenthos | Period[b] | 0.07 | 20.3 NS |
| | Station[b] | 0.61 | 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

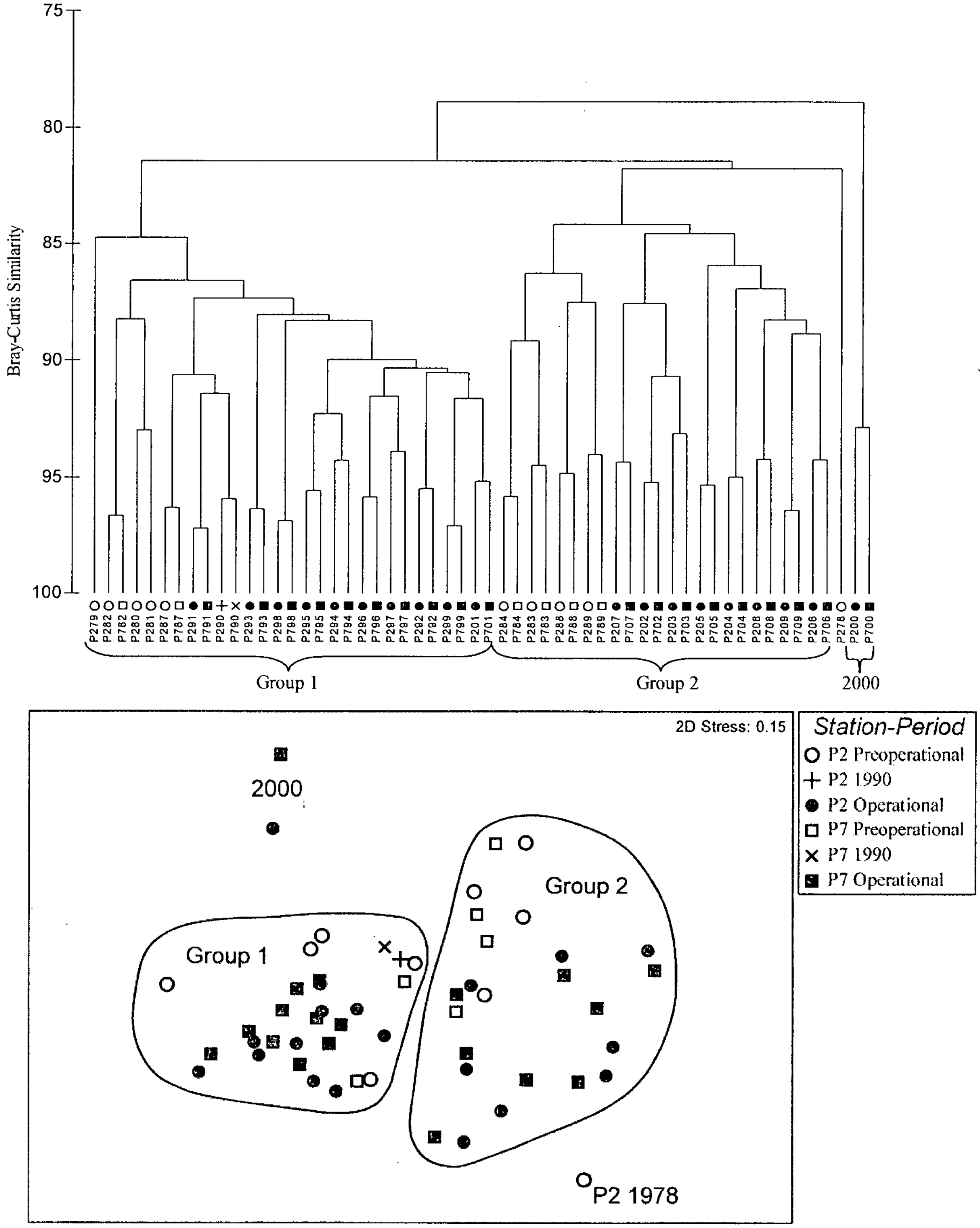



Figure 3-3. Cluster dendrogram and multi-dimensional scaling of the holoplankton community at Stations P2 and P7 from 1978 to 1984 and 1987 to 2009. Seabrook Operational Report, 2009.

**Table 3-4. Geometric Mean Density (no./1000 m$^3$) of Dominant[a] Holoplankton in Groups Formed by Cluster Analysis. Seabrook Operational Report, 2009.**

| | Group 1 | | | Group 2 | | |
|---|---|---|---|---|---|---|
| Species | LCL[b] | MEAN | UCL[c] | LCL | MEAN | UCL |
| *Centropages typicus* | 6,147 | 8,926 | 12,962 | 428 | 766 | 1,370 |
| *Calanus finmarchicus* | 2,882 | 3,604 | 4,508 | 4,252 | 5,489 | 7,086 |
| *Temora longicornis* | 903 | 1,576 | 2,749 | 714 | 1,120 | 1,756 |
| *Tortanus discaudatus* | 574 | 925 | 1,492 | 239 | 532 | 1,185 |
| *Metridia* sp. | 260 | 400 | 615 | 33 | 49 | 73 |
| *Parasagitta elegans* | 288 | 359 | 446 | 158 | 220 | 307 |
| *Pseudocalanus* sp. | 208 | 270 | 350 | 89 | 134 | 202 |
| *Centropages* sp. | 160 | 258 | 416 | 18 | 29 | 48 |
| Appendicularia | 139 | 205 | 302 | 20 | 28 | 39 |
| *Centropages hamatus* | 43 | 61 | 85 | 70 | 131 | 245 |

| | 1978 | | | 2000 | | |
|---|---|---|---|---|---|---|
| Species | LCL | MEAN | UCL | LCL | MEAN | UCL |
| *Centropages typicus* | - | 327 | - | 5,5557 | 81,397 | 1,191,986 |
| *Calanus finmarchicus* | - | 10,528 | - | 0 | 640 | 2.52x10$^8$ |
| *Temora longicornis* | - | 35 | - | 3 | 495 | 62,011 |
| *Tortanus discaudatus* | - | 249 | - | 18 | 393 | 8,214 |
| *Metridia* sp. | - | 139 | - | 9 | 20 | 44 |
| *Parasagitta elegans* | - | 321 | - | 13 | 150 | 1,609 |
| *Pseudocalanus* sp. | - | 2,536 | - | 1 | 13 | 97 |
| *Centropages* sp. | - | 17 | - | 182 | 3,803 | 79,292 |
| Larvacea | - | 3 | - | 0 | 21 | 520 |
| *Centropages hamatus* | - | 27 | - | 8 | 61 | 416 |

[a] Taxa contributing >1% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

assemblages were more common from 1983 to 1989 and have appeared consistently since 2002. Smaller trends appear within the larger multi-year trends as collections from consecutive years tend to group together within the dendrogram. Both the *Centropages typicus*- and *Calanus finmarchicus*-dominated assemblages have occurred in both the preoperational and operational periods and no significant differences were detected (Table 3-3).

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 planktic stages of benthic invertebrates, including many 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). Several smaller groups representing early preoperational collections (Group 3) and a few later operational collections (Group 2 and 2000) were also defined as distinct groups by numerical classification. In general the dendrogram displays a considerable degree of chaining within Group 1, and the differences between 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, especially *Eualus pusiolus* and *Crangon septemspinosa* (Table 3-5). In general, total meroplankton densities were greatest in Group 1. Lower densities of the veligers of the snail *Lacuna vincta* in the early preoperational period (Group 3) and again in the later operational period (Group 2) in comparison to Group 1 helped distinguish those groups. Densities of *Carcinus maenas* larvae were slightly greater in 2000 relative to other years. In general however, abundances of most of the meroplankton taxa and the community composition were similar among the groups formed by numerical classification.

Collections from some of the recent years, 2000 and Group 2 (which includes 2004, 2005, 2008 and 2009), formed a new group, distinct from the typical meroplankton assemblage (Group 1), suggesting that a new trend may be developing. The abundances of all of the dominant meroplankton species were lower in 2000 and Group 2 compared to other groups (Table 3-5); especially *Crangon septemspinosa* and *Lacuna vincta*.

No long term trends were indicated by numerical classification. Consecutive years were sometimes grouped, but there did not appear to be any consistent trends. Although numerical classification defined a group composed entirely of operational period collections, most operational collections were associated with preoperational collections and no significant differences were detected between the preoperational and operational periods (Table 3-3). The MDS plot lacks any clearly segregated groups, suggesting that differences among the groups formed by numerical classification were small. Station differences were negligible as Stations P2 and P7 were usually paired, and always occurred in the same group. Significant differences were not detected between stations and the indirect test for interaction was not significant (Table 3-3).

**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 *Phyllothalestris, Parathalestris* and *Alteutha*) and swarming reproductive adults of some polychaetes are also present.

Large station differences have been observed throughout the study. Numerical classification defined two major groups, one composed mostly of Station P2 collections (Group 1) and the other (Group 2) composed almost entirely of Station P7 collections (Figure 3-5). Group 1 consisted of nearly all Station P2 collections (P2 collections in 2005 were the only exception) and a few P7 collections. 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

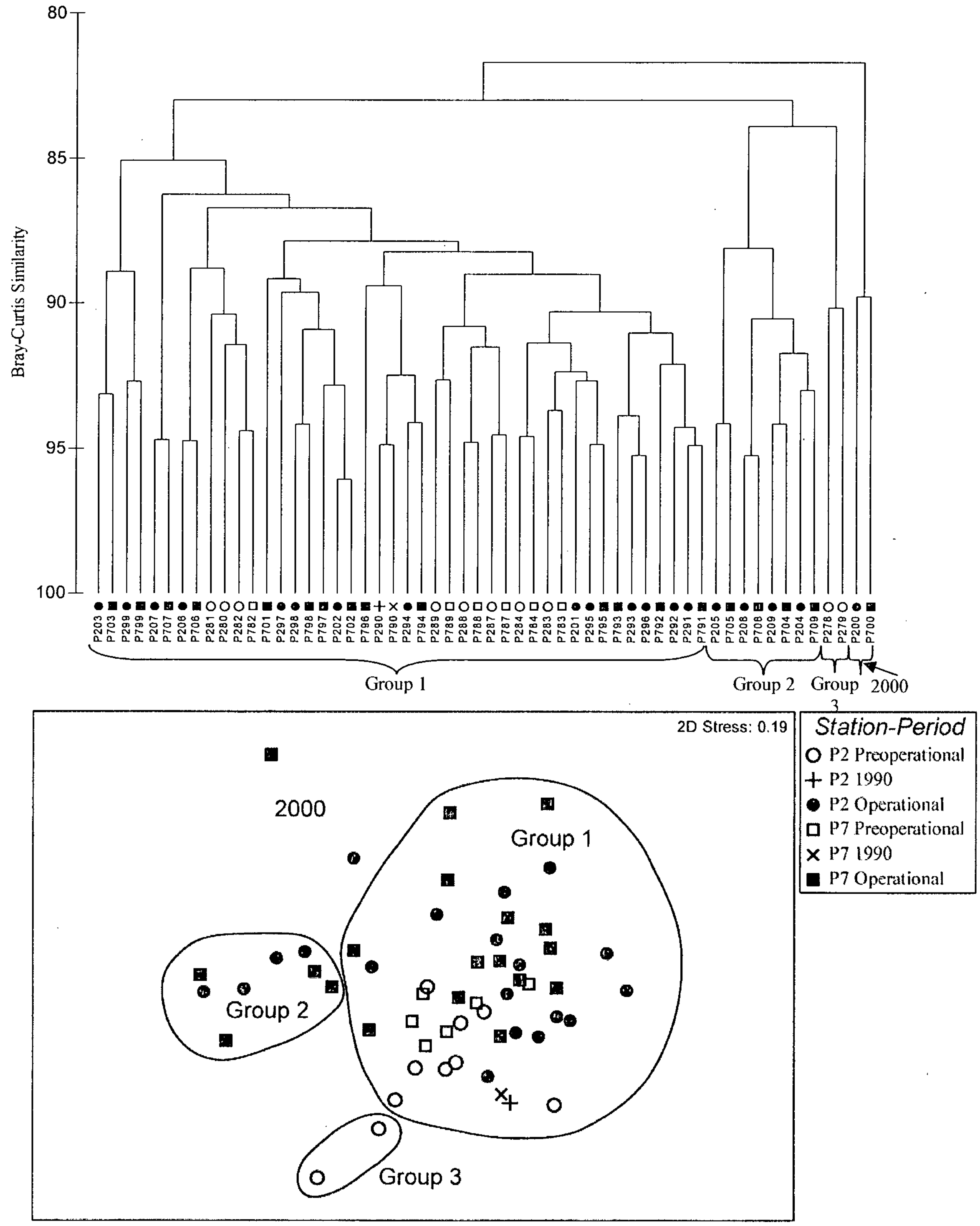



Figure 3-4. Cluster dendrogram and multi-dimensional scaling of the meroplankton community at Stations P2 and P7 from 1978 to 1984 and 1987 to 2009. Seabrook Operational Report, 2009.

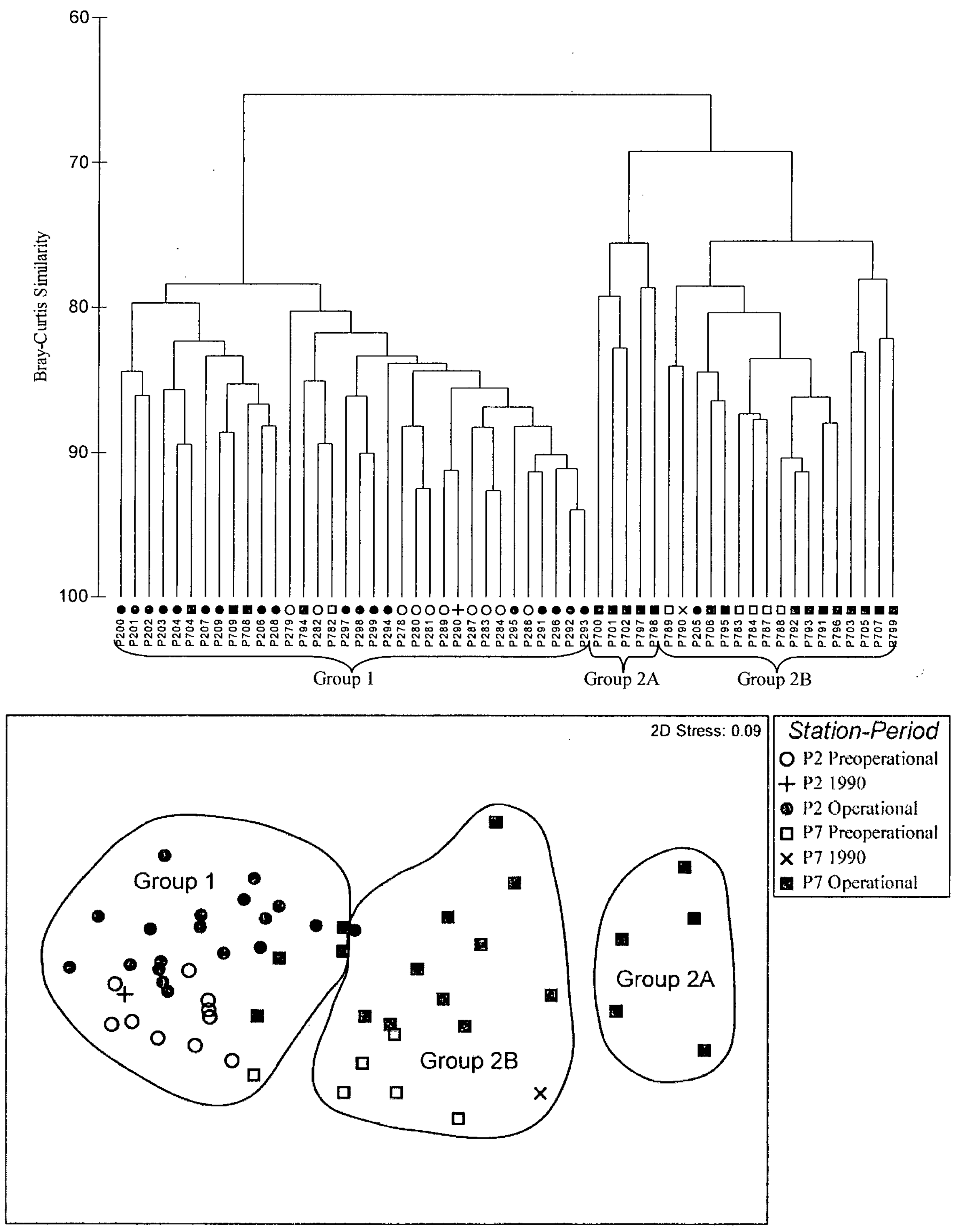



Figure 3-5. Cluster dendrogram and multi-dimensional scaling of the hyperbenthos assemblage at Stations P2 and P7 from 1978 to 1984 and 1987 to 2009. Seabrook Operational Report, 2009.

**Table 3-5. Geometric Mean Density (no./1000m$^3$) of Dominant[a] Meroplankton in Groups formed by Cluster Analysis. Seabrook Operational Report, 2009.**

| | Group 1 | | | Group 2 | | | Group 3 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | LCL[b] | MEAN | UCL[c] | LCL | MEAN | UCL | LCL | MEAN | UCL | LCL | MEAN | UCL |
| *Eualus pusiolus* | 553 | 659 | 784 | 307 | 388 | 489 | 1 | 150 | 9,950 | 156 | 282 | 507 |
| *Crangon septemspinosa* | 124 | 150 | 182 | 33 | 44 | 58 | 361 | 390 | 420 | 0 | 83 | 14,466 |
| *Cancer* sp. | 108 | 124 | 143 | 59 | 78 | 103 | 37 | 164 | 716 | 31 | 72 | 163 |
| *Carcinus maenas* | 34 | 39 | 46 | 15 | 20 | 26 | 0 | 23 | 401 | 4 | 58 | 766 |
| Cirripedia | 26 | 32 | 39 | 8 | 13 | 20 | 1 | 20 | 256 | 1 | 5 | 18 |
| *Lacuna vincta* | 23 | 31 | 42 | 1 | 2 | 4 | 0 | 2 | 123,025 | 0 | 11 | 2,324 |
| *Pagurus* sp. | 24 | 28 | 33 | 13 | 17 | 23 | 20 | 29 | 40 | 0 | 18 | 4,376 |
| *Obelia* sp. | 9 | 11 | 14 | 1 | 2 | 3 | 0 | 6 | 1,016 | 0 | 1 | 15 |
| Tubulariidae | 6 | 8 | 10 | 1 | 2 | 3 | 0 | 0 | 1 | 0 | 7 | 766 |
| *Hyas* sp. | 5 | 6 | 7 | 4 | 5 | 6 | 0 | 9 | 85 | 0 | 1 | 62 |

[a] Taxa contributing >1% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

**Table 3-6. Geometric Mean Density (no./1000m$^3$) of Dominant[a] Hyperbenthos in Groups formed by Cluster Analysis. Seabrook Operational Report, 2009.**

| | Group 1 | | | Group 2A | | | Group 2B | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | LCL[b] | MEAN | UCL[c] | LCL[b] | MEAN | UCL[c] | LCL[b] | MEAN | UCL[c] |
| *Neomysis americana* | 72 | 108 | 162 | 4 | 8 | 15 | 11 | 18 | 27 |
| *Diastylis* sp. | 25 | 33 | 45 | 0 | 1 | 3 | 3 | 4 | 5 |
| *Pontogeneia inermis* | 22 | 29 | 37 | 0 | 1 | 2 | 3 | 4 | 6 |
| Harpacticoida | 14 | 19 | 26 | 4 | 8 | 16 | 5 | 7 | 10 |
| Oedicerotidae | 11 | 14 | 17 | 0 | 1 | 1 | 3 | 5 | 7 |
| *Pseudoleptocuma minor* | 6 | 8 | 10 | 0 | 1 | 2 | 1 | 2 | 2 |
| Syllidae | 4 | 5 | 6 | 4 | 7 | 14 | 6 | 8 | 11 |
| Amphipoda | 4 | 5 | 6 | 1 | 1 | 1 | 2 | 2 | 3 |
| *Mysis mixta* | 2 | 3 | 4 | 0 | 0 | 1 | 1 | 2 | 3 |
| *Calliopius laeviusculus* | 1 | 1 | 2 | 0 | 1 | 2 | 0 | 0 | 1 |
| *Jassa marmorata* | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |

[a] Taxa contributing >1% of geometric mean in any group.
[b] LCL = Lower 95% confidence limit.
[c] UCL = Upper 95% confidence limit.

(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). Almost all Station P2 annual collections were united within Group 1 and tightly grouped in the MDS ordination (Figure 3-5). In contrast, farfield station (P7) collections formed two distinct subgroups. Sub-group 2A included all years from 1997 to 2002, except for 1999. Subgroup 2B included most of the remaining collections from Station P7. Species abundances were low in both sub-groups, relative to the nearfield site (Table 3-6). The principal difference between subgroups 2A and 2B was lower densities in subgroup 2A, especially among the larger peracarid species including *Neomysis* *americana*, which resulted in a change of the relative ranking of the dominant taxa.

In numerical classification, a group composed exclusively of collections from only one station in the operational period could indicate a potential plant impact. The differences between the preoperational and operational periods were observed only at the farfield site (sub-group 2A was composed of Station P7 operational period collections only). In contrast, the hyperbenthos assemblage at the nearfield site, where an impact is likely to occur, has been relatively consistent throughout the study. The consistency of the assemblage at the nearfield site does not suggest a plant impact, but rather that some other factor has affected hyperbenthos densities at the farfield site. Sub-group 2A consists of collections that follow modest method changes instituted in 1996 (see Discussion). Also, all farfield collections from the early part of the operational period, 1991 to 1996 were associated with preoperational period collections.

Stations P2 and P7 are generally similar in terms of hydrography and gross habitat. Both have predominantly sandy bottoms in about 18 meters of water. Because differences in hyperbenthic species abundances between the two stations 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 lower at Station P7, which could be attributed to the earlier sampling times there (see Discussion). The ANOSIM model could not test the interaction of main effects because of station differences in the preoperational period (Table 3-3).

### 3.3.2 Selected Species

Five species were selected from the zooplankton program for further investigation due to either their abundance, 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. Mytilid spat (< 25 mm) 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 typically 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 veligers in mid-May were considerably greater during the operational period compared to the preoperational period, indicating 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

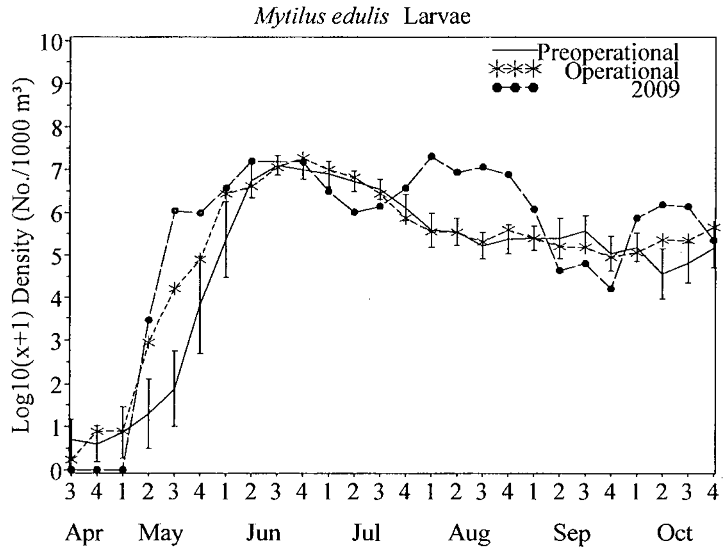



Figure 3-6. Weekly log(x+1) density of *Mytilus edulis* larvae at Station P2; preoperational period (1978-1984, 1986-1989) log (x+1) weekly means and 95% confidence intervals, and the operational period (1991-2009) and 2009 weekly means. Seabrook Operational Report, 2009.

magnitude greater when compared to the preoperational and early operational years through 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. The past two years have shown conditions similar to the 1996 to 2002 period with large numbers of veligers appearing in mid-May. The seasonal occurrence of veligers in 2009 was atypical of the preoperational and operational periods, appearing to be a tri-modal with greater abundances in June, August and October. Climate conditions in 2009 were unusual due to heavier than normal rains in July and August, which may have affected the spawning, development or distribution of the larvae.

The geometric mean larval density in 2009 exceeded the 95% confidence intervals for the preoperational and operational means at both stations (Table 3-7). Densities were greater at Station P7 than Station P2 and the annual density of 424,930 larvae/1000m$^3$ was the third greatest ever recorded at the farfield site (Figure 3-7). Geometric means indicate a large increase in veliger density between the preoperational and operational periods. A 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* based on a period that was established to monitor the soft-shell clam *Mya arenaria*. A slight shift in the seasonal occurrence such as the earlier appearance of larvae can dramatically increase the annual mean values because fewer zero or near-zero values are included in the mean. Weekly operational period means (Figure 3-6) are higher than preoperational means in April and May, then similar for the remainder of the year, contributing to the higher operational period average presented in Table 3-7. Annual average 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

**Table 3-7. Zooplankton Species at Stations P2 and P7 During the Preoperational and Operational Periods and in 2009. Seabrook Operational Report, 2009.**

| Species/Lifestage | Station | Preoperational | | | Operational | | | 2009 |
|---|---|---|---|---|---|---|---|---|
| | | LCL[c] | Mean | UCL[d] | LCL[c] | Mean | UCL[d] | Mean |
| *Mytilus edulis*[a] | P2 | 26,666 | 65,181 | 159,327 | 73,460 | 130,550 | 232,009 | 283,578 |
| | P7 | 23,885 | 64,444 | 173,877 | 74,273 | 133,018 | 238,224 | 424,930 |
| *Calanus finmarchicus*[b] | P2 | 3,424 | 5,198 | 7,892 | 4,113 | 5,390 | 7,064 | 7,755 |
| | P7 | 1,595 | 3,082 | 5,957 | 2,315 | 3,532 | 5,389 | 8,318 |
| *Carcinus maenas*[b] | P2 | 22 | 28 | 36 | 31 | 43 | 61 | 35 |
| | P7 | 23 | 32 | 46 | 27 | 35 | 45 | 26 |
| *Crangon septemspinosa*[b] | P2 | 220 | 270 | 330 | 90 | 134 | 198 | 49 |
| | P7 | 92 | 161 | 281 | 56 | 74 | 99 | 45 |
| *Neomysis americana*[b] | P2 | 68 | 143 | 298 | 61 | 106 | 184 | 34 |
| | P7 | 17 | 43 | 105 | 9 | 13 | 18 | 21 |

[a] Years sampled: Preoperational: P2=1978-1984, 1986-1989, P7=1982-1984, 1986-1989
Operational: P2 and P7=1991-2009
*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=1991-2009

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

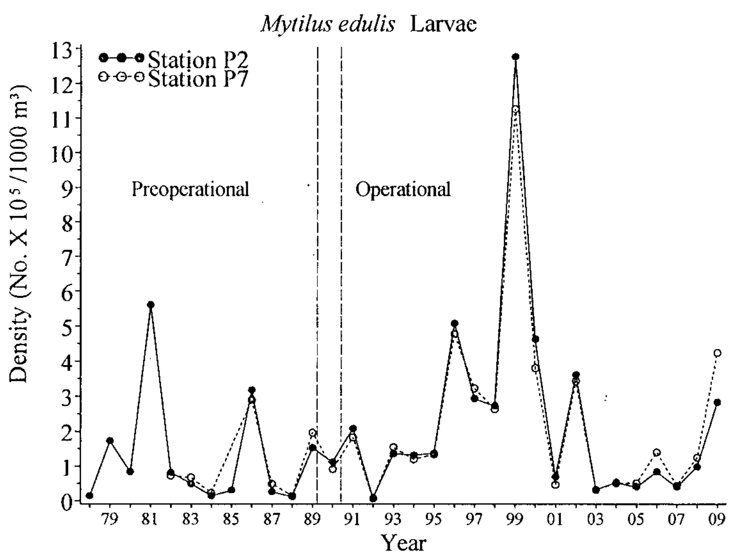



Figure 3-7. Annual geometric mean density of *Mytilus edulis* larvae at Stations P2 and P7 from 1978 to 2009. Seabrook Operational Report, 2009.

densities, attributed in part to the seasonal shift (above), occurred from 1996 to 2000 and 2002. Larval densities in recent years (2003 to 2008) were typically low, similar to the preoperational years 1982 to 1985. Collections from 2009 had large numbers of larvae, similar to the 1996 to 2000 period.

Differences between stations in veliger abundance in most years were very small in comparison to the large differences among years, a pattern present in both the preoperational and operational periods. Despite the the large differences in geometric means between the preoperational and operational periods (Table 3-7), there were no significant differences between the preoperational and operational periods (Table 3-8). Station differences were also not detected and the interaction of the main effects was not significant, indicating that no effect from the operation of Seabrook occurred.

***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 2009 were very high at both stations, continuing a trend of high densities that has been observed for the past three years (Figure 3-8). The 2009 mean density at Station P2 (7,755/1000m$^3$) was near or above the upper confidence limits of the preoperational and operational periods (Table 3-7, Figure 3-8). The 2009 density at Station P7 (8,318/1000m$^3$) was the second highest observed at that station, slightly less than the record high of 10,172/1000m$^3$ observed in 2001 (Table 3-7, Figure 3-8). Average density in both the preoperational and operational periods has been greater at Station P2 than Station P7, which may be surprising for such a ubiquitous organism at these spatial scales. *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 higher mean preoperational and operational abundances at Station P2 may reflect the tendency to sample Station P2 later in the night after Station P7.

In coastal New Hampshire waters, *Calanus finmarchicus* was seasonally most abundant in spring and summer, when it is usually among the dominant plankton species. At Station P2, densities increased in the early spring and were relatively consistent during the peak period from May to August (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 have declined more gradually in the late summer and fall from the maximum in July. *Calanus finmarchicus* in 2009 were typical of previous years except that winter densities were slightly greater than normal.

Annual densities of *Calanus finmarchicus* indicate several long-term trends. Although variation among years was great, abundances generally declined from 1978 through 1990 (Figure 3-8). Densities remained relatively low from 1991 through 2000; thereafter the densities have increased to levels observed in the early preoperational period. Although annual densities at Station P7 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

**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, 2009.**

| 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, 24 | 1.72 | 0.2018 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0998 | 3.29 | 0.0348* | |
| | Half Month(Year)[c] | 1.5153 | 799.03 | <0.0001* | |
| | Station[d] | 0 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 0.5545 | | | |
| *Calanus finmarchicus* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Jan-Dec) | Preop-Op[a] | 1, 296 | 0.47 | 0.4956 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.4997 | |
| | Month(Year)[c] | 1.0667 | 514.41 | <0.0001* | |
| | Station[d] | 0.0111 | 0.76 | 0.1921 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4997 | |
| | Error | 0.6652 | | | |
| *Carcinus maenas* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (May-Dec) | Preop-Op[a] | 1, 98 | 0.03 | 0.8672 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.4996 | |
| | Month(Year)[c] | 2.0860 | 723.81 | <0.0001* | |
| | Station[d] | 0.0031 | 0.13 | 0.3605 | |
| | Preop-Op X Station[e] | 0.0009 | 0.03 | 0.4346 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4998 | |
| | Error | 0.4888 | | | |
| *Crangon septemspinosa*[c] | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Jan-Dec) | Preop-Op[a] | 1, 268 | 4.16 | 0.0424* | Preop>Op |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.4999 | |
| | Month(Year)[c] | 1.1993 | 790.18 | <0.0001* | |
| | Station[d] | 0.0274 | 2.11 | 0.0731 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4999 | |
| | Station X Year (Preop-Op)[f] | 0.0140 | 4.89 | 0.0135* | |
| | Error | 0.4254 | | | |
| *Neomysis americana*[c] | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Jan-Dec) | Preop-Op[a] | 1, 23 | 7.85 | 0.0103* | Preop>Op |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0424 | 2.00 | 0.0786 | |
| | Month(Year)[c] | 0.3613 | 164.16 | <0.0001* | |
| | Station[d] | 0.3601 | 3.26 | 0.0354* | P2 > P7 |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0.0513 | 18.22 | <0.0001* | |
| | Error | 0.6242 | | | |

[a] Preop-Op compares 1982-1989 to 1991-2009 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 $H_o$: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

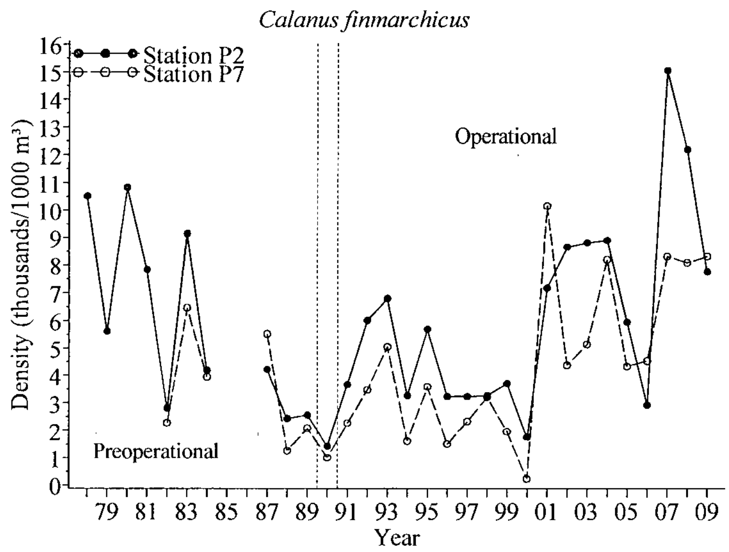



Figure 3-8. Annual geometric mean density of *Calanus finmarchicus* at Stations P2 and P7 from 1978 to 2009. Seabrook Operational Report, 2009.

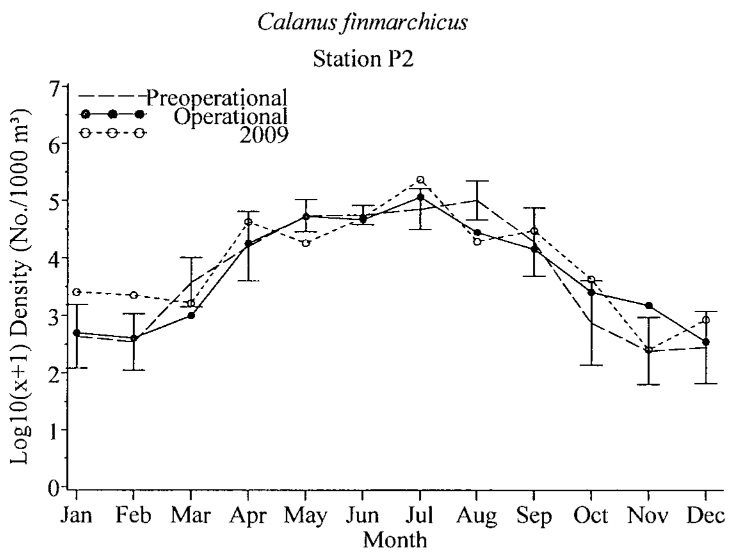



Figure 3-9. Monthly log(x+1) density of *Calanus finmarchicus* at Station P2; preoperational period (1978-1989, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2009) monthly means. Seabrook Operational Report, 2009.

adult crabs are strictly benthic, but the larval zoea and megalopa are common in the plankton. Adults are abundant and they are important predators on soft-shell clams. Adults exhibit thermal stress at 31-35°C (Cuculescu et al. 1998).

In 2009, larval *Carcinus maenas* densities were typical of previous years. Densities at both stations were near the lower confidence limits of the operational period means (Table 3-7). Densities were greater at both stations in the operational period, but station differences were small. The higher operational period densities were due to a period of high larval abundance that occurred from 1997 to 2002 (Figure 3-10), during which Station P2 abundances tended to be greater. In most other years, larval density was generally similar between the two stations and displayed similar trends. Larval densities have been low in recent years, 2003 through 2009, similar to the preoperational period.

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 2009, larvae first appeared in May and the annual peak occurred in June (Figure 3-11). 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 confidence limits of the preoperational period. The seasonal occurrence of larvae in 2009 was very similar to previous years except for minor deviations, notably slightly greater abundances in the fall.

Monthly and annual means suggest, at most, minor spatial or temporal differences for the larvae of the green crab. 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 planktic. Juveniles and adults are benthic, but are occasionally encountered in plankton tows.

Geometric mean *Crangon septemspinosa* densities in 2009 were below the confidence limits of both the preoperational and operational periods at both stations (Table 3-7). Larval densities in 2009 were among the lowest observed since sampling began in 1978 (Figure 3-12). In 2009, densities at Stations P2 and P7 were similar. *Crangon septemspinosa* densities have fluctuated widely among years and there appears to be a decreasing trend in recent years. Larval abundances have been lower than average since 1998, especially at Station P2, coinciding with the reduction in the number of tows taken (see Discussion). Average densities of this nighttime vertical migrant were generally lower at Station P7, probably due to the tendency to sample Station P7 first (also see Discussion).

In Chesapeake Bay, larval *Crangon septemspinosa* were present all year, but they 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. In 2009, larval densities were well below the preoperational confidence limits for ten of the 12 months, and were only within the confidence limits in March and during peak abundance in May. Larval densities during the operational period have declined from the preoperational period and were below the preoperational confidence limits in January and from August through December.

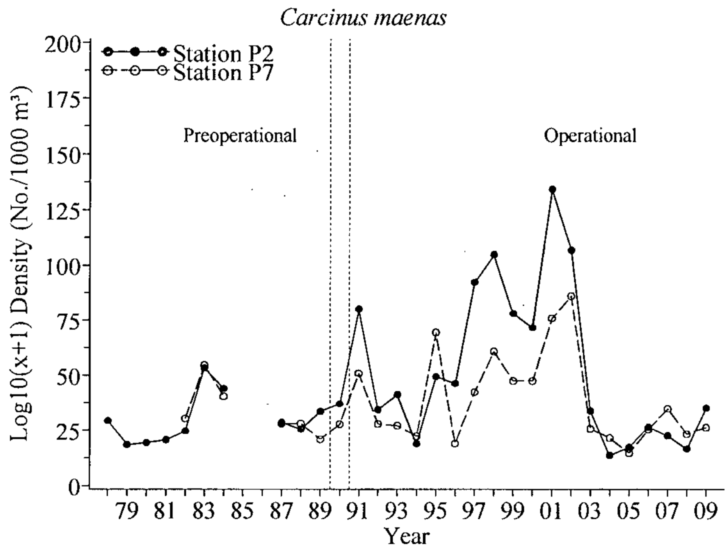



Figure 3-10. Annual geometric mean density of *Carcinus maenas* larvae at Stations P2 and P7 from 1978 to 2009. Seabrook Operational Report, 2009.

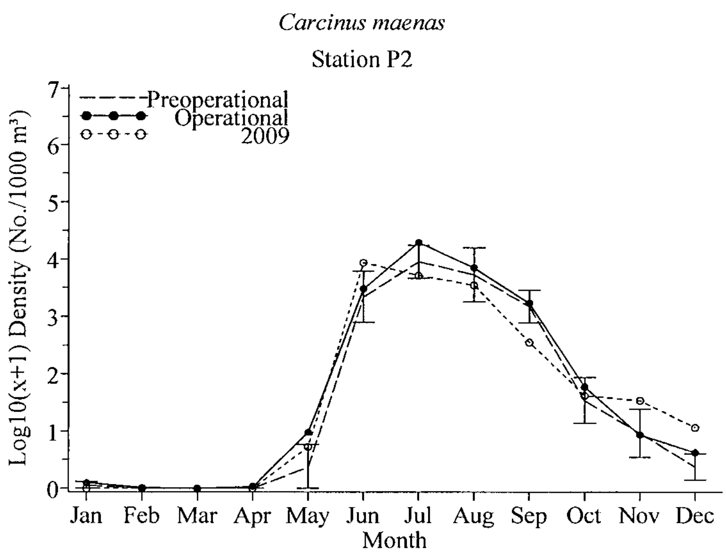



Figure 3-11. Monthly log(x+1) density of *Carcinus maenas* larvae at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2009) monthly means. Seabrook Operational Report, 2009.

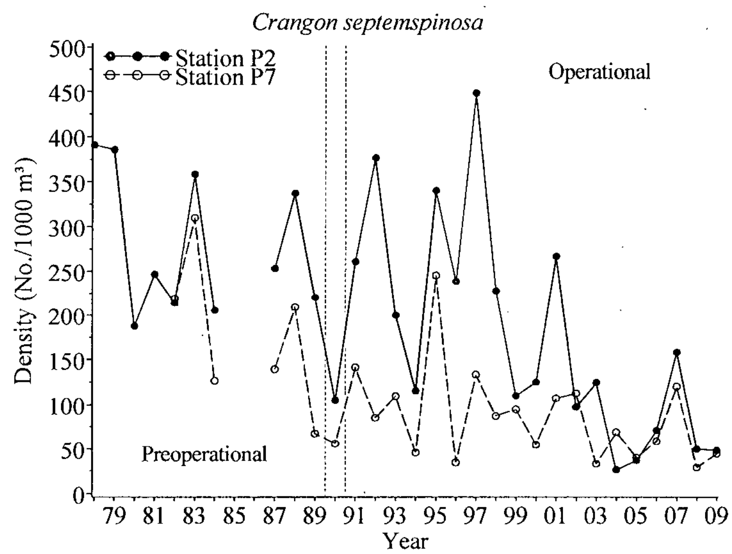



Figure 3-12. Annual geometric mean density of *Crangon septemspinosa* larvae at Stations P2 and P7 from 1978 to 2009. Seabrook Operational Report, 2009.

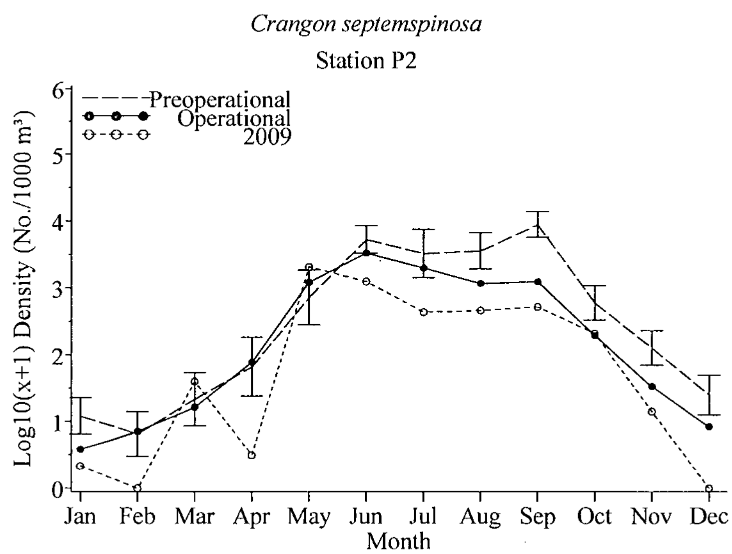



Figure 3-13. Monthly log(x+1) density of *Crangon septemspinosa* larvae at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2009) monthly means. Seabrook Operational Report, 2009.

The lower operational period abundance was significant, likely due to the decrease in average annual abundance since 1998 (Table 3-8). Significant differences were not detected between stations, 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. 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 Georges Bank and in this study (NAI 1995, 1996, 1998a).

*Neomysis americana* density at Station P2 in 2009 was below the preoperational and operational means (Table 3-7). The Station P7 density in 2009 was similar to the operational period average, but lower than the preoperational average. *Neomysis americana* was more abundant at Station P2 than at Station P7 in 2009, which was typical of previous years (Figure 3-14). This trend was attributed to the tendency to sample Station P7 earlier in the evening (see Discussion). 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). The seasonal cycle was similar in both the preoperational and operational periods, although March operational period densities were somewhat lower than preoperational. *Neomysis americana* densities in 2009 generally followed the usual seasonal pattern, although they were generally lower than what has been historically observed. Densities of the fall generation decreased substantially in November and December.

Annual geometric means indicate clear station differences. Densities at Station P2 were significantly greater than Station P7 (Table 3-8). The preoperational period had significantly higher densities than the operational period. However, the dissimilarity between stations observed in the preoperational period was maintained in the operational period and the interaction was not significant, indicating that the operation of Seabrook Station did not affect the population of *Neomysis americana*.

### 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 were related to the volume of cooling water circulating and larval abundance 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 2009 was 35,983 X $10^9$ (Table 3-9). In years when entrainment has been measured throughout most of the sampling period (excludes 1991, 1992 and 1994), total entrainment has ranged from 2,909 X $10^9$ to 67,415 X $10^9$ (Appendix Table 3-2). Entrainment numbers in 2009 were the third greatest recorded. As observed in previous years, *Anomia squamula* was the most common bivalve larva entrained in 2009 (77%). *Mytilus edulis* (11%) and *Hiatella* sp. (7%) accounted

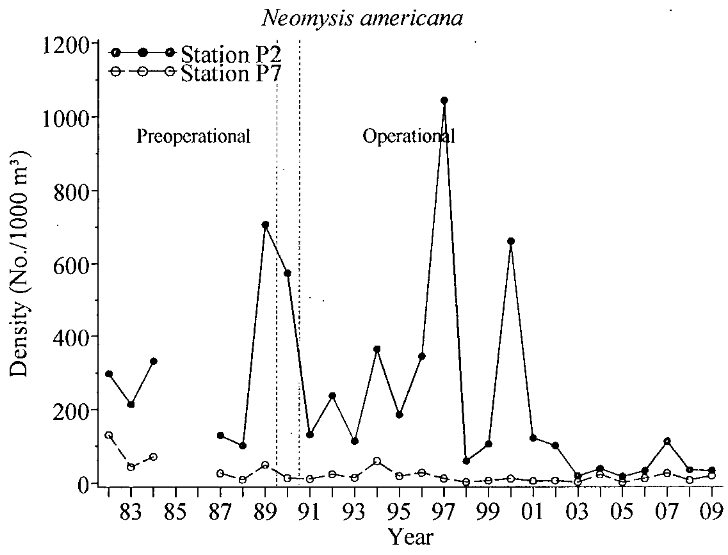



Figure 3-14. Annual geometric mean density of *Neomysis americana* at Stations P2 and P7 from 1978 to 2009. Seabrook Operational Report, 2009.

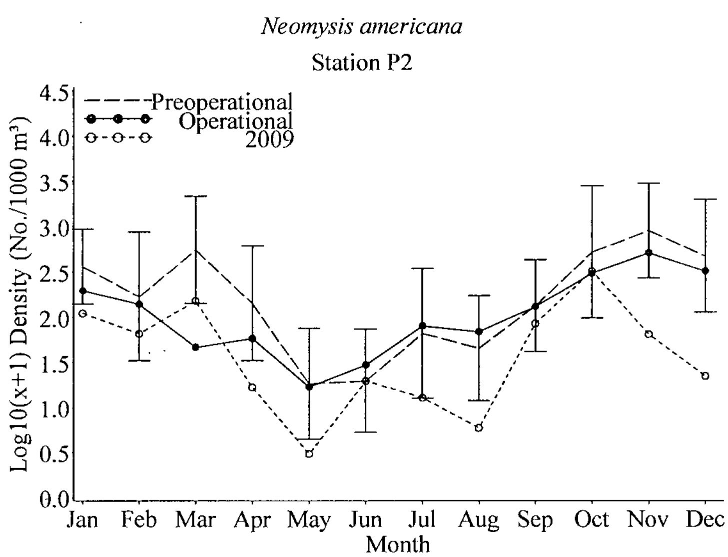



Figure 3-15. Monthly log(x+1) density of *Neomysis americana* at Station P2; preoperational period (1978-1984, 1987-1989) log (x+1) monthly means and 95% confidence intervals and the operational (1991-2009) and 2009 monthly means. Seabrook Operational Report, 2009.

**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, 2009 Seabrook Operational Report, 2009.**

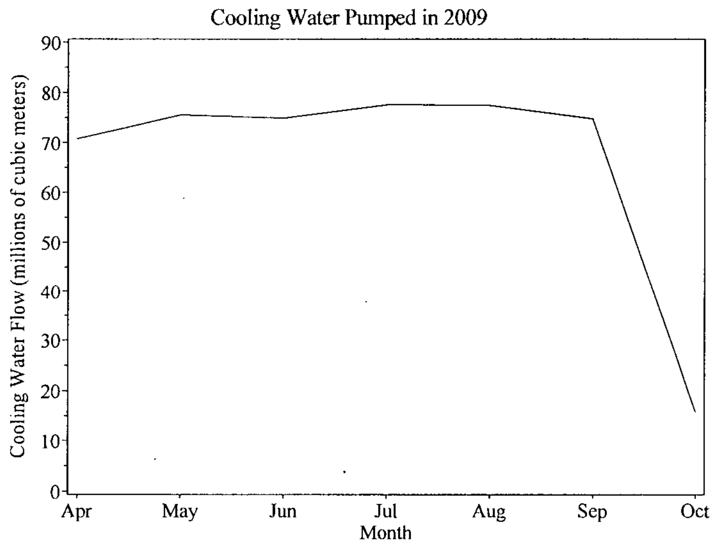
| Species | Apr | May | Jun | Jul | Aug | Sep | Oct | Total | % |
|---|---|---|---|---|---|---|---|---|---|
| *Anomia squamula* | 0.00 | 0.28 | 397.60 | 3098.06 | 23751.98 | 438.75 | 46.10 | 27732.76 | 77.07 |
| Bivalvia | 0.10 | 1.18 | 21.62 | 28.94 | 19.13 | 2.90 | 0.37 | 74.25 | 0.21 |
| *Hiatella* sp. | 56.25 | 300.47 | 890.59 | 376.13 | 906.64 | 17.31 | 0.29 | 2547.68 | 7.08 |
| *Modiolus modiolus* | 0.00 | 0.00 | 228.42 | 397.52 | 723.83 | 69.76 | 0.98 | 1420.52 | 3.95 |
| *Mya arenaria* | 0.00 | 0.11 | 12.05 | 3.18 | 7.20 | 8.67 | 0.53 | 31.75 | 0.09 |
| *Mya truncata* | 0.01 | 1.03 | 3.77 | 0.00 | 0.00 | 0.00 | 0.00 | 4.81 | 0.01 |
| *Mytilus edulis* | 0.00 | 125.89 | 2544.74 | 414.31 | 855.04 | 32.41 | 1.19 | 3973.58 | 11.04 |
| *Placopecten magellanicus* | 0.00 | 0.00 | 0.00 | 0.22 | 0.79 | 0.23 | 0.00 | 1.24 | 0.00 |
| Solenidae | 0.43 | 42.10 | 115.47 | 3.10 | 0.00 | 0.91 | 0.39 | 162.41 | 0.45 |
| *Spisula solidissima* | 0.00 | 0.00 | 8.68 | 7.03 | 0.79 | 13.68 | 1.36 | 31.54 | 0.09 |
| *Teredo navalis* | 0.00 | 0.00 | 0.05 | 0.34 | 0.00 | 1.86 | 0.01 | 2.26 | 0.01 |
| **Total** | 56.80 | 471.05 | 4222.99 | 4328.84 | 26265.39 | 586.48 | 51.24 | 35982.80 | 100.00 |
| **% of Total** | 0.16 | 1.31 | 11.74 | 12.03 | 72.99 | 1.63 | 0.14 | 100.00 | |

for most of the remaining larvae that were entrained.

Most larvae were entrained in August, due primarily to large numbers of *Anomia squamula* (Figure 3-16). Peak densities of *Anomia squamula* at the nearshore stations (P2 and P7) were much greater than normal, with densities exceeding 100,000 larvae per cubic meter in August 2009 (NAI 2010). The unusually large numbers of larvae in the coastal waters accounted for the high entrainment levels in August and overall for 2009. Entrainment levels in June and July were typical of previous years.

Seasonally, the bivalve larvae community in coastal New Hampshire waters has been dominated by *Hiatella* sp., which typically peaks in May and June; *Mytilus edulis,* which usually peaks in June and July; and *Anomia squamula,* which is generally present in large numbers from July to October (NAI 1990). The seasonal shift in the three dominant species was apparent in the entrainment numbers as *Hiatella* sp. was the most entrained larvae in April and May, *Mytilus edulis* in June and *Anomia squamula* thereafter. (Figure 3-16; Table 3-9).

There were seasonal differences in the density of bivalve larvae in the entrainment and coastal samples. From July through early September, the concentration of bivalve larvae in the cooling water system was substantially greater than the densities observed in the nearshore waters at Station P2 (Figure 3-17). A possible explanation is that the 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 a net tow through 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



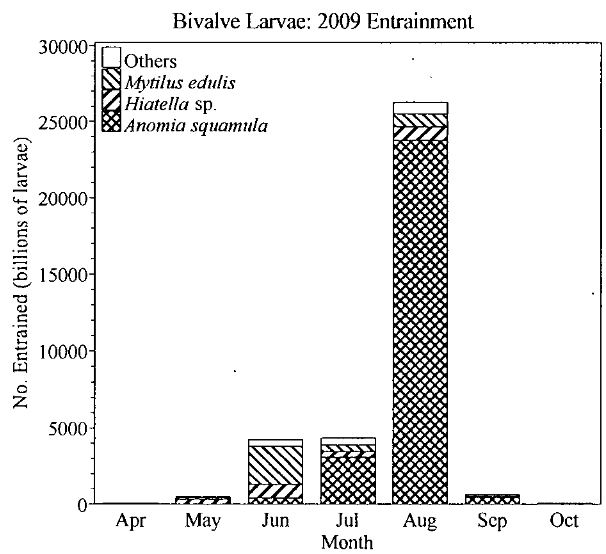




Figure 3-16. Volume of cooling water pumped during months of bivalve larvae sampling and total number of bivalve larvae (x $10^9$) entrained by Seabrook Station in 2009. Seabrook Operational Report, 2009.

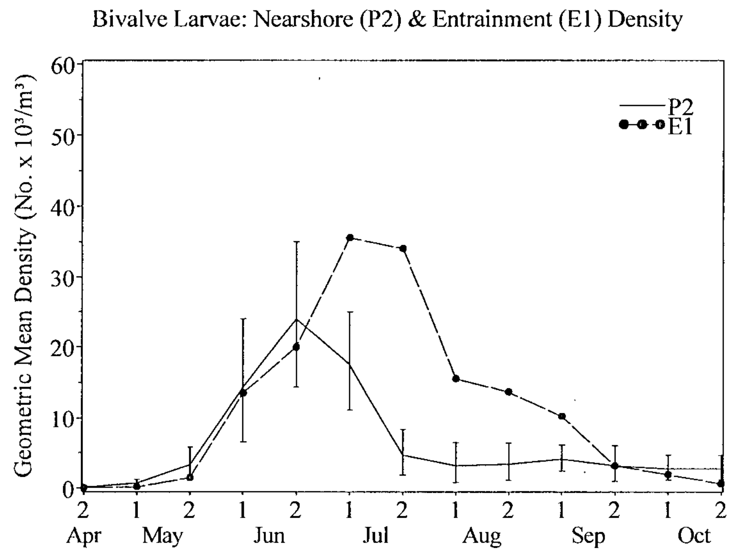



Figure 3-17. Geometric mean density of total bivalve larvae at Station E1 and P2 (95% confidence levels for P2) in 1993 and 1995-2009. Seabrook Operational Report, 2009.

depth distribution of chlorophyll *a*. The distribution of phytoplankton may be affected by thermal stratification and the depth of the thermocline. The seasonal difference in larval concentrations would likely affect summer dominants more. For example, *Anomia squamula* typically contributes over 75% of the individuals in entrainment samples annually, although it typically accounts for less than half of the total larvae collected in the nearfield waters (see Table 3-2). *Anomia squamula, Modiolus modiolus, Spisula solidissima, Teredo navalis* and several species lumped as Bivalvia have peak abundances in the summer months. The effect of the midwater intake may differ among species based on their individual behaviors. However, the greater densities observed in the entrainment samples can mostly be attributed to *Anomia squamula*.

The number of *Mya arenaria* entrained in 2009 was 31.75 X $10^9$ larvae (Appendix Table 3-2). 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, making 2009 a typical year. The actual entrainment numbers bracket the predicted entrainment level of 41 X $10^9$ larvae (NAI 1977). Entrainment of *Mya arenaria* may have little effect on settlement of young-of-the-year-clams as a strong relationship does not exist between larval abundance and settlement (see Section 7.0). Entrainment of *Mytilus edulis* larvae in 2009 (3,974 X $10^9$ larvae) was above 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 2009 among the lowest years in the time series. The low estimate for *Mytilus edulis* larvae entrainment is probably due to the estimate being based on samples collected from late June to October 1976, as part of the *Mya arenaria* monitoring. *Mytilus edulis* has peak densities in June and the original estimate likely underestimated the average annual density. Entrainment of *Mytilus edulis* has apparently not affected local populations of spat (juveniles) monitored in the marine macrobenthos program (Section 5.0).

## 3.4 DISCUSSION

### Possible effects of methodological changes initiated in 1996, 1998 and 2006

There were two methodological changes that likely 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. The reduction in replicates in 1996 effectively resulted in earlier sampling times at Station P7. The reduction in the number of oblique tows in 1998 effectively resulted in earlier sampling times at Station P2. The 1996 method change likely had a much greater effect on the results of the study.

Since the beginning of the study, 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 densities of many species at the farfield station. Lower densities at Station P7 in the preoperational period were observed for the selected species *Calanus finmarchicus*, *Crangon septemspinosa* and *Neomysis americana*. The lower densities at the farfield site, relative to the nearfield site, were observed in the preoperational and early operational periods, prior to the methodological changes in 1996 and 1998, which resulted in a further lowering of densities at the farfield site. The reduction in replication in 1996 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 taken consecutively (not simultaneously) 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. Prior to 1996, the lower-abundance A and B replicates from Station P7 were averaged with the higher-abundance C and D replicates. After 1996, the higher abundance C and D replicates were not analyzed, as a result, species densities at Station P7 were further reduced because the higher abundance replicates were no longer included in the mean. In contrast to Station P7, differences between the two sets of tows were generally not observed at Station P2, which was typically sampled later in the night. 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 were most noticeable among known vertical migrants and the hyperbenthos (NAI 2005). Beginning in 1996, 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 first set of tows was 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.

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, because sampling at Station P7 was completed earlier. It is not clear if this method change had an effect on results. Some differences in species abundance or community composition have been observed at Station P2 since 1998 (most notably the decrease in *Crangon septemspinosa* abundance and the formation of new groups in the meroplankton assemblage), but these results may also be attributed to a general decrease in total zooplankton abundance in the GOM from 2002 to 2006 (Kane 2009).

In 2006, 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 would hopefully be more uniform between the stations. Densities of the selected species *Neomysis americana* and *Crangon septemspinosa* from 2006 through 2009 did not increase at Station P7 as expected. However, densities of these species were also lower at Station P2 from 2006 to 2009 relative to earlier years, suggesting that the 2006 method change most likely occurred during a period of lower plankton abundance. In the hyperbenthos assemblage, most Station P7 collections from 1997 to 2002, characterized by extremely low abundances of the larger peracarid species, formed a group distinct from preoperational and earlier operational Station P7 collections in the dendrogram. After initiating a later sampling time at Station P7 in 2006, peracarid abundances have increased slightly and community composition is more similar to the preoperational and early operational periods; Station P7 collections have been associated with either the earlier Station P7 collections or with the higher density Station P2 collections in numerical classification.

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. The effect of the reduction in replicates, lower abundances of some species in the samples and the alteration of historically observed patterns in the multivariate analyses, are largely limited to the hyperbenthos and to a lesser extent, the meroplankton. 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.

**Assessment of potential plant impacts on the zooplankton community**

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 or nearfield site) collections from the operational period were grouped together and were distinct from the Station P7 (control or farfield 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 of the zooplankton communities by the ANOSIM model (Table 3-10). However, the ANOSIM model could not be used for the hyperbenthos assemblage because spatial differences in the preoperational period existed. Numerical classification results indicate that differences between the preoperational and operational periods were not consistent between the two the stations. The hyperbenthic

**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, 2009.**

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

assemblage at the nearfield site, where a plant impact would be anticipated, has been relatively consistent throughout the study. In contrast, a hyperbenthic assemblage was observed at the farfield site during the operational period that was not observed during the preoperational period. However, the operational period changes observed at Station P7 were most likely caused by the sampling method changes initiated in 1996 and 1998 (see above). From 1978 to 1996, which spans the preoperational period and the early part of the operational period before the method changes, the hyperbenthic assemblage was relatively consistent. Large station differences existed, but the community composition at each station remained relatively consistent from year to year. From 1995, to 2005, following the method changes, the hyperbenthos community at Station P7 was characterized by very low abundances, especially peracarid species resulting in changes in community composition and the formation of a unique group of collections in numerical classification. In 2006, sampling time was moved to nautical sunset to compensate for the method changes. The community composition of the hyperbenthos since then has been similar to the pre-methodological changes, although densities have remained very low. The similarity of the preoperational and operational periods at the nearfield site along with consideration of the likely method change effects at the farfield site do not suggest a plant impact on the hyperbenthic assemblage.

Significant interactions, suggesting the possibility of plant impacts, were also not observed for any of the selected species by the ANOVA model (Table 3-11). In general, temporal trends account for most of the variation in the selected species abundances. Large increases in abundance of *Mytilus edulis* veligers and *Carcinus maenas* larvae occurred in the late 1990s and early 2000s. *Calanus finmarchicus* abundances appear to follow decadal trends. Large interannual variation was observed for *Crangon septemspinosa* zoea (which almost appears as a three-year cycle) and *Neomysis americana.* Average abundances of these species were significantly different between the preoperational and operational periods, but consistent between stations. Spatial differences in the abundance of selected species were generally small in comparison to the temporal variation.

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,

**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, 2009.**

| 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 |
| *Carcinus maenas* larvae | Yes | Yes |
| *Crangon septemspinosa* larvae | Preop > Op | Yes |
| *Neomysis americana* | Preop > Op | Yes |

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. The community is dominated by coastal and marine species. Estuarine species such as *Acartia tonsa, Eurytemora* spp. and *Palaemonetes* spp. are rare or uncommon in these samples and are very rarely dominant, indicating that the estuaries have very little influence at these sampling stations, although the coarse mesh size of the nets may under-sample the smaller estuarine species.

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). More recently, Kane (2009) noted an increase in zooplankton abundance throughout the Gulf of Maine from about 1990 to 2001, with a sudden drop in 2002. Total zooplankton densities from 2002 to 2006 were average or below average. Kane (2009) also noted a marked change in community composition during the 1990s from previous and subsequent years. The pattern described by Pershing et. al (2005) and Kane (2009) 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 (Section 2.0). 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, 2008.**

| | | |
|---|---|---|
| **Bivalve Larvae** | | |
| | | *Anomia squamula* Linnaeus, 1758 |
| | | *Hiatella* Bosc, 1801 |
| | | *Macoma balthica* (Linnaeus, 1758) |
| | | *Modiolus modiolus* Linnaeus, 1758 |
| | | *Mya arenaria* Linnaeus, 1758 |
| | | *Mya truncata* Linnaeus, 1758 |
| | | *Mytilus edulis* Linnaeus, 1758 |
| | | *Placopecten magellanicus* (Gmelin, 1791) |
| | | Solenidae Lamarck, 1809 |
| | | *Spisula solidissima* (Dillwyn, 1817) |
| | | *Teredo navalis* Linnaeus, 1758 |
| **Holoplankton** | | |
| | Cnidaria | *Aglantha digitale* (O.F. Müller, 1776) |
| | Mollusca | *Clione limacina* Phipps, 1774 |
| | | *Limacina retroversa* Fleming, 1823 |
| | Annelida | *Tomopteris helgolandicus* Greeff, 1879 |
| | Arthropoda/Cladocera | *Evadne* Lovén, 1835 |
| | | *Podon* Lilljeborg,1853 |
| | Arthropoda/Copepoda | *Acartia* Dana, 1846 |
| | | *Acartia hudsonica* Pinhey, 1926 |
| | | *Acartia longiremis* (Lilljeborg, 1853) |
| | | *Acartia tonsa* Dana, 1849 |
| | | Aetideidae Giesbrecht, 1893 |
| | | *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 Dana, 1849 |
| | | *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, 1835) |
| | | *Thysanoessa* Brandt, 1851 |
| | Chaetognatha | *Sagitta elegans* Verrill, 1873 |
| | Urochordata | Appendicularia |
| **Meroplankton** | | |
| | Cnidaria | Hydrozoa Owen, 1843 |
| | | *Bougainvillia principis* (Steenstrup, 1850) |
| | | *Melicertum octocostatum* (M. Sars, 1835) |
| | | *Obelia* Péron and Lesueur, 1809 |
| | | *Phialidium* Leuckart, 1856 |
| | | *Rathkea octopunctata* (M. Sars, 1835) |
| | | *Sarsia* Lesson, 1843 |
| | | Scyphozoa Götte, 1887 |
| | | Tubulariidae Fleming, 1828 |

**Appendix Table 3-1. (Continued)**

**Meroplankton (continued)**

| | |
|---|---|
| Mollusca | Cephalopoda Cuvier, 1797 |
| | *Lacuna vincta* Montagu, 1803 |
| Arthropoda/Cirripedia | Cirripedia Burmeister, 1834 |
| Arthropoda/Decapoda | *Axius serratus* Stimpson, 1852 |
| | Brachyura Latrielle, 1802 |
| | *Cancer* Linnaeus, 1758 |
| | *Carcinus maenas* (Linnaeus, 1758) |
| | *Caridion gordoni* (Bate, 1858) |
| | *Crangon septemspinosa* Say, 1818 |
| | *Eualus pusiolus* (Krøyer, 1841) |
| | *Hemigrapsus sanguineus* (de Haan, 1953) |
| | Hippolytidae Dana, 1852 (enumerated as *Eualus* Thallwitz, 1892, *Lebbeus* White, 1847, *Spirontocaris* Bate, 1888) |
| | *Homarus americanus* H. Milne-Edwards, 1837 |
| | *Hyas* Linnaeus, 1758 |
| | *Pagurus* Fabricius, 1775 |
| | *Palaemonetes* Heller, 1869 |
| | Pandalidae Haworth, 1825 |
| Echinodermata | Echinodermata Klein, 1734 |

**Hyperbenthos**

| | |
|---|---|
| Polychaeta | Nereidae Johnston, 1865 |
| | Syllidae Grube, 1850 |
| Arthropoda/Copepoda | Harpacticoida G. O. Sars, 1903 |
| Arthropoda/Mysida | *Erythrops erythrophthalma* (Göes) 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 Latreille, 1817 |
| Arthropoda/Amphipoda | Amphipoda Latreille, 1816 |
| | *Calliopius laeviusculus* (Krøyer, 1838) |
| | *Corophium* Latreille, 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 2009[a]. Seabrook Operational Report, 2009.**

| Species | 1990[b] | 1991[c] | 1992[d] | 1993[e] | 1995[e] | 1996[e] | 1997[e] | 1998[e] | 1999[e] |
|---|---|---|---|---|---|---|---|---|---|
| *Anomia squamula* | 1691.4 | 250.8 | 6.9 | 3922.7 | 8905.9 | 23521.6 | 2883.3 | 3827.3 | 36495.2 |
| Bivalvia | 181.7 | 38.1 | 14.5 | 334.5 | 797.1 | 671.4 | 71.1 | 64.5 | 651.3 |
| *Hiatella* sp. | 876.6 | 421.3 | 189.8 | 2405.5 | 2598.2 | 4670.2 | 923.7 | 609.7 | 4416.5 |
| *Modiolus modiolus* | 909.7 | 160.2 | 0.3 | 1283.9 | 546.4 | 5144.8 | 614.7 | 241.7 | 2376.0 |
| *Mya arenaria* | 8.1 | 0.6 | 0.2 | 22.5 | 4.3 | 33.2 | 53.7 | 11.4 | 45.7 |
| *Mya truncata* | 249.2 | 6.5 | 1.1 | 2.1 | 27.6 | 123.0 | 0.8 | 8.3 | 66.0 |
| *Mytilus edulis* | 3991.3 | 1687.5 | 121.9 | 10050.7 | 13231.0 | 17931.8 | 1744.5 | 1493.0 | 22374.0 |
| *Placopecten magellanicus* | 0.7 | 0.7 | 0.1 | 16.9 | 6.2 | 31.0 | 0.8 | 0.8 | 11.5 |
| Solenidae | 61.1 | 0.0 | 75.7 | 102.5 | 1092.3 | 241.9 | 49.5 | 20.9 | 773.2 |
| *Spisula solidissima* | 69.0 | 4.4 | 0.0 | 48.5 | 112.5 | 171.1 | 22.5 | 14.8 | 175.5 |
| *Teredo navalis* | <0.1 | 15.9 | 0.0 | 0.0 | 4.8 | 7.4 | 1.7 | 0.8 | 29.9 |
| **Total** | **8038.9** | **2586.0** | **410.5** | **18189.8** | **27326.5** | **52547.4** | **6366.3** | **6293.4** | **67414.9** |

| Species | 2000[e] | 2001[e] | 2002[e] | 2003[e] | 2004[e] | 2005[f] | 2006[g] | 2007[e] | 2008[e] | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Anomia squamula* | 7542.2 | 4128.7 | 8203.5 | 3218.1 | 2595.0 | 1217.4 | 3965.8 | 3949.8 | 18452.3 | 27732.8 |
| Bivalvia | 228.6 | 483.0 | 194.2 | 73.7 | 89.6 | 40.4 | 73.9 | 46.2 | 411.8 | 74.3 |
| *Hiatella* sp. | 1920.8 | 1575.2 | 567.3 | 1203.9 | 1024.2 | 352.9 | 604.6 | 650.7 | 3136.5 | 2547.7 |
| *Modiolus modiolus* | 2520.7 | 251.6 | 776.4 | 240.8 | 843.2 | 292.9 | 715.1 | 172.5 | 2270.2 | 1420.5 |
| *Mya arenaria* | 23.9 | 26.4 | 60.2 | 5.1 | 15.1 | 9.2 | 11.1 | 4.7 | 45.8 | 31.8 |
| *Mya truncata* | 34.9 | 26.3 | 1.9 | 13.8 | 5.2 | 2.3 | 0.6 | 3.0 | 6.4 | 4.8 |
| *Mytilus edulis* | 10254.7 | 9621.3 | 3318.4 | 2199.0 | 1526.1 | 921.5 | 1351.4 | 834.4 | 2699.6 | 3973.6 |
| *Placopecten magellanicus* | 9.9 | 8.5 | 0.8 | 0.0 | 0.7 | 0.1 | 0.0 | 0.1 | 0.3 | 1.2 |
| Solenidae | 150.4 | 922.9 | 150.8 | 85.5 | 113.4 | 57.9 | 65.2 | 156.1 | 85.1 | 162.4 |
| *Spisula solidissima* | 33.6 | 50.8 | 44.2 | 3.1 | 10.0 | 14.5 | 20.0 | 2.8 | 100.7 | 31.5 |
| *Teredo navalis* | 1.5 | 0.3 | 2.3 | 0.1 | 0.6 | 0.3 | 0.8 | 0.0 | 1.8 | 2.3 |
| **Total** | **22721.1** | **17094.8** | **13320.0** | **7043.1** | **6223.0** | **2909.3** | **6808.5** | **5820.1** | **27210.5** | **35982.8** |

[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 2009 was similar to other operational years and was characterized by a high abundance of American sand lance, cunner, and Atlantic herring.

There were no significant differences in larval density of six of the nine selected species between the preoperational and operational periods. Densities of larval Atlantic herring, Atlantic cod, 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 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 2009 decreased from the previous year and was within the ranges of annual CPUE in the operational period, but lower than all but one year (1985) of the preoperational period. CPUE in 2009 at all stations was dominated by winter flounder (4.8), hakes (3.2), and longhorn sculpin (2.8). CPUE of rainbow smelt, Atlantic cod, hakes, and 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 a significant negative trend in CPUE at the farfield station (T3) from 1976 through 1993, and a significant positive trend after that. There were no significant trends at the other stations. At Stations T1 and T2 CPUE was significantly higher in 1976 through 1989 (T1) and 1976 through 1990 (T2) compared to later years.

CPUE was significantly higher from 1976 through the late 1980s or mid 1990s at most stations for rainbow smelt, Atlantic cod, hakes, and yellowtail flounder. CPUE of winter flounder was significantly higher from the mid 1990s through 2009 at Stations T1 and T3. The consistent negative trends in CPUE for many of the selected species from 1976 through the 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 increases in commercial landings, although recent data indicate a decrease in the Gulf of Maine winter flounder stock.

CPUE (catch per seine haul) for estuarine fishes in 2009 was 6.0, a decrease from the previous year (10.0). CPUE in 2009 at all stations was dominated by Atlantic silverside (2.6), American sand lance (0.3), and Atlantic herring (0.2). CPUE was significantly higher in the preoperational period for rainbow smelt, Atlantic silverside, and winter flounder.

In 2009, an estimated 2,077 million eggs were entrained. This was an increase from the 2008 estimate of 791 million. Cunner/ yellowtail flounder (1,448 million), silver hake (196 million), hake/fourbeard rockling (121 million), Atlantic mackerel (83 million), and hake species (72 million) were the dominant eggs entrained. Based on the ratio of cunner to yellowtail flounder larvae, almost 100% of the cunner/ yellowtail flounder eggs were cunner.

An estimated 523 million fish larvae were entrained in 2009, the third-highest estimate to date when sampling occurred in all 12 months. American sand lance (129 million), cunner (106 million), and rock gunnel (83 million) were the most abundant larval taxa entrained in 2009. Entrainment of larvae in 2009 was highest in June when cunner (70 million) and Atlantic mackerel (25 million) were most abundant.

An estimated 9,283 fish and 21 lobsters were impinged in 2009 at Seabrook Station based on impingement samples and cooling water flow. The largest impingement estimate was for December (3,523: 38%) and November (1,669: 18%). Hake sp. (1,427: 15%), cunner (837: 9%), American sand lance (796: 9%), rock gunnel (701: 8%), and northern pipefish (698: 8%) composed 49% of the fish impinged.

It appears that the majority of the fish impinged at Seabrook Station are YOY and age 1 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 in 2009 indicated that estimated average losses of adult fish due to entrainment ranged from 6 (yellowtail flounder) to 1,976 (winter flounder). Losses due to impingement ranged from 0 (yellowtail flounder and Atlantic mackerel) to 547 (pollock). EA losses due to entrainment for most species were larger than impingement losses.

The operation of Seabrook Station did not significantly affect the ichthyoplankton and fish communities of the Hampton-Seabrook area. Relatively few individuals were removed by station operation through entrainment. CPUE of most demersal fishes in the operational period was lower than the preoperational 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 2009 by various ichthyoplankton and adult finfish sampling programs is given in Appendix Table 4-1.

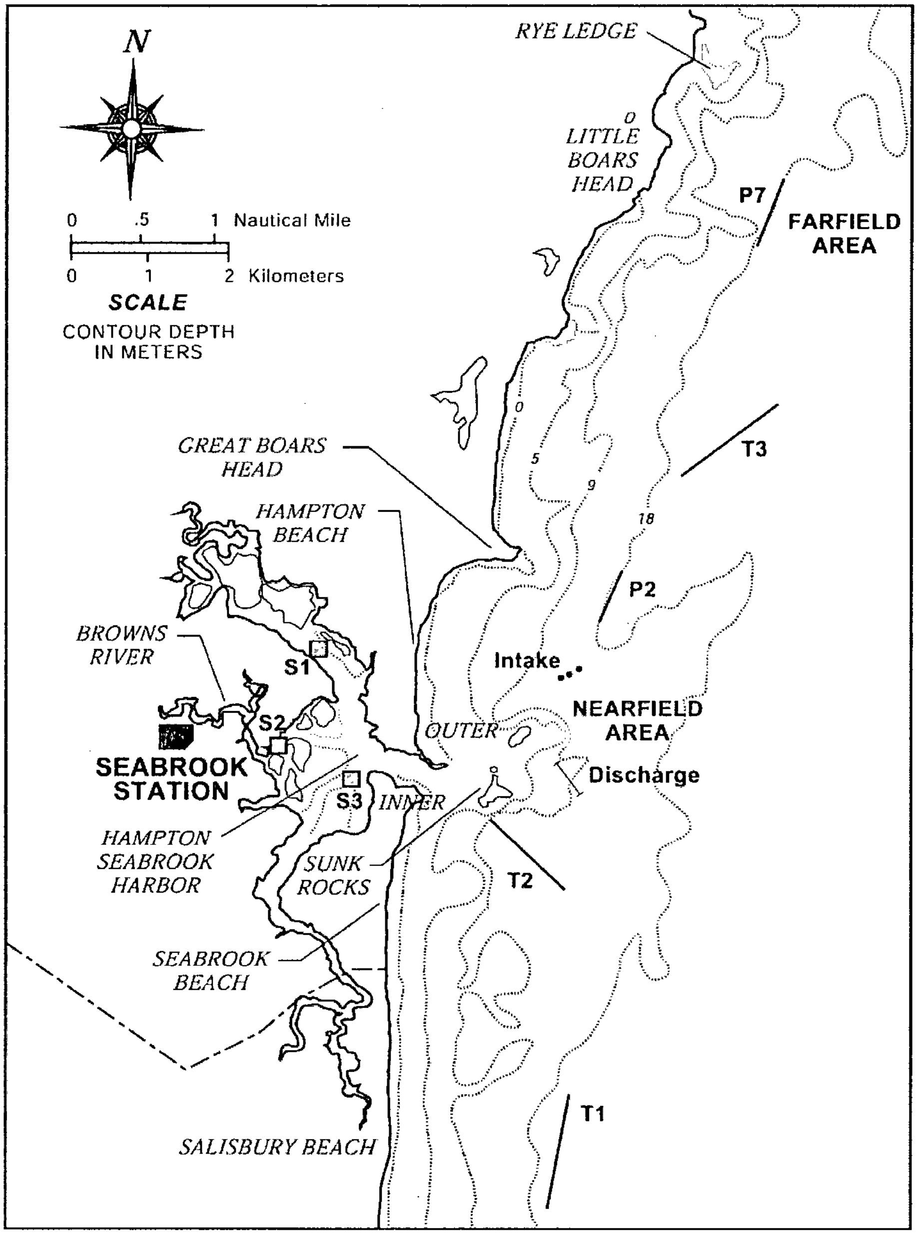
## 4.2 METHODS

### 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 2009. 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 2009.

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, 2009.

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 cod end 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 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 July through October, due to the presence of commercial lobster gear, particularly since 1983. In 2009, no samples were collected at Station T2 from June through November 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

**Table 4-1. Description of Finfish Sampling Stations. Seabrook Operational Report, 2009.**

| 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) |

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, NextEra 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 2009 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. 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 significant differences between stations in the preoperational period, 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 preoperational and operational periods. Geometric means were compared among the preoperational, operational, and 2009 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 symmetrical 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

**Table 4-2. Selected Finfishes and Sampling Programs that Contributed Abundance Data for Species-Specific Analyses. Seabrook Operational Report, 2009.**

| 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 |

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 2009, and for selected taxa collected by trawl and seine, the data used were from July 1975 through December 2009. 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 2009).

### *Adult Equivalency Methods*

An adult equivalency analysis of selected species of entrained larvae and juvenile fish 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 and juvenile fish 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 2009, and entrainment data from 1998 through 2009 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:

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

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

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

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:

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

Where

$N_R$ = the number of mature fish at age R (years)

$N_0$ = the number of fish impinged

Z = the instantaneous juvenile total 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 2009 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 54 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). The annual means for each station for the remaining years composed Group 2, with the exception of 1982, which was ungrouped. Stations were paired together in 19 of 27 years indicating a higher degree of similarity in structure between stations than among years. In 11 of the 19 operational years (1991-2009), the egg assemblages at the nearfield and farfield stations were more similar to each

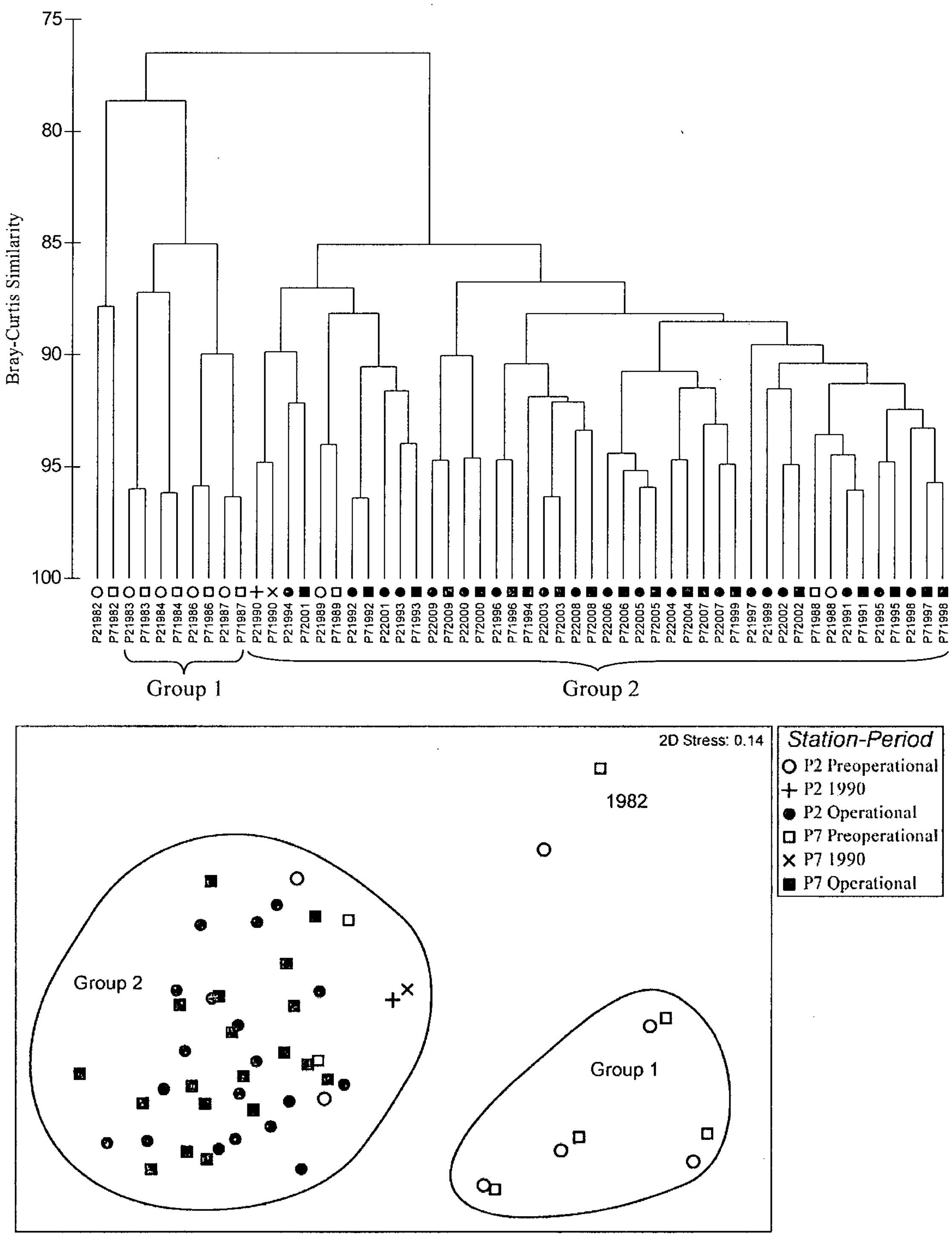



Figure 4-2. Dendrogram and temporal/spatial occurrence pattern of fish egg assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m$^3$) at Seabrook intake (P2) and farfield (P7) stations, 1982-1984, 1986-2009. Seabrook Operational Report, 2009.

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 preoperational and operational years, and 2009, 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. Taxa that made the greatest contributions to the percent dissimilarity between Groups 1 and 2 were hake/fourbeard rockling (19%), Atlantic cod/haddock (17%), and fourbeard rockling (15%) (Table 4-4). Atlantic mackerel and windowpane were abundant in both groups and made 4% contributions to the

**Table 4-3. Analysis of Similarities (ANOSIM) between Station and Period of the Fish Egg and Larvae Assemblages. Seabrook Operational Report, 2009.**

| Community | Comparison | R | P[a] |
|---|---|---|---|
| **Egg** | Period[b] | 0.69 | <0.01* |
| | Station[b] | 0.04 | 0.10 NS |
| | Preop: P2 vs. P7[c] | -0.09 | 0.81 NS |
| | P2: Preop vs. Op[c] | 0.69 | <0.01* |
| | P7: Preop vs. Op[c] | 0.68 | <0.01* |
| | Interaction of Main Effects | | NS |
| **Larvae** | Period[b] | 0.35 | <0.01* |
| | Station[b] | 0.03 | 0.15 NS |
| | Preop: P2 vs. P7[c] | -0.11 | 0.90 NS |
| | P2: Preop vs. Op[c] | 0.30 | 0.01* |
| | P7: Preop vs. Op[c] | 0.39 | <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, 2009.**

| | Group 1 | | | Group 2 | | | Percent Contribution to Dissimilarity between Groups |
|---|---|---|---|---|---|---|---|
| TAXON | LCL[a] | Mean | UCL[b] | LCL | Mean | UCL | |
| **Eggs** [c] | | | | | | | |
| Atlantic mackerel | 650 | 1,009 | 1,369 | 1,344 | 1,941 | 2,538 | 4 |
| Cunner/Yellowtail flounder | 2,764 | 5,003 | 7,243 | 6,577 | 7,239 | 8,081 | 9 |
| Hakes | 235 | 1,226 | 2,217 | 332 | 488 | 643 | 8 |
| Hake/Fourbeard rockling | 45 | 215 | 386 | 503 | 626 | 749 | 19 |
| Atlantic cod/haddock | 79 | 153 | 226 | 63 | 92 | 120 | 17 |
| Windowpane | 73 | 147 | 221 | 160 | 232 | 304 | 4 |
| Fourbeard rockling | 168 | 248 | 328 | 34 | 49 | 65 | 15 |
| Silver hake | 45 | 77 | 109 | 149 | 322 | 494 | 6 |
| **Larvae**[d] | | | | | | | |
| Cunner | 143 | 425 | 707 | 828 | 1,386 | 1,945 | 7 |
| American sand lance | 57 | 182 | 307 | 160 | 234 | 308 | 5 |
| Atlantic mackerel | 28 | 179 | 330 | 65 | 121 | 176 | 4 |
| Fourbeard rockling | 40 | 68 | 96 | 56 | 78 | 99 | 5 |
| Atlantic herring | 37 | 68 | 99 | 23 | 29 | 35 | 5 |
| Rock gunnel | 14 | 31 | 49 | 32 | 42 | 52 | 3 |
| Winter flounder | 18 | 44 | 70 | 8 | 11 | 14 | 6 |
| Silver hake | 14 | 23 | 32 | 35 | 67 | 100 | 6 |
| Radiated shanny | 15 | 26 | 36 | 3 | 27 | 50 | 6 |
| Witch flounder | 9 | 18 | 28 | 3 | 5 | 6 | 8 |

[a] LCL = Lower 95% confidence limit.
[b] UCL = Upper 95% confidence limit.
[c] Egg Group 1 Years = 1983, 1984, 1986, 1987. Egg Group 2 Years = 1988-2008.
[d] Larvae Group 1 Years = 1982-1984, 1986-1989. Larvae Group 2 Years = 1989-1991, 1993-2009.

dissimilarity between groups. Low densities of hake/fourbeard rockling, fourbeard rockling, and windowpane eggs characterized the ungrouped year 1982.

The larval assemblage exhibited a higher degree of homogeneity among collections than 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 with the exception of 1989. Group 2 consisted of collections at each station all operational years, except for the station pairs from 1992 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 and silver hake larvae were greater in Group 2 compared to Group 1 (Table 4-4). Atlantic herring, winter flounder, and witch flounder larval densities were lower in Group 2 compared to Group 1. Although not among the most abundant species in either group, witch flounder made

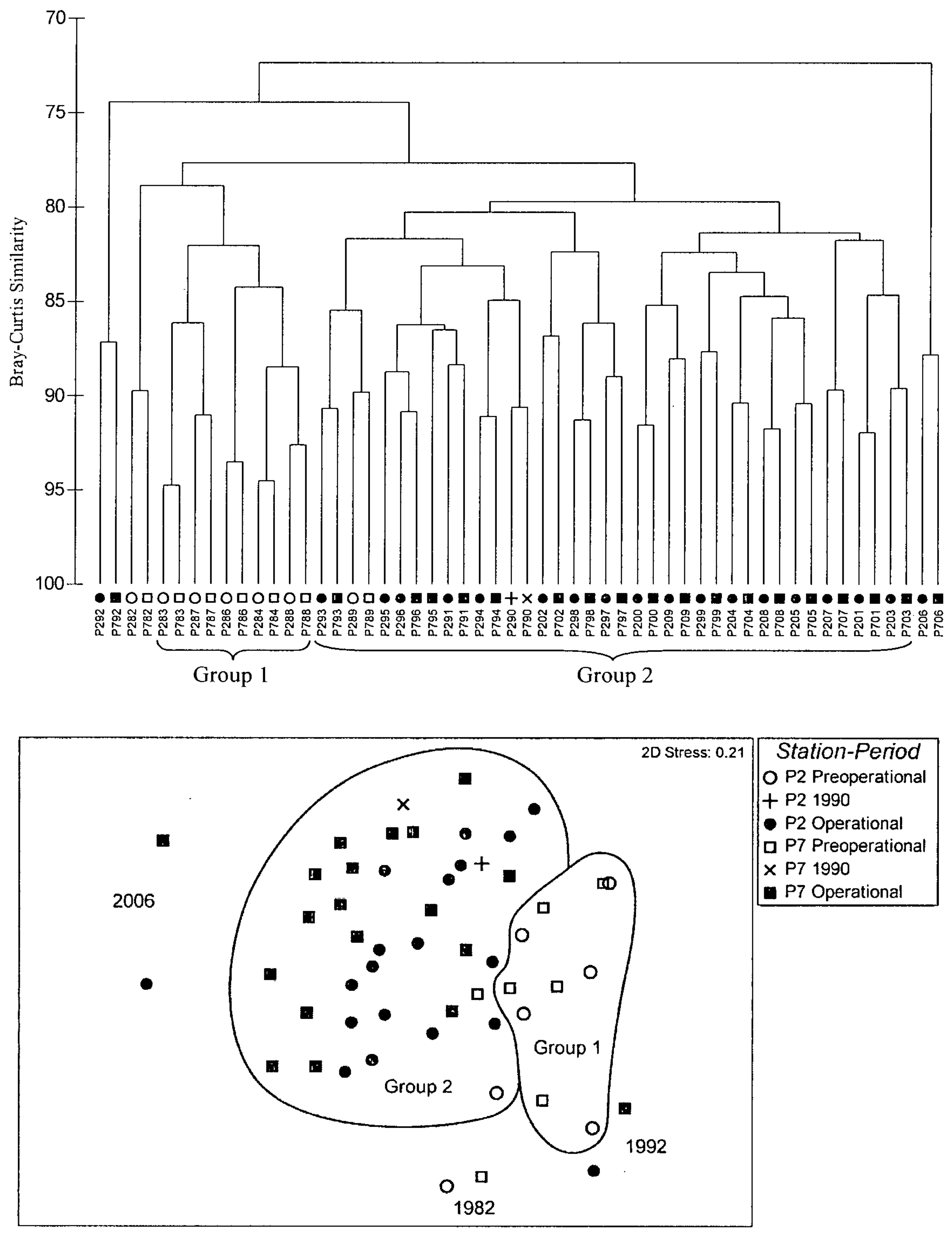



Figure 4-3. Dendrogram and temporal/spatial occurrence pattern of fish larvae assemblages formed by numerical classification of ichthyoplankton samples (monthly means of log (x+1) transformed number per 1000 m$^3$) at Seabrook intake (P2), and farfield (P7) stations, 1982-1984, 1986- 2009. Seabrook Operational Report, 2009.

the greatest contribution (8%) to the dissimilarity between groups. Cunner (7%), silver hake (6%), radiated shanny (6%), and winter flounder (6%) also made substantive contributions to the dissimilarity between groups (Table 4-4).

Collections from the years 2006, 1992 and 1982 were ungrouped as they were substantially different from all other years (Figure 4-3). 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. Collections from 1982 were characterized by high abundance of American sand lance larvae.

The MDS plot generally supported the results of the cluster analysis. The station pairs for 1982, 1992 and 2006 were separated from the other years (Figure 4-3). 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 periods 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 ichthyoplankton at 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 20 taxa and larvae of 35 taxa (plus one group of unidentified larvae) were collected in entrainment samples in 2009 (Table 4-5). Total estimates of entrainment for 2009 were 2,072 million eggs and 523 million larvae. About 64% of the egg entrainment occurred in July and about 26% of larval entrainment occurred in June (Figure 4-4; Table 4-5). The reduction in entrainment

**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 2009. Seabrook Operational Report, 2009.**

Eggs

| Taxon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Plaice | 0.00 | 0.00 | 0.02 | 3.96 | 27.51 | 4.45 | 0.72 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 36.67 |
| Atlantic Cod | 0.38 | 0.00 | 0.00 | 0.00 | 0.13 | 0.29 | 0.15 | 0.00 | 0.00 | 0.00 | 2.26 | 2.50 | 5.70 |
| Atlantic Cod/Haddock | 0.00 | 0.10 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 |
| Atlantic Cod/Witch Flounder | 0.00 | 0.00 | 0.00 | 0.24 | 2.99 | 2.41 | 6.87 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 12.52 |
| Atlantic Mackerel | 0.00 | 0.00 | 0.00 | 0.00 | 29.20 | 36.51 | 17.75 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 83.46 |
| Atlantic Menhaden | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.44 | 0.74 | 0.11 | 0.00 | 0.29 | 0.00 | 0.00 | 1.57 |
| Cunner | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.75 |
| Cunner/Yellowtail Flounder | 0.00 | 0.00 | 0.00 | 0.08 | 26.69 | 444.98 | 971.08 | 4.50 | 0.24 | 0.00 | 0.00 | 0.00 | 1447.57 |
| Cusk | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.90 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 1.08 |
| Fourbeard Rockling | 0.00 | 0.00 | 0.00 | 0.00 | 1.85 | 6.25 | 13.70 | 0.43 | 0.54 | 0.00 | 0.00 | 0.00 | 22.76 |
| Hake | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.40 | 57.62 | 3.89 | 3.42 | 0.01 | 0.00 | 0.00 | 72.33 |
| Hake/Fourbeard Rockling | 0.00 | 0.00 | 0.00 | 0.71 | 9.30 | 23.99 | 77.14 | 3.67 | 5.80 | 0.19 | 0.00 | 0.00 | 120.80 |
| Pollock | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.18 |
| Silver Hake | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 10.24 | 141.19 | 22.53 | 22.14 | 0.05 | 0.00 | 0.00 | 196.22 |
| Tautog | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 |
| Unidentified Sculpin | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| Unidentified Searobin | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.29 | 0.00 | 1.16 | 0.00 | 0.00 | 0.00 | 1.53 |
| Windowpane | 0.00 | 0.00 | 0.00 | 0.00 | 5.59 | 18.52 | 30.30 | 1.77 | 5.62 | 0.02 | 0.00 | 0.00 | 61.82 |
| Winter Flounder | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 |
| Witch Flounder | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.19 |
| **Total** | **0.53** | **0.10** | **0.10** | **5.06** | **103.43** | **564.21** | **1317.78** | **36.98** | **38.93** | **0.57** | **2.27** | **2.54** | **2072.50** |

(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 | 0.12 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 |
| American plaice | 0.00 | 0.00 | 0.00 | 0.00 | 4.64 | 6.21 | 0.59 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 11.46 |
| American sand lance | 2.65 | 21.97 | 47.14 | 56.02 | 0.73 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 128.62 |
| Atlantic cod | 0.03 | 0.03 | 0.00 | 0.00 | 0.18 | 0.56 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 1.35 |
| Atlantic herring | 0.20 | 0.77 | 2.95 | 11.69 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.61 | 3.48 | 27.72 |
| Atlantic mackerel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25.48 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25.73 |
| Atlantic menhaden | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.14 | 3.98 | 0.00 | 0.00 | 0.00 | 4.14 |
| Atlantic seasnail | 0.00 | 0.03 | 0.26 | 2.58 | 23.63 | 11.24 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 37.77 |
| Butterfish | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.21 | 0.00 | 0.00 | 0.00 | 0.21 |
| Cunner | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 69.99 | 34.64 | 0.25 | 0.82 | 0.00 | 0.00 | 0.00 | 105.69 |
| Cusk | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.04 |
| Fourbeard rockling | 0.00 | 0.00 | 0.00 | 0.00 | 0.32 | 7.51 | 6.53 | 4.41 | 1.51 | 0.00 | 0.04 | 0.00 | 20.32 |
| Fourspot flounder | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.08 |
| Goosefish | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.02 |
| Grubby | 0.02 | 2.38 | 12.71 | 13.59 | 2.76 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 31.57 |
| Gulf snailfish | 0.03 | 0.27 | 0.39 | 0.06 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.83 |
| Hake | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.48 | 0.00 | 3.49 | 0.00 | 0.00 | 0.00 | 3.97 |
| Herring family | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.02 |
| Longhorn sculpin | 0.33 | 1.93 | 1.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.29 |
| Lumpfish | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| Northern pipefish | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.03 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.10 |
| Pollock | 0.02 | 0.10 | 0.08 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.29 |
| Radiated shanny | 0.00 | 0.00 | 0.00 | 0.00 | 0.74 | 2.86 | 0.92 | 0.02 | 0.03 | 0.00 | 0.00 | 0.00 | 4.57 |
| Rainbow smelt | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.29 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 |
| Rock gunnel | 0.27 | 21.55 | 48.94 | 11.63 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 82.88 |
| Sea raven | 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 |
| Shorthorn sculpin | 0.02 | 2.08 | 2.45 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.68 |
| Silver hake | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.23 | 0.07 | 7.85 | 0.00 | 0.00 | 0.00 | 8.15 |
| Tautog | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 |
| Unidentified | 0.02 | 0.02 | 0.03 | 0.40 | 0.05 | 0.10 | 0.02 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.67 |
| Unidentified sculpin | 0.00 | 0.17 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.42 |
| Windowpane | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.23 | 0.16 | 1.51 | 0.00 | 0.00 | 0.00 | 1.91 |
| Winter flounder | 0.00 | 0.00 | 0.00 | 0.00 | 3.41 | 9.11 | 2.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.22 |
| Witch flounder | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.11 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.42 |
| Wrymouth | 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 |
| Yellowtail flounder | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.13 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 |
| **Total** | **3.58** | **51.30** | **116.36** | **96.39** | **37.16** | **133.98** | **47.26** | **5.29** | **19.67** | **0.00** | **8.67** | **3.59** | **523.26** |

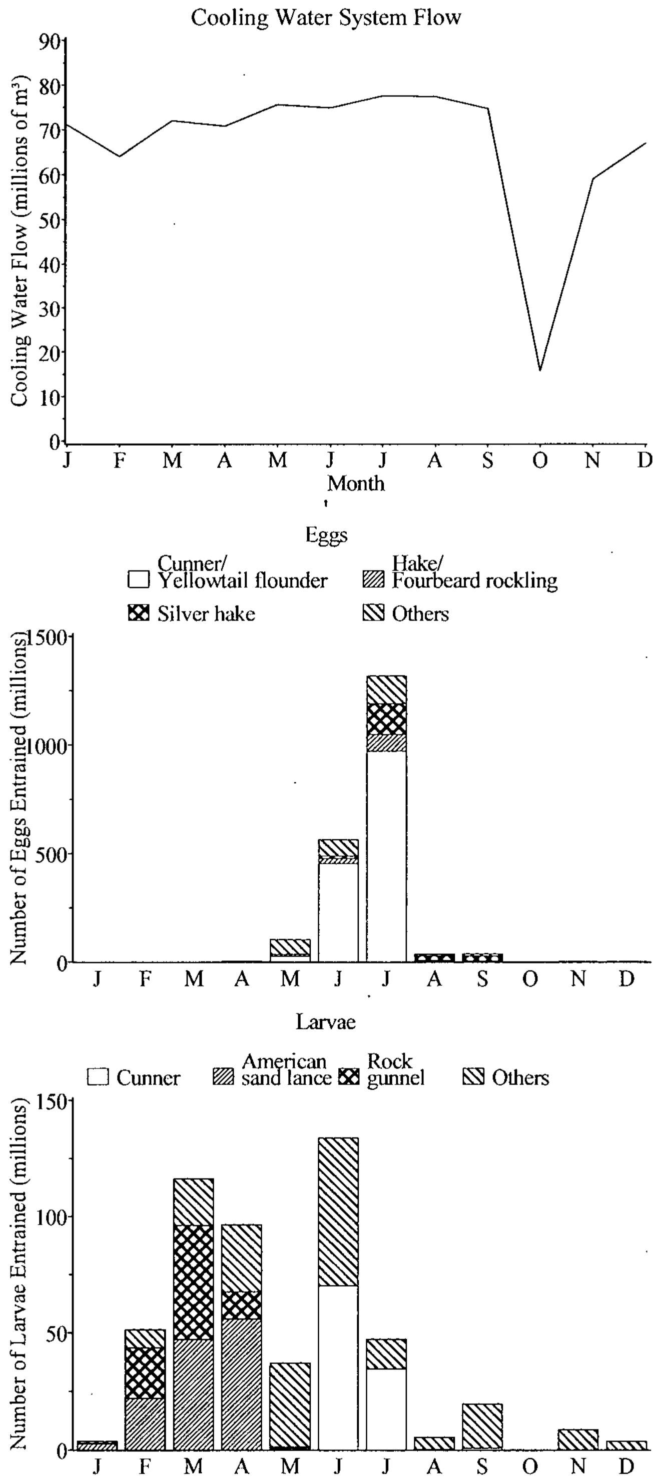



Figure 4-4. Total monthly cooling water system flow and estimated numbers of fish eggs and larvae entrained during 2009. Seabrook Operational Report, 2009.

estimates in October is most likely due to the reduced cooling water flow in that month due to a planned refueling outage from October 1 through November 12 (Figure 4-4).

Egg entrainment in previous years ranged from 5 million in 1994 (8 months of sampling) to 2,104 million in 2000, and the estimate for 2009 is the third highest to date (Table 4-6). Entrainment was greatest in July due to large numbers of entrained cunner/yellowtail flounder eggs (Figure 4-4). Cunner/yellowtail flounder (1,448 million), silver hake (196 million), hake/fourbeard rockling (121 million), Atlantic mackerel (83 million), and hake species (72 million) were the most numerous fish eggs entrained in 2009 (Table 4-5). Cunner/yellowtail eggs from July alone made up about 47% of the total estimated annual egg entrainment.

The entrainment estimate for the most abundant egg taxon in 2009, cunner/ yellow-tail flounder, increased compared to 2008 and was the highest estimate to date (Table 4-6). Estimates in previous years ranged from 0 (1994: no sampling from April through August) to 1,397 million in 2002. Cunner/ yellowtail flounder eggs occurred from April through September and the peak month for entrainment in 2009 was July when 67% of the annual cunner/yellowtail flounder estimate was entrained (Table 4-5, Figure 4-4). Almost all of the annual total of these eggs were probably cunner, because few yellowtail flounder larvae were present in entrainment samples in 2009.

Silver hake eggs in 2009 (196 million) ranked second in entrainment abundance with the highest monthly estimate occurring in July when 72% of the annual total occurred (Table 4-5, Figure 4-4). Silver hake eggs occurred from May through October. The 2009 estimate was the fourth highest to date (Table 4-6).

Hake/fourbeard rockling eggs ranked third in entrainment abundance (121 million) in 2009 (Table 4-5). The 2009 estimate was the second-highest to date, only exceeded by the 2000 estimate of 231 million (Table 4-6). Hake/fourbeard rockling eggs were entrained from April through October with 64% of the annual total occurring in July (Figure 4-4).

Atlantic mackerel egg entrainment ranked fourth (83 million) in abundance in 2009 and occurred only from May through August with 44% of the estimate occurring in July (Table 4-5). The 2009 estimate was within the range of previous years (Table 4-6).

Entrainment of hake species eggs ranked fifth in 2009 with an estimate of 72 million (Table 4-5). Hake species eggs comprised red and white hake and possibly spotted hake. Hake species eggs were entrained from June through October with 80% of the annual total occurring in July (Table 4-5). The 2009 estimate was the fourth highest to date (Table 4-6).

Record high estimates of cusk (1 million) and fourbeard rockling (23 million) egg entrainment occurred in 2009 (Table 4-6).

An estimated 523 million fish larvae were entrained in 2009, the third highest estimate to date (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 2009 was highest in June when cunner (70 million) and Atlantic mackerel (25 million) were most abundant (Figure 4-4). American sand lance (129 million), cunner (106 million), and rock gunnel (83 million) were the most abundant larval taxa entrained in 2009 (Table 4-5).

American sand lance was the most common species entrained in 2009 and represented 25% of the total larval entrainment estimate (Table 4-5). Entrainment of this species was highest in March and April when 80% of the annual estimate of 129 million occurred. Entrainment of American

**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 2009. Seabrook Operational Report, 2009.**

**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] | 2008[f] | 2009[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 | 48.02 | 36.67 |
| 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 | 9.51 | 5.70 |
| 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 | 0.27 | 0.18 |
| 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 | 38.81 | 12.52 |
| 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 | 82.42 | 83.46 |
| Atlantic menhaden | | 0.5 | 1.4 | 0.1 | | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | | | <0.1 | | | | 3.08 | 0.07 | 1.57 |
| 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 | 16.03 | 7.75 |
| 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 | 428.44 | 1447.57 |
| 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 | 0.07 | 1.08 |
| 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 | 8.65 | 22.76 |
| 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 | 20.78 | 72.33 |
| 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 | 53.96 | 120.80 |
| 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 | 5.02 | 0.18 |
| 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 | 50.89 | 196.2 |
| Tautog | | 0.2 | | | | | 0.3 | 0.1 | 0.1 | | | 0.1 | 3.8 | | 0.1 | 0.2 | | | 0.02 | 0.06 |
| 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 | | 0.38 | 1.53 |
| Unidentified sculpin | | | | | | | | | | <0.1 | | | 0.6 | 0.1 | | | | | 0.13 | 0.02 |
| 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 | 25.93 | 61.82 |
| Winter flounder | | | | | | | | | | | 0.3 | | | 0.3 | | | | 0.2 | 1.05 | 0.08 |
| Witch flounder | 0.4 | | | | | 0.7 | 0.1 | 0.9 | 0.1 | 0.1 | 0.2 | | | | | 0.2 | | | 0.13 | 0.19 |
| 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** | **790.61** | **2072.5** |

(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] | 2008[f] | 2009[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 | 0.01 | 0.16 |
| 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 | 3.47 | 11.46 |
| 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 | 71.18 | 128.62 |
| 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 | 1.35 | 1.35 |
| 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 | 28.23 | 27.72 |
| 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 | | 0.02 | 25.73 |
| Atlantic menhaden | 0.1 | | | | | | | | 0.1 | 0.1 | | | 0.1 | | <0.1 | | 0.15 | 33.65 | 0.77 | 4.14 |
| 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 | | 27.38 | 37.77 |
| Atlantic silverside | | | | | | | | | | | | | | <0.1 | | | | | | |
| Bluefish | | | | | | | | 0.1 | | | | | | | | | | | | |
| Butterfish | | | | | | 0.3 | 0.1 | | | | | | | | | | | 1.19 | | 0.21 |
| 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 | 86.17 | 105.69 |
| Cusk | | | | | | | | | <0.1 | | | 0.4 | 1.8 | 0.1 | 2.1 | | 0.09 | | | 0.04 |
| 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 | 11.86 | 20.32 |
| Fourspot flounder | 0.2 | | | | | | | 0.1 | <0.1 | | | | <0.01 | | | | | | | 0.08 |
| Goosefish | 0.1 | | | | | | | | | | 2.0 | | | | 0.1 | | | | | 0.02 |
| 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 | 8.29 | 31.57 |
| 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 | 2.21 | 0.83 |
| 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 | | 0.21 | 3.97 |
| Herring family | | | | | | | | | | | | | | | | 0.5 | 0.04 | | 0.13 | 0.02 |
| Liparis sp. | | | | | | | | | | | | | | | | | 0.16 | | 0.03 | |
| 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 | 3.01 | 3.29 |
| 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 | 0.12 | 0.02 |
| Moustache sculpin | | 0.1 | 0.3 | 0.4 | 2.2 | | 0.6 | 0.3 | <0.1 | | | | | | | <0.1 | | | 0.03 | |
| Northern pipefish | | | | | | | 0.1 | | | 0.1 | | 0.1 | 0.1 | | 0.1 | <0.1 | 0.02 | | | 0.10 |
| 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] | 2008[f] | 2009[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 | 0.25 | 0.29 |
| 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 | 4.68 | 4.57 |
| Rainbow smelt | 0.2 | | 0.1 | | | | | | 0.2 | | 0.3 | 0.1 | | 0.5 | <0.1 | 0.5 | 4.27 | 0.38 | 2.16 | 0.40 |
| 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 | 48.16 | 82.88 |
| Sea raven | | | | | | | | | <0.1 | <0.1 | | | | <0.1 | 0.2 | 0.1 | 0.02 | 0.03 | 0.03 | 0.07 |
| 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 | 1.42 | 4.68 |
| 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 | | 17.94 | 8.15 |
| Snailfish | 0.1 | 0.3 | | 0.2 | | | 0.4 | | | | | | <0.1 | | | 0.2 | | | | |
| Snakeblenny | | | | | | | | | | | | | | | | | 0.02 | | 0.01 | |
| Summer flounder | | | | | | | | | <0.1 | | | | | <0.1 | | | | 0.02 | | |
| Spotted hake | | | | | | | | | | | | | | | | | | | 0.44 | |
| Tautog | 0.3 | | | | | | 0.2 | | | | 0.1 | | | 0.1 | | | | | 0.06 | 0.10 |
| Spotted hake | | | | | | | | | | | | | | | | | | | 0.74 | |
| 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 | 0.94 | 0.67 |
| Unidentified sculpin | | | 0.1 | | | | 0.6 | 0.05 | | 0.1 | | | <0.1 | 0.5 | 4.4 | 1.2 | 0.42 | 0.16 | | 0.42 |
| Unidentified searobin | | | | | | | 0.1 | | | | 0.1 | | | | | | | | 0.82 | |
| 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 | 11.41 | 1.91 |
| 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 | 0.12 | 15.22 |
| 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 | 0.02 | 0.42 |
| Wrymouth | | 0.1 | | | | | | | | <0.1 | | | | | <0.1 | | | | | 0.07 |
| 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 | | 0.30 |
| **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** | **333.69** | **523.26** |

[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.

sand lance larvae occurred from January through June and December. The 2009 estimate was the highest observed among years when sampling occurred in all 12 months (Table 4-6).

Cunner were the second-most most abundant larvae entrained in 2009 and composed 20% of the annual total (Table 4-5). Approximately 66% of the annual total entrainment of cunner occurred in June and larvae were entrained from June through September (Figure 4-4). The 2009 estimate for cunner was within the range of other years when all months were sampled (Table 4-6).

Rock gunnel were the third most abundant larvae entrained in 2009 and composed 16% of the annual total (Table 4-5). Approximately 59% of the annual total entrainment of rock gunnel occurred in March and larvae were entrained from January through May (Figure 4-4). The 2009 estimate of 83 million was within the range of previous years (Table 4-6).

In 2009, there were record estimates of entrainment for American plaice (12 million), Atlantic mackerel (26 million), Atlantic menhaden (4 million), and grubby (32 million) (Table 4-6). The entrainment estimate for Atlantic mackerel of 25 million was particularly striking as in most years no Atlantic mackerel larvae are entrained, and the previous high estimate was 20 million in 2004. The high 2009 estimate was due to exceptionally high abundance in samples collected on June 23 and 24.

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 avoid entrainment, although a record number were entrained in 2009 (Table 4-6).

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). Pilgrim and Millstone Stations have shoreline bulkhead intakes while Seabrook Station has an offshore mid-water intake. Except for Atlantic cod and cunner larvae, 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 2009, the geometric mean CPUE (catch per 10-minute tow) of fish caught at all stations combined (25.0) decreased from the previous year and was within the range of previous operational years, but lower than all but one (1985) of the preoperational years (Figure 4-5). Since a record low CPUE of 6.4 for all stations combined in 1995, CPUE has

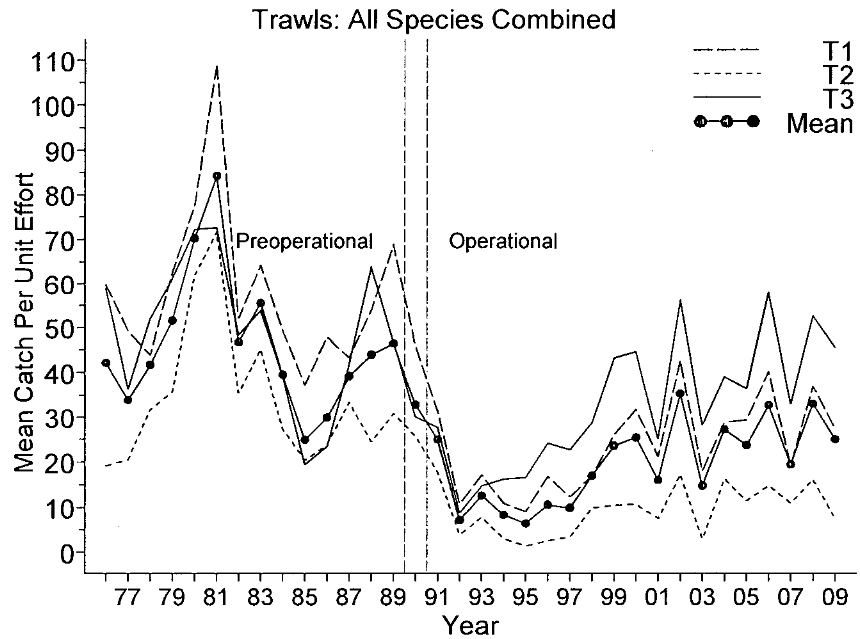



Figure 4-5. Annual geometric mean catch of all species combined per unit effort (number per 10-minute tow) in trawl samples by station and the mean of all stations, 1976-2009. Seabrook Operational Report, 2009.

**Table 4-7. Comparison of Entrainment Estimates (in millions) of Selected Taxa at Selected New England Power Plants (nominal cooling water flow in m³/sec) with Marine Intakes from 1990 through 2009. Seabrook Operational Report, 2009.**

| Taxon | Seabrook[a] (31.5) | Pilgrim[b] (20.3) | Millstone[c] (95.9) |
|---|---|---|---|
| Cunner/yellowtail flounder eggs[d] | 18.6-1,447.6 | 581-6,576 | 595-6,331 |
| Cunner larvae | 2.5-451.2 | 2.8-576 | <1–148 |
| Atlantic cod larvae | <0.1-34.6 | 0.1-4.2 | |
| Atlantic mackerel eggs | 23.1-475.6 | 6.2-4,674 | – |
| Atlantic mackerel larvae | 0-25.7 | 0.3-320 | – |
| Atlantic herring larvae | <1-28.2 | 0.3-43.2 | – |
| Atlantic menhaden eggs | <0.1-3.1 | 0.3-948 | |
| Atlantic menhaden larvae | <0.1-33.7 | 0.2-69 | |
| Grubby larvae[e] | 2.2-51.8 | – | 11-228 |
| Atlantic seasnail larvae[f] | 1.2-76.5 | – | – |
| Rock gunnel larvae | 3.5-109.0 | – | – |
| American sand lance larvae | 1.0-128.6 | – | 3-177 |
| Winter flounder larvae | 2.2-34.8 | 3.5-86.8 | 29-500 |

[a] Restricted to 1995-2009, years when sampling occurred in all 12 months.
[b] Entergy Nuclear Generation Company (2009); Cape Cod Bay. Based on full load flow.
[c] Dominion Resources Services (2010); 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.

generally increased through 2009, although CPUE has been variable since 2000. The highest CPUE occurred in 1981 (84.2) and 1980 (70.3) primarily due to large catches of yellowtail flounder (see Section 4.3.3.11). In 2009, the catch was dominated by winter flounder, hakes, and longhorn sculpin (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 the 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 with sandy bottoms. CPUE in the preoperational period was usually lower at Station T2 than at Stations T1 and T3 (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 period, longhorn sculpin, winter flounder, and skates were dominant (Table 4-8).

The total catch of demersal fishes caught by otter trawl showed periodic trends in annual geometric mean CPUE (Table 4-9). At Station T1, CPUE was significantly higher from 1976 through 1989 compared to the period 1990 through 2009. There were no significant trends within each of these periods. At Station T2, CPUE was significantly higher from 1976 through 1990 compared to 1991 through 2009. As with Station T1, there were no significant trends within each of these periods. At Station T3, there was no significant difference in CPUE between the period 1976 through 1993 compared to 1994 through 2009. There was a significant negative trend in the first period and a significant positive trend in the second period.

Groundfish abundance data from the Seabrook Station Monitoring Program is in general agreement with the data collected by the National Marine Fisheries Service (NMFS) (NEFSC 2008). The spring and fall indices of abundance (kg/tow) for principal groundfish (Atlantic cod, haddock, pollock, white hake, ocean pout, Atlantic halibut, yellowtail, witch, and winter flounders, American plaice, windowpane, and Acadian redfish) off the northeastern United States was highest in 1960s; however, beginning in the early 1970s, the index began to decline. After a smaller peak in late 1970s (fall) and early 1980s (spring) the index reached record lows in 1990-1994. The index began to increase through 2003, but the spring index has been variable though 2007 while the fall index has declined slightly. Our CPUE data show the same general trend as the NMFS fall index with a peak in the early 1980s followed by a decline through the early 1990s, a general increase through 2002, and then variable CPUE through 2009.

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

**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 2009 Mean. Seabrook Operational Report, 2009.**

| | | Preoperational Period | | | 2009 | Operational Period | | |
|---|---|---|---|---|---|---|---|---|
| | | LCL[a] | Mean | UCL[b] | Mean | LCL | Mean | UCL |
| Yellowtail flounder | T1 | 15.7 | 20.6 | 26.9 | 2.3 | 1.8 | 2.4 | 3.1 |
| | T2 | 2.7 | 3.7 | 5.0 | 0.1 | 0.1 | 0.2 | 0.3 |
| | T3 | 6.6 | 9.2 | 12.8 | 3.7 | 1.4 | 2.1 | 3.0 |
| | All Stations | 7.3 | 9.4 | 12.0 | 2.0 | 1.0 | 1.4 | 1.8 |
| Longhorn sculpin | T1 | 2.3 | 3.2 | 4.5 | 2.8 | 2.3 | 3.1 | 4.1 |
| | T2 | 0.6 | 1.0 | 1.5 | 0.5 | 0.4 | 0.6 | 0.8 |
| | T3 | 4.2 | 6.1 | 8.5 | 4.9 | 4.8 | 6.4 | 8.4 |
| | All Stations | 2.1 | 3.0 | 4.2 | 2.8 | 2.1 | 2.7 | 3.5 |
| Winter flounder | T1 | 2.1 | 2.8 | 3.6 | 6.8 | 3.0 | 4.0 | 5.4 |
| | T2 | 3.7 | 5.5 | 8.0 | 3.1 | 1.6 | 2.3 | 3.1 |
| | T3 | 1.1 | 1.4 | 1.9 | 3.8 | 2.7 | 3.6 | 4.8 |
| | All Stations | 2.2 | 2.9 | 3.7 | 4.8 | 2.5 | 3.3 | 4.3 |
| Hakes | T1 | 1.3 | 1.7 | 2.0 | 2.7 | 0.4 | 0.6 | 0.8 |
| | T2 | 0.6 | 0.9 | 1.2 | 0.4 | 0.3 | 0.4 | 0.5 |
| | T3 | 0.8 | 1.1 | 1.4 | 9.6 | 0.4 | 0.9 | 1.4 |
| | All Stations | 0.9 | 1.2 | 1.5 | 3.2 | 0.4 | 0.6 | 0.9 |
| Atlantic cod | T1 | 1.7 | 2.6 | 3.7 | 0.3 | 0.2 | 0.3 | 0.5 |
| | T2 | 0.5 | 0.8 | 1.2 | 0.2 | 0.1 | 0.2 | 0.4 |
| | T3 | 2.6 | 4.1 | 6.2 | 0.6 | 0.8 | 1.1 | 1.5 |
| | All Stations | 1.5 | 2.3 | 3.2 | 0.4 | 0.4 | 0.5 | 0.7 |
| Raja sp. | T1 | 0.8 | 1.4 | 2.3 | 1.3 | 1.6 | 2.2 | 2.9 |
| | T2 | 0.4 | 0.6 | 0.7 | 0.2 | 0.4 | 0.7 | 0.9 |
| | T3 | 2.0 | 2.6 | 3.2 | 2.1 | 2.6 | 3.5 | 4.7 |
| | All Stations | 1.0 | 1.4 | 1.8 | 1.2 | 1.5 | 1.9 | 2.4 |
| Windowpane | T1 | 1.1 | 1.6 | 2.3 | 1.3 | 1.4 | 1.8 | 2.2 |
| | T2 | 0.8 | 1.2 | 1.6 | 0.5 | 0.7 | 1.0 | 1.3 |
| | T3 | 0.6 | 0.9 | 1.4 | 3.1 | 1.0 | 1.7 | 2.6 |
| | All Stations | 0.9 | 1.2 | 1.6 | 1.6 | 1.1 | 1.5 | 1.9 |
| Rainbow smelt | T1 | 1.6 | 2.3 | 3.1 | 0.7 | 0.4 | 0.6 | 0.9 |
| | T2 | 2.2 | 3.2 | 4.3 | 0.4 | 0.3 | 0.5 | 0.8 |
| | T3 | 0.9 | 1.6 | 2.5 | 1.4 | 0.4 | 0.6 | 0.8 |
| | All Stations | 1.6 | 2.3 | 3.1 | 0.8 | 0.4 | 0.6 | 0.8 |
| Ocean pout | T1 | 0.6 | 0.7 | 1.0 | 0.2 | 0.1 | 0.1 | 0.2 |
| | T2 | 0.6 | 0.8 | 1.0 | 0.0 | 0.2 | 0.2 | 0.3 |
| | T3 | 1.4 | 1.8 | 2.3 | 0.2 | 0.1 | 0.2 | 0.3 |
| | All Stations | 0.9 | 1.1 | 1.3 | 0.2 | 0.1 | 0.2 | 0.2 |
| Silver hake | T1 | 0.1 | 0.2 | 0.4 | 2.5 | 0.3 | 0.6 | 0.9 |
| | T2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 |
| | T3 | 0.1 | 0.2 | 0.3 | 0.9 | 0.1 | 0.3 | 0.6 |
| | All Stations | 0.1 | 0.2 | 0.3 | 1.2 | 0.2 | 0.3 | 0.5 |
| Pollock | T1 | 0.2 | 0.3 | 0.4 | 0.0 | 0.0 | 0.1 | 0.2 |
| | T2 | 0.2 | 0.5 | 0.8 | 0.0 | 0.0 | 0.1 | 0.2 |
| | T3 | 0.1 | 0.2 | 0.3 | 0.0 | 0.1 | 0.1 | 0.2 |
| | All Stations | 0.2 | 0.3 | 0.5 | 0.0 | 0.0 | 0.1 | 0.2 |

(continued)

**Table 4-8 (Continued)**

| | | Preoperational Period | | | 2009 | Operational Period | | |
|---|---|---|---|---|---|---|---|---|
| | | LCL | Mean | UCL | Mean | LCL | Mean | UCL |
| Haddock | T1 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | T2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | T3 | 0.1 | 0.2 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 |
| | All Stations | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Spiny dogfish | T1 | 0.0 | 0.0 | 0.0 | 0.1 | 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 | 0.0 | 0.0 | 0.0 | 0.0 |
| | All Stations | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other species | T1 | 1.1 | 1.5 | 1.9 | 2.3 | 0.9 | 1.2 | 1.5 |
| | T2 | 1.0 | 1.5 | 2.0 | 0.9 | 0.6 | 0.7 | 0.9 |
| | T3 | 1.0 | 1.3 | 1.7 | 2.0 | 0.6 | 0.8 | 1.1 |
| | All Stations | 1.1 | 1.4 | 1.8 | 1.9 | 0.7 | 0.9 | 1.1 |

[a] Preoperational 1976-1989; geometric mean of annual means. [b] Geometric mean of the 2009 data. [c]Operational: 1991-2009; 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.

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).

More recent information indicates that Atlantic cod, windowpane, winter flounder, yellowtail flounder, witch flounder pollock and white hake are currently overfished in some part of their range (NEFSC 2008). Atlantic herring, Atlantic mackerel, silver hake, pollock, and red hake 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 9.4 in the preoperational period to 1.4 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 and windowpane in the operational period was higher than that of the preoperational period even though these species are considered overfished (NEFSC 2008). 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.

#### 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 S1 increased from the previous year, mean CPUE of all fish at all stations during 2009 decreased to 6.2 from 10.0 in 2008 due to decreases at Station S2 and S3 (Figure 4-6). Atlantic silverside, American sand lance, and Atlantic herring were the dominant fishes in the seine in 2009 (Table 4-10). CPUE in the seine was highest in 1979, and has generally declined since then to a time series low in 2004. CPUE subsequently increased through 2007 and declined since then. Overall, CPUE has been lower during 1987 through 2009

**Table 4-9. Results of Segmented Regression Analysis. Seabrook Operational Report, 2009.**

| 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 | 1976-1992 > 1993-2009 ** | Negative* | NS |
| S2 | 1976-1995 > 1996-2009 *** | Negative*** | NS |
| S3 | 1976-1993 > 1994-2009 *** | Negative** | NS |
| **Otter Trawl (No./10-min tow)[d]** | | | |
| **Demersal Fish Catch** | | | |
| T1 | 1976-1989 > 1990-2009 *** | NS | NS |
| T2 | 1976-1990 > 1991-2009 *** | NS | NS |
| T3 | 1976-1993 > 1994-2009 NS | Negative** | Positive** |
| **Rainbow Smelt** | | | |
| T1 | 1976-1990 > 1991-2009 *** | NS | NS |
| T2 | 1976-1990 > 1991-2009 *** | NS | NS |
| T3 | 1976-1990 > 1991-2009 ** | NS | NS |
| **Atlantic cod** | | | |
| T1 | 1976-1993 > 1994-2009 ** | Negative * | NS |
| T2 | 1976-1987 > 1988-2009 *** | NS | NS |
| T3 | 1976-1988 > 1989-2009 *** | NS | NS |
| **Hakes** | | | |
| T1 | 1976-1996 > 1997-2009 NS | Negative*** | NS |
| T2 | 1976-1994 > 1995-2009 ** | NS | NS |
| T3 | 1976-2006 < 2007-2009 *** | NS | NS |
| **Winter Flounder** | | | |
| T1 | 1976-1995 < 1996-2009 *** | NS | Positive ** |
| T2 | 1976-1986 > 1987-2009 ** | NS | NS |
| T3 | 1976-1993 < 1994-2009 *** | NS | Positive *** |
| **Yellowtail Flounder** | | | |
| T1 | 1976-1995 > 1996-2009 *** | Negative ** | NS |
| T2 | 1976-1990 > 1991-2009 *** | NS | NS |
| T3 | 1976-1991 > 1992-2009 *** | 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. June through November deleted for all species.
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 ($p\leq 0.001$)

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 2009 Mean. Seabrook Operational Report, 2009.**

| Species | | Preoperational Period | | | 2009 | Operational Period | | |
|---|---|---|---|---|---|---|---|---|
| | | LCL[a] | Mean | UCL[b] | Mean | LCL | Mean | UCL |
| Atlantic silverside | S1 | 5.1 | 7.2 | 10.2 | 7.0 | 3.6 | 4.8 | 6.2 |
| | S2 | 5.1 | 6.8 | 9.1 | 1.5 | 2.4 | 3.1 | 4.1 |
| | S3 | 4.0 | 6.7 | 10.7 | 1.4 | 2.1 | 2.9 | 3.9 |
| | **All Stations** | **4.8** | **6.9** | **9.7** | **2.6** | **2.9** | **3.5** | **4.3** |
| Winter Flounder | S1 | 0.6 | 0.9 | 1.2 | 0.3 | 0.2 | 0.4 | 0.5 |
| | S2 | 0.6 | 1.0 | 1.5 | 0.0 | 0.1 | 0.2 | 0.3 |
| | S3 | 2.2 | 3.2 | 4.4 | 0.2 | 0.3 | 0.5 | 0.7 |
| | **All Stations** | **1.2** | **1.5** | **2.0** | **0.1** | **0.2** | **0.3** | **0.4** |
| Killifishes | S1 | 0.8 | 1.1 | 1.5 | 0.3 | 0.5 | 0.9 | 1.3 |
| | S2 | 0.6 | 1.2 | 2.0 | 0.0 | 0.1 | 0.2 | 0.3 |
| | S3 | <0.1 | <0.1 | 0.1 | 0.0 | 0.0 | <0.1 | 0.1 |
| | **All Stations** | **0.5** | **0.7** | **1.0** | **0.1** | **0.2** | **0.3** | **0.4** |
| Ninespine stickleback | S1 | 0.4 | 0.7 | 1.2 | 0.1 | 0.1 | 0.2 | 0.3 |
| | 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** | **0.1** | **0.1** | **0.2** | **0.2** |
| Rainbow smelt | S1 | <0.1 | 0.1 | 0.2 | 0.0 | <0.1 | 0.1 | 0.2 |
| | S2 | <0.1 | 0.2 | 0.3 | 0.1 | 0.1 | 0.1 | 0.2 |
| | S3 | 0.3 | 0.7 | 1.2 | 0.1 | 0.1 | 0.2 | 0.4 |
| | **All Stations** | **0.2** | **0.3** | **0.4** | **0.1** | **0.1** | **0.2** | **0.2** |
| American sandlance | S1 | <0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 |
| | S2 | 0.0 | 0.2 | 0.5 | 0.0 | 0.0 | 0.1 | 0.1 |
| | S3 | <0.1 | 0.1 | 0.2 | 0.8 | 0.3 | 0.6 | 0.9 |
| | **All Stations** | **0.1** | **0.1** | **0.2** | **0.3** | **0.2** | **0.3** | **0.4** |

(continued)

**Table 4-10. (Continued)**

| Species | | Preoperational Period LCL | Preoperational Period Mean | Preoperational Period UCL | 2009 Mean | Operational Period LCL | Operational Period Mean | Operational Period UCL |
|---|---|---|---|---|---|---|---|---|
| Pollock | S1 | <0.1 | 0.1 | 0.2 | 0.1 | <0.1 | <0.1 | <0.1 |
| | S2 | <0.1 | 0.2 | 0.3 | <0.1 | 0.0 | <0.1 | <0.1 |
| | S3 | 0.1 | 0.4 | 0.8 | 0.1 | <0.1 | 0.1 | 0.1 |
| | **All Stations** | **<0.1** | **0.2** | **0.4** | **0.1** | **<0.1** | **<0.1** | **0.1** |
| Blueback herring | S1 | 0.1 | 0.2 | 0.3 | 0.1 | 0.1 | 0.3 | 0.4 |
| | S2 | <0.1 | 0.1 | 0.1 | 0.1 | <0.1 | 0.1 | 0.1 |
| | S3 | <0.1 | 0.1 | 0.3 | 0.0 | <0.1 | <0.1 | 0.1 |
| | **All Stations** | **<0.1** | **0.1** | **0.2** | **<0.1** | **0.1** | **0.1** | **0.2** |
| Atlantic herring | S1 | 0.0 | 0.1 | 0.2 | 0.3 | 0.1 | 0.2 | 0.3 |
| | S2 | 0.1 | 0.3 | 0.5 | 0.1 | <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** | **0.2** | **0.1** | **0.1** | **0.1** |
| Alewife | S1 | <0.1 | 0.1 | 0.2 | 0.3 | 0.1 | 0.2 | 0.4 |
| | S2 | 0.0 | 0.1 | 0.2 | 0.1 | <0.1 | <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 | 0.8 | 0.3 | 0.4 | 0.6 |
| | S2 | 0.9 | 1.1 | 1.4 | 0.1 | 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** | **0.5** | **0.4** | **0.5** | **0.6** |

[a] Preoperational: 1976-1989; geometric mean of annual means
[b] Geometric mean of the 2009 data.
[c] Operational; 1991-2009; geometric mean of annual means
[d] LCL = Lower 95% confidence limit.
[e] UCL = Upper 95% confidence limit.

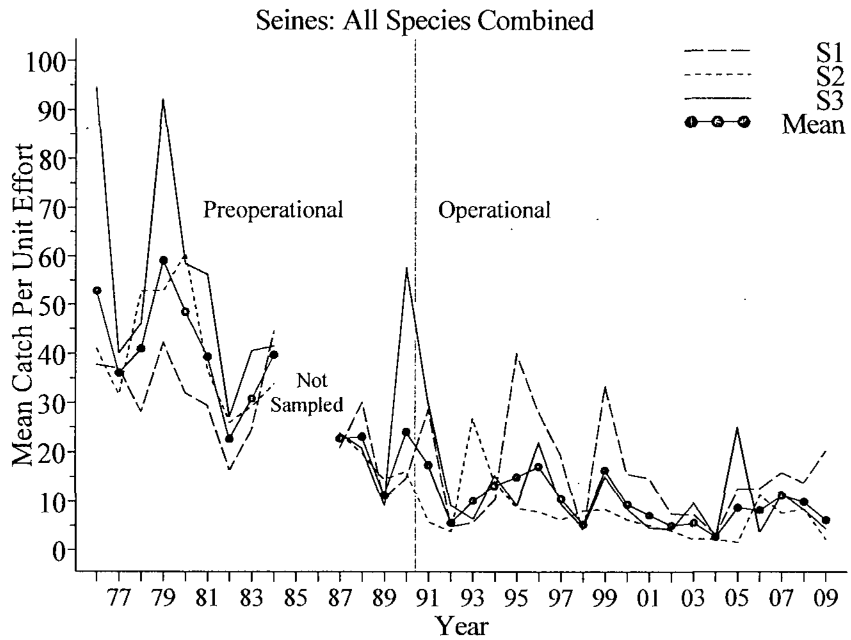



Figure 4-6. Annual geometric mean catch of all species combined per unit effort (number per haul) in seine samples by station and the mean of all stations, 1976-2009. Seabrook Operational Report, 2009.

(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.

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 2009 due to high catches of Atlantic silverside, continuing a trend that started in 2006. 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, and 2006 through 2009. In 2009, CPUE was lower and very similar at Stations S2 and S3 (Figure 4-6, Table 4-10). CPUE was highest at Station S3 in 1976, 1977, 1979, 1981, 1983, 1990, 2003, and 2005. CPUE in 2009 at Station S2, located in the Browns River, 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 breakpoints in CPUE occurred between 1992 and 1993 at Station S1, 1995 and 1996 at Station S2, and 1993 and 1994 at Station S3 (Table 4-9). At all stations CPUE was significantly greater in the earlier period and there were significant negative trends in the earlier period. There were no trends in CPUE in the later periods. 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 estimated 9,283 fish and 21 lobsters (see Section 6.0) were impinged in 2009 at Seabrook Station (Table 4-11). This estimate was a substantial decrease from last year (17,935) and from the record high estimate of 71,946 in 2003 for the period 1994-2009 (Appendix Table 4-3). The months with the high impingement of fish were November (1,669; 18%) and December (3,523; 38%). Daily average circulating water flow ranged from 135 MGD in October due to a refueling outage, to 661 MGD in July (Table 4-11).

In 2009, hake sp. (1,427: 15%), cunner (837: 9%), American sand lance (796: 9%), rock gunnel (701: 8%), and northern pipefish (698: 8%) composed 49% of the fish impinged (Table 4-11). Impingement of hake species (red, white, and possibly spotted hake) occurred in every month and was greatest in December when 33% (474) of the annual total was impinged. The 2009 impingement estimate for hake sp. was less than 2008 and within the range of previous years (Appendix Table 4-3). Red and white hake are commercially important fishes and both species occur in the study area. Red hake are more common inshore (<110 m) and white hake occur more often in offshore deeper waters (Collette and Klein-MacPhee 2002). The largest number of hake species impinged were between 42 and 55 mm (Figure 4-7) and probably were YOY fish.

Cunner were impinged every month except January, February, and October with the highest estimates occurring in June and July when 48% (400) of the annual total was impinged (Table 4-11). Cunner are a small non-commercial fish that is typically associated with some sort of structure (Collette and Klein-MacPhee 2002). The largest number of cunner impinged were between 70 and 97 mm (Figure 4-7) and probably were age 1 and older fish (Serchuck and Cole 1974). The 2009 estimate was the fourth-highest observed (Appendix Table 4-3).

American sand lance were impinged every month except June through October (Table 4-11). American sand lance are ecologically important and are a prey item for many other fish (Collette and Klein-MacPhee (2002). The highest impingement estimate occurred in December when 87% of the annual total (796) were impinged. A wide length range of American sand lance were impinged (Figure 4-7). Fish in the 96-103 mm size class were probably ages 1 to 2 and larger fish in the 160-167 mm size class could be as old as age 7 (Brethes et al. 1992).

Rock gunnel were impinged every month except January, February and October (Table 4-11). The largest impingement estimate occurred in September when 45% of the annual total was impinged. Most impinged rock gunnel were less than 153 mm and probably were as old as age 4 (Collette and Klein-MacPhee 2002).

Northern pipefish were impinged every month except January, February, July and October. The largest impingement estimates occurred in September and November when 72% (506) of the annual estimate was impinged. A wide range of lengths were impinged (Figure 4-7), and fish in the 96-119 mm length classes may be YOY fish approaching age 1 (Collette and Klein-MacPhee 2002).

Total impingement in 2009 was less than in 2008, but the impingement estimates for several commercial fish was higher in 2009 compared to the previous year. An estimated 490 Atlantic herring, 657 pollock, and 655 winter flounder were impinged in 2009 (Table

**Table 4-11. Species Composition and Total Number of Finfish and American Lobster Impinged at Seabrook Station by Month During 2009. Seabrook Operational Report, 2009.**

| | Month | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Total** | **Percent** |
| Alewife | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 7 | 0 | 0 | 10 | 7 | 34 | 0.37 |
| American eel | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 0.04 |
| American lobster | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 11 | 0 | 0 | 7 | 21 | 0.23 |
| American sand lance | 7 | 24 | 4 | 59 | 7 | 0 | 0 | 0 | 0 | 0 | 3 | 692 | 796 | 8.56 |
| American shad | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 4 | 11 | 0.12 |
| Atlantic cod | 0 | 0 | 4 | 25 | 16 | 46 | 0 | 0 | 0 | 0 | 22 | 34 | 147 | 1.58 |
| Atlantic herring | 0 | 0 | 0 | 11 | 0 | 24 | 11 | 46 | 11 | 0 | 293 | 94 | 490 | 5.27 |
| Atlantic menhaden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 39 | 0.42 |
| Atlantic silverside | 3 | 4 | 11 | 0 | 0 | 0 | 0 | 7 | 4 | 0 | 0 | 496 | 525 | 5.64 |
| Blueback herring | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 10 | 4 | 20 | 0.21 |
| Butterfish | 0 | 0 | 0 | 0 | 0 | 17 | 3 | 6 | 3 | 0 | 0 | 0 | 29 | 0.31 |
| Cunner | 0 | 0 | 10 | 61 | 113 | 212 | 188 | 83 | 96 | 0 | 44 | 30 | 837 | 9.00 |
| Cusk | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0.20 |
| 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 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0.12 |
| Fourspot flounder | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 10 | 0.11 |
| Grubby | 45 | 97 | 88 | 52 | 27 | 15 | 18 | 7 | 11 | 0 | 7 | 154 | 521 | 5.60 |
| Haddock | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 4 | 0 | 15 | 0.16 |
| Hake species | 37 | 3 | 61 | 195 | 130 | 117 | 4 | 32 | 273 | 4 | 97 | 474 | 1,427 | 15.34 |
| Longhorn sculpin | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 62 | 0.67 |
| Lumpfish | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 69 | 72 | 0.77 |
| Northern pipefish | 0 | 0 | 35 | 79 | 11 | 7 | 0 | 7 | 274 | 0 | 232 | 53 | 698 | 7.50 |
| Pollock | 0 | 0 | 0 | 4 | 0 | 53 | 3 | 7 | 3 | 0 | 559 | 28 | 657 | 7.06 |
| Radiated shanny | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 80 | 0.86 |
| Rainbow smelt | 4 | 3 | 0 | 0 | 0 | 4 | 0 | 7 | 0 | 0 | 7 | 18 | 43 | 0.46 |
| Rock gunnel | 0 | 0 | 32 | 77 | 25 | 44 | 71 | 82 | 312 | 0 | 54 | 4 | 701 | 7.53 |
| Scup | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 11 | 0 | 15 | 0.16 |
| Sea lamprey | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.04 |
| Sea raven | 4 | 0 | 0 | 21 | 11 | 4 | 3 | 0 | 26 | 0 | 3 | 7 | 79 | 0.85 |
| Shorthorn sculpin | 50 | 57 | 28 | 32 | 7 | 10 | 3 | 0 | 4 | 0 | 37 | 38 | 266 | 2.86 |
| Silver hake | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 11 | 4 | 0 | 114 | 193 | 325 | 3.49 |
| Skate sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 7 | 27 | 41 | 0.44 |
| Snailfish sp. | 8 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 24 | 41 | 85 | 0.91 |
| Tautog | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0.06 |
| Threespine stickleback | 0 | 4 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 66 | 118 | 1.27 |
| Windowpane | 8 | 7 | 14 | 21 | 0 | 3 | 4 | 60 | 0 | 0 | 59 | 251 | 427 | 4.59 |
| Winter flounder | 15 | 0 | 7 | 42 | 4 | 0 | 4 | 0 | 0 | 0 | 14 | 569 | 655 | 7.04 |
| Wrymouth | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 14 | 0.15 |
| **All** | **181** | **200** | **305** | **718** | **360** | **609** | **320** | **376** | **1,039** | **4** | **1,669** | **3,523** | **9,304** | **100.0** |
| **Daily impingement Rate (Fish/day)** | **5.8** | **7.1** | **9.8** | **23.9** | **11.6** | **20.3** | **10.3** | **12.1** | **34.6** | **0.1** | **53.8** | **113.6** | **25.5** | |
| **Ave. Daily Flow ($10^6$ G)** | **606** | **604** | **614** | **623** | **644** | **659** | **661** | **660** | **658** | **135** | **520** | **570** | **580** | |
| **Impingement Rate (fish/$10^9$ G)** | **9.6** | **11.8** | **16.1** | **38.4** | **18.0** | **30.8** | **32.2** | **18.4** | **52.6** | **1.0** | **107.0** | **199.0** | **43.8** | |

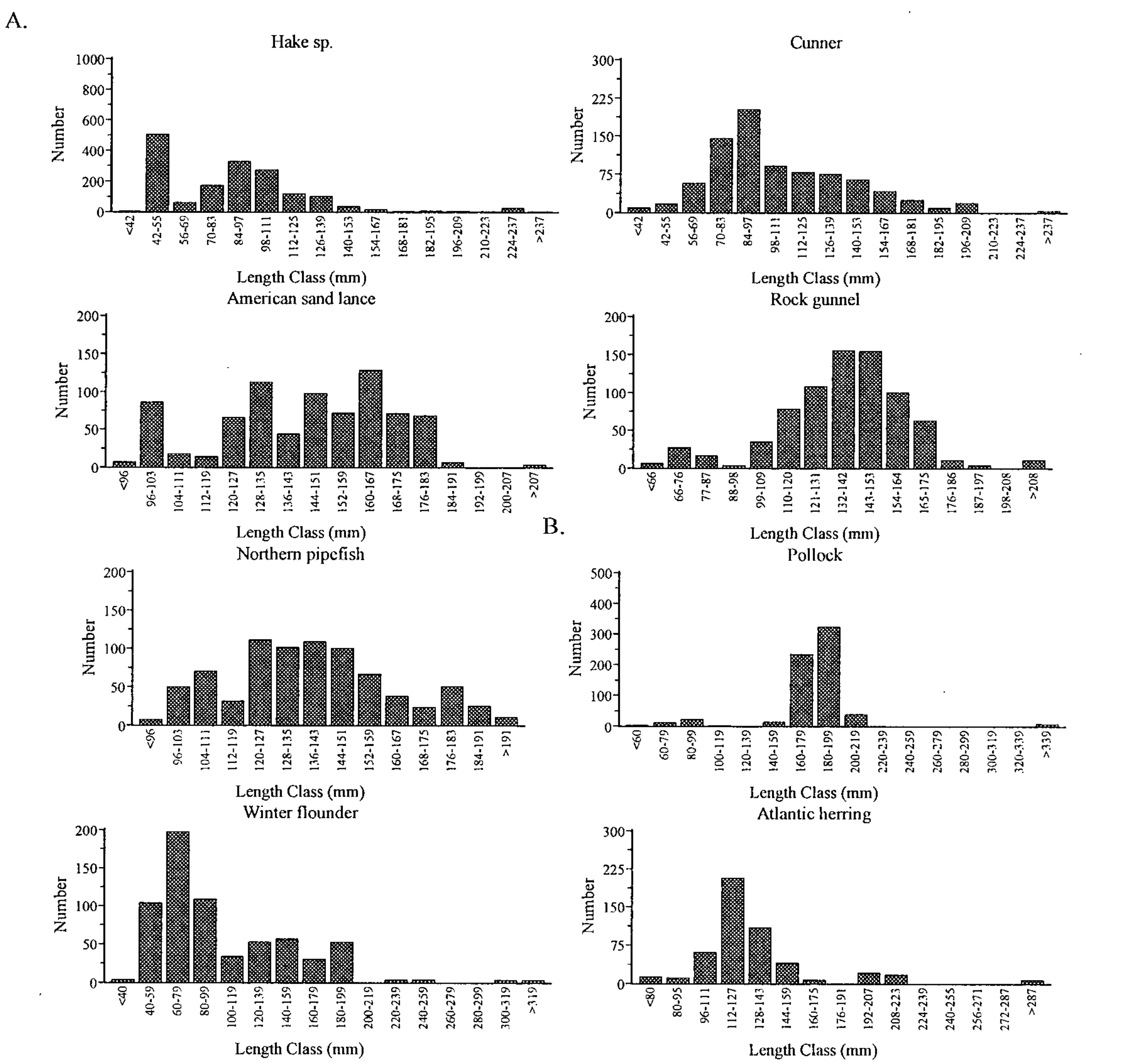



Figure 4-7. Length frequency distributions of (A) the four most abundant impinged fish and (B) commercially-important fish impinged at Seabrook Station in 2009. Seabrook Operational Report, 2009.

4-11). All of these estimates are within the range of previous years, but an increase over the 2008 estimates with the exception of winter flounder (and hakes discussed earlier). Most of these impinged commercial fish were YOY or age 1 fish (Figure 4-7) (Collette and Klein MacPhee 2002).

Estimated impingement of American eel (4), Atlantic menhaden (39), butterfish (29), and silver hake (325) was each less than 400 fish for the year. No Atlantic mackerel, yellowtail flounder, or haddock were collected in impingement samples in 2009. These losses represent a small fraction of the stock size of these commercial fishes. Based on impingement data from the end of 1994 through 2009, 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 2009 was 20,987 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 46,451 fish/year at Pilgrim Station to 65,927 fish/year at Millstone 2.

During 2009, about 38% of the total annual impingement estimate occurred in December. High impingement events at Seabrook Station and other plants were often associated with storm events. In 2007 and 2008, strong storms were accompanied by high impingement estimates (NAI 2009). In 2009, a strong northeast storm occurred on 9 December (NCDC 2010) and impingement estimates for that week were the highest of the year and contributed 21% to the total annual estimate. 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.

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, 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 spawning sites (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, 2009.**

| 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 | 1995-2009[a] | 20,987[a] | 76 | 7,281-71,950 | 57 | – |
| 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 | 1980-2009 | 46,451[c] | 142 | 1,112-302,883[c] | 127 | Environmental Protection Group, Entergy Nuclear-Pilgrim Station (2009) |
| 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]<br>65,927[e] | 59<br>214 | 8,560-60,410[d]<br>8,560-511,387[e] | 71<br>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 increased steadily from 1982 to 1997 and has fluctuated without trend since then (TRAC 2009). The 1994 and 1998 year classes were extremely large and recruitment for the 1999-2000 year classes has been weaker than average (NEFSC 2006) although 2005 year class appears to be strong (TRAC 2009a). 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 2009, average larval density was lower than the preoperational and operational means at both stations (Table 4-13). Atlantic herring larval densities have been variable with major peaks in 1975-76, 1986, and 2001 (Figure 4-8). In 2009, larval density decreased at both stations compared to 2008. 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 490 Atlantic herring were impinged in 2009 (Table 4-11) and length ranged from 67 to 296 mm with the majority YOY between 112 and 143 mm (Figure 4-7). An estimated 27.8 million Atlantic herring were entrained in 2009, which was only exceeded by the 2008 estimate of 28.2 million (Table 4-6). 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. Entrainment of these larvae and impingement of adults resulted in the estimated average loss of 1,028 equivalent adults each year for the period 1998 through 2009. An estimated 1,055 equivalent adults were lost in 2009 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 2009, geometric mean CPUE for all trawl stations combined decreased compared to 2008 (Figure 4-9). CPUE was highest at Station T2, especially during 1978, 1981, 1983, 1987-1989, 1998, and 2006

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 2009. Seabrook Operational Report, 2009.

| | | Preoperational Period | | | 2009 | Operational Period | | |
|---|---|---|---|---|---|---|---|---|
| | | LCL[a] | Mean | UCL[b] | Mean | LCL | Mean | UCL |
| American sand lance | P2 | 106.9 | 159.6 | 238.1 | 592.8 | 100.2 | 141.3 | 199.1 |
| | P7 | 56.0 | 106.0 | 199.9 | 597.7 | 80.3 | 112.6 | 157.7 |
| | **All Stations** | **95.4** | **144.2** | **217.6** | **595.2** | **91.5** | **126.2** | **173.9** |
| Atlantic cod | P2 | 1.3 | 2.5 | 4.4 | 0.5 | 0.3 | 0.6 | 0.9 |
| | P7 | 0.3 | 1.0 | 2.1 | 0 | 0.2 | 0.3 | 0.4 |
| | **All Stations** | **1.2** | **2.4** | **4.3** | **0.2** | **0.2** | **0.4** | **0.6** |
| Atlantic herring | P2 | 14.8 | 29.0 | 55.9 | 11.4 | 8.2 | 11.6 | 16.2 |
| | P7 | 15.8 | 33.2 | 68.5 | 10.2 | 9.1 | 12.9 | 18.3 |
| | **All Stations** | **15.5** | **29.7** | **55.9** | **10.8** | **8.7** | **12.2** | **17.0** |
| Atlantic mackerel | P2 | 4.5 | 6.9 | 10.4 | 4.0 | 2.0 | 3.5 | 5.7 |
| | P7 | 3.8 | 5.9 | 9.1 | 2.5 | 1.9 | 3.3 | 5.2 |
| | **All Stations** | **4.5** | **6.8** | **9.9** | **3.2** | **2.0** | **3.4** | **5.4** |
| Cunner | P2 | 28.9 | 48.5 | 81.0 | 75.0 | 74.8 | 123.4 | 203.0 |
| | P7 | 23.9 | 59.0 | 143.9 | 86.2 | 86.5 | 135.1 | 210.8 |
| | **All Stations** | **31.0** | **51.4** | **84.7** | **80.4** | **81.3** | **129.1** | **204.9** |
| Hakes | P2 | 2.4 | 3.9 | 6.2 | 8.4 | 1.9 | 4.2 | 8.4 |
| | P7 | 1.4 | 3.9 | 9.0 | 1.7 | 1.9 | 4.1 | 8.1 |
| | **All Stations** | **2.5** | **4.1** | **6.3** | **4.1** | **2.0** | **4.2** | **8.1** |
| Pollock | P2 | 3.1 | 6.8 | 13.7 | 20.4 | 0.6 | 1.4 | 2.7 |
| | P7 | 0.8 | 2.4 | 5.6 | 8.5 | 0.6 | 1.3 | 2.2 |
| | **All Stations** | **3.1** | **6.8** | **13.8** | **13.3** | **0.6** | **1.3** | **2.4** |
| Winter flounder | P2 | 9.0 | 12.1 | 16.0 | 4.0 | 2.9 | 4.0 | 5.3 |
| | P7 | 4.7 | 8.0 | 13.4 | 1.5 | 1.4 | 2.0 | 2.7 |
| | **All Stations** | **7.7** | **10.5** | **14.1** | **2.5** | **2.2** | **2.9** | **3.6** |
| Yellowtail flounder | P2 | 1.9 | 3.4 | 5.8 | 0.9 | 0.6 | 1.1 | 1.8 |
| | P7 | 1.2 | 2.9 | 5.7 | 0.7 | 0.5 | 1.0 | 1.6 |
| | **All Stations** | **2.1** | **3.7** | **6.1** | **0.8** | **0.6** | **1.1** | **1.7** |

[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 2009 data.
[c] Operational: August 1990-December 2009; 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 2009 includes November through December 2008 and January through February 2009.

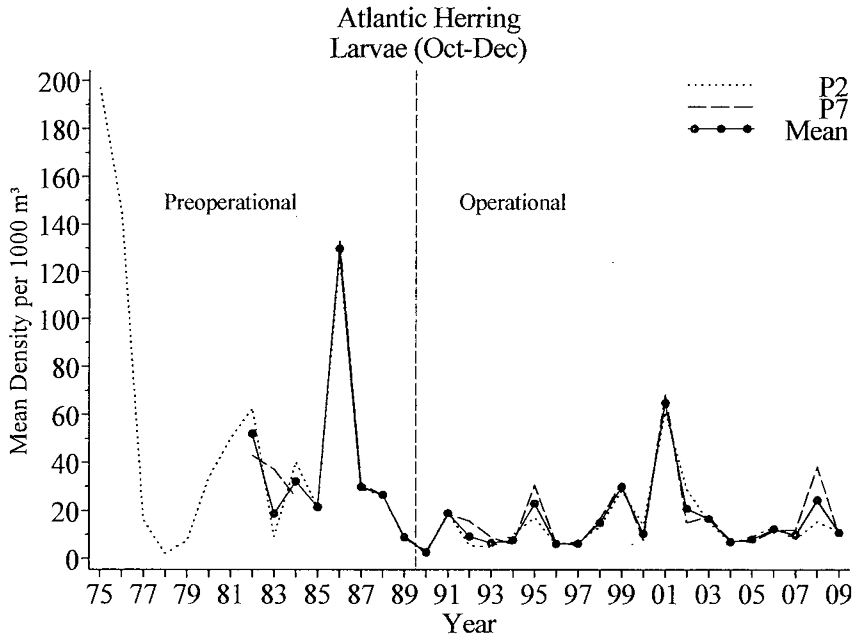



Figure 4-8. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of Atlantic herring in ichthyoplankton samples by station and the mean of all stations, 1975-2009. Seabrook Operational Report, 2009.

**Table 4-14. Results of Analysis of Variance of Atlantic Herring Densities by Sampling Program. Seabrook Operational Report, 2009.**

| Program/ Months Used | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Ichthyoplankton** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Oct.-Dec.) (1982-2009) | Preop-Op[a] | 1, 79.3 | 4.55 | 0.0361* | Op<Preop |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| $Log_{10}(x+1)$ | Year (Preop-Op)[b] | 0 | 0.00 | 0.4996 | |
| | Month(Year)[c] | 0.3514 | 174.64 | <0.0000* | |
| | Station[d] | <0.0001 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4996 | |
| | Error | 0.4291 | | | |

[a] Preop-Op compares 1982-1984, 1986-1989 to 1990-2009 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).

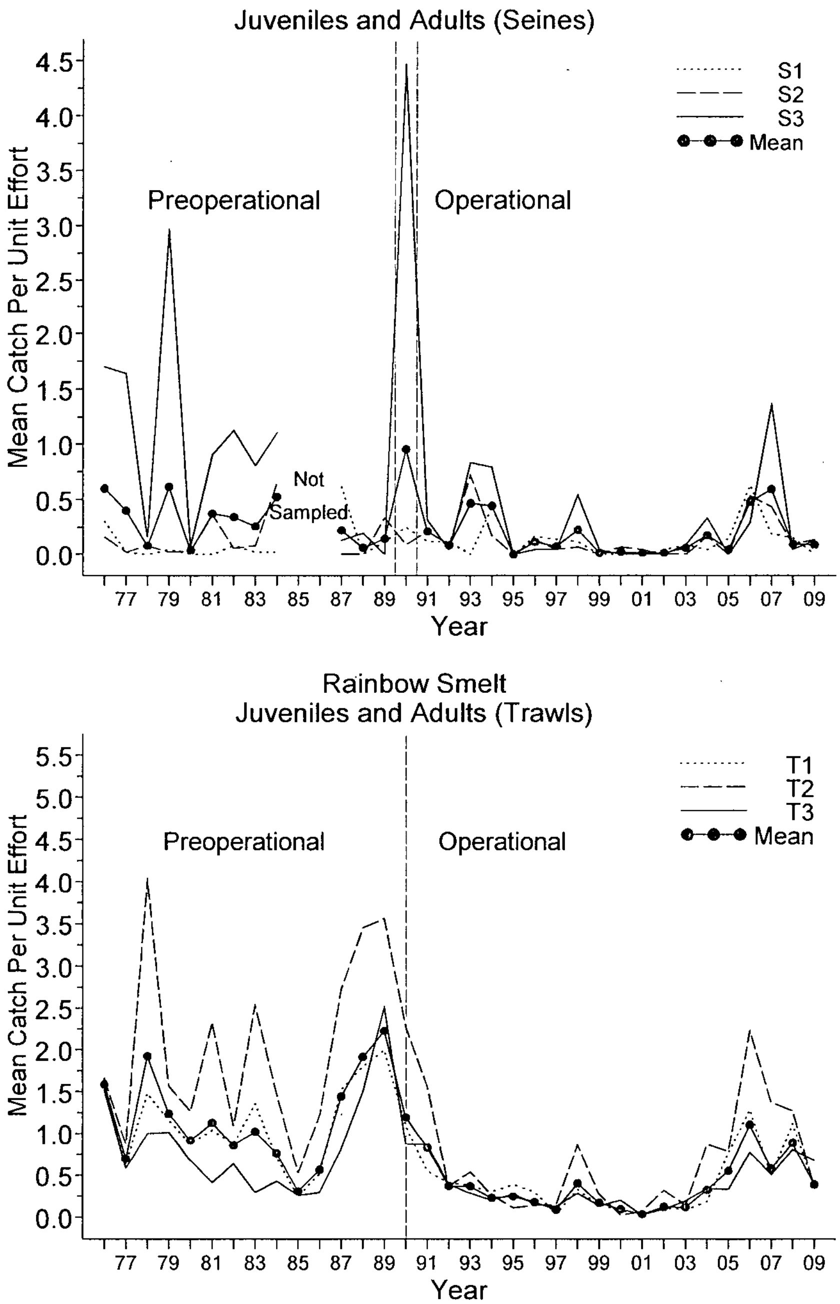



Figure 4-9. Annual geometric mean catch of rainbow smelt per unit effort in trawl (number per 10-minute tow) and seine (number per haul) samples by station and the mean of all stations, 1975-2009 (data between two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

through 2008, although in 2009 CPUE was highest at Station T3 (Figure 4-9). CPUE was higher in the period 1976 though 1990 compared to 1991 through 2009 at all stations, but there were no significant trends within the periods (Table 4-9).

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 2009 was similar to 2008 (Figure 4-9). Seine CPUE was variable, especially at Station S3 during the preoperational period. CPUE at Station S3 was the highest observed in the operational period in 2007, but declined in 2008 and 2009. Mean CPUE peaked in the preoperational 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 43 rainbow smelt were impinged in 2009, with the largest estimates occurring in March and November (Table 4-11). Rainbow smelt impinged were on average 111 mm in total length (range= 63-190 mm) and were probably Age 2-3 fish based on length (Murawski and Cole 1978). An estimated total of 17,487 rainbow smelt have been impinged since 1994, resulting in an average of 1,166 impinged per year (Appendix Table 4-3). To put this loss in perspective, an estimated average of 91,000 rainbow smelt were taken by recreational anglers in the Great Bay ice fishery each year between 1994 and 2009 (no estimate was possible for 2002 and 2006 due to lack of ice cover; NHFG 2010).

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. 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 2009 accounting for a total entrainment estimate of about 9.2 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 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

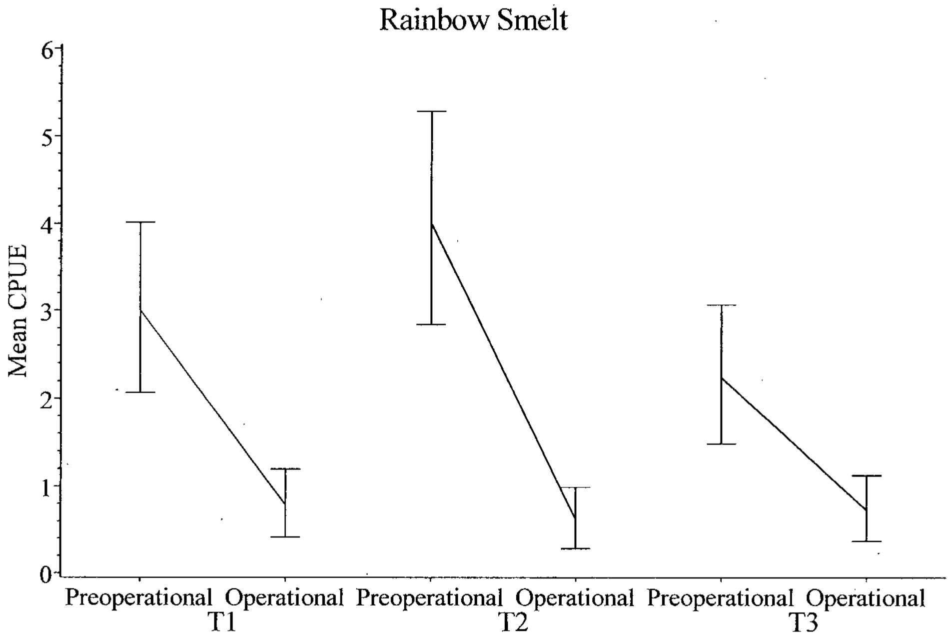



Figure 4-10. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of rainbow smelt caught by trawl during the preoperational (December 1975-May 1990) and operational (November 1990-May 2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-14). Seabrook Operational Report, 2009.

**Table 4-15. Results of Analysis of Variance of Rainbow Smelt Densities by Sampling Program. Seabrook Operational Report, 2009.**

| 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, 28.8 | 3.77 | 0.0619 | |
| (1976-1984, 1987-2009 | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0002 | 0.02 | 0.4403 | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.0066 | 8.51 | 0.0018* | |
| | Station[d] | 0.0027 | 10.45 | 0.0006* | S3> S2 S1 |
| | Station X Year (Preop-Op)[f] | 0.0039 | 7.16 | 0.0037* | |
| | Error | 0.0494 | | | |
| **Trawl** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Dec-May) | Preop-Op[a] | 1, 13 | 17.59 | 0.0010* | Op<Preop |
| (1975-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | Year (Preop-Op)[b] | 0.0144 | 4.21 | 0.0201* | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.1011 | 197.97 | <0.0001* | |
| | Station[d] | 0 | 0 | 0.5000 | |
| | Preop-Op X Station[e] | 0.0053 | 15.21 | 0.0001* | 2Pre 1Pre 3Pre 1Op 3Op 2Op |
| | Station X Year (Preop-Op)[f] | 0 | 0.000 | 0.5000 | |
| | Error | 0.0658 | | | |

[a] Preop-Op for seine compares 1976-1984 and 1987-1989 to 1991-2009 regardless of station. Preop-Op for trawl compares 1990-2009 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 ($p \leq 0.05$)

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). Year class strength did not appear to be related to egg or larval abundance, but instead was more closely related to the abundance of pelagic and settled juveniles (Campana et al. 1989). 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. Overexploitation of Atlantic cod stocks in the northwest Atlantic may be having life history effects and genetic implications. Both age and lengthy at maturity (Hutchings 2006) and size at age (Swain et al. (2007) may be reduced in response to selective removal of fast growing fish by the commercial fishery. The removal of these genotypes from the population may not be reversible by limiting fishing mortality and may be inhibiting recovery of the stocks.

The Gulf of Maine Atlantic cod stock is not overfished, but overfishing is occurring (NEFSC 2008). The strong 1987 year class is no longer predominant and was replaced by the less numerous year classes from the 1990s. The 2000 year class appears to be very weak, but the 2003 and 2005 year classes appear to be strong. Spawning stock biomass estimates conducted in the spring and fall were low through 2000, but increased in 2001 and possibly again in 2002. The spring indices from 2003 through 2005 suggest a decline in biomass to historically low levels, followed by an increase after 2005, while the fall indices have remained low through 2007 (NEFSC 2008).

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, and in 1997 at both stations (Figure 4-11). Since then density has declined to relatively low and stable levels. Densities in 2009 were below the preoperational and operational means at both stations and no Atlantic cod larvae were collected at Station P7 (Table 4-13). Due to the low abundance of Atlantic cod larvae since 2002, 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 in 2009 compared to 2008 (Figure 4-11), and was lower than the lower preoperational confidence limit (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 1976-1993 at Station T1, and no trend after that (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 1987 compared to 1988-2009 at Station T2, and higher during 1976-1988 compared to 1989-2009 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 88% at Station T1, 75% at Station T2, and 73% at Station T3 (Table 4-8). 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 low levels in recent years suggest a regional trend (NEFSC 2008).

An estimated 147 Atlantic cod were impinged in 2009 (Table 4-11). The lengths of impinged Atlantic cod were variable, and ranged from 47 to 583 mm with the majority less than 107 mm in length (Figure 4-7). Impingement was highest in November and December (38%) and most of these fish appeared to be YOY (Collette and Klein-MacPhee 2002). Since 1994 an estimated 5,225 fish were impinged, a total not likely to affect Atlantic cod resources in the study area (Appendix Table 4-3).

Egg entrainment (5.7 million in 2009) was 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 2009

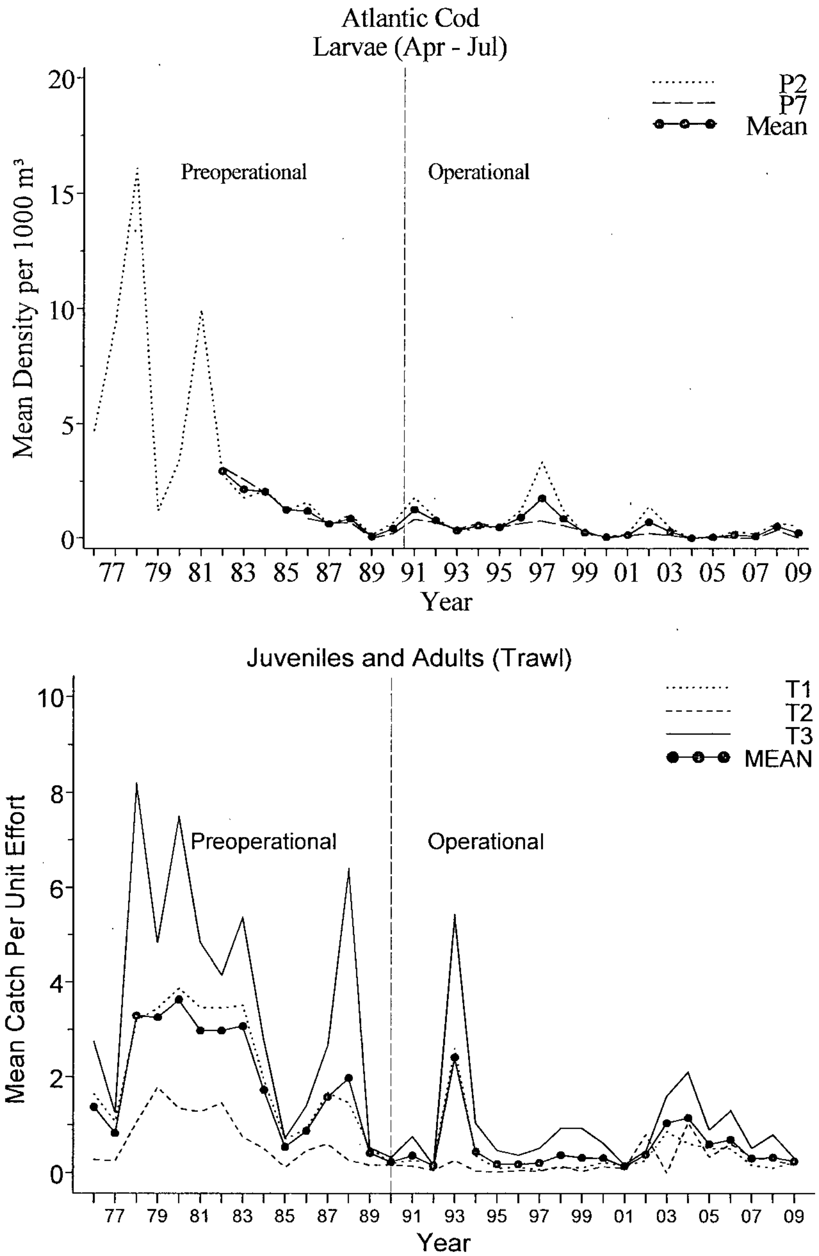



Figure 4-11. Annual geometric mean catch of Atlantic cod per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2009. Seabrook Operational Report, 2009.

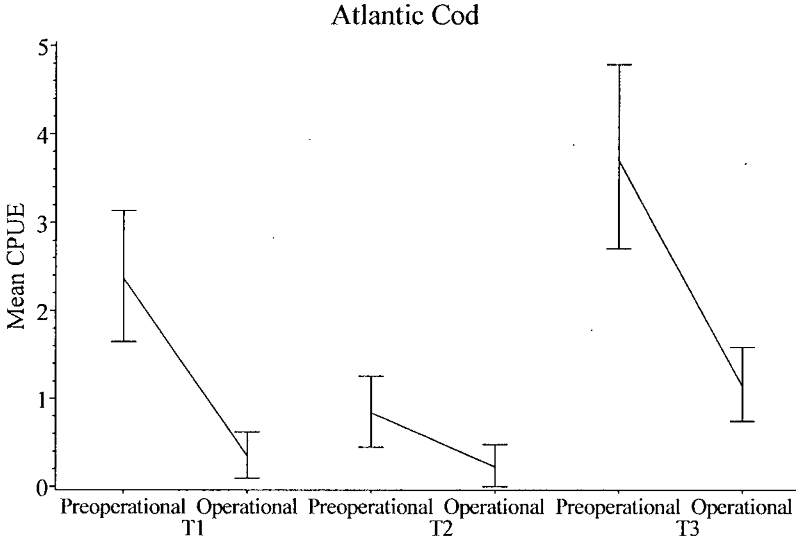



Figure 4-12. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of Atlantic cod caught by trawl during the preoperational (December 1975-June 1990) and operational December 1990-June 2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-15). Seabrook Operational Report, 2009.

**Table 4-16. Results of Analysis of Variance of Atlantic Cod Densities by Sampling Program. Seabrook Operational Report, 2009.**

| 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, 24.6 | 4.50 | 0.0442* | Op<Preop |
| (1982-1984, | | | | | |
| 1986-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0077 | 1.71 | 0.0969 | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.0371 | 44.12 | <0.0001* | |
| | Station[d] | 0.0023 | 1.08 | 0.1499 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4999 | |
| | Error | 0.1687 | | | |
| **Trawl** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Dec.-Jun.) | Preop-Op[a] | 1, 4.79 | 11.27 | 0.0216* | Op<Preop |
| (1975-2008) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | Year (Preop-Op)[b] | 0.0205 | 30.04 | <0.0001* | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.0290 | 78.92 | <0.0001* | |
| | Station[d] | 0.0232 | 1.65 | 0.0994 | |
| | Preop-Op X Station[e] | 0.0072 | 15.94 | <0.0001* | 3Pre 1Pre 3Op 2Pre 1Op 2Op |
| | Station X Year (Preop-Op)[f] | 0.0028 | 3.59 | 0.0291* | |
| | Error | 0.0473 | | | |

[a] Preop-Op for ichthyoplankton compares 1991-2009 to 1982-1984 and 1986-1990 regardless of station. Preop-Op for trawl compares 1990-2009 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 ($p \leq 0.05$)

(1.4 million) was the second highest observed. It is not likely that entrainment of cod eggs and larvae would affect recruitment to the juvenile stage because year class strength is related to body size at age at the early pelagic juvenile stage (Camapana 1996), overfishing and climate change (Rose 2004), biological productivity (Rothschild 1994), 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 flounder larvae are common, so the ratio of Atlantic cod to witch flounder larvae each year from 1998 through 2009 was used to estimate the number of Atlantic cod eggs in this group. Entrainment of cod eggs and larvae could potentially result in the loss of an average of 536 adult Atlantic cod per year for the period 1998 through 2009 with an estimate of 52 for 2009. An estimated 41 equivalent adult cod were also lost in 2009 due to impingement, with a mean annual loss of 42 for the period 1998-2009. 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 1986-1995, declined to a low of 4,500 metric tons in 1996, but have steadily increased to a recent high of 9,00 metric tons in 2007 (NEFSC 2008). 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 2008). Relatively strong year classes occurred in 1999 and 2001. As of 2008, the stock is overfished and overfishing is 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 peaks in 1987, 2006, and 2008 (Figure 4-13). In 2008, (November 2008 through February 2009), density of pollock larvae was near or above the preoperational and operational upper confidence limits and the second highest in the operational period (Table 4-13; Figure 4-13). There were no significant differences between stations or between preoperational and operational periods (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.

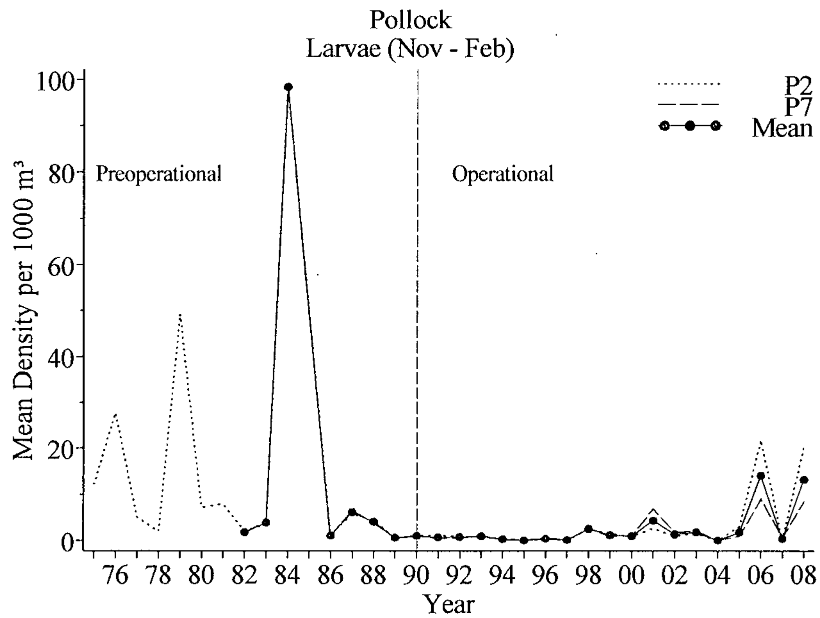



Figure 4-13. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of pollock in ichthyoplankton samples by station and the mean of all stations, 1975-2008. Note, 2008 includes November and December of 2008 and January and February of 2009. Seabrook Operational Report, 2009.

**Table 4-17. Results of Analysis of Variance of Pollock Densities by Sampling Program. Seabrook Operational Report, 2009.**

| Program/ Months Used | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Ichthyoplankton** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Nov.-Feb.) | Preop-Op[a] | 1, 21.5 | 3.37 | 0.0804 | |
| (1982-1983, | | | | | |
| 1986-2008) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | Year (Preop-Op)[b] | 0.0602 | 8.57 | 0.0017* | |
| | Month(Year)[c] | 0.1017 | 98.61 | <0.0001* | |
| | Station[d] | 0 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 0.2156 | | | |

[a] Preop-Op for ichthyoplankton compares 1990-2008 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 $H_o$: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

An estimated 657 pollock were impinged in 2009, primarily in November October (85%; Table 4-11). Lengths of impinged pollock ranged from 58 to 352 and were primarily YOY and age 1 fish based on the length frequency distribution (Figure 4-7; Collette and Klein-MacPhee 2002).

An estimated 180,000 pollock eggs and 290,000 larvae were entrained in 2009 (Table 4-6). Pollock eggs were entrained most years and larvae were entrained only in 1990, 1992, 1998, and 2002 through 2009 (Table 4-6).

An estimated 416 equivalent adult pollock per year were lost due to impingement for the years 1998 through 2008. In 2009, an estimated 547 equivalent adults were lost due to impingement. Entrainment losses of pollock eggs and larvae at Seabrook Station in 1998 through 2009 were estimated to result in the annual loss of 31 equivalent adults annually, with an estimate of 10 equivalent adults for 2009.

#### 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 2008). The NEFSC index of white hake biomass 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 2008). The biomass index increased in between 2000 and 2002 due to the recruitment of the strong 1998 year class, 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

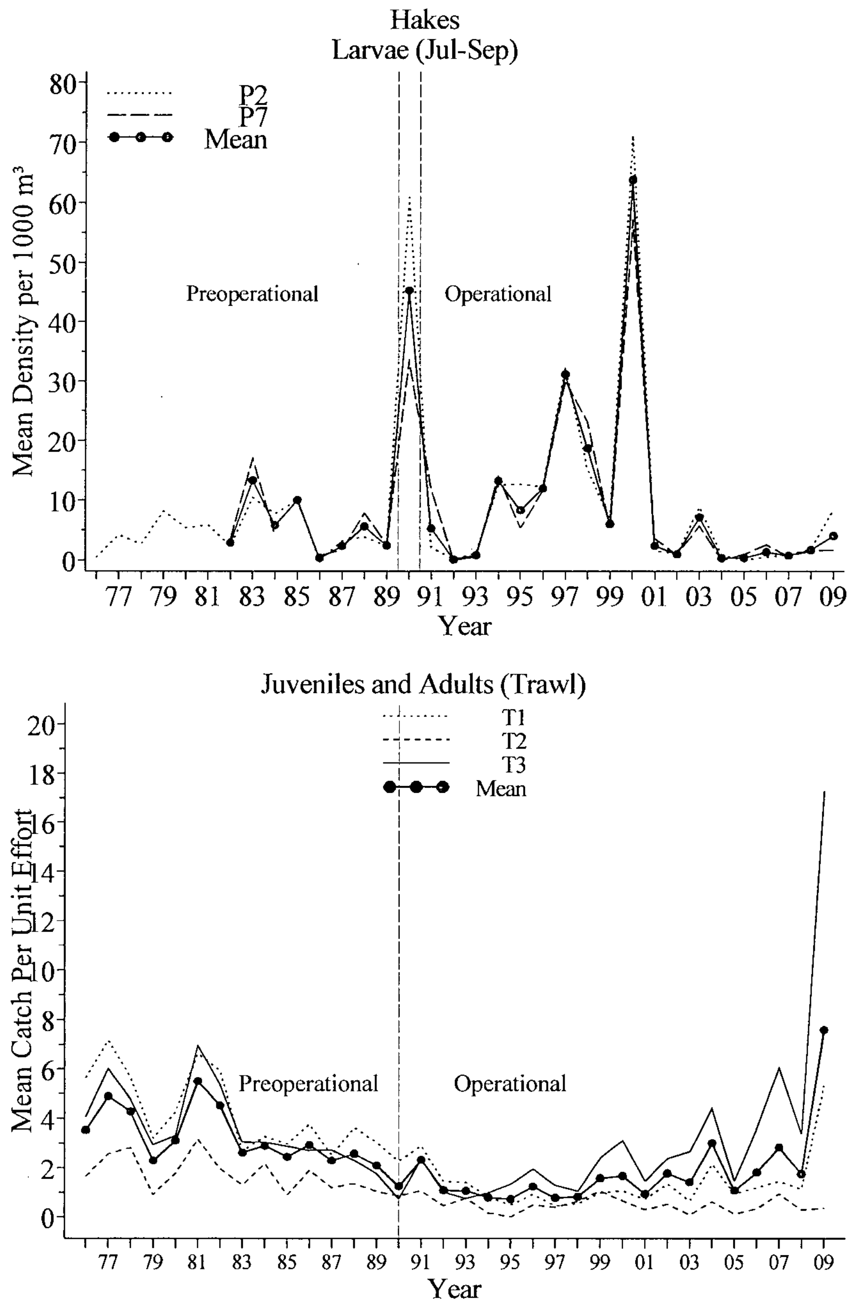



Figure 4-14. Annual geometric mean catch of hakes per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2009 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

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). Overall mean density in 2009 was similar to the preoperational and operational means primarily due to relatively high density at Station P2 (Table 4-13). Despite the increases in larval density from 1993 through 2000 and in 2003 and 2009, 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 were significant negative trends in geometric mean CPUE during 1976-1996 at Station T1 and there were no trends at Stations T2 and T3 (Table 4-9). CPUE was significantly higher from 1976 through 1994 at Station T2 compared to later periods. At Station T3, the recent CPUE from 2006 through 2009 was significantly higher than the earlier period. CPUE in 2009 at Stations T1 and T3 was higher than the preoperational and operational means and upper confidence limits, with CPUE at T3 the highest recorded at that station. CPUE at Station T2 in 2009 was below the preoperational mean and equal to the operational mean (Table 4-8). 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).

Entrainment and impingement losses due to plant operation did not appear to affect local populations. In 2009, an estimated 72.3 million hake eggs and 120.8 million hake/fourbeard rockling eggs were entrained and 4 million hake larvae were collected in entrainment samples (Table 4-6). These estimates were within the range of previous years. An estimated 1,427 hakes (red hake and hake sp.) were impinged at Seabrook Station in 2009 (Table 4-11). The 2009 impingement estimate was with the range of previous years (Appendix Table 4-3). These fish ranged in length from 37 to 240 mm and most 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 219 per year for 1998 through 2009. In 2009, the estimate was 680 equivalent adults. Equivalent adult losses due to impingement averaged 239 per year for 1998 through 2009. In 2009, an estimated 182 equivalent adults were lost due to impingement. Saila et al. (1997) had similar results and estimated that impingement of red hake at Seabrook Station 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

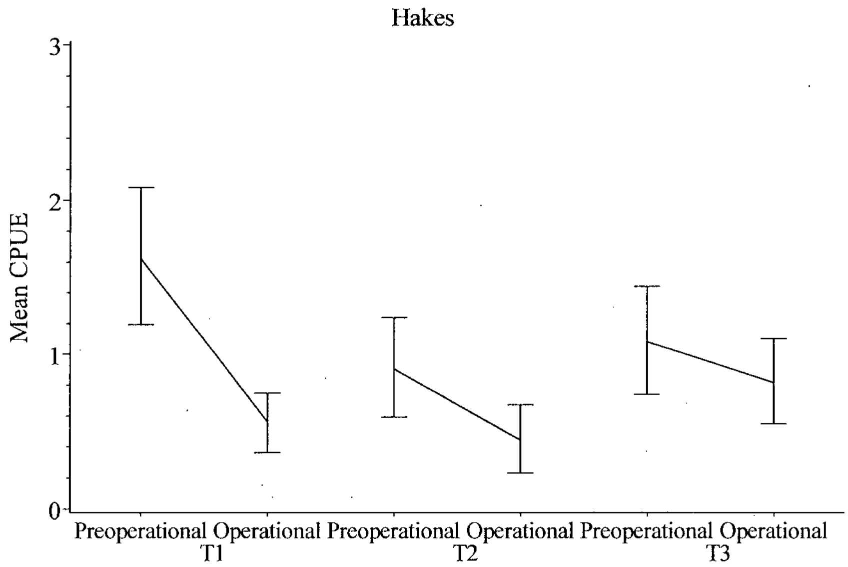



Figure 4-15. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of hakes caught by trawl during the preoperational (December 1976-June 1990) and operational (December 1990-June 2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-17). Seabrook Operational Report, 2009.

**Table 4-18. Results of Analysis of Variance of Hake (red, white, and spotted hake) Densities by Sampling Program. Seabrook Operational Report, 2009.**

| 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, 24.3 | 0.07 | 0.8008 | |
| (1982-1984, 1986-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | Year (Preop-Op)[b] | 0.1328 | 8.07 | 0.0023* | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.1725 | 44.20 | <0.0001* | |
| | Station[d] | 0 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4999 | |
| | Error | 0.6012 | | | |
| **Trawl** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Dec.-Jun.) | Preop-Op[a] | 1, 4.6 | 4.12 | 0.1031 | |
| (1976-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.5000 | |
| $Log_{10}(x+1)$ | Month(Year)[c] | 0.0823 | 297.43 | <0.0001* | |
| | Station[d] | 0.0007 | 0.04 | 0.4177 | |
| | Preop-Op X Station[e] | 0.0036 | 8.43 | <0.0019* | 1Pre 3Pre 2Pre 3Op 1Op 2Op |
| | Station X Year (Preop-Op)[f] | 0.0030 | 5.60 | 0.0090* | |
| | Error | 0.0390 | | | |

[a] Preop-Op for ichthyoplankton compares 1990-2009 to 1982-1984 and 1986-1989 regardless of station. Preop-Op for trawl compares 1990-2009 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 ($p \leq 0.05$)

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 2008 although CPUE declined at Stations S2 and S3 in 2009. In 2009, as in previous years, Atlantic silverside was the most numerous fish captured in the beach seine (Table 4-10). CPUE in 2009 was below the preoperational and operational means at Stations S2 and S3, but similar to the preoperational mean and above the operational mean at Station S1.

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).

An estimated 525 Atlantic silverside were impinged in 2009, with about 95% impinged in December (Table 4-11). Most of these fish were less than 100 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 2009 was within the range of previous years (Appendix Table 4-3). An estimated average of 2,405 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

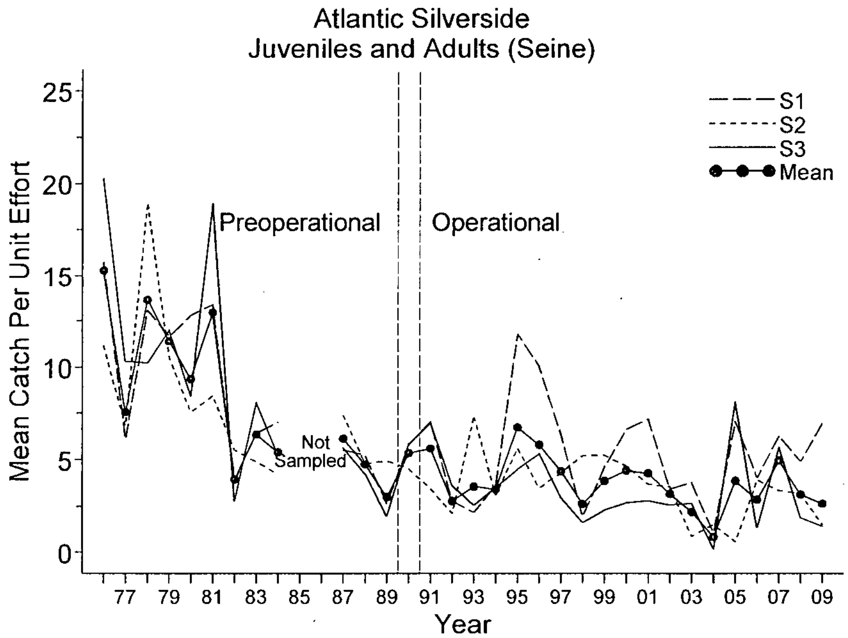



Figure 4-16. Annual geometric mean catch per unit effort of Atlantic silverside in seine samples (number per haul) by station and the mean of all stations, 1976-2009 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

**Table 4-19. Results of analysis of variance of Atlantic Silverside Densities by Sampling Program. Seabrook Operation Report, 2009.**

| 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, 239 | 7.58 | 0.0064* | Op<Preop |
| (1976-1984, | Random Effects | Estimate[j] | $\chi^2$ | P | |
| 1987-2009) | Year (Preop-Op)[b] | 0 | 0.00 | 0.5000 | |
| | Month(Year)[c] | 0.5062 | 452.22 | <0.0001* | |
| $Log_{10}(x+1)$ | Station[d] | 0.0027 | 3.60 | 0.0289* | S1 S2 S3 |
| | Station X Year (Preop-Op)[f] | 0.0030 | 0.52 | 0.2349 | |
| | Error | 0.1676 | | | |

[a] Preop-Op for seine compares 1991-2009 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 ($p \leq 0.05$)

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 about 99% of the eggs in the cunner/yellowtail flounder group in 2009 were likely cunner, because few yellowtail flounder larvae were collected (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 2009 was above the preoperational period mean and below the operational period mean (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, 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 2009, cunner/yellowtail flounder eggs (1,448 million) and cunner eggs (8 million) combined ranked first in entrainment abundance and accounted for about 70% 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 2009 (106 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 837 cunner were impinged in 2009 (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, February, and October with most taken in May through July (Table 4-11). The majority of impinged cunner were less than 97 mm (Figure 4-7). Impingement of smaller cunner (< 50mm) first occurred in abundance in June indicating recruitment of the 2008 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 relatively high in the 1980s, reached an all time low in 2006, and in 2009 increased to the highest density in the time series (Figure 4-18). The decline in the 1980s was also apparent in other areas of the

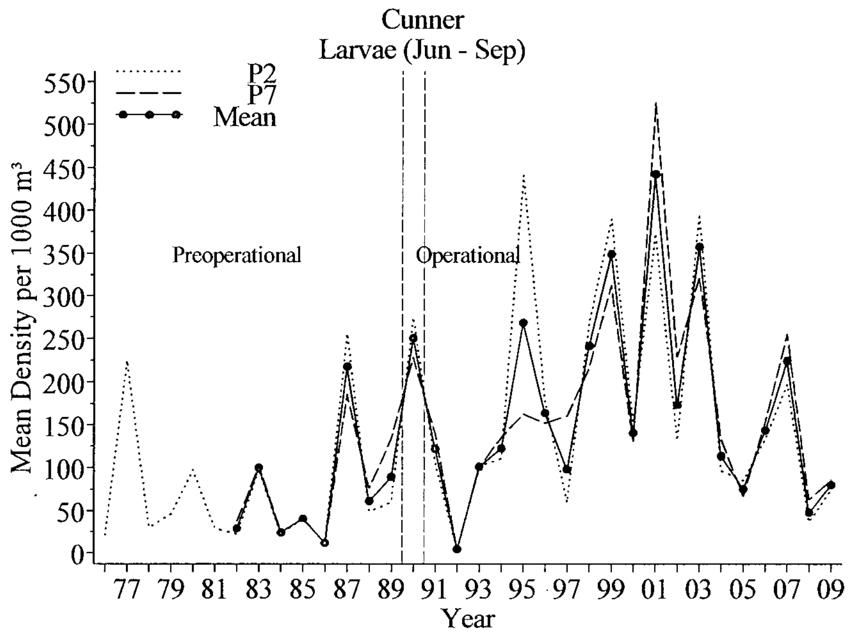



Figure 4-17. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of cunner in ichthyoplankton samples by station and the mean of all stations, 1976-2009 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

**Table 4-20. Results of Analysis of Variance of Cunner Densities by Sampling Program. Seabrook Operational Report, 2009.**

| 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, 103 | 2.41 | 0.1233 | |
| (1982-1984, | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| 1986-2009) | Year (Preop-Op)[b] | 0 | 0.00 | 0.4997 | |
| | Month(Year)[c] | 1.1176 | 401.11 | <0.0001* | |
| | Station[d] | <0.0000 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4999 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4997 | |
| | Error | 0.8651 | | | |

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1989 to 1991-2009 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 ($p \leq 0.05$)

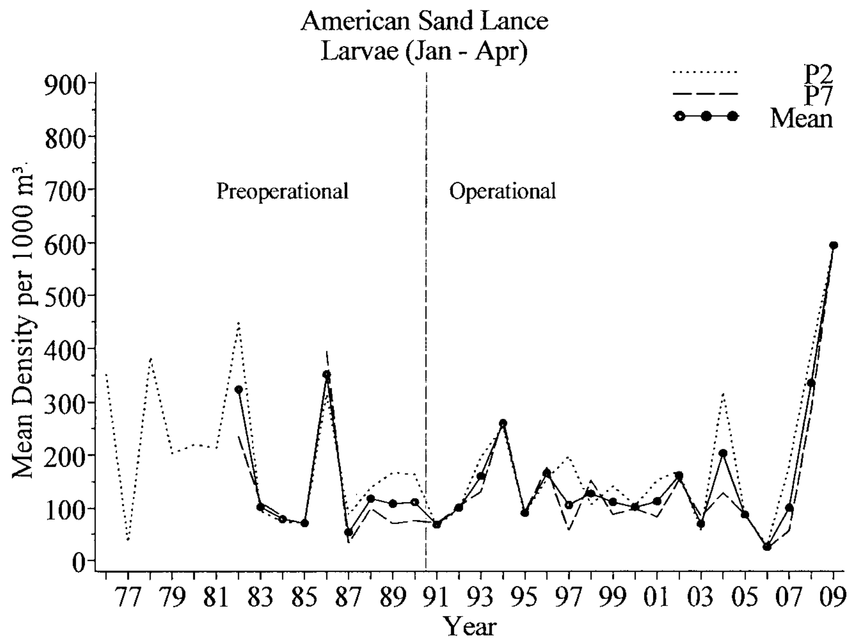



Figure 4-18. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of American sand lance in ichthyoplankton samples by station and the mean of all stations, 1976-2009 (data between the two vertical dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

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 (DRS 2010). 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 prior to 2009.

Abundance of larval American sand lance in the Hampton-Seabrook area was higher at Station P2 compared to Station P7 in preoperational and operational periods (Table 4-13) and major peaks in density occurred at both stations in 1982, 1986, 1994, 2004, and 2009 (Figure 4-18). Mean density in 2009 was above the confidence limits of the pre-operational and operational means (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 796 in 2009 and 87% of this estimate occurred in December (Table 4-11).

**Table 4-21. Results of Analysis of Variance of American Sand Lance Densities by Sampling Program. Seabrook Operational Report, 2009.**

| Program/ Months Used | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Ichthyoplankton** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Jan.-Apr.) | Preop-Op[a] | 1, 106 | 0.86 | 0.3563 | |
| (1982-1984, 1986-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0.00 | 0.4999 | |
| | Month(Year)[c] | 0.2945 | 141.12 | <0.0001* | |
| | Station[d] | 0.0048 | 1.04 | 0.1544 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.4999 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.4999 | |
| | Error | 0.5360 | | | |

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1990 to 1991-2009 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 ($p \leq 0.05$)

Fish impinged were 90 to 200 mm and were probably age 1 and 2 fish (Figure 4-7; Westin et al. 1979). Impingement of sand lance in 2009 was below the average of 946 fish per year for the study period (Appendix Table 4-3). Larval entrainment in 2009 (129 million) was the highest observed consistent with the high densities observed in the offshore sampling program (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.

#### 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 (TRAC 2010). Spawning biomass reached a record high in 1969-1973 and peaked again in 1985 and 2002. Age 1 recruitment was highest in 1968, 1983, and 2000. The status of the stock is considered to be "unknown" due to the uncertainty in the assessment results (TRAC 2010).

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 2009 was below the preoperational means at both stations and above the operational mean at Station P2 (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). Density has remained relatively low since 2002 with a slight increase in 2009. There were no significant differences between periods or stations, and the interaction of the main effects was not significant (Table 4-22).

No Atlantic mackerel were present in impingement samples in 2009 (Table 4-11; only ten have been impinged in previous years (Appendix Table 4-3). Entrainment of Atlantic mackerel eggs in 2009 (83.5 million) was within the range of previous years (Table 4-6). In 2009 an estimated 25.7 million Atlantic mackerel larvae were collected in entrainment samples, which was the highest recorded (Table 4-6). Entrainment of mackerel larvae usually 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 2009 averaged 222 per year. In 2009, estimated equivalent adult losses due to entrainment were 625 fish and were due to the relatively large numbers of Atlantic mackerel larvae 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

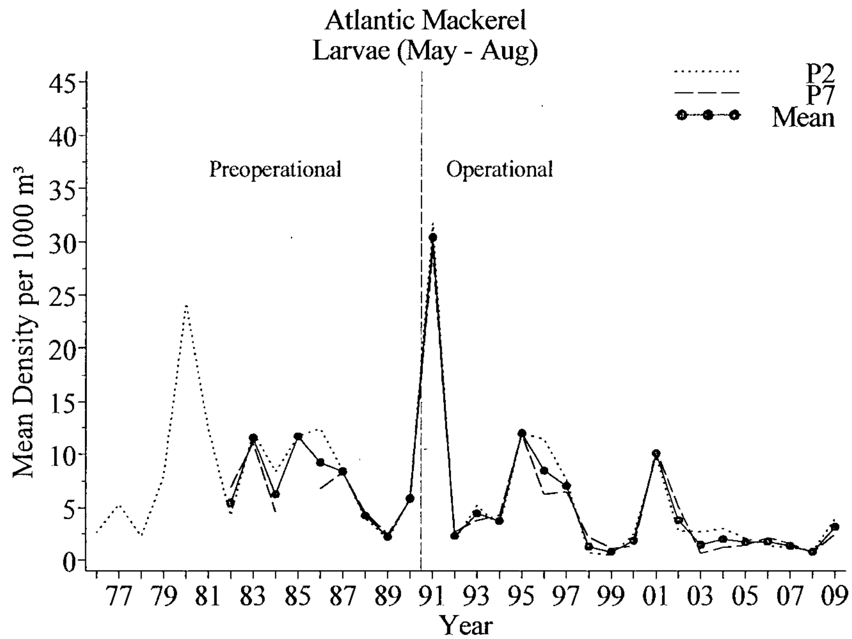



Figure 4-19. Annual geometric mean catch per unit effort (number per 1000 cubic meters) of Atlantic mackerel in ichthyoplankton samples by station and the mean of all stations, 1976-2009. Seabrook Operational Report, 2009

**Table 4-22. Results of Analysis of Variance of Atlantic Mackerel Densities by Sampling Program. Seabrook Operational Report, 2009.**

| 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, 106 | 1.58 | 0.2114 | |
| (1982-1984, 1986- | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| 2009) | Year (Preop-Op)[b] | 0 | 0.00 | 0.5000 | |
| | Month(Year)[c] | 0.4702 | 212.63 | <0.0001* | |
| $Log_{10}(x+1)$ | Station[d] | 0 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 0.7009 | | | |

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1990 to 1991-2009 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 ($p \leq 0.05$)

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/shell-litter 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).

Indices of winter flounder abundance in the Gulf of Maine had been reduced substantially since the early 1980s to a period of low abundance in the early 1990s. Abundance increased in 1998 and 1999 but has decreased since 2001(NEFSC 2008). The status of the Gulf of Maine stock of winter flounder was uncertain, but it was felt that the population levels were low due to a lack of agreement between survey indices and modeling results (NEFSC 2008). Our CPUE data are not consistent with low population levels as mean CPUE has generally increased since 1995. CPUE reached a time series high in 2004, decreased in 2005 but has increased since then and remains higher than the preoperational years (Figure 4-20). Survey indices conducted by NMFS indicate a peak in 2001 followed by a decline.

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 1990 (Figure 4-20). In the operational period, larval density was typically lower than the preoperational period. Mean density in 2009 was below the preoperational confidence limits at both stations, but similar to the operational period means (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

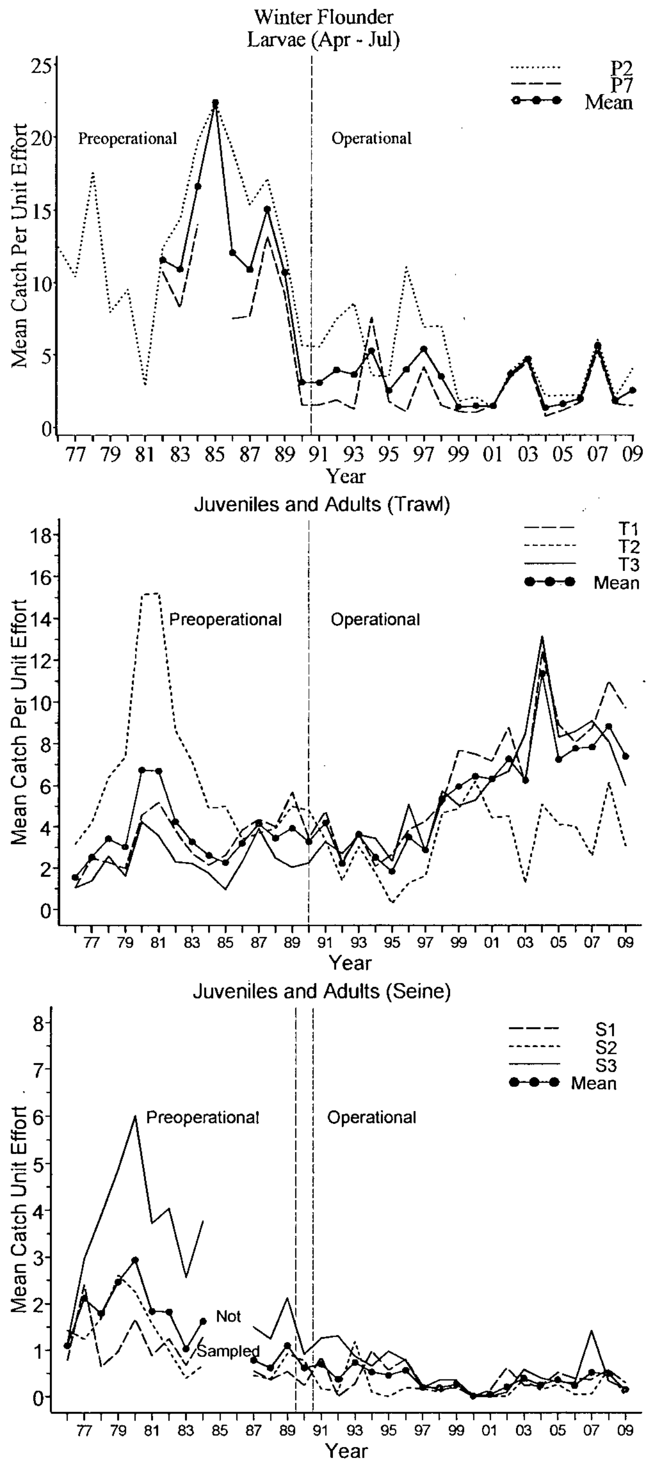



Figure 4-20. Annual geometric mean catch of winter flounder per unit effort in ichthyoplankton (number per 1000 cubic meters), trawl (number per 10-minute tow), and seine (number per haul), samples by station and the mean of all stations, 1975-2009 (data between the two vertical dashed lines were excluded from ANOVA model). Seabrook Operational Report, 2009.

**Table 4-23. Results of Analysis of Variance of Winter Flounder Densities by Sampling Program. Seabrook Operational Report, 2009.**

| Program/ Months Used | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Ichthyoplankton** | **Fixed Effects** | DF[g] | F[h] | DF[g] | |
| (Apr.-Jul.) | Preop-Op[a] | 1, 106 | 13.16 | 1, 106 | Op<Preop |
| (1982-1984, 1986- | Random Effects | **Estimate[j]** | $\chi^2$ | **Estimate[j]** | |
| 2009) | Year (Preop-Op)[b] | 0 | 0.00 | 0 | |
| | Month(Year)[c] | 0.2372 | 171.84 | 0.2372 | |
| $Log_{10}(x+1)$ | Station[d] | 0.0237 | 2.66 | 0.0237 | |
| | Preop-Op X Station[e] | 0 | 0.00 | 0 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0 | |
| | Error | 0.4252 | | 0.4252 | |
| **Trawl** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Dec-Jun) | Preop-Op[a] | 1, 5.44 | 0.10 | 0.7662 | |
| | Random Effects | **Estimate[j]** | $\chi^2$ | **p** | |
| (1976-2009) | Year (Preop-Op)[b] | 0.0154 | 9.04 | 0.0013* | |
| | Month(Year)[c] | 0.0589 | 199.04 | <0.0001* | |
| $Log_{10}(x+1)$ | Station[d] | 0 | 0.00 | 0.4997 | |
| | Preop-Op X Station[e] | 0.0239 | 43.40 | <0.0001* | 2Pre 1Op 3Op 1Pre 2Op 3Pre |
| | Station X Year (Preop-Op)[f] | 0.0101 | 34.91 | <0.0001* | |
| | Error | 0.0409 | | | |
| **Seine** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Apr.-Nov.) | Preop-Op[a] | 1, 29 | 69.27 | <0.0001* | Op<Preop |
| (1976-1984, 1987- | Random Effects | **Estimate[j]** | $\chi^2$ | **p** | |
| 1989, 1991-2009) | Year (Preop-Op)[b] | 0.0028 | 2.20 | 0.0717 | |
| | Month(Year)[c] | 0.0081 | 19.94 | <0.0001* | |
| $Log_{10}(x+1)$ | Station[d] | 0.0076 | 23.45 | <0.0001* | S3>S1 S2 |
| | Station X Year (Preop-Op)[f] | 0.0079 | 34.63 | <0.0001* | |
| | Error | 0.0362 | | | |

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1990 to 1991-2009 regardless of station. Preop-Op for trawl compares 1990-2009 to 1976-1990 regardless of station. Preop-Op for seine compares 1991-2009 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 $H_0$: LSMEAN (i)= LSMEAN(j).
* = significant ($p \leq 0.05$)

at Station T2 most years. Mean CPUE at Stations T1 and T3 in 2009 was above the preoperational and operational period upper confidence intervals but at Station T2 was lower than the lower preoperational confidence interval (Table 4-8; Figure 4-20).

There was a significant positive trend in winter flounder CPUE during 1996 through 2009 at Station T1 and from 1994 through 2009 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 1988 through 2009 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. Mean CPUE subsequently declined in 2003, rose through 2008 and decreased again in 2009.

Younger winter flounder (juveniles through age 2; NAI 1993) were collected in the Hampton-Seabrook Harbor by seine throughout the April-November sampling period. CPUE was generally higher in the period 1976 through 1984 than in 1987 through 2009 (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 generally low since 1987. Mean CPUE in 2009 decreased from 2008 and was the second lowest in the operational period (Figure 4-20). Mean CPUE (all stations) in 2009 was lower than the preoperational and operational period lower confidence intervals at all stations (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 15.2 million larvae were entrained in 2009 (Table 4-5) and this estimate was within the range of previous years (Table 4-6). Despite their demersal and adhesive characteristics, 80,000 winter flounder eggs were entrained (Table 4-5). In 2009, an estimated 655 winter flounder were impinged (Table 4-11), within the range of previous years (Appendix Table 4-3). Impingement of winter flounder in 2009 was highest (87%) in December. Lengths of impinged winter flounder ranged from 36 to 335 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 1,390 per year for 1998 through 2009. In 2009, the estimate of equivalent adult loss of winter flounder due to entrainment was 1,976 fish, from entrainment of larvae and <1 due to egg entrainment. An annual mean of 83 winter flounder were lost each year due to impingement for 1994 through 2009. In 2009, the estimate of equivalent adult winter flounder lost due to impingement was 47.

#### 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

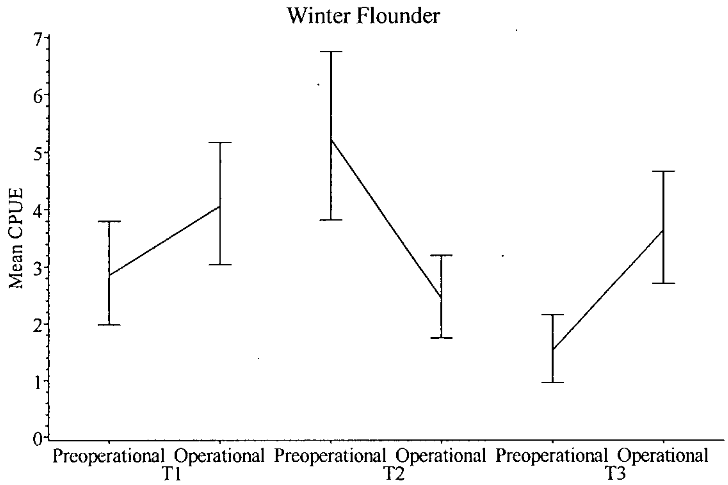



Figure 4-21. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of winter flounder caught by trawl during the preoperational (December 1975-June 1990) and operational (December 1990-June 2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-22). Seabrook Operational Report, 2009.

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 was occurring (NEFSC 2008). The index of yellowtail flounder spawning stock biomass peaked in 2000-2001 (NEFSC 2008) and then decreased steadily through 2004. Since 2004 there has been an increase in the index and the 2005 year class appears to be moderately strong. The spawning stock biomass on Georges Bank peaked was lowest in 1995 and 2006, but has recently increased to the highest levels observed in 2009 (TRAC 2009b).

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). Based on the ratio of yellowtail flounder and cunner larvae collected in 2009 ichthyoplankton samples, it is likely that the cunner/yellowtail flounder egg group was about 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 from 2006 through 2008, but increased slightly in 2009 (Figure 4-22; Table 4-13). Mean density in 2009 at both stations was below the preoperational confidence limits and within the operational period confidence intervals (Table 4-13). There were no significant differences between

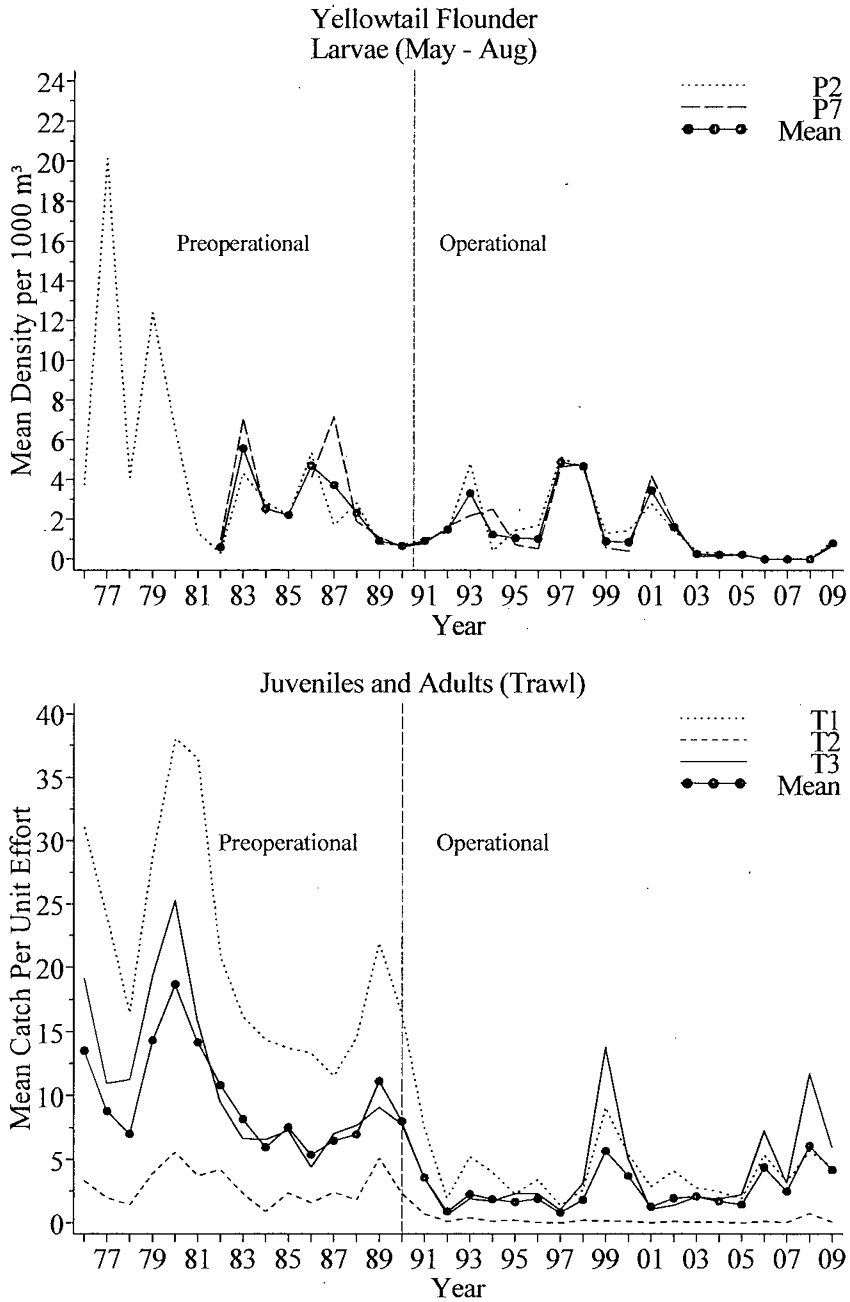



Figure 4-22. Annual geometric mean catch of yellowtail flounder per unit effort in ichthyoplankton (number per 1000 cubic meters) and trawl (number per 10-minute tow) samples by station and the mean of all stations, 1976-2009. Seabrook Operational Report, 2009.

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 the preoperational period was one of the most abundant fishes taken by otter trawl sampling (Table 4-8). Yellowtail flounder are most common in trawl samples from May through October (NAI 1993). CPUE of yellowtail flounder 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 and 2008 (Figure 4-22). Mean CPUE in 2009 was lower than the lower preoperational confidence intervals at all stations and similar to the operational period means at Stations T1 and T2 (Table 4-8). Annual geometric mean CPUE was significantly higher in 1976-1995 at Station T1, 1976-1990 at T2 and 1976-1991 at T3 compared to the years after each of those periods (Table 4-9). CPUE significantly declined in the earlier periods at Stations T1 and Station T3.

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 basis, the decreases were similar. CPUE decreased 88% at Station T1, 95% at Station T2 and 77% at Station T3.

In 2009, no 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, and no yellowtail flounder were collected in 1994, 2000, and 2003-2005 (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 2009 was 1,448 million, and it is likely that this group was about 99% cunner eggs, based on the relative abundance of cunner and yellowtail flounder larvae. An estimated 300,000 yellowtail founder larvae were collected in entrainment samples in 2009.

Equivalent adult losses of yellowtail flounder due to entrainment averaged 6 per year for 1998 through 2009. An estimated 6 equivalent adults were lost due to entrainment in 2009. Losses due to impingement were estimated at less than 1 equivalent adult for the period 1994 through 2009 and no yellowtail flounder were collected in impingement samples in 2009.

## 4.4 EFFECTS OF SEABROOK STATION OPERATION

The fish community of the Gulf of Maine has undergone extensive changes over the last several decades. What was once a community dominated by vertebrate apex predators such as Atlantic cod has been replaced by a community dominated by macroinvertebrate predators such as crabs and lobsters (Steneck et al. 2004), and non-commercial fish and pelagic fish (Fogarty and Murawski 1998). This is a wide-spread phenomenon not just restricted to the Gulf of Maine. Similar changes have been reported for Narragansett

**Table 4-24. Results of Analysis of Variance of Yellowtail Flounder Densities by Sampling Program. Seabrook Operational Report, 2009.**

| Program/ Months Used | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Ichthyoplankton** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (May-August.) | Preop-Op[a] | 1, 24.4 | 3.95 | 0.0582 | |
| (1982-1984, | | | | | |
| 1986-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0260 | 3.43 | 0.0321* | |
| | Month(Year)[c] | 0.0937 | 75.02 | <0.0001* | |
| | Station[d] | 0 | 0.00 | 0.5000 | |
| | Preop-Op X Station[e] | <0.0001 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0 | 0.00 | 0.5000 | |
| | Error | 0.3065 | | | |
| **Trawl** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (Dec.-Jun.) | Preop-Op[a] | 1, 3.37 | 42.33 | 0.0051* | Op<Preop |
| (1976-2009) | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0143 | 10.93 | 0.0005* | |
| | Month(Year)[c] | 0.0284 | 48.90 | <0.0001* | |
| | Station[d] | 0.0737 | 2.87 | 0.0452* | T1 T3 T2 |
| | Preop-Op X Station[e] | 0.0096 | 10.61 | 0.0006 | 1Pre 3Pre 2Pre 1Op 3Op 2Op |
| | Station X Year (Preop-Op)[f] | 0.0097 | 16.50 | <0.0001* | |
| | Error | 0.0646 | | | |

[a] Preop-Op for ichthyoplankton compares 1982-1984 and 1986-1989 to 1991-2009 regardless of station. Preop-Op for trawl compares 1990-2009 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 ($p \leq 0.05$)

Bay and Rhode Island Sound (Collie et al. 2008) and the Scotian Shelf (Bundy 2005). Commercial overexploitation of demersal species is the generally accepted cause of the changes in the fish community (Fogarty and Murawski 1998). The reduction in the abundance of demersal species may have resulted in a competitive release of non-commercial and pelagic species that currently dominate the community. Link's (2007) "ugly fish" hypothesis states that 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. At least on the Scotian Shelf, these changes have resulted in the development of an alternate state where the benthic and pelagic systems have become decoupled (Choi et al. 2004). This alternate state is characterized by decreased body size, biomass, and physiological condition of demersal species and an increase in biomass of pelagic species. 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).

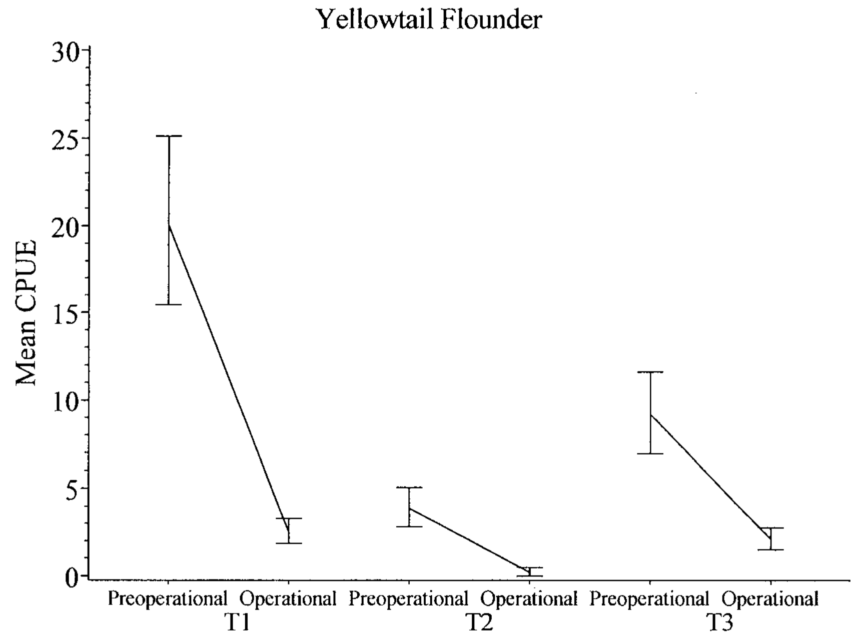



Figure 4-23. A comparison among stations of the geometric mean CPUE (number per 10-minute tow) and 95% confidence intervals of yellowtail flounder caught by trawl during the preoperational (December 1975-June 1990) and operational (December 1990-June 2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model (Table 4-23). Seabrook Operational Report, 2009.

Changes in oceanographic conditions have contributed to community changes. A decrease in salinity of surface waters has resulted in increased stratification of the top 50 m of water and decreased intermixing of surface and deeper waters limiting the exchange of limiting nutrients (Drinkwater et al. 2003) and potentially decreasing productivity of the benthic community (Choi et al. 2004). Decreased surface salinity was also the potential cause for a shift in the in the zooplankton to smaller sized species and changes in the survivorship of Atlantic cod (decreasing) and haddock (increasing) on Georges Bank (Mountain and Kane 2010). Nye et al. (2009) examined temporal trends in the mean center of biomass, mean depth, mean temperature of occurrence and area occupied of 36 fish stocks in the northeast continental shelf. Stocks located to the south exhibited a northern shift in center of biomass and some stocks occupied deeper depths. Stocks limited to the Gulf of Maine that were decreasing in size occupied habitats at deeper depths. These changes in distribution were associated with temperature increases and correlated with the Atlantic multidecadal oscillation.

Although overexploitation of the demersal fish community and oceanographic changes are currently accepted as the proximal causes for the current low levels of some demersal fish, removal of fishing effort alone may not be enough to restore the demersal fish community to its previous biomass levels and species composition. 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). With the removal of Atlantic cod as a top predator, seals have filled that ecological niche (Bundy et al. 2009). Atlantic cod may now be caught in a "trophic vise" where adult cod are preyed upon by seals, and small pelagic fish, released from adult cod predation, compete with small cod for food items.

Evolutionary factors may also 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. Hutchings (2005) presented evidence that exploitation of Atlantic cod stocks has resulted earlier maturity and increased natural mortality that can be explained by genetic responses to overfishing. Because genes for these traits now are now common in the population, removal of fishing effort will not quickly result in restoration to previous condition. In fact, many stocks have not recovered after more than a decade of greatly reduced fishing effort (Swain et al. 2007).

A long-term monitoring that attempts to compare current conditions to conditions that existed decades ago may find that significant changes have occurred in part due the concept of a shifting baseline. The history of the demersal fish community in the Gulf of Maine clearly shows that conditions that existed several years ago are no longer current, and any comparisons to previous baselines will not be valid due to the extensive regional changes in the community that have occurred beyond the influence of Seabrook Station. However, our monitoring program can show that changes in the fish community of nearshore New Hampshire are not related to the operation of Seabrook Station and have occurred at both the nearfield and farfield stations. Community trends we have seen in our data parallel trends in the larger Gulf of Maine and northwest Atlantic and direct impacts due to entrainment and impingement have been minimal.

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 while there were changes over time, station pairs were consistently similar throughout 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 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 2009 were similar to most operational years. There was an overall low abundance of some fish larvae in 2009, especially Atlantic cod and yellowtail flounder. However, relative abundances of American sand lance and pollock in 2009 were higher than the preoperational and operational means. The low abundance of larvae of commercially-important fishes in 2009 occurred at both stations and cannot be attributed to the operation of Seabrook Station.

Entrainment of fish eggs (2,072 million) in 2009 was the second highest to date. Cunner/ yellowtail flounder (1,448 million), silver hake (196 million), hake/fourbeard

**Table 4-25. Summary of Potential Effects of the Operation of Seabrook Station on the Ichthyoplankton Assemblages and Selected Fish Taxa. Seabrook Operational Report, 2009.**

| 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 | | Not overfished |
| Rainbow smelt | Trawl | – | No | Unknown | Unknown |
| | Seine | Op=Preop | – | | |
| Atlantic cod | Ichthyoplankton | Op<Preop | yes | | |
| | Trawl | – | No | Increase since 2005 | Overfished |
| Pollock | Ichthyoplankton | Op=Preop | yes | Variable | Overfished |
| Hakes | Ichthyoplankton | Op=Preop | yes | | |
| | Trawl | – | No | Red hake: Decreasing since 2002<br>White hake: decreasing since 2002 | Red Hake: Not overfished<br>White hake: overfished |
| Atlantic silverside | Seine | Op<Preop | – | Unknown | Unexploited |
| Cunner | Ichthyoplankton | Op=Preop | yes | | Unexploited |
| American sand lance | Ichthyoplankton | Op=Preop | yes | | Unexploited |
| Atlantic mackerel | Ichthyoplankton | Op=Preop | yes | | Not overfished |
| Winter flounder | Ichthyoplankton | Op<Preop | yes | | |
| | Trawl | – | No | Decrease since 2003 | Overfished |
| | Seine | Op<Preop | – | | |
| Yellowtail flounder | Ichthyoplankton | Op=Preop | yes | | |
| | Trawl | – | No | Increase since 2003 | 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, 2008)

rockling (121 million),and Atlantic mackerel (83 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 (523 million) was the third highest estimate recorded. American sand lance (129 million), cunner (106 million), and rock gunnel (83 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 2009 (9,283 fish and 21 lobsters) was within the range of previous years. Hake sp. (1,427: 15%), cunner (837: 9%), American sand lance (796: 9%), rock gunnel (701: 8%), and northern pipefish (698: 8%) composed 49% of the fish impinged. Impingement in 2009 was highest in November and December (56% of annual estimate), possibly due to strong northeast storms. 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 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 2009 resulted in the estimated loss of 6 equivalent adult yellowtail flounder to 2,023 equivalent adult winter flounder (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 2008). However, estimates of fishing mortality (F) have changed substantially in recent years. 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) will have an overestimate of equivalent adults because the probability of a fish surviving to spawn repeatedly decreases. Similarly, stocks that are increasing in size will have underestimates of equivalent adults because lifetime fecundity increases.

The estuarine fish community has been apparently unaffected by the operation of

**Table 4-26. Annual Equivalent Adult Losses of Seven Commercially Important Species Impinged and Entrained at Seabrook Station in 2009. Seabrook Operational Report, 2009.**

| | Equivalent Adults | | |
|---|---|---|---|
| **Species** | **Impingement** | **Entrainment** | **Total** |
| Atlantic Cod | 41 | 52 | 93 |
| Atlantic Herring | 188 | 867 | 1,055 |
| tlantic Mackerel | 0 | 625 | 625 |
| Pollock | 547 | 10 | 557 |
| Hakes[a] | 182 | 680 | 862 |
| Winter Flounder | 47 | 1,976 | 2,023 |
| Yellowtail Flounder | 0 | 6 | 6 |

[a] Includes red and white hake.

Seabrook Station. After 18 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 2008). 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.

There appears to have been a recent change in the status of several stock of commercially important fishes. Previously, 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 were not considered to be overfished (NEFSC 2006). However a recent assessment (NEFSC 2008) indicates that the Gulf of Maine stocks of windowpane, pollock, and possibly winter flounder are now considered overfished. Among pelagic species, Atlantic mackerel and Atlantic herring are not considered to be overfished, consistent with the observation that biomass is now being transferred into the pelagic community. Regardless, 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.

Segmented regression analyses for all species combined in the trawl and for the selected species indicated that CPUE was usually greater in an earlier period than a later period. Exceptions to this generalization were winter flounder at Stations T1 and T3, and hakes at Station T3 where CPUE was greater in the later period. Only for rainbow smelt and yellowtail founder (one station) did the breakpoint in the CPUE trend occur in 1990, the year of plant start up. In five out of 18 cases there was a negative trend within the earlier period and in the later periods there was either a positive trend or no trend. These patterns are 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.

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. These changes are also apparent in the Gulf of Maine and Scotian Shelf. Little impact to the fish community can be attributed to Seabrook Station operation (Table 4-25). Direct losses due to entrainment and impingement are small compared to the stocks in 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) introduce 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 2008. Seabrook Operational Report, 2009[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 ferruginea* | 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 | Larvae | Adult and Juvenile Finfish Trawls | Gill nets | 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 |
| *Leptoclinus 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)**

| | | Ichthyoplankton Tows | | Adult and Juvenile Finfish | | | |
|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **Eggs** | **Larvae** | **Trawls** | **Gill nets** | **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, 2009.**

| Species | Gear | Season | Preoperational | Operational | Pooling | Deletions |
|---|---|---|---|---|---|---|
| Atlantic cod | Trawl | Dec-Jun | 1975-1990 | 1990-2009 | Dec with following year | Dec 2009 |
| Atlantic cod | Ichthyo | Apr-Jul | 1987-1990 | 1991-2009 | None | None |
| Atlantic herring | Ichthyo | Oct-Dec | 1986-1989 | 1990-2009 | None | None |
| Atlantic silverside | Seine | Apr-Nov | 1976-1984; 1987-1989 | 1991-2009 | None | 1990 |
| Atlantic mackerel | Ichthyo | May-Aug | 1987-1990 | 1991-2009 | None | Aug 1990 |
| American sand lance | Ichthyo | Jan-Apr | 1987-1990 | 1991-2009 | None | None |
| Cunner | Ichthyo | Jun-Sep | 1987-1989 | 1991-2009 | None | 1990 |
| Hakes | Trawl | Dec-Jun | 1976-1990 | 1990-2009 | Dec with following year | Dec 2009 |
| Hakes | Ichthyo | Jul-Sep | 1986-1989 | 1991-2009 | None | 1990 |
| Pollock | Ichthyo | Nov-Feb | 1986-1989 | 1990-2009 | Jan-Feb with previous year | Nov-Dec 2009 |
| Rainbow smelt | Trawl | Dec-May | 1975-1990 | 1990-2009 | Nov-Dec with following year | Nov-Dec 2009 |
| Rainbow smelt | Seine | Apr-Nov | 1976-1984;1987-1989 | 1991-2009 | None | 1990 |
| Winter flounder | Trawl | Dec-Jun | 1975-1990 | 1990-2009 | Dec with following year | Dec 2009 |
| Winter flounder | Seine | Apr-Nov | 1976-1984; 1987-1989 | 1991-2009 | None | 1990 |
| Winter flounder | Ichthyo | Apr-Jul | 1987-1990 | 1991-2009 | None | None |
| Yellowtail flounder | Trawl | Dec-Jun | 1975-1990 | 1990-2009 | Dec with following year | Dec 2009 |
| Yellowtail flounder | Ichthyo | May-Aug | 1987-1990 | 1991-2009 | 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 2009[a]. Seabrook Operational Report, 2009.**

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acadian redfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 12 | 0 | 0 | 15 |
| Alewife | 0 | 8 | 1,753 | 2,797 | 14 | 16 | 4 | 35 | 1 | 9 | 212 | 87 | 255 | 244 | 41 | 0 | 5,476 |
| American lobster | 31 | 16 | 31 | 20 | 4 | 6 | 0 | 1 | 23 | 19 | 0 | 77 | 5 | 21 | 3 | 21 | 278 |
| American plaice | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 12 |
| American shad | 0 | 0 | 20 | 21 | 1 | 6 | 10 | 3 | 7 | 10 | 7 | 7 | 0 | 188 | 0 | 11 | 291 |
| American sand lance | 1,215 | 1,324 | 823 | 182 | 708 | 234 | 423 | 114 | 245 | 3,396 | 665 | 1,029 | 213 | 2,073 | 758 | 796 | 14,198 |
| American eel | 0 | 5 | 6 | 42 | 1 | 2 | 0 | 2 | 0 | 0 | 9 | 0 | 0 | 0 | 7 | 4 | 78 |
| Atlantic menhaden | 0 | 7 | 97 | 0 | 1 | 957 | 142 | 19 | 1,022 | 7 | 361 | 7,226 | 94 | 160 | 67 | 39 | 10,199 |
| Atlantic hagfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,396 | 0 | 0 | 0 | 0 | 0 | 0 | 1,396 |
| Atlantic torpedo | 0 | 1 | 5 | 0 | 0 | 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 | 247 | 525 | 38,490 |
| Atlantic tomcod | 1 | 0 | 0 | 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 | 0 | 0 | 21 |
| Atlantic cod | 58 | 119 | 94 | 69 | 38 | 66 | 29 | 30 | 199 | 3,091 | 467 | 454 | 113 | 178 | 73 | 147 | 5,225 |
| Atlantic mackerel | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 10 |
| Atlantic herring | 0 | 0 | 485 | 350 | 582 | 20 | 5 | 11 | 159 | 198 | 118 | 93 | 189 | 260 | 27 | 490 | 2,987 |
| Atlantic moonfish | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 54 |
| Bigeye soldierfish | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 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 | 0 | 0 | 152 |
| Black sea bass | 0 | 3 | 0 | 0 | 3 | 3 | 17 | 12 | 12 | 10 | 11 | 4 | 0 | 22 | 11 | 0 | 108 |
| Blueback herring | 13 | 0 | 111 | 323 | 7 | 53 | 1 | 59 | 475 | 50 | 380 | 130 | 138 | 237 | 59 | 20 | 2,056 |
| Bluefish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| Butterfish | 3 | 14 | 3 | 223 | 9 | 5 | 1 | 28 | 1,170 | 4 | 35 | 54 | 44 | 199 | 7 | 29 | 1,828 |
| Cunner | 32 | 342 | 1,121 | 233 | 309 | 255 | 324 | 341 | 291 | 554 | 625 | 893 | 687 | 922 | 731 | 837 | 8,497 |
| Cusk | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 19 | 39 |
| Flounders | 77 | 0 | 0 | 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 | 0 | 0 | 1 |
| Fourbeard rockling | 0 | 6 | 0 | 0 | 3 | 1 | 1 | 1 | 0 | 0 | 7 | 3 | 0 | 7 | 3 | 11 | 43 |
| Fourspine stickleback | 0 | 0 | 0 | 0 | 23 | 24 | 0 | 6 | 3 | 0 | 0 | 0 | 0 | 13 | 3 | 0 | 72 |
| Fourspot flounder | 2 | 1 | 2 | 3 | 4 | 1 | 11 | 0 | 7 | 0 | 7 | 24 | 0 | 3 | 3 | 10 | 78 |
| Goosefish | 3 | 13 | 0 | 0 | 7 | 17 | 15 | 59 | 18 | 10 | 0 | 8 | 0 | 11 | 0 | 0 | 161 |
| Gray triggerfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 5 |

(continued)

**Appendix Table 4-3 (Continued)**

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grubby | 2,678 | 2,415 | 1,457 | 430 | 3,269 | 3,953 | 1,174 | 549 | 1,089 | 2,523 | 676 | 531 | 235 | 869 | 3,919 | 521 | 26,288 |
| Haddock | 0 | 1 | 397 | 0 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 7 | 3 | 25 | 0 | 15 | 455 |
| Hakes | 2,822 | 2,188 | 156 | 122 | 4 | 68 | 113 | 523 | 1,813 | 166 | 35 | 11 | 6 | 1,184 | 3,216 | 1,427 | 13,854 |
| Herrings | 514 | 231 | 72 | 218 | 0 | 0 | 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 | 0 | 0 | 4 |
| Lefteye flounder | 0 | 0 | 2 | 0 | 0 | 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 | 222 | 62 | 1,566 |
| Lookdown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 |
| Lumpfish | 182 | 190 | 51 | 62 | 137 | 344 | 85 | 158 | 84 | 370 | 68 | 61 | 176 | 420 | 70 | 72 | 2,530 |
| Mummichog | 0 | 0 | 47 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 75 |
| Northern kingfish | 0 | 0 | 2 | 0 | 0 | 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 | 1,082 | 698 | 16,541 |
| Northern puffer | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 12 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 20 |
| Northern searobin | 0 | 0 | 0 | 11 | 1 | 2 | 0 | 1 | 2 | 564 | 0 | 11 | 0 | 7 | 0 | 0 | 599 |
| Ocean pout | 0 | 6 | 1 | 0 | 7 | 3 | 2 | 21 | 1 | 13 | 3 | 3 | 6 | 3 | 0 | 0 | 69 |
| Planehead filefish | 0 | 15 | 0 | 0 | 0 | 8 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 |
| Pollock | 1,681 | 899 | 1,835 | 379 | 536 | 11,392 | 534 | 405 | 719 | 499 | 80 | 218 | 73 | 340 | 123 | 657 | 20,370 |
| Radiated shanny | 0 | 92 | 40 | 2 | 39 | 108 | 11 | 53 | 4 | 158 | 18 | 49 | 44 | 119 | 49 | 80 | 866 |
| Rainbow smelt | 545 | 213 | 4,489 | 365 | 535 | 100 | 8 | 65 | 323 | 3,531 | 2,085 | 3,314 | 878 | 572 | 421 | 43 | 17,487 |
| Red hake | 1 | 16 | 1,478 | 371 | 903 | 1,120 | 112 | 155 | 52 | 271 | 892 | 821 | 546 | 1,389 | 14 | 0 | 8,141 |
| Righteye flounder | 0 | 3 | 4 | 0 | 0 | 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 | 937 | 701 | 35,198 |
| Sand tiger shark | 0 | 0 | 57 | 0 | 0 | 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 | 0 | 0 | 205 |
| Scup | 0 | 14 | 9 | 0 | 3 | 1 | 0 | 3 | 11 | 11 | 0 | 21 | 4 | 8 | 13 | 15 | 113 |
| Sea raven | 78 | 125 | 1,015 | 223 | 137 | 132 | 206 | 271 | 166 | 217 | 129 | 221 | 138 | 164 | 138 | 79 | 3,439 |
| Sea lamprey | 0 | 0 | 1 | 6 | 7 | 2 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 71 | 0 | 4 | 96 |
| Sheepshead | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Short bigeye | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 |
| Shorthorn sculpin | 14 | 156 | 282 | 123 | 190 | 296 | 923 | 621 | 642 | 7,450 | 876 | 2,214 | 1,258 | 465 | 1,515 | 266 | 17,291 |
| Silver hake | 0 | 49 | 58 | 108 | 13 | 100 | 41 | 5 | 1,177 | 22 | 212 | 306 | 31 | 21 | 204 | 325 | 2,672 |
| Skates | 190 | 157 | 225 | 177 | 41 | 41 | 42 | 17 | 299 | 145 | 60 | 170 | 33 | 64 | 39 | 41 | 1,741 |

(continued)

## Appendix Table 4-3 (Continued)

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Smooth flounder | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 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 | 233 | 85 | 8,363 |
| Snakeblenny | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 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 | 0 | 0 | 1 |
| Spiny dogfish | 1 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 6 | 8 | 11 | 8 | 0 | 3 | 4 | 0 | 48 |
| Striped bass | 0 | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 14 | 0 | 4 | 0 | 4 | 0 | 0 | 29 |
| Striped cusk-eel | 0 | 0 | 0 | 3 | 0 | 0 | 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 | 0 | 0 | 1 |
| Striped searobin | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| Summer flounder | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 7 |
| Tautog | 0 | 0 | 34 | 0 | 3 | 5 | 1 | 1 | 3 | 0 | 0 | 0 | 3 | 8 | 7 | 6 | 71 |
| Threespine stickleback | 67 | 155 | 320 | 174 | 773 | 506 | 10 | 280 | 34 | 1,549 | 130 | 307 | 139 | 193 | 80 | 118 | 4,835 |
| Unidentified | 6 | 40 | 88 | 49 | 0 | 15 | 0 | 0 | 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 | 0 | 0 | 10 |
| Whiptail Conger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 |  | 0 | 0 | 6 |
| White hake | 1 | 7 | 967 | 0 | 6 | 19 | 18 | 30 | 16 | 65 | 62 | 103 | 20 | 140 | 0 | 0 | 1,454 |
| White perch | 0 | 0 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 201 | 0 | 3 | 0 |  | 0 | 0 | 210 |
| Windowpane | 980 | 943 | 1,164 | 1,688 | 772 | 692 | 251 | 161 | 2,242 | 4,749 | 936 | 2,034 | 572 | 1,502 | 1,640 | 427 | 20,753 |
| Winter flounder | 1,435 | 1,171 | 3,231 | 468 | 1,143 | 3,642 | 102 | 777 | 897 | 10,491 | 783 | 1,875 | 767 | 3,949 | 1,920 | 655 | 33,306 |
| Wrymouth | 55 | 9 | 206 | 3 | 21 | 10 | 1 | 135 | 17 | 72 | 7 | 64 | 15 | 60 | 49 | 14 | 738 |
| Yellowtail flounder | 0 | 1,149 | 4 | 23 | 11 | 97 | 0 | 8 | 5 | 0 | 0 | 0 | 10 | 11 | 3 | 0 | 1,321 |
| **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** | **17,935** | **9,304** | **334,011** |

[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 2009 at the nearfield station, 9 algal taxa were collected, while at the farfield station there were 13 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 (B17:849 g/m$^2$; B35:759 g/m$^2$) periods at both stations. In 2009, biomass at the nearfield (615 g/m$^2$) and farfield (619 g/m$^2$) stations increased from the lows of the previous year, but was lower than the preoperational and operational period means.

Macrofaunal species richness (taxa per 0.0625 m$^2$) in 2009 (B17:29; B35:26) was the same as the previous year at the nearfield station (B17:29) and was lower than the previous year (B35:38) at the farfield station. The annual mean number of taxa has declined over time at both of these stations. A comparison of time periods suggests an area-wide decline between preoperational (B17:41; B35:42) and operational (B17:35; B35:34) 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 2009 at Station B17 (12,414/m$^2$) were well below the preoperational and operational averages. Densities at Station B35 in 2009 (6,040/m$^2$) were also well below the average for both periods. There were no significant differences in total faunal density between the preoperational (B17:22,835/m$^2$; B35:28,371/m$^2$) and operational (B17:18,747/m$^2$; B35:18,788/m$^2$) periods at both stations. Cluster analysis and MDS ordination iden-

tified 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 commercial operation began in 1990.

Selected taxa studies in the shallow subtidal zones revealed period differences that varied between nearfield and farfield stations for two habitat-forming species. The subdominant kelp *Laminaria digitata* and dominant kelp *Saccharina latissima* are large macrophytes that grow over the more abundant understory species of red algae 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: 15.2/100 $m^2$) than at the farfield area (Preop: 155.8/100 $m^2$, Op: 73.9/100 $m^2$). Likewise, density of the kelp *Saccharina latissima* declined significantly at the nearfield station (Preop: 415.1/100 $m^2$; Op: 137.9/100 $m^2$) although there was no significant difference at the farfield station (Preop: 325.7/100 $m^2$; Op: 326.0/100 $m^2$). In 2009 at the nearfield station, densities of *L. digitata* (3.2/100 $m^2$) and *Saccharina latissima* (35.7/100 $m^2$) were low relative to the operational means (15.2/100 $m^2$ and 137.9/100 $m^2$, respectively). However the farfield densities of *L. digitata* (2009: 100.8/100 $m^2$; Op: 73.9/100 $m^2$) and *Saccharina latissima* (2009: 361.0/100 $m^2$; Op: 326.0/100 $m^2$) increased in 2009 and were above the operational means. There is no clear causative factor for the decline between the preoperational and operational periods of *L. digitata* at both stations and *Saccharina latissima* at the nearfield station. Physical and biological factors may both play a role. Annual mean surface water temperature and mean summer temperature at nearfield and farfield stations has increased significantly during the study period. The number of warm days above 18° C, a critical maximum for *Laminaria digitata* reproduction, has increased during the entire period. 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 discharge effects such as increases in sedimentation, turbidity, shading, and organic loading were not evident at the nearfield area. Nearfield Station B19 and farfield Station B31 are located at depths of 12.2 m and 9.4 m, respectively. The nearfield station is about 3 km offshore of Hampton Harbor Inlet, while the farfield station is about 8.8 km north of the inlet. Macroalgal community structure was generally similar between the preoperational and operational periods at nearfield and farfield stations, as demonstrated by numerical classification and MDS analysis. Multivariate analyses (dendrograms and MDS) revealed that algal collections were generally separated into two major groups, defined spatially (by station) 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. 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*. In 2009, algal collections from Stations B19 and B31 were assigned to the groups that contain the majority of preoperational and operational collections at each station. Multivariate analyses suggest subtle changes over time in macrofaunal community structure at the mid-depth stations. Recent (1995-2009) faunal collections from Station B31 were assigned to a unique group by the cluster analysis and contained high numbers of *Lacuna vincta* and relatively low numbers of *Pontogeneia inermis*. Most collections since 1995 at Station B19 were also assigned to a distinct cluster grouping although these samples were more similar to collections from the preoperational period than were the recent collections from B31.

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 2009, the numbers of algal taxa at Station B19 (8.5) was below the 95% confidence limits of the operational means and Station B31 (12.1) was within the confidence limits. In 2009, the algal biomass values at Station B19 (150.1 g/m$^2$) and Station B31 (231.2 g/m$^2$) were below the preoperational and operational confidence limits. 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: 228.8 g/m$^2$; B31: 328.6 g/m$^2$) periods, although there was significantly higher algal biomass during the preoperational period when compared to the operational period at both stations combined.

Numbers of macrofaunal taxa (per 0.0625 m$^2$) in 2009 at both mid-depth stations (B19:28; B31:28) were marginally lower than the previous year (B19:33; B31:29) and lower than most historical averages. 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 2009 (B19:4,051 /m$^2$) was lower than in the previous year (B19: 6,687 /m$^2$). Mean density at the farfield station (B31) in 2009 (B31:6,264 /m$^2$) was also slightly lower than the previous year (B31: 7,637 /m$^2$) and lower than historical averages. Spikes in density such as those reported in 2007at the nearfield station and in 1985 at the farfield station were largely due to high numbers of Mytilidae spat, and relatively low density values in 2009 largely reflect low numbers of this dominant taxon. 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 exposed for three months and removed in April, August and December were generally similar during the preoperational and operational periods. *Balanus* spp. (barnacles) typically was most abundant on panels collected in April during the preoperational and operational periods. However, in 2009 the December panels had the highest abundance, an indication of a strong fall set. Bottom water temperature in 2009 was cool in April and warm in September, November and December compared to the operational average. Two sessile bivalves, *Hiatella* sp. and Mytilidae have historically been most common on panels harvested in August. This pattern repeated in 2009 except that the highest Mytilidae numbers at Station B19 were reported for December. The jingle shell *Anomia* sp. was most abundant on the December panels historically, but 2009, no *Anomia* sp. were collected in December at Station B19, and few were taken at Station B31.

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 *Saccharina latissima* 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: 158 /100 $m^2$) stations, but the decline was greater at the farfield station, resulting in a significant interaction term. In 2009, the density of *Laminaria digitata* at Station B19 was 0/100$m^2$, while at Station B31 it was 50/100 $m^2$. The cause of this decline remains uncertain. Since sporogenesis declines at temperatures above 18 °C, the area-wide warming trend in surface water temperatures may play a role. 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 farfield 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: 40 /100 $m^2$) while there was no significant difference temporally at the nearfield (Preop: 2/100 $m^2$; Op: 2/100 $m^2$) station. The decline was greater at the farfield station, in part because the preoperational density was much higher than at the nearfield station. The decline in *A. esculenta* began in the early 1980s (before the operation of Seabrook Station), and only very low densities have been reported at Station B19 (the deepest station) since 1981. Trends in abundance of the faunal selected species (Mytilidae spat, *Strongylocentrotus droebachiensis* and *Modiolus modiolus*) were consistent at the mid-depth stations between the preoperational and operational periods. However, there was a significant decline during the operational period for the amphipod *Pontogenia inermis* at the farfield station (B31), while there were no significant differences at the nearfield station (B19). No significant differences were found between the time periods for any faunal selected species. Since the decline was at the farfield station, it is not a direct effect of the operation of Seabrook Station. No localized effects from the operation of Seabrook Station were detected on benthic communities or on populations of selected species.

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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; 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 intra-specific 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. Benthic communities, particularly the perennial algae, have a great potential for being impacted by the cooling water discharge from Seabrook Station because they are fixed to the bottom and are relatively stable. 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 1998; NUSCO 2008; DNC 2002; DRS 2010; 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

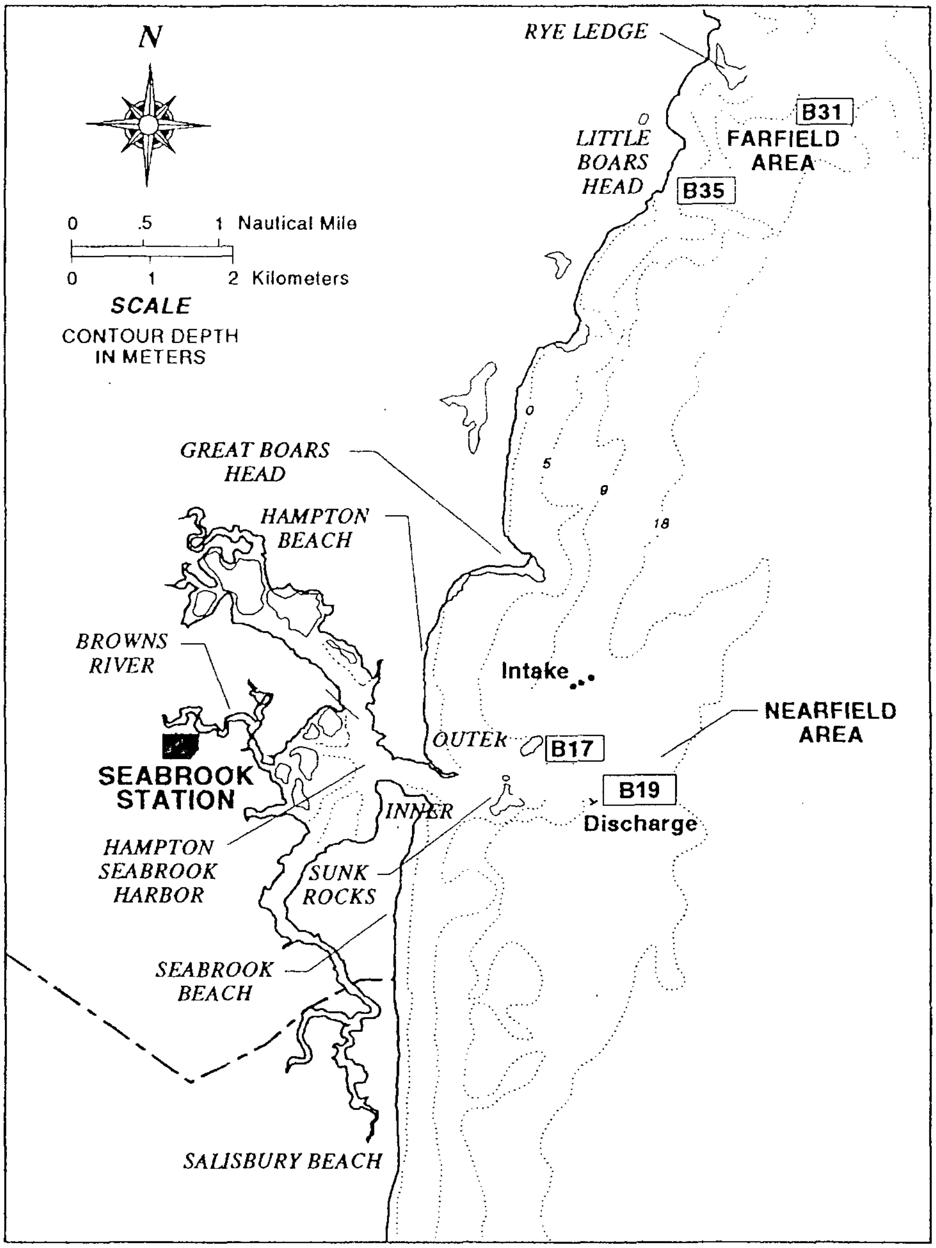
### 5.2.1 Field Methods

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, and brought to the field laboratory for preservation with 6% buffered formalin (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 were placed in plastic bags, chilled and taken to the laboratory in Bedford, NH. They 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 *Modiolus modiolus* and the kelp species *Laminaria digitata, Saccharina latissima (formerly Laminaria saccharina), Alaria esculenta*, and *Agarum clathratum* were made at seven 1-$m^2$ quadrats per transect. However at Stations 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.




**LEGEND**

[ ] = benthic samples

Figure 5-1. Marine benthic sampling stations. Seabrook Operational Report, 2009.

### 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. Crustose coralline algal species were processed for August samples only. Fauna were preserved in 70% ethanol, identified and counted from May and November macrofaunal samples. Fauna previously designated as selected species were determined from previous studies to be those species that are the most useful as indicators of overall community type in the study area, based on abundance, trophic level, and habitat specificity. All 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, the colonial organisms 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. To maintain consistency within the long-term database, taxonomy is based on morphological characteristics described by Sears (2002) and Villalard-Bohnsack (2003). Beginning in 2009, several name changes were made in the historical data: *Saccharina latissima*, *Ceramium virgatum*, *Neosiphonia harveyi* and *Ulva* will replace *Laminaria saccharina*, *Ceramium rubrum*, *Polysiphonia harveyi* and *Enteromorpha*, respectively (Appendix Table 5-2). Beginning in May 2006 *Membranipora membranacea* on kelp fronds in the general algae collections was identified using a dissecting microscope, and the percent coverage of each frond was recorded.

Recruitment of selected species (*Balanus* spp., *Anomia* sp., *Hiatella* sp, Mytilidae and Spirorbidae) was studied from short-term bottom panels. The whole panel was removed after approximately three months of exposure and it was brought to the Hampton field station and submerged in a seawater bath, while organisms were alive. A 50 cm x 50 cm frame was placed over the top surface of each panel and the area within the frame was divided into four quadrats for processing. *Balanus* spp. (primarily *Balanus crenatus*) and Spirorbidae were enumerated. Then the area within the frame was scraped to remove sessile bivalves and solitary chordates for identification under a dissecting microscope and enumeration.

### 5.2.3 Analytical Methods

#### 5.2.3.1 Destructive Monitoring Program: Community Analyses

Statistical analyses, data summaries, and graphical presentations 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-E (version 6.1.12; Clark and Warwick 2001).

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 are excluded from the historical data for temporal analyses that span 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).

ANOVAs for the number of taxa and total abundance of macrofauna and total algal biomass 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). The SAS univariate procedure was used to compare the distribution of data with the distribution of the transformed data, and the distribution that most closely approximated the normal distribution was selected. 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 preoperational period). Seabrook Station began commercial operation in August 1990, and operated intermittently beginning in May 1990. The triannual (May, August and November) collections of selected species from 1990 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 and multi-dimensional scaling (Clarke and Warwick 2001). The analysis was performed separately by depth zone for shallow subtidal (Stations B17 and B35) and mid-depth (Stations B19 and B31) August (peak season) collections. Bray-Curtis similarity indices were computed for the annual August log-transformed mean densities (macrofauna) and log-transformed mean biomass (macroalgae). All macroalgal (shallow subtidal: 49; mid-depth subtidal: 45) and macrofaunal (shallow subtidal: 242; mid-depth subtidal: 273) taxa were included in each analysis. The group average method (Boesch 1977) was used to classify the samples into groups or clusters. Computations were done with the computer program PRIMER-E (see Clarke and Warwick

**Table 5-1. Selected Benthic Taxa and Parameters Used in ANOVAs. Seabrook Operational Report, 2009.**

| Community | Sample Type | Parameter | Station | Data Periods Used In Analysis | Data Characteristics[a] | Source of Variation In ANOVAs[b] |
|---|---|---|---|---|---|---|
| Benthic Macroalgae | Non-Dest. | **Kelp** *Saccharina latissima, L. digitata, Alaria esculenta,* and | B17, B35 | 1982-1989, 1991-2009 | Mean number per sample period and station, log (x+1) transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Saccharina latissima, L. digitata, Agarum clathratum* | B19, B31 | 1978-1989, 1991-2009 | 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, 1991-2009 | Mean % frequency per year, arcsin √Y transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Chondrus crispus* and *Ptilota serrata* | B17, B35 | 1982-1989, 1991-2009 | Mean % frequency per year, arcsin √Y transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Phyllophora/Coccotylus* | B19, B31 | 1981-1989, 1991-2009 | Mean % frequency per year, log (x+1) transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Phyllophora/Coccotylus* | B17, B35 | 1982-1989, 1991-2009 | Mean % frequency per year, log (x+1) transformation | Preop-Op, Station, Year, Month |
| | Dest. | Number of taxa | B17, B35 | 1982-1989, 1991-2009 | Number per station, year, month and replicate, no transformation | Preop-Op, Station, Year, Month |
| | Dest. | Total biomass | B19, B31 | 1980-1989, 1991-2009 | Biomass per station, year, month and replicate, no transformation | Preop-Op, Station, Year, Month |
| | Dest. | *C. crispus* biomass | B17, B35 | 1982-1998, 1991-2009 | 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, 1991-2009 | Mean number per sample period and station, log (x+1) transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Strongylocentrotus droebachiensis* > 10 mm | B19, B31 | 1985-1989, 1991-2009 | Mean number per sample period and station, log (x+1) transformation | Preop-Op, Station, Year, Month |
| | Non-Dest. | *Modiolus modiolus* | B19, B31 | 1980-1989, 1991-2009 | Ranked densities; mean per sample period, no transformation. | Preop-Op, Station, Year, Month |
| | Dest. | *Jassa marmorata* and Mytilidae spat | B17, B35 | 1982-1989, 1991-2009 | Abundance per replicate; 3 dates per year. | Preop-Op, Station, Year, Month |
| | Dest. | Asteriidae | B17, B35 | 1982-1989, 1991-2009 | Abundance per replicate; 3 dates per year. | Preop-Op, Station, Year, Month |
| | Dest. | *Pontogeneia inermis* and Mytilidae spat 10 mm | B19, B31 | 1978-1989, 1991-2009 | Abundance per replicate; 3 dates per year. | Preop-Op, Station, Year, Month |
| | Dest. | *Strongylocentrotus droebachiensis* <10 mm | B19, B31 | 1985-1989, 1991-2009 | Abundance per replicate; 3 dates per year. | Preop-Op, Station, Year, Month |
| | Dest. | Total density, Number of Taxa | B17, B35; B19, B31 | 1982-2009 1978-2009 | 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.

2001). 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 2001). The adequacy of the representation of the relationships among samples is measured by the "stress" variable as defined in Clarke and Warwick (2001). 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 (2001) 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 between 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 2001).

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 2001). 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 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 rejecttion 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. The SAS univariate procedure was used to compare the distribution of data used for the ANOVA with the distribution of the transformed data, and the one that most closely approximated the normal distribution was selected. If the interaction between period (preoperational vs. operational) and station (nearfield vs. farfield) was significant, a 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.

#### 5.2.3.4 Effects of Water Temperature on Kelp Reproduction

Daily estimates of surface water temperature were used to evaluate the impact of the number of days with water temperatures $\geq$ 18 °C, a critical temperature for *Laminaria digitata* reproduction (See Table 5-23). The daily estimates were interpolated from water quality data collected at Stations P2 and P7 four times each month from July through August each year. Data from Station P2 represented the nearfield benthic stations B17 and B19, and data from Station P7 represented the farfield stations B31 and B35. The number of days each year with water temperature $\geq$ 18 °C was tabulated for each year. These annual totals were then used to calculate the mean number of days with water temperature $\geq$ 18 °C for the preoperational and operational periods. These means were quantitatively compared using a two-sample t-test.

## 5.3 RESULTS AND DISCUSSION

### 5.3.1 Marine Macroalgae

#### 5.3.1.1 Horizontal Ledge Communities

*Number of Taxa: Algae from Qualitative Samples (General Algae)*

Large and uncommon algal species, not taken in the five replicate 0.0625 m$^2$, destructive samples, were collected from a larger area around each benthic station by SCUBA divers. These qualitative collections are termed General Algae collections and were used to augment the species list. A total of 160 taxa has been collected from the two programs during the study period; this total includes species collected from intertidal sampling prior to 2002 (Appendix Table 5-3). No new species were collected in 2009. Of the introduced algal species in the Gulf of Maine listed by the Massachusetts Office of Coastal Zone Management (2002), only *Codium fragile* ssp. *tomentosoides* occurred in the study area in 1998 and 1999 (Appendix Table 5-3).

The number of taxa collected in the qualitative samples in the shallow subtidal zone in 2009 (nearfield Station B17: 30 taxa; farfield Station B35: 31 taxa) was below the preoperational and operational medians but within the ranges at both stations (Figure 5-2). In the mid-depth zone the number of taxa collected in 2009 (nearfield Station B19: 22 taxa; farfield Station B31: 31 taxa) was also

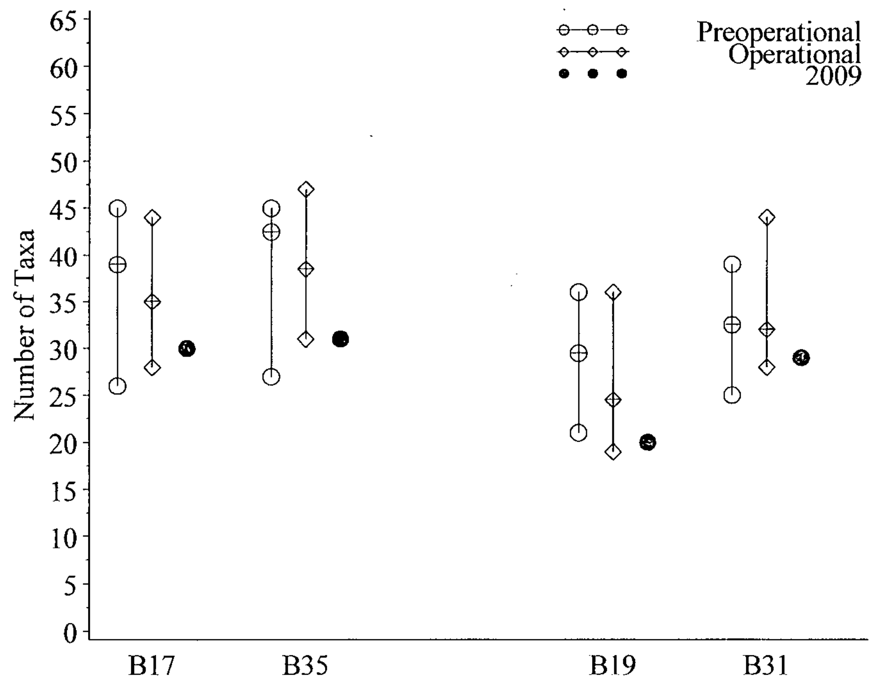



Figure 5-2. Number of macroalgal taxa in general algae collections from the subtidal zone. Median, minimum, and maximum numbers (calculated from annual totals) during the preoperational and operational periods, and the 2009 total. Seabrook Operational Report, 2009.

below the preoperational and operational medians but within the ranges at both stations. Appendix Table 5-4 gives the depth and characterizes the substrate for each station.

Patterns in the number of taxa collected between 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. Farfield stations (B35 and B31) had a higher number of taxa than nearfield stations (B17 and B19) during the preoperational and operational periods. Station B19 typically had the lowest number of taxa during both periods and is 2.8 m deeper than its farfield counterpart (B31).

### *Number of Taxa: Destructive Samples*

In the shallow subtidal zone, the number of taxa (species richness) collected in quantitative destructive samples in 2009 at nearfield Station B17 was the lowest reported for the study period (Figure 5-3) and was below the preoperational and operational confidence limits (Table 5-2). At farfield Station B35 the mean number of taxa was also lower than the previous year and was below the preoperational and operational means. The ANOVA results indicated that there were no significant differences in number of taxa between the preoperational and operational periods, and Station B35 had significantly more taxa than Station B17 (Table 5-3). The annual mean number of taxa at Station B35 was consistently higher than at Station B17 (Figure 5-3). The relationship between stations was

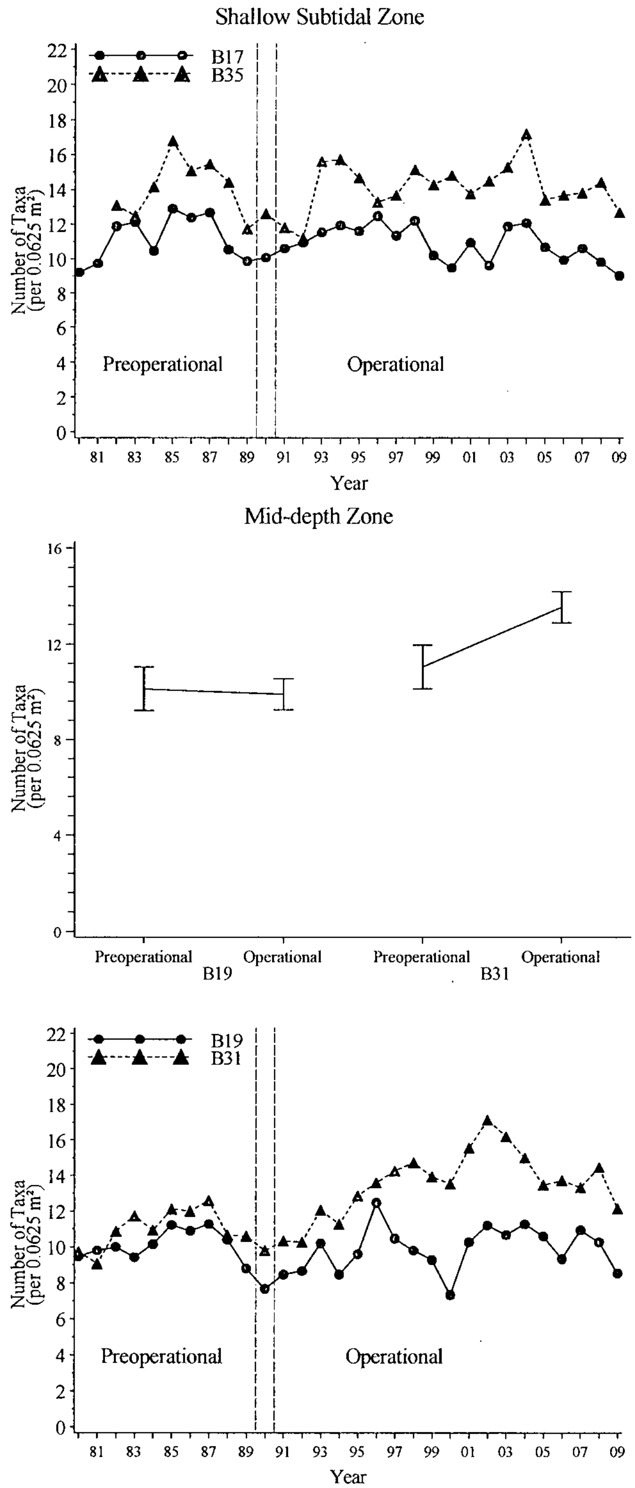



Figure 5-3. Annual mean number of macroalgal taxa (per 0.0625 m$^2$) each year in the shallow and mid-depth subtidal zones and the comparison between stations of number of taxa in the mid-depth subtidal zone during the preoperational (1980-1989) and operational (1991-2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model. Seabrook Operational Report, 2009.

**Table 5-2. Arithmetic Means and Confidence Limits of Biomass (g per $m^2$) and Number of Macroalgal Taxa (per 0.0625 $m^2$) from Destructive Samples during the Preoperational and Operational Periods. Seabrook Operational Report, 2009.**

| | | Preoperational | | | 2009 | Operational | | |
|---|---|---|---|---|---|---|---|---|
| **Depth Zone** | **Station** | **LCL[a]** | **Mean** | **UCL[b]** | **Mean** | **LCL** | **Mean** | **UCL** |
| **Number of Taxa (per 0.0625 $m^2$)** | | | | | | | | |
| Shallow subtidal | B17[c] | 10.2 | 11.2 | 12.1 | 9.0 | 10.4 | 10.9 | 11.4 |
| | B35[d] | 12.8 | 14.2 | 15.5 | 12.7 | 13.5 | 14.1 | 14.8 |
| Mid-depth | B19[c] | 9.6 | 10.1 | 10.7 | 8.5 | 9.3 | 9.9 | 10.5 |
| | B31[c] | 10.2 | 11.0 | 11.8 | 12.1 | 12.7 | 13.6 | 14.5 |
| **Total Biomass (g/$m^2$)** | | | | | | | | |
| Shallow subtidal | B17[c] | 809.7 | 892.3 | 974.9 | 614.9 | 778.0 | 848.8 | 919.7 |
| | B35[d] | 774.2 | 891.4 | 1008.7 | 619.0 | 678.8 | 758.7 | 838.6 |
| Mid-depth | B19[c] | 232.1 | 277.3 | 322.6 | 150.1 | 186.2 | 228.8 | 271.5 |
| | B31[c] | 348.6 | 419.1 | 489.6 | 231.2 | 279.3 | 328.6 | 377.8 |

[a] LCL = Lower 95% confidence limit.
[b] UCL = Upper 95% confidence limit.
[c] Years = 1980-1989 (Preoperational); 1991-2009 (Operational)
[d] Years = 1982-1989 (Preoperational); 1991-2009 (Operational)

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 numbers of taxa found at the nearfield (B19) and farfield (B31) stations in 2009 was lower than the operational means (Table 5-2). The relationship between 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 Station B31, while there was no significant change at Station B19. ANOVA results were 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). The number of taxa at the two stations followed similar annual trends until 1996, when fluctuations in the occurrence of species not normally found in the mid-depth zone began to occur (Figure 5-3). For example, the peak number of taxa at Station B31 occurred in 2002 when *Ceramium virgatum (*annual, often epiphytic), *Polysiphonia flexicaulis*, *P. fucoides* and *P. nigra*, typically more common in the shallow subtidal zone, were also present at the mid-depth stations.

### *Total Biomass: Destructive Samples*

Algal biomass generally decreased with increasing depth (Table 5-2, Figure 5-4). Depth (MLLW; mean lower low water) ranged from 4.6 to 4.9 m at shallow subtidal stations (B35 and B17, respectively) and from 9.4 to 12.2 m at mid-depth stations (B31 and B19, respectively; Appendix Table 5-4). Mean biomass in 2009 at both shallow subtidal stations was lower than the preoperational and operational confidence limits (Table 5-2), but higher than the lows of the previous years (Figure 5-4). There were no significant differences between stations or periods. The interacttion 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).

**Table 5-3. Results of Analysis of Variance Comparing the Mean Number of Macroalgal Taxa (per 0.0625 $m^2$) and Total Macroalgal Biomass (g per $m^2$ of all species) from Destructive Samples at Shallow Subtidal and Mid-Depth Subtidal Stations During 2009. Seabrook Operational Report, 2009.**

| Parameter | Source of Variation | Test Statistics (Data not transformed) | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| Number of Taxa | Fixed Effects | DF[g] | F[h] | p[i] | |
| | Preop-Op[a] | 1, 3.72 | 0.53 | 0.5079 | |
| Shallow Subtidal (B17, B35) | Random Effects | Estimate[j] | $\chi^2$ | p | |
| | Year (Preop-Op)[b] | 0.14 | 0.14 | 0.3524 | |
| | Month(Year)[c] | 1.74 | 103.61 | <0.0001* | |
| | Station[d] | 4.53 | 2.90 | 0.0444* | B35>B17 |
| | Preop-Op X Station[e] | 0.04 | 0.08 | 0.3924 | |
| | Station X Year (Preop-Op)[f] | 0.62 | 22.68 | <0.0001* | |
| | Error | 4.19 | | | |
| Number of Taxa | Fixed Effects | DF[g] | F[h] | p[i] | |
| | Preop-Op[a] | 1, 1.17 | 0.61 | 0.5619 | |
| Mid-depth (B19, B31) | Random Effects | Estimate[j] | $\chi^2$ | p | |
| | Year (Preop-Op)[b] | 0.81 | 5.44 | 0.0098* | |
| | Month(Year)[c] | 0.76 | 55.44 | <0.0001* | |
| | Station[d] | 1.65 | 0.23 | 0.3159 | |
| | Preop-Op X Station[e] | 1.91 | 16.04 | 0.0001* | B31Op>B31Pre B19Pre B19Op |
| | Station X Year (Preop-Op)[f] | 0.67 | 41.29 | <0.0001* | |
| | Error | 3.18 | | | |
| Total Biomass | Fixed Effects | DF[g] | F[h] | p[i] | |
| | Preop-Op[a] | 1, 6.44 | 1.18 | 0.3168 | |
| Shallow Subtidal (B17, B35) | Random Effects | Estimate[j] | $\chi^2$ | p | |
| | Year (Preop-Op)[b] | 0.00 | 0.00 | 0.4997 | |
| | Month(Year)[c] | 16.72 | 251.72 | <0.0001* | |
| | Station[d] | 0.22 | 0.06 | 0.4029 | |
| Data sq. rt. transformed | Preop-Op X Station[e] | 0.45 | 1.28 | 0.1294 | |
| | Station X Year (Preop-Op)[f] | 0.48 | 1.37 | 0.1239 | |
| | Error | 18.11 | | | |
| Total Biomass | Fixed Effects | DF[g] | F[h] | p[i] | |
| | Preop-Op[a] | 1, 77 | 6.66 | 0.0118* | Pre>Op |
| Mid-depth (B19, B31) | Random Effects | Estimate[j] | $\chi^2$ | p | |
| | Year (Preop-Op)[b] | 0.00 | 0.00 | 0.4999 | |
| | Month(Year)[c] | 3.66 | 48.45 | <0.0001* | |
| Data sq. rt. transformed | Station[d] | 4.81 | 2.49 | 0.0573 | |
| | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 4.61 | 68.03 | <0.0001* | |
| | Error | 15.48 | | | |

[a] Compares Preop to Op, regardless of station; years included in each station grouping: Op years = 1991-2009, 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 $H_o$: Estimate(i)= Estimate(j).
* = significant ($p \leq 0.05$)

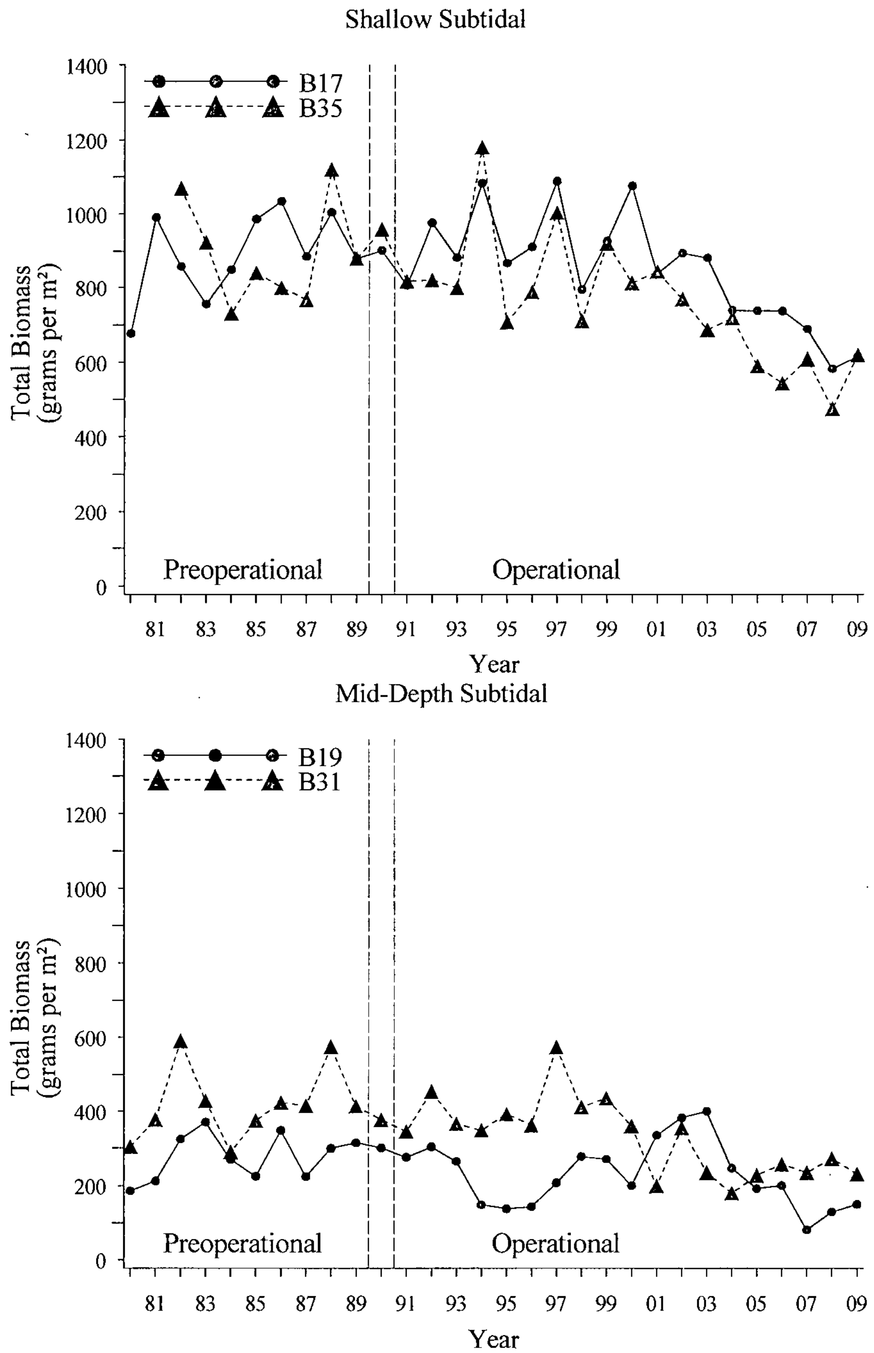



Figure 5-4. Annual mean biomass (g/m$^2$) from destructive samples collected triannually in the shallow subtidal and mid-depth subtidal zones during the preoperational and operational (1991-2009) periods. Seabrook Operational Report, 2009.

**Table 5-4. `Results of Segmented Regression Analysis on Number of Algal Taxa from Destructive Samples in the Mid-Depth Zones. Seabrook Operational Report, 2009.**

| Parameter | Station | Comparison Based on Breakpoints[a] | Period 1 Slope | Period 2 Slope |
|---|---|---|---|---|
| No. of taxa | B19 | 1980-2009 NS | – | – |
| No. of taxa | B31 | 1980-1995 <1996-2009 *** | 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)

At the mid-depth stations, mean biomass in 2009 was lower than both the preoperational and operational period confidence limits (Table 5-2). In 2009, biomass at Station B19 increased for the second consecutive year from the low in 2007. At Station B31, biomass was slightly lower 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 period. 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 in each depth zone to quantify similarity among all macroalgal collections made at the macrobenthic sampling stations in August since 1982. For each group there were 56 station-year collections represented by 49 taxa in the shallow subtidal zone, and 45 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 (1990-2009) 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 taken in August from the shallow subtidal zone (Stations B17 and B35) did not show strong annual or spatial trends in the cluster analysis as evidenced by the high degree of similarity (over 75%) among all collections except for one of the outliers (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 included Stations B17 and B35 for 2009. Group 2 consisted of a mixture of collections from both stations and periods. The 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 after commercial operation of the plant began in August 1990. Four collections from Station B35 taken in 2002, 2003, 2005 and 2008 were not closely allied with Groups 1 and 2 and were considered outliers. The MDS plot also indicates the high level of similarity among all samples, with the outliers having the most distance from the groups. No pattern of pre-operational/operational differences or station differences occurred (Figure 5-5). Since assemblages at the stations were significantly different during the preoperational period, ANOSIM could not be used to test for the interaction of main effects (Table 5-5).

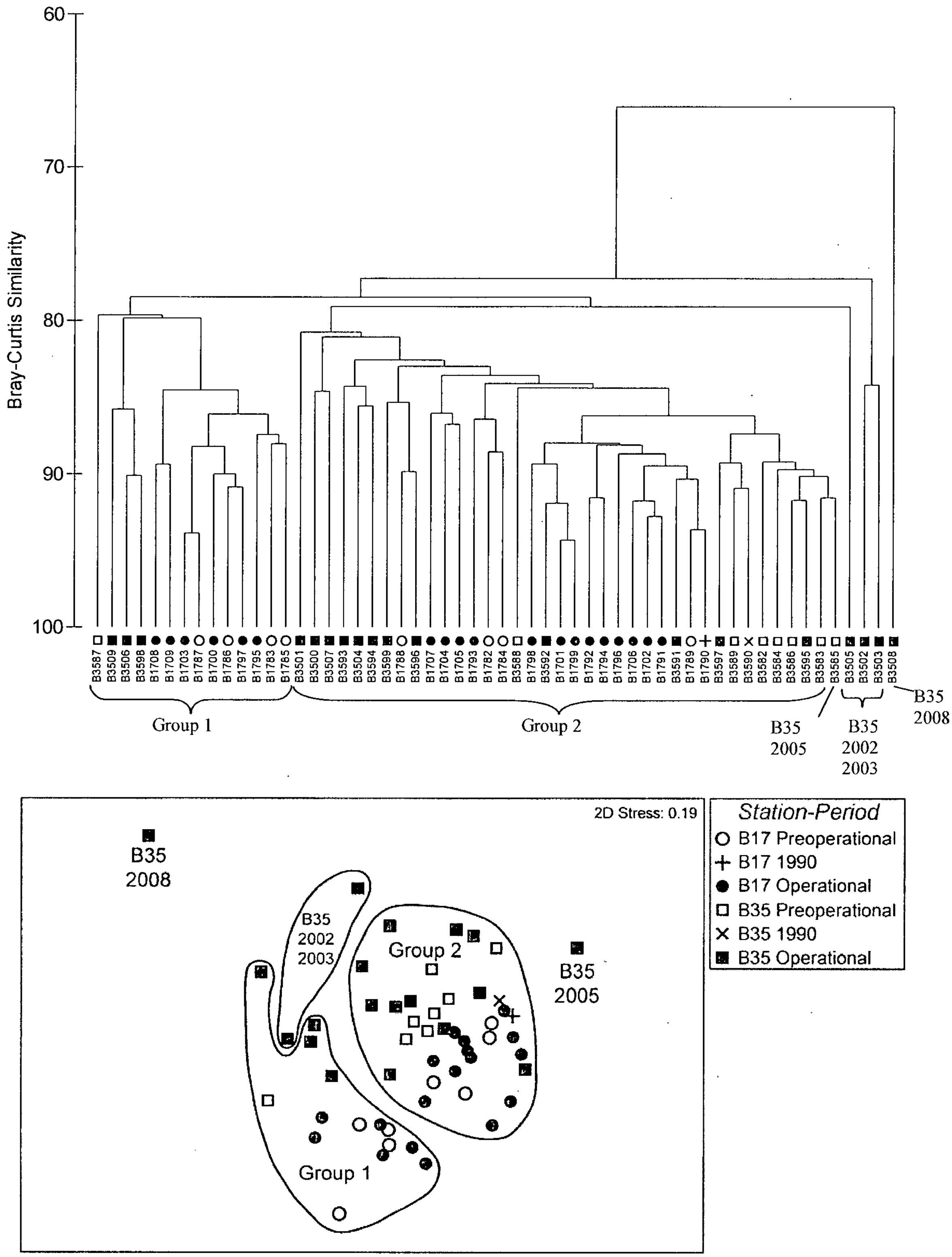



Figure 5-5. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August macroalgae collections from shallow subtidal Stations B17 and B35, 1982-2009. Seabrook Operational Report, 2009.

**Table 5-5. Analysis of Similarities (ANOSIM) of Spatial and Temporal Differences between August Macroalgae Communities. Seabrook Operational Report, 2009.**

| Community | Comparison | R | p (%) [a] |
|---|---|---|---|
| Shallow Subtidal (B17, B35) | Period[b] | -0.04 | 73.1 NS |
| | Station[b] | 0.23 | 0.1* |
| | B17 Pre vs. B35 Pre[c] | 0.39 | 0.2* |
| | Interaction of Main Effects | | Not testable |
| Mid-depth Subtidal (B19, B31) | Period[b] | -0.23 | 56.5 NS |
| | Station[b] | 0.77 | 0.1* |
| | B19 Pre vs. B31 Pre[c] | 0.93 | 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. Geometric 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, 2009.**

**A. Group Means of Macroalgae for Shallow Subtidal Zone**

| | Group 1 | | | Group 2 | | | B35:2002/2003 | | | B35 2005 | B35 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon[a] | LCL[b] | MEAN | UCL[c] | LCL | MEAN | UCL | LCL | MEAN | UCL | MEAN | MEAN |
| *Chondrus crispus* | 551.6 | 721.6 | 943.7 | 473.3 | 544.3 | 625.9 | 0.0 | 356.2 | 194188 | 127.9 | 116.9 |
| *Ceramium virgatum* | 20.6 | 30.3 | 44.4 | 49.6 | 60.6 | 74.0 | 1.7 | 85.9 | 2768.3 | 14.4 | 26.7 |
| *Phyllophora/Coccotylus* | 13.8 | 23.7 | 40.3 | 95.9 | 118.2 | 145.6 | 0.0 | 36.2 | 11134 | 79.6 | 173.7 |
| *Corallina officinalis* | 11.7 | 15.7 | 21.1 | 8.2 | 11.5 | 15.9 | 0.0 | 2.7 | 102.5 | 1.5 | 10.8 |
| *Cystoclonium purpureum v. cirrhosum* | 3.9 | 6.4 | 10.0 | 18.8 | 26.0 | 35.7 | 0.0 | 4.6 | 130.0 | 127.4 | 0.3 |
| *Phycodrys rubens* | 2.6 | 3.5 | 4.6 | 11.0 | 13.3 | 16.1 | 0.0 | 6.5 | 117.2 | 21.0 | 0.1 |
| *Euthora cristata* | 1.6 | 2.5 | 3.8 | 6.8 | 8.5 | 10.5 | | 5.2 | 252.1 | 21.0 | 0.2 |
| *Membranoptera alata* | 0.1 | 0.3 | 0.4 | 0.5 | 0.8 | 1.0 | 0.0 | 0.7 | 658.5 | 0.2 | 0.2 |
| *Chaetomorpha picquotiana* | 0.0 | 0.4 | 0.9 | 0.1 | 0.3 | 0.5 | 0.0 | 5.1 | 76.1 | 0.8 | 7.5 |
| Total biomass of taxa [d] | | 804.4 | | | 783.9 | | | 506.3 | | 395.4 | 338.0 |

[a] Species with biomass greater than or equal to 0.5 g/m$^2$
[b] LCL = Lower 95 % Confidence limit
[c] UCL = Upper 95% Confidence limit
[d] Sum of the biomass of all species with the mean biomass greater than or equal to 0.5 g/m$^2$ in a group or outlier

**Table 5-6. (Continued)**

**B. Group Means of Macroalgae for Mid-depth Zone**

| Taxon [a] | Group 1 | | | Group 2 | | | Group 3 | | | B19:2007 |
|---|---|---|---|---|---|---|---|---|---|---|
| | LCL[b] | MEAN | UCL[c] | LCL | MEAN | UCL | LCL | MEAN | UCL | MEAN |
| *Phyllophora/Coccotylus* | 144.0 | 173.7 | 209.4 | 81.8 | 106.3 | 137.9 | 6.7 | 16.4 | 38.1 | 50.0 |
| *Phycodrys rubens* | 25.2 | 33.3 | 43.8 | 8.7 | 11.8 | 15.8 | 0.6 | 2.0 | 4.9 | 2.7 |
| *Euthora cristata* | 6.4 | 8.2 | 10.3 | 2.7 | 4.1 | 6.0 | 1.4 | 2.4 | 3.7 | 1.6 |
| *Ptilota serrata* | 4.4 | 5.8 | 7.5 | 1.1 | 1.8 | 2.7 | 0.0 | 0.1 | 0.3 | 1.2 |
| *Corallina officinalis* | 3.1 | 4.1 | 5.5 | 30.7 | 39.4 | 50.4 | 10.6 | 24.1 | 53.2 | 2.6 |
| *Membranoptera alata* | 1.8 | 2.6 | 3.6 | 1.7 | 2.7 | 4.0 | 0.4 | 1.2 | 2.4 | 1.3 |
| *Cystoclonium purpureum v. cirrhosum* | 1.6 | 2.3 | 3.2 | 1.0 | 1.9 | 3.1 | 0.0 | 0.8 | 4.6 | 0.1 |
| *Chondrus crispus* | 0.4 | 0.7 | 1.1 | 27.0 | 39.8 | 58.6 | 2.2 | 32.1 | 340.3 | 0.8 |
| *Polysiphonia stricta* | 0.1 | 0.2 | 0.3 | 0.5 | 1.2 | 2.1 | 9.3 | 23.9 | 59.3 | 0.0 |
| *Ceramium rubrum* | 0.0 | 0.1 | 0.2 | 0.3 | 0.5 | 0.7 | 0.2 | 3.9 | 19.8 | 0.0 |
| *Rhodomela confervoides* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.3 | 1.3 | 3.0 | 0.0 |
| Total biomass of taxa [d] | | 231.0 | | | 209.6 | | | 108.2 | | 60.3 |

[a] Species with biomass greater than or equal to 0.5 $g/m^2$
[b] LCL = Lower 95 % Confidence limit
[c] UCL = Upper 95% Confidence limit
[d] Sum of the biomass of all species with the mean biomass greater than or equal to 0.5 $g/m^2$ in a group or outlier

In the shallow subtidal zone differences in the mean biomass of nine dominant taxa accounted for the major distinctions among the groups (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 the other groups. In Group 1, *Chondrus crispus,* a perennial turf-forming red alga, represented 90% of the total biomass whereas it represented about 70% in Group 2 and at Station B35: 2002/2003, and was around 30% at the outliers (Station B35: 2005 and Station B35: 2008). Biomass of *Phyllophora/ Coccotylus* was five times higher in Group 2 when compared to Group 1. Mean biomass of *Ceramium virgatum, 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 in deeper water, while *Ceramium virgatum* and *Cystoclonium purpureum 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 green alga, often found on the bottom or entangled with coarse algae (Sears 2002), and was most abundant at the outliers, B35:2008 and B35:2002/2003. At Station B35 in 2008, *Phyllophora/Coccotylus* (typically the most abundant taxa at the mid-depth stations) dominated the collections, followed by *Chondrus crispus*, and the unattached algae *Chaetomorpha picquotiana.* The total biomass of the four outliers (B35: 2002, 2003, 2005 and 2008) was lower than the total biomass within the two major groups (Table 5-6 A).

The multivariate analysis of mid-depth subtidal collections (Stations B19 and B31) identified two major groups at about the 70% similarity level that separated primarily by station (Group 1: Station B19; Group 2: 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 in Groups 1 and 2; preoperational and operational years were mixed within each group (Figure 5-6). ANOSIM indicated stations were significantly different in the pre-operational period, therefore it could not be used to test for the interaction of main effects (Table 5-5). Differences in algal assemblages at these stations likely reflect differences in depth and bottom substrate. Station B31 was 9.4 m deep and the substrate was 41% ledge, 14% cobble and 42% was a mixture that included sand and gravel over rock (Appendix Table 5-4). Station B19 was 12.2 m deep with a substrate of 87% ledge, 6% cobble and 7% was a mixture. Species composition was more similar to the shallow subtidal stations at Station B31 than at Station B19, with more *Chondrus crispus* and *Corallina officinalis*. Since there is a mix of preoperational and operational collections in the major groups, these data suggest that there has been 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 the deepest station, B19) was dominated by the deep-water species *Phyllophora/ Coccotylus* and *Phycodrys rubens. Coccotylus truncatus* and *P. rubens* are cold-water perennials, present to the extinction depth of foliose algae. *P. rubens* is one of the most common sublittoral red algae and occurs as an epiphyte and on stones or shells, while *C. truncatus* occurs on rock and other hard substrate (Sears 2002). *Phyllophora pseudoceranoides* is a cold-water perennial that can form extensive beds on boulders or occur in shifting sands. 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, *Chondrus crispus* and *Corallina officinalis.* Total biomass in Group 3 (Station B31:2001-2004) was about half of Groups 1 and 2 and was dominated by *Chondrus crispus*, *Corallina officinalis,* and the annual *Polysiphonia stricta.* The outlier, Station B19:2007, had the lowest overall biomass, and *Phyllophora/ Coccotylus* remained dominant, but at only about one third of the biomass typical for Station B19. In 2009 Station B19 and B31 were assigned to Groups 1 and 2 respectively, consistent with most preceding years.

Since the community analysis focuses on dominant taxa, a separate analysis was performed on uncommon species (< 4% of the total occurrences) from destructive samples taken in August (Table 5-7). Power plant impact would be evident by an increase in the occurrence of species with warm-water affinities or a decrease in species with cold-water affinities at a nearfield station (B17 or B19) in comparison to a farfield station during the operational period. All of the uncommon species (Table 5-7) are within their geographical ranges as listed in Sears (2002). There is no indication of an increase in species with warm-water affinities or a decline is species with cold-water affinities at the nearfield stations.

Six uncommon species were found in destructive collections from the shallow subtidal (Stations B17 and B35) and mid-depth (Stations B19 and B31) zones during preoperational years, but have not yet been collected during the operational period: *Ulva prolifera, Ulva* sp., *Dumontia contorta, Neosiphonia harveyi, Petalonia fascia,* and *Ceramium deslongchampii. Petalonia fascia* is a shallow water species associated with a cold-water habitat, and is usually found in late

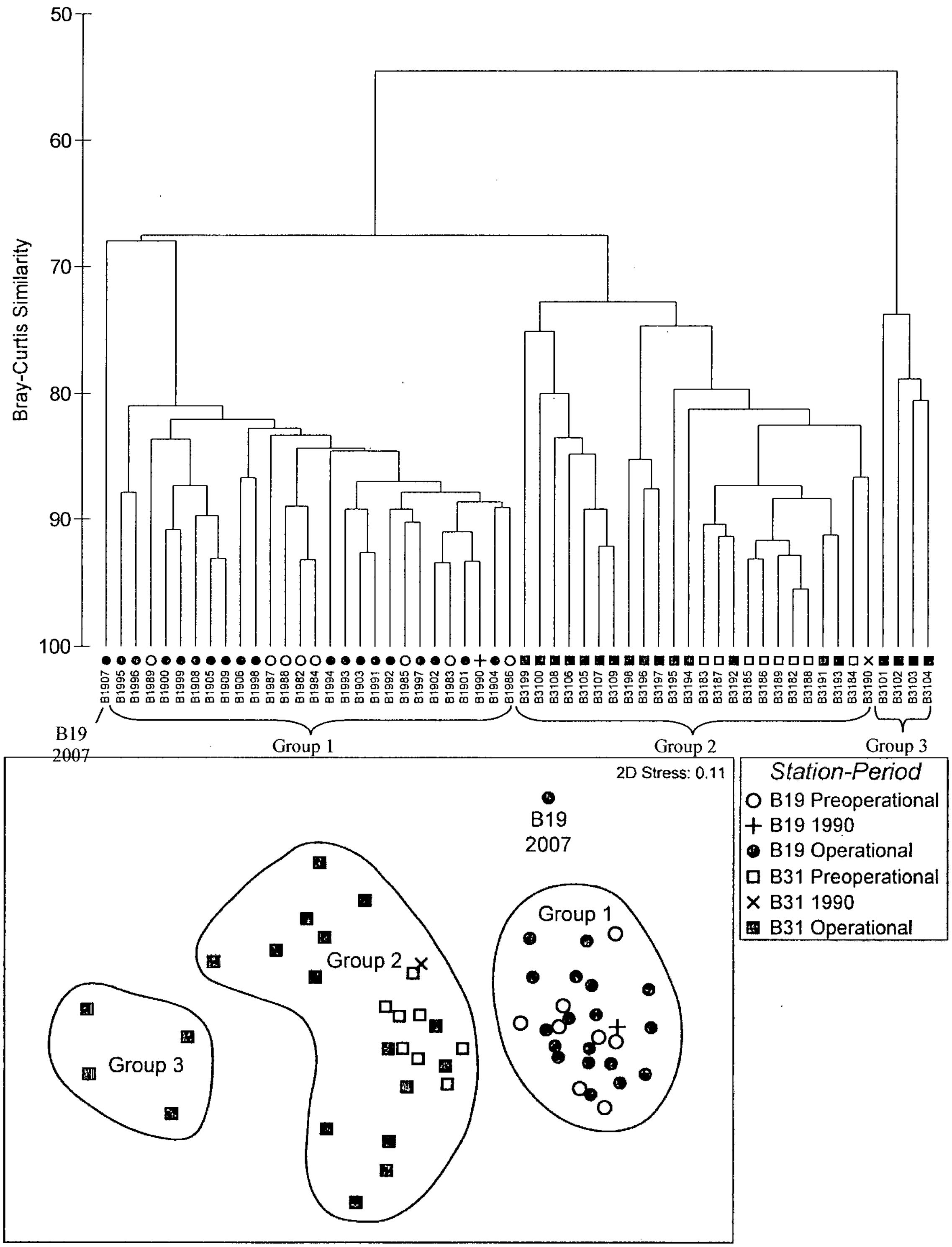



Figure 5-6. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August macroalgae collections from mid-depth subtidal Stations B19 and B31, 1982-2009. Seabrook Operational Report, 2009.

**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 (1990-2009) Periods. Seabrook Operational Report, 2009.**

| | Shallow Subtidal | | | | Mid-depth Subtidal | | | |
|---|---|---|---|---|---|---|---|---|
| | B17 | | B35 | | B19 | | B31 | |
| Taxa | Preop | Op | Preop | Op | Preop | Op | Preop | Op |
| **Chlorophyta** | | | | | | | | |
| *Blidingia minima* | 0 | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cladophora sericea* | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 |
| *Ulva compressa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 |
| *Ulva intestinalis* | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 0 |
| *Ulva lactuca* | 5.2 | 0 | 2.6 | 3.0 | 0 | 0 | 0 | 1.0 |
| *Ulva prolifera* | 1.7 | 0 | 0 | 0 | 1.7 | 0 | 0 | 0 |
| *Ulva* sp. | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Phaeophyta** | | | | | | | | |
| *Ectocarpus fasciculatus* | 0 | 0 | 10.5 | 1.0 | 1.7 | 0 | 0 | 0 |
| *Ectocarpus siliculosus* | 0 | 2.0 | 0 | 6.0 | 0 | 0 | 0 | 3.0 |
| *Petalonia fascia* | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphacelaria cirrosa* | 0 | 0 | 2.6 | 0 | 0 | 1.0 | 0 | 2.0 |
| *Sphacelaria plumosa* | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.0 |
| *Sphacelaria radicans* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 |
| **Rhodophyta** | | | | | | | | |
| *Ceramium deslongchampii* | 0 | 0 | 2.6 | 0 | 0 | 0 | 0 | 0 |
| *Dumontia contorta* | 0 | 0 | 2.6 | 0 | 1.7 | 0 | 0 | 0 |
| *Fimbrifolium dichotomum* | 1.7 | 0 | 2.6 | 0 | 10.3 | 2.0 | 0 | 0 |
| *Mastocarpus stellatus* | 6. 9 | 1.0 | 0 | 2.0 | 0 | 0 | 0 | 0 |
| *Neosiphonia harveyi* | 1.7 | 0 | 2.6 | 0 | 0 | 0 | 0 | 0 |
| *Palmaria palmata* | 1.7 | 1.0 | 0 | 0 | 0 | 0 | 1.8 | 0 |
| *Polysiphonia elongata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 |
| *Polysiphonia lanosa* | 0 | 0 | 7.9 | 4.0 | 1.7 | 0 | 1.8 | 6.0 |
| *Polysiphonia* sp. | 1.7 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 |
| *Porphyra miniata* | 5. 2 | 0 | 0 | 1.0 | 0 | 0 | 1.8 | 0 |
| *Porphyra* sp. | 0 | 3.0 | 0 | 3.0 | 0 | 0 | 0 | 0 |
| *Porphyra umbilicalis* | 3.4 | 6.0 | 2.6 | 0 | 0 | 0 | 0 | 1.0 |
| *Pterothamnion plumula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.0 |

winter to early spring (Sears 1998, Taylor 1957). *Neosiphonia harveyi* is a warm-water summer annual and an introduced species from Japan (Carlton 2004, Mathieson et al. 2008). *U. 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 that provide shade (Sears 2002). *D. contorta* is an introduced species with cold-water affinities and is a winter, late-spring annual that occurs predominantly in the mid- to lower intertidal or to 7 m in the shallow subtidal (Sears 2002, Mathieson et al. 2008). All species are within their range according to Sears (2002), suggesting that plant operation has not affected their distribution.

Ten uncommon species have been identified as occurring only during the operational period (1990-2009): *Ulva compressa*, *Ulva intestinalis*, *Blidingia minima*, *Ectocarpus siliculosus*, *Pterothamnion plumula*, *Sphacelaria plumosa*, *Cladophora sericea*, *Sphacelaria radicans*, *Porphyra* sp. and *Polysiphonia elongata*. *Sphacelaria plumosa* is a cold water species that is not found south of Cape Ann Massachusetts, but all other species are cold water species that occur south of Cape Cod and extend northward into Maine and Canada (Sears 2002). All of these species are within their geographical ranges, suggesting that plant operation has not altered their distribution. The macroalgal communities in the vicinity of Seabrook Station are typical of those reported elsewhere in northern New England (Mathieson et al. 1981a, 1981b; Mathieson and Hehre 1986).

### 5.3.1.2 Selected Macroalgal Species: Destructive Samples

#### *Chondrus crispus*

Shallow subtidal horizontal rock surfaces near the Seabrook Station 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). This wide distribution indicates that it is able to tolerate and grow in a wide range of temperatures. Off New Hampshire, Mathieson and Burns (1971) found *C. crispus* exhibits an increase in growth with a corresponding increase in temperature from 3° to 19° C. 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.

*Chondrus crispus* comprised at least 50% of the total biomass of the quantitative, destructive samples at shallow subtidal stations during the preoperational and operational periods (Table 5-8). Biomass was usually lower at Station B35 than at Station B17 (Figure 5-7). The 2009 biomass at both stations increased from the lows of the previous year, but was below the preoperational and operational confidence limits at both stations (Figure 5-7; Table 5-8). Biomass was not significantly different between periods or stations (Table 5-9). The relationship between stations was consistent across periods as indicated by the non-significant interaction term (Table 5-9), an indication that the operation of Seabrook Station was not affecting the population.

### 5.3.1.3 Non-destructive Monitoring Program

#### *Kelp Canopy*

Historically, extensive canopies of several kelp species have covered subtidal zones (4-18 m) in the northwestern Atlantic, and can account for up to 80% of total algal biomass (Mann 1973, Steneck 1997, Steneck et al. 2002). In the Gulf of Maine, *Saccharina latissima* and *Laminaria 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). In 2009 as in previous years, *Saccharina latissima* was the dominant kelp species at shallow subtidal stations, while *Agarum clathratum* was the dominant at the mid-depth stations (Table 5-10). *Laminaria*

**Table 5-8. Arithmetic Means and 95% Confidence Limits of *Chondrus crispus* and Total Algal Biomass (g per m$^2$) Collected in Triannual (May, August, November), Destructive Samples During 2009 and During the Preoperational and Operational Periods. Seabrook Operational Report, 2009.**

| | | Preoperational[a] | | | 2009 | Operational[b] | | |
|---|---|---|---|---|---|---|---|---|
| *Chondrus crispus* (g/m$^2$) | | LCL[c] | Mean | UCL[d] | Mean | LCL | Mean | UCL |
| Shallow subtidal | B17 | 541.8 | 652.2 | 762.6 | 443.0 | 526.5 | 592.8 | 659.2 |
| | B35 | 433.9 | 477.3 | 520.8 | 246.3 | 318.4 | 382.4 | 446.5 |
| Total algal biomass | B17 | 809.7 | 892.3 | 974.9 | 614.9 | 778.0 | 848.8 | 919.7 |
| | B35 | 774.2 | 891.4 | 1,008.7 | 619.0 | 678.8 | 758.7 | 838.6 |

[a] Preoperational years are 1982-1989. The years are the same years used for the ANOVA.
[b] Operational years are 1991-2009. The years are the same years used for the ANOVA.
[c] LCL = Lower 95% confidence limit.
[d] UCL = Upper 95% confidence limit.

**Table 5-9. Results of Analysis of Variance of *Chondrus crispus* Biomass (g per m$^2$) Collected in Triannual (May, August, November) Destructive Samples During the Preoperational (1982-1989) and Operational (1991-2009) Periods. Seabrook Operational Report, 2009.**

| 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, 81.6 | 3.58 | 0.0619 | |
| Shallow Subtidal | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| (B17, B35) | Year (Preop-Op)[b] | 0.00 | 0.00 | 0.4998 | |
| (square root | Month(Year)[c] | 12.99 | 77.98 | <0.0001* | |
| transformation) | Station[d] | 11.90 | 2.58 | 0.0540 | |
| | Preop-Op X Station[e] | <0.01 | 0.00 | 0.4989 | |
| | Station X Year (Preop-Op)[f] | 2.20 | 5.53 | 0.0094* | |
| | Error | 40.77 | | | |

[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 $H_o$: Estimates(i)= Estimate(j).
* = significant ($p \leq 0.05$)

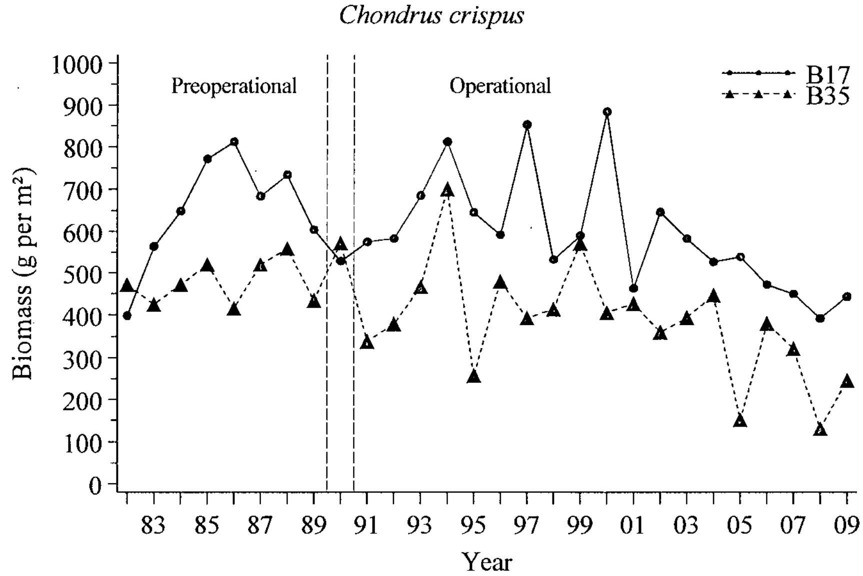



Figure 5-7. Annual mean density (grams per $m^2$) of *Chondrus crispus* in destructive samples from the shallow subtidal zone (Stations B17 and B35), 1982-2009. Seabrook Operational Report, 2009.

*digitata* has been secondary in abundance at both the shallow subtidal and mid-depth stations throughout the study period.

***Laminaria digitata***

*Laminaria digitata* occurs from Long Island to southern Massachusetts at a few exposed sites, but becomes common north of Cape Cod to the lower St. Lawrence River, Hudson Bay and Ile Miquelon (Taylor 1957). It commonly prefers rocky substrate in a location that is exposed to wave action or currents and is below the low-tide level. In the western North Atlantic, the 19°C summer isotherm (Long Island) is the southern lethal boundary of the population (Van den Hoek 1982). It is a perennial and lives 4 to 6 years (Gayral and Cosson 1973).

In the shallow subtidal zone, *Laminaria digitata* density in 2009 was below the preoperational means at Stations B17 and B35 (Table 5-10). In 2009, density increased for the second consecutive year at Station B35 and remained stable and low at Station B17 (Figure 5-8), as did the percent cover (Figure 5-9). Two storms in 1991 (Hurricane Bob on August 19 and the "Perfect Storm" on October 31) may have contributed to the drop in annual mean abundance noted at both stations between 1990 and 1991 (Figure 5-8). The decline that occurred between the preoperational and the operational periods 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 1991 was significantly higher than the period after 1991, 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 did not exhibit a significant trend from 2002 through 2009 (Table 5-12, Figure 5-8). Since a significant 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. In the shallow subtidal zone, both stations had

**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, 2009.**

| | Station | Preoperational[b] | | | 2009 | 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 | 5.3 | 15.2 | 25.2 |
| | B35 | 96.5 | 155.8 | 215.1 | 100.8 | 52.3 | 73.9 | 95.6 |
| | B19 | 81.5 | 139.9 | 198.3 | 0.0 | 3.1 | 7.5 | 11.9 |
| | B31 | 401.6 | 500.2 | 598.7 | 50.0 | 106.0 | 157.7 | 209.5 |
| *Saccharina latissima* | B17 | 270.7 | 415.1 | 559.4 | 35.7 | 66.1 | 137.9 | 209.7 |
| | B35 | 210.9 | 325.7 | 440.5 | 361.0 | 247.8 | 326.0 | 404.2 |
| | B19 | 2.0 | 59.1 | 116.3 | 0.0 | 1.5 | 10.1 | 18.7 |
| | B31 | 59.6 | 95.5 | 131.3 | 2.4 | 29.3 | 48.2 | 68.2 |
| *Alaria esculenta* | B19 | 0.0 | 2.4 | 7.2 | 0.0 | 0.3 | 2.3 | 4.2 |
| | B31 | 19.9 | 75.2 | 130.5 | 0.8 | 20.3 | 40.0 | 59.6 |
| *Agarum clathratum* | B19 | 613.5 | 786.6 | 959.6 | 1,032.9 | 792.2 | 955.2 | 1,118.1 |
| | B31 | 280.2 | 366.4 | 452.6 | 613.6 | 407.3 | 503.6 | 599.9 |
| **Understory (% frequency)** | | | | | | | | |
| *Chondrus crispus* | B17 | 67.5 | 71.8 | 76.0 | 71.3 | 75.3 | 78.1 | 80.9 |
| | B35 | 46.5 | 54.1 | 61.7 | 58.7 | 62.9 | 67.0 | 71.1 |
| | B19 | 0.4 | 4.2 | 7.9 | 2.3 | 6.3 | 8.8 | 11.4 |
| | B31 | 14.2 | 21.0 | 27.8 | 27.0 | 24.6 | 29.1 | 33.5 |
| *Phyllophora /Coccotylus* | B17 | 14.6 | 20.3 | 26.0 | 26.3 | 20.2 | 23.1 | 26.0 |
| | B35 | 11.2 | 19.9 | 28.7 | 21.3 | 16.1 | 19.9 | 23.7 |
| | B19 | 28.5 | 34.0 | 39.6 | 64.3 | 35.2 | 41.6 | 48.0 |
| | B31 | 25.5 | 31.8 | 38.0 | 56.7 | 23.3 | 29.3 | 35.4 |
| *Ptilota serrata* | B17 | 0.0 | 0.8 | 1.6 | 3.7 | 0.5 | 2.0 | 3.5 |
| | B35 | 0.0 | 0.6 | 1.1 | 3.3 | 1.4 | 3.8 | 6.2 |
| | B19 | 28.6 | 35.6 | 42.5 | 30.3 | 33.2 | 38.0 | 42.9 |
| | B31 | 9.3 | 13.1 | 16.8 | 4.3 | 7.7 | 12.1 | 16.6 |

[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] 1991-2009.

[d] LCL = Lower 95% confidence limit.

[e] UCL = Upper 95% confidence limit

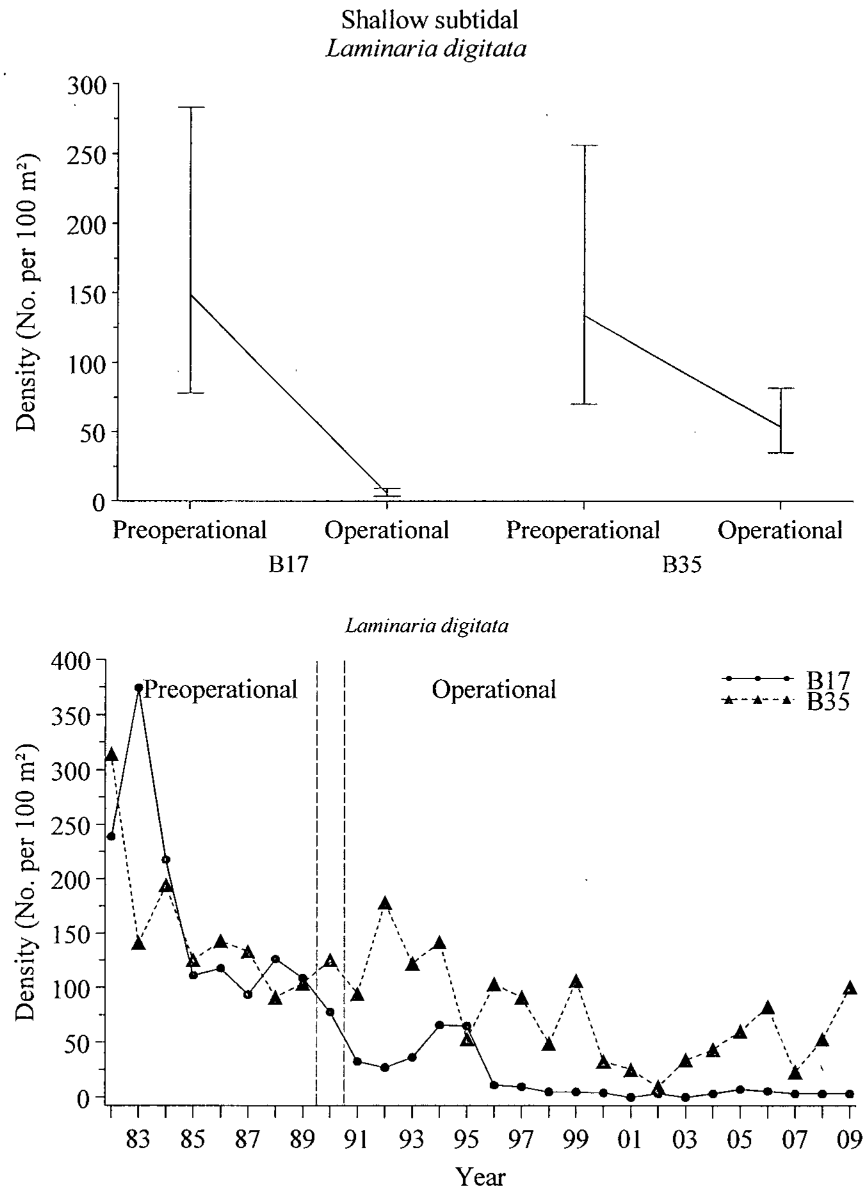
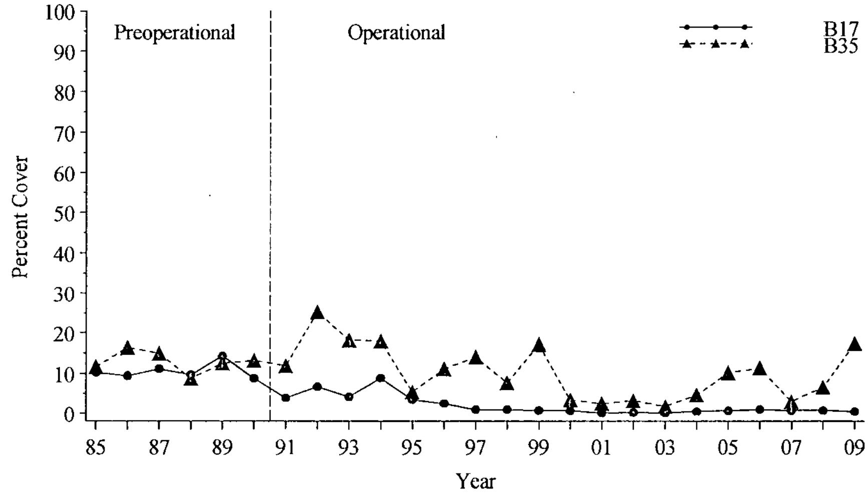



Figure 5-8. Comparison between stations of number of *Laminaria digitata* holdfasts/100 $m^2$ in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density in the shallow subtidal. Seabrook Operational Report, 2009.



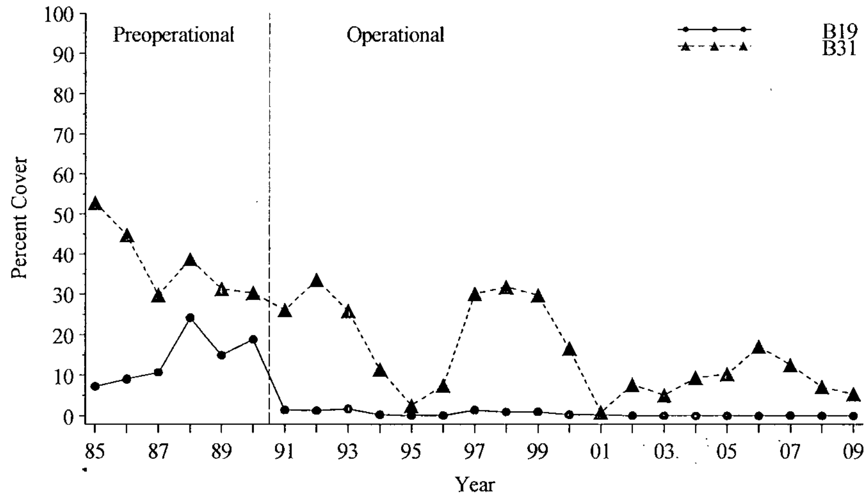




Figure 5-9. Annual mean percent cover of *Laminaria digitata* in the shallow and mid-depth subtidal zones, 1985-2009. Seabrook Operational Report, 2009.

**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, 2009.**

| 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, 2.36 | 3.25 | 0.1936 | |
| (#/100 m$^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.09 | 11.18 | 0.0004* | |
| | | Month(Year)[c] | <0.01 | 0.10 | 0.3773 | |
| | | Station[d] | <0.01 | 0.00 | 0.5000 | |
| | | Preop-Op X Station[e] | 0.21 | 22.37 | >0.0001* | B17Pre B35Pre>B35Op>B17Op |
| | | Station X Year (Preop-Op)[f] | 0.03 | 7.89 | 0.0025* | |
| | | Error | 0.07 | | | |
| *Laminaria digitata* | **Mid-Depth (B19, B31)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 1.3 | 5.66 | 0.2304 | |
| (#/100 m$^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.08 | 9.33 | 0.0011* | |
| | | Month(Year)[c] | 0.02 | 5.81 | 0.0080* | |
| | | Station[d] | 0.71 | 0.72 | 0.1993 | |
| | | Preop-Op X Station[e] | 0.19 | 22.38 | <0.0001* | B31Pre>B19Pre B31Op>B19Op |
| | | Station X Year (Preop-Op)[f] | 0.05 | 17.82 | <0.0001* | |
| | | Error | 0.06 | | | |
| *Saccharina latissima* | **Shallow Subtidal (B17,B35)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 1.26 | 1.08 | 0.4579 | |
| (#/100 m$^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.08 | 3.86 | 0.0247* | |
| | | Month(Year)[c] | 0.05 | 5.61 | 0.0090* | |
| | | Station[d] | 0.02 | 0.01 | 0.4585 | |
| | | Preop-Op X Station[e] | 0.13 | 7.35 | 0.0034* | B35Pre B17Pre B35Op>B17Op |
| | | Station X Year (Preop-Op)[f] | 0.08 | 15.02 | 0.0001* | |
| | | Error | 0.10 | | | |
| *Saccharina latissima* | **Mid-Depth (B19, B31)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 3.8 | 12.91 | 0.0249* | Preop>Op |
| (#/100 m$^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.12 | 8.68 | 0.0016* | |
| | | Month(Year)[c] | 0.07 | 7.51 | 0.0031* | |
| | | Station[d] | 0.21 | 1.84 | 0.0873 | |
| | | Preop-Op X Station[e] | 0.01 | 0.82 | 0.1827 | |
| | | Station X Year (Preop-Op)[f] | 0.05 | 4.92 | 0.0133* | |
| | | Error | 0.14 | | | |

(continued)

**Table 5-11. (Continued)**

| Parameter | Depth Zone (Stations) | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|---|
| *Alaria esculenta* | **Mid-Depth (B19, B31)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 1.04 | 0.64 | 0.5665 | |
| (#/100 $m^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.01 | 0.12 | 0.3651 | |
| | | Month(Year)[c] | 0.01 | 0.15 | 0.3474 | |
| | | Station[d] | 0.75 | 1.45 | 0.1141 | |
| | | Preop-Op X Station[e] | 0.09 | 4.38 | 0.0182* | B31Pre>B31Op> <u>B19Op B19Pre</u> |
| | | Station X Year (Preop-Op)[f] | 0.14 | 24.94 | <0.0001* | |
| | | Error | 0.15 | | | |
| *Agarum clathratum* | **Mid-Depth (B19, B31)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 29 | 3.64 | 0.0663 | |
| (#/100 $m^2$) | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| Data log (X+1) transformed | | Year (Preop-Op)[b] | 0.02 | 11.91 | 0.0003* | |
| | | Month(Year)[c] | <0.01 | 0.72 | 0.1975 | |
| | | Station[d] | 0.05 | 4.14 | 0.0209* | B19>B31 |
| | | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4997 | |
| | | Station X Year (Preop-Op)[f] | 0.01 | 5.00 | 0.0129* | |
| | | Error | 0.02 | | | |
| **Understory (% frequency)** | **Shallow Subtidal (B17, B35)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *Chondrus crispus* | | Preop-Op[a] | 1, 4.66 | 10.88 | 0.02* | Op>Preop |
| Data Arcsin √Y transformed | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| | | Year (Preop-Op)[b] | 8.83 | 4.02 | 0.0225* | |
| | | Month(Year)[c] | 9.70 | 3.03 | 0.0408* | |
| | | Station[d] | 34.29 | 2.52 | 0.0562 | |
| | | Preop-Op X Station[e] | 0.50 | 0.08 | 0.3876 | |
| | | Station X Year (Preop-Op)[f] | <0.01 | <0.01 | 0.4998 | |
| | | Error | 35.96 | | | |
| *Chondrus crispus* Data Arcsin √Y transformed | **Mid-Depth) (B19, B31** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 26 | 6.29 | 0.0187* | Op>Preop |
| | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| | | Year (Preop-Op)[b] | 19.51 | 8.45 | 0.0018* | |
| | | Month(Year)[c] | 8.73 | 1.71 | 0.0960 | |
| | | Station[d] | 155.25 | 5.09 | 0.0120 * | 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 | 46.92 | | | |
| *Phyllophora/Coccotylus* | **Shallow Subtidal (B17,B35)** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | | Preop-Op[a] | 1, 25.1 | 0.11 | 0.7418 | |
| Arcsin √Y transformed | | **Random Effects** | **Estimate[j]** | $\chi^2$ | p | |
| | | Year (Preop-Op)[b] | 5.51 | 0.43 | 0.2549 | |
| | | Month(Year)[c] | 14.47 | 2.26 | 0.0665 | |
| | | Station[d] | 2.25 | 0.54 | 0.2313 | |
| | | Preop-Op X Station[e] | <0.01 | <0.01 | 0.4993 | |
| | | Station X Year (Preop-Op)[f] | 9.57 | 1.49 | 0.1112 | |
| | | Error | 57.00 | | | |

(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, 1.82 | 0.09 | 0.8000 | |
| Arcsin √Y transformed | | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | | Year (Preop-Op)[b] | 18.56 | 3.33 | 0.0340* | |
| | | Month(Year)[c] | 12.58 | 3.00 | 0.0417* | |
| | | Station[d] | 6.31 | 0.14 | 0.3533 | |
| | | Preop-Op X Station[e] | 7.74 | 1.53 | 0.1082 | |
| | | Station X Year (Preop-Op)[f] | 16.35 | 5.64 | 0.0089* | |
| | | Error | 42.52 | | | |
| *Ptilota serrata* | **Shallow** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| Data | **Subtidal** | Preop-Op[a] | 1, 7.45 | 1.63 | 0.2403 | |
| Arcsin √Y transformed | **(B17,B35)** | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | | Year (Preop-Op)[b] | 11.58 | 5.93 | 0.0074* | |
| | | Month(Year)[c] | <0.01 | <0.01 | 0.5000 | |
| | | Station[d] | <0.01 | <0.00 | 0.4999 | |
| | | Preop-Op X Station[e] | 1.41 | 1.00 | 0.1582 | |
| | | Station X Year (Preop-Op)[f] | <0.01 | <0.00 | 0.5000 | |
| | | Error | 42.87 | | | |
| *Ptilota serrata* | **Mid-Depth** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| Data | **(B19, B31)** | Preop-Op[a] | 1, 4.89 | 0.01 | 0.9249 | |
| Arcsin √Y transformed | | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p** | |
| | | Year (Preop-Op)[b] | 19.17 | 6.79 | 0.0046* | |
| | | Month(Year)[c] | 15.06 | 5.06 | 0.0122* | |
| | | Station[d] | 159.86 | 3.30 | 0.0346* | B19>B31 |
| | | Preop-Op X Station[e] | 1.67 | 0.45 | 0.2516 | |
| | | Station X Year (Preop-Op)[f] | 3.20 | 0.49 | 0.2417 | |
| | | Error | 36.79 | | | |

[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 = 1991-2009. 1990 is excluded from data base which includes all three seasons.
[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 $H_o$: Estimate(i)= Estimate(j).
* = significant (p ≤ 0.05)

**Table 5-12. Results of Segmented Regression Analysis on the Density (no./100 m$^2$) 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, 2009.**

| Parameter | Station | Comparisons Based on Breakpoints[a] | Period 1 Slope | Period 2 Slope | Entire Period | R- Square (Entire Period) |
|---|---|---|---|---|---|---|
| **Kelp** | | | | | | |
| *Laminaria digitata* | B17 | 1982-1991>1992-2009*** | Neg. ** | Neg. ** | Neg. *** | 0.62 |
| (no./100 m$^2$) | B35 | 1982-2001>2002-2009** | Neg. *** | NS | Neg. *** | 0.53 |
| | B19 | 1978-1988>1989-2009** | NS | Neg.** | Neg. *** | 0.33 |
| | B31 | 1978-2001>2002-2009*** | Neg.*** | NS | Neg. *** | 0.69 |
| *Saccharina latissima* | B17 | 1982-1998>1999-2009*** | NS | NS | Neg. *** | 0.56 |
| (no./100 m$^2$) | B35 | 1982-2009 | | | NS | <0.01 |
| *Alaria esculenta* | B19 | 1978-1984>1985-2009 NS | NS | NS | NS | 0.02 |
| (no./100 m$^2$) | B31 | 1978-1981>1982-2009*** | NS | Neg.* | Neg. ** | 0.23 |

[a] As identified using segmented regression. Differences in means between periods were 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)

a significant decline during the entire 28-year study period (Table 5-12), a further indication that the decline was regional, not a localized effect of the operation of Seabrook Station.

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 (Figure 5-9). 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).

*Membranipora membranacea* is an introduced encrusting bryozoan that may have a negative effect on kelp (Lambert et. al. 1992, Saunders and Metaxas 2009). In 2009 the percent coverage of *M. membranacea* on single blades of *Laminaria digitata* and *Saccharina latissima* from the general algae collections in the shallow subtidal zone ranged from 0% to 10%. For *Agarum clathratum* it ranged from <5% in May to 75% in November.

In the mid-depth subtidal zone, densities of *Laminaria digitata* in 2009 at Stations B19 and B31 were below the preoperational and operational confidence limits (Table 5-10, Figure 5-10). No *L. digitata* were observed at Station B19 in 2009 for the second consecutive year, and densities have been below 10 per 100m$^2$ for a decade. The decline between periods at the farfield station (B31) 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). The farfield

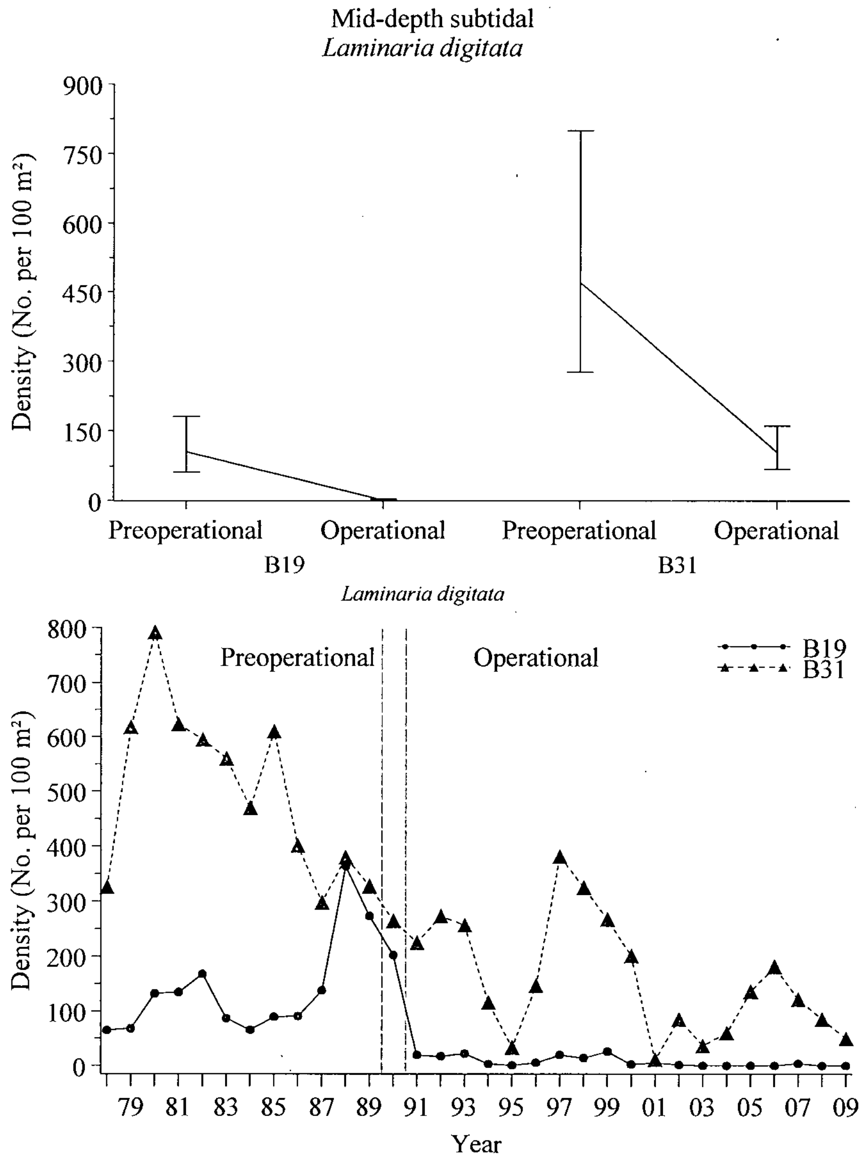



Figure 5-10. Comparison between stations of number of *Laminaria digitata* holdfasts/100 $m^2$ in the mid-depth subtidal zone during the preoperational (1978-1989) and operational (1991-2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year. Seabrook Operational Report, 2009.

station typically had higher density than the nearfield station, an indication that it is a better habitat for *L. digitata*. Segmented regression analysis at Station B19 indicated that density of *L. digitata* was significantly higher from 1978 through 1988 compared to 1989 through 2009 (Table 5-12). There was a significant negative trend in the later period indicating that the decline at Station B19 began prior to plant operation. At Station B31, density was significantly higher from 1978 through 2001 compared to 2002 through 2009, and there was a significant negative trend in the earlier period. The significant negative trend at Station B31 from 1978 through 2001 (Table 5-12) is further evidence of a regional decline not due to the operation of Seabrook Station. In the mid depth zone, both stations had a significant decline during the entire 32-year study period (Table 5-12), a further indication that the decline was regional, not a localized effect of the operation of Seabrook Station. The regional decline has also been reported by Steneck (1997).

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 2009. 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, increased to over 15% by 2006, and gradually decreased to 5% in 2009 (Figure 5-9).

The percent coverage of the encrusting bryozoan *Membranipora membranacea* on *Laminaria digitata* and *Saccharina latissima* blades in the qualitative, general algae collections from the mid depth zone in 2009 was low, and ranged from 0% - <5%. For *Agarum clathratum* it ranged from <5% in May to 50% in November at Stations B19 and B31.

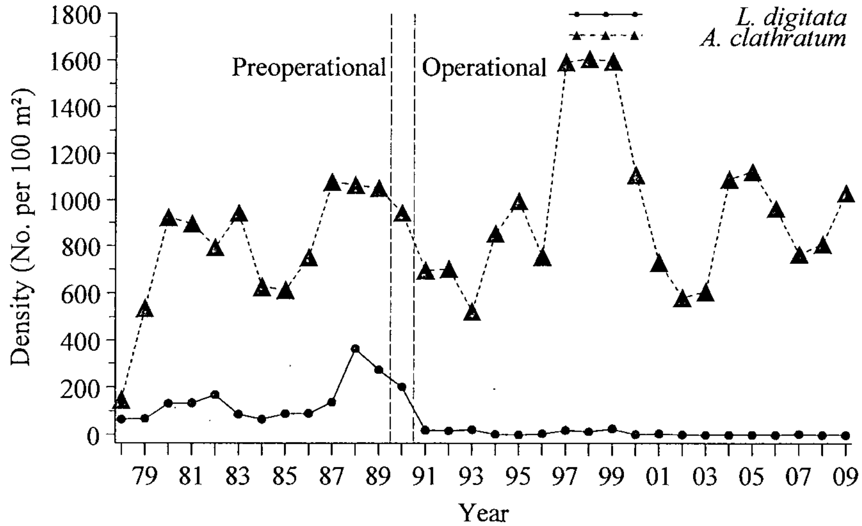
***Agarum clathratum***

*Agarum clathratum* is a kelp of deep water and northern distribution (northern Massachusetts to the high arctic) 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 (dwarf form, Taylor 1957) and the shallow subtidal to 50m or more (Sears 2002). *Agarum clathratum* was generally the numerically dominant kelp at the mid-depth Stations B19 and B31 from 1988 through 2009 (Figure 5-11). Mean densities of *A. clathratum* were greater in the operational period compared to the preoperational period at nearfield Station B19 and at farfield Station B31 (Table 5-10). Densities observed in 2009 were above the operational and preoperational period means at both stations. 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). Competition between *Laminaria digitata* and *Agarum clathratum* may also be contributing to the decline of *L. digitata* at Station B19.

***Saccharina latissima***

*Saccharina latissima* occurs from northern Massachusetts to the high arctic and is typically found growing on rocks (Taylor 1957). It typically occurs in low tide pools to 20m, but offshore of Long Island it occurs at 30m (Sears 2002). At the shallow subtidal stations, density of *Saccharina latissima* in 2009 increased at Station B17 and tripled at Station B35 (Figure 5-12, Table 5-10). Average density during the operational period 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 1998 was higher than the period from 1999 through 2009. There was no significant trend found for either period identified with segmented regression analysis, while a significant negative trend occurred for the entire 28-year study period at Station B17 (Table 5-12). There were no significant break-points and no significant trends at Station B35. Densities have been highly variable at both stations and the peak densities in the time series have occurred during the operational period. Recently, densities peaked in 2005, declined for two years, and increased once again in 2009 at both stations. Densities have been consistently lower at the nearfield station compared to the farfield station since 1994.

Station B19




Station B31

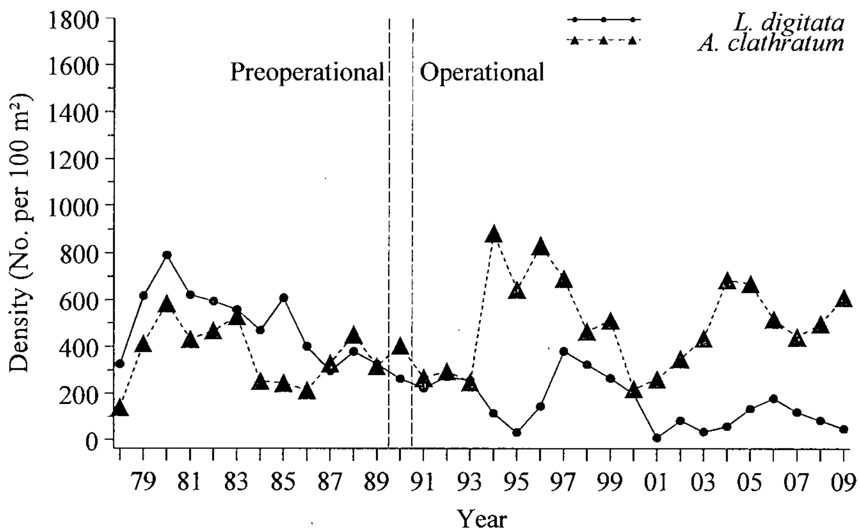



Figure 5-11. Annual mean densities (number per 100 m$^2$) of *Laminaria digitata* and *Agarum clathratum* in the mid-depth subtidal zone (Stations B19 and B31), 1978-2009. Seabrook Operational Report, 2009.

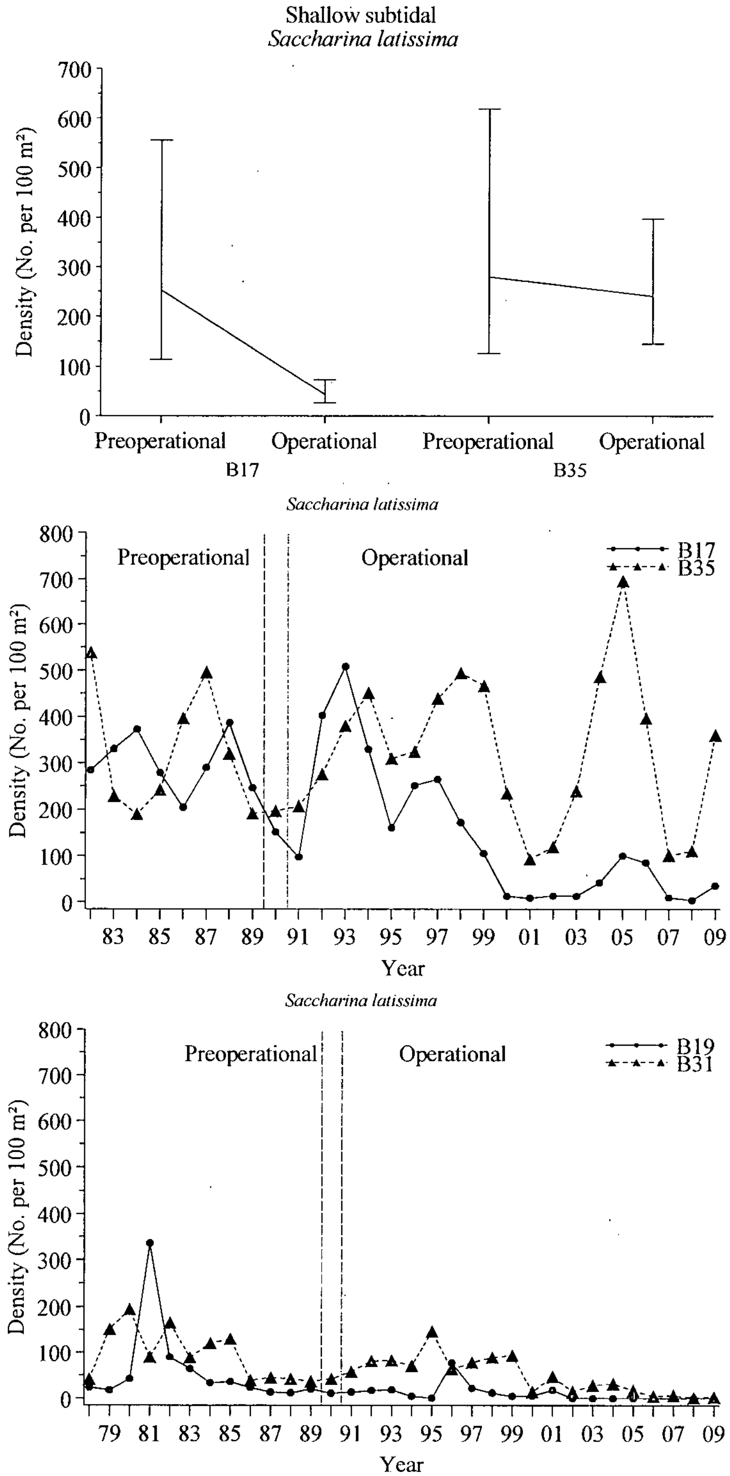



Figure 5-12. Comparison between stations of annual mean density of *Saccharina latissima* in the shallow subtidal zone during the preoperational (1982-1989) and operational (1991-2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and annual mean density each year in the shallow and mid-depth zones. Seabrook Operational Report, 2009.

In the mid-depth subtidal zone, *Saccharina latissima* mean densities were lower than at the shallow subtidal stations (Table 5-10), an indication that the mid-depth zone is not its preferred habitat. Densities in 2009 were below both the preoperational and operational confidence limits at both stations, and at Station B19, no individuals were collected for the eighth consecutive year (Figure 5-12). The ANOVA indicated that density of *Saccharina latissima* was significantly higher in the pre-operational period compared to the operational period (Table 5-11). No difference was found between stations, and the relationship between stations was consistent between periods, as indicated by the non-significant interaction term.

### *Alaria esculenta*

*Alaria esculenta* occurs from Cape Cod (northern Massachusetts) to the high arctic (Sears 2002). It prefers subtidal sites with a strong surge (Sears 2002), and is a minor component of the mid-depth kelp assemblage in the study area. The annual mean densities were historically lower at nearfield Station B19 (12.2 m) than at farfield Station B31 (9.4 m) (Figure 5-13), most likely due to habitat differences between the stations. In 2009, the density at Station B19 was zero for the fourth consecutive year, and at Station B31 the density increased from 0 to 0.8 (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 had extremely low densities in the preoperational period.

### *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 nondestructive 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). The extensive turfs of *C. crispus* occurred in the shallow subtidal along with *Phyllophora/ Coccotylus*. In the mid-depth zone at nearfield Station B19 (12.2 meters) *Phyllophora/ Coccotylus* and *Ptilota serrata* were most abundant, while at farfield Station B31 (9.4 meters) *Chondrus crispus* and *Phyllophora/ Coccotylus* were most abundant (Table 5-10).

### *Chondrus crispus*

*Chondrus crispus* occurs from New Jersey (Taylor 1957) to southern Labrador in the Strait of Belle Isle (Sears 2002). Overall, relationships in patterns of percent frequency of occurrence of understory taxa between depth zones and between nearfield-farfield stations remained remarkably consistent over the study period (Table 5-10) and paralleled patterns in biomass. *Chondrus crispus* was more abundant at the shallow subtidal stations than the mid-depth stations. It was the least abundant at nearfield Station B19, the deepest of the four stations that was located very close to the extinction depth of *Chondrus*. In the shallow subtidal zone, annual means at both stations tracked each other consistently (Figure 5-14). The percent frequency of occurrence of *Chondrus crispus* in 2009 in both the shallow subtidal and mid-depth zones was within the preoperational confidence limits at both stations (Table 5-10). In both depth zones, there was a significantly higher frequency of occurrence during the operational period than the preoperational period (Table 5-11), in contrast to biomass patterns, where there was no significant difference. There were no significant differences between stations in the shallow subtidal zone, but in the

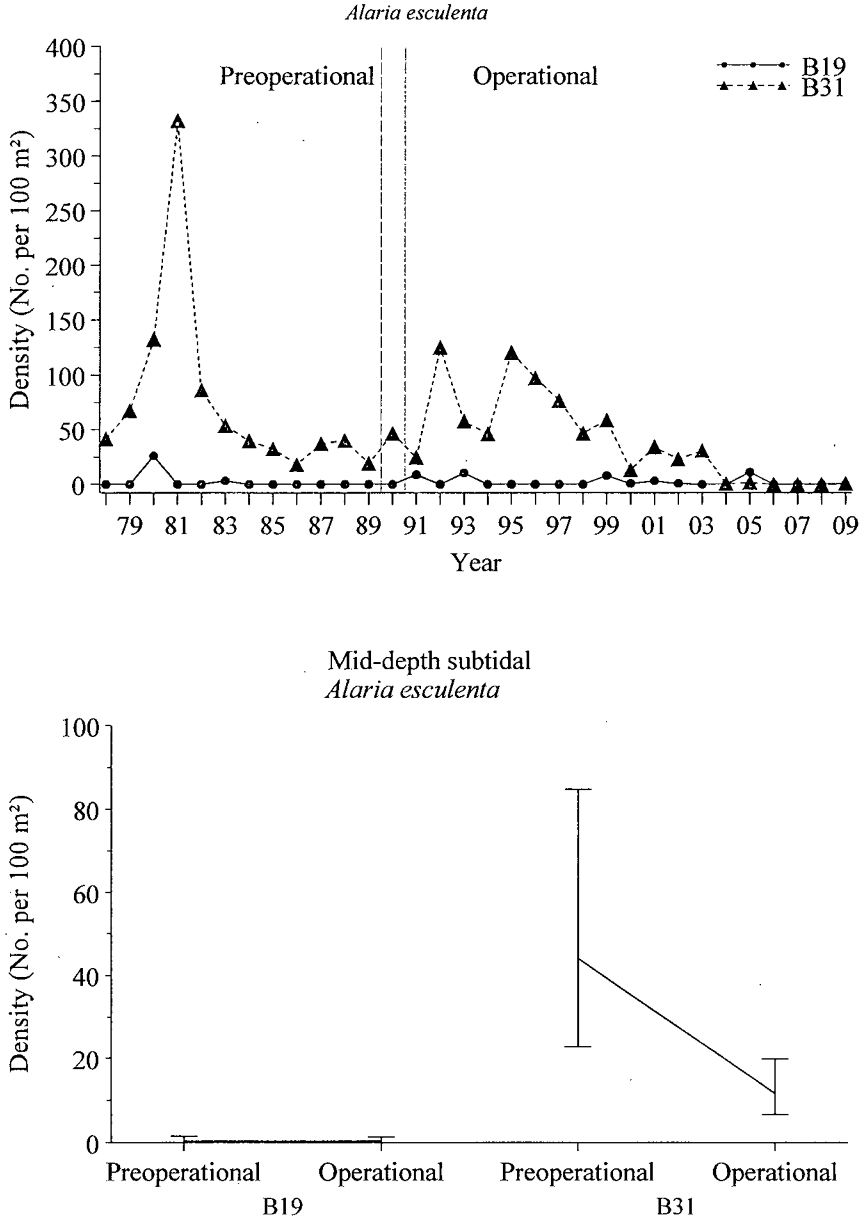



Figure 5-13. Comparison between stations of number of *Alaria esculenta* holdfasts/100 $m^2$ in the mid-depth zone during the preoperational (1978-1989) and operational (1991-2009) periods for the significant interaction term (Preop-Op X Station) of the ANOVA model, and the annual mean density in non-destructive transects in the mid-depth zone (Stations B19 and B31). Seabrook Operational Report, 2009.

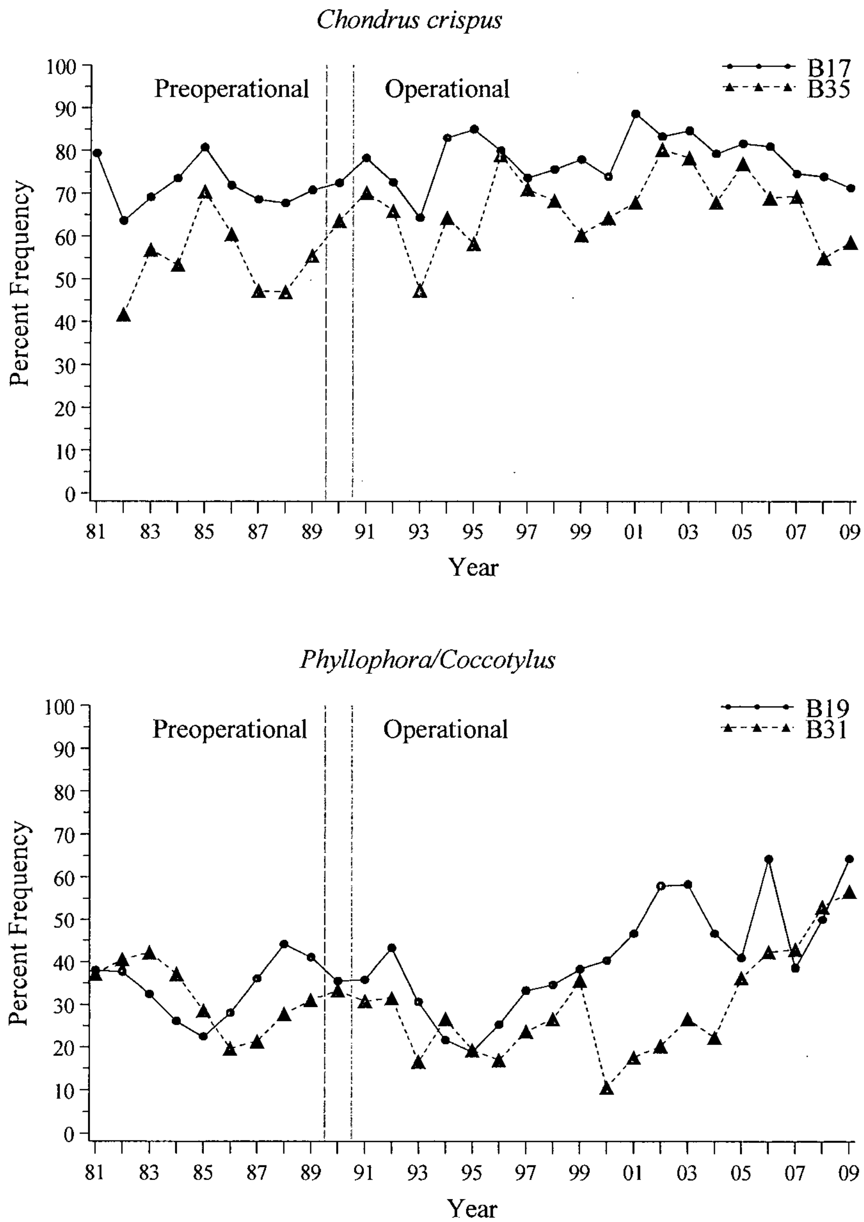



Figure 5-14. Annual mean percent frequency of *Chondrus crispus* observed at non-destructive transects in the shallow subtidal zone (Stations B17 and B35) and *Phyllophora/Coccotylus* in the mid-depth zone (Stations B19 and B31) from 1981-2009. Seabrook Operational Report, 2009.

mid-depth zone percent frequency of occurrence was significantly greater at Station B31. The interaction terms in both depth zones were not significant indicating that percent frequency of occurrence has remained consistent before and after the operation of Seabrook Station.

***Phyllophora/Coccotylus***

*Phyllophora pseudoceranoides* is perennial and occurs in scattered or extensive beds on rock and in areas of shifting sand within the sublittoral to 20 m (Sears 2002). *Coccotylus truncata* is perennial and occurs in the sublittoral to 40 m on rock or other hard substrate (Sears 2002). Both species occur from New Jersey to the lower St. Lawrence (Taylor 1957). The *Phyllophora/Coccotylus* complex was common at both the shallow subtidal and mid-depth zones. The preoperational and operational period means were similar to each other and the annual mean for 2009 was higher than both period means at the shallow subtidal stations, B17 and B35. At the mid-depth zone, the annual means at both nearfield and farfield stations tracked each other fairly closely from 1981 to 2000, when Station B31 had a sharp decrease followed by relatively lower values through 2004 (Figure 5-14). In the mid-depth zone the frequency of occurrence of *Phyllophora/ Coccotylus* in 2009 reached the peak for the time series at both stations. 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). No effect from the operation of Seabrook Station was evident.

***Ptilota serrata***

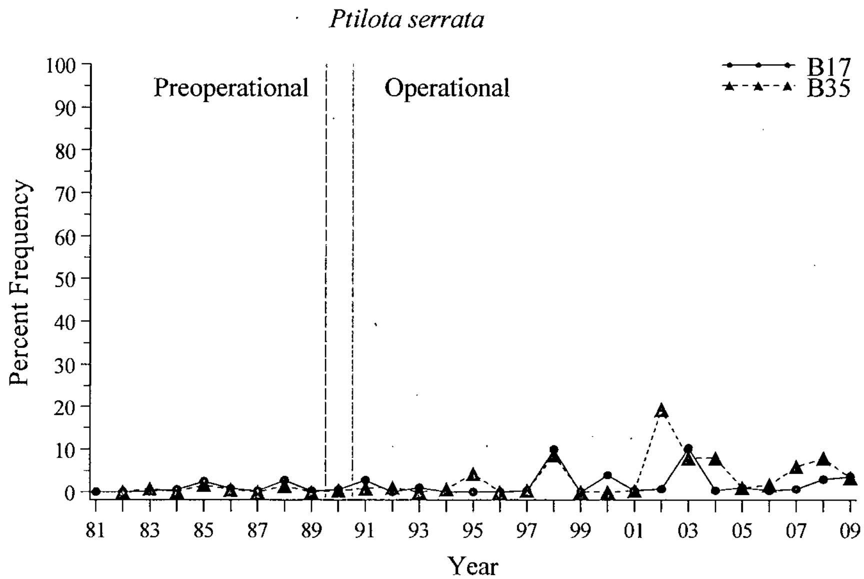
*Ptilota serrata* occurs from Cape Cod to the high arctic (Sears 2002). In the Gulf of Maine, *Ptilota serrata* is perennial and a subdominant understory alga in the shallow sublittoral, but becomes dominant beyond 10 m. It often forms monospecific turfs at the extinction depth of foliose algae to 43 m (Sears 2002). The frequency of occurrence of *Ptilota serrata* in the shallow subtidal zone was typically lower than the other common understory species (Table 5-10, and Figure 5-15). In 2009, it was above the upper confidence limits for the preoperational period at the shallow subtidal stations (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 (Figure 5-15). The nearfield station (deepest station at 12.2 m, Appendix Table 5-4) has always had a higher frequency of occurrence than the shallower farfield station (9.4 m) (Figure 5-15). The frequency of occurrence in 2009 was within the confidence limits of the preoperational period and below the confidence limits of the operational period at Station B19 (Table 5-10). At Station B31, 2009 values were below the confidence limits of both periods (Table 5-10). Overall, percent frequency of occurrence was significantly higher at Station B19 than at Station B31, as would be expected due to the habitat differences (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).

### 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 relationship among stations was similar with marginally higher species richness at B19 in comparison to other stations. Mean numbers of taxa at all stations have been from 12 to 20% lower during the operational period as compared to the preoperational period (Table 5-13). The overall



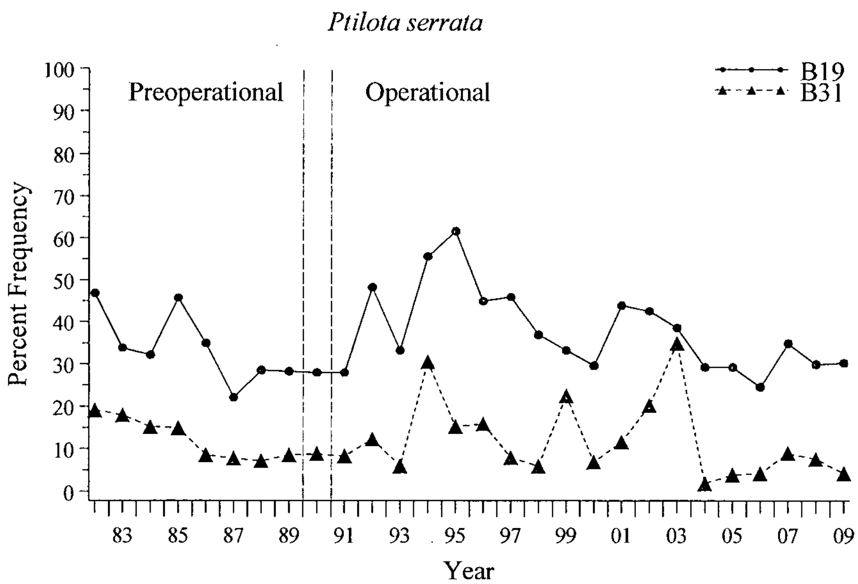




Figure 5-15. Annual mean percent frequency of *Ptilota serrata* observed at non-destructive transects in the shallow and mid-depth zones. Seabrook Operational Report, 2009.

**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 2008 Means. Seabrook Operational Report, 2009.**

| | | Preoperational[a] | | | 2009 | Operational[b] | | |
|---|---|---|---|---|---|---|---|---|
| Depth Zone | Station | LCL[c] | Mean | UCL[d] | Mean | LCL | Mean | UCL |
| **No. of Taxa[e] (per 0.0625 $m^2$)** | | | | | | | | |
| Shallow subtidal | B17 | 38 | 41 | 45 | 29 | 32 | 35 | 38 |
| | B35 | 39 | 42 | 46 | 26 | 31 | 34 | 38 |
| Mid-depth | B19 | 42 | 48 | 54 | 28 | 34 | 38 | 43 |
| | B31 | 35 | 40 | 45 | 28 | 31 | 35 | 39 |
| **Total Faunal Density[f] (no. per $m^2$)** | | | | | | | | |
| Shallow subtidal | B17 | 16,955 | 22,835 | 30,754 | 12,414 | 14,772 | 18,747 | 23,790 |
| | B35 | 19,173 | 28,371 | 41,981 | 6,040 | 13,842 | 18,788 | 25,501 |
| Mid-depth | B19 | 8,343 | 12,562 | 18,914 | 4,051 | 7,497 | 10,160 | 13,769 |
| | B31 | 7,764 | 15,846 | 32,344 | 6,264 | 8,835 | 10,982 | 13,650 |

[a] Preoperational period extends through 1989 (Stations B17, B19, B31: 1978-1989; Station B35: 1982-1989).
[b] Operational period: 1990-2009.
[c] LCL = Lower 95% confidence limit.
[d] UCL = Upper 95% confidence limit.
[e] Arithmetic mean
[f] Geometric mean

decline in species richness occurred around 1995 (Figure 5-16).

In 2009, the annual mean number of macrofaunal taxa was the same as the previous year at the shallow nearfield station (B17) and lower than the previous year at the shallow farfield station (B35; Figure 5-16). Overall, species richness at the shallow subtidal stations has been lower during the operational period than in the preoperational period. Mean values during the operational period were below the lower confidence limits of the average number of taxa during the preoperational period (Table 5-13). When the shallow subtidal stations were examined together using analysis of variance (ANOVA), the mean number of taxa was significantly lower during the operational 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.

Species richness during 2009 was lower than the previous year at the mid-depth nearfield station (B19), and comparable to the previous year at the farfield station (B31; Figure 5-16). On average, 28 species per sample were collected at both mid-depth stations for 2009, and these values were below the lower confidence limits of the average number of taxa during the preoperational and operational periods (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 the shallow nearfield station (B17) in 2009 was slightly higher than the previous year, but below the lower confidence limits of the mean faunal

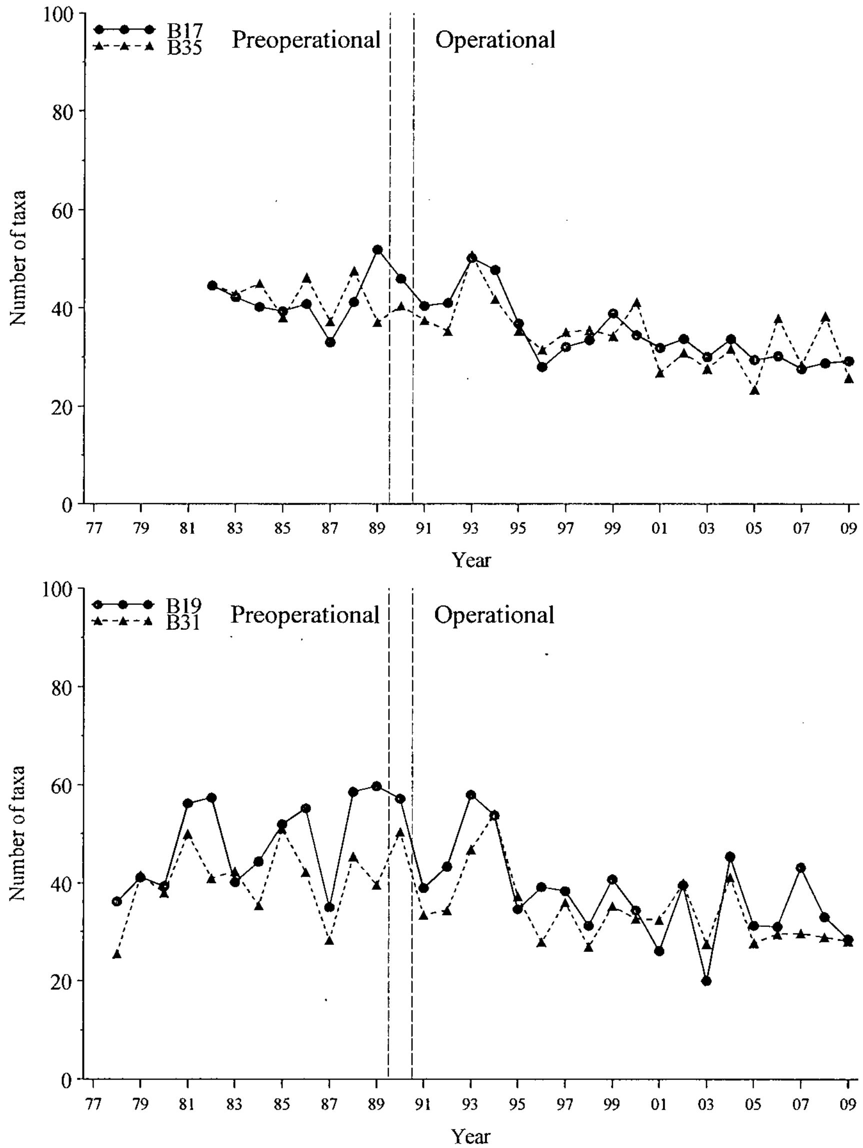
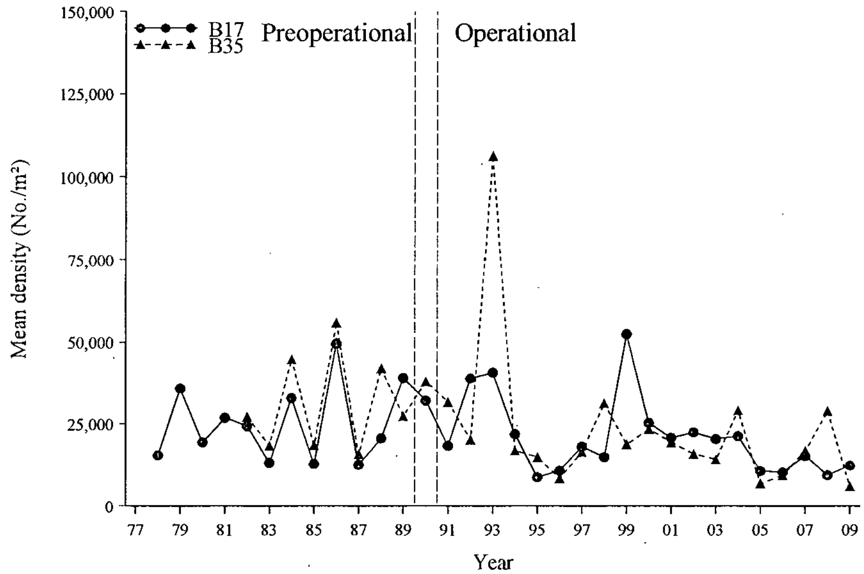



Figure 5-16. Annual arithmetic mean number of macrofaunal taxa (per 0.0625 $m^2$) in the shallow subtidal (B17, B35) and mid-depth (B19, B31) stations during the preoperational and operational (1991-2009) periods, and the comparison between stations of mean number of macrofaunal taxa in the mid-depth zone during the preoperational and operational periods. Seabrook Operational Report, 2009.

**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 (1982-2009) and Mid-Depth (1978-2009) Stations. Seabrook Operational Report, 2009.**

| Parameter | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| **Number of Taxa** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 26.3 | 9.47 | 0.0048* | Preop>Op |
| Shallow | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **P** | |
| Subtidal | Year (Preop-Op)[b] | 24.43 | 14.13 | 0.0001* | |
| (B17, B35) | Station[d] | 0.00 | 0.00 | 0.5000 | |
| (Data not | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4999 | |
| transformed) | Station X Year (Preop-Op)[f] | 7.10 | 7.40 | 0.0033* | |
| | Error | 34.64 | | | |
| **Number of Taxa** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 6.0 | 4.04 | 0.0910 | |
| Mid-depth | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **P** | |
| (B19, B31) | Year (Preop-Op)[b] | 59.74 | 26.07 | <0.0001* | |
| (Data not | Station[d] | 13.12 | 0.77 | 0.1903 | |
| transformed) | Preop-Op X Station[e] | 3.77 | 1.48 | 0.1121 | |
| | Station X Year (Preop-Op)[f] | 6.59 | 2.88 | 0.0446* | |
| | Error | 58.24 | | | |
| **Total Density** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 26.2 | 2.07 | 0.1618 | |
| Shallow | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **p** | |
| Subtidal | Year (Preop-Op)[b] | 0.04 | 12.23 | 0.0002* | |
| (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 | 14.37 | 0.0001* | |
| | Error | 0.05 | | | |
| **Total Density** | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 29.6 | 1.91 | 0.1771 | |
| Mid-depth | **Random Effects** | **Estimate[j]** | **$\chi^2$** | **p** | |
| (B19, B31) | Year (Preop-Op)[b] | 0.03 | 2.66 | 0.0515 | |
| (Data log (X+1) | Station[d] | 0.00 | 0.00 | 0.4999 | |
| transformed) | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0.05 | 41.55 | <0.0001* | |
| | Error | 0.07 | | | |

[a] Compares Preop to Op, regardless of station; years included in each station grouping: Op years = 1990-2009 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).



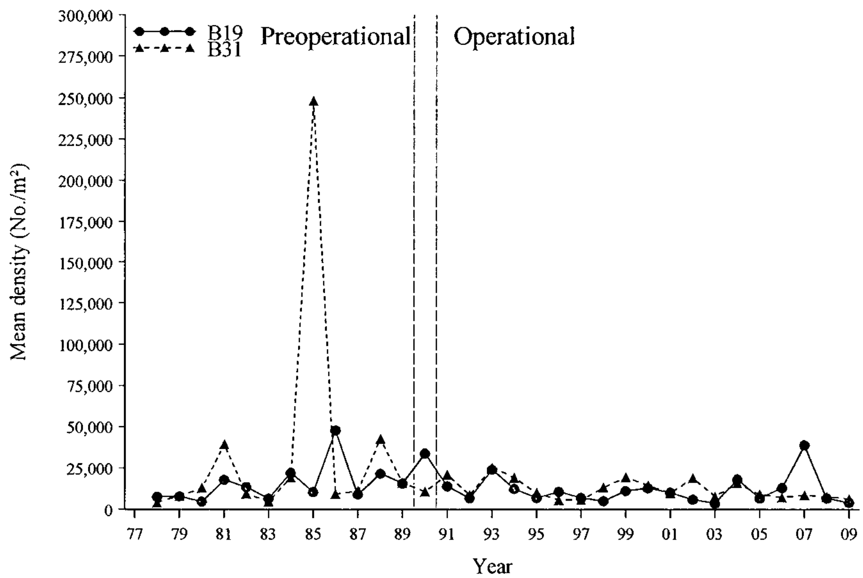




Figure 5-17. Annual geometric mean total density of macrofauna (no./$m^2$) in the shallow subtidal (B17, B35) and mid-depth (B19, B31) stations during the preoperational and operational (1991-2009) periods. Seabrook Operational Report, 2009.

density for both the preoperational and operational periods (Figure 5-17, Table 5-13). Mean faunal density at the shallow farfield station (B35) during 2009 was well below the previous year and at the lowest level reported in the time series. These relatively low density values reflect the low numbers of Mytilidae collected during 2009 (see section 5.3.2.2.). 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, overall, any 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 mid-depth nearfield station (B19), mean density in 2009 was slightly lower than the previous year and below the lower confidence limits for both the preoperational and operational periods (Figure 5-17, Table 5-13). At the farfield station (B31), mean density in 2009 was comparable to the previous year and was also below the lower confidence limits for both periods. Analysis of variance indicated that faunal density at Stations B19 and B31 was not significantly different between 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 5-5). In total, 339 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 (B17; B19), and at farfield stations further north (B35; B31). The results of multivariate analyses would be consistent with a power plant-induced impact to the macrofaunal community if the operational years' collections (1990-2008) 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 28-year study period discriminated between three highly similar assemblages (Figure 5-18). The average similarity between the main groupings was nearly 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 0.19, the two-dimensional plot provided useful information, revealing a gradual continuum of subtle differences between assemblages identified by the cluster analysis. Nonetheless, 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.

Group 1 contained most collections from both shallow stations (B17, B35) through 1995. The herbivorous gastropod *Lacuna vincta* was the most abundant species, followed by Mytilidae spat, the isopod *Idotea phosphorea*, and the amphipods *Pontogeneia inermis* and *Jassa marmorata* (Table 5-15). Group 1 was distinguished by having higher than average densities of the amphipod *Pontogeneia inermis* and no occurrences of the gastropod *Mitrella lunata*. Most collections from both stations after 1995 were classified into Group 2 (Figure 5-18). *L. vincta* was again the numerical dominant, followed by *I. phosphorea* and Mytilidae spat (Table 5-15). Mean numbers of Mytilidae spat were lower 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, an outlier was identified by the cluster analysis (Figure 5-18). The 2005 collection at Station B35 differed from all other samples in having comparatively low numbers of dominant taxa such as *L. vincta*, Mytilidae, *I. phosphorea*, and *J. marmorata*. Also in contrast, the

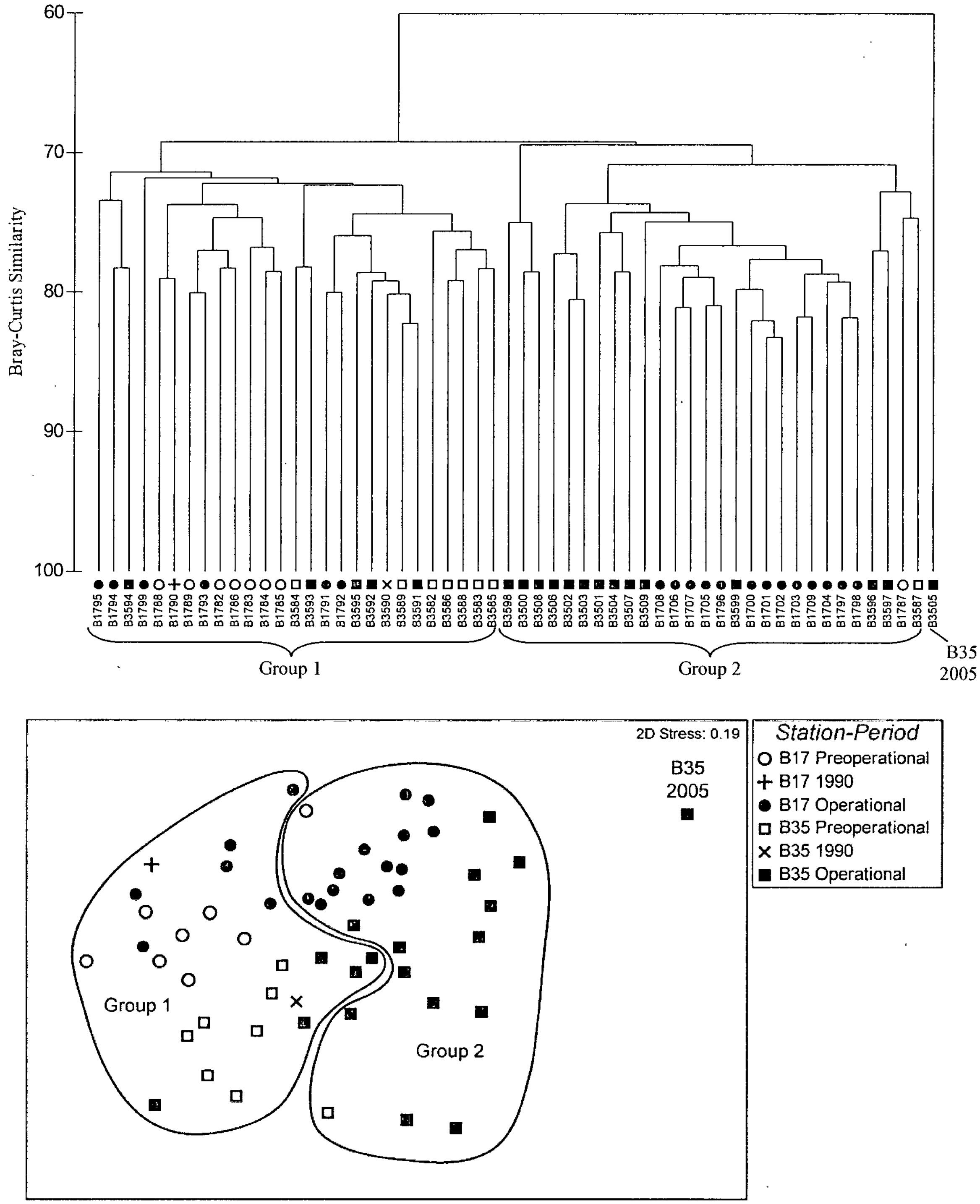



Figure 5-18. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August benthic macrofauna collections from shallow subtidal Stations (B17 and B35), 1982-2009. Seabrook Operational Report, 2009.

**Table 5-15. Geometric Mean Density (no./m$^2$) of Dominant Macrofaunal Taxa[a] in Groups formed by Cluster Analysis. Seabrook Operational Report, 2009.**

| Shallow Subtidal Zone (Stations B17, B35) Taxa [a] | Group 1 | | | Group 2 | | | B35 2005 |
|---|---|---|---|---|---|---|---|
| | LCL | Mean | UCL | LCL | Mean | UCL | Mean |
| *Lacuna vincta* | 4592 | 6279 | 8584 | 3687 | 4540 | 5590 | 1528 |
| Mytilidae | 1953 | 3104 | 4932 | 807 | 1268 | 1992 | 587 |
| *Idotea phosphorea* | 1481 | 1837 | 2278 | 1041 | 1311 | 1651 | 299 |
| *Pontogeneia inermis* | 1114 | 1432 | 1840 | 317 | 467 | 686 | 249 |
| *Jassa marmorata* | 591 | 971 | 1596 | 531 | 844 | 1342 | 23 |
| *Caprella septentrionalis* | 380 | 510 | 686 | 177 | 231 | 302 | 633 |
| *Idotea balthica* | 265 | 488 | 898 | 119 | 209 | 366 | 4 |
| *Calliopius laeviusculus* | 344 | 478 | 665 | 107 | 182 | 310 | 33 |
| Asteriidae | 269 | 451 | 756 | 195 | 321 | 528 | 16 |
| *Ischyrocerus anguipes* | 222 | 364 | 598 | 42 | 70 | 116 | 10 |
| *Caprella* sp. | 66 | 107 | 175 | 21 | 35 | 56 | 165 |
| *Ampithoe rubricata* | 11 | 28 | 72 | 66 | 123 | 228 | 113 |
| *Balanus crenatus* | 1 | 1 | 2 | 0 | 1 | 2 | 297 |
| *Mitrella lunata* | – | – | – | 1 | 4 | 10 | 302 |

| Mid-Depth Zone (Stations B19, B31) Taxa [a] | Group 1 | | | Group 2 | | | Group 3 | | | B19 01/03/09 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | LCL | Mean | UCL | LCL | Mean | UCL | LCL | Mean | UCL | Mean | Mean |
| Mytilidae | 2242 | 3948 | 6953 | 755 | 1616 | 3459 | 968 | 1918 | 3799 | 186 | 244 |
| *Pontogeneia inermis* | 552 | 810 | 1190 | 633 | 958 | 1449 | 100 | 191 | 364 | 1257 | 1391 |
| *Anomia* sp. | 500 | 732 | 1072 | 160 | 345 | 741 | 424 | 579 | 790 | 21 | 195 |
| *Caprella septentrionalis* | 378 | 543 | 781 | 285 | 529 | 980 | 296 | 454 | 696 | 737 | 238 |
| *Hiatella* sp. | 294 | 444 | 670 | 33 | 75 | 167 | 391 | 536 | 734 | 14 | 65 |
| *Lacuna vincta* | 224 | 312 | 433 | 120 | 201 | 338 | 738 | 1105 | 1654 | 181 | 217 |
| Asteriidae | 89 | 141 | 221 | 137 | 244 | 435 | 13 | 30 | 68 | 130 | 212 |
| *Achelia spinosa* | 33 | 63 | 120 | 89 | 145 | 236 | 2 | 3 | 4 | 83 | 36 |
| *Onchidoris* sp. | 13 | 28 | 59 | 33 | 97 | 283 | 8 | 20 | 50 | 10 | 0 |
| *Jassa marmorata* | 1 | 1 | 2 | 4 | 11 | 31 | 3 | 9 | 25 | 59 | 2 |

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

caprellid amphipod *Caprella septentrionalis*, the gastropod *Mitrella lunata*, and the barnacle *Balanus crenatus* were relatively abundant in this assemblage.

Results of the multivariate analyses provide no evidence of plant impact at the near-field shallow station (B17). The main assemblages identified by these analyses were found at both stations (B17 and B35) and 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 or subdominant species in all groups was the mollusc *L. 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 *P. inermis, I. phosphorea, Idotea balthica*, *J. marmorata,* and *A. rubricata*. The macrofaunal community at the shallow

**Table 5-16. Significance Test of Spatial and Temporal Differences of Macrofaunal Communities. Seabrook Operational Report, 2009.**

| Community | Comparison | R | p (%) [a] |
|---|---|---|---|
| Shallow Subtidal (B17, B35) | Period[b] | 0.34 | 0.1* |
| | Station[b] | 0.26 | 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] | 0.37 | 0.1* |
| | Station[b] | 0.47 | 0.1* |
| | B19 Pre vs. B31 Pre[c] | 0.32 | 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.

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 32 years identified five groupings at a similarity level around 65% (Figure 5-19). Distinctions between these assemblages were also apparent in an MDS ordination plot. Group 1 contained more collections than any other group, including both nearfield and farfield stations in the preoperational and operational periods from 1979 to 1994. It was distinguished by the highest abundance of the numerically dominant Mytilidae spat (Table 5-15) and relatively high numbers of the tunicate *Molgula* sp. (mean density of 150.3 compared to densities from 0.3 to 30.2 for other groups) and the barnacle *Balanus crenatus* (mean density of 64.4 compared to densities from 0.2 to 12.1 for other groups). Group 2 was composed of nearfield samples collected mostly during 1995 to 2008. Like Group 1, it was dominated by Mytilidae spat, although density was less than half. Relatively high numbers of the pycnogonid (sea spider) *Achelia spinosa* and the nudibranch mollusc *Onchidoris* sp. distinguished this group from the others (Table 5-15). Group 3 was composed of farfield collections taken from 1995 through 2009. Similar to Groups 1 and 2, it was dominated by Mytilidae spat. Group 3 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 (Table 5-15). In addition to the major groupings, two outlier groups were identified. The 2001, 2003 and 2009 collections from B19 were distinguished by high densities of *Caprella septentrionalis* and *P. inermis*, and low Mytilidae density. Macrofaunal assemblages from both stations in 1978 differed from the majority of the collections and were characterized by elevated densities of *P. inermis* and reduced densities of other taxa, including the subdominants Mytilidae and *L. vincta*. *Onchidoris* sp. was absent from all samples in 1978.

The MDS plot illustrates the relatively high level of similarity among all collections at the mid-depth stations. Nonetheless, the multivariate results suggest that subtle differences

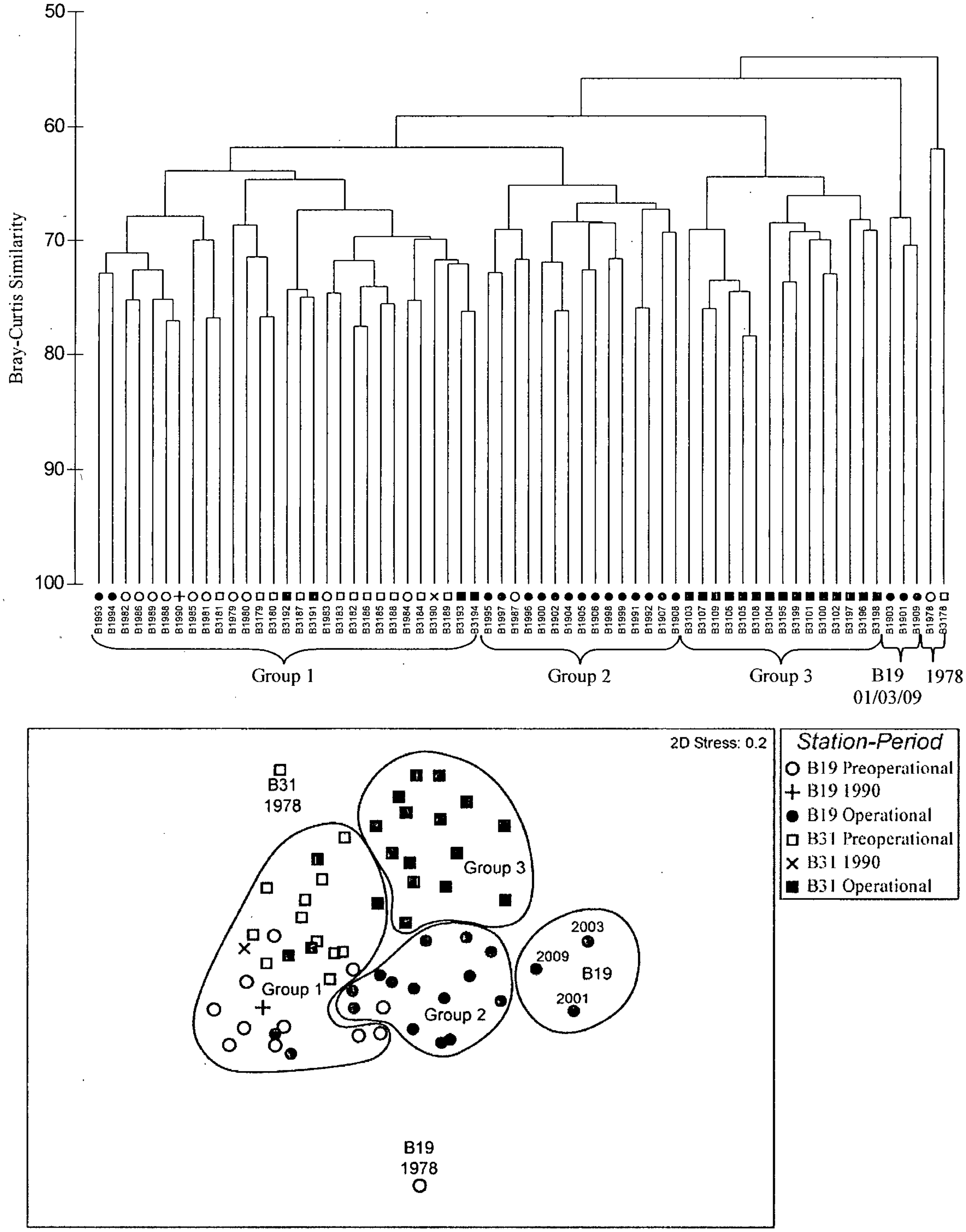



Figure 5-19. Dendrogram formed by numerical classification and multidimensional scaling results of Seabrook August benthic macrofauna collections from mid-depth Stations (B19 and B31), 1978-2009. Seabrook Operational Report, 2009.

in species composition differentiate recent samples at both nearfield and farfield stations from the majority of samples in the pre-operational and early operational periods. The distinction of late operational period collections at Stations B19 (Group 2) and B31 (Group 3) 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 at B31 compared to B19 (Appendix Table 5-4). For example, Group 3 had considerably higher abundance of the gastropod *Lacuna vincta*, which is the numerical dominant at the shallow subtidal stations (Table 5-15). Since the cluster analysis indicates that there was greater similarity in assemblages at the nearfield station between preoperational and operational periods than found at the farfield station, a pattern of direct impact to the macrofaunal community due to plant operation is not indicated. 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).

***Subtidal Fouling Community (Bottom Panel Monitoring Program) updated***

Recruitment patterns of sessile, solitary (non-colonial) macroinvertebrates in the mid-depth zone were monitored with bottom panels exposed during four month intervals. Recruitment is influenced by several factors including substrate, time of year, length of exposure, and predation by 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 (Figure 5-1). Fixed duration sampling periods (January through April, May through August, and September through December) provided an adequate interval for larval settlement and development. Four 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 on the bottom panels 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 the heaviest recruitment on panels collected in April and substantially lower recruitment in subsequent exposure periods (Table 5-17). However, in 2009, the April value was lower than average for the panels collected in April, and the December value was well above the historical average. Bottom water temperatures were above the operational average in September, November and December 2009 (Figure 2-3), and may have contributed to the recruitment of barnacles in the fall of 2009. 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 2009 was within the confidence limits of the operational period for both stations.

The second-most abundant taxon on the bottom panels was the bivalve *Hiatella* sp. This species typically had the heaviest settlement in May through August, at both stations, and this trend continued in 2009 (Table 5-17). The greatest number of larvae in the water column during the preoperational period occurred from May to July (NAI 1990), consistent with the high densities observed on the August panels. Mean densities have historically been higher at the farfield station. In 2009, recruitment of *Hiatella* sp. was low in

**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 1981-2009 (except April 1985 through August 1986). Seabrook Operational Report, 2009.**

| 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] | 15,196 | 22,401 | 29,605 | 4,951 | 8,226 | 11,501 | 0 | 1,526 | 3,502 | 7,267 | 10,718 | 14,168 |
| 2009[c] | | 8,175 | | | 2,629 | | | 14,519 | | 0 | 8,441 | 23,220 |
| 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 | 18,789 | 27,251 | 35,712 | 4,272 | 7,159 | 10,046 | 0 | 1,694 | 4,204 | 7,905 | 12,034 | 16,164 |
| 2009 | | 18,333 | | | 5,831 | | | 21,475 | | 0 | 15,213 | 35,771 |
| ***Hiatella sp.*** | | | | | | | | | | | | |
| Nearfield (B19) | | | | | | | | | | | | |
| Preop | 0 | 1 | 3 | 982 | 3,966 | 6,950 | 0 | 27 | 58 | 26 | 1,333 | 2,639 |
| Op | 2 | 9 | 15 | 1,368 | 3,081 | 4,794 | 1 | 13 | 24 | 374 | 1,034 | 1,694 |
| 2009 | | 4 | | | 126 | | | 88 | | 0 | 73 | 228 |
| Farfield (B31) | | | | | | | | | | | | |
| Preop | 0 | <1 | 1 | 0 | 11,659 | 23,840 | 0 | 16 | 37 | 0 | 3,891 | 8,306 |
| Op | 6 | 15 | 25 | 4,215 | 7,335 | 10,456 | 19 | 70 | 120 | 1,133 | 2,474 | 3,814 |
| 2009 | | 71 | | | 6,524 | | | 71 | | 0 | 2,222 | 11,477 |
| Mytilidae | | | | | | | | | | | | |
| Nearfield (B19) | | | | | | | | | | | | |
| Preop | 0 | 2 | 5 | 83 | 367 | 651 | 2 | 58 | 115 | 15 | 134 | 254 |
| Op | 57 | 191 | 324 | 78 | 1,578 | 3,077 | 36 | 76 | 117 | 111 | 615 | 1,119 |
| 2009 | | 31 | | | 22 | | | 309 | | 0 | 121 | 526 |
| Farfield (B31) | | | | | | | | | | | | |
| Preop | 0 | 8 | 20 | 0 | 5,035 | 16,595 | 0 | 36 | 71 | 698 | 1,690 | 2,682 |
| Op | 38 | 131 | 224 | 1,417 | 2,637 | 3,858 | 51 | 173 | 295 | 485 | 980 | 1,476 |
| 2009 | | 127 | | | 554 | | | 137 | | 0 | 273 | 878 |
| ***Anomia* sp.** | | | | | | | | | | | | |
| Nearfield (B19) | | | | | | | | | | | | |
| Preop | 0 | <1 | 1 | 0 | 31 | 92 | 306 | 1,232 | 2,158 | 21 | 431 | 842 |
| Op | 3 | 94 | 185 | 25 | 111 | 196 | 1,011 | 2,638 | 4,266 | 346 | 948 | 1,549 |
| 2009 | | 21 | | | 7 | | | 0 | | 0 | 9 | 36 |
| Farfield (B31) | | | | | | | | | | | | |
| Preop | 0 | 0 | 0 | 0 | 36 | 78 | 0 | 993 | 2,170 | 0 | 373 | 815 |
| Op | 7 | 18 | 29 | 33 | 140 | 248 | 619 | 1,297 | 1,974 | 221 | 485 | 749 |
| 2009 | | 3 | | | 236 | | | 152 | | 0 | 130 | 423 |

[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 = 1991-2009
[c] 2009 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.

each season at Station B19. The all-season mean density in 2009 was below the preoperational and operational means at both stations, particularly at Station B19. At Station B31 the mean annual density in 2009 was within the confidence limits of the preoperational and operational periods.

Seasonal patterns of settlement of Mytilidae spat (primarily juvenile *Mytilus edulis*) have generally been consistent for the preoperational and operational periods, with heaviest recruitment on panels collected in August (Table 5-17). In contrast to the typical pattern, the August 2009 set and the average density across all seasons was below the operational and preoperational average at both stations. Destructive samples showed a similar pattern of depressed densities in 2009 (Section 5.3.2.2). Densities were typically higher at the farfield station (B31), and the trend continued into 2009. Similarly, the destructive macro-faunal samples show densities of mytilids were generally higher at the farfield station (Table 5-18). Differences between stations may be due to differences in the surrounding habitat noted in Appendix Table 5-4, prevailing currents, or proximity to Hampton Harbor Inlet.

The jingle shell, *Anomia* sp., was also commonly found on the bottom panels, and typically, the heaviest settlement was on the December panels and lowest on the April panels at both stations during the preoperational and operational periods (Table 5-17). However, in 2009 the highest density occurred in April at Station B19 and in August at Station B31. Larvae were typically most abundant in the water column from July through September during the preoperational period (NAI 1990). In recent years (2005-2008 and 2001), *Anomia squamula* was the only dominant species in bivalve larvae collections (NAI 2009; Section 3.3.1). Recently-settled *Anomia* sp. were more abundant in the operational period than the preoperational means at both stations. The 2009 (and 2007, 2008; see NAI 2008, 2009) all-season mean density was below the preoperational and operational means at Stations B19 and B31, an indication that numbers have declined in recent years.

Shipworms (*Teredo* spp.) were absent during 2009 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*

Mytilids are important prey items of marine predators such as sea stars, lobsters, crabs, and fishes 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; Petraitis 1990; 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). 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.

**Table 5-18. Geometric Mean Densities (no./m$^2$) and 95% Confidence Limits of Selected Benthic Macrofauna Species Collected During Preoperational and Operational Periods and During 2009. Seabrook Operational Report, 2009**

| Taxon and Station[a] | Preoperational[b] LCL[g] | Preoperational[b] Mean | Preoperational[b] UCL[h] | 2009 Mean | Operational[c] LCL | Operational[c] Mean | Operational[c] UCL |
|---|---|---|---|---|---|---|---|
| **Mytilidae spat <25mm** | | | | | | | |
| B17 | 1,508 | 2,580 | 4,413 | 46 | 718 | 1,233 | 2,118 |
| B35 | 2,241 | 4,449 | 8,832 | 23 | 1,265 | 2,565 | 5,200 |
| B19 | 901 | 1,947 | 4,205 | 24 | 429 | 993 | 2,300 |
| B31 | 2,735 | 6,196 | 14,034 | 70 | 1,145 | 2,279 | 4,538 |
| **Asteriidae** | | | | | | | |
| B17 | 409 | 590 | 849 | 545 | 377 | 513 | 698 |
| B35 | 90 | 184 | 378 | 463 | 75 | 134 | 240 |
| ***Pontogenia inermis*** | | | | | | | |
| B19 | 488 | 604 | 748 | 523 | 349 | 461 | 608 |
| B31 | 294 | 404 | 556 | 139 | 135 | 173 | 223 |
| ***Jassa marmorata*** | | | | | | | |
| B17 | 661 | 1,045 | 1,653 | 1,469 | 779 | 1,162 | 1,734 |
| B35 | 1,028 | 1,888 | 3,467 | 1,833 | 951 | 1,467 | 2,263 |
| ***Strongylocentrotus droebachiensis***[d] **<10 mm** | | | | | | | |
| B19 | 36 | 66 | 123 | 2 | 13 | 27 | 55 |
| B31 | 16 | 31 | 58 | 3 | 10 | 17 | 30 |
| ***S. droebachiensis***[e] **>10 mm** | | | | | | | |
| B17 | 0.00 | 0.14 | 0.52 | 0.00 | 0.00 | 0.02 | 0.05 |
| B35 | 0.00 | 0.03 | 0.07 | 0.00 | 0.00 | 0.06 | 0.15 |
| B19 | 0.02 | 0.09 | 0.17 | 0.00 | 0.00 | 0.21 | 0.54 |
| B31 | 0.00 | 0.04 | 0.16 | 0.00 | 0.00 | 0.39 | 0.93 |
| ***Modiolus modiolus***[f] | | | | | | | |
| B19 | 86 | 97 | 108 | 62 | 64 | 70 | 76 |
| B31 | 71 | 89 | 106 | 28 | 37 | 50 | 63 |

[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, 1991-2009, 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=1991-2009.
[f] Arithmetic means for *M. modiolus* from subtidal transect program; preoperational years=1980-1989, operational years=1991-2009
[g] LCL = Lower 95% confidence limit.
[h] UCL = Upper 95% confidence limit.

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 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 typically 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 2009 annual abundance was the lowest since the study began at both stations and was below the confidence limits of the preoperational and operational period means at both stations (Table 5-18). In 2009, very few mytilid spat occurred in spring and summer collections, although the abundance of fall was within the normal range. Throughout most of the 28-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). 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), although in 2009, the set of Mytilidae was the lowest of the study period, and the 2008 set was also low (NAI 2009). Mytilid abundances in 2009 at Stations B19 and B31 were below the confidence limits of the preoperational and operational means (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). The biggest set at Station B19 occurred in 2007. Differences between the preoperational and operational periods, or in the Preop-Op X Station interaction term (Table 5-19) were not significant, an indication that a localized effect from Seabrook Station did not occur.

***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 were within the preoperational and operational confidence intervals in 2009 at Station B17 and higher than the preoperational and operational confidence limits at B35 (Table 5-18). The mean abundance in 2009 at Station B35 was the fourth highest in the study period (Figure 5-22). 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.

**Table 5-19. Results of Analysis of Variance Comparing Densities [$Log_{10}$ (#/m²+1)] of Selected Macrofaunal Taxa Collected in May, August and November at Nearfield-Farfield Station Pairs During the Preoperational (1982-1989) and Operational (1991-2009) Periods. Seabrook Operational Report, 2009.**

| 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, 25.3 | 1.74 | 0.1993 | |
| Shallow | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| subtidal | Year (Preop-Op)[b] | 0.01 | 2.57 | 0.0544 | |
| (B17,B35) | Month(Year)[c] | 0.37 | 368.80 | 0.0000 * | |
| | Station[d] | 0.04 | 2.03 | 0.0770 | |
| (destructive) | Preop-Op X Station[e] | <0.01 | 0.00 | 0.5000 | |
| | Station X Year (Preop-Op)[f] | 0.03 | 16.07 | 0.0000 * | |
| | Error | 0.25 | | | |
| Mytilidae | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| (spat<25 mm) | Preop-Op[a] | 1, 29.1 | 3.17 | 0.0853 | |
| Mid-Depth | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| (B19/B31) | Year (Preop-Op)[b] | 0.13 | 3.03 | 0.0409 * | |
| | Month(Year)[c] | 0.22 | 217.11 | 0.0000 * | |
| (destructive) | Station[d] | 0.08 | 1.94 | 0.0817 | |
| | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 0.19 | 162.82 | 0.0000 * | |
| | Error | 0.31 | | | |
| Asteriidae | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| Shallow | Preop-Op[a] | 1, 11.5 | 0.17 | 0.6851 | |
| subtidal | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| (B17,B35) | Year (Preop-Op)[b] | 0.07 | 5.95 | 0.0073* | |
| | Month(Year)[c] | 0.11 | 179.52 | 0.0000 * | |
| (destructive) | Station[d] | 0.14 | 2.54 | 0.0554 | |
| | Preop-Op X Station[e] | <0.01 | 0.03 | 0.4334 | |
| | Station X Year (Preop-Op)[f] | 0.04 | 41.97 | 0.0000 * | |
| | Error | 0.15 | | | |
| *Pontogeneia* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *inermis* | Preop-Op[a] | 1, 1.82 | 3.15 | 0.2299 | |
| Mid-Depth | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| (B19/B31) | Year (Preop-Op)[b] | 0.00 | 0.00 | 0.4999 | |
| | Month(Year)[c] | 0.11 | 126.11 | 0.0000 * | |
| (destructive) | Station[d] | 0.04 | 0.81 | 0.1838 | |
| | Preop-Op X Station[e] | 0.01 | 3.64 | 0.0283* | B19 Pre B19 Op B31 Pre >B31Op |
| | Station X Year (Preop-Op)[f] | 0.01 | 2.54 | 0.0553 | |
| | Error | 0.28 | | | |
| *Jassa* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *marmorata* | Preop-Op[a] | 1, 9.11 | 0.00 | 0.9551 | |
| Shallow | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| subtidal | Year (Preop-Op)[b] | 0.05 | 3.41 | 0.0324* | |
| (B17,B35) | Month(Year)[c] | 0.11 | 99.99 | 0.0000 * | |
| | Station[d] | 0.01 | 0.69 | 0.2033 | |
| (destructive) | Preop-Op X Station[e] | <0.01 | 0.04 | 0.4206 | |
| | Station X Year (Preop-Op)[f] | 0.02 | 8.88 | 0.0014 * | |
| | Error | 0.28 | | | |
| *Strongylocentrotus* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *droebachiensis* | Preop-Op[a] | 1, 12.7 | 3.30 | 0.0927 | |
| juveniles<10mm | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| Mid-Depth | Year (Preop-Op)[b] | 0.13 | 8.48 | 0.0018 * | |
| (B19/B31) | Month(Year)[c] | 0.14 | 63.12 | 0.0000 * | |
| | Station[d] | 0.03 | 1.17 | 0.1399 | |
| (destructive) | Preop-Op X Station[e] | 0.00 | 0.00 | 0.4911 | |
| | Station X Year (Preop-Op)[f] | 0.05 | 11.15 | 0.0004 * | |
| | Error | 0.55 | | | |

(continued)

**Table 5-19. (Continued)**

| Parameter | Source of Variation | Test Statistics | | | Multiple Comparisons[k] |
|---|---|---|---|---|---|
| *Strongylocentrotus* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *droebachiensis*[l] | Preop-Op[a] | 1, 22 | 0.57 | 0.4572 | |
| >10mm | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| Shallow | Year (Preop-Op)[b] | <0.01 | 0.02 | 0.4424 | |
| subtidal | Month(Year)[c] | <0.01 | 6.10 | 0.0068 * | |
| (B17,B35) | Station[d] | 0 | 0.00 | 0.4999 | |
| (non-destructive | Preop-Op X Station[e] | 0 | 0.00 | 0.4998 | |
| transects) | Station X Year (Preop-Op)[f] | <0.01 | 0.81 | 0.1839 | |
| | Error | <0.01 | | | |
| *Strongylocentrotus* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *droebachiensis*[l] | Preop-Op[a] | 1, 21.9 | 0.54 | 0.4708 | |
| >10mm | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| Mid-Depth | Year (Preop-Op)[b] | 0.04 | 23.72 | 0.0000 * | |
| (B19,B31) | Month(Year)[c] | <0.01 | 8.83 | 0.0015 * | |
| (non-destructive | Station[d] | 0 | 0.00 | 0.4998 | |
| transects) | Preop-Op X Station[e] | <0.01 | 0.37 | 0.2706 | |
| | Station X Year (Preop-Op)[f] | <0.01 | 17.12 | <0.0001 * | |
| | Error | <0.01 | | | |
| *Modiolus* | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| *Modiolus* | Preop-Op[a] | 1, 1.25 | 25.43 | 0.0882 | |
| (adults)[m] | **Random Effects** | **Estimate[j]** | $\chi^2$ | **p[i]** | |
| Mid-Depth | Year (Preop-Op)[b] | 4.57 | 0.00 | 0.4788 | |
| (B19,B31) | Month(Year)[c] | 99.24 | 25.06 | 0.0000 * | |
| | Station[d] | 107.33 | 0.70 | 0.2018 | |
| (non-destructive | Preop-Op X Station[e] | 7.35 | 0.02 | 0.4379 | |
| transects) | Station X Year (Preop-Op)[f] | 342.42 | 116.98 | 0.0000 * | |
| | Error | 1867.17 | | | |

[a] Preop-Op compares 1982-1989 to 1991-2009 regardless of station for B17/B35.
Preop-Op compares 1978-1989 to 1991-2009 regardless of station for B19/B31.
Preop-Op compares 1980-1989 to 1991-2009 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 $H_o$: LSMEAN (i)= LSMEAN(j).

[l] Density ($\log_{10}$ (#/m$^2$+1)) of adult urchins from subtidal transect program; preoperational years = 1985-1989, operational years = 1991-2009.

[m] Analyses for *M. modiolus* adults were performed on untransformed density (#/m$^2$) data.

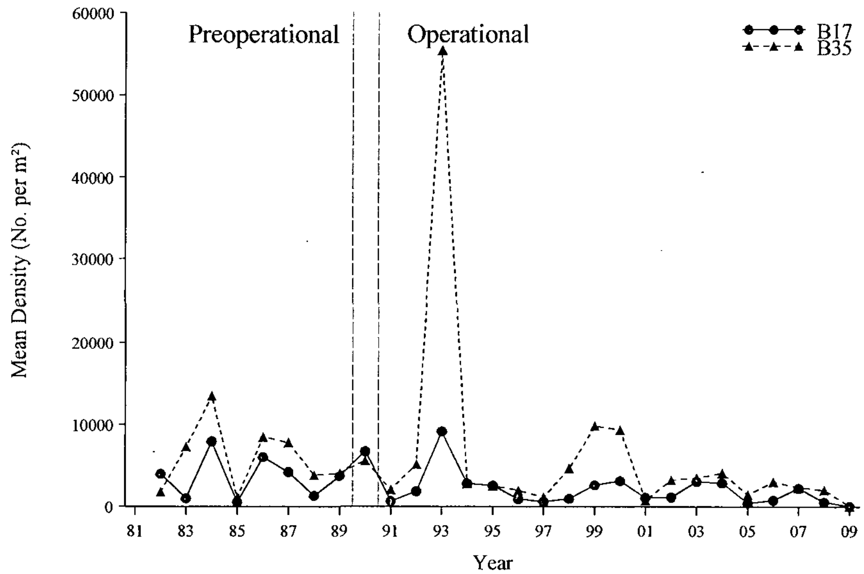



Figure 5-20. Annual geometric mean density (no./m$^2$) of Mytilidae at the shallow subtidal Stations B17 and B35, 1982-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

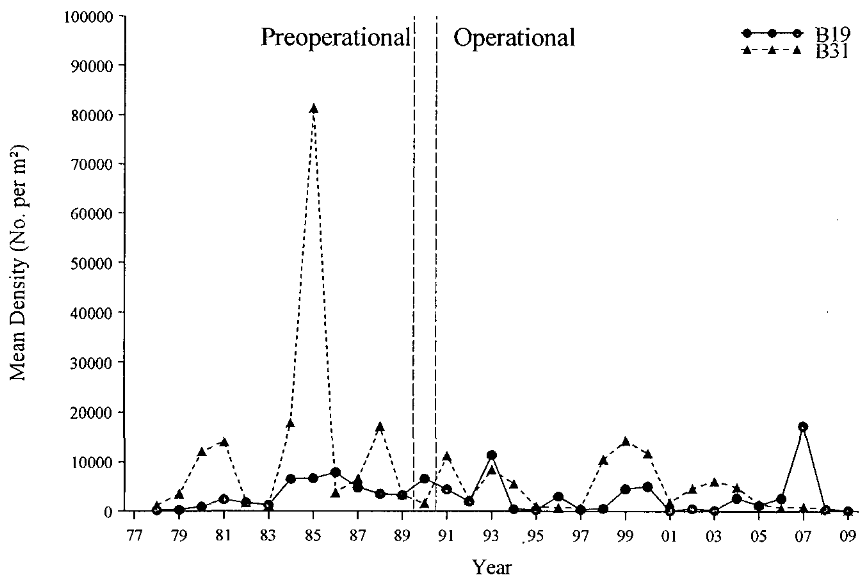



Figure 5-21. Annual geometric mean density (no./m$^2$) of Mytilidae at the mid-depth Stations B19 and B31, 1978-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

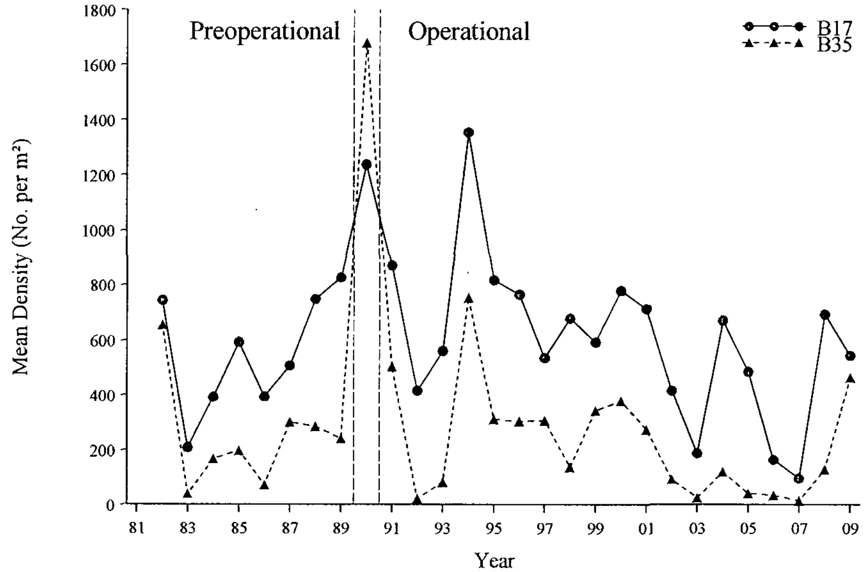



Figure 5-22. Annual geometric mean density (no./m$^2$) of Asteriidae at the shallow subtidal Stations B17 and B35, 1982-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

### *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 2009, the abundance at both mid-depth stations increased from the previous year (Figure 5-23). The 2009 annual average was within the confidence limits for the preoperational and operational periods at B19 and near or below the preoperational and operational confidence limits at B31 (Table 5-18). Density has typically been higher at Station B19 than Station B31, and that pattern continued in 2009 (Figure 5-23). The decline between periods was significant at Station B31 (far-field), but there was no significant difference at Station B19 (nearfield), and resulted in a significant interaction term for the second consecutive year (Table 5-19, NAI 2008). Further analysis shows that at Station B31, the mean density from 1978 through 1989 was significantly higher than the period after 1989 (Table 5-20). Since the significant decline was at the farfield station (Station B31) presumeably beyond the influence of Seabrook Station, and it began in 1989, a year before the Station began commercial operation, it is not likely to be due to station operation. At Station B19, the mean density was higher from 1978 through 1993 than the period after 1993 (Table

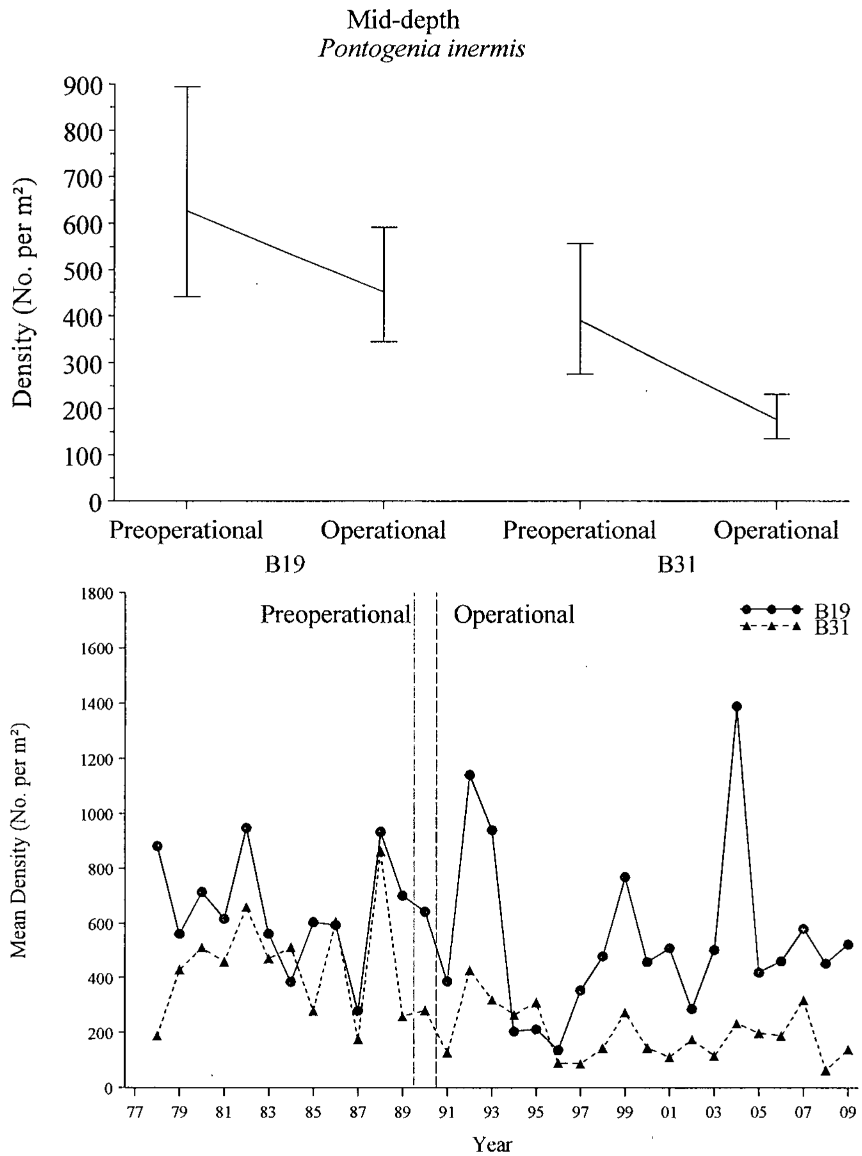



Figure 5-23. Annual geometric mean density (no./m$^2$) of *Pontogeneia inermis* at the mid-depth Stations B19 and B31, 1978-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

**Table 5-20. Results of Segmented Regression Analysis on the Density (no./ $m^2$) of Selected Macrofauna with a significant ANOVA interaction term collected from Destructive Samples. Seabrook Operational Report, 2009.**

| Parameter | Station | Comparisons Based on Breakpoints[a] | Period 1 Slope | Period 2 Slope | Entire Period |
|---|---|---|---|---|---|
| *Pontogenia inermis* | B19 | 1978-1993>1994-2009 * | NS | NS | NS |
| | B31 | 1978-1989>1990-2009*** | NS | NS | Neg. *** |

[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≥p>0.01)
** = Highly Significant (0.01≥p>0.001)
*** = Very Highly Significant ((0.001≥p)

5-20). This indicates that mean densities have declined at both stations relative to historical levels and may suggest a regional trend.

### *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 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 2009 means increased from the previous year and were within the preoperational and operational confidence limits at Station B17 and Station B35 (Figure 5-24; 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*

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; Johnson and Mann 1988; Novaczek and McLachlan 1986) such as the kelp *Saccharina latissima* and *L. longicruris* (Larson et al. 1980; Mann et al. 1984). It is a major biological factor influencing abundance of kelp. Dense aggregates of *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

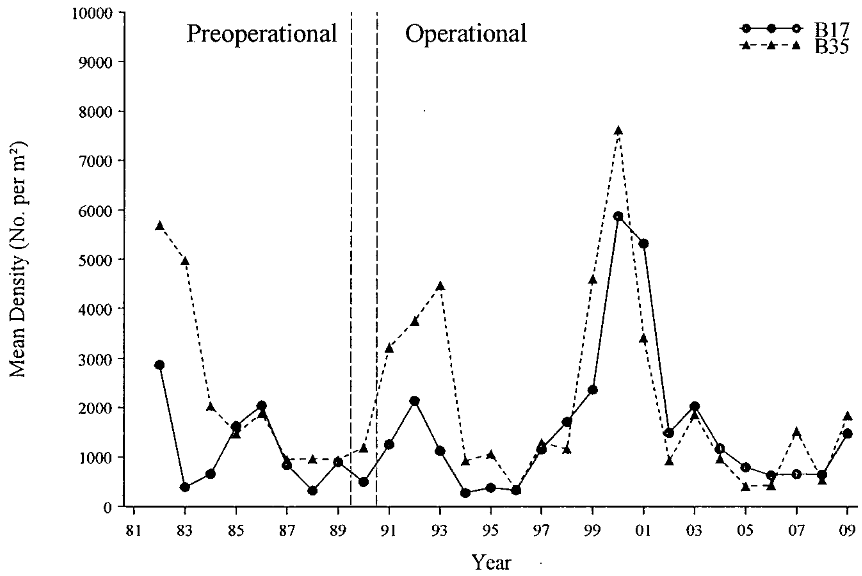



Figure 5-24. Annual geometric mean density (no./m$^2$) of *Jassa marmorata* at the shallow subtidal Stations B17 and B35, 1982-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

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 to 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 New Hampshire and Maine, may take from 2 to 16 years. Growth curves constructed by Russell et al. (1998) show that growth rate was fastest until the 50 mm size was reached, averaging 2.6 to 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 away 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 success of recruitment from planktonic larvae). Harvesting pressure has been intense in the Gulf of Maine from the late 1980s (prior to operation of Seabrook Station) through 1999, 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 42 million pounds, and have decreased to 3.5 million pounds in 2009 (http://www.maine.gov/dmr/commercialfishing/documents/urchin.table.pdf). The Maine Department of Marine Resources initiated cutbacks in the number of fishing days for the sea urchin fishery starting in fall 2003, and restrictions are still in effect.

#### *Juvenile sea urchins < 10 mm in diameter: Destructive Monitoring Program*

Although present in all depth zones studied, juvenile sea urchins 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; during the operational period farfield means exceed the nearfield means in most years (Table 5-18; Figure 5-25). In 2009, densities decreased compared to the previous year, and were below the confidence limits for the preoperational and operational periods at both stations (Figure 5-25;Table 5-18). 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 2009, no sea urchins were observed at any of the four stations (Table 5-18). Mean annual densities at the mid-depth stations were usually at or 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 nearly zero at both stations and the very low densities have continued through 2009. There were no significant differences between periods or stations and the interaction between period and station was not significant for both depth zones (Table 5-19). Urchins are often considered a keystone species because of their ability to graze-down laminarians and other

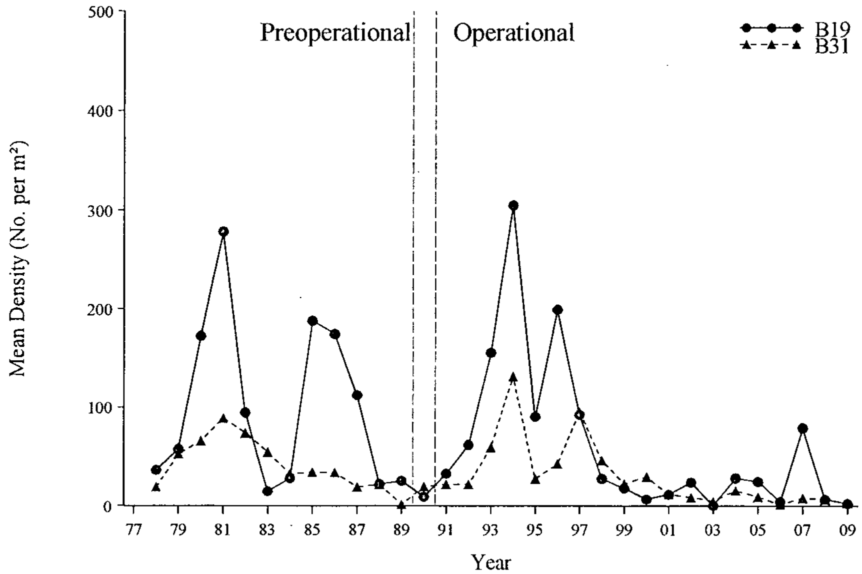



Figure 5-25. Annual geometric mean density (no./m$^2$) of juvenile *Strongylocentrotus droebachiensis* collected from destructive samples at the mid-depth Stations B19 and B31, 1978-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

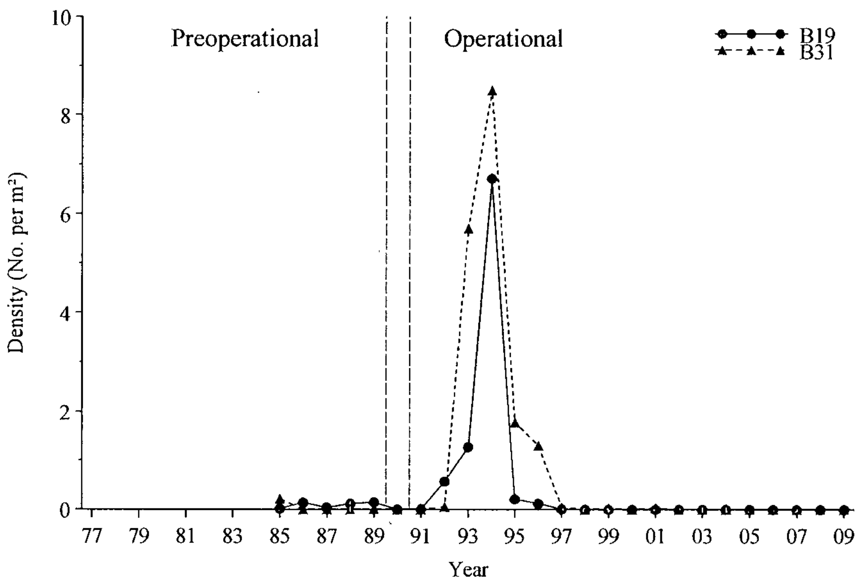



Figure 5-26. Annual geometric mean density of adult *Strongylocentrotus droebachiensis* (no./m$^2$) in the mid-depth subtidal zone, 1978-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

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 (cold-water) 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 small *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 the warming trend may prevent recovery of the cold-water species (Hiscock et al. 2004).

Mean densities of *Modiolus modiolus* in 2009 were below the preoperational and operational lower confidence limits at both stations (Table 5-18). In 2009, Station B19 exhibited a small increase in density from the previous year (Figure 5-27), while Station B31 decreased.. 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, no significant differences were detected between periods or 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 benthic community located near the discharge diffusers 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 effects at shallow subtidal stations include those related to direct contact with the thermal plume such as changes in the temperature regime and the corresponding changes in dissolved oxygen. Potential 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 increases in warm-water species (Vadas et al. 1976; Wilce et al. 1978; BECO 1994; NUSCO 1994, 2008; DRS 2010). Temperature-related impacts are likely to be restricted to the shallow subtidal habitat. 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 discharge 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

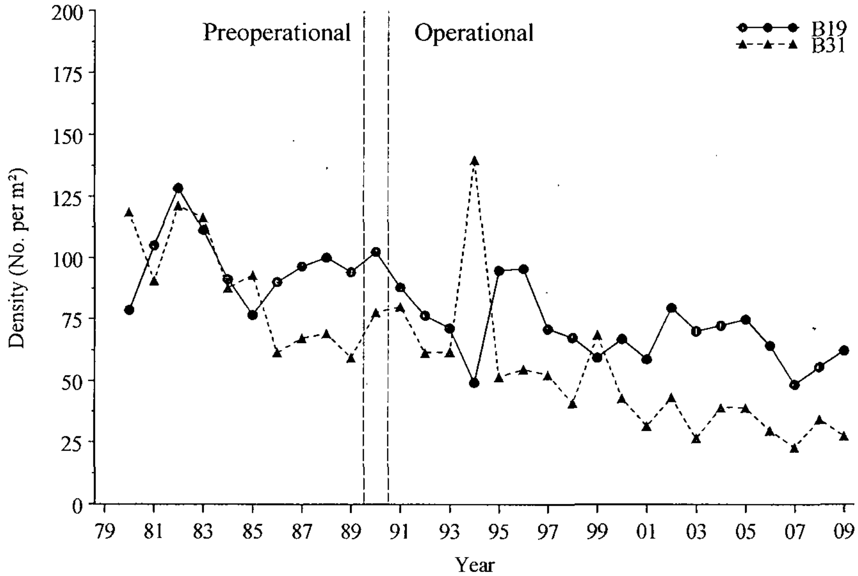



Figure 5-27. Annual arithmetic mean density (no./m$^2$) of *Modiolus modiolus* at the mid-depth Stations B19 and B31, 1980-2009 (data between the two dashed lines were excluded from the ANOVA model). Seabrook Operational Report, 2009.

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, any benthic 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, closer to the diffusers. The intake of Seabrook Station is located approximately 5.2 m off the bottom. Although the intake is at 5.2 m, flow of water to the intake includes vertical components such that a mixture of water from throughout the water column is entrained. The circulating water system discharges at approximately 2-3 m off the bottom where the warm water 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/cm$^2$ 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 the mid-depth habitat near the discharge, which is more quiescent and therefore likely to be more susceptible to the accumulation of detritus compared to the shallow subtidal habitat.

A special study on suspended sediment from Hampton Harbor, the Seabrook Station discharge, nearfield Stations B17, B19, and farfield Station B31 was conducted to investigate whether the suspended sediment from the discharge may be contributing to the decline of kelp at nearfield stations (McDowell 2009). The purpose of the study was to determine if the discharge water from Seabrook Station had a specific biochemical fingerprint that could be detected at the nearfield stations. Farfield Station B31 was considered a reference (control) station and water from Hampton Harbor on an outgoing tide was also collected because this estuarine water could influence the coastal environment. Water samples for the benthic stations and Hampton Harbor were collected at 1-2 feet off the bottom and the discharge sample was taken directly from the discharge nozzle. Eleven parameters were measured including total suspended sediment (TSS), organic mater (LOI), total carbon and nitrogen, chlorophyll *a*, phaeophytin, isotopes of carbon and nitrogen, and derivatives that would allow a "fingerprint" of the water from the Seabrook Station discharge to be identified. Hampton Harbor was significantly different from all other stations because it had higher concentrations of TSS, organic matter, particulate carbon and nitrogen and chlorophyll *a*, as would be expected when comparing estuarine water to coastal water. The farfield station (B31) is the furthest station from Hampton Harbor. It ranked lowest for the parameters that were highest in Hampton Harbor (HH), with the exception of chlorophyll *a*. For example TSS (mg $l^{-1}$) was 15.3 at HH, 4.3 at the discharge, 3.5 at B17, 3.0 at B19 and 2.2 at B31. The results indicate that the coastal water that passes through the cooling system is not significantly different from water at any of the offshore stations. It is only different from the estuarine water from Hampton Harbor. There is no evidence to suggest that the environment at the nearfield benthic Stations B17 and B19 is subject to particularly large sediment or detrital inputs originating from Seabrook Station or Hampton Harbor because there were no differences between the characteristics of the water discharged from the plant and the nearfield and farfield stations. Unlike the San Onofre Nuclear Generating Station (Jahn et al. 1998), Seabrook Station takes in and discharges water that is not detectably different from surrounding coastal waters,as evidenced by the similarity between the parameters tested at the Seabrook Station discharge and Stations B17, B19 and B31 (Mc Dowell 2009).

### 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 nearfield Station B17. 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 5-21, 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 taken from destructive samples were consistent between periods in this zone (Table 5-21). 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, including *Chondrus crispus* (biomass and % frequency), *Phyllophora/Coccotylus*, *Ptilota serrata*, Mytilidae, Asteriidae and *Jassa marmorata* were consistent between periods (Table 5-22).

ANOVA results revealed that two of the selected benthic species, *Saccharina latissima* and *Laminaria digitata* had significant differences in density between the preoperational and operational periods, and these differences were not consistent between the nearfield and farfield stations. Density of *Saccharina latissima*, the dominant kelp in the shallow subtidal zone, decreased between periods (preoperational and operational) at the nearfield station, but was similiar at the farfield station, resulting in a significant interaction term (Table 5-22; Figure 5-12). The breakpoint in the annual time series at the nearfield station occurred between 1992 and 1993, and density at the nearfield station reached its peak in 1993, three years 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 suggest 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 between 1991 and 1992, 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 likely to be a regional occurrence, and is not due to plant operation.

Physical factors may be contributing to the regional decline in *Laminaria digitata*. Seawater temperature has the greatest potential to be influenced by station operation at the shallow subtidal stations. *L. digitata* are "cold water plants" which are genetically conservative with respect to temperature tolerance (Bolton and Luning 1982). Table 5-23 lists critical temperatures for various stages and reproductive processes of *L. digitata*. Plants (sporophytes) can adapt to local conditions within about 2°C, up to 20°C (Fortes and Luning 1980; Luning 1984). The distribution of *L. digitata* is probably determined by the temperature requirements for reproduction rather than the temperature tolerance of the non-hardiest stage [the sporophyte: 18-20°C; (tom Dieck (Bartsch) 1993)]. In the northeast Atlantic, sori naturally occur throughout the year, but are most abundant in summer and fall, that is July through November or December (Bartsch et

**Table 5-21. 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, 2009.**

| 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 = 1990-2009 (August only for fauna.)

**Table 5-22. 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, 2009.**

| 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* (biomass) | Yes | Yes |
| | | *Chondrus crispus* (% frequency) | Op>Pre | Yes |
| | | *Laminaria digitata* | — | NF: Op<Preop<br>FF: Op<Preop |
| | | *Saccharina latissima* | — | NF: Op<Preop<br>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 = 1990-2009 (August only for and fauna); NF = nearfield, FF = farfield.

**Table 5-23. Critical Temperatures for *Laminaria digitata*. Seabrook Operational Report, 2009.**

| Life Stage | Temperature (° C) | Lab/ Field | Origin of Plants | Source |
|---|---|---|---|---|
| Gametophytes-Upper Survival | 22-23 | lab | North Atlantic | Table 7.3 Luning 1990 |
| Production of Gametangia | Below 18 | lab | North Atlantic | Table 7.3 Luning 1990 |
| Sporophytes (February)-Upper Survival | 18 | lab | Helgoland, Germany | Table 7.1 Luning 1990 |
| Sporophytes (July)-Upper Survival | 20 | lab | Helgoland, Germany | Table 7.1 Luning 1990 |
| Population-Southern Lethal Limit | 19 | | western N. Atlantic | van den Hoek 1982 |
| Sporogenesis-drastic reduction | 17 | lab | Helgoland, Germany | personal communication, 2009 |
| Sporogenesis-cessation | 20 | lab | Helgoland, Germany | personal communication, 2009 |
| Reduction of Sori | 17-19 summer surface temperature | field | Helgoland, Germany | Bartsch et al. (unpublished, 2004) |
| No Meiospore Release | 17 | field | Helgoland, Germany | Bartsch et al. (unpublished, 2004) |

al. 2008). Few studies have been done in the northwest Atlantic, but one study done at Cape Cod, MA recorded the presence of sori only from November through March (Sears and Wilce 1975). Bartsch (Alfred Wegenar Institute for Polar and Marine Research, Bremerhaven and Sylt, Germany; personal communication, July 8, 2009) found that in the lab, sporogenesis is drastically reduced above 17°C and no spores were formed at 20° C. Bartsch et al. (unpublished 2004) noted during an unusually warm summer when sea surface temperatures (SST) were above 17°C (up to about 19°C), there was a reduction in sori and no meiospores were released. Bolton and Luning (1982) took gametophytes (microscopic) of *L. digitata* from the western North Atlantic (Halifax) and found their upper survival limit was 22-23°C; however, gametangia were only formed below 18°C (also in Luning 1990 Table 7.3). Gametophytes become fertile in optimal conditions: low temperatures and low light (Van den Hoek et al. 1995). Based on this literature, it appears that 18°C is a conservative critical temperature above which reproduction is constrained. In our study, the annual mean number of warm days with surface water temperature ≥ 18°C was significantly greater in the operational period compared to the preoperational period at the farfield (Pr>t=<0.001) station, but not at the nearfield station (Table 5-24). At the nearfield station (P2) the annual mean number of days ≥ 18°C in the operational period (15.3 days) was almost twice the number in the preoperational period (7.8 days), although the difference as not statistically significant. At the farfield station (P7) the annual mean number of days ≥ 18°C in the operational period (12.8 days) was nearly five times the number in the preoperational period (2.6 days). These periods of warm water temperature occurred during summer (July, August and September), the time when *L. digitata* is typically the most fertile and produces the maximum number of sori (Roleda et al. 2005). It is possible that increased temperature, in particular the number of days ≥ 18°C, may have contributed to a decreased reproductive capacity in *L. digitata*, and could be a factor in the reduced *L. digitata* densities during the operational period.

Other physical factors that can have a role in determining abundance and species composition of kelps include episodic periods of large waves (Dayton and Tegner 1984, Dayton

**Table 5-24. Comparisons of Annual Mean Number of Days with Surface Temperature ≥ 18° C at the Nearfield (P2) and Farfield (P7) Water Quality Stations in the Preoperational (1979-1989) and Operational (1991-2009) periods. Seabrook Operational Report, 2009.**

| Station | Preoperational Period | | Operational Period | | Pr > t[b] |
|---|---|---|---|---|---|
| | Mean (no. of days/year) | SD[a] | Mean (no. of days/year) | SD[a] | |
| P2 (Nearfield) | 7.8 | 6.6 | 15.3 | 12.1 | 0.0681 |
| P7 (Farfield) | 2.6 | 3.2 | 12.8 | 11.1 | <0.001* |

[a] SD = standard deviation

[b] Two-sample t-test: * = significant ($p \leq 0.05$)

et al. 1984, Seymour et al. 1989, Graham et al. 1997, Duggins et al. 2003, Eckman et al. 2003). Hurricane Bob and the "Perfect Storm" may have accounted for a decrease in abundance between 1990 and 1991 (Figure 5-8). Additionally, the nearfield stations are closest to the Hampton Harbor Inlet, and may be the stations most likely to receive nutrients and increased turbidity from Hampton Harbor (NAI 1999a). Higher turbidity at the nearfield stations may cause decreased light levels compared with the farfield stations that could affect growth and reproduction. Cosson (1999) reported a decline in *L. digitata* in the shallow sublittoral zone off the coast of France, coincident with an increase in turbidity, coastal eutrophication and the establishment of *Sargassum multicum*, although a definite relationship among these factors was not clear. In the preoperational and operational periods, *L. digitata* has typically been more abundant at the farfield station when compared to the nearfield station, and increased turbidity due to proximity to Hampton Harbor Inlet could be a contributing factor.

Biological factors such as grazing by urchins have been reported to have a negative effect on kelp populations (Mann 2000, Scheibling and Hennigar 1997, Scheibling et al. 1999). 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. In the study area, a comparison of annual mean densities of *L. digitata* and urchins showed that prior to 2001, increases in urchin density coincided with decreases in kelps, although the relationship was not statistically significant (Section 5.3.2.2 in NAI 2001). Sea urchin density has been very low since 1996, and thus is not a factor in the current low kelp densities.

Urchin barrens provided niches for introduced species including *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) (Harris and Tyrrell 2001). The warm-water species *C. fragile* subsp. *tomentosoides* became the dominant canopy species to a depth of 8 m around much of the sheltered areas near the Isles of Shoals, NH (Harris and Mathieson 2000). Mathieson et al. (2003) located 26 *C. 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. Factors that may slow its expansion to other nearshore sites include temperature instability due to a variety of factors including localized, wind-driven upwelling (Harris and Jones in press). Kelp communities are slowly beginning to reestablish around the Isles of Shoals and *C. fragile* subsp. *tomentosoides* is being overgrown and ripped out by storms (personal communication: L. Harris University of New Hampshire, April, 2009). C. *fragile* subsp. *tomentosoides* is not established in the Seabrook study area, and has only been reported in 1998 and 1999.

Twenty introduced species of marine algae occur in the northwest Atlantic (Mathieson et al. 2008). Only three introduced species, *Bonnemaisonia hamifera*, *Dumontia contorta* and *Neosiphonia harveyi*, occur at the shallow subtidal stations, and they are rare (comprising 0.1 g /$m^2$ or less) and are not likely to be important competitors of kelp. An increase in the introduced bryozoan *Membranipora membranacea* to 52% cover per kelp blade is another biological factor reported to reduce populations of *L. digitata* in southern Maine (Cape Neddick) between 1989 and 1990 (Lambert et al. 1992). Based on a very limited sample (one kelp blade from general algae collections in the May, August and November surveys), *M. membranacea* increased throughout the summer season at shallow subtidal stations in 2009. Percent cover of *M. membranacea* on kelp blades ranged from zero in May to 75 % in November at the nearfield station and from zero in May to <5 % in August at the farfield station.

Another biological factor that can affect kelp is disease (Ellertsdottir and Peters 1997). Microscopic examination of kelp thalli from the North Sea showed that 85% were infected, much higher than was inferred by gross lesions alone. One quarter of the *Saccharina latissima* was crippled (heavily deformed thalli including twisted stipe). Disease symptoms were more severe in shallower water than in deeper water and prevalence was high throughout the year with a minimum in the spring.

In the northwestern Atlantic region, 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 (grazing on macroalgae) and lasted from the 1970s to the 1990s. Phase 3 developed since 1995 and is dominated by invertebrate predators such as large crabs. These findings indicate that the trophic structure of benthic communities of the western Gulf of Maine is very dynamic and has been influenced by the removal of apex predators and the introduction of non-native species. The magnitude and scale of these larger regional influences complicates the task of detecting potential impacts from power plant operation.

### 5.4.3 Evaluation of Potential Turbidity Effects on the Mid-Depth Benthic Communities

The nearfield mid-depth station represents the macrobenthic community in closest proximity to the Seabrook Station discharge. Temperature effects at this site are unlikely since the discharge is through a diffuser system that jets the effluent into the water column, 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 sedimentation rates (and impacts to nearby macrobenthic communities) associated with a thermal effluent have been documented for the San Onofre Nuclear Generating Station 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. Suspended sediments in water samples taken in March 2008 at the Seabrook discharge, Hampton Harbor, nearfield stations B17 and B19, and farfield Station B31 found no differences between the discharge and the nearfield and farfield stations. However, the Hampton Harbor station was significantly higher than all other stations in total suspended sediments, organic matter, and particulate carbon and nitrogen (McDowell 2009).

In May and October 1998, turbidity was monitored at the mid-depth stations and in Hampton Harbor in October only (NAI 1999a). Turbidity is the measurement of the effect that suspended solids and other substances such as tannins have on the transmission of light through water. Turbidity in Hampton Harbor was greater than the discharge plume and the nearfield station, similar to the findings of the sediment study (McDowell 2009). Turbidity was significantly higher at the nearfield station (Station B19) when compared to the farfield station, and this was attributed to the proximity of the station to the outflow from Hampton Harbor. The outflow from Hampton Harbor is likely to represent a more important source for turbidity at the nearfield station than the discharge plume (NAI 1999a).

Community parameters measured from the destructive monitoring samples indicate that in the mid-depth zone, total macrofaunal density, and number of macrofaunal taxa remained consistent between nearfield-farfield stations over the course of the study; total algal biomass was similar between periods (Table 5-25). 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 5-25), resulting in a significant interaction term in the ANOVA model. The annual mean numbers of algal taxa at these stations were generally similar until 1997 when numbers of taxa became consistently higher than historical values at the farfield station while remaining within historical levels at the nearfield station (Figure 5-3). The difference in number of taxa is related to fluctuations in species that are typically found in shallower water. In addition, numerical classification revealed the formation of two major groups based on station location (Figure 5-6). Station B31 (shallower station) had more *Chondrus crispus,* while Station B19 had higher abundance of the deeper water species *Ptilota serrata* and *Phyllophora/Coccotylus* (Table 5-6). 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 (light levels, temperature), are greater than for the shallow subtidal stations (Appendix Table 5-4), which may contribute to the inconsistency between stations.

Species abundance measured from the non-destructive monitoring program indicates that

**Table 5-25. 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, 2009.**

| 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<br>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 = 1990-2009 (August only for fauna); NF = nearfield, FF = farfield.

at mid-depth stations, density of the dominant kelps, *Agarum clathratum* and *Saccharina latissima,* the understory red algae *Phyllophora/Coccotylus and Ptilota serrata,* and the selected macrofaunal taxa including Mytilidae spat, *Modiolus modiolus* and *Strongylocentrotus droebachiensis* (>10 mm and <10 mm) were consistent between periods (Table 5-26). However, the densities of the subdominant kelp, *Laminaria digitata* declined significantly at both the nearfield (Station B19) and farfield (Station 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 Harris and Tyrrell (2001) and Steneck et al. (2004). Density of 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 cannot be related to plant operation. The amphipod *Pontogeneia inermis* also had a significant interaction, and densities declined significantly at the farfield Station B31, but not at the nearfield Station B19 (Figure 5-23). Since the decline occurred only at the farfield station and it began in 1989, it is not a direct effect of the operation of Seabrook Station.

Stability of local patches of kelp populations is 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 Laminariales 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* has a dispersal range of at least 200 m (Fredriksen et

**Table 5-26. 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, 2009.**

| 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<br>FF: Op<Preop |
| | | | Yes | |
| | | *Agarum clathratum* | — | Yes |
| | | *Alaria esculenta* | | NF: Op=Preop<br>FF: Op<Preop |
| | | *Saccharina latissima* | Op<Preop | Yes |
| | | *Chondrus crispus* (% frequency) | Op>Preop | Yes |
| | | *Phyllophora/Coccotylus* | Yes | Yes |
| | | *Ptilota serrata* | Yes | Yes |
| Macrofauna | Mid-depth | Mytilidae spat | Yes | Yes |
| | | *Pontogeneia inermis* | — | FF: Op<Preop |
| | | *Strongylocentrotus droebachiensis* < 10 mm | Yes | Yes |
| | | *S. droebachiensis* > 10 mm | Yes | Yes |
| | | *Modiolus modiolus* | 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 = 1990-2009 (August only for fauna); NF = nearfield, FF = farfield.

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. The primary dispersal mechanism for *L. digitata* is by flagellated zoospores, which lose their flagellae after 24 hours and settle on any available substrate (Birkett et al. 1998). With limited dispersal capability, the distance between an area that has experienced even a single severe disturbance (such as grazing by an urchin front, damage by a storm or a prolonged period of warm days) 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 on August 19, 1991 contributed to the reduction to the small population 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.

### 5.4.4 Overall Effect of Seabrook Operation on the Local Marine Macrobenthos

Monitoring studies document that balanced indigenous, cold-water macrobenthic communities continue to occupy subtidal rocky habitats near 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 long-term cycle that began prior to commercial operation of Seabrook Station.

During the entire study period, the average summer surface temperature has increased significantly. Surface water temperature warms earlier and stays warm later in the fall when compared to the preoperational period. The increase in the number of warm summer days (with surface water above 18° C) and elevated temperatures in fall is likely to result in a shortening of the reproductive period of *Laminaria digitata* (Bartsch, personal communication, July 2009). A decline in *L. digitata* at all stations in both the shallow and mid-depth subtidal zones occurred predominantly during the operational period. At the discharge (nearfield, mid-depth) station (12.2 m at MLW), the deep-water kelp *Agarum clathratum* has increased during the operational period when compared to the preoperational period, although the increase is not statistically significant. At the mid-depth farfield station (9.4 m at MLLW), the understory algae *Chondrus crispus* has increased significantly during the operational period. The increase in these species may make it more difficult for *L. digitata* populations to become reestablished, due to competition. The population of *L. digitata*, a subdominant throughout the study period, has been reduced by a combination of physical and biological factors, in addition to the area-wide trend of increasing temperatures since the late 1970s. An increase in sea urchin densities may have contributed to the observed decreases in *L. digitata* in the mid-depth subtidal zone during the period when adult sea urchins were the most abundant (1993 and 1994). 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 probable that the decreases in *L. digitata* and *Saccharina latissima* from their peaks in the 1980s are part of the regional decline. Breeman (1990) suggests that far-reaching effects of temperature rise will cause marked northward shifts of the southern boundaries of kelps *L. digitata* and *Saccharina latissima* 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). 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).

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**Appendix Table 5-1. Marine Macrobenthos Sampling History. Seabrook Operational Report, 2009.**

| 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 | 1982-2009 |
| | | Non-destructive | April, July, October | 1982-2009 |
| B31 | (mid-depth) | Destructive | May, August, November | 1978-2009 |
| | | Non-destructive | April, July, October | 1978-2009 |
| | | Panel Studies | Short Term | 1982-2009 |
| | | 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 | 1978-2009 |
| | | Non-destructive | April, July, October | 1979-2009 |
| B16 | (mid-depth) | Destructive | August | 1980-1984, |
| | | Non-destructive | | 1985-1997 |
| B19 | (mid-depth) | Destructive | May, August, November | 1978-2009 |
| | | Non-destructive | April, July, October | 1978-2009 |
| 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 – January through April, May through August, September through December.

Long-term panel studies: one-year exposure, August to August.

**Appendix Table 5-2. Algal taxonomic name changes made in 2009 for all historical data. Seabrook Operational Report, 2009.**

| Old Name | New Name | Reference |
|---|---|---|
| **Chlorophyta** | | |
| *Enteromorpha compressa* (L.) Nees | *Ulva compressa* (L.) | Hayden et al. 2003 |
| *Enteromorpha flexuosa* (Wulf.ex Roth) J.Agardh ssp. *paradoxa* | *Ulva flexuosa* ssp. *paradoxa* (C. Agardh) M. Wynne | Hayden et al. 2003 |
| *Enteromorpha intestinalis* (L.) Nees | *Ulva intestinalis* (L) | Hayden et al. 2003 |
| *Enteromorpha linza* (L.) J. Agardh | *Ulva linza* (L.) | Hayden et al. 2003 |
| *Enteromorpha prolifera* (O.F. Mull) J. Agardh | *Ulva prolifera* (O. Mull.) | Hayden et al. 2003 |
| *Enteromorpha* sp. | *Ulva* sp. | Hayden et al. 2003 |
| **Phaeophyta** | | |
| *Laminaria saccharina* (L.) J.V.Lamour. | *Saccharina latissima* (L.) C. Lane, C. Mayes, Druehl & G. Saunders comb.nov. | Lane et al. 2006 |
| **Rhodophyta** | | |
| *Ceramium rubrum* (Huds) C. Ag. | *Ceramium virgatum* (Roth) | Maggs et al. 2002 |
| *Polysiphonia harveyi* Bailey | *Neosiphonia harveyi* (Bailey) M. Kim, H. Chol, G. & G. Saunders | Choi et al. 2001 |

Appendix Table 5-3. **The Occurrence of Macroalgae from General Collections and Destructive Samples at all Intertidal and Subtidal Stations Sampled between 1978 and 2009 (Intertidal Collections have not been made since the end of 2001). Seabrook Operational Report, 2009.**



| 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 | 08 |
| *Blidingia minima* (Naegeli ex Kütz.) Kylin | x | | x | x | x | x | x | x | x | | | | | | | | | | x | | | | | | | | | | | | |
| *Bryopsis plumosa* (Huds.) C.Agardh | | | | | | | x | | | | | | | | x | x | | | | | | | | | | | | | | | |
| *Chaetomorpha aerea* (Dillwyn) Kütz. | | | | | 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 | | x |
| *Chaetomorpha linum* (O.F.Mull.) Kütz. | 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 | x |
| *Chaetomorpha melagonium* (F.Weber et D.Mohr) Kütz. | 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 | x |
| *Chaetomorpha picquotiana* Mont. ex Kütz. | 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* sp. | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | | | | | | | | | | | |
| *Cladophora albida* (Nees) Kütz. | | | | | | | | | | | | | | | | | | | | x | | | | | | | | | | | |
| *Cladophora sericea* (Huds.) Kütz. | 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* Kütz. | 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) Kütz. | 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 | x |
| *Spongomorpha aeruginosa* (L.) C. Hoek | | | | | | | | | | | | | | | | | | | | | x | | x | | | | | | | | |
| *Spongomorpha arcta* (Dillwyn) Kütz. | x | x | | x | x | x | x | | x | | | x | | x | x | | | x | x | x | | x | x | x | | | x | | | | |
| Spongomorpha sp. | x | | | | | | | | | | | | | | | | | | x | | | | | | | | | | | | |
| *Spongomorpha spinescens* Kütz. | 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 | x |
| *Ulvaria obscura* (Kütz.) 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 | 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** | **7** |

(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 | 08 |
| *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 | 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 | 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* L. var. spiralis Farl. | | | | | | x | | | | | | | x | | | | | | x | | x | x | | | | | | | | | |
| *Halosiphon tomentosus* (Lyngb.) Jaasund | | | | | | | | | | | | | | | | | | | x | | x | | | | | x | | | | | |
| *Halothrix lumbricalis* (Kütz.) 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 | x |
| *Saccharina latissima* (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 | 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* (Börgesen) 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 | 08 |
| *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.) Kütz. | | | 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 | 4 |

(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** | **08** |
| *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 | 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 | x |
| *Audouinella bonnemaisoniae* (Batters) P.S. Dixon | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Audouinella daviesii* (Dillwyn) Woelk. | | | | | | | | | | | | | | x | | | x | | | | | | | | | | | | | | |
| *Audouinella membranacea* (Magnus) Papenf. | | | | | | | | | | | | | | | x | x | | | | | | | | | | | | | | | |
| *Audouinella purpurea* (Lightf.) Woelk. | | | | | | | x | | x | x | | x | | | | | | | | | | | | | | | | | | | |
| *Audouinella* sp. | | | | | | | | | | | | x | | | | | x | 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 | 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 | 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 | 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 | 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 | 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 | | 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 | 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 | 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 | 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 | x |
| *Hildenbrandia rubra* (Sommerf.) Menegh. | | | x | | | 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 | 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 | 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 | 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** | **08** |
| *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 | 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 | 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 | 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 | 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 | x |
| *Plumaria plumosa* (Huds.) Kuntze | | | x | | x | x | x | x | x | x | | x | | | | | | | x | x | x | | | | | | | | | | |
| *Pneophyllum fragile* Kütz. | 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 | 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 | 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 | 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 | 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 | 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 | 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 | | | | | | | | 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* Kütz. | 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 | 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 | 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 | 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 | 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** | **32** |

(continued)

## Appendix Table 5-3. (Continued)

| OVERALL TOTAL | |
|---|---|
| | All Years |
| Total Taxa Over All Years | 160 |

| TOTAL TAXA BY YEARS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 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 | 08 |
| 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 | 43 |

* To maintain consistency within the long-term data base, taxonomy will be based on morphological characteristics such as those described by Sears (2002) and Villalard-Bohnsack (2003). The evolving algal taxonomy based on molecular investigations will not be incorporated into this report. For example, *Saccharina latissima* (Linnaeus) J.V. Lamouroux 1813 is used instead of *Saccharina latissima* (Linnaeus) C.E. Lane, C. Mayes, Druehl & G.W. Saunders 2006.

**Appendix Table 5-4. Description of Benthic Stations Sampled at Non-destructive Transects in Summer 2009. Seabrook Operational Report, 2009.**

| | | Depth[a] | | | Substrate[b] | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Station** | **Zone** | **Feet** | **Meters** | **Ledge** | **Cobble** | **Mixture[c]** |
| **Nearfield** | **B17** | **shallow** | 16 | 4.9 | 100 | 0 | 0 |
| | **B19** | **mid-depth** | 40 | 12.2 | 87 | 6 | 7 |
| **Farfield** | **B35** | **shallow** | 15 | 4.6 | 86 | 8 | 6 |
| | **B31** | **mid-depth** | 31 | 9.4 | 41 | 14 | 42 |

[a] bottom depth at mean low water
[b] Mean percent cover of substrate types (from Appendix Table 9-11B. NAI 2009. Seabrook 2009 Data Report (in press))
[c] Mixture=gravel and sand, which may be over rock

**Appendix Table 5-5. Nomenclatural Authorities and Common Names of Macrofaunal Taxa Cited in the Marine Macrobenthos Section. Seabrook Operational Report, 2009.**

| Scientific Name | Common Name[a] |
|---|---|
| Ectoprocta | moss animals |
| *Membranipora membranacea* (Linnaeus 1767) | membranipora |
| Mollusca | |
| Gastropoda | snails |
| *Lacuna vincta* (Montagu 1803) | Atlantic chink shell |
| *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 |
| *Mytilus edulis* (Linnaeus 1758) | blue mussel |
| *Mytilus trossulus* (Gould 1850) | mussel |
| *Modiolus modiolus* (Linnaeus 1758) | horse mussel |
| *Anomia* sp. | jingle shell |
| *Hiatella* sp. | arctic saxicave |
| 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 |
| *Caprella* sp. | skeleton shrimp |
| *Ampithoe rubricata* (Montagu 1808) | amphipod |
| *Calliopius laeviusculus* (Kroyer 1838) | planktonic amphipod |
| *Ericthonius rubricornis* (Stimpson 1853) | amphipod |
| *Gammarellus angulosus* (Rathke 1843) | amphipod |
| *Ischyrocerus anguipes* (Kroyer 1838) | amphipod |
| *Jassa marmorata* (Holme 1903) | amphipod |
| *Pontogeneia inermis* (Krøyer 1842) | hyperbenthic amphipod |
| *Cancer spp.* | crab |
| *Carcinus maenas* (Linnaeus 1758) | European green crab |
| Echinodermata | spiny-skinned animals |
| Echinoidea | sea urchins |
| *Strongylocentrotus droebachiensis* (Müller 1776) | green sea urchin |
| Asteroidea | sea stars |
| Asteriidae | sea stars |
| *Asterias forbesii* (Descor, 1848) | common sea star |
| *Asterias rubens* (Linnaeus 1758) formerly *A.vulgaris* | northern sea star |
| *Asterias spp.* | sea star |
| *Henricia spp.* | blood star |
| *Solaster spp.* | sun star |
| Chordata | chordates |
| *Molgula* sp. | sea squirt |
| *Diplosoma listerianum (Milne-Edwards 1841)* | tunicate |

[a] Primarily from Gosner 1971, Barns 1987, Abbott 1974 and the World Register of Marine Species at www.marinespecies.org.

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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 2009 (0.6 – 0.9/ 1000m$^2$) was higher than preoperational mean (0.4 - 0.6/m$^2$) but equal to or lower than the operational means (0.9 - 1.1/1000m$^2$). The lobster larval density in 2009 decreased from the previous year at the intake station (P2) and the farfield station (P7), and increased slightly at the discharge station (P5). 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 2009, lobster larvae at Station P2 were not present until the second week of June and then increased to a peak in the fourth week of June with secondary peaks in the second week of August and the third week of September. In the preoperational and operational periods, density at P2 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 2009 increased from the previous year at the nearfield station (116.8) and farfield station (130.4). Total $CPUE_2$ at both stations was greater than both the preoperational (nearfield: 65.5; farfield: 81.4) and operational (nearfield: 89.8; farfield: 103.7) means. Total $CPUE_2$ was significantly higher in the operational period than the preoperational period, but 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 2009 (nearfield: 4.7; farfield: 4.1) was higher than the operational means (nearfield: 3.8; farfield: 3.5) and lower than the preoperational means (nearfield and 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: $r_S$=0.51; farfield: $r_S$=0.55) with June through November mean surface water temperature lagged by six years. This correlation suggests that recruitment from the larval stage is enhanced by warm water temperatures during the larval period.

An estimated 21 lobsters were impinged in 2009. The 20-year average of lobster impingement was 15.9/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 2009 (9,878/1000 $m^3$ and 8,565/1000 $m^3$) were lower than the operational means and similar to the preoperational means. 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 2009 at the nearfield station (6.8) and the farfield station (2.9) was lower than the operational period (nearfield: 14.1; farfield: 8.2) and the pre-operational period means (nearfield: 12.2; farfield: 9.6) means. 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 $CPUE_2$ has followed similar trends among years with $CPUE_2$ usually higher at the nearfield station.

Rock crab CPUE in 2009 at the nearfield (1.9) and farfield stations (1.0) was lower than the preoperational (nearfield: 2.6; farfield: 1.5) and operational means (nearfield: 2.8; farfield 4.4). 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 through 2000 but decreased from 2001 through 2009. 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 as they transition from planktonic to benthic (bottom dwelling) stages. Lobster larvae may also be entrained in the buoyant discharge plume, which may affect survival, molting, and settlement to the bottom. The benthic 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 2,874 to 4,300 $m^2$).

***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 were classified as legal. For the purposes of this report, 3-1/4 inches was converted to 83 mm and lobsters

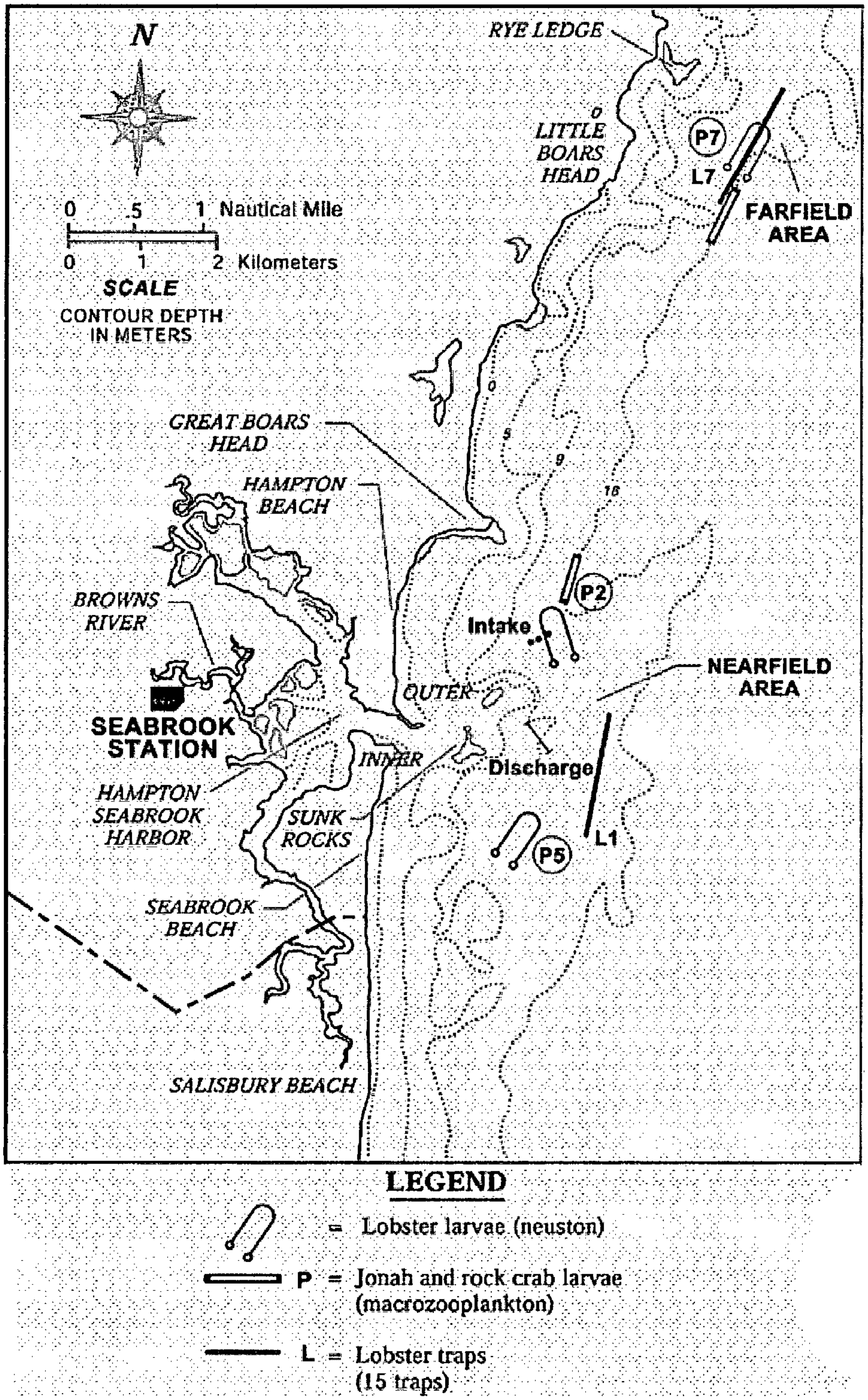



Figure 6-1. Epibenthic crustacea (American lobsters, Jonah and rock crabs) sampling stations. Seabrook Operational Report, 2009.

greater than or equal to 83 mm were presented as legal. Jonah and rock crab carapace widths (CW) were recorded to the nearest mm. The total numbers 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 (1991-2009) 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 a soak time of five days, 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 3% 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 times

$C_2$ = Mean catch of samples with soak time of 2 days (90.4 lobsters and 11.1 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 (1991-2009) 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).

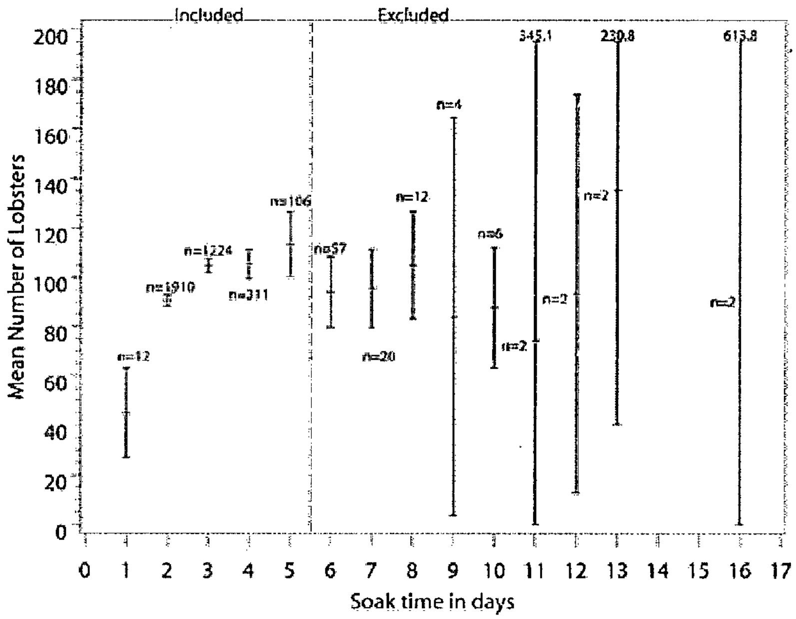
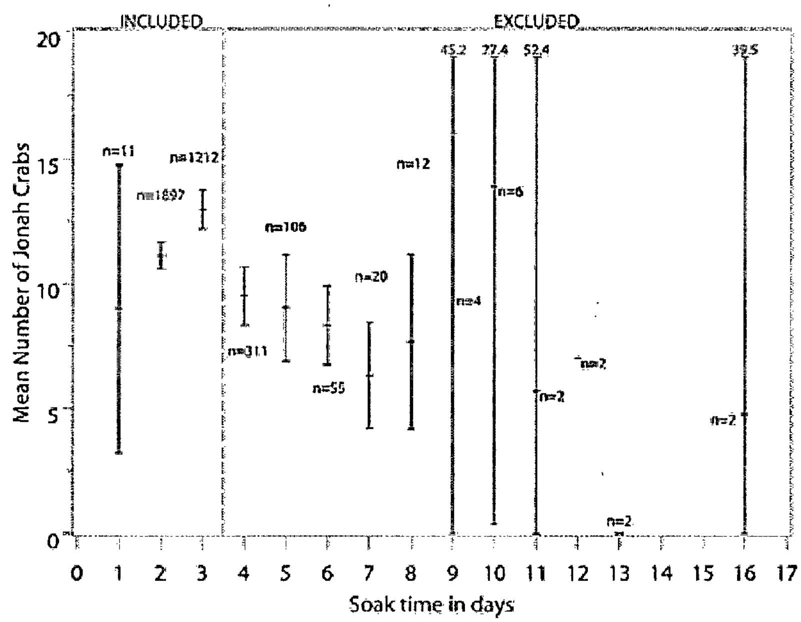



Figure 6-2. The relationship between soak time (number of days submerged) and mean catch of lobsters (per 15 traps) with 95% confidence intervals (C.I.), 1982-2009 at Stations L1 and L7. Seabrook Operational Report, 2009.

**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, 2009.**

| 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 | 2.009 | 9.0 | 1.233 |
| 2 | 90.4 | 1.000 | 11.1 | 1.000 |
| 3 | 104.8 | 0.863 | 13.0 | 0.854 |
| 4 | 105.4 | 0.858 | n/a | n/a |
| 5 | 113.4 | 0.797 | n/a | n/a |

a.




b.

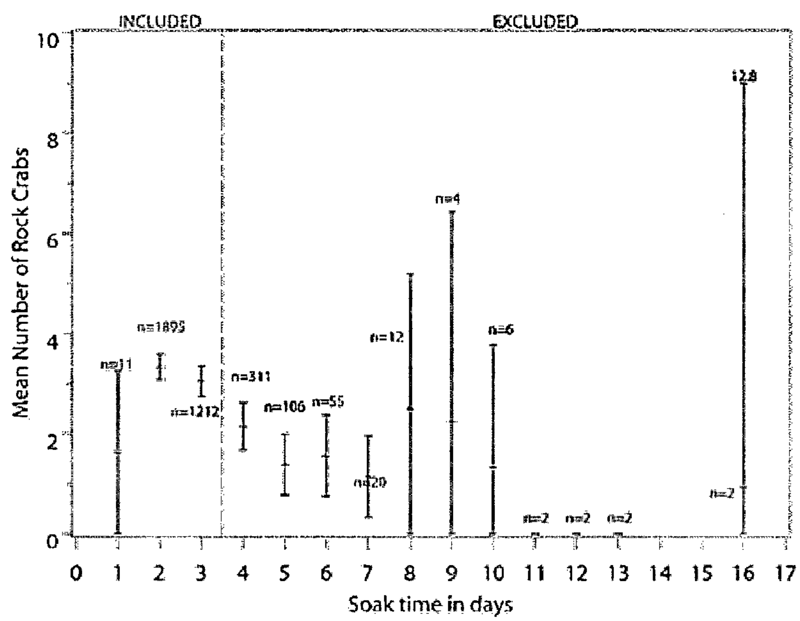



Figure 6-3. The relationship between soak time (number of days submerged) and mean catch of a) Jonah crab and b) rock crab (per 15 traps) with 95% confidence intervals (C.I.), 1982-2007 at Stations L1 and L7. Seabrook Operational Report, 2009.

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 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 13% 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 2009 at each station was equal to or higher than the corresponding preoperational mean and equal to the operational period mean at Station P2 (Table 6-2). Density at Station P7 was higher than Stations P2 and P5 in both the preoperational and operational periods. The larval densities in 2009 decreased from larval densities in 2008 at Stations P2 and P7, but increased at Station 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

**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 2009. Seabrook Operational Report, 2009.**

| Species (period sampled) | Station | Preoperational[a] LCL[d] | Preoperational[a] Mean | Preoperational[a] UCL[e] | 2009[b] Mean | Operational[c] LCL[d] | Operational[c] Mean | Operational[c] UCL[e] |
|---|---|---|---|---|---|---|---|---|
| **Lobster larvae** (May-Oct) | P2 | 0.4 | 0.4 | 0.5 | 0.9 | 0.8 | 0.9 | 1.1 |
| | P5 | 0.0 | 0.4 | 3.2 | 0.7 | 0.7 | 0.8 | 0.9 |
| | P7 | 0.4 | 0.6 | 0.8 | 0.6 | 0.9 | 1.1 | 1.1 |
| **Lobster, total** (Jun-Nov) | L1 | 54.5 | 65.5 | 76.7 | 116.8 | 79.1 | 89.8 | 100.4 |
| | L7 | 69.7 | 81.4 | 93.2 | 130.4 | 89.0 | 103.7 | 118.4 |
| **Lobster, legal** (Jun-Nov) | L1 | 4.1 | 5.6 | 7.0 | 4.7 | 3.2 | 3.8 | 4.4 |
| | L7 | 3.9 | 5.6 | 7.4 | 4.1 | 2.9 | 3.5 | 4.1 |
| **Lobster, female** (Jun-Nov) | L1 | 30.4 | 36.3 | 42.1 | 62.4 | 42.5 | 48.0 | 53.6 |
| | L7 | 37.7 | 44.2 | 50.6 | 70.1 | 48.1 | 56.0 | 63.9 |
| **Lobster, egg-bearing** (Jun-Nov) | L1 | 0.4 | 0.5 | 0.6 | 1.8 | 0.9 | 1.4 | 1.8 |
| | L7 | 0.4 | 0.5 | 0.7 | 2.2 | 1.3 | 1.8 | 2.3 |
| ***Cancer* spp. larvae** (May-Sep)[f] | P2 | 6,791 | 9,532 | 13,380 | 9,878 | 6,897 | 10,671 | 16,510 |
| | P7 | 4,926 | 8,426 | 14,414 | 8,565 | 8,115 | 11,130 | 15,265 |
| **Jonah crab, total** (Jun-Nov) | L1 | 7.3 | 12.2 | 17.0 | 6.8 | 11.6 | 14.1 | 16.5 |
| | L7 | 7.0 | 9.6 | 12.2 | 2.9 | 5.3 | 8.2 | 11.0 |
| **Jonah crab, female** (Jun-Nov) | L1 | 5.8 | 9.4 | 13.1 | 3.9 | 8.1 | 9.8 | 11.4 |
| | L7 | 5.1 | 6.9 | 8.7 | 1.5 | 3.1 | 4.8 | 6.4 |
| **Rock crab, total** (Jun-Nov) | L1 | 0.9 | 2.6 | 4.2 | 1.9 | 2.1 | 2.8 | 3.6 |
| | L7 | 0.0 | 1.5 | 3.1 | 1.0 | 3.0 | 4.4 | 5.8 |
| **Rock crab, female** (Jun-Nov) | L1 | 0.0 | 0.5 | 1.0 | 0.2 | 0.1 | 0.4 | 0.7 |
| | L7 | 0.0 | 0.3 | 0.6 | 0.2 | 0.3 | 0.6 | 0.9 |

[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] 2009 mean; mean of the total number of samples collected during the period sampled.

[c] Operational: 1991-2009, 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).

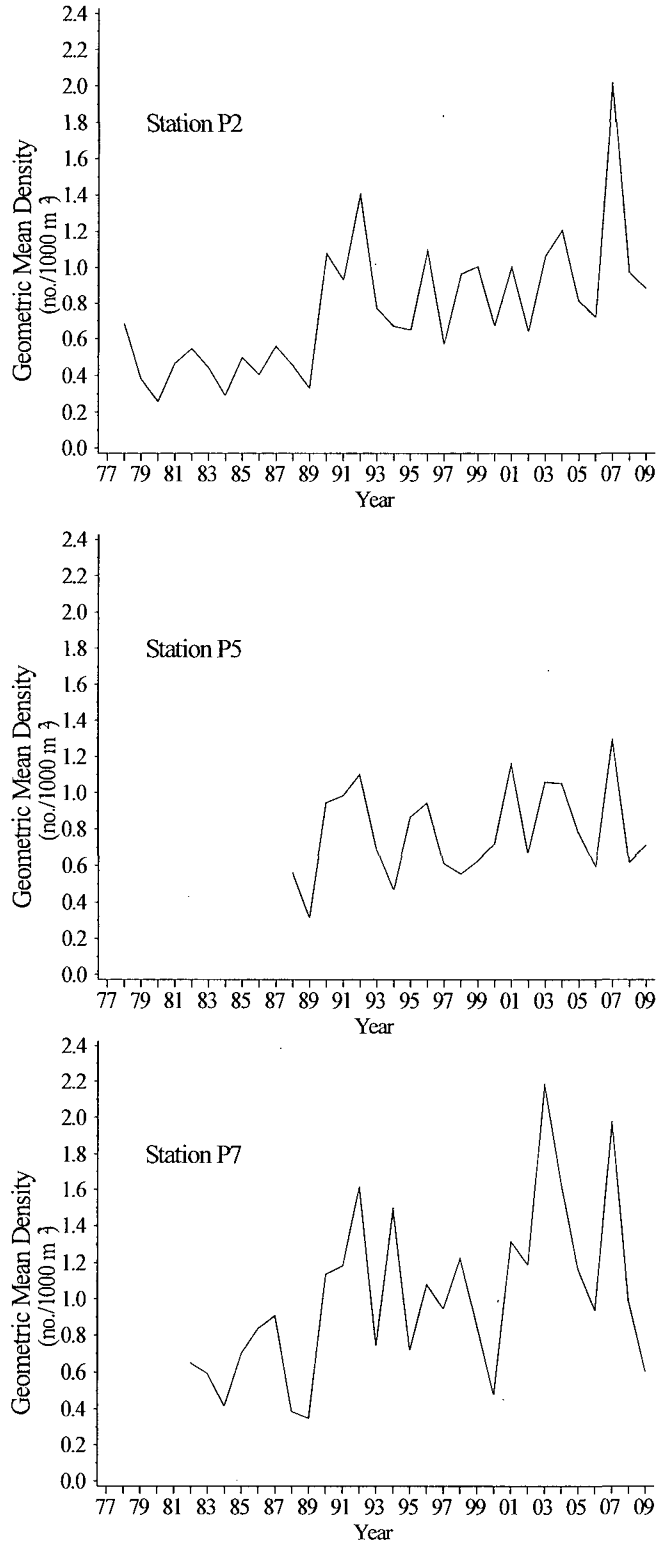



Figure 6-4. Geometric mean density (no./1000 $m^2$) of lobster larvae at Stations P2 (1978-2009), P5 (1988-2009) and P7 (1982-2009). Seabrook Operational Report, 2009.

**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, 2009.**

| 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, 79.7 | 6.90 | 0.0103* | Op >Preop |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0 | 0.5000 | |
| | Week(Year)[c] | 0.08 | 522.74 | <0.0001* | |
| | Station[d] | 0 | 0 | 0.5000 | |
| | Preop-Op X Station[e] | <0.01 | 1.90 | 0.0840 | |
| | Station X Year (Preop-Op)[f] | 0 | 0 | 0.5000 | |
| | Error | 0.05 | | | |
| Lobster (total catch) | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 24.2 | 6.51 | 0.0174* | Op >Preop |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 225.39 | 4.84 | 0.0139* | |
| | Month(Year)[c] | 1,259.93 | 2,672.49 | <0.0001* | |
| | Station[d] | 104.38 | 3.00 | 0.0412 | |
| | Preop-Op X Station[e] | 0 | 0 | 0.4997 | |
| | Station X Year (Preop-Op)[f] | 69.75 | 103.75 | <0.0001* | |
| | Error | 709.98 | | | |
| Lobster (legal size) | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 25.7 | 9.42 | 0.0050* | Preop > Op |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 1.52 | 23.90 | <0.0001* | |
| | Month(Year)[c] | 2.86 | 854.07 | <0.0001* | |
| | Station[d] | 0 | 0 | 0.4996 | |
| | Preop-Op X Station[e] | 0.02 | 0.92 | 0.1694 | |
| | Station X Year (Preop-Op)[f] | 0.06 | 3.72 | 0.0269* | |
| | Error | 5.84 | | | |
| *Cancer* spp. Larvae | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 120 | 0.10 | 0.7511 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0.0 | 0 | 0.5000 | |
| | Month(Year)[c] | 0.80 | 154.16 | <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 | 0.70 | | | |
| Jonah Crab (Jun-Nov) | **Fixed Effects** | **DF[g]** | **F[h]** | **p[i]** | |
| | Preop-Op[a] | 1, 3.74 | 0.02 | 0.8890 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 9.71 | 4.46 | 0.0173* | |
| | Month(Year)[c] | 43.04 | 953.71 | <0.0001* | |
| | Station[d] | 8.17 | 0.71 | 0.1991 | |
| | Preop-Op X Station[e] | 2.33 | 1.66 | 0.0988 | |
| | Station X Year (Preop-Op)[f] | 6.72 | 88.52 | <0.0001* | |
| | Error | 70.32 | | | |

(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, 3.51 | 1.59 | 0.2844 | |
| | **Random Effects** | **Estimate[j]** | $\chi^2$ | **P** | |
| | Year (Preop-Op)[b] | 0 | 0 | 0.5000 | |
| | Month(Year)[c] | 7.78 | 639.41 | <0.0001* | |
| | Station[d] | 0 | 0 | 0.4988 | |
| | Preop-Op X Station[e] | 0.72 | 2.88 | 0.0449* | OpL7>OpL1 PreL1>PreL7 |
| | Station X Year (Preop-Op)[f] | 3.08 | 170.44 | <0.0001* | |
| | Error | 18.66 | | | |

[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: 1991-2009 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)

preoperational and operational periods at all 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 2009 differed from the preoperational and operational patterns (Figure 6-5a). In 2009, as in the previous year, larvae at Station P2 were not present until the second week of June. Density increased to a peak for 2009 in the fourth week of June with secondary peaks in the second week of August and the first week of September. Larvae were absent by the second week in 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 2009, lobster larval density at Station P2 exceeded the preoperational upper confidence limits during the second week of June, the fourth week of June through the first week of July, the second week of August, and the first week of September. Stage I and secondarily Stage IV larvae were the most abundant life stages in 2009 at Station P2, whereas Stage IV larvae were typically most abundant for most preoperational and operational years (Figure 6-5b). The high annual density of Stage I larvae in 2009 is a result of the peak in density that occurred in the first week of June that was composed entirely of Stage I larvae. Mean density of Stage I larvae in 2009 was higher than the preoperational and operational confidence limits. Mean density of Stage II larvae in 2009 was within the 95% confidence limits for the preoperational and operational periods, and no Stage III larvae were captured in 2009. Mean density of Stage IV larvae in 2009 was below the confidence intervals of both periods (Figure 6-5b).

***Total Catch: Legal- and Sublegal-Size***

Annual mean $CPUE_2$ of total lobster in 2009 was above the preoperational and operational 95% confidence limits at both stations (Table 6-2). Sublegal lobsters were the primary component of total lobsters (Figure 6-6a). The $CPUE_2$ of sublegal lobsters

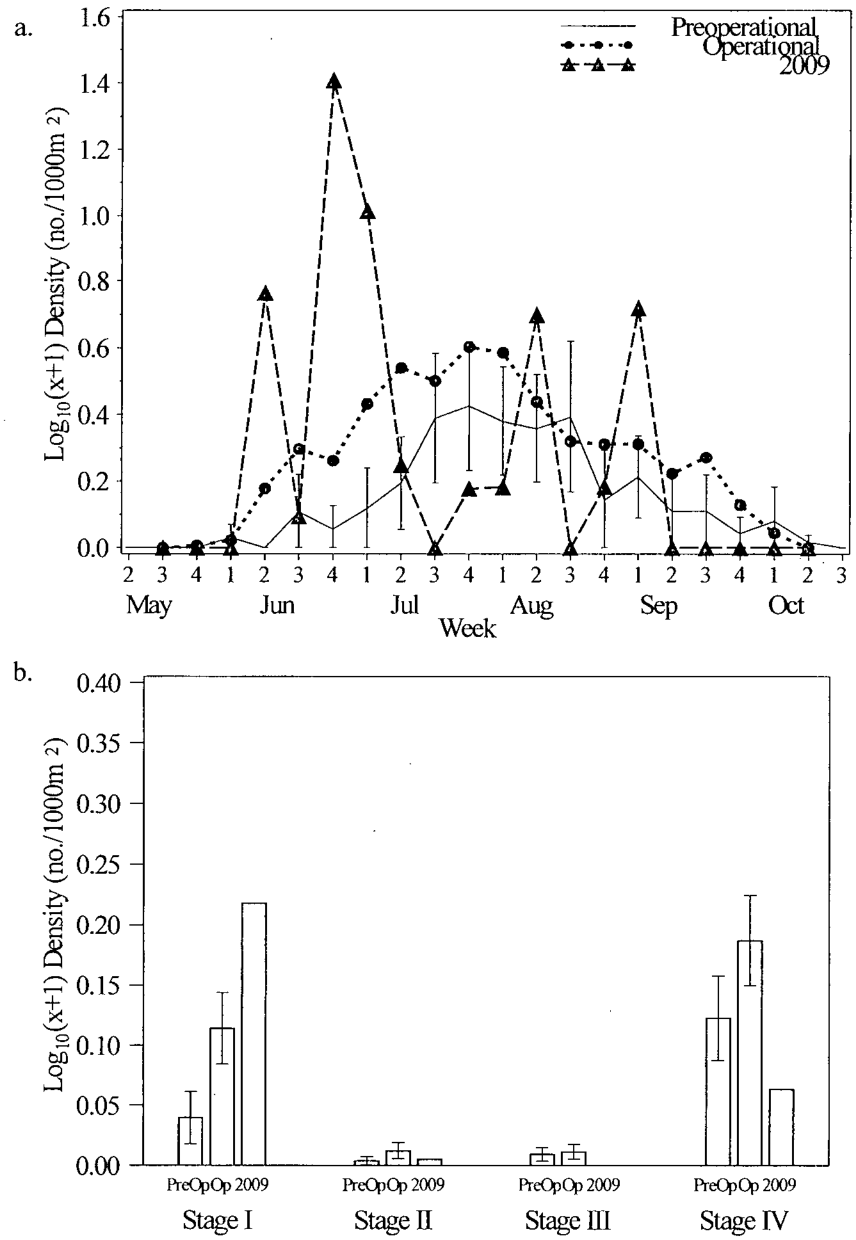



Figure 6-5. Preoperational and operational means with 95% confidence limits and 2009 means of a) weekly density (no./1000 m$^2$) of lobster larvae at Station P2, b) lobster larvae density by lifestage at P2. Seabrook Operational Report, 2009.

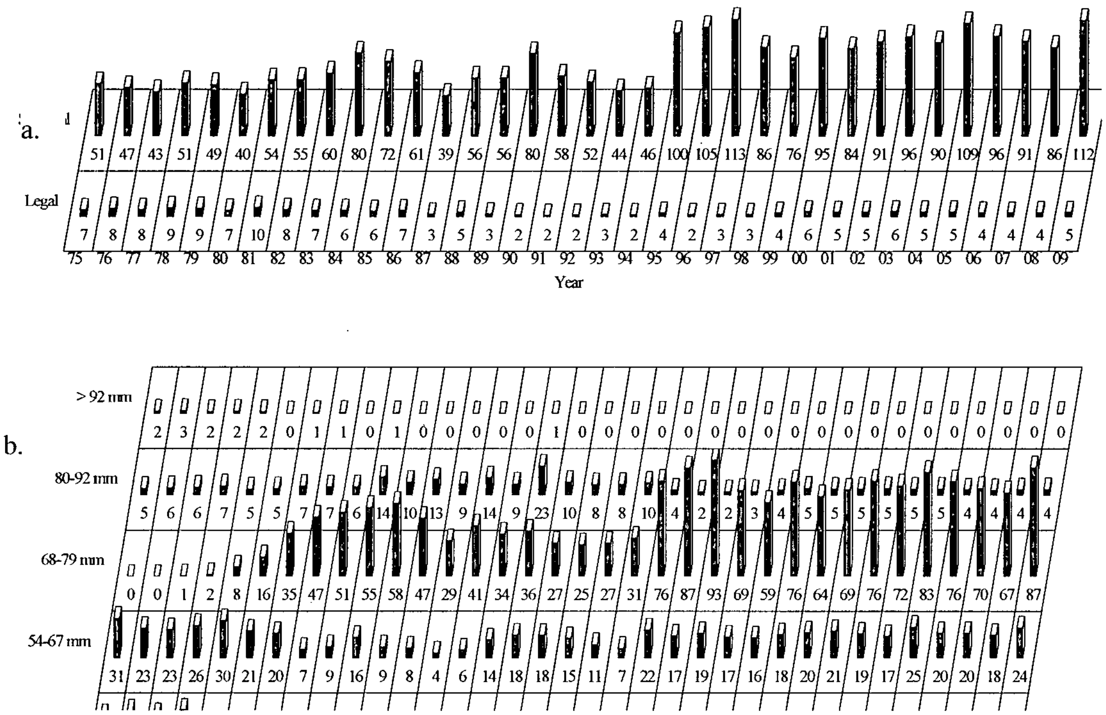


Figure 6-6. a) $CPUE_2$ of sublegal- and legal-size lobster at Station L1 and b) size class distribution at Station L1 from 1975-2009. Seabrook Operational Report, 2009.

at Station L1 was relatively low from 1975 through 1994 and reached the highest point in the time series in 1997 with a secondary peak in 2005. $CPUE_2$ declined from 2006 through 2008, but in 2009 the $CPUE_2$ was the second highest in the time series.

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 been higher than the Station L1 every year except 1991 and 1992. $CPUE_2$ was almost identical between the stations in 1994 through 1996, and 1998, and reverted to the usual pattern of higher catches at Station L7 in 1997 and 1999 through 2009 (Figure 6-7). Annual mean $CPUE_2$ at both stations decreased from 2006 through 2008 and increased in 2009. Mean $CPUE_2$ at both stations followed a similar trend in the operational period except in 1993, 2004 and 2006 (Figure 6-7).

Monthly mean $CPUE_2$ of total lobster at Station L1 in 2009 increased from June through August and decreased from September through November (Figure 6-8a). The pattern of monthly mean $CPUE_2$ in the operational period was slightly different with peak $CPUE_2$ occurring in October. Monthly mean $CPUE_2$ in 2009 was higher than the corresponding preoperational monthly means every month and higher than the operational monthly means every month except October and November (Figure 6-8a). Mean $CPUE_2$ of total lobster in the operational period was significantly greater than in the preoperational period, but there were no significant differences between stations (Table 6-3). The

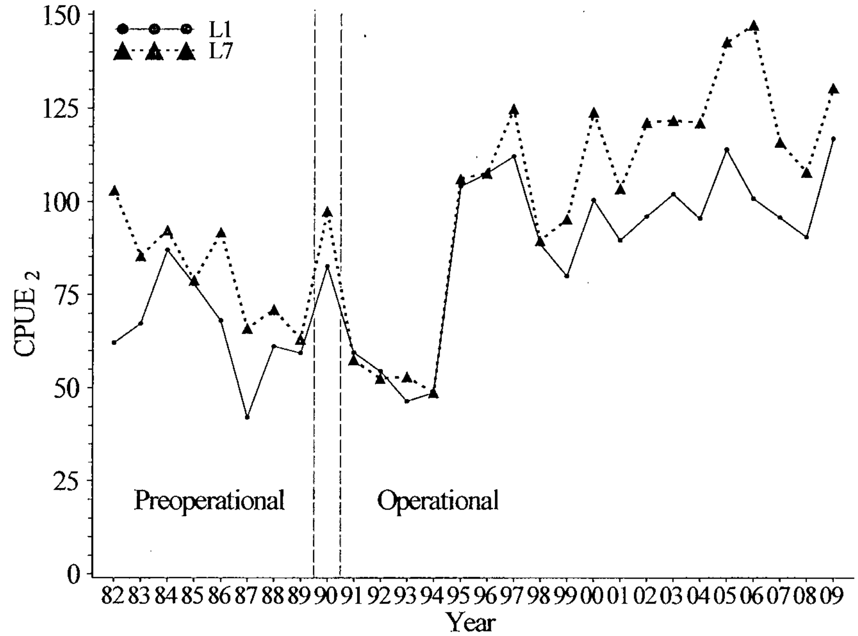



Figure 6-7. Annual mean $CPUE_2$ of total lobster, 1982-2009 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2009.

interaction term was not significant, indicating consistency in $CPUE_2$ of total lobsters between stations.

Water temperature in previous years may have affected total catch of 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 ($r_S$=0.63) and six years ($r_S$=0.51) at Station L1, and lagged by one ($r_S$=0.41) and six years ($r_S$=0.55) at Station L7 (Table 6-4; Figure 6-9). Within the sublegal category, the greatest correlations between water temperature lagged by 1 or 6 years and $CPUE_2$ occurred in the 54-67 mm length groups at Station L1, and the 68-79 mm length group at Station L7.

### *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 2009, $CPUE_2$ 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 in 2009 increased from the previous year to 4.7 lobsters per 15 traps at Station L1 and 4.1 lobsters per 15 traps at Station L7 (Figure 6-6; Table 6-2). The monthly pattern of mean $CPUE_2$ at Station L1 in 2009 showed an early peak in July compared to the preoperational and operational period peaks in August (Figure 6-8b). In the preoperational period and 2009 there was second peak in $CPUE_2$ in October. Mean $CPUE_2$ of legal-size lobsters in 2009 was lower than the lower 95%

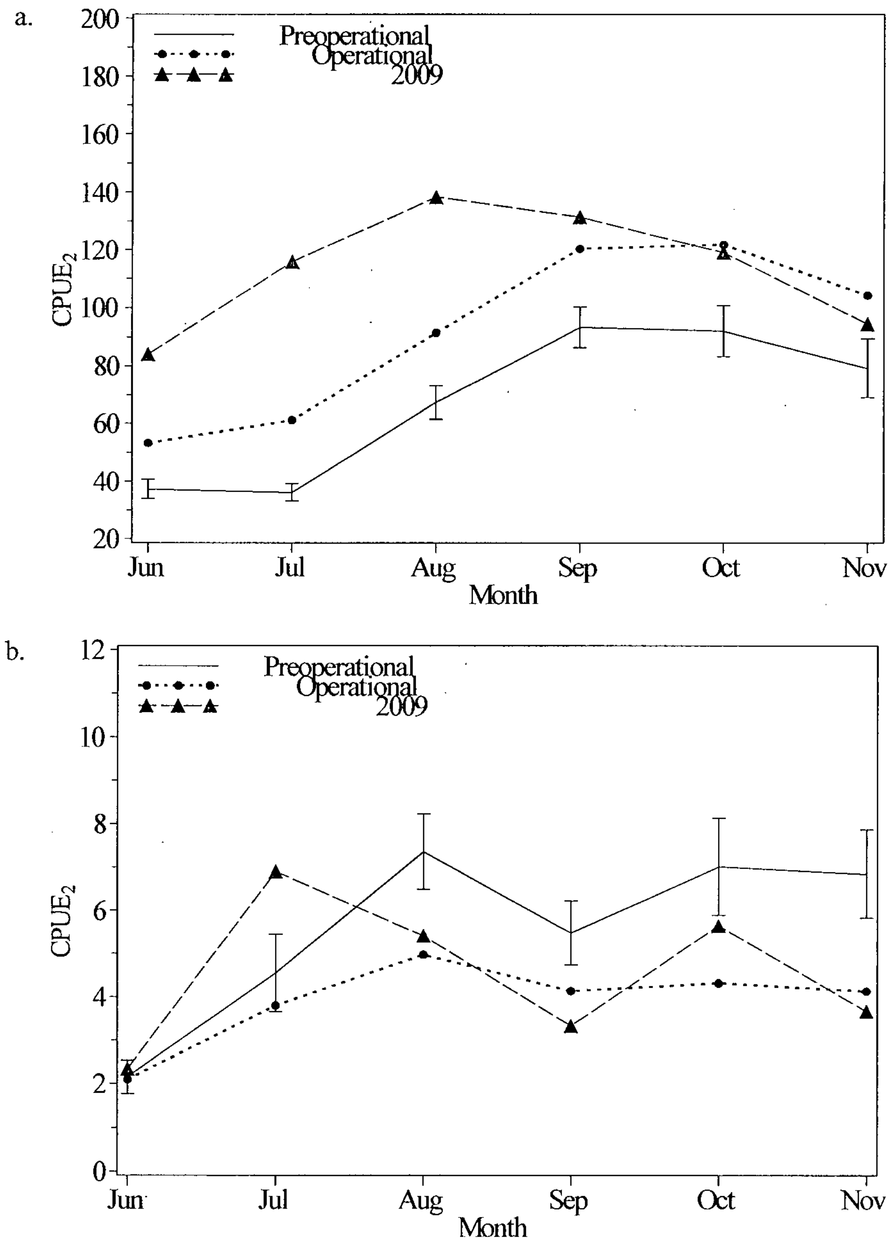
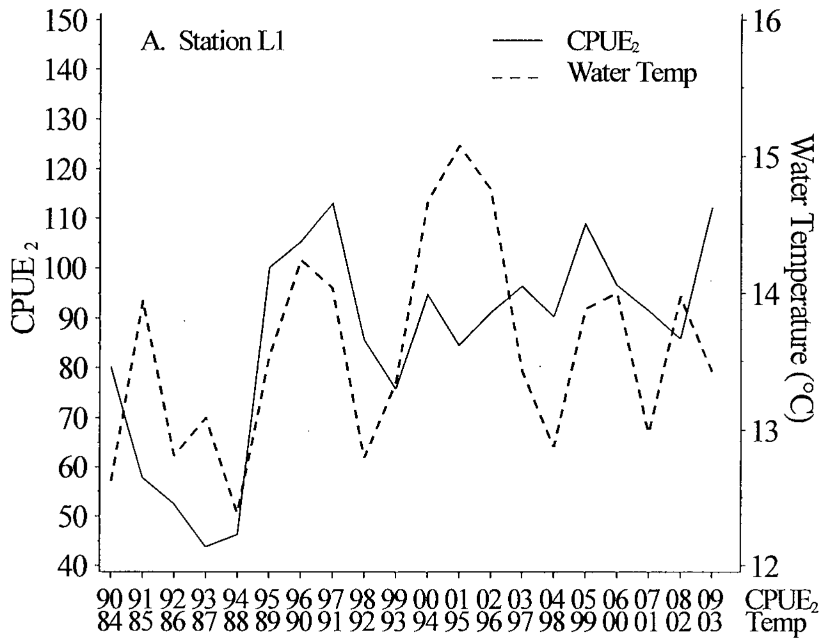



Figure 6-8. Preoperational and operational means with 95% confidence limits and 2009 means of a) monthly $CPUE_2$ of total (legal and sublegal) lobster at Station L1, and b) monthly $CPUE_2$ of legal-size lobster at Station L1. Seabrook Operational Report, 2009.



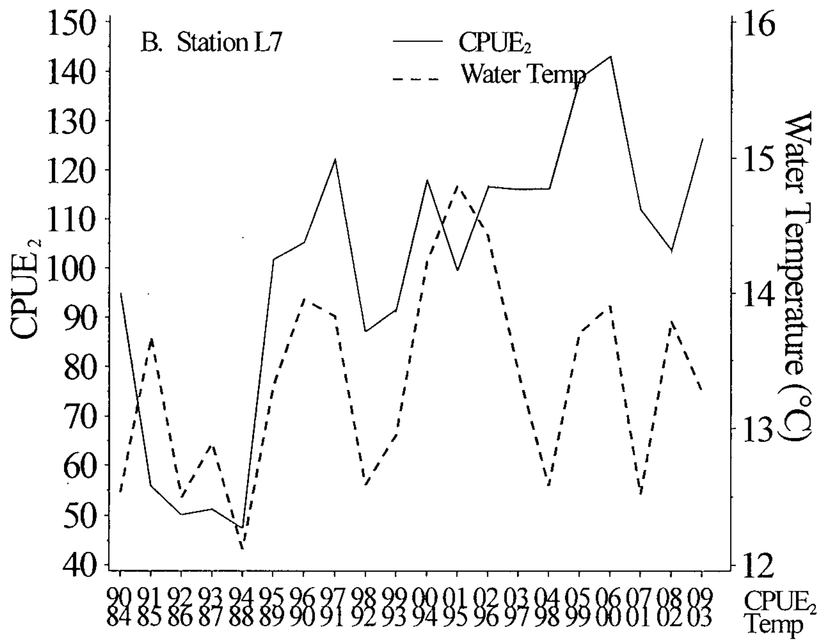




Figure 6-9. Relationship between sublegal-size lobster $CPUE_2$ from 1990 through 2009 and mean June through November surface water temperature lagged by six years at Stations: a. L1 (nearfield) and b. L7 (farfield). Seabrook Operational Report, 2009.

**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, 2009.**

**Correlation Coefficients/probability>r/Lag (Years)**

| | Station | |
|---|---|---|
| **Size Class** | **L1** | **L7** |
| Sublegal (<83 mm) | 0.63**/(1) | 0.41*/(1) |
| | 0.51*/(6) | 0.55**/(6) |
| 68-79 mm | 0.54**/(1) | 0.41*/(1) |
| | 0.45*/(6) | 0.49*/(6) |
| 54-67 mm | 0.57**/(1) | |
| | 0.56**/(6) | 0.46*/(6) |
| Legal | 0.42 NS/(6) | 0.43 NS/(6) |

(n) = lag time in years
NS = Not Significant ($p > 0.05$)
* Significant ($0.05 \geq p > 0.01$)
** Highly Significant ($0.01 \geq p > 0.001$)

confidence limit for the preoperational period every month except June and July (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 2009, legal-size lobsters were also 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.

### *Size Class and Sex Distribution*

Most lobsters collected in 2009 were sublegal and in the 68-79 mm (2 5/8-3 1/8 in.) carapace length size class (Figures 6-6 a, b). This size class has been most numerous every year since 1981. $CPUE_2$ in this size class in 2009 was within the range of recent years, and the highest since 1997 (Figure 6-6b). $CPUE_2$ of female lobsters in 2009 increased from 2008 at both stations (NAI 2008) and was above the preoperational and operational period confidence limits at each station (Table 6-2). Females comprised a relatively constant percentage of the total catch throughout the study period. In 2009, females were 53 to 54% of the total catch at the nearfield and farfield stations respectively, similar to that in the operational (53% nearfield; 54% farfield) and preoperational periods (55% nearfield; 54% farfield).

Mean $CPUE_2$ of ovigerous females for 2009 at both stations was higher than the mean $CPUE_2$ for the preoperational and operational periods, but lower than the means for 2008 at both stations (Table 6-2; NAI 2009). In 2009, ovigerous females were 1.5% of the total catch at the nearfield station and 1.7% 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 1.6% (nearfield) and 1.7% (farfield) of the catch.

### *Impingement*

An estimated 21 lobsters were impinged in 2009. The 20-year average of lobster impingement was 15.9/year. In previous years, lobster impingement ranged from 0 in 2000 to 77 in 2005 (Table 6-5).

## 6.3.2 Jonah and Rock Crabs

### *Larvae*

Density of *Cancer* spp. (*Cancer borealis* and *C. irroratus*) larvae in 2009 was similar to the preoperational means and lower than the operational means at both stations (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 nearly identical trends at both stations (Figure 6-10). Mean density was highest in 1999 at both stations, and has generally decreased since then at both stations. In 2009, mean density increased from the low densities of the previous years at both stations.

The monthly abundance of *Cancer* spp. larvae in 2009 was generally similar to the preoperational and operational periods (Figure 6-11a). Monthly mean density of *Cancer* spp. larvae in 2009 was higher than the preoperational and operational means in May and June and was below the preoperational and operational means from July through December. The highest monthly mean in 2009 occurred in June with a secondary peak in August. In the preoperational and operational periods, density was low until May, increased through August, and then decreased through December. The monthly means for the operational period were within the 95% confidence intervals of the preoperational means for every month except March.

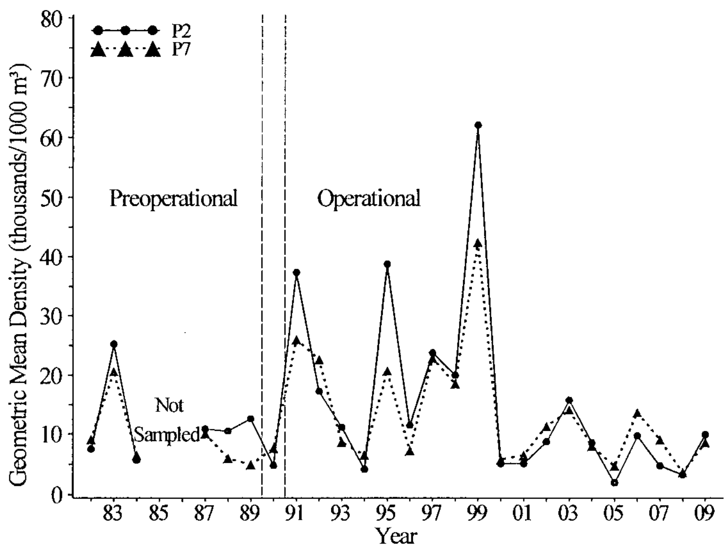



Figure 6-10. Annual geometric mean density (thousands/1000 m$^3$) of *Cancer* spp. larvae from 1982-2009 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2009.

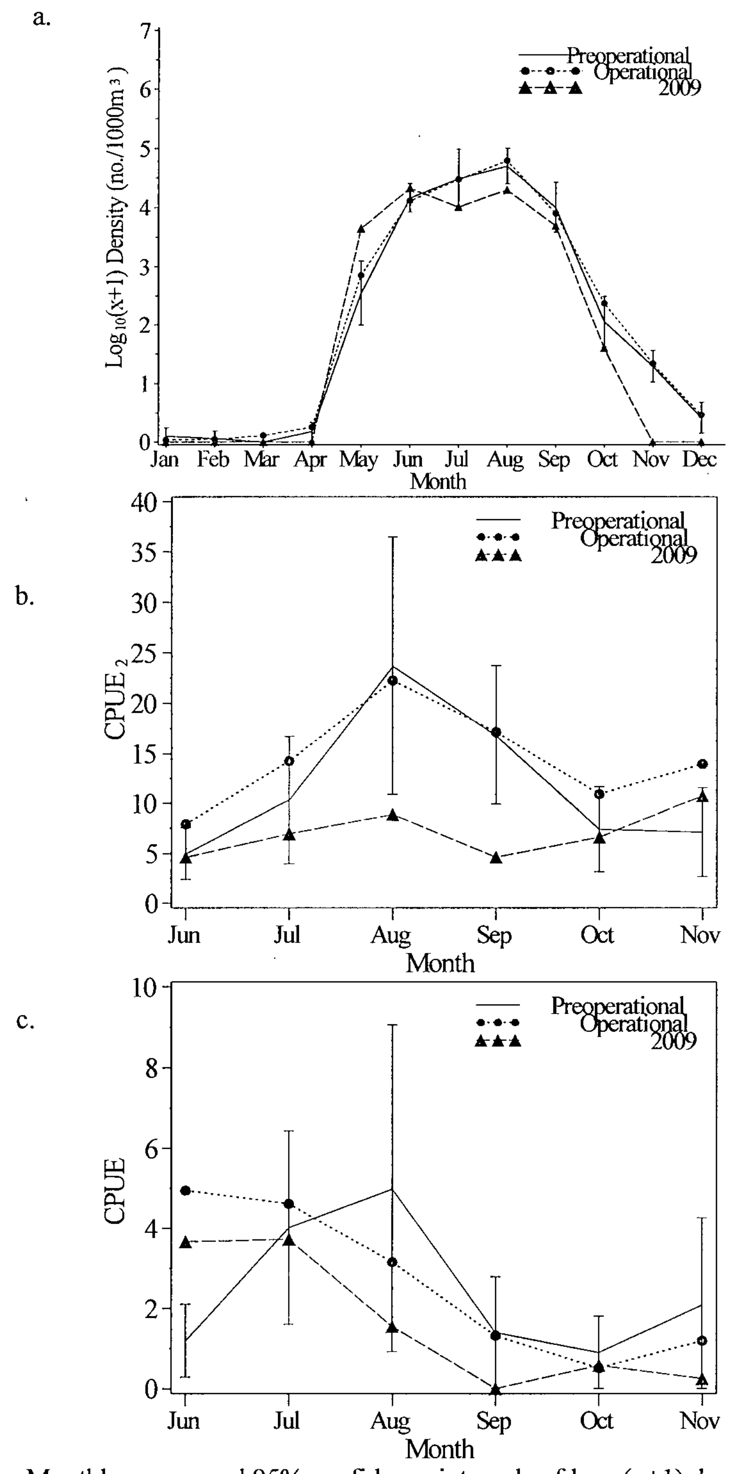



Figure 6-11. Monthly means and 95% confidence intervals of $\log_{10}(x+1)$ density (no./1000m$^3$) of a) *Cancer* spp. larvae at Station P2, and monthly mean catch per unit effort (15 traps) of b) Jonah and c) rock crabs at Station L1 during the preoperational period (1978-1984, 1986-1989: larvae; 1982-1989: adults) and monthly means during the operational period (1991-2009) and in 2009. Seabrook Operational Report, 2009.

**Table 6-5. Estimated Number of Lobsters Impinged in the Cooling Water System of Seabrook Station During 1990 Through 2009. Seabrook Operational Report, 2009.**

| Year | Number of Lobsters Impinged |
|---|---|
| 2009 | 21 |
| 2008 | 3 |
| 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** | **318** |

### *Total Catch: Juveniles and Adults*

In 2009, the $CPUE_2$ for Jonah crabs was below the preoperational and operational 95% confidence limits at both stations (Table 6-2). $CPUE_2$ in 2009 was the fourth lowest at the nearfield station and the third lowest at the farfield station (Figure 6-12). 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. After 1996, $CPUE_2$ at both stations increased to a peak in 2004 and has generally decreased through 2009 (Figure 6-12). There were no significant differences between periods or stations in Jonah crab $CPUE_2$ and the interaction term was not significant (Table 6-3).

Monthly mean Jonah crab $CPUE_2$ at Station L1 in 2009, the preoperational period and the operational period increased from June through August and decreased I September. In contrast to the preoperational period, in 2009 $CPUE_2$ increased from September through November reaching the highest levels in November (Figure 6-11b). In 2009, $CPUE_2$ was within the 95% confidence intervals of the preoperational means in four out of six months, however in August and September it was below the confidence limits. Female Jonah crabs were more abundant than male

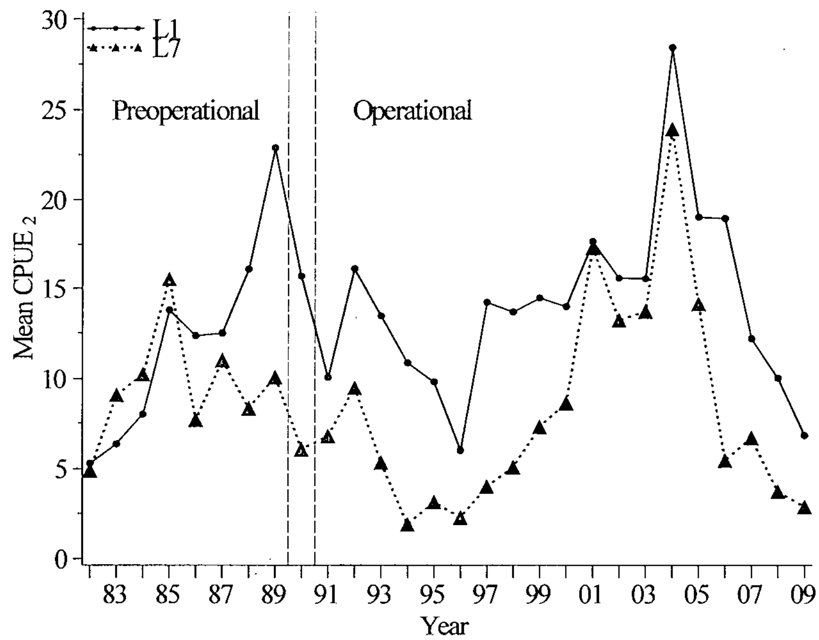



Figure 6-12. Annual mean $CPUE_2$ of Jonah crab, 1982-2009 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2009.

crabs, and were 72% (L7) to 77% (L1) of the catch in the preoperational period, and 59% (L7) to 70% (L1) in the operational period (Table 6-2). Percentage of females in 2009 at Station L1 (57%) and L7 (52%) was lower than the preoperational percentage. The percentage 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 more common in the study area. Rock crab CPUE in 2009 was lower than the preoperational and operational means at both stations (Table 6-2). CPUE decreased at both stations in 2009 continuing a general decrease since 2003 (Figure 6-13). CPUE of rock crab increased significantly between periods only at Station L7, resulting in a significant interaction term (Table 6-3; Figure 6-14).

Rock crab CPUE at both stations has been variable among years (Figure 6-13). 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 (Figure 6-13). CPUE at Station L1 was generally greater at Station L7 in the preoperational period but generally lower between 1994 and 2004. Since 2005 CPUE has been greater at Station L1, similar to the preoperational pattern. Rock crab CPUE at Station L1 significantly increased from 1982 through 1993, but was not significantly greater than the mean CPUE 1994 through 2009 (Table 6-6). There was no significant trend for the period 1994 through 2009. Mean CPUE for rock crab at Station L7 significantly increased during the period 1982 through 2000 and significantly decreased from

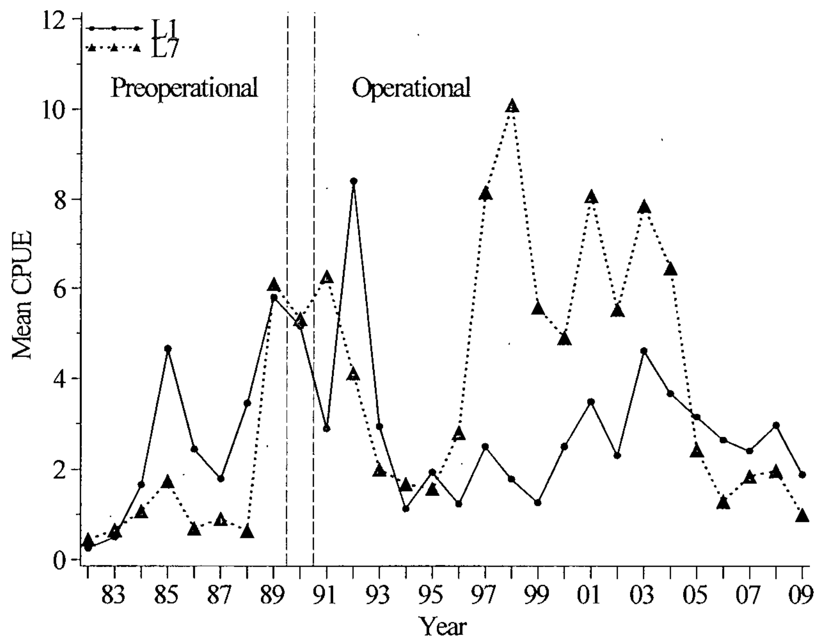



Figure 6-13. Annual mean CPUE of rock crab, 1982-2009 (data between dashed lines excluded from the ANOVA model). Seabrook Operational Report, 2009.

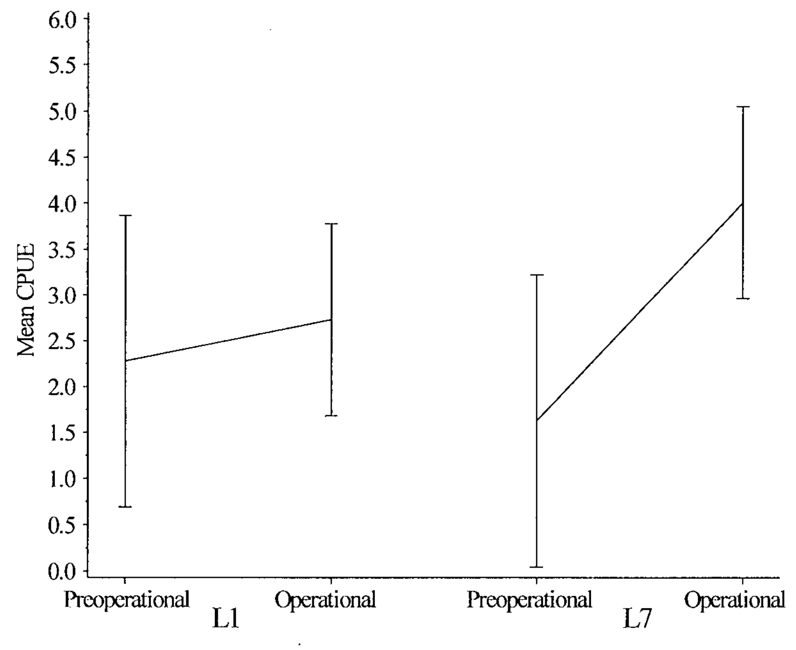



Figure 6-14. Comparison of mean CPUE with 95% confidence intervals of rock crab by station during the preoperational (1982-84; 1986-89) and operational (1991-2009) periods when the interaction term (Preop-Op X Station) of the ANOVA model was significant (Table 6-3). Seabrook Operational Report, 2009.

**Table 6-6. Results of Segmented Regression Analysis of Annual CPUE of Rock Crabs. Seabrook Operational Report, 2009.**

| Species and Station | Mean Comparison Based on Break Points[a] | Period 1 Slope | Period 2 Slope |
|---|---|---|---|
| L1 | 1982-1993 > 1994-2009 NS | Positive* | NS |
| L7 | 1982-2000 < 2001-2009 NS | Positive* | Negative* |

[a] As identified using segmented regression analysis.
NS = Not significant ($p>0.05$)
* Significant $p<0.05$)

2001 through 2009 (Table 6-6). As with Station L1, there were no significant differences in mean CPUE between the two segments.

The monthly pattern of rock crab CPUE at Station L1 in 2009 was similar to the operational period (Figure 6-11c). In the operational period CPUE was highest in June, and declined steadily through October, and increased in November. In 2009, CPUE for rock crab was highest in June and July and decreased through September, increased slightly in October and then declined in November. Monthly CPUE in 2009 was within the confidence intervals for the preoperational period in every month except June. 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.

Percentage of females in the preoperational period was 19-20%, while in the operational period females made up 14%. In 2009, percentage of females was 11-20%.

The majority of the Jonah and rock crabs captured in this program were between 100 and 119 mm CW (Figure 6-15). 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 2009, $CPUE_2$ of Jonah and rock crabs in the 100-119 mm and >119 mm size class decreased from levels in 2008, consistent with decrease in total catch.

## 6.4 DISCUSSION

There have been substantial changes to the Gulf of Maine ecosystem that have the potential to affect the abundance of epibenthic Crustacea in the study area. These changes include increased surface water temperatures, increased lobster fishing effort, substantial changes in the trophic structure of the demersal fish community due to overfishing, and changes in the relative abundance of lobsters and rock crabs. These changes to the ecosystem are reflected in the increased abundance of epibenthic crustaceans lobsters and *Cancer* spp. crabs in our study.

There has been a significant positive trend in surface water temperature (Section 2.0) that has the potential to increase larval survival and potentially the abundance of juvenile and adult lobsters in later years. There were significant correlations between $CPUE_2$ of sublegal lobsters and mean surface water temperatures in June through November lagged by six years at both stations. 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

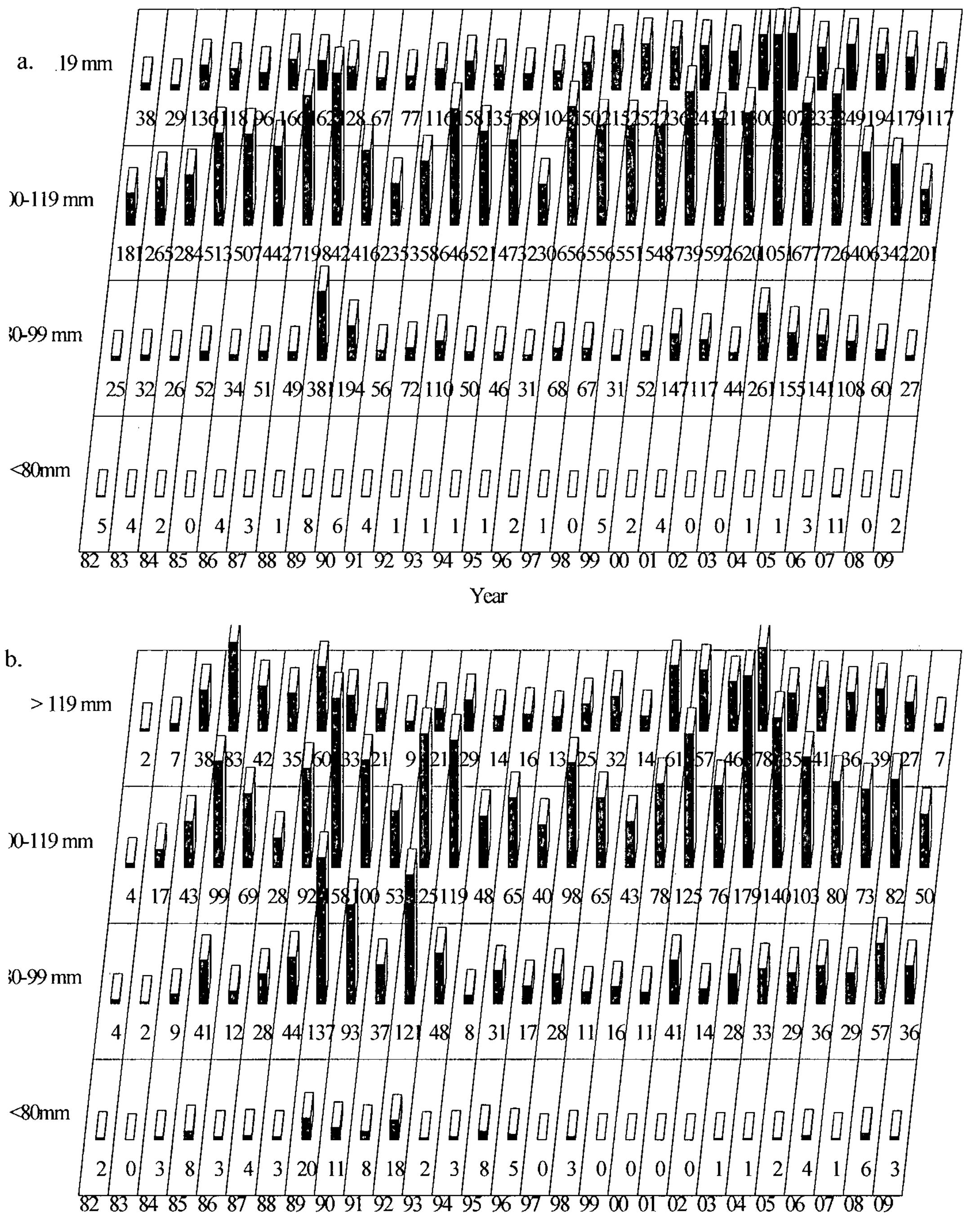


Figure 6-15. CPUE$_2$ of Jonah crab (a) and CPUE of rock crab (b) at Station L1 by size class from 1982 –2009. Seabrook Operational, Report, 2009.

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).

Increases in lobster catch have been correlated with increasing bottom 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).

Lobster trap bait could be an important food subsidy contributing to the recent increases in the abundance and landings of lobsters in the inshore Gulf of Maine (Saila et al. 2002b). Between 25% and 33% of the lobster landings from the inshore area could be supported by bait in lobsters traps and discarded bait assuming that lobsters are food limited and the bait represents an import of energy to the inshore area. Ecosystem modeling by Zhang and Chen (2007) also indicated that discarded lobster bait had a positive effect on lobster stock biomass.

Recent changes in the trophic structure of the demersal fish community may have resulted in an increase in abundance of mega crustaceans such as lobsters and *Cancer* crabs. Zhang and Chen (2007) found that the Gulf of Maine ecosystem shifted from a groundfish-dominated system in the 1980s to a system dominated by shelled crustaceans in the 1990s. The reduced abundance of groundfish, presumably due to overfishing, benefited the crustacean community through reduced predation. Steneck et al. (2004) theorized that a reduction in the abundance of vertebrate apex fish predators such as Atlantic cod, haddock, and wolfish has resulted in an increase in the abundance of prey species. The ability of lobster to survive intense commercial exploitation may be due to them evolving in an environment of heavy predation in the juvenile and adult stages, and the subsequent removal of that predation (Steneck 2006a).

The reduction in fish predators in the mid to late 20th century resulted in an increase in the abundance of urchins and other mobile benthic invertebrates in kelp beds. In addition, the reduction in abundance of apex fish predators allowed an increase in the abundance of crabs such as Jonah and rock crabs (Steneck et al. 2004). Urchins overgrazed the kelp beds resulting in "urchin barrens" dominated by crustose and coralline algae. A new fishery for urchins reduced the abundance of urchins in the late 1980s and kelp beds recovered. However, apex fish predators were still overfished and not abundant. As a result, abundance of crab predators such as Jonah crabs and other invertebrates may have increased and now these invertebrate predators appear to be controlling urchin populations rather than the apex fish predators. Leland (2002) stated that crabs may be the apex predator because there are few fish predators available to control urchin abundance.

Increases in water temperature and the increased food subsidy through bait import in the lobster fishery may have made substantial contributions to the significant increase in $CPUE_2$ of lobsters observed in the operational period in this study. Changes in the trophic structure also may have contributed to the increased abundance of crustaceans in the Gulf of Maine. These factors are regional influences that have affected the abundance of epibenthic crustaceans over a large geographical scale beyond the influence of Seabrook Station.

Larval and adult stages of epibenthic crustaceans 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 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. Potential impacts on these specific lifestages and species are discussed below.

### 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 has occurred 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). Acheson and Steneck (1997) summarized the relationship between water temperature and larval survival and presented evidence that larval survival is most successful at water temperatures of 15 °C and greater.

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 varying 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 2009, peak abundances of lobster larvae at Station P2 occurred in the third week of June, the first week of August, and the third 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 2009 was equal to or higher than the preoperational 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 appreciably in the operational period.

### 6.4.2 *Cancer* spp. Larvae

The density of *Cancer* spp. larvae in 2009 was lower than the operational means and similar to the preoperational means at both stations (Table 6-2). 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 6-11a), 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 2009). However, the high level of fishing effort is considered an area of concern. In the Gulf of Maine, relative abundance of legal-size lobsters is at or near all-time highs (Selberg et al. 2003), and the estimate of spawning biomass is at a record high compared to the 26-year time series. 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 in the Gulf of Maine have increased since the early 1970s, primarily due to increased fishing effort, and reached a record high of 37,297 metric tons in 2006

(ASMFC 2009). In addition to commercial landings, the NMFS index of stock abundance in the Gulf of Maine has also risen since 1987, and increased in 2005 to the highest level in the time series (ASMFC 2009). In the Gulf of Maine, the 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, a minimum carapace length that allows lobsters to spawn at least once before they are recruited to the fishery, a maximum carapace length of size limit of 127 mm (5 inches) to conserve large egg producing lobsters, and v-notching the tails of ovigerous lobsters. 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), although increases in water temperature (Campbell et al. 1991) and changes in the trophic structure of the Gulf of Maine are possible reasons (Zhang and Chen 2007). Steneck (2006a) suggested that the higher-than-average egg survival and lower than average post-settlement mortality contributed to current lobster abundance when coupled with management practices such as v-notching that can help ensure a constant supply of eggs. Furthermore, the lobster trap is not an efficient capture device as up to 94% of the lobsters entering traps escape (Jury et al. 2001). The bait in traps may provide a substantial contribution to lobster production (Saila et al. 2002b) or conversely, 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 and changes in the trophic structure 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 2006b). At small scale experimentation, Steneck (2006b) has shown large lobsters leave or avoid areas of high population 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 lobsters 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) 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 recreational 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. The most recent report available on lobster monitoring using traps 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 2000, and has generally decreased from 2001 through 2007 (Glenn et al. 2008). The Massachusetts index of sublegal lobster abundance in the Gulf of Maine waters was highest in the early 1990s and has decreased steadily through 2007 (Glenn et al. 2008). The New Hampshire index of juvenile lobster abundance had the highest catch rates in 2000 and a decline from 2006 through 2008 and an increased in 2009 (Carloni 2010) Our data closely agree with the NHFG data. In our study $CPUE_2$ of sublegal lobsters decreased from 2005 through 2008, but in 2009 was the highest since 1997.

Our results are also in general agreement with the well-established pattern of abundance of lobsters being related to water temperature in earlier years. $CPUE_2$ of sublegal sized lobsters were significantly correlated with surface water temperature six years earlier. The majority of sublegal lobsters are in the 68-79 mm size classes and probably are members of the year class spawned six years earlier. The correlation between $CPUE_2$ of sublegal-size lobsters and surface water temperature of the preceding 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 lobsters 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. It is instead likely related to increases in the legal size definition over the course of the study. The index for legal-size lobster CPUE in Massachusetts (Dean et al. 2008) has decreased since 1999, while our data indicate relatively stable $CPUE_2$ (Figure 6-6). The Gulf of Maine stock of lobsters appears to be stable, but dependent on continued good recruitment from the sublegal population (ASMFC 2009). 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 2009, an estimated 21 lobsters were impinged, and the total for the operational period (1990-2008) was 318 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 were 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

**Table 6-7. Summary of Potential Plant Effects on Abundance of Epibenthic Crustacea. Seabrook Operational Report, 2009.**

| 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<br>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)

differences lobster and legal-size lobster CPUE$_2$ were consistent with larger trends in the Gulf of Maine.

### 6.4.4 Jonah and Rock Crabs

Jonah and rock crabs are captured incidentally in experimental lobster traps and could be subject to the same potential plant impacts as lobsters. 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 greatest increase at the farfield station began after 1996, after the plant began operation. In 2009, annual CPUE of rock crabs at the farfield station was lower than the CPUE at the nearfield station for the fifth consecutive year 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 up to at least 2004 may be a result of the restructuring of the food web observed by Steneck et al. (2004) and modeled by Zhang and Chen (2007). However, Jonah crabs began to decline in 2004, and rock crabs began to decline in 2003 at both nearfield and farfield stations.

Despite the literature contending that abundance of Jonah and rock crabs is increasing, our most recent data show a large decline in CPUE from 2004 through 2009 for Jonah crabs and 1998 through 2009 for rock crabs. 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. Recent field and laboratory studies by Wells et al. (2010) showed that rock crabs in the presence of lobsters retreated from preferred habitat on the bottom to the fronds of kelp plants.

$CPUE_2$ 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.

These behavioral studies and our CPUE data suggest that the presence of lobsters affects the behavior and potentially the CPUE of crabs in traps. The current and continuing high abundance of lobsters may be partially responsible for the decreases in CPUE of Jonah observed since 2004 and for rock crabs observed since 1998.

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 pre-operational 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 2009, 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 there was no significant trend after that. The trend in annual CPUE at the nearfield station was positive up until 2000 and then negative after 2000. The change in trends at both stations occurred 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 in 2009 that 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, or adults between the preoperational and operational periods. Density of yearlings was significantly greater in the preoperational period.

Geometric mean densities of clam larvae in 2009 at the nearfield Station P2 (9.7/m$^3$) and farfield Station P7 (14.9/m$^3$) were above the preoperational 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 2009 (75.5/m$^2$) decreased compared to 2008, but was higher than the preoperational and operational means. YOY density at Flat 1 (146.4/m$^2$), Flat 2 (71.1/m$^2$), and Flat 4 (38.3/m$^2$) in 2009 decreased from 2008 and was higher than the preoperational and operational means at Flats 1 and 2. Mean density of YOY clams at Flat 1 was the third highest recorded. There were no significant differences in YOY clam density between the preoperational and operational periods or among flats.

Density in 2009 of yearling clams (26-50 mm) at all flats combined (0.1/m$^2$) was equal to the 2008 density and continued the pattern of poor recruitment into this size class. Mean densities in 2009 at Flat 1 (0.2/m$^2$), Flat 2 (<0.1/m$^2$), and Flat 4 (0.2 /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, and was highest 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 2009 at all flats combined (2.5/m$^2$) decreased from 2008, and was higher than the preoperational mean. Mean density at Flat 1 (2.4/m$^2$) and Flat 4 (1.3/m$^2$) in 2009 was below the preoperational and operational period means, while mean density at Flat 2 (4.0/m$^2$) was above the preoperational and operational period means. Mean density at Flat 4 (1.3/m$^2$) was below both means. Mean density in 2009 increased compared to 2008 only at Flat 2.

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 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. Adult density appears to be affected primarily by disease and digging pressure.

Direct relationships between densities of earlier and later lifestages were not always apparent. There was a significant relationship between larval density and settlement of YOY, but density of larvae was not related to older lifestages. Furthermore, density of YOY did not appear related to density of older lifestages in later years. There was no significant relationship between entrainment of larvae and settlement of YOY. 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 19 years of monitoring of plant operation, it is clear that such excursions do not occur. Other factors unrelated to Seabrook Station that may affect clam density such as predation, disease, and recreational clamming on clam density were also considered. Nearfield/farfield comparisons of seed clam densities (1-12 mm) were made between Hampton Harbor and a nearby estuary, Plum Island Sound, Ipswich, MA, both before and during plant operation to test whether the population in Hampton Harbor has been affected by the operation of Seabrook Station.

## 7.2 METHODS

### 7.2.1 Bivalve Larvae

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 1974-2009 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).

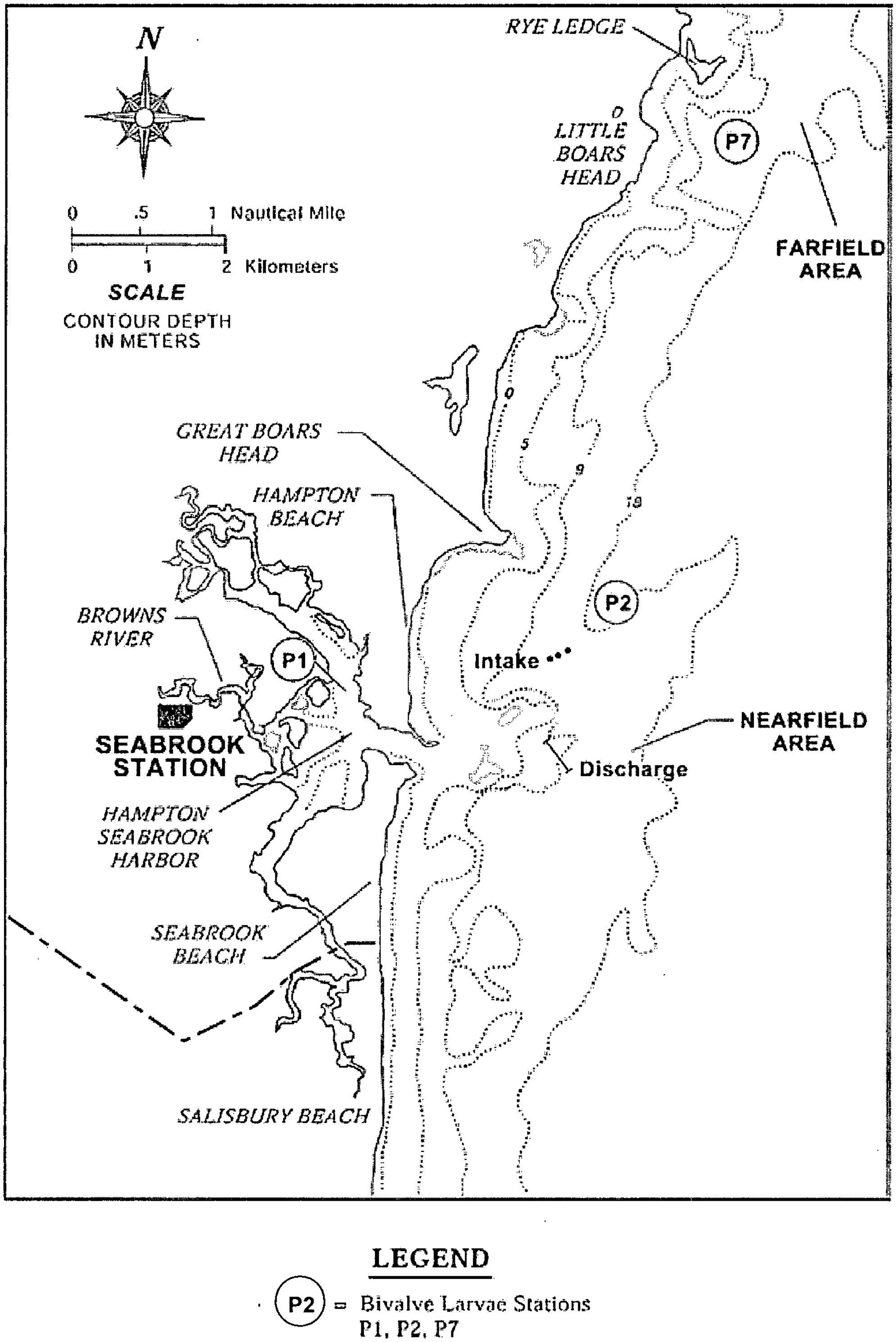


Figure 7-1. Bivalve larvae (including *Mya arenaria*) sampling stations.

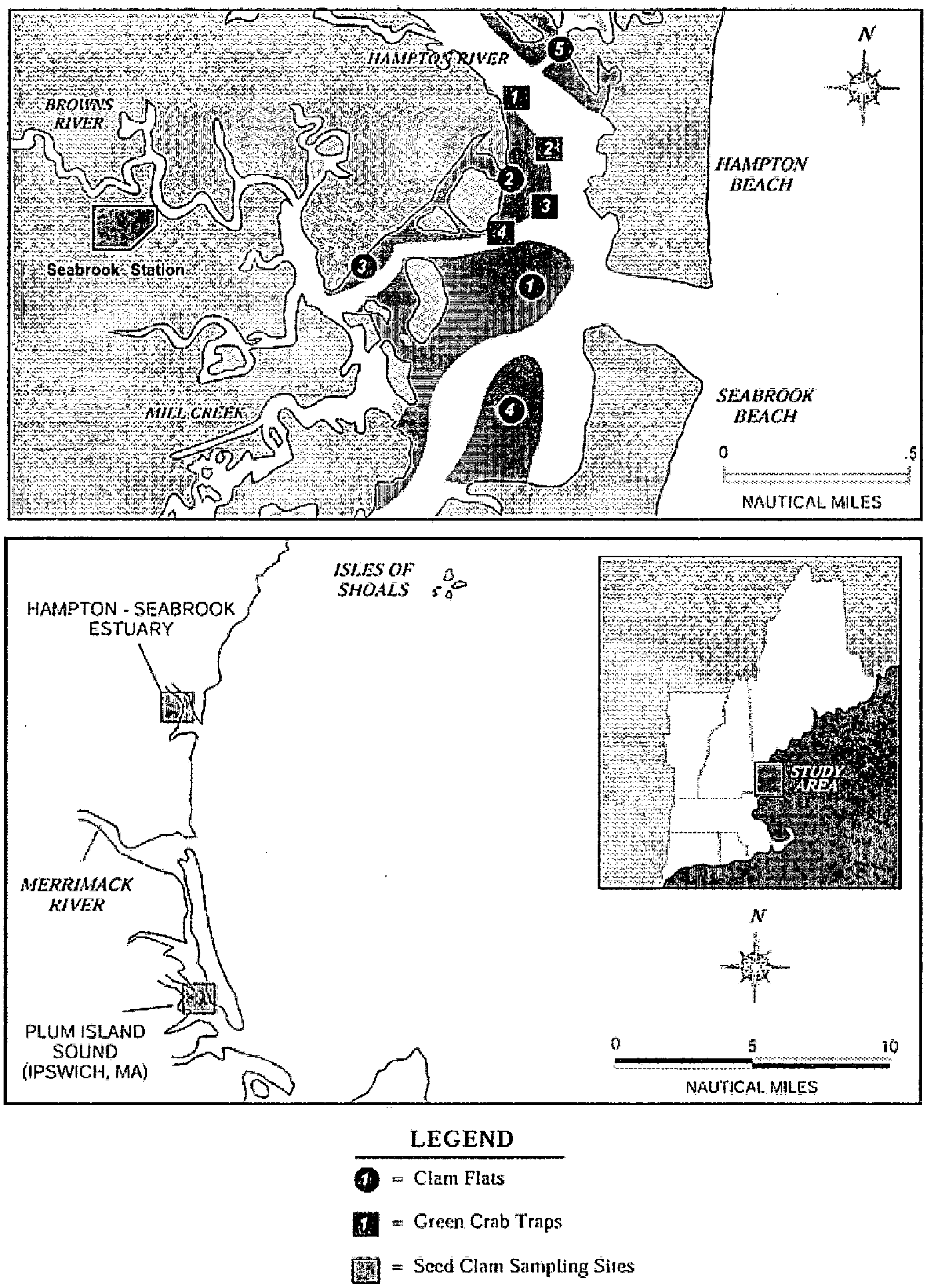


Figure 7-2. Hampton-Seabrook estuary and Plum Island Sound softshell clam (*Mya arenaria*) and green crab (*Carcinus maenas*) sampling areas.

Samples were sieved with a 1-mm mesh sieve, 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. Sampling within each site took place on the same day.

### 7.2.4 Green Crab (*Carcinus maenas*)

Beginning in 1978, green crabs (*Carcinus maenas* L. 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 2009 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 1974-2009 in the Hampton Harbor survey, and from 1987-2009 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. 2009) for the period 1990 through 2009. 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). Correlation analysis was used to describe the relationship between entrainment of larval softshell clams and settlement of YOY. Correlation was used because it did not appear that one variable was dependent on the other.

## 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 2009, softshell clam larvae were first present in the first week of June through the fourth week of October. Highest densities for the year occurred during the first week of July.

Geometric mean density of softshell clam larvae in 2009 was higher than the preoperational and operational means at the nearfield (P2) and farfield stations (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 2009 at Station P7 was higher than any year in the preoperational period, and at Station P2 density was higher than all but one year in the preoperational period (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.

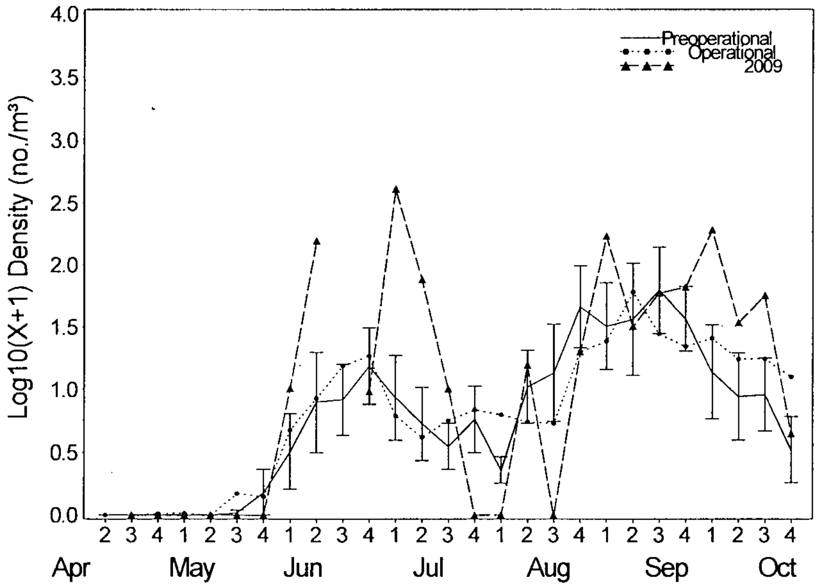


Figure 7-3. Weekly mean and 95% confidence interval of log10(x+1) density (no./m$^3$) of *Mya arenaria* larvae at Station P2 during preoperational (1977-84, 1986-89) and operational (1991-2009) periods and in 2009. Seabrook Operational Report, 2009.

**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 2009. Seabrook Operational Report, 2009.**

| | | Preoperational[a] | | | 2009 | 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 | 9.7 | 4.5 | 6.0 | 7.8 |
| | P7 | 4.0 | 5.5 | 7.5 | 14.9 | 4.9 | 6.8 | 9.3 |
| 1-25 mm | HH-1 | 10.6 | 24.1 | 53.2 | 146.4 | 21.3 | 38.8 | 69.8 |
| (young-of-the- | HH-2 | 21.6 | 62.7 | 178.5 | 71.1 | 28.6 | 46.2 | 74.3 |
| year) | HH-4 | 60.7 | 142.9 | 334.6 | 38.3 | 11.5 | 21.5 | 39.6 |
| | All | 22.1 | 52.8 | 124.3 | 75.5 | 19.7 | 32.6 | 53.6 |
| 26-50 mm | HH-1 | 1.6 | 5.1 | 13.3 | 0.2 | 0.5 | 1.2 | 2.0 |
| (yearlings) | HH-2 | 0.4 | 1.2 | 2.4 | <0.1 | 0.1 | 0.5 | 0.9 |
| | HH-4 | 2.4 | 7.0 | 17.7 | 0.2 | 0.9 | 1.8 | 3.2 |
| | All | 1.5 | 3.9 | 8.4 | 0.1 | 0.4 | 1.0 | 1.7 |
| >50 mm | HH-1 | 1.3 | 2.6 | 4.4 | 2.4 | 2.3 | 3.5 | 5.1 |
| (adults) | HH-2 | 0.8 | 1.6 | 2.9 | 4.0 | 1.5 | 2.4 | 3.5 |
| | HH-4 | 1.3 | 2.5 | 4.4 | 1.3 | 3.9 | 6.0 | 9.1 |
| | All | 1.2 | 2.2 | 3.8 | 2.5 | 2.4 | 3.4 | 4.6 |
| 1-12 mm | Hampton Harbor | 15.5 | 36.8 | 85.7 | 136.8 | 31.8 | 45.9 | 66.1 |
| (seed clams) | Plum Island Sound | 35.9 | 107.0 | 315.4 | 33.1 | 22.4 | 32.9 | 48.1 |

[a] Larvae PREOP = 1982-1984, 1986-1989. OP = 1991-2009. Hampton Harbor (HH) PREOP = 1974-1989; OP = 1990-2009
Hampton Harbor-Plum Is. PREOP = 1987-1989; OP = 1990-2009

[b] LCL = Lower 95% confidence limit.

[c] PREOP and OP means = mean of annual means. 2009 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, 2009.**

| *Mya arenaria* Lifestage | Station/Flat | Source of Variation | Test Statistics | | | Multiple Comparisons[n] |
|---|---|---|---|---|---|---|
| Larvae[a] | Nearfield (P2) | **Fixed Effects** | **DF[j]** | **F[k]** | **p[l]** | |
| | Farfield (P7) | Preop-Op[c,d] | 1, 302 | 0.49 | 0.4856 | |
| | | **Random Effects** | **Estimate[m]** | $\chi^2$ | **P** | |
| | | Year (Preop-Op)[e] | 0 | <0.001 | 0.5000 | |
| | | Week (Preop-Op X Year)[f] | 0.49 | 389.61 | <0.0001* | |
| | | Station[g] | <0.01 | 0.27 | 0.3026 | |
| | | Preop-Op X Station[h] | 0 | <0.001 | 0.4998 | |
| | | Station X Year (Preop-Op)[i] | <0.01 | 0.141 | 0.5374 | |
| | | 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, 33.7 | 1.75 | 0.1943 | |
| | | **Random Effects** | **Estimate[m]** | $\chi^2$ | **P** | |
| | | Year (Preop-Op) | 0.24 | 33.59 | <0.0001* | |
| | | Flat | 0.01 | 2.10 | 0.15 | |
| | | Flat X Year(Preop-Op) | 0.13 | 142.29 | <0.0001* | |
| | | Error | 1.11 | | | |
| 26-50 mm[b] Yearlings | 1, 2, 4 | **Fixed Effects** | **DF[j]** | **F[k]** | **p[l]** | |
| | | Preop-Op | 1, 33.9 | 6.48 | 0.0156* | Pre>Op |
| | | **Random Effects** | **Estimate[m]** | $\chi^2$ | **P** | |
| | | Year (Preop-Op) | 0.16 | 60.74 | <0.0001* | |
| | | Flat | 0.04 | 32.75 | <0.0001* | 4>1>2 |
| | | Flat X Year(Preop-Op) | 0.05 | 216.47 | <0.0001* | |
| | | Error | 0.33 | | | |
| >50 mm[b] Adult | 1, 2, 4 | **Fixed Effects** | **DF[j]** | **F[k]** | **p[l]** | |
| | | Preop-Op | 1, 33.8 | 3.52 | 0.0693 | |
| | | **Random Effects** | **Estimate[m]** | $\chi^2$ | **P** | |
| | | Year (Preop-Op) | 0.06 | 31.91 | <0.0001* | |
| | | Flat | 0.01 | 12.90 | <0.0002* | 4 1>2 |
| | | Flat X Year(Preop-Op) | 0.03 | 199.41 | <0.0001* | |
| | | Error | 0.33 | | | |
| 1-12 mm[b] Seed | Nearfield/ Farfield | **Fixed Effects** | **DF[j]** | **F[k]** | **p[l]** | |
| | | Preop-Op | 1,2 1 | 0.63 | 0.4354 | |
| | Hampton Harbor | **Random Effects** | **Estimate[m]** | $\chi^2$ | **P** | |
| | Plum Island Sound | Year (Preop-Op) | 0.02 | 0.12 | 0.3638 | |
| | | Area | 0.00 | 0.00 | 0.5000 | |
| | | Preop-Op X Area | 0.00 | 0.00 | 0.5000 | |
| | | Area X Year (Preop-Op) | 0.19 | 14.85 | <0.0001* | |
| | | Error | 1.08 | | | |

[a] Larval comparisons based on weekly sampling periods, mid-April through October; where preop = 1982-84, 1986-89 and op = 1991-2009.
[b] For Hampton Harbor Survey preop = 1974-89 and op = 1990-2009. For the Nearfield/Farfield Survey preop = 1987-89 and op = 1990-2009.
[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 ($p \leq 0.0500$)

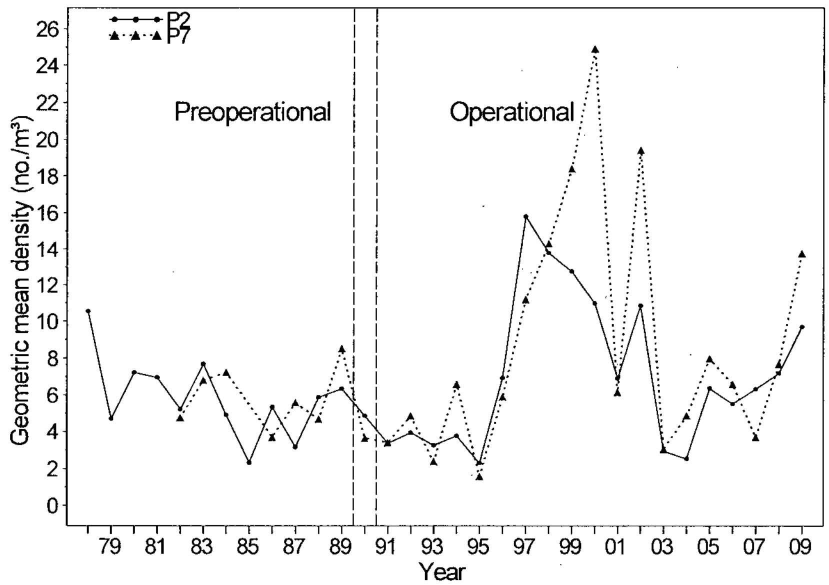


Figure 7-4. Annual geometric mean density (no./m$^3$) of larval *Mya arenaria*, 1978-2009. Seabrook Operational Report, 2009.

### 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 2009. Mean density of YOY clams in 2009 at Flats 1, 2, and 4, and at all flats combined decreased from 2008 (Figure 7-5, NAI 2009) but was higher than the preoperational mean at Flats 1 and 2 and higher than the operational and preoperational means at all flats combined (Table 7-1). Mean YOY density at Flat 1 in 2009 was the second highest recorded in the operational period, exceeded only by the 2008 mean (Figure 7-5). There were no significant differences in density of young-of-the-year clams between the preoperational and operational periods or among flats (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 2009 at Flats 1 and 2, and all flats combined were similar to the low levels of 2008, but increased at Flat 4 (Figure 7-6 and NAI 2009). Density in 2009 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 the last three years ended a generally increasing trend that occurred from 2002-2006 (Figure 7-6). For the third consecutive year, 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 2009, geometric mean density of adult clams decreased at Flats 1 and 4, and all flats combined, but increased at Flat 2 (Figure 7-7 and NAI 2009). Density in 2009 was lower than the preoperational and operational

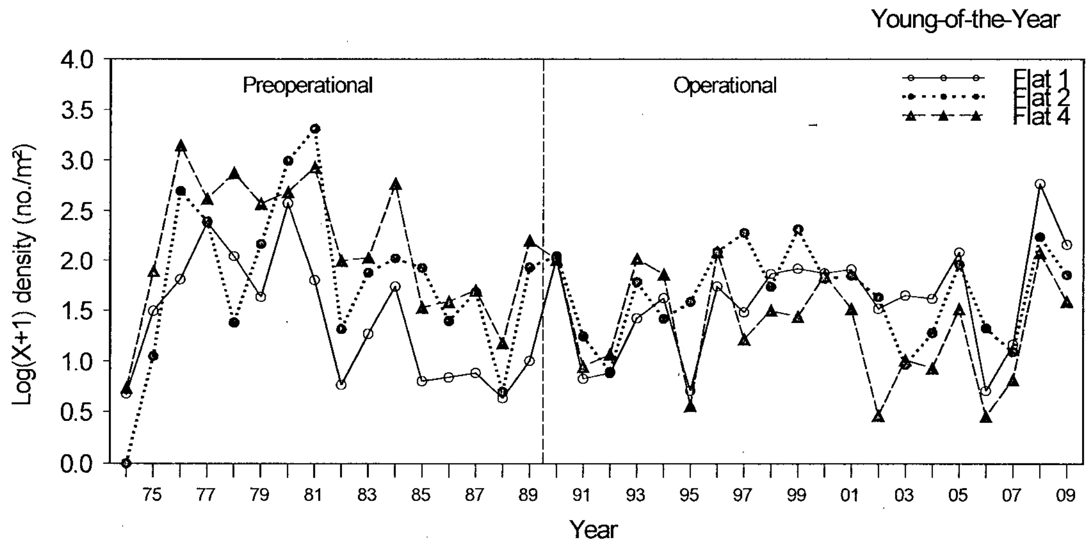


Figure 7-5. Annual mean log10(x+1) density (no./m$^2$) of young-of-the-year clams (1-25 mm), 1974-2009. Seabrook Operational Report, 2009.

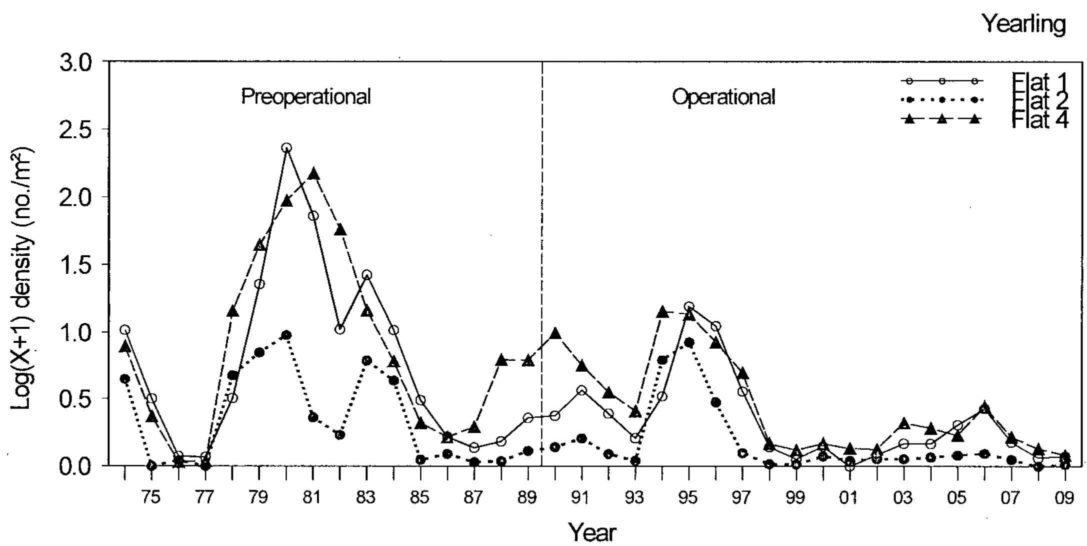


Figure 7-6. Annual mean log10(x+1) density (no./m$^2$) of yearling clams (26-50 mm), 1974-2009. Seabrook Operational Report, 2009.

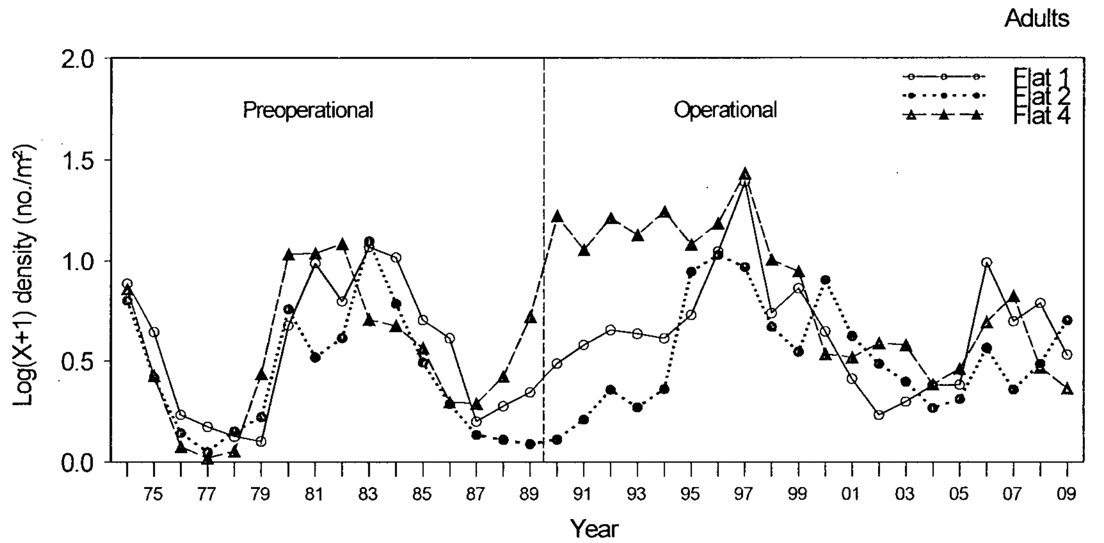


Figure 7-7. Annual mean log10(x+1) density (no./m$^2$) of adult clams (>50 mm), 1974-2009. Seabrook Operational Report, 2009.

means at Flats 1 and 4, but higher than both means at Flat 2 (Table 7-1).

Trends in density of adult clams were generally similar among the three flats (Figure 7-7). 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 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 followed by a general increase through 2006. There were no significant differences in density of adult clams between the preoperational and operational periods (Table 7-2). Density was significantly higher at Flats 4 and 1, followed by Flat 2.

### 7.3.3 Nearfield/Farfield Study

In 2009, density of seed clams (1-12 mm) in Hampton Harbor was higher than both the preoperational and operational means (Table 7-1). In Plum Island Sound, density of seed clams was lower than the preoperational mean and similar to the operational mean. Density of seed clams in 2009 in Hampton Harbor and Plum Island Sound decreased from the relatively high densities observed in 2008 (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,

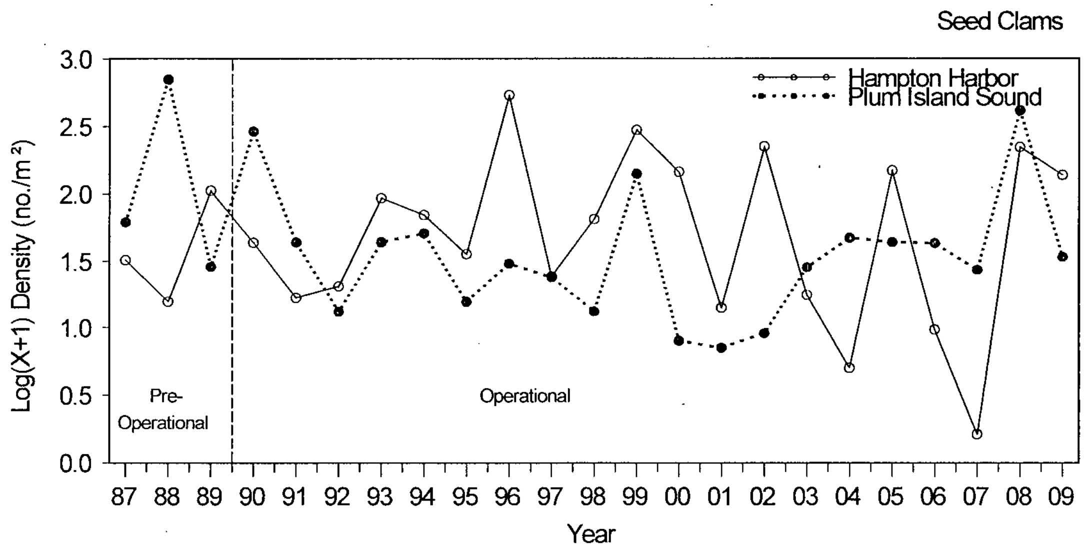


Figure 7-8. Annual mean log10(x+1) density (no./$m^2$) of seed clams (1-12 mm), in Hampton Harbor and Plum Island Sound 1974-2009. Seabrook Operational Report, 2009.

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 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 in New Brunswick and Nova Scotia 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 also conducted in New Brunswick and Nova Scotia, 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 to stable levels in 2006 through 2009.

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.

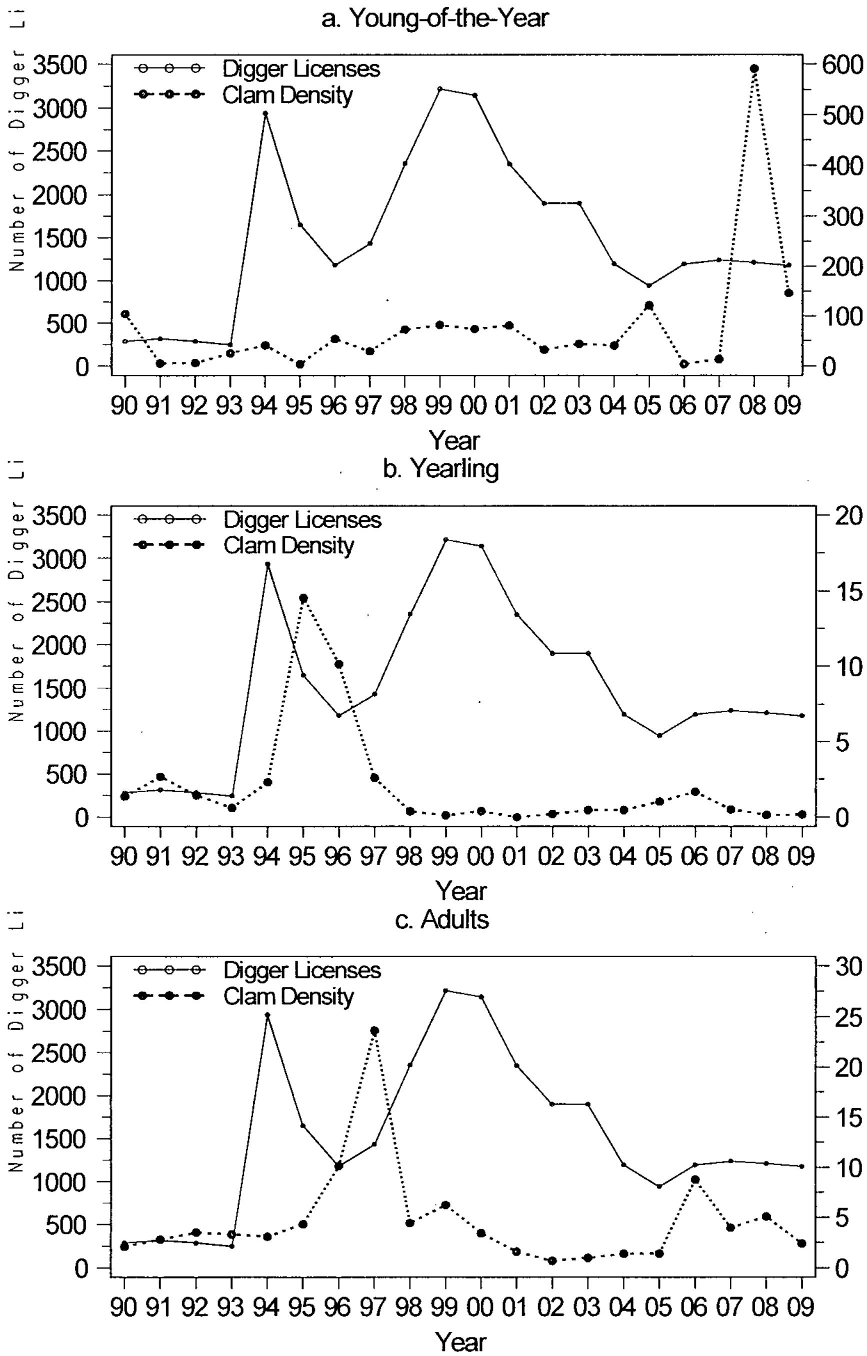


Figure 7-9. The relationship between digging effort (number of licenses) and density of (a) young-of-the-year (1-25 mm), (b) yearling (26-50 mm), and (c) adult (>50 mm) clams on Flat 1 in Hampton Harbor from 1990 through 2009. Seabrook Operational Report, 2009.

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. However in 2008 and 2009 density of YOY clams differed by a factor of about 4 while license sales were relatively similar. Therefore, it does not appear that there is a relationship between number of license sold and density of YOY clams.

There was no strong evidence of a consistent relationship between licenses issued and yearling clam density on Flat 1 (Figure 7-9). It might 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, the data do not support any relationship between license sales and yearling density. Density of yearling clams was highest in 1995, one year after a peak in license sales. License sales peaked again in 1999 and 2000 but there was no corresponding increase in yearling density in the following years. 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 from 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 was lower in 2007 through 2009.

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 2009 was below the preoperational and operational period monthly means every month except May and November.

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. To investigate this relationship green crab CPUE was regressed on mean winter (December through March) water temperature. The relationship was not significant ($p=0.07$; Figure 7-11). Several years such as 2007 and 1992 did not follow the trend. In 2007, water temperature was above average but green crab CPUE was the lowest observed. In 1992, water temperature was near average but green crab CPUE was the highest observed. Regardless, winter water temperature is probably one of the many factors affecting the abundance of green crabs.

Green crabs are voracious predators of young clams, and their abundance is probably

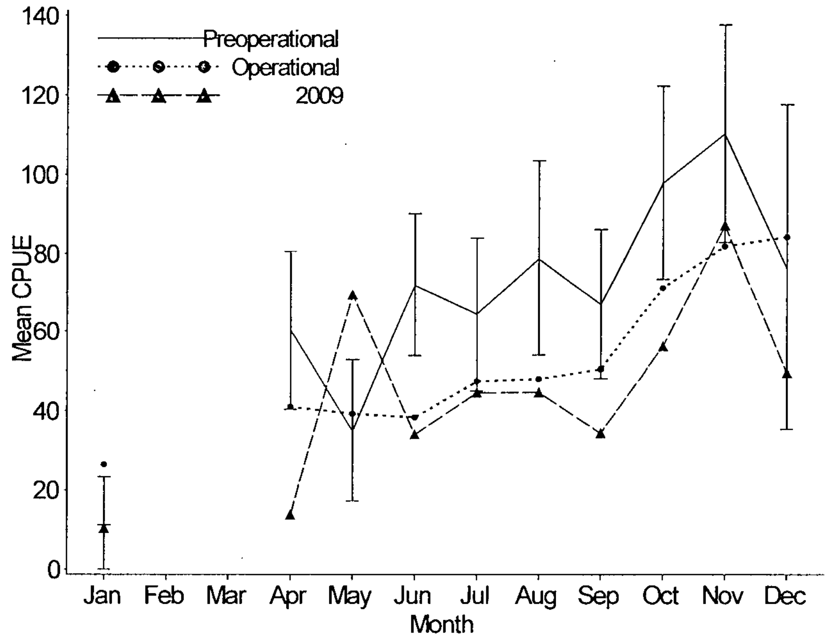


Figure 7-10. Mean monthly catch per unit effort and 95% confidence intervals (based on annual means) of green crabs (*Carcinus maenas*) collected during preoperational years (1983-1989), operational years (1991-2009), and 2009. Seabrook Operational Report, 2009.

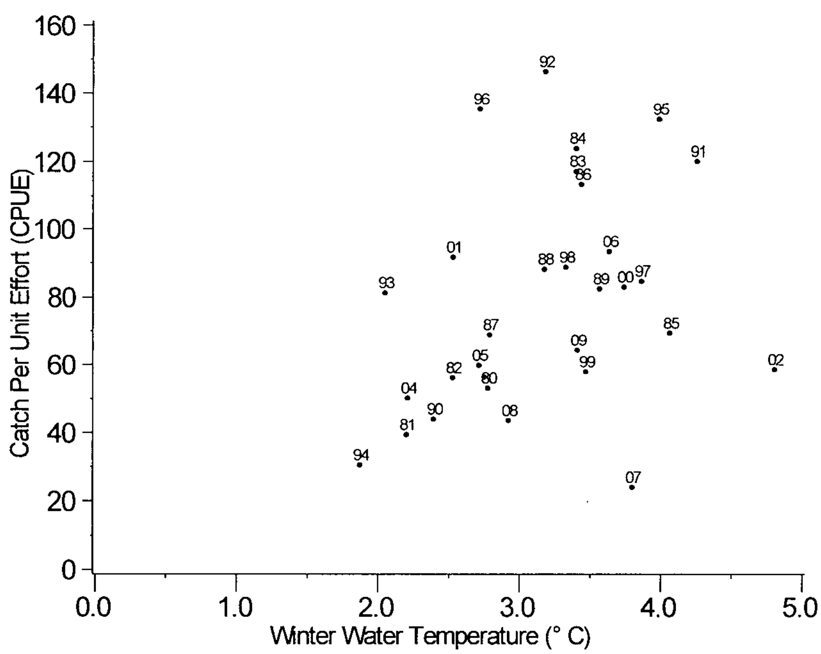


Figure 7-11. Mean fall (October-December) catch per unit effort of green crabs in Hampton-Seabrook Harbor and its relationship to minimum winter (preceding December through March) water temperature, 1977-2009. Seabrook Operational Report, 2009.

an important factor affecting density of YOY and yearling clams. To investigate this relationship, green crab CPUE was regressed on the $\log_{10}$ density of YOY clams from each of the flats and all flats combined. There was a significant negative relationship at Flat 1, but not at all flats combined, or Flats 2 and 4 (Table 7-3). The negative slope for Flat 1 indicates that as abundance of green crabs increases, the density of YOY decreases presumably from predation. However, the relationships were not strong as indicated by non-significant relationship at most flats, and the coefficient of determination ($r^2$) of 0.17 at Flat 1, meaning at most 17% of the variation in YOY density was explained by variation in green crab CPUE.

### 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, and all flats combined (Table 7-4). Although all regressions were significant, at most 25% of 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 25% of the variation in YOY density was explained by larval density (Table 7-4). The strengths of the relationships were weaker at Flats 1 and 4 where 6% and 3% of the variation in YOY density was explained by larval density. At Flats 1, 2, and 4 combined, 11% 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 2008, well above the regression line (Figure 7-12). However, larval densities for this year (11.4/m$^3$) ranked 16th out of the 22 year time series. Similarly, the highest larval densities at Station P1 (30.0/m$^3$) occurred in 2009, but YOY density was below the regression line at Flats 2, 4, and all flats combined.

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. However, larval density (30.0/m$^3$) in 2009 was the highest recorded but YOY recruitment (71.4/m$^2$) in 2009 was similar to the average (67.1/m$^2$).

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 2009 was the highest in larval density (30.0/m$^3$) and ninth in YOY recruitment (38.3/m$^2$; Figure 7-12).

When data from all flats were combined, 11% of the variation in YOY recruitment was explained by variation in larval density (Table 7-4). 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

**Table 7-3. Regression Statistics for the Regression of Annual Mean $Log_{10}$ Young-of-the-Year *Mya arenaria* Density (no./m$^2$) on Annual Mean Green Crab Catch per Unit Effort during the Years 1978 through 2009. Seabrook Operational Report, 2009.**

| Flat | Regression Equation | Pr > F[a] | $r^2$ |
|---|---|---|---|
| 1 | y=– 0.007x + 2.05 | 0.02 * | 0.17 |
| 2 | y= – 0.004x + 2.05 | 0.24 (NS) | 0.05 |
| 4 | y= – 0.002x + 1.77 | 0.53 (NS) | 0.01 |
| Flats 1, 2, 4 Combined | y=– 0.005 + 1.99 | 0.08 (NS) | 0.11 |

[a] probability of achieving a higher F value; * = significant.

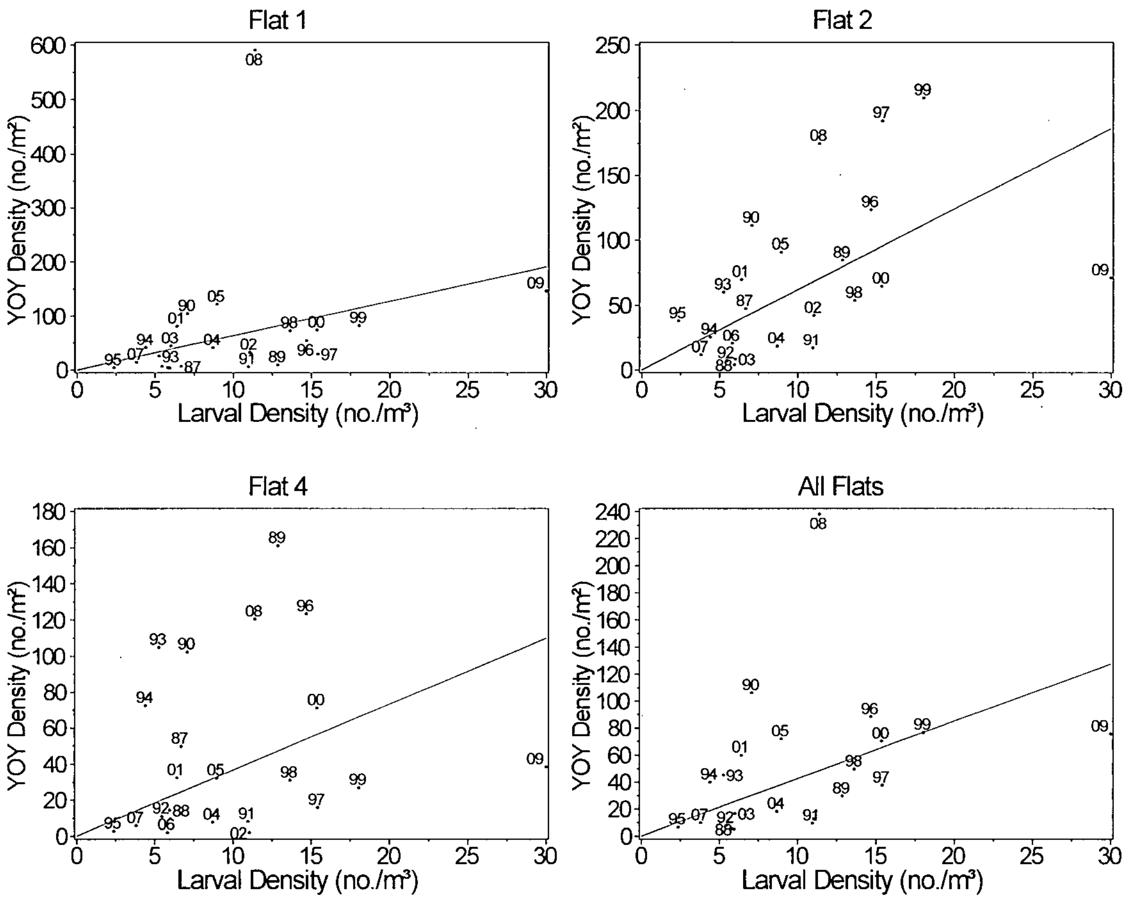


Figure 7-12. Relationship between larval density (no./m$^3$) and recruitment of young-of-the-year (YOY) softshell clam (no./m$^2$) in Hampton Harbor. Seabrook Operational Report, 2009.

**Table 7-4. 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 2009. Seabrook Operational Report, 2009.**

| Flat | Regression Equation | Pr > F[a] | $r^2$ |
|---|---|---|---|
| 1 | y=6.38 x | 0.006 * | 0.06 |
| 2 | y=6.21 x | <0.0001 * | 0.25 |
| 4 | y=3.67 x | 0.0004 * | 0.03 |
| Flats 1, 2, 4 Combined | y=4.25 x | <0.0001 * | 0.11 |

[a] probability of achieving a higher F value; * = significant.

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 any of the individual flats, or at all flats combined, and larval density explained between 5% (Flat 2) and 15% (Flat 1 and all flats) of the variation in adult density (Table 7-5; Figure 7-13). 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 intra-specific 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 7-6; Figure 7-14). This lack of a significant relationship indicates that year class strength is set some time after YOY clams settle to the bottom.

Among the variables monitored, larval density and green crab CPUE seem to be the most important biological factors in determining set of YOY. To investigate the relative strength of these variables in determining set of YOY, a multiple regression was calculated using green crab CPUE and larval density as independent variables and density of YOY on each flat and all flats combined as the dependent variable. The multiple regressions were significant at Flats 1 and 2, and all flats combined, but not at Flat 4 (Table 7-7). At Flat 1 both larval density (p=0.0124) and green crab abundance (p=0.0122) contributed significantly to the multiple regression. At Flat 2 larval density was significant (p=0.0151) but green crab CPUE was not (p=0.5599). However, the addition of this variable increased the $r^2$ and marginally improved the overall fit of the model. Similarly for all flats combined, only larval abundance (p=0.0130) was significant in the multiple regression. Green crab CPUE (p=0.1049) was not significant in the model, but improved the overall fit.

### 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,

**Table 7-5. Regression Statistics for the Regression of Annual (1989-2009) Geometric Mean Adult (>50 mm) *Mya arenaria* Density (no./m$^2$) on Annual (1987-2007) Geometric Mean Larval *Mya arenaria* Density (no./m$^3$) Lagged by Two Years. Seabrook Operational Report, 2009.**

| Flat | Regression Equation | Pr > F[a] | $r^2$ |
|---|---|---|---|
| 1 | y= 8.16-0.41 x | 0.10 NS | 0.13 |
| 2 | y= 4.19-0.14 x | 0.94 NS | 0.05 |
| 4 | y= 13.30-0.58 x | 0.08 NS | 0.15 |
| Flats 1, 2, 4 Combined | y= 6.53-0.29 x | 0.11 NS | 0.13 |

[a] probability of achieving a higher F value; * = significant.

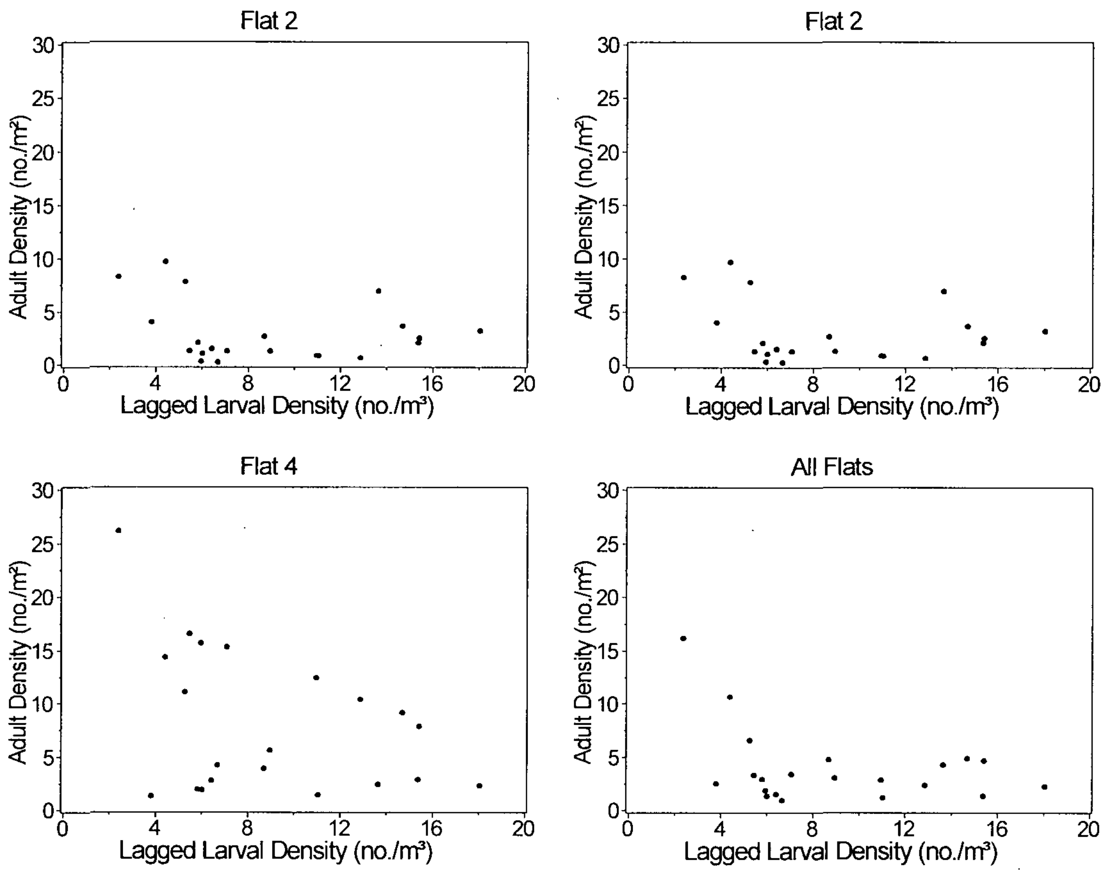


Figure 7-13. Relationship between larval density (no./m$^3$) and density of adult (>50 mm) softshell clam (no./m$^2$) two years later in Hampton Harbor. Seabrook Operational Report, 2009.

Table 7-6. **Regression Statistics for the Regression of Annual (1989-2009) Geometric Mean Adult (>50 mm) *Mya arenaria* Density (no./m$^2$) on Annual (1987-2007) Geometric Mean Young-of-the-Year *Mya arenaria* Density (no./m$^2$) Lagged by Two Years. Seabrook Operational Report, 2009.**

| Flat | Regression Equation | Pr > F[a] | $r^2$ |
|---|---|---|---|
| 1 | y= 5.82-0.03 x | 0.3062 NS | 0.05 |
| 2 | y= 3.03-0.001x | 0.9205 NS | <0.01 |
| 4 | y= 7.10+0.02 x | 0.4889 NS | 0.03 |
| Flats 1, 2, 4 Combined | y= 4.33-0.01 x | 0.7102 NS | 0.01 |

[a] probability of achieving a higher F value; * = significant.

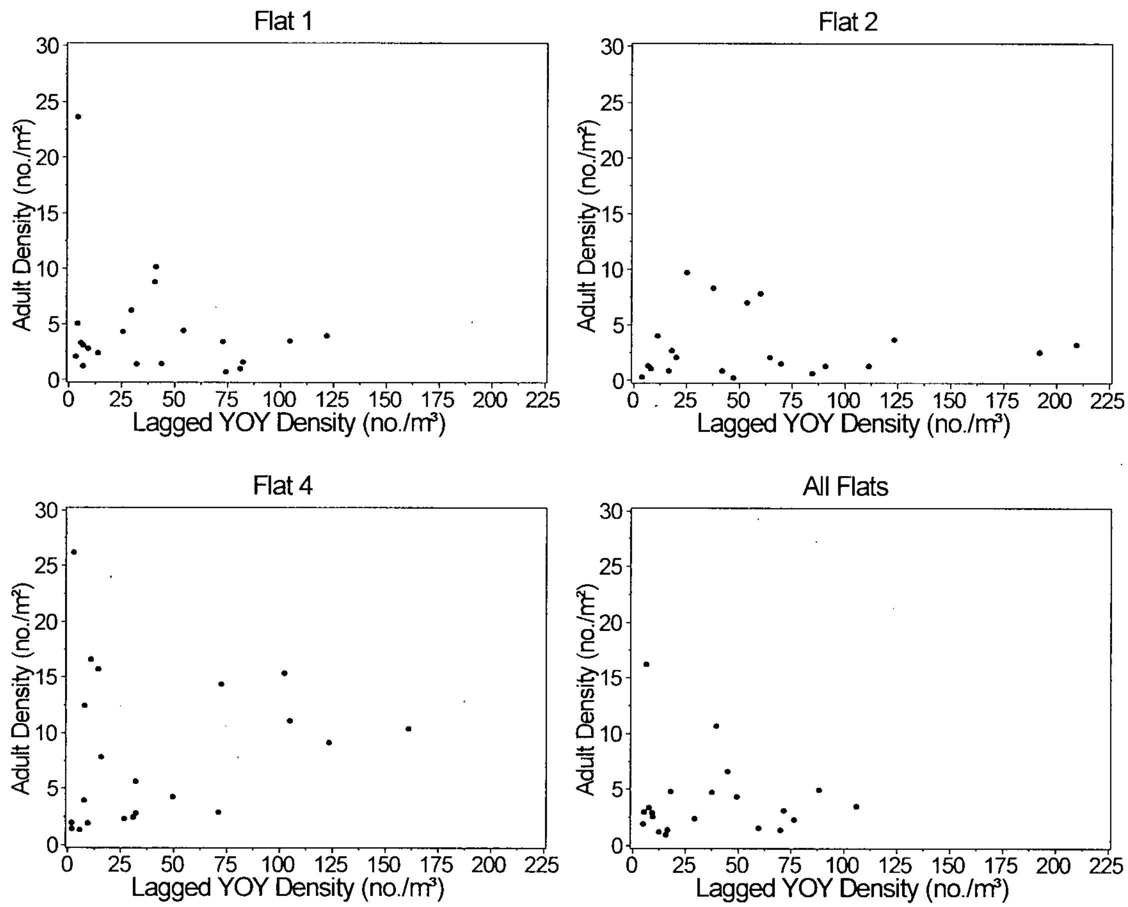


Figure 7-14. Relationship between density of young-of-the-year (no./m$^2$) and density of adult (>50 mm) softshell clam (no./m$^2$) two years later in Hampton Harbor. Seabrook Operational Report, 2009.

**Table 7-7. Multiple Regression Statistics for Annual Mean Density of $\log_{10}$ Larval *Mya arenaria* (no./m$^3$) and green crab CPUE (no./trap) on Geometric Mean Young-of-the-Year *M. arenaria* Density (no./m$^2$), 1987-2009. Seabrook Operational Report, 2009.**

| Flat | Independent Variables[a] | Equation | Pr>F | Adjusted $r^2$ |
|---|---|---|---|---|
| Flat 1 | L: p=0.0124<br>G: p=0.0122 | Y=1.675+0.045L-0.008C | 0.003 | 0.38 |
| Flat 2 | L: p=0.0151<br>G: p=0.5599 | Y= 1.358+0.039L-0.002C | 0.04 | 0.20 |
| All Flats | L: p=0.0130<br>G: p=0.1049 | Y=1.419+0.038L-0.004C | 0.01 | 0.28 |

L= Larval density
C= Green crab CPUE

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 and C. Walker of the University of New Hampshire repeated a study of the prevalence of neoplasia in the softshell clams of Hampton Harbor in 2002 through 2009. In 2009, the incidence of neoplasia in clams ranged from 64% (Flat 3) to 21% (Flat 4; Table 7-8). At each flat the incidence of neoplasia in 2009 decreased from the relatively high levels observed in 2008 (Figure 7-15). There was no clear pattern among years as to which flat had the highest incidence of neoplasia. In 2002, 2005, and 2008 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. In 2009 neoplasia was highest at Flat 3 for the first time.

## 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 19 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 7-9). 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, although in 2008 and 2009 YOY density at all flats combined was relatively high. 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 2002, increased slightly in through 2006, but generally decreased at all flats through 2009. 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 was countered by a decline in density

**Table 7-8. Percentage (number collected) of clams with neoplastic cells in Hampton Harbor during 2009. Seabrook Operational Report 2009.**

| Flat | Clams with Percent Occurrence of Neoplastic Cells | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0% | 1-25% | 26-50% | 51-75% | 76-100% | Neoplastic (1-100%) | Total Collected |
| 1 | 51 (29) | 28 (16) | 12 (7) | 5 (3) | 4 (2) | 49 (28) | (57) |
| 2 | 48 (26) | 41 (22) | 6 (3) | 2 (1) | 4 (2) | 53 (28) | (54) |
| 3 | 35 (14) | 48 (19) | 8 (4) | 3 (1) | 5 (2) | 64 (26) | (40) |
| 4 | 45 (17) | 34 (13) | 16 (6) | 3 (1) | 3 (1) | 56 (21) | (38) |
| 5 | 50(26) | 40(21) | 8 (4) | 2 (1) | 0 (0) | 50 (26) | (52) |

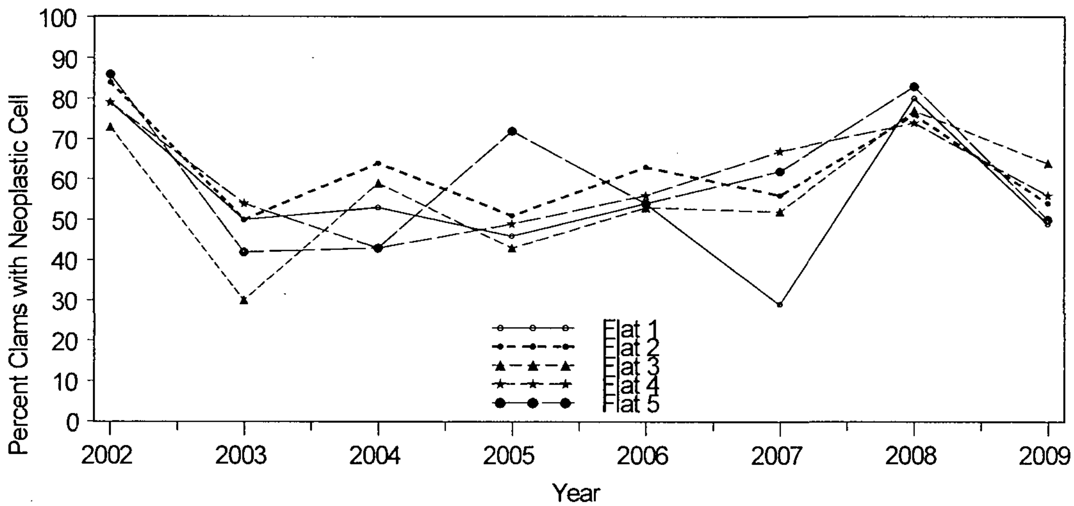


Figure 7-15. Percentage of softshell clams with neoplastic cells in Hampton Harbor, 2002 through 2009. Seabrook Operational Report, 2009.

**Table 7-9. Summary of Evaluation of Effects of Operation of Seabrook Station on *Mya arenaria*. Seabrook Operational Report, 2009.**

| 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 = 1991-2009; 1->50 mm size classes = 1990-2009; 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 1997 through 2004, possibly related to the cumulative impacts of up to nine years of digging effort and reduced recruitment from yearlings. Recently, density of adult clams generally increased at all flats through 2007, possibly a result of recent closing of the flats to digging on Fridays. However, density of adults declined in 2008 and 2009 at Flats 1 and 4.

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 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 and correlation analyses were used to evaluate the concern that YOY density could be decreased through the removal of larvae by entrainment (NAI 2009). The correlation between the annual entrainment estimate of softshell clam larvae and recruitment of YOY in Hampton Harbor was significant; however the relationship was positive indicating that years with high levels of YOY settlement occurred during years when the plant entrained more larvae. This significant correlation is probably the result of years of high YOY settlement and entrainment both occurring when larval densities are high.

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 11% or less of the variability in YOY density at Flats 1, 4, and for all flats combined. However, at Flat 2, 25% 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.

There was no significant relationship between clam larvae and adult clams, and between 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 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). The strong 2008 year class (NAI 2009) also appears to have undergone significant mortality between the YOY and yearling stages.

As there does not appear to be a direct relationship between density of adult 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, 1996-1999, and 2008 (Figure 7-5). Densities of both yearling and adult clams are presently low except for adults at Flat 2, which increased in 2009. 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 later lifestages 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, 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. 2007). 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). Jennings and Hunt (2009) found that densities of newly settled softshell clams could be reduced by half after 2.5 to 5 hours and the dispersal distance due to bedload transport were on the order of cm/hour. 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. Bedload transport has the potential to alter the distribution of juvenile bivalves over the scale of several kilometers in one month (Hunt et al. 2009). 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 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 (Beukema 1991; Strasser 2002). Behrens-Yamada and Gillespie (2008) found increased recruitment of young crabs in Oregon following warm winters. Congleton et al. (2006) investigated the relationship between winter water temperature and clam landings and found a positive relationship in eastern Maine, but a negative relationship in southern Maine. Due to the warmer surface water temperatures in eastern Maine (Mountain and Manning 1994), the authors hypothesized that widespread winter kill of green crabs may not occur and there may be a longer growing season for clams and an earlier spring bloom of plankton. In southern Maine the colder winter water temperatures may be sufficient to cause a significant winter kill of green crabs and subsequently reduce predation.

Our data (Figure 7-11) imply a possible positive relationship between green crab CPUE and average winter water temperatures. 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 affect 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 clam density. Digging effort is represented by the number of licenses sold, and this is not a good 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) 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 represents only a crude measure of digging effort as it is not known how many diggers are actively fishing, on what flats the effort is being expended, and how many clams are removed by each digger.

Resumption of digging from 1994 through 1998 may have resulted in the 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, conservation measures instituted by New Hampshire Fish and Game in 2003 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 has generally increased at all flats after 2004, although density decreased at Flats 1 and 4 in 2009.

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. In 1987, 6% of the clams on Flat 1, 27% of the clams on Flat 2 and no clams on Flat 4 contained neoplastic cells (NAI 1998). A less comprehensive survey in 1988 indicated 80% of the clams on Flat 2 contained neoplastic cells (NAI 1998). By 1996 and 1997, 100% of the clams on each flat contained some neoplastic cells (NAI 1998). This percentage is higher than that observed in 2002 through 2009, where the percentage of infected clams ranged from 29% on Flat 1 in 2007 to 86% on Flat 4 in 2002. 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. However, in 2008 between 74% and 83% of clams had neoplastic cells, similar to 2002 (Figure 7-15). In 2009 the percentage of clams with neoplasia decreased at all flats was at levels comparable to 2003 through 2007. In contrast to our findings, Beal (2002), sampling clams measuring less than 20 mm in length, 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 in the future due to the relatively large percentage of clams that exhibited some degree of this usually fatal disease in 2009.

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 2009, 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.

After 36 years of monitoring of some parameters, it is possible to determine some of the factors that affect settlement of YOY clams, and the relationships between younger and older lifestages of softshell clams. It is apparent that larval density and abundance of green crabs are important factors affecting the settlement of YOY clams. Larval density alone explained between 3-6% (Flats 1 and 4) and 25% (Flat 2) of the variation in YOY settlement. Green crab CPUE alone explained between 1-2% (Flats 2 and 4) and 22% (Flat 1) of the variation in YOY settlement. In a multiple regression model using both these factors, the amount of variation explained by the model increased to 38% at Flat 1, but was not significant at Flat 4 and was essentially unchanged at Flat 2 at 20%. These factors appear to be of varying importance among the flats in determining settlement with larval and green crab abundance approximately of equal importance at Flat 1, larval abundance more important at Flat 2, and neither important at Flat 4.

Even though larval density can affect settlement of YOY, there were no significant relationships between larval density and abundance of adult clams two years later. This suggests that concerns that larval entrainment could affect abundance of adult clams were not justified. Larval entrainment and settlement of YOY were positively correlated (NAI 2009) most likely because both entrainment and settlement were related to larval density. Therefore it appears that entrainment of softshell clam larvae has not affected settlement of YOY or density of adult clams.

The recent work by Flach (2003), Hunt (2004a and b), Hunt et al. (2003; 2007; 2009), 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 recently settled softshell clams in Hampton Harbor. The lack of a significant negative 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, disease 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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NEXTera ENERGY SEABROOK

July 23, 2010

NPDES Permit No. NH0020338
SBK-L-10131

Environmental Protection Agency
NPDES Program Operation Section
P.O. Box 8127
Boston, MA 02114

Seabrook Station
2010 Environmental Monitoring Program Mid-Year Report

NextEra Energy Seabrook, LLC, the operator of Seabrook Station, has enclosed the 2010 Environmental Monitoring Program Mid-Year Report in accordance with Part I.A.24.d of the referenced NPDES Permit. The enclosed mid-year report provides the status of the on-going Seabrook Station Biological, Hydrological and Chlorination Monitoring Programs and a synopsis of the key data and information compiled since the last annual report.

Seabrook Station's Environmental Monitoring Program continues to demonstrate that Seabrook Station has not had a significant impact on the balanced indigenous populations in the coastal waters of New Hampshire after approximately twenty years of plant operation (August 1990 commercial).

If you have questions on this matter, please call Mr. Allen Legendre, Principal Engineer, at (603) 773-7773.

Sincerely,

NextEra Energy Seabrook, LLC

Michael O'Keefe
Licensing Manager

cc: New Hampshire Department of Environmental Services (NHDES)
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I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Michael O'Keefe
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**ENCLOSURE TO SBK-L-10131**

# Seabrook Station
## 2010 Environmental Monitoring Program Mid-Year Report

### 1. Environmental Monitoring Program

The Seabrook Station Environmental Monitoring Program continues to be implemented through Normandeau Associates of Bedford, NH and the Hampton, NH field office. The 2009 Environmental Monitoring Report is currently being completed and critically reviewed by the Seabrook Station Ecological Advisory Committee. The annual report will be submitted by September 1, 2010 in accordance with the NPDES Permit. No significant impacts to the balanced indigenous populations in the coastal waters of New Hampshire, associated with the operation of Seabrook Station, have been identified. No significant changes have occurred in the Environmental Monitoring Program during the first six months of 2010 and none are expected during the ensuing six months.

A special study to investigate the decline of the kelp species *Laminaria digitata* which has been detected by the environmental monitoring program was initiated in June 2010. Temperature loggers were deployed at the 4 kelp monitoring stations, B17, B19, B31 and B35. The loggers will record bottom temperatures at these stations to determine if the kelp beds are exposed to temperatures that may inhibit the reproductive cycle of the species.

An estimated 9,283 fish and 21 lobsters were impinged in 2009. This estimate is the third lowest impingement estimate since reliable estimates were first made in 1994. Additional adult equivalency information on the key species impinged will be included in the 2009 Seabrook Station Environmental Monitoring Report.

A preliminary estimate of the number of fish impinged for the first six months of 2010 (January-June) is about 20,079 fish and 0 lobsters. More than half of the 2010 impingement occurred during the March 2010 storm events.

### 2. Hydrological Monitoring Program

The Hydrological Monitoring Program continues to demonstrate that the thermal component of the discharge from Seabrook Station is in compliance with Part I.A.11.e of the NPDES Permit. The NPDES Permit establishes a limit of 5 °F on the thermal discharge measured at the surface relative to a reference station outside the influence of the discharge. The monthly average of the temperature differences (delta-T) forms the compliance basis.

The ocean thermal monitoring data for the first six months of 2010 indicates that Seabrook Station continues to operate well within the NPDES Permit thermal limit. The January through June 2010 delta-T values were 3.59°F, 3.34°F, 1.00°F, 0.77°F, 1.19°F and – 2.13°F respectively. Temperature data was not recorded during the period of May 24 thru June 15. Attempts to retrieve the data were unsuccessful. The data loss was caused by a faulty shuttle which shorted out all four continuous monitoring loggers at stations DS and T7. In the field, the loggers appeared to download properly and when the data was viewed it indicated the correct recorded dates, but the data was a copy of the temperatures from the previous week and no new data was recorded. Four new loggers were deployed in the field and a new shuttle placed in service. Going forward the data will be reviewed after downloading to ensure it is not a copy of the previous week.

## 3. Chlorine Minimization Program

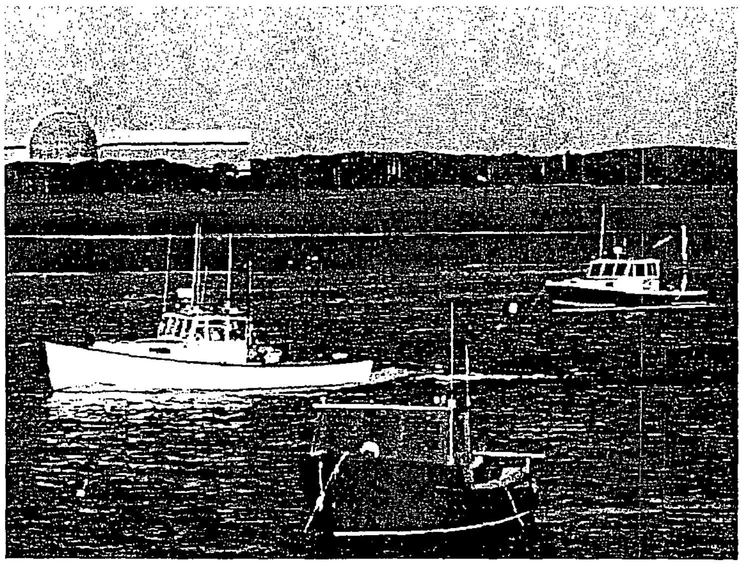
The Chlorine Minimization Program continues to minimize the use of chlorine (sodium hypochlorite) consistent with maintaining suitable biofouling control in Seabrook Station's Cooling Water System Intake and maintaining optimal condenser efficiency. No changes have occurred in the Chlorine Minimization Program during the first six months of 2010 and none are expected during the ensuing six months.

SBN-0064
NAI & Arcadis 2008

# Appendix A

Revised PIC

# SEABROOK NUCLEAR POWER STATION
# EPA 316(b) PHASE II RULE PROJECT
# REVISED PROPOSAL FOR INFORMATION COLLECTION



JUNE 2008

# SEABROOK NUCLEAR POWER STATION
# EPA 316(b) PHASE II RULE PROJECT
# REVISED PROPOSAL FOR INFORMATION COLLECTION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## 1.0 INTRODUCTION

Submittal of a Proposal for Information Collection (PIC) is the first step in compliance with the Phase II rule of Section 316(b) of the Clean Water Act (CWA). This PIC for the FPL Energy Seabrook Nuclear Power Station (Seabrook Station) is submitted to EPA Region I to allow review and comment on Seabrook Station's plan to collect information to support the Comprehensive Demonstration Study (CDS). The CDS is the document that will demonstrate the means of compliance by Seabrook Station with the Phase II rule. The PIC also provides descriptive information on the Cooling Water System (CWS) and the source waterbody for cooling water for Seabrook Station.

This document is intended to document Seabrook Station's compliance with Section 125.95(b)(1) of the Phase II rule. It includes:

- a brief overview of Section 316(b) Phase II regulatory requirements (Section 2.0),
- a description of Seabrook Station and the cooling water system, including the descriptions required in Sections 122.21(r)(2), (3), and (5) of the Phase II rule are presented in Section 3.0.
- a description of existing and potential technology, operational and restoration measures that can be used to demonstrate compliance (Section 4.0),
- a description of historical studies that were used to characterize impingement mortality and entrainment (Section 5.0),
- a description of historical consultations with environmental regulatory agencies, and future impingement and entrainment sampling plans (Section 6.0), and
- a summary of the current environmental monitoring program.

## 2.0 SECTION 316(B) COMPLIANCE REQUIREMENTS

The final Section 316(b) Phase II rule (40 CFR Parts 9, 122, 123, 124, and 125) implements section 316(b) of the Clean Water Act for existing power production facilities that employ a cooling water intake structure and are designed to withdraw 50 MGD or greater from the waters of the United States for cooling purposes. According to Part 125.91, this rule is applicable to Seabrook Station because:

- Seabrook Station's primary activity is to generate electric power,
- Seabrook Station is a point source that uses a cooling water intake structure,
- the cooling water intake withdraws cooling water from waters of the United States and at least 25% is used exclusively for cooling purposes, and
- the cooling water intake structures have a total design flow 50 MGD or more.

The Phase II rule in Part 125.94(a) presents five alternatives for compliance:

**Alternative 1**—Demonstrate facility has reduced flow commensurate with closed-cycle recirculating system or demonstrate facility has reduced design intake velocity to less than 0.5 foot per second (fps).

**Alternative 2**—Demonstrate that existing design and construction technologies, operational measures, and/or restoration measures meet the performance standards.

**Alternative 3**—Demonstrate facility has selected design and construction technologies, operational measures, and/or restoration measures that will, in combination with any existing design and construction technologies, operational measures, and/or restoration measures, meet the performance standards.

**Alternative 4**—Demonstrate facility has installed and properly operates and maintains an approved technology (cylindrical wedgewire screens for intakes in freshwater rivers and streams).

**Alternative 5**—Demonstrate a site-specific determination of BTA is appropriate.

Four of these compliance alternatives require that the station meet the established performance standards and the fifth option allows for a site-specific determination of BTA. These compliance options can potentially be achieved through the implementation of a technological, operational, and/or restoration measures.

# 3.0 SEABROOK NUCLEAR POWER STATION

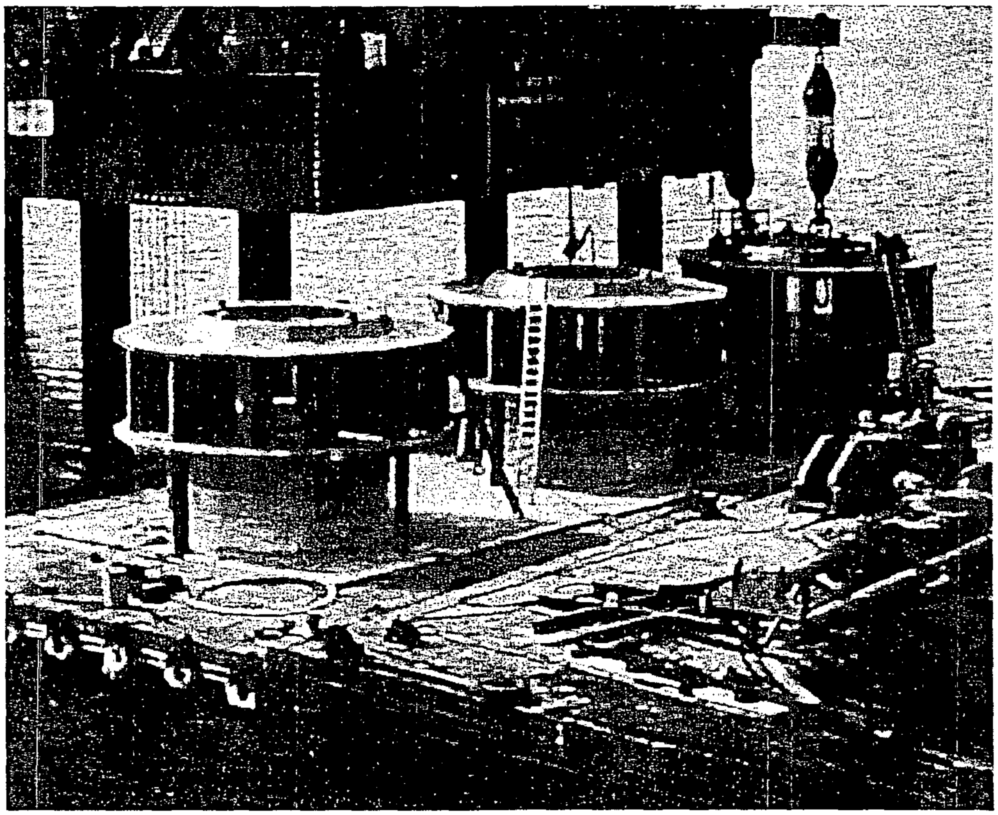
## 3.1 STATION DESCRIPTION

Seabrook Station, a 1,221 MW nuclear power plant located in Seabrook, NH, started commercial operation in August 1990. Cooling water enters the once-through cooling water system through three offshore intake structures equipped with 30 foot diameter velocity caps and nominal 5-inch vertical bar racks. The intakes are located in about 60 feet of water, approximately 7,000 feet offshore in the western Gulf of Maine, an embayment of the North Atlantic Ocean. Each intake rises a total of approximately 18 feet off the bottom and water enters the intakes through 7-foot tall intake bays (Figure 3-1). Water is withdrawn primarily from the middle of the water column and travels down vertical risers to a 19-foot diameter intake tunnel 17,000 feet long that delivers cooling water to traveling screens located in the screenhouse at the plant. Average cooling water flow is 599.5 million gallons per day (MGD) and the maximum design flow is 684 MGD.

The design locations of the intakes were moved several times for environmental concerns during the permitting process. Early proposed intake designs (Ebasco Services Inc. 1969) included:

- an intake pipe withdrawing from the ocean at a depth of 18 feet to a canal dredged across the saltmarsh to the plant,
- an intake pipe withdrawing from the ocean at a depth of 18 feet running directly to the plant, and
- an intake pipe withdrawing water from Hampton Harbor to a canal dredged across the saltmarsh to the plant.

The intake designs that withdrew cooling water from either Hampton Harbor or from the ocean at a depth of 18 feet were eliminated from consideration for environmental reasons. The March 1973 Construction Permit Application to the Nuclear Regulatory Commission included a proposed intake location 3,000 feet offshore in 30 feet of water. The cooling water would be conveyed to the power plant through an intake tunnel bored through the bedrock. In September 1975, the Regional Administrator of the Environmental Protection Agency issued a ruling adding 4,000 feet to the intake



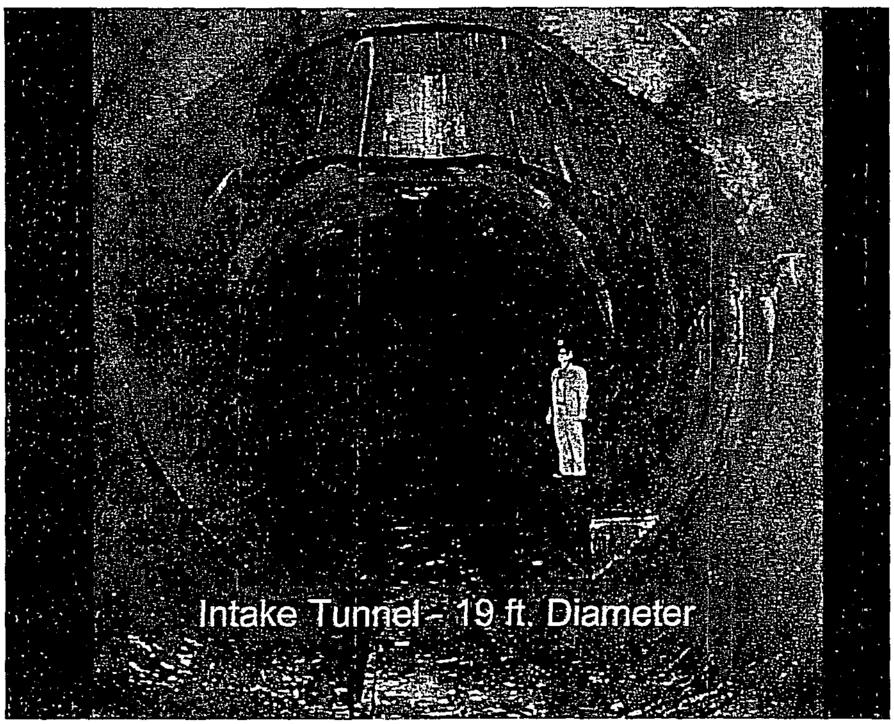



Figure 3-1. Seabrook Nuclear Power Station intake structures on construction barge prior to installation (top) and intake tunnel (bottom).

tunnel for environmental reasons moving the intake location to 60 feet of water. After a series of reversals, reaffirmations, and appeals to the U.S. First Circuit Court of Appeals, an intake tunnel with an intake location 7,000 feet offshore in 60 feet of water was approved and constructed.

## 3.2. Seabrook Station Source Water Physical Data (40CFR 122.21(r)(2))

The following water body description complies with the EPA Clean Water Act 316 (b) Phase II Rule. Although the Rule was remanded in 2006, requirements for source water description outlined below provide input for the regulator to exercise Best Professional Judgment (BPJ) in evaluating the appropriate technology for potential reductions in impingement mortality and entrainment at Seabrook Station.

Specifically, the rule requires the following:

1. A narrative description and scaled drawings of the physical configuration of all source water bodies used by Seabrook Station, including areal dimensions, depths, salinity and temperature regimes.
2. An identification and characterization of the source water body's hydrological and geomorphologic features
3. Location maps

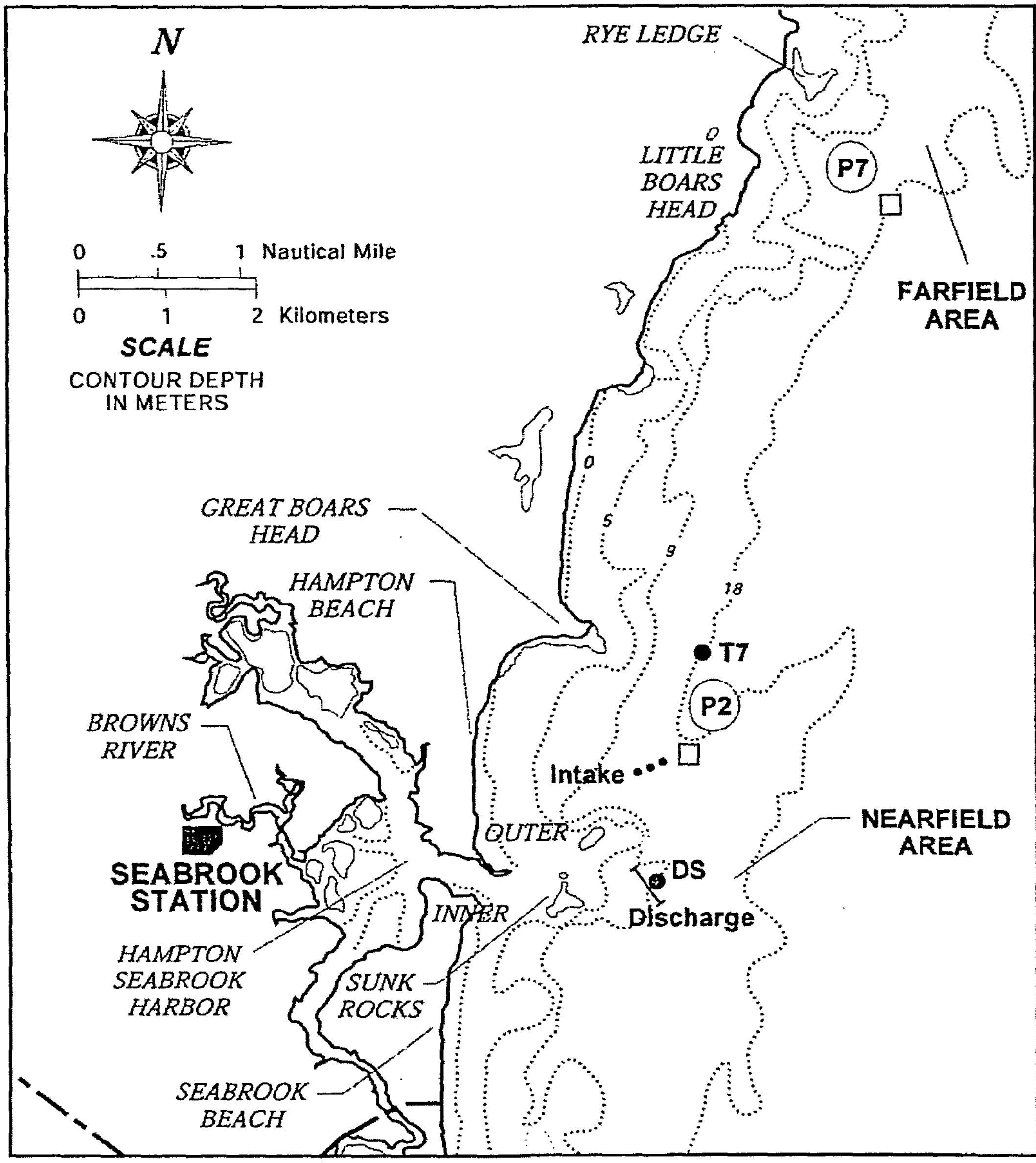
### 3.2.1 Source Water Body

The source water body for the Seabrook Station is the Western Gulf of Maine. There is an extensive source of data (e.g., bathymetry, ocean currents, water temperature, etc.) available for the Gulf of Maine from the Gulf of Maine Ocean Data Partnership (www.gomodp.org) which began compiling data in 2001. The founding members of the Partnership include government agencies, intergovernmental organizations, and nongovernmental organizations, including academic, research, and other nonprofit entities. Each participant is engaged in the collection of physical, biological, chemical or geologic data on the Gulf of Maine.

The GoMODP data base will be used to provide information to describe the general bathymetry and ocean currents near the intakes of the Seabrook Station. However, Seabrook Station has established an extensive water quality (water temperature, salinity and dissolved oxygen) data base from two sampling stations, one located in the nearfield area (Station P2) of the Seabrook Station cooling water intake structure in 57 feet MLW, and the other located in the farfield area (Station P7) approximately 4 miles north of the Seabrook cooling water intake in 60 feet MLW(Figure 3-2). Water quality data from the nearfield and farfield are examined for the period Seabrook Station was operational (1991-2007) to provide the environmental setting.

Water quality methods are provided in more detail in the attached document "Seabrook Station Environmental Studies Quality Program and Standard Operating Procedures, Revision 10." Temperature, dissolved oxygen, and salinity measurements began in 1979 at the Nearfield Station P2 and in 1982 at the Farfield Station P7 (Figure 3-2). Sampling at Stations P2 and P7 has continued to the present.

From 1991 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




## LEGEND

□ = water quality stations

● = continuous temperature monitoring stations

Figure 3-2. Seabrook Station water quality sampling stations.

March 1989) or a YSI™ (Model 33) S-C-T 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. 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) depths. Samples were fixed in the field with manganese sulfate and alkaline iodide-azide, and analyzed by titration within eight hours of collection using EPA Methods for Chemical Analyses of Water and Wastes (USEPA 1979) and Standard Methods (APHA 1989). Beginning in 1997, dissolved oxygen profiles were recorded *in situ* using a YSI 600XL Water Quality Monitor at the same depths as previous measurements.

Water quality was evaluated to determine seasonal patterns and to detect trends among years, means and confidence limits (Sokal and Rohlf 1981) were calculated and tabulated for operational years (1991-2007). Monthly means and their 95% confidence limits period were compared graphically to the monthly means for 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.

### *3.2.1.1 Water Temperature*

Heating of the surface water in the spring and summer can cause thermal stratification, which can affect the vertical distribution of pelagic organisms and nutrient cycling. Monthly surface temperature at Station P2 peaked in August and was lowest in February. Monthly mean bottom temperatures were highest in September and lowest in February. Differences between monthly mean surface and bottom temperatures at P2 were most pronounced between May and October, indicating that the nearshore water column was stratified during these months (Figure 3-3).

During the period that Seabrook Station was in operation, there were no significant differences in surface or bottom water temperatures between the nearfield and farfield stations (NAI 2007). Mean water surface water temperature was 9.7 °C in the nearfield area and 9.6 °C in the farfield area (Table 3-1). Bottom water temperatures averaged 7.7 °C in the nearfield area and 7.6 °C in the farfield area. The time series of annual means for surface and bottom temperatures at both stations P2 and P7 indicate that there were no obvious trends in water temperatures across years (Figure 3-4). Quantitative comparisons of mean water temperature from the nearfield and farfield arras, and from both before and after the plant started operation indicate that there has been no evidence of an impact on water temperature due to the operation of Seabrook Station (NAI 2007).

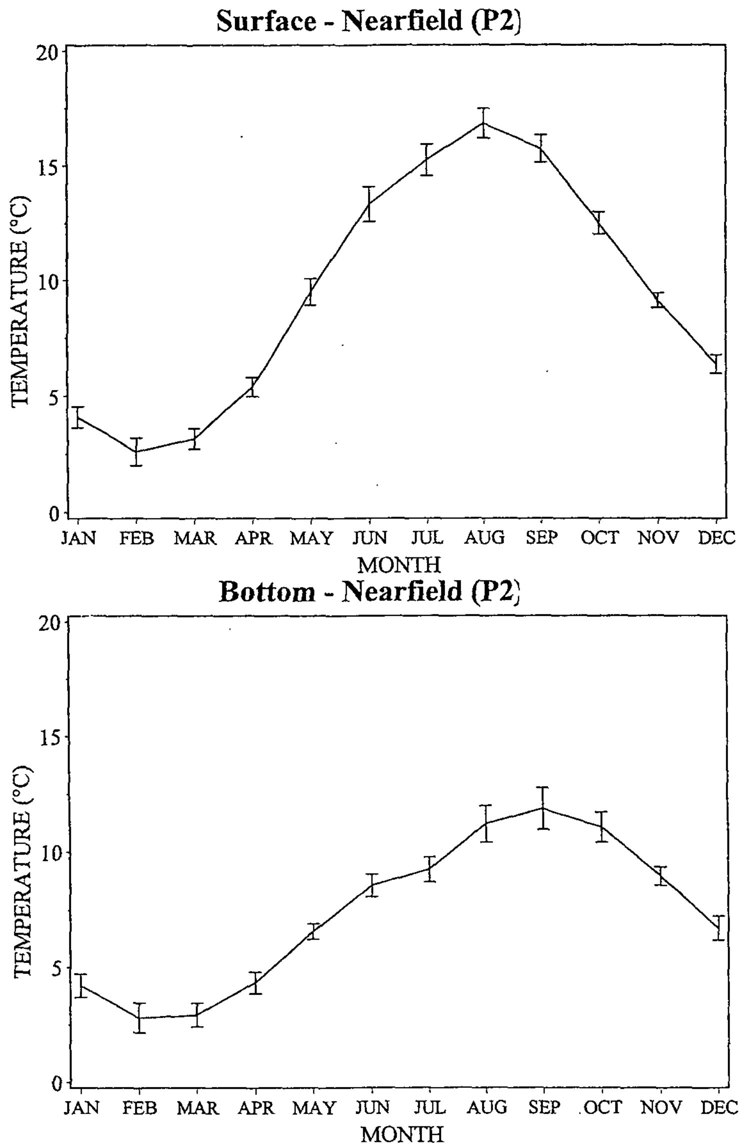



Figure 3-3. Surface and bottom temperature (°C) at nearfield station P2, monthly means and 95% confidence intervals from 1991-2007.

**Table 3-1. 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 Operational Years 1991-2007.**

| | | LCL | Mean | UCL | MIN | MAX |
|---|---|---|---|---|---|---|
| **Temperature (°C)** | | | | | | |
| **Surface** | **P2** | 9.3 | 9.5 | 9.7 | 0.0 | 20.4 |
| | **P7** | 9.1 | 9.3 | 9.6 | 0.2 | 20.9 |
| **Bottom** | **P2** | 7.1 | 7.4 | 7.7 | 0.1 | 17.7 |
| | **P7** | 6.9 | 7.3 | 7.6 | 0.2 | 18.5 |
| **Salinity (PSU)** | | | | | | |
| **Surface** | **P2** | 30.9 | 31.2 | 31.5 | 25.5 | 34.2 |
| | **P7** | 30.8 | 31.2 | 31.5 | 25.2 | 34.4 |
| **Bottom** | **P2** | 31.6 | 31.8 | 32.1 | 26.9 | 34.2 |
| | **P7** | 31.6 | 31.9 | 32.1 | 26.2 | 34.7 |
| **Dissolved Oxygen (mg/l)** | | | | | | |
| **Surface** | **P2** | 9.6 | 9.7 | 9.9 | 4.2 | 13.9 |
| | **P7** | 9.6 | 9.7 | 9.9 | 5.2 | 14.7 |
| **Bottom** | **P2** | 8.8 | 9.2 | 9.2 | 2.6 | 12.6 |
| | **P7** | 8.7 | 9.0 | 9.2 | 3.4 | 12.2 |

Operational years: P2 and P7 = 1991–2007
LCL = Lower 95% confidence limit
Mean of annual means
UCL = Upper 95% confidence limit

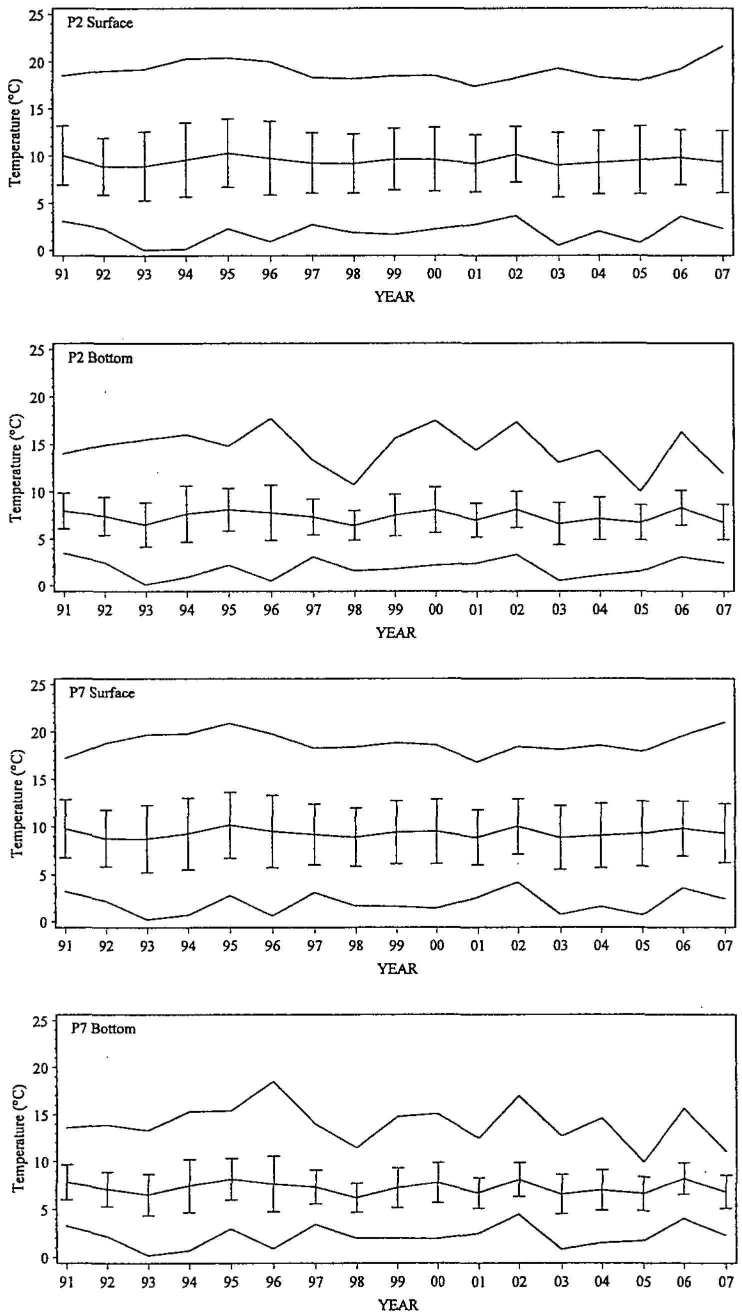



Figure 3-4. Time series of annual means and 95% confidence intervals and minima and maxima of surface and bottom water temperatures (°C) at nearfield station P2 and farfield station P7 from 1991-2007.

#### *3.2.1.2 Salinity*

Mean monthly salinities at the surface and bottom at Station P2 were similar (Figure 3-5). Salinity was generally lowest in April through June and highest in December and January. Annual mean surface salinity was identical (31.2 PSU) at the nearfield Station P2 and farfield Station P7 (Table 3-1). Similarly annual mean bottom salinity was almost identical at Station P2 (31.8 PSU) and Station P7 (31.9 PSU). Annual mean salinity and upper and lower 95% confidence intervals over the 1991-2007 operational period indicated no substantial differences in salinities between surface and bottom depths at either the nearfield (P2) or farfield (P7) areas (Table 3-1).

Long-term patterns in annual surface and bottom salinity from 1991 through 2007 indicated that similar conditions and trends occurred at both stations and at both depths (Figure 3-6). Salinity was lowest at both stations and depths in 2005 due to higher than normal freshwater runoff. Quantitative comparisons of mean salinity from the nearfield and farfield areas, and from both before and after the plant started operation indicate that there has been no evidence of an impact on salinity due to the operation of Seabrook Station (NAI 2007).

#### *3.2.1.3 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 through photosynthesis, 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 regular seasonal pattern with higher dissolved oxygen at both the surface and bottom occurring in the colder months of February through April (Figure 3-7). Lower water temperature, phytoplankton blooms and reduced abundance of consumers can increase DO concentrations in the winter and spring. Lowest DO concentration occurred in August through October, primarily due to higher water temperatures and increased respiration (Figure 3-7). Mean surface DO concentration (9.2 mg/l) was identical between the nearfield (P2) and farfield (P7) stations (Table 3-1). Mean bottom DO concentration was similar between the nearfield (9.2 mg/l) and farfield areas (9.0 mg/l). A time series plot of mean DO concentration and 95% confidence intervals indicated generally similar concentrations and 95% confidence intervals of DO among years except for 2006 where mean DO concentration appeared to be lowest at both the nearfield and farfield areas (Figure 3-8). Quantitative comparisons of mean DO concentrations from the nearfield and farfield areas, and from both before and after the plant started operation indicated that there has been no evidence of an impact on DO due to the operation of Seabrook Station (NAI 2007).

### 3.2.2 Bathymetry

The intakes for Seabrook Station are located in about 60 ft MLW and the general bottom topography is relatively flat with a gradual slope to deeper water several miles offshore. Approximately 20 miles offshore of the Seabrook intakes running from Gloucester Point in the southeast for about 40 miles in a northwesterly direction is an underwater structure known as Jeffreys Ledge. This ledge generally varies in depth from 50-100 ft. Inshore of Jeffreys Ledge and offshore of the intakes is Scantum Basin where water depths can be as great as 300-400 ft (Figure 3-9). The Isle of Shoals, a series of small rock islands are located about 10 miles to the northwest of the intakes (Figure 3-9).

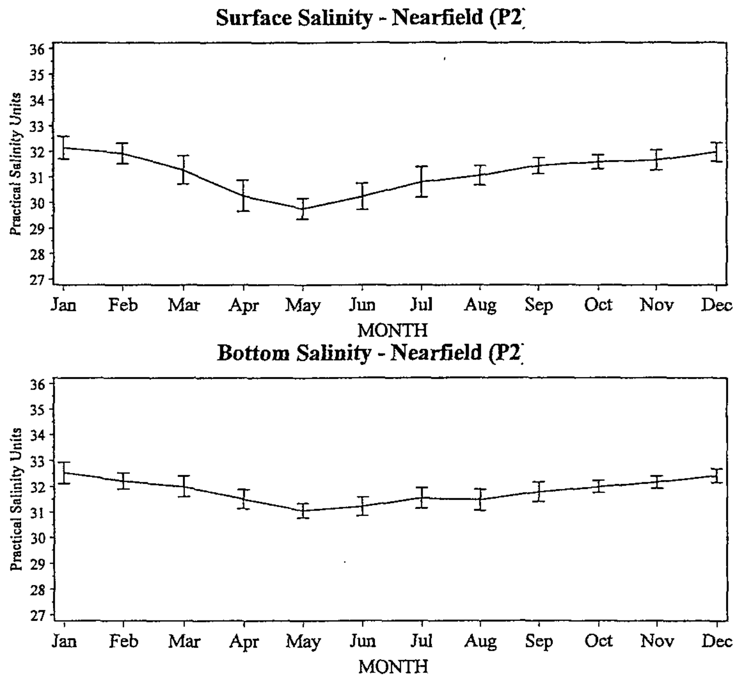



Figure 3-5. Surface and bottom salinity (PSU) at nearfield station P2, monthly means and 95% confidence intervals from 1991-2007.

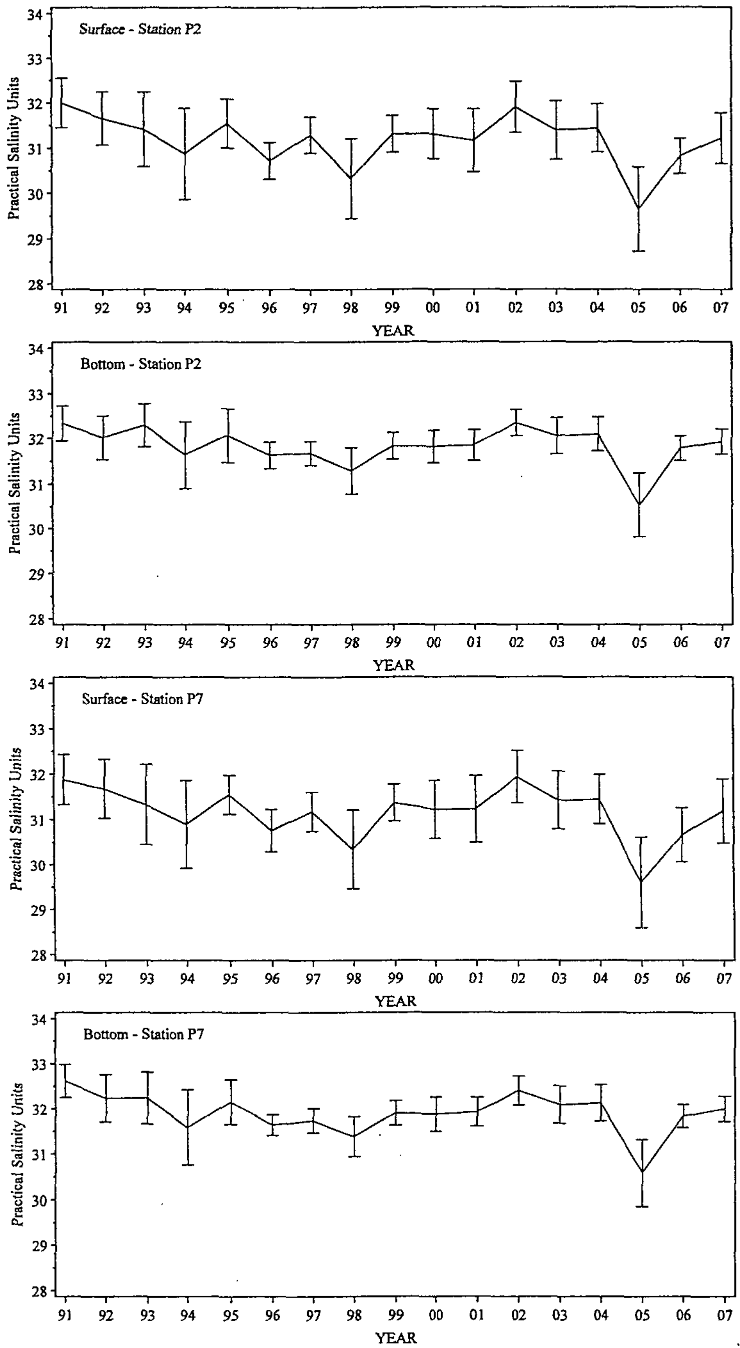



Figure 3-6. Time series of annual means and 95% confidence intervals of surface and bottom salinity (PSU) at nearfield station P2 and farfield station P7 from 1991-2007.

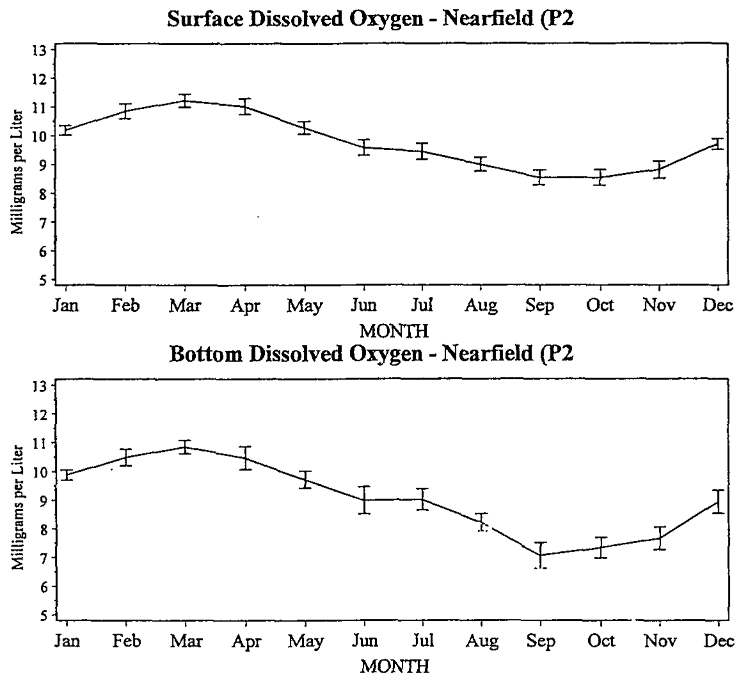



Figure 3-7. Surface and bottom dissolved oxygen (mg/l) at nearfield station P2; monthly means and 95% confidence intervals during 1991-2007.

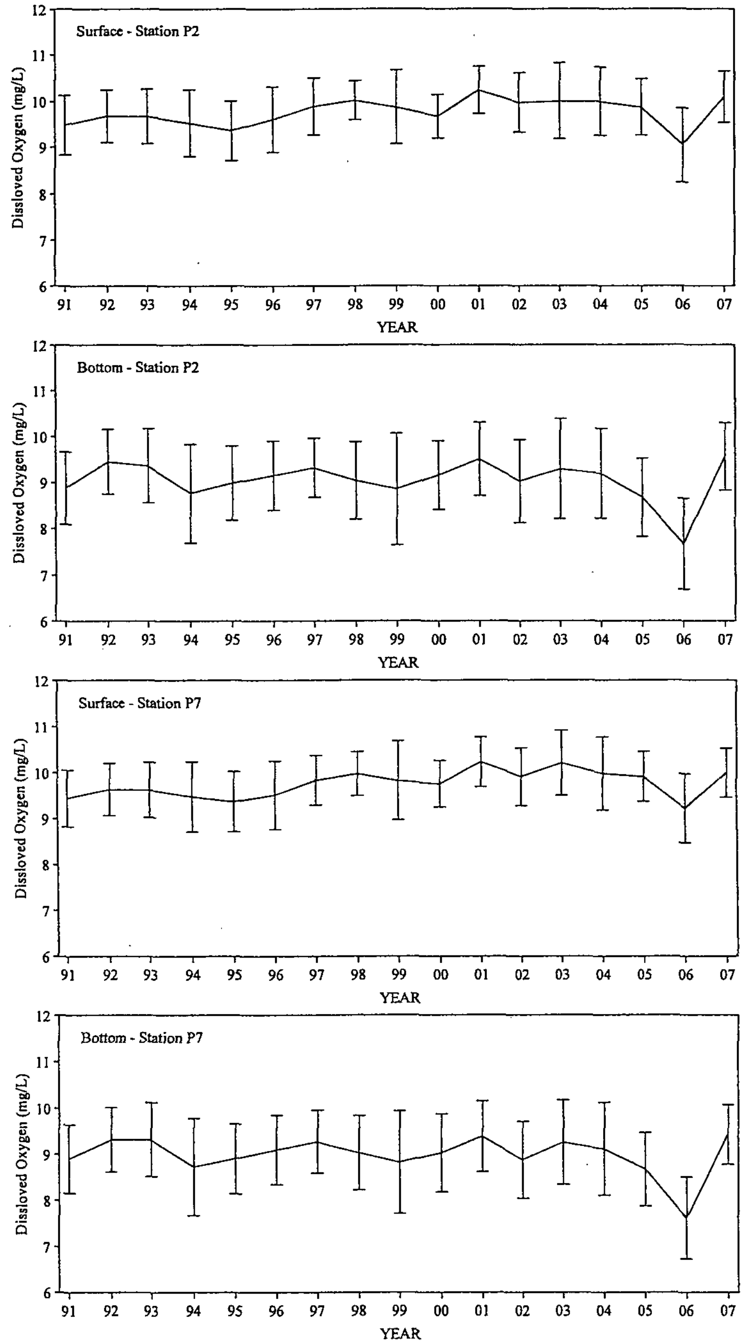



Figure 3-8. Time series of annual means and 95% confidence intervals of surface and bottom dissolved oxygen (mg/L) at nearfield station (P2) and farfield station (P7) from 1991-2007.

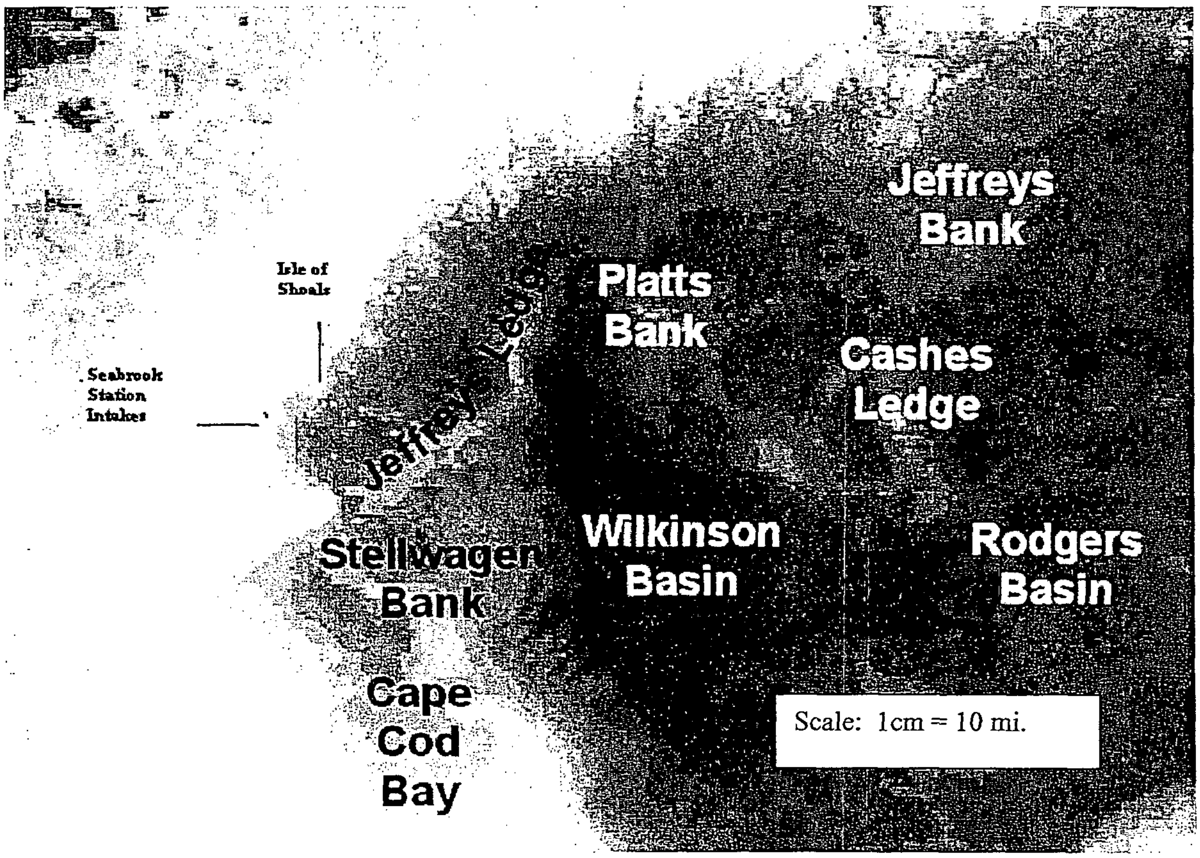



Figure 3-9. Bathymetry of the western Gulf of Maine near Seabrook Station. (From Gulf of Maine Data Partnership).

The bottom topography and fish habitat in the vicinity the Seabrook Intakes is a generally uniform sandy bottom. There are no major outcroppings of bedrock or relief in the vicinity of the intakes that could provide exceptional fish habitat. Potential rocky areas or steep sloping bottom contours that could provide varied habitat such as Jeffreys Ledge or the Isle of Shoals are miles beyond the zone of influence of the intakes.

The three intake velocity caps are located in approximately the same depth of 60 ft MLW. The substrate in the areas of the intake structures consists of several feet of sand overlying bedrock. This sand substrate extends for several hundred feet around each of the intake structures. Observations by Normandeau Associates divers who routinely clean the structures of fouling organisms (bivalves, barnacles, etc.) report that the sand substrate around the base of each structure has remained undisturbed (i.e., sand has not migrated up sides of the structures) because they see original small construction debris (e.g., concrete remnants) left over from the construction of the intakes in the late 1980s (Erik Fel'Dotto, Personal Communication, 2007).

The intake structures are described in Section 3.3.1 and consist of three velocity caps arrayed in a straight line, approximately 100 ft apart and located approximately one mile offshore. Fish impingement patterns indicate that the bulk of impinged fish are primarily demersal fish such as flounder and rock gunnel. These species tend to be impinged during and after storm events when surface wave action potentially brings fish off the bottom to the height of the intake manifold (i.e., about 10 ft off the sandy bottom). Diver observations during cleaning of the intake structure indicates that when there is a greater than 5 ft swell and long periodicity between waves, these conditions tend to create turbulence at the 60 ft depth of the structure, occasionally hampering cleaning efforts by the divers (Erik Fel'Dotto, Personal Communication, 2007).

### 3.2.3 Water Circulation and Hydraulic Zone of Influence

The currents in the vicinity of the intakes in coastal New Hampshire are divided into tidal and non-tidal types (NAI 1978). Regular tidal currents are predominant and have a reversing northward flowing flood component and a southward flowing ebb component. About 42% of all flows were reversing tidal currents. Weak tidal currents occur at the slack tides and these account for 12% of all flows. Tidal amplitude ranges from about 9 to 12 ft.

Non-tidal flows make up the remaining current type, about 46% of all flows. There is a net movement of water along the shoreline from northwest to southeast as part of the Gulf of Maine counter-clockwise gyre (Figure 3-10: GoMODP, 2007). Although the net flow is to the southeast, both north and south currents are present (NAI 1978). Flows to the south are more frequent during the winter and spring. Conversely, flows to the north are more frequent in the summer and fall. The net current flow near the intake structure (after accounting for inshore-offshore tidal currents) is approximately 0.1 m/s. However, as indicated from diver observations during storm events, it is apparent that there is also a significant groundswell or, water turbulence at the depth of the intake structures, caused by surface wave action.

The horizontal flow patterns for the intake structures were determined using a physical model under a two operating unit scenario for Seabrook Station and a cooling water flow of 1,177.6 MGD (March and Nyquist 1976). Only one unit was built at Seabrook Station, therefore the modeled flow is about twice the average actual flow. Nevertheless, the modeling exercise provides a conservative upper bound of estimates of the withdrawal zone and flow patterns. At zero ambient current, which would correspond to slack tide, the intakes withdraw from the entire water column. At an ambient current of 0.2 kt, the intakes withdraw from the lower 35 ft (depths of 60-25 ft depth). At an ambient current of 0.4 kt the intakes withdraw from the lower 25 feet (depths of 60-35 ft).

The hydraulic zone of influence (HZI) of the intakes was also estimated under a variety of ambient current conditions using a physical model and plan-view streak lines. As with the horizontal flow patterns, the model assumed two units were built, and therefore provides a very conservative estimate of the HZI. The HZI was estimated for 0.1 m/s and 0.2 m/s South, and 0.1 m/s and 0.2 m/s SW ambient currents. At a velocity of 0.1 m/S the HZI was limited to one intake diameter (30 ft) to either side of the periphery of the intake. At the higher ambient currents of 0.2 m/s the HZI was limited to about ½ intake diameter (15 ft) to either side of the intake. As these models were constructed with the flow from two units, the actual HZI for the one unit that was built could be roughly half the estimated HZI for two units.

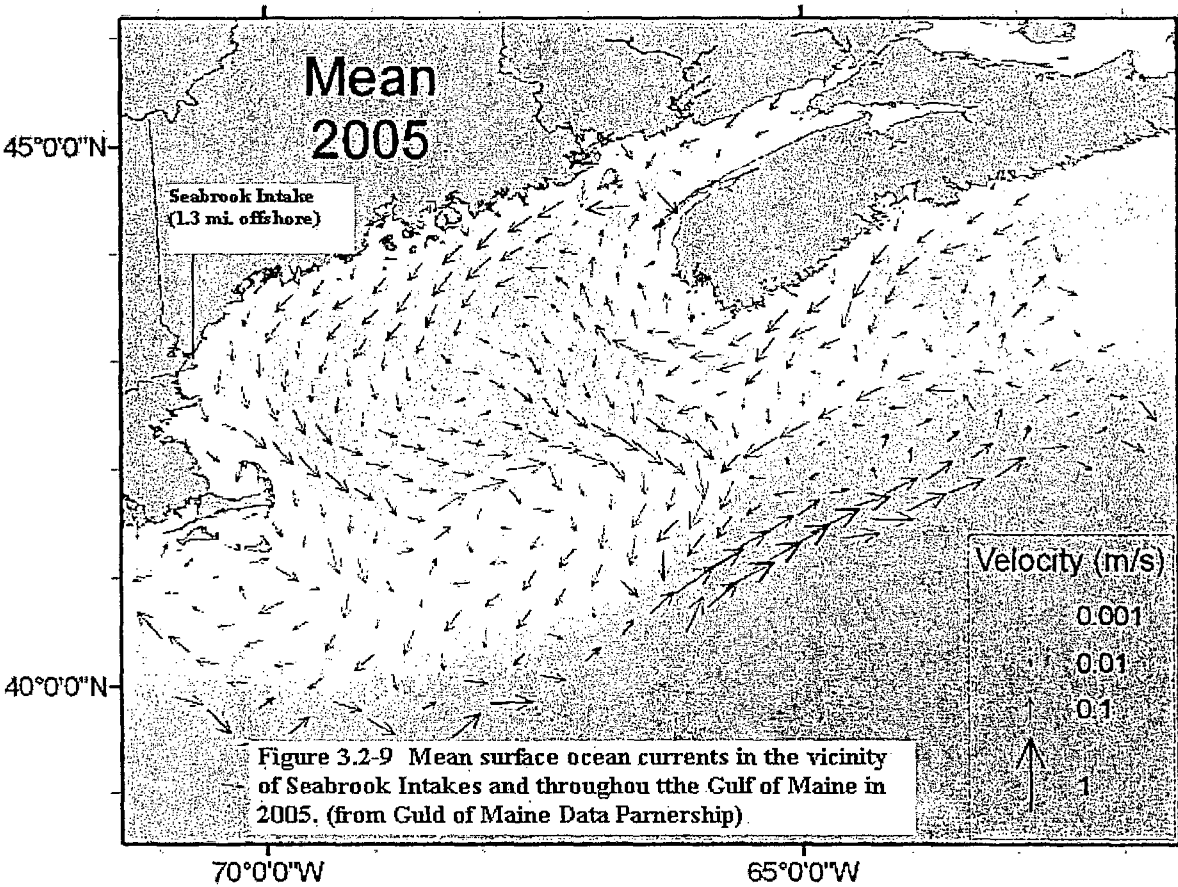



Figure 3-10. Mean surface ocean currents in the vicinity of Seabrook Intakes and throughout the Gulf of Maine in 2005. (From Gulf of Maine Data Parnership).

### 3.2.4 Location Maps

Seabrook Station is located in southeastern New Hampshire in the town of Seabrook (Figure 3-11). The Station was built primarily on upland on the edge of the Hampton-Seabrook saltmarsh complex near the tidal portion of the Browns River (Figure 3-12). The Station is located about 2 miles from the open water at Seabrook Beach. Nearby large population centers include Portsmouth, NH, Portland, ME, Manchester, NH, and Boston MA.

## 3.3 COOLING WATER INTAKE STRUCTURE

Seabrook Station's CWIS consists of three submerged offshore intake structures, an intake tunnel, a structure to transition the flow from the tunnel to the on-shore intake structure, traveling intake screens, and three circulating water and four service water pumps. The following sections will provide a more thorough discussion of the CWIS and include the information required under 40 CFR 122.21(r)(3).

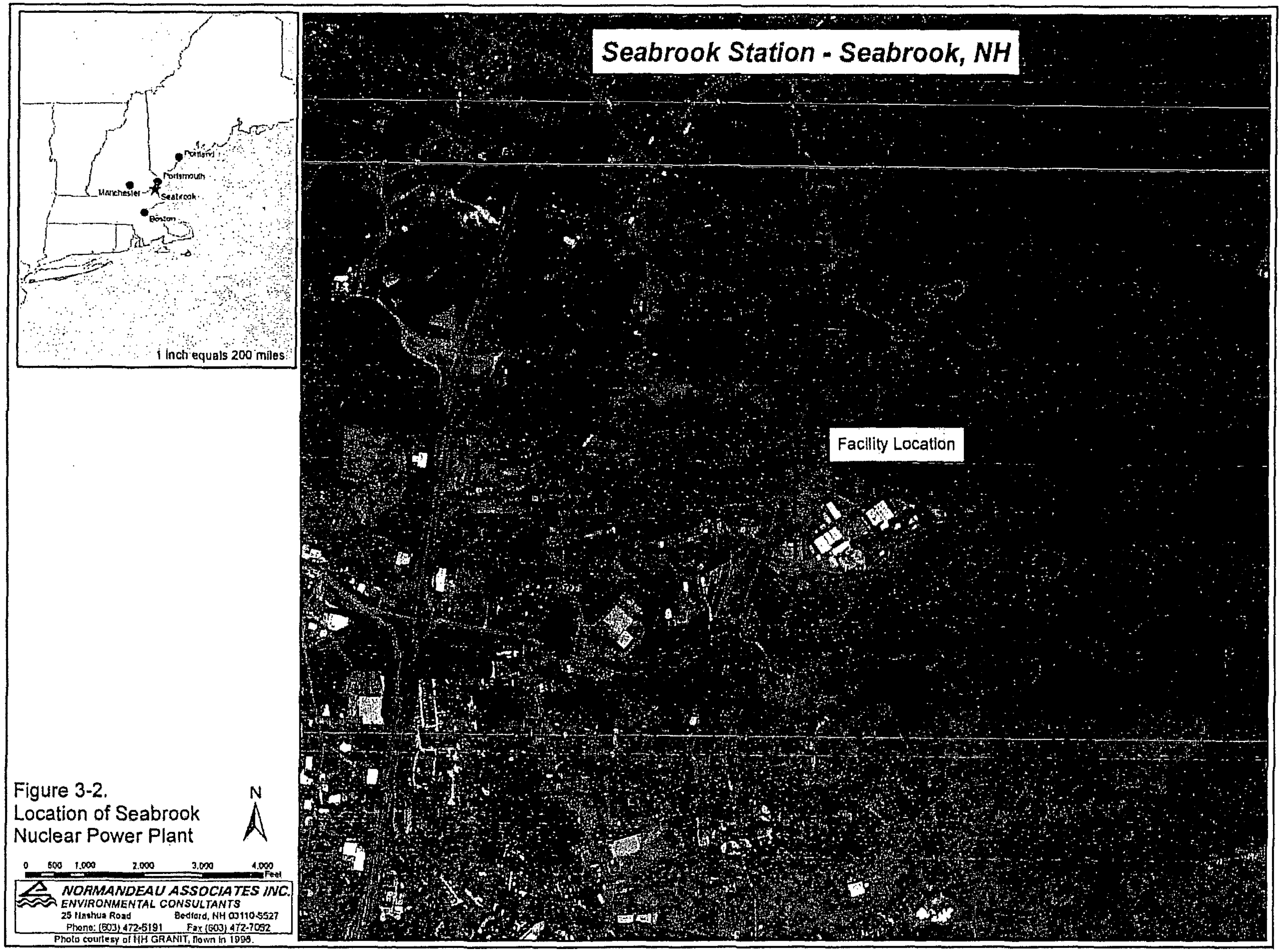



Figure 3-11. Location of Seabrook Nuclear Power Station.

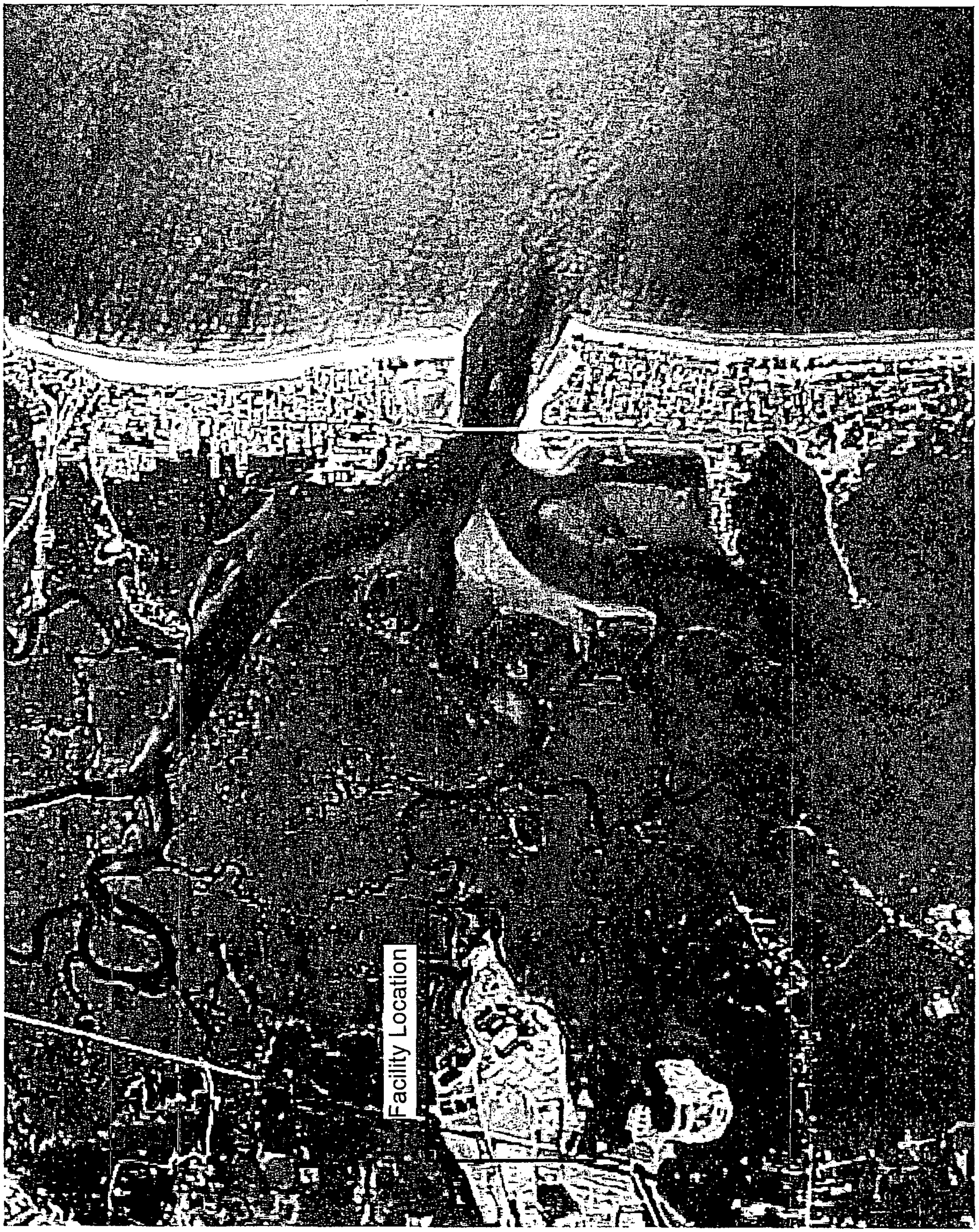



Figure 3-12. Location of Seabrook Nuclear Power Station in relation to the Hampton-Seabrook estuary.

### 3.3.1 Cooling Water Intake Structure Description

As defined in the 316(b) regulations, §125.93, the "cooling water intake structure extends from the point at which water is withdrawn from the surface water source up to, and including, the intake pumps".

Seabrook Station makes use of a once-through circulating water system with an offshore cooling water intake for both the condenser cooling water and the plant service water. There are three offshore submerged intake structures which are located approximately 1.3 miles offshore and draw water from the western Gulf of Maine. The three intake structures are approximately 110 feet apart and each has a 9'-10" inside diameter (ID) vertical intake shaft. Each intake shaft connects to the intake tunnel at approximately 160 feet below mean sea level (MSL). The 19-foot ID intake tunnel then conveys the water approximately 3.22 miles to an inland termination point which consists of a 19-foot ID vertical shaft and the transition structure. From the transition structure the water is distributed to the circulating water (CW) and the service water (SW) pumphouses.

As an alternate source of cooling water for the service water system, cooling towers were installed to provide shutdown cooling in the event the intake and/or discharge tunnels are blocked due to a seismic event. There are two cooling trains provided from the cooling tower to provide water to both trains of the service water system.

Each offshore intake structure consists of a 30-foot diameter prefabricated reinforced concrete velocity cap with copper-nickel cladding that draws the water in horizontally and directs it to the vertical intake shaft (Figure 3-13). Each velocity cap is located in about 60 feet of water at MSL, and extends approximately 18 feet above the ocean floor with the top of the structures approximately 42 feet below MSL. The opening around the periphery of the velocity cap where cooling water enters is approximately 7-feet high. The original design included vertical trash bars placed in the opening around the periphery that were spaced with 17-inch openings between bars. In August of 1999, modifications were made which reduced the openings between bars to 5 inches. This modification was made to prevent the entrance of seals into the intake structure.

The vertical intake shafts extend from the submerged intake structures to the intake tunnel which is approximately 160 feet below MSL at this location. Each vertical intake shaft is concrete lined, has a finished inside diameter of 9'-10", and has six 2-inch risers for the injection of sodium hypochlorite into the cooling water intake system from the intake tunnel chlorination system.

The concrete lined intake tunnel has an inside diameter of 19 feet The tunnel slopes downward from a depth of 160 feet below MSL at the location of the submerged intake structures to a depth of 240 feet below MSL at the location of the intake transition structure (Figure 3-14). Approximately 1.89 miles of the 3.22 mile long tunnel are inland.

The vertical shaft at the plant end of the intake tunnel is also concrete lined and has an inside diameter of 19 feet. The vertical shaft terminates at a ground-level transition structure, which is a large surge chamber open to the atmosphere (Figure 3-15). At the transition structure are four 102-inch diameter valved connections for circulating water supply, two 42-inch diameter valved connection for service water supply, two 120-inch valved connections for the return of heated circulating water, and one 38-inch diameter valved connection for the return of heat treated service water. Two of the circulating water connections, one of the service water connections, and one of the

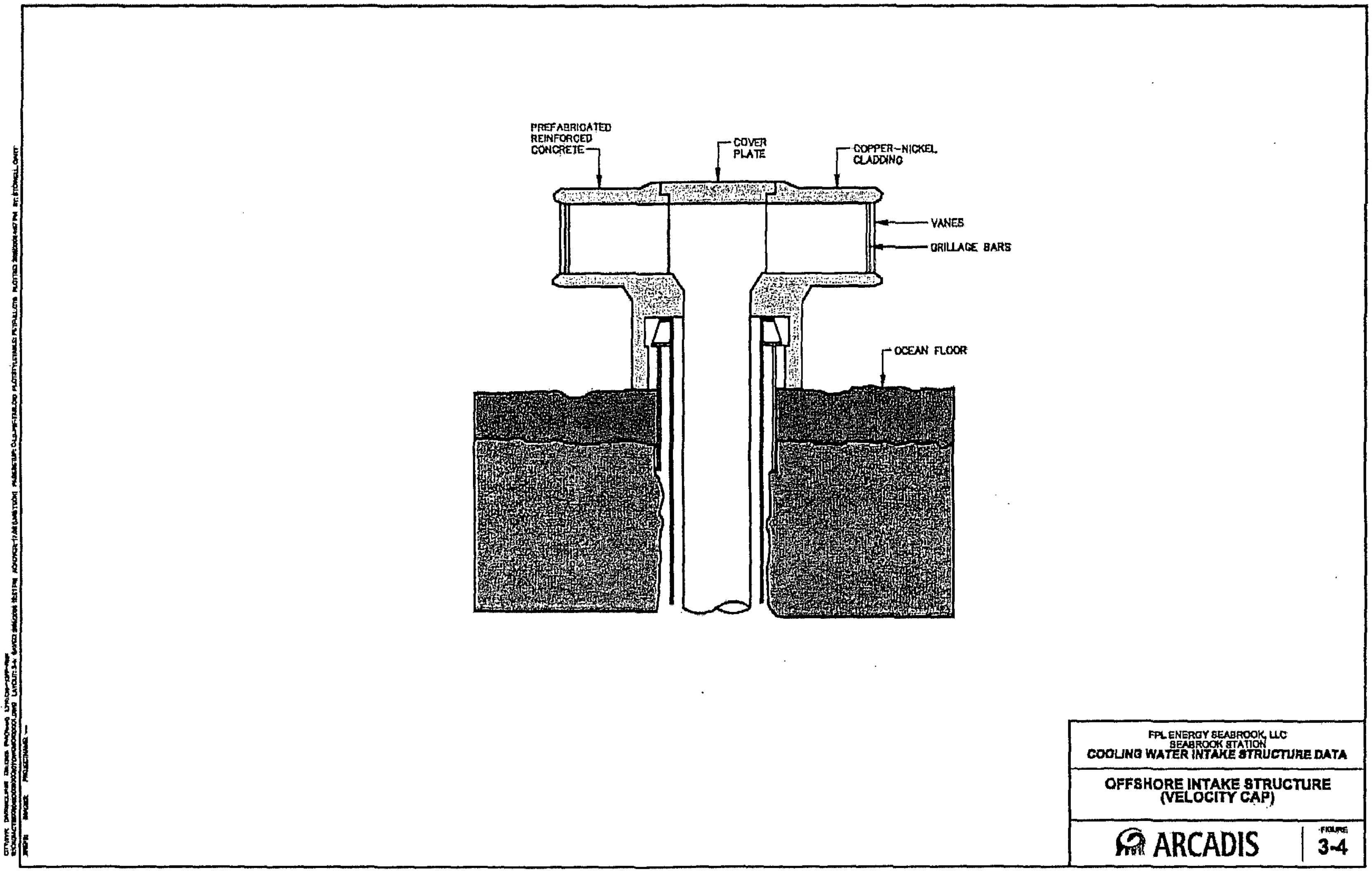



Figure 3-13. Offshore Intake (Velocity Cap) at Seabrook Station.

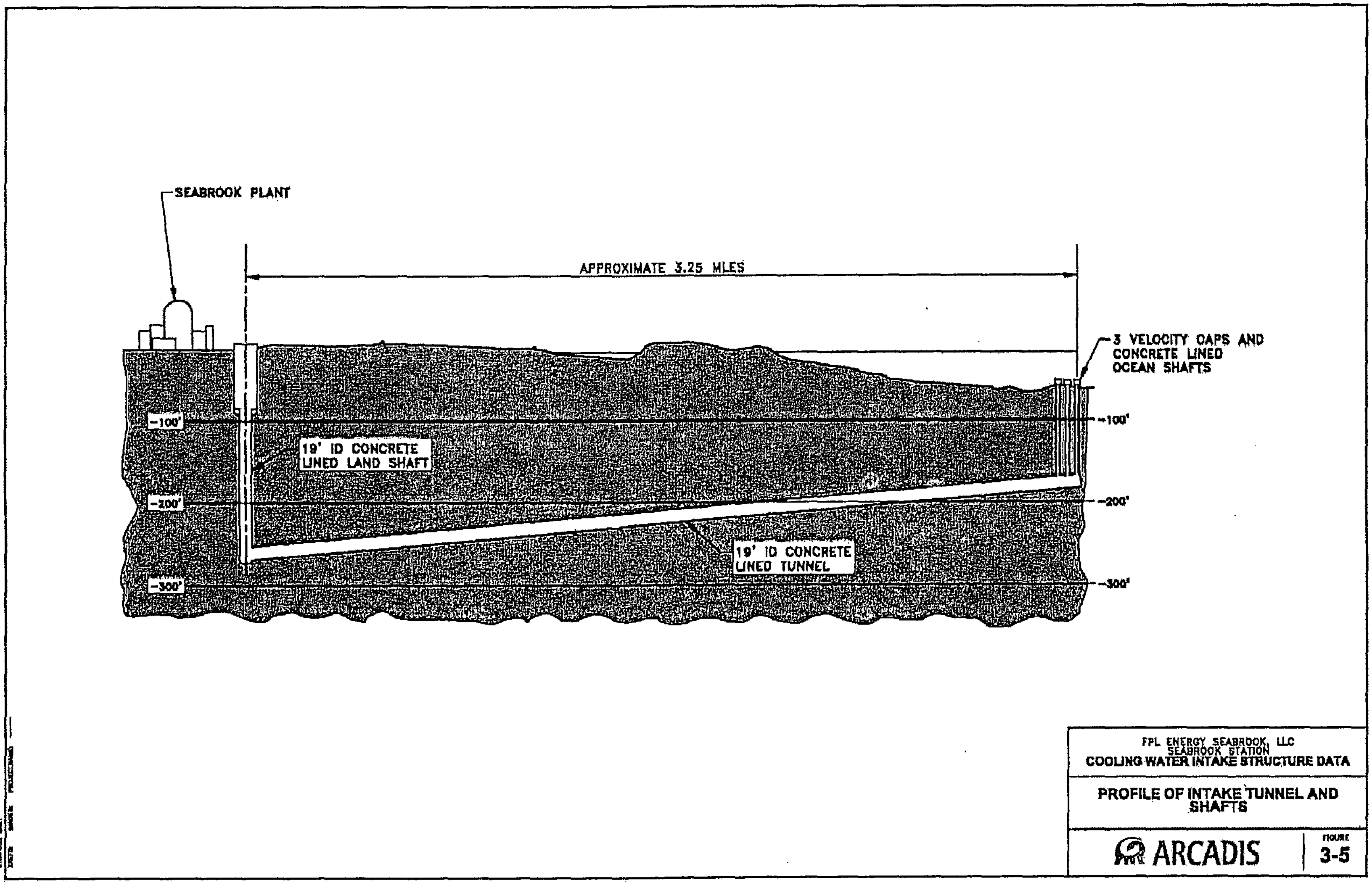



Figure 3-14. Profile of Intake Tunnel and Shafts at Seabrook Station.

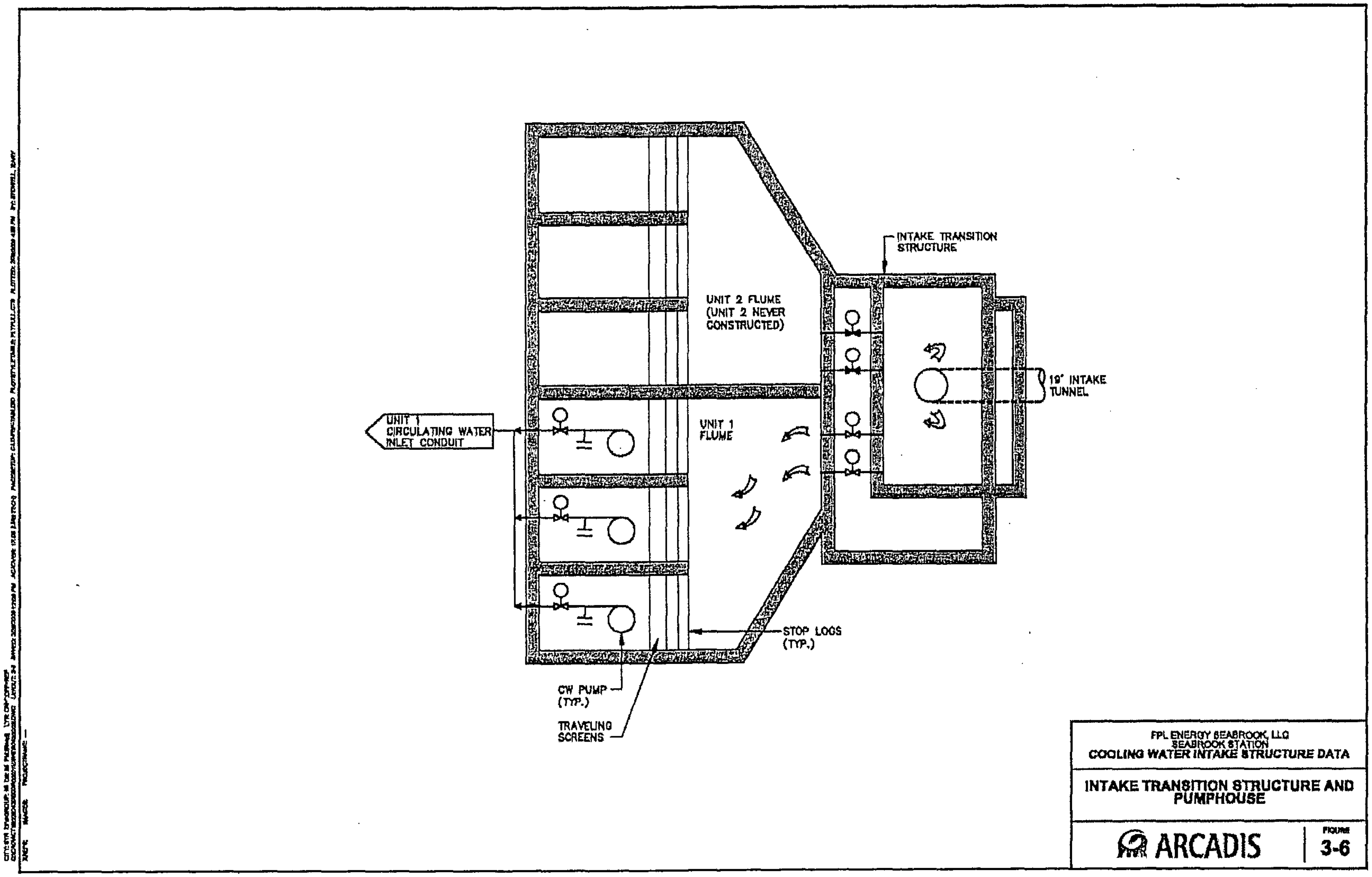



Figure 3-15. Intake Transition Structure and Pumphouse at Seabrook Station.

heated circulating water return connections were installed for Unit 2, which was planned, but never constructed.

Adjacent to the transition structure is the circulating water pumphouse. The water from the two 102-inch diameter circulating water connections at the transition structure enter a below-grade flume and the flow then separates into three screenwells (Figures 3-15 and 3-16). Each screenwell contains stop log guides, a flow-through traveling screen and a 130,000 gpm circulating water pump that supplies circulating water to the condensers. The three screens are designated as 1-CW-SR-1A, 1B, and 1C. Each screen is 14 feet wide and has ⅜-in. mesh baskets. The water depth at the screens is approximately 43 feet at MSL. The screens have two operating speeds which are 5 feet per minute (fpm) and 20 fpm. Debris is removed from the upstream (ascending) side of the screens with water sprays and is sluiced via a trough to a metal collection basket, where the debris is removed and the water drains into the intake transition structure. The screen wash water is supplied from two screen wash pumps (1-CW-SR-1A and 1-CW-SR-1B) which draw water from the discharge of the circulating water pumps.

Normally all three circulating water pumps are operated at full load conditions. As noted above, the rated design flow for each pump is 130,000 gallons per minute (gpm). Each pump has a 3,400 hp electric motor drive which operates at 400 revolutions per minute (rpm). The pumps are designated as P-39A, P-39B, and P-39C. The plant can also be operated at full load with two circulating water pumps, however the NPDES Permit only authorizes this condition for 15 days per year to support online pump maintenance.

An associated subsystem of the CWIS is the chlorination system which provides sodium hypochlorite to several locations within the CWIS. The system has the ability to inject sodium hypochlorite in the vertical shafts below the submerged intakes, the intake transition structure, circulating water pump bays, service water pump bays, and the discharge transition structure. The sodium hypochlorite prevents the growth of microorganisms on the inside of the system piping, structures, and equipment. Should this growth of microorganisms occur in the condenser tubes, the resultant fouling would prevent efficient heat transfer and reduce the condensers capability to effectively remove the heat from the turbine exhaust steam. The chlorination system is located in the chlorination building adjacent to the discharge transition structure. The major components in this system are the two metering pumps that discharge at a rate of 4 gpm each, and three sodium hypochlorite storage tanks. In 2004, due to the buildup of calcium carbonate in the chlorination system as a byproduct of the combination of sodium hypochlorite, salt water and low water temperature, a scale inhibitor (Dynacool 1383) injection system was installed. The scale inhibitor is stored in a 400 gallon tank in the circulating water pumphouse and injects the anti-scalant into the salt water supply line prior to the chlorination tank connection via the anti-scalant injection pump that discharges at a rate of 0.02 gpm.

### 3.3.2 Cooling Water Intake Structure Location

The three offshore submerged intake structures are located in the Gulf of Maine (Atlantic Ocean) east of Hampton Beach, New Hampshire, approximately 1.3 miles offshore. The three structures are aligned in an east-west direction and are separated by approximately 110 feet. The water depth at the intake location is approximately 60 feet at MSL and the tops of the intake structures are located 42 feet below the water surface. The intake structures are located at 42° 54′ 17" N Latitude and 70° 47′ 12" W Longitude.

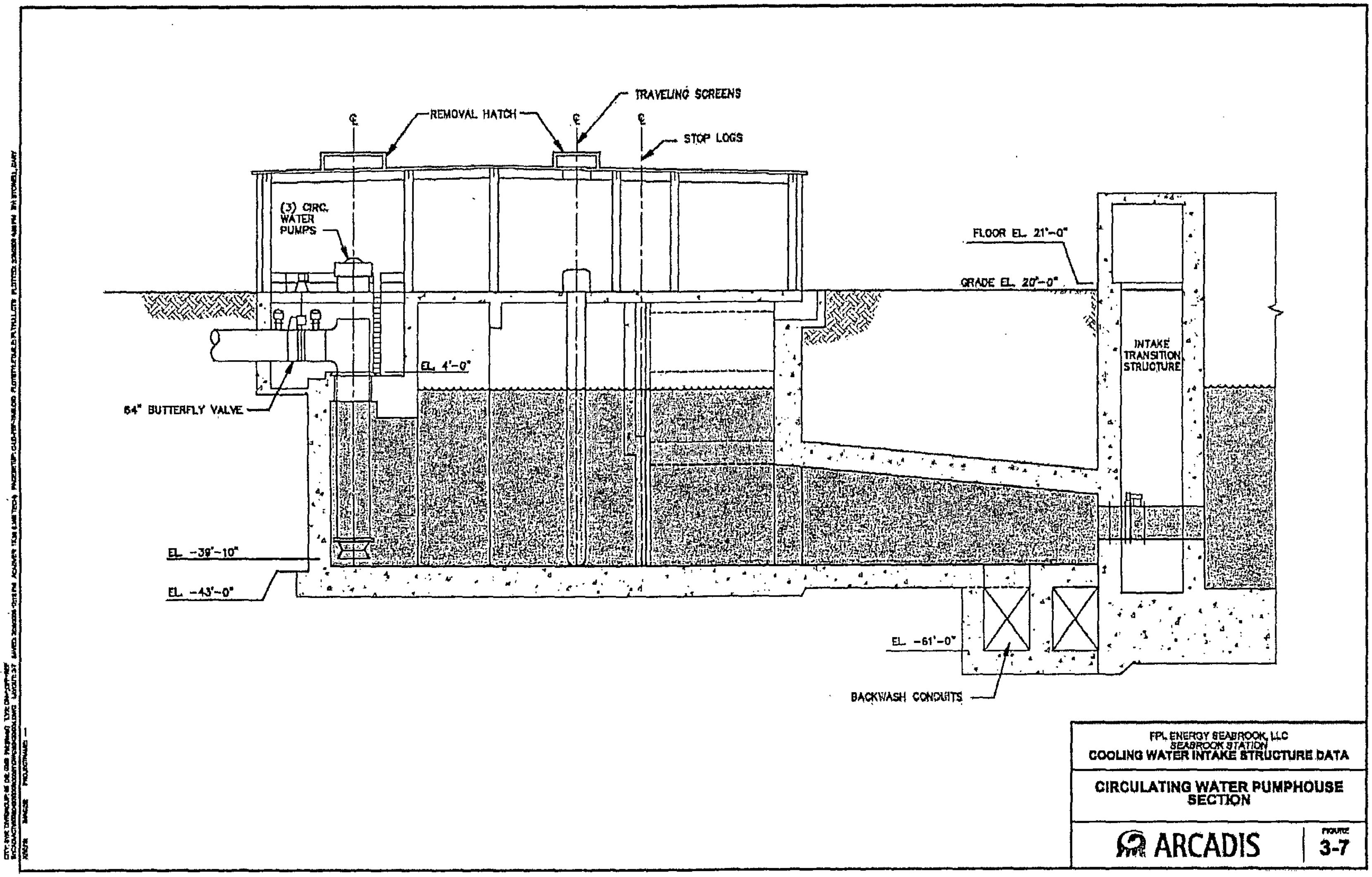



Figure 3-16. Seabrook Nuclear Power Station circulating water pumphouse section.

### 3.3.3 Cooling Water Intake System Operation

The CWIS provides water for condenser cooling and the plant service water system and the service water system that cools a number of primary and secondary heat loads. The CWIS is the only system for providing condenser cooling water, however service water for shutdown cooling can be provided with the closed loop cooling tower system. A flow diagram of the CWIS and the systems it serves are presented on Figure 3-17.

The CWIS at Seabrook was designed with the necessary capacity for two operating units, therefore, the intake was designed for a flow of 854,000 gpm (1,230 MGD), which would support full load operation of the two units. Only one generating unit was constructed at Seabrook, therefore, the CWIS is operating under the flow requirements of a single unit only. With the three circulating water pumps (130,000 gpm each) and the two service water pumps (11,500 gpm each) operating at their design points, the CWIS flow would be 413,000 gpm (595 MGD). At actual operating conditions, the highest average daily cooling water intake flow (circulating water and service water) during full load operation for the years 2002 through 2006 occurred during the month of August and was 471,000 gpm (678 MGD). Therefore, this flow (471,000 gpm) is representative of total CWIS flow for full load operation at maximum annual water temperature. Since the Seabrook CWIS operates at a flow considerably less than the original design of 854,000 gpm, the head loss under the current operating conditions is less than design, causing the pumps to operate at a lower total head loss and higher flow than their original design point.

At a flow of 471,000 gpm, the approach velocity at the intake (velocity cap) is approximately 0.5 feet per second (fps). As the water passes through the vertical bars, the velocity increases to 0.8 fps. It is not possible to isolate any of the submerged intakes, therefore, all three intakes are in operation at all times. It is a NPDES Permit requirement that the velocity at the velocity caps be less than 1.0 fps.

Within the 19-foot diameter intake tunnel, the velocity is 3.7 fps at 471,000 gpm. With the water level at MSL in the screen wells, the velocity through the traveling screens is approximately 1.0 fps.

Seabrook Station is a base loaded facility and the average capacity utilization rate for the last five years (2002-2006) has been 92.3%. Over this same time period, the generator operated for 92.8% of the available hours. Therefore, when the generating unit is operating, it typically runs at full load (1221 MW). Net generating capacity increased from 1151 MW to 1221 MW after the April 2005 refueling outage. Figure 3-18 demonstrates that there is not any seasonal pattern to the level of generation. For each month where the capacity utilization rate was down to 96% or less, it was the result of a refueling outage during that month in one or more of the five years.

Since the circulating water system must be in operation whenever the steam turbine/generator is operating and may also be operated for some period of time when the steam turbine/generator is idle, the CWIS is in operation over 90% of the time. The normal operation is to run all three circulating water pumps to provide the necessary cooling for full load operation, which as noted above, is where the generating unit typically operates. Operating with only two circulating water pumps running is limited due to the resulting performance penalty and due to the limitations within the NPDES Permit. Seabrook is limited to an average monthly temperature differential of 39°F and maximum daily temperature differential of 41°F. The NPDES Permit does allow for these maximum

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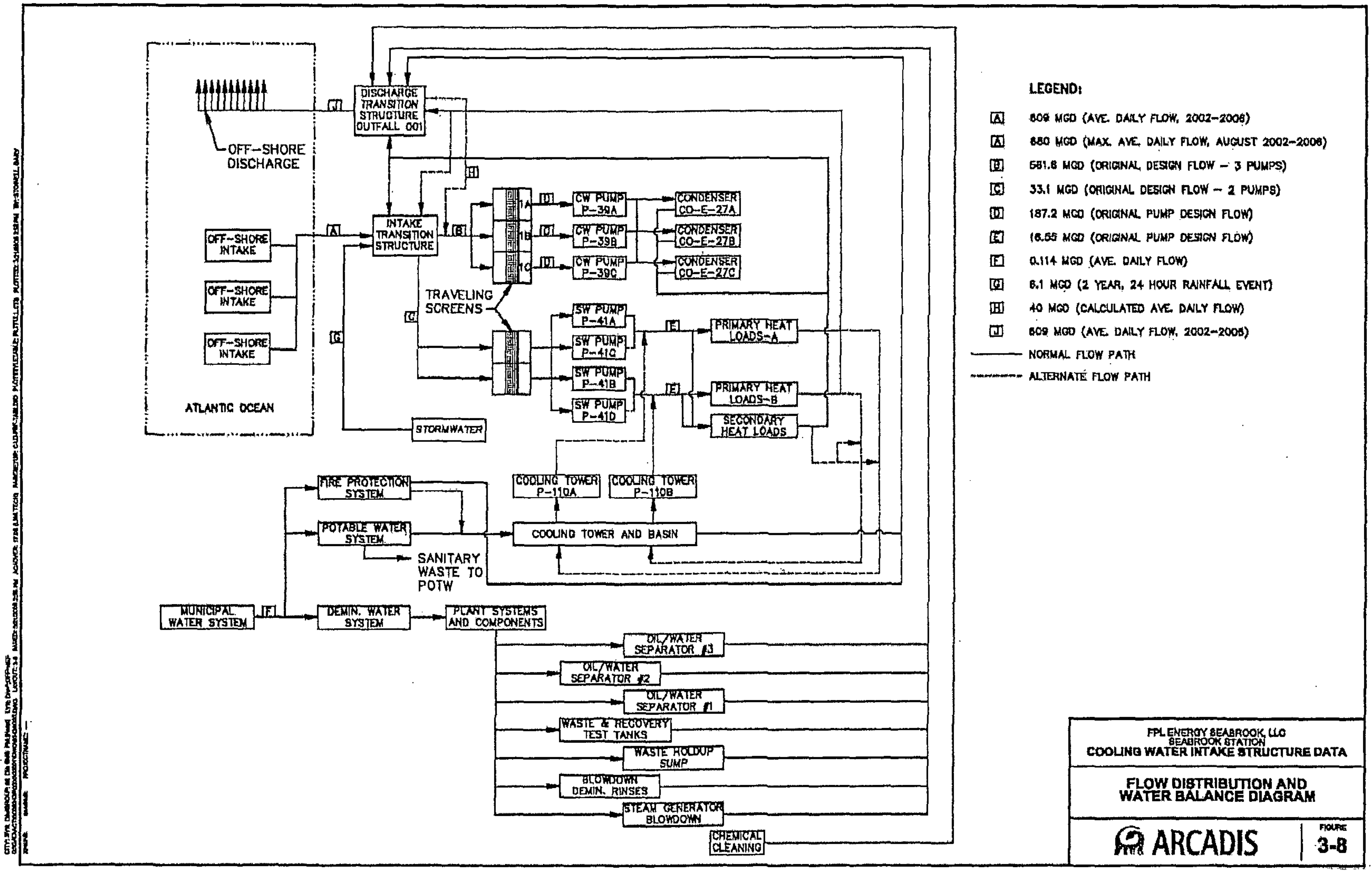


Figure 3-17. Seabrook Nuclear Power Station flow distribution and water balance diagram.

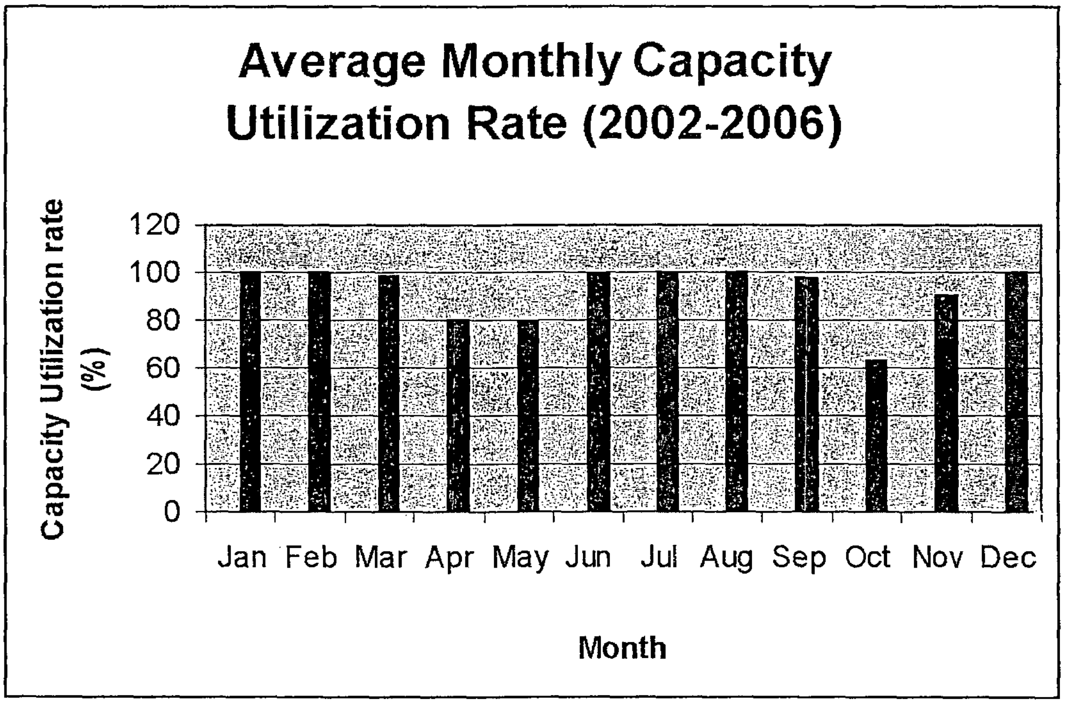


Figure 3-18. Average monthly utilization rate at Seabrook Nuclear Power Station from 2002-2006.

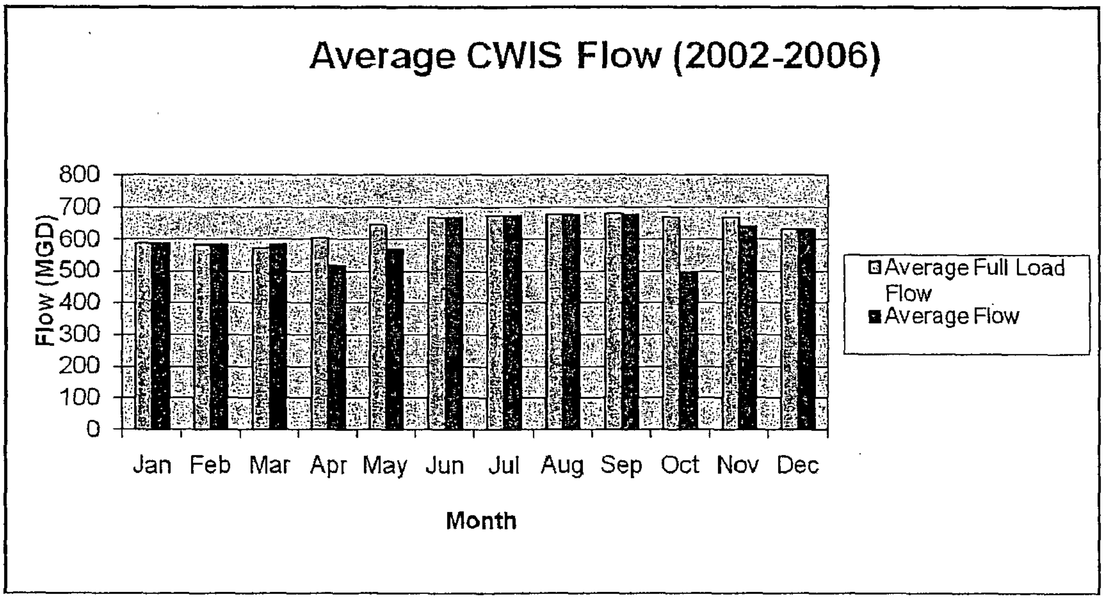


Figure 3-19. Average cooling water intake structure flow 2002-2006 at Seabrook Nuclear Power Station.

differential temperatures to be exceeded for a "maximum of 15 days per year and only when one circulating water pump has been taken out-of-service for corrective or preventative maintenance".

Historical operating data for the Seabrook CWIS is presented on Figure 3-19. The flow values represent the actual amount of water drawn into the intake from the source waterbody. The data is presented as actual average daily flow on a monthly basis for the years 2002 through 2006 and the daily average flow for the same time period when the generating unit is operating at full load. What this chart indicates is that CWIS flow is not only affected by the station capacity factor or hours of operation, but there is also a seasonal trend in flow due to the variations in water temperatures throughout the year. During unit operation, the average flow entering the intake in March (lowest) is 15.6% lower than the average flow in September (highest). The reduced intake flow when the unit is in generation in the winter months is due to the recirculation of discharge water into the intake. As circulating water temperatures drop, subcooling of the condensate will begin to occur. The subcooling of the condensate has a negative effect on the unit performance, therefore, discharge water is recirculated back to the intake to increase the intake water temperature and prevent the subcooling of the condensate. The recirculation provides the added benefit of reducing the actual water intake flow.

The traveling intake screens can be operated in either a manual or automatic mode. In the manual mode, the operator will place the selector switch in the run position, which starts the screen wash pumps and then the screens. If the water level differential pressure across the screens is greater than 12 inches, the screen will operate at fast speed, which is 20 feet per minute (fpm). If the screen differential pressure is greater than 6 inches, but less than 12 inches, the screen will operate at slow speed, which is 5 fpm. In the automatic mode, the starting of the screen wash pumps and the rotation of the screens are initiated by a screen differential pressure of 6 inches. The operating speeds are similar to the manual mode and the screens stop when the differential pressure drops below 4 inches. In the automatic mode the screens will also start once every 8 hours and run for approximately ½ hour, regardless of the screen differential. Should the differential pressure across any screen reach 60 inches, the associated circulating water pump will trip.

## 3.4 Cooling Water System Data

Seabrook Station has two cooling water systems which utilize the CWIS as a source of cooling water. The condenser circulating water system (circulating water) supplies cooling water to the steam surface condensers, and the service water system supplies cooling water to miscellaneous plant equipment, which are classified as primary and secondary heat loads. The following sections will provide a more thorough discussion of the operation of the plant cooling water systems as required by 40 CFR 122.21(r)(5).

### 3.4.1 Description of Operation

Seabrook Station has two cooling water systems that use cooling water supplied by the CWIS. The two systems are the circulating water system and the service water system. Both systems draw water through the three off-shore intakes, the intake tunnel, and the intake transition structure. After the intake transition structure, each system has an independent set of traveling screens. There are three traveling screens for the circulating water system and two traveling screens for the service water system.

The majority of all water entering the CWIS is for the circulating water system, which provides cooling water to the steam surface condenser for the condensing of the steam after it leaves the steam turbine. After the steam is condensed, the condensate can then be pumped back through the condensate and feedwater heating systems and then to the steam generator, where it is converted back to steam. The following paragraphs provide a description of the circulating water system, which is the primary use of cooling water, and the service water system, which provides cooling water to considerably smaller heat loads.

The circulating water system has three vertical, electric motor driven, circulating water pumps. Each pump is located in a separate pump well, each with a dedicated traveling intake screen. The discharge lines from each of the three pumps combine into a common line, which provides water to the steam surface condenser (three separate shells). The water exiting the condensers combines in a common line that flows into the discharge transition structure (Outfall 001). From the transition structure the water flows to the off-shore discharge.

In addition to supplying water to the condenser, a small portion of the circulating water pump discharge supplies water to the screen wash pumps. The water used for screen wash purposes is directed back to the intake transition structure after fish and debris are removed.

Each circulating water pump has a rated design flow of 130,000 gpm and the system was designed for all three pumps to be utilized for full load operation. The circulating water system was designed to operate with an average ocean temperature of 55° F and, at full load heat rejection, to maintain a circulating water temperature differential within the requirements of the NPDES Permit, which are 39° F maximum monthly average and 41° F maximum daily average.

The service water system provides cooling water for the plant's primary and secondary heat loads. The primary heat loads include the heat exchangers for the Primary Component Cooling Water System, the Diesel Generator Water Jacket, and the Auxiliary Spent Fuel Pool Cooling system. The secondary heat loads include the heat exchangers for the Secondary Component Cooling Water System and the Condenser Water Box Priming Pump. The service water system includes two trains of components with two Service Water Pumps for each train. Under normal full load operation both trains are required with one pump operating from each train. The Service Water Pumps are rated at 11,500 gpm each.

The off-shore intake is the primary source of water for the service water system. Should the intake tunnel fail or become blocked to the point where adequate flow for the service water system cannot be achieved, the cooling tower system is the alternate source of cooling for the service water system.

All intake water entering the CWIS flows through either the circulating water pumps or the service water pumps. Therefore, essentially 100% of the intake flow is for cooling purposes. At original design conditions, with three circulating water pumps and two service water pumps operating, the total intake flow would be 413,000 gpm (595 MGD). The highest average daily cooling water intake flow (circulating water and service water) during full load operation for the years 2002 through 2006 occurred during the month of August and was 471,000 gpm (678 MGD). Therefore, the total CWIS flow for full load operation at maximum annual water temperature is approximately 471,000 gpm.

Since the Seabrook Station operates at such a high capacity factor (average capacity factor for the last five years has been 92.3%), the cooling water system is in operation a very high percentage of the time. The condenser circulating water system and/or the service water system, with the cooling water intake structure as the primary source of water, essentially operates continuously. The system is typically removed completely from service for a few days during a refueling outage which occurs every 18 months.

Seabrook Station operates as a base load unit throughout the year, therefore, there is not a fluctuation in the cooling water flow associated with reduced power output. There are however, seasonal flow fluctuations during the colder months of the year when some water from the discharge transition structure is recirculated back to the intake transition structure, therefore, reducing the flow through the off-shore intakes. However, the overall cooling water flow through the circulating water system and the service water system remains unchanged when recirculation occurs.

Several operational and permit limitations also prevent major fluctuations on the cooling water flow. Within the current NPDES Permit[1], the average monthly and maximum daily circulating water discharge flow (includes condenser circulating water, service water, and some miscellaneous discharge streams which are supplied from the municipal water system) is limited to 720 MGD. In addition, the maximum temperature differential between the intake and discharge transition structures is limited to 39° F on an average monthly basis and 41° F on a daily basis. These temperatures can be increased to 45° F and 47° F respectively for a maximum of 15 days per year.

### 3.5 Regulatory Requirements And Performance Standards

The Phase II rule in Part 125.94(b) specifies performance standards for the reduction of impingement mortality and entrainment (IM&E). These standards are based on the operating characteristics of the plant, the design of the cooling water system, and the source water body for cooling water. Seabrook Station is baseload plant with a five-year capacity factor of 92.3%, and a once-through cooling water system with marine intakes. Based on these characteristics, Seabrook Station is required to meet the performance standards for both impingement mortality and entrainment.

## 4.0 Existing and Proposed Technology and Operational Measures

### 4.1 Applicable Performance Standards

The performance standard specified in the Phase II rule (since rescinded) called for a reduction of impingement mortality of 80-95%, and a reduction in entrainment of 60-90% from the calculation baseline for plants with ocean intakes and capacity utilization factors over 15%. The calculation baseline is defined in Part 125.93 as an estimate of IM&E that would occur assuming:

- A once-through cooling water system,
- the opening of the cooling water intake structure is located at, and the face of the standard 3/8 inch mesh traveling screen is oriented parallel to, the shoreline near the surface of the source water body, and

[1] National Pollutant Discharge Elimination System Permit No. NH0020338, FPL Energy Seabrook, LLC, Effective date of April 1, 2002.

- the baseline practices, procedures, and structural configuration are those that would be maintained in the absence of any structural or operational controls, including flow or velocity reduction implemented in whole or in part for the purposes of reducing impingement mortality and entrainment.

In practice, this means the calculation baseline is the theoretical level of IM&E that would occur at a facility assuming there were no controls that reduced IM&E. IM&E controls at Seabrook Station include at a minimum:

- The offshore location of the intakes,
- The design of the intakes which includes velocity caps, and
- The reduced volume of cooling water withdrawn due to the colder water at the offshore location of the intakes compared to an inshore location.

To estimate the calculation baseline at Seabrook Station, comparisons will be made to Pilgrim Station in Plymouth, MA. Special concern will be taken to establish the appropriateness of this comparison through the presentation of sample collection methods, quality assurance, quality control (QA/QC) procedures, and how the data are representative of the current conditions.

## 4.2 Existing Technology and Operational Methods

For compliance under Alternative 2 in the regulations, it is required that the facility demonstrate that it has existing design and construction technologies, operational measures, and/or restoration measures that will meet the performance standards. Seabrook Station has an intake technology that significantly reduces IM&E in the form of offshore intakes with velocity caps.

The level of IM&E at Seabrook Station that occurs with the offshore intake with the velocity cap is substantially less than the calculation baseline. There are three specific reasons for the success of the offshore intake in reducing IM&E. These are the location of the intake in an area of reduced biological activity, the tendency of fish to avoid the changes in horizontal flow created by the velocity cap, and the reduced cooling water flow requirements due to cooler water temperatures. For Seabrook Station, the baseline flow was calculated to be 744.5 MGD, as compared to the design cooling water flow of 684 MGD for the Seabrook Station (Appendix A).

The reduction in IM&E at Seabrook Station due to reduced biological activity associated with the intake location and the effectiveness of the velocity cap is quantified by a comparison of the average impingement and entrainment rates (no./unit of cooling water flow) at Seabrook to the impingement and entrainment rates at Pilgrim Station, which has a shoreline intake and is located on the same waterbody and in close proximity to where a shoreline intake would be located for Seabrook. The calculation baseline is estimated as the product of the cooling water flow for Seabrook Station if it had a shoreline intake (Appendix A) and the impingement and entrainment density at Pilgrim Station. This is a very conservative estimation because it assumes that there are no fish conservation strategies at Pilgrim Station that would reduce impingement and entrainment density. These strategies most likely do exist, therefore percent reduction from the calculation baseline are probably the smallest reductions that could be expected.

The comparison of IM&E between Seabrook and Pilgrim Stations follows a precedent set by EPA in their case studies (USEPA 2002). In the case study, EPA states that both "...facilities are located in the same ecological region, but differ in the locations of their CWIS…". Both are located in the western Gulf of Maine, and north of Cape Cod, which forms a zoogeographic boundary between a boreal fish community to the north, and a southern fish community. Further evidence of the similarity in fish communities comes from a calculation of similarity indices for the impingement and entrainment communities at the two plants for the years 2002-2006 (Table 4-1). Similarity coefficients (100 = complete similarity) for the egg entrainment community ranged from 61 to 79. The similarity indices for the larval entrainment community ranged form 64 to 78 and the indices for the impingement community ranged from 63 to 78. These coefficients generally indicated a high degree of similarity between the stations. However, because the intake structures are so different with regard to location and portion of water column from which they withdraw water, it can be assumed that the similarities would be even greater if the plants had similar intake structures.

**Table 4-1. Similarity coefficients between Seabrook and Pilgrim Stations for the egg and larval entrainment communities and the impingement community.**

| | Similarity Coefficient | | |
|---|---|---|---|
| **Similarity Index[a]** | **Egg Entrainment Community** | **Larval Entrainment Community** | **Impingement Community** |
| **Jaccard** | 61 | 64 | 63 |
| **Sorenson** | 76 | 78 | 77 |
| **McConnaughey** | 79 | 78 | 78 |

[a] Clarke and Warwick (1994)

The EPA case studies concluded that : "…I&E at Seabrook's offshore intake is substantially lower than I&E at Pilgrim's nearshore intake." Furthermore, the case studies stated that impingement losses of Age 1 equivalents were 68% less at Seabrook and entrainment losses were 58% less. The EPA comparison between stations did not take into account any reductions in cooling water flow at Seabrook due to the offshore intake but did rely on two monitoring programs that have achieved a degree of credibility with regulators. A more detailed and updated comparison for the years 2002 through 2006 shows that the impingement rate at Pilgrim is 0.718 fish per million gallons, while the impingement rate at Seabrook is 0.135 fish per million gallons (Appendix Table B-1). This is a reduction of 81% due solely to the location and design of the Seabrook intake.

The estimated calculation baseline for impingement at Seabrook Station is 195,111 fish (Appendix Table B-2) based on the amount of cooling water required if the Seabrook intakes were located inshore and the impingement density from Pilgrim Station (Appendix Table B-1). The primary factor that allows for the reduction in cooling water flow at Seabrook Station from the baseline calculation is the lower temperature water at the offshore intake location (Appendix A). Actual impingement at Seabrook has never approached the calculation baseline. Assuming average annual cooling water flow (222,372 million gallons) and average impingement rate at Seabrook Station (0.135 fish/$10^6$ gallons) for the past five years (2002-2006) the average annual impingement would be 30,020 fish; an 85% reduction from the calculation baseline (Appendix Table B-2; calculation 1). Assuming design flow and the average impingement rate of 0.135 fish/$10^6$ gallons an estimated 33,704 would be impinged per year; an 83% reduction from the calculation baseline (Appendix Table B-2; calculation 2).

A similar substantial reduction in entrainment is also realized through the reduced cooling water flow at Seabrook Station (Appendix C). The average density of entrained ichthyoplankton at Pilgrim Station is 0.0092 organisms/million gallons while the density at Seabrook Station is 0.0069 organisms/million gallons (Appendix Table C-1). Therefore, there is a reduction of 25% due solely to the design and location of the Seabrook Station intakes. Using average flows, there is a 38% reduction in entrainment from the calculation baseline (Appendix Table C-2; calculation 3), and a 31% reduction using design flows (Appendix Table C-2; calculation 4).

There are many sources of variability in estimating the calculation baseline and percent reduction for IM&E. Many of these sources occur at the sample level and become propagated when means and their associated confidence intervals calculated from individual samples are combined with other means and scaled up by very large cooling water flows to estimate impingement. Further error is introduced when the percent reduction is calculated from the calculation baseline and the estimated impingement or entrainment, both of which are means with associated errors. Estimating the confidence intervals around impingement or entrainment estimates is more sophisticated than multiplying the upper and lower confidence intervals calculated from samples by the cooling water flow. However, even when proper statistical procedures are used, the percentage error can be so large as to be meaningless because multiple scaling and calculation steps. It is probably more instructive to examine how the percent reduction varies among years to get an idea of the uncertainty in the average annual reduction from the calculation baseline.

The calculation baseline is dependent on the density of organisms in the vicinity of the intake, environmental factors such as water temperature and storm action which affect impingement and entrainment vulnerability, and cooling water flow. Only cooling water flow can be considered without uncertainty and the others are variable. Therefore, the percent reduction in IM&E is calculated from two variables (calculation baseline and IM&E under design flow) that will vary annually. This annual variation can be thought of as the error in the percent reduction calculation. Figure 4-1 presents the calculation baseline impingement estimate for the years 2002 through 2006 and the impingement estimate at Seabrook under design flow conditions. The percent reduction ranged from 66% in 2004 and 93% in 2005 (Table 4-2). Based on five years of data, this is the degree of annual variation that can be expected in the future. The calculation baseline was estimated from Pilgrim Station impingement densities and the estimated impingement at Seabrook at design flow was estimated from Seabrook Station impingement densities. The impingement densities at the two plants showed the same directional trends among years and were correlated at r= 0.50, which is further indication that the impingement community is similar at both plants.

Figure 4-2 presents the presents the calculation baseline for entrainment for the years 2002 through 2006 and the entrainment estimate at Seabrook under design flow conditions. The annual percent reduction varied from -36% in 2002 to 68% in 2005. The year 2002 presents a special case where the estimated entrainment at Seabrook was larger than the calculation baseline. Ichthyoplankton are notoriously patchy, and the high entrainment estimate at Seabrook in 2002 was due to an unusually high density of cunner eggs in June 2002. This monthly entrainment estimate of cunner/yellowtail flounder eggs alone made up 62% of the annual total 2002 entrainment estimate for all species. Based on the ratio of cunner larvae to yellowtail flounder larvae, 99.7% of these eggs were cunner. Despite the unusually high density of cunner eggs in a few samples from June of 2002, entrainment densities from Seabrook and Pilgrim Stations showed the same directional annual trends. The correlation coefficient for entrainment density for all five years between the two plants was 0.42, but improved to 0.97 if 2002 was excluded, which is further evidence that entrainment density at the two plants are closely related.

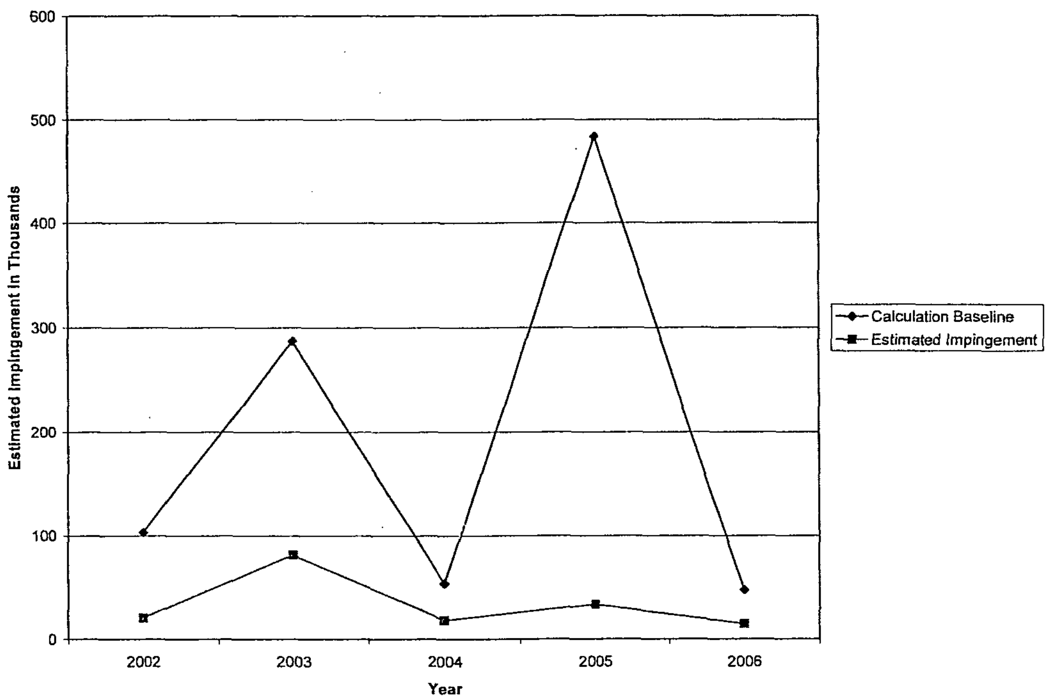


Figure 4-1. Comparison of the calculation baseline for impingement and estimated impingement at Seabrook Station 2002-2006.

**Table 4-2. Annual variation in percent reduction from the calculation baseline for impingement and entrainment at Seabrook Station.**

| | Impingement | | | Entrainment | | |
|---|---|---|---|---|---|---|
| **Year** | **Calculation Baseline (Fish)** | **Estimated Impingement at Design Flow (Fish)** | **Percent Reduction (%)** | **Calculation Baseline (eggs and larvae in millions)** | **Estimated Entrainment at Design Flow (eggs and larvae in millions)** | **Percent Reduction** |
| 2006 | 47,484 | 14,772 | 69 | 2,674 | 1,367 | 49 |
| 2005 | 484,064 | 33,376 | 93 | 2,230 | 706 | 68 |
| 2004 | 53,685 | 18,173 | 66 | 3,103 | 2,535 | 18 |
| 2003 | 287,047 | 81,353 | 72 | 2,167 | 902 | 58 |
| 2002 | 103,252 | 20,608 | 80 | 2,311 | 3,146 | -36 |
| **Average** | **195,106** | **33,656** | **83** | **2,497** | **1,731** | **31** |

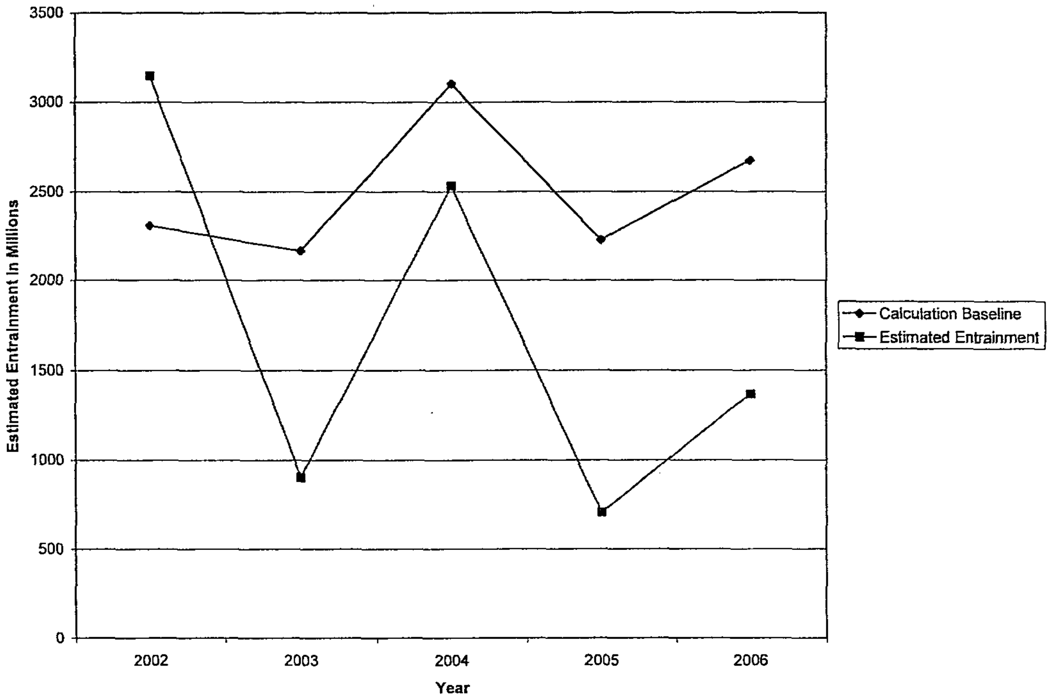


Figure 4-2. Comparison of the calculation baseline for entrainment and estimated entrainment at Seabrook Station 2002-2006.

The appropriateness of these comparisons is dependent on the validity of the data collection methods, and the representativeness of the data presented to current conditions. The validity of the data collection methods is demonstrated through the QA/QC programs of the impingement and entrainment monitoring programs at Seabrook and Pilgrim Stations. The Standard Operating Procedures (SOPs) for Seabrook Station are presented in Appendix E. These SOPs present the methods and QA/QC procedures for the collection (impingement and entrainment) and laboratory (entrainment) analysis of samples. The SOP for the Pilgrim impingement and entrainment program was deemed to be Confidential Business Information and was not made available to us by the owners of Pilgrim Station. However, these SOPs were presented in Appendix 2 of the Pilgrim Station Proposal for Information Collection.

In general, at Seabrook Station two 24-hour impingement samples were collected each week, usually on Monday and Thursday mornings. All fish and lobsters are identified and counted, and a maximum of 20 individuals of each species are measured for total length. Entrainment samples were collected four times each month from a tap off the cooling water system. Each sample consisted of a two-hour collection made within each of the following 6-hour diel periods (morning: 0415-1015; day: 1015-1615; evening: 1615-2215; night: 2215-0415) for a total of 4 collections in each 24-hour sample. Collections were made with a 0.333 mm mesh net and have a target volume of 275 $m^3$. All ichthyoplankton were identified to the lowest practical taxon.

At Pilgrim Station, impingement samples were collected three times per week, with each collection representing a different 8-hour diel period. Specific details are available in the SOP submitted with the Pilgrim Station PIC, but the following information was available in the annual monitoring reports. Collections were made at 0830 on Monday, 1630 on Wednesday, and 0030 on Saturday. Additional samples were collected if the impingement rate exceeded 20/hour. All fish and lobsters were identified and counted, and a maximum of 20 individuals were measured and weighed. Entrainment samples were collected at the same time as impingement samples using a 60-cm net suspended in the discharge canal. The standard mesh size was 0.333 mm except for late March through May when a 0.202-mm mesh was used and the target sample volume was 100 $m^3$. The data presented in the comparisons between stations are obviously related to current conditions because they are for years 2002 through 2006. These are the most recent data available.

The intake technology currently installed at Seabrook Station resulted in an average reduction in impingement mortality from the calculation baseline of 83% with an annual range of 66% to 93%. Reduction in entrainment from the calculation baseline is more variable due to the inherently patchy nature of plankton distribution, with the result that in 2002 estimated entrainment at Seabrook Station increased from the calculation baseline. The maximum reduction in entrainment was 68% with an average reduction of 31%.

## 4.3 PROPOSED TECHNOLOGY AND OPERATIONAL MEASURES

EPRI has identified many intake technologies for consideration in achieving compliance with the 316(b) performance standards. EPRI has categorized the intake technologies by the methods of operation. They have been categorized as Physical Barriers, Collection Systems, Diversion Systems, and Behavioral Deterrent Systems. However, most, if not all, of these technologies have been developed and tested for inshore type intakes constructed at the shoreline. We are not aware of a single technology in the Physical Barrier, Collection Systems, or Diversions Systems categories that has been installed at an offshore intake. Velocity caps, which are installed at Seabrook Station, and behavioral deterrents have been used at offshore intakes. The primary reason for the lack of installation of physical barriers, collection and diversion systems at offshore intakes is the excessive cost associated with designing and constructing these technologies in an open water environment. At Seabrook Station, the location of the intakes in 60 feet of water, 1.33 miles offshore, compounds these costs, especially when coupled with the nuclear safety concern with reducing flow to safety related systems. Therefore, we do not consider that any physical barriers, collection or diversion systems are practical for Seabrook Station. These technologies and restoration are discussed in more detail in Appendix D.

## 4.4 COST ESTIMATES FOR COMPLIANCE

In Appendix A of the Phase II rule, the EPA provided cost estimates for "the most appropriate compliance technology" for many plants to meet the appropriate performance standards. These cost estimates can then be used in the cost-cost benefit test specified in compliance alternative 5. EPA's cost estimates were based on, among other factors, the actual facility design intake flow and the EPA assumed facility design flow. However, EPA did not estimate the design flow for many plants including Seabrook Station as indicated by the notation N/A in the "EPA assumed design intake flow" in column 3 of Appendix A". In the preamble to the final Phase II rule on page 41646, EPA states:

> "...some entries in Appendix A have NA indicated for the EPA assumed design intake flow in column 2 (sic). These are facilities for which EPA projected that they would already meet

> otherwise applicable performance standards based on existing technologies and measures. EPA projected zero compliance costs for these facilities..."

Furthermore in the same paragraph EPA states:

> "These facilities should use $0 as their value for the costs considered by EPA for a like facility in establishing the applicable performance standard."

## 5.0 ECOLOGICAL STUDIES AND HISTORICAL IMPINGEMENT MORTALITY AND ENTRAINMENT STUDIES

Preconstruction environmental evaluation began at Seabrook Station in 1969. A comprehensive environmental monitoring program has been in place for some parameters (softshell clam) since 1974 providing 15 years of preoperational data. Monitoring for most parameters began in the late 1970s or early 1980s and provides approximately 10 years of preoperational data, and as of 2007, 17 years of operational data including impingement and entrainment data. These studies are relevant to current conditions because they are presently ongoing and represent the most up to data available regarding New Hampshire nearshore environmental conditions and potential impacts due to impingement and entrainment. Ecological parameters monitored included water quality and nutrients, phytoplankton, zooplankton, ichthyoplankton and fish, macroflora and macrofauna (including estuarine benthos and offshore fouling panels), *Cancer* sp. crabs and lobsters, and softshell clams and bivalve larvae. A summary of the present environmental monitoring program is presented in Table 5-1. Further information can be found in NAI (2005).

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).

A previous Summary Report (NAI 1977) concluded that the balanced indigenous community in the Seabrook study area should not be adversely influenced by loss of individuals due to entrapment in the Circulating Water System (CWS), exposure to the thermal plume, or exposure to increased particulate material (dead organisms) settling from the discharge. The current study continues to focus on the likely sources of potential influence from plant operation, and the sensitivity of a community or parameter to that influence within the framework of natural variability. A community or species within the study area might be affected by more than one aspect of the CWS.

**Table 5-1. Summary of the Study Design for the Environmental Monitoring Program at Seabrook Station.**

| Program | Parameter | Number of Stations | Sampling Frequency |
|---|---|---|---|
| Water Quality | Discharge Temperature | 1 Farfield<br>1 Nearfield | Continuous. |
| | Water Temperature | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Salinity (S and B) | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Dissolved Oxygen (S and ) | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Estuarine water Temperature | 1 | Weekly at high and low tides. |
| | Estuarine Salinity | 1 | Weekly at high and low tides |
| Zooplankton | Bivalve larvae | 1 Farfield<br>1 Nearfield | Paired tows weekly April-Oct. |
| | Macrozooplankton | 1 Farfield<br>1 Nearfield | Paired tows 2/month. |
| Fish | Ichthyoplankton | 1 Farfield<br>1 Nearfield | Paired tows 4/month. |
| | Fish (otter trawl) | 2 Farfield<br>1 Nearfield | Replicate tows 2/month. |
| | Estuarine fish (seine) | 3 Farfield | 1/month, April-Nov. |
| Macrobenthos | Macroflora and fauna | 2 Farfield<br>2 Nearfield | 3/year destructive sampling. |
| | Macroflora and fauna | 2 Farfield<br>2 Nearfield | 3/year nondestructive sampling. |
| | Settling organisms (panels) | 1 Nearfield<br>1 Farfield | 3/year. |
| Epibenthic Crustaceans | Lobsters and *Cancer* sp. crabs | 1 Nearfield<br>1 Farfield | 3/week, June-Nov. |
| | Lobster larvae | 1 Nearfield<br>2 Farfield | 1/week, May-Oct. |
| Softshell clams | Adults and spat | Hampton Harbor (Farfield) | Annual population survey. |
| Impingement | Adult fish | 1 in-plant | 2/week, year round |
| Entrainment | Ichthyoplankton | 1 in-plant | 4 diel periods, 1/week, year round. |
| | Bivalve larvae | 1 in-plant | 1/week, mid April-Oct. |

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.

Several changes have occurred in the environmental monitoring program since its inception. Table 5-2 summarizes the various ecological parameters monitored and the current status of these monitoring programs. 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,

**Table 5-2. Summary of Biological Communities and Taxa Monitored for Each Potential Impact Type (NAI 2005).**

| 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 |
| | | Subsurface fouling community | x | x |
| | Turbidity (Detrital Rain) | Mid-depth macrofauna and macroalgae | x | x |
| | | Deep macrofauna and macroalgae | * | *<br>x |
| | | Demersal fish | x | x |
| | | Bottom fouling community | * | * |
| | | 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

and macrobenthos at the intertidal stations, and were eliminated. Intensive ecological monitoring in the nearfield and farfield environments of almost all trophic levels from 1990 through 2006 has not detected any significant impact due to the operation of the Seabrook Station CWIS (NAI 2007).

Direct impacts due to operation of the CWIS are limited to impingement and entrainment. An impingement and entrainment monitoring program has been in place since Seabrook Station began operation in 1990. Methodology used to collect impingement and entrainment procedures are provided in Appendix E. To summarize, 24-hour impingement collection are made twice per week for a total of 104 scheduled samples in the year. Four entrainment samples, each representing one 6-hour diel period, are collected weekly using a 0.333 mm mesh net for a total of 208 samples each year. The Standard Operating Procedures are Seabrook Station controlled documents and the sampling evolution is observed by Seabrook Station personnel. Procedures for the laboratory analysis of entrainment samples are found in the Seabrook Environmental Studies Quality Program and Standard Operating Procedures Revision 10 (Section VA), which refers to the Normandeau Technical Procedures Manual (Section VI). Appropriate excerpts from both documents that pertain to the analysis of plankton samples are also presented in Appendix E.

Appendix F contains a summary of the results of the annual impingement and entrainment monitoring programs. These data are obviously relevant to current conditions because they include the most recent impingement and entrainments estimates of 2006. Fish egg and larvae entrainment estimates averaged 928 million eggs (Appendix Table F-1) and 306 million larvae (Appendix Table F-2) for the period 1995 through 2006 when sampling occurred year round. The primary fish eggs entrained were cunner/yellowtail flounder which were about 99% cunner (NAI 2005), silver hake, and Atlantic mackerel. The primary fish larvae entrained were cunner, Atlantic seasnail, and American sand lance.

Entrainment of bivalve larvae has been monitored at Seabrook Station since 1990 (Appendix Table F-3). Consistent sample collection during the bivalve larvae season (third week of April through October) occurred in 1993, and 1995 through 2006. The primary bivalve larvae entrained were *Anomia squamula*, *Mytilus edulis*, *Hiatella* sp., and *Modiolus modiolus*. Larvae of *Mya arenaria* were also entrained, but their entrainment did not appear to affect the set of young-of-the year (NAI 2007).

At Seabrook, Station mean annual impingement for 1995 through 2006 was 22,091 fish/year, and annual estimates ranged from 7,281 (2000) to 71,950 (2003; Appendix Table F-4). The most common fish impinged were Atlantic silverside (3,090/year), rock gunnel (2,532/year), and winter flounder (2,232/year).

Mean annual impingement estimates for other plants ranged from 44,755 fish/year at Pilgrim Station to 65,927 fish at Millstone 2. Based on impingement data from 1995 through 2006, it appears that the majority of the fish impinged are young-of-the-year 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.

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 and pollock.

Equivalent Adult (EA) analyses 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 to1995 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 (2003 through 2006). 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 2006). Entrainment and impingement of seven species of commercially-important fishes in 2003 through 2006 resulted in the annual estimated loss of 2 (yellowtail flounder) to 1,820 (Atlantic herring) (Table 5-3). Losses due to entrainment were larger than impingement losses for most species evaluated.

**Table 5-3. Mean Annual Equivalent Adult Losses of Seven Commercially Important Species Impinged and Entrained at Seabrook Station in 2003 through 2006.**

| | Equivalent Adults | | |
|---|---|---|---|
| Species | Impingement | Entrainment | Total |
| Atlantic Cod | 42 | 504 | 546 |
| Atlantic Herring | 22 | 1,798 | 1,820 |
| Atlantic Mackerel | 0 | 239 | 239 |
| Pollock | 79 | 25 | 104 |
| Hake spp.[a] | 208 | 82 | 290 |
| Winter Flounder | 34 | 326 | 360 |
| Yellowtail Flounder | 1 | 1 | 2 |

[a] Includes red and white hake.

# 6.0 AGENCY CONSULTATIONS

## 6.1 ONGOING CONSULTATIONS

Seabrook Station is not engaged in any ongoing agency consultations

## 6.2 HISTORIC CONSULTATIONS

Consultations with the National Oceanic and Atmospheric Administration, National Marine Fisheries Service were initiated in 1997 after a number of seals were taken in the Seabrook Station cooling water system. A Limited Take Permit application was filed by Seabrook Station in June 1997. Subsequently a Limited Take Permit and Letter of Authorization were issued by NMFS in July 1999. The provisions of the Limited Take Permit and LOA included enhanced monitoring, reporting and the requirement to design and install a mitigation device to minimize or eliminate seal takes. Design and installation of a mitigation device was completed in August 1999. Additional vertical bars were installed on the intake velocity caps to reduce the bar spacing from approximately fourteen inches to five inches. The reduced bar spacing mitigation design has been completely successful in eliminating seal takes. In light of the proven effectiveness of the mitigation device design the Limited Take Permit was allowed to expire in June 2004. A copy of the Limited Take Permit and Letter of Authorization (as renewed 11/1/03) are enclosed.

Consultations with various federal agencies were initiated in April 1974 by the United States Atomic Energy Commission upon publication of the "Draft Environmental Statement" for the proposed construction of Seabrook Station Units 1 and 2. The environmental statement was prepared in accordance with the AEC regulations at 10 CFR 50 Appendix D which implemented the requirements of the National Environmental Policy Act of 1969. Letters from the following federal agencies are enclosed:

***Department of the Army (June 7, 1974)***: Comment letter identifies the requirement for a Department of the Army Permit for dredging and disposing of dredged material for installation of intake and discharge facilities. The requisite Army Corps of Engineers Permits were subsequently obtained.

***Department of Commerce (June 28, 1974)***: Comment letter identifies that the location of the intake structures in relation to the Hampton Harbor inlet and natural rock outcroppings could make significant numbers of organisms vulnerable to loss through impingement and entrainment. The location of the intake structures was substantially revised during the Environmental Protection Agency review and public proceeding relative to 316 (b) during the January 1975 to August 1978 time period. The initial proposed intake location 3000 feet from the shoreline was revised during the 316 (b ) proceeding to a location 7000 feet from the shoreline.

***Department of the Interior (June 10, 1974)***: Comment letter identifies that an intake velocity of less than 1 cfs may be necessary to adequately protect aquatic life. The intake velocity originally proposed for two Seabrook Station units was approximately 1 foot per second. The velocity associated with operation of a single unit is approximately .5 foot per second at the velocity caps.

***Department of Transportation (June 14, 1974)***: Comment letter identifies the requirement for a Private Aid to Navigation for the intake and discharge structures due to the possible hazard to navigation. The requisite Private Aids to Navigation are installed and maintained at the intake and discharge locations.

Consultations with various federal agencies were initiated in May 1982 by the United States Nuclear Regulatory Commission upon publication of the "Draft Environmental Statement" for the proposed operation of Seabrook Station Units 1 and 2. The environmental statement was prepared in accordance with the NRC regulations at 10 CFR 51 which implemented the requirements of the National Environmental Policy Act of 1969. Letters from the following federal agencies are enclosed:

***Department of Commerce (July 6, 1982):*** Comment letter identifies that since the agency's initial comments were filed on June 28, 1974, changes in plant design and operation have been instituted which will minimize impacts on fisheries resources and associated habitats.

## 7.0 Sampling Plans

Seabrook Station is not planning any additional sampling beyond its current ongoing, extensive environmental monitoring program delineated in Table 5-1. This program will continue in the future. We believe this is the most extensive monitoring program for any power plant in EPA Region 1 and it will be sufficient to provide data for verification monitoring if required.

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# APPENDIX A

## Calculation Baseline
## Cooling Water Flow at Seabrook Station

**Effect of Offshore Intakes at Seabrook Station**

The Seabrook once through cooling system currently draws water through the intake structure from approximately 7,000 feet offshore from Hampton Beach in the Gulf of Maine. The water enters through three separate offshore intake structures and travels through a 19 ft diameter tunnel approximately 3.22 miles long to the screen house location.

The existing cooling water intake system at Seabrook differs from the design of the cooling water intake structure identified in the regulations for use in determining the calculation baseline for IM&E. As defined in § 125.93, the "calculation baseline means an estimate of impingement mortality and entrainment that would occur at your site assuming that: the cooling water system had been designed as a once-through system; the opening of the cooling water intake structure is located at, and the face of the standard ⅜-inch mesh traveling screen is oriented parallel to, the shoreline near the surface of the source waterbody; and the baseline practices, procedures, and structural configuration are those that your facility would maintain in the absence of any structural or operational controls, including flow or velocity reductions, implemented in whole or in part for the purposes of reducing impingement mortality and entrainment".

To determine what the IM&E would be with the baseline intake configuration, it is first necessary to determine the cooling water flow requirements if that configuration were utilized. Since the baseline configuration would draw water from the waterbody surface at the shoreline, the intake water would have a higher maximum temperature than the water drawn into the existing off-shore intake. Therefore, a higher circulating water flow would be required to maintain the same discharge temperature. At the Seabrook Station the actual construction of a shoreline intake matching the description above would be faced with many technical and environmental issues that would be extremely difficult, if not impossible, to address. For this reason, any discussion of this baseline intake design is theoretical in nature only.

For this analysis it is assumed that the baseline intake would be located at the Gulf of Maine shoreline near the inlet to Hampton Harbor. At this location the temperature of the water drawn into the intake would be considerably higher than the temperature of the water drawn into the existing offshore intake structures. At the current intake location the monthly average daily water temperature ranges from a minimum of 36.9 °F in February to a maximum of 55.4 °F in September. At the theoretical baseline intake location, where water temperatures will be affected due to the proximity to the estuary and shallower water, the monthly average mean daily water temperature ranges from a minimum of 35.8 °F in February to a maximum of 62.0 °F in July. This temperature data represents the five year average from 2000 through 2004.

To determine the required cooling water flow with the baseline intake configuration, it is necessary to establish criteria for the discharge temperature. It will be assumed here that the discharge temperature will not be allowed to exceed the current discharge temperatures. Although discharge criteria can be based on many different assumptions, it is our opinion that the use of the same discharge temperature for the baseline intake is a reasonable assumption. In the current NPDES Permit for Seabrook, the maximum monthly average difference between the intake temperature and discharge temperature is 39 °F. If the maximum intake temperature is 55.4 °F at the current intake location, then the discharge temperature at the maximum allowable differential of 39 °F is 94.4 °F. Using 94.4 °F as the maximum monthly average discharge temperature for the theoretical baseline intake, the maximum allowable monthly average differential temperature with the baseline intake design must be reduced to 32.4 °F. This maximum temperature rise is similar to the limit in the NPDES Permit for the Pilgrim Nuclear Station, which has a shoreline intake and a temperature increase limit of 32 °F.

Using the criteria established above and the current design heat load rejection of 8,000 MMBtu/hr, the required circulating water flow rate must increase to 494,000 gpm. If the current service water flow rate of 23,000 gpm is kept unchanged, the total baseline flow would be 517,000 gpm (744.5 MGD). Therefore, the current total cooling water flow rate, including circulating water and service water, at full load operation of 475,000 gpm (684.0 MGD) is 8.1% less than the baseline flow.

In this analysis it is assumed that the baseline flow is determined by the design flow throughout the year. Flow reduction which could be achieved through recirculation or through the shutdown of a singe pump is not considered in the baseline flow analysis since such operational measures are not considered as flow reduction in calculation baseline unless they are implemented for the purpose of reducing impingement mortality or entrainment.

# APPENDIX B

## Calculation Baseline of Impingement Mortality

**Table B-1. Comparison of fish impinged per unit of cooling water flow between Seabrook and Pilgrim Stations.**

| Year | Seabrook[a] | | | Pilgrim[b] | | |
|---|---|---|---|---|---|---|
| | Annual Flow ($10^6$ gallons) | Fish Impinged | Fish/$10^6$ gallons | Annual Flow ($10^6$ gallons) | Fish Impinged | Fish/$10^6$ gallons |
| 2006 | 218,953 | 12,955 | 0.059 | 170,032 | 29,711 | 0.175 |
| 2005 | 219,675 | 29,368 | 0.134 | 170,032 | 302,883 | 1.781 |
| 2004 | 229,373 | 16,696 | 0.073 | 170,032 | 33,591 | 0.198 |
| 2003 | 220,792 | 71,946 | 0.326 | 170,032 | 179,608 | 1.056 |
| 2002 | 223,066 | 18,413 | 0.082 | 170,032 | 64,606 | 0.380 |
| Average | 222,372 | 29,876 | 0.135 | 170,032 | 122,080 | 0.718 |

[a] Actual flows. Impingement estimate is based on actual flows.
[b] Design flows of 155,500 gpm for each of two circulating water pumps, and 2,500 gpm for each five service water pumps. Impingement estimates are based on 100% flow capacity.

**Table B-2. Comparison of calculation baseline impingement and actual impingement at Seabrook Station.**

| Parameter | Calculation Baseline | Actual Seabrook Data[a] | Design Seabrook Flow |
|---|---|---|---|
| Cooling Water Flow ($10^6$ gallons/year) | 271,743 | 222,372 | 249,660 |
| Impingement Density (fish/$10^6$ gallons | 0.718[b] | 0.135 | 0.135 |
| Impingement Estimate | 195,111 | 30,020 | 33,704 |

[a] Averages from 2002-2006, see Table B-1.
[b] From Pilgrim Station data, see Table B-1.

Calculation 1. Percent reduction from calculation baseline using average Seabrook Station flows: (195,111-30,020)/195,111 = 85%

Calculation 2. Percent reduction from calculation baseline using design Seabrook Station flows: (195,111-33,704)/195,111 = 83%

# APPENDIX C

## Calculation Baseline for Entrainment

**Table C-1. Comparison of ichthyoplankton entrained per unit of cooling water flow between Seabrook and Pilgrim Stations**

| Year | Seabrook[a] | | | Pilgrim[b] | | |
|---|---|---|---|---|---|---|
| | Annual Flow ($10^6$ gallons) | Ichthyoplankton Entrained (millions) | Ichthyoplankton entrained/$10^6$ gallons | Annual Flow ($10^6$ gallons) | Ichthyoplankton Entrained (millions) | Ichthyoplankton entrained/$10^6$ gallons |
| 2006 | 218,953 | 1,198.6 | 0.0055 | 170,032 | 1,673.6 | 0.0098 |
| 2005 | 219,675 | 621.4 | 0.0028 | 170,032 | 1,395.4 | 0.0082 |
| 2004 | 229,373 | 2,328.6 | 0.0102 | 170,032 | 1,941.8 | 0.0114 |
| 2003 | 220,792 | 797.9 | 0.0036 | 170,032 | 1,355.8 | 0.0080 |
| 2002 | 223,066 | 2,811.2 | 0.0126 | 170,032 | 1,446.0 | 0.0085 |
| Average | 222,372 | 1,551.5 | 0.0069 | 170,032 | 1,562.5 | 0.0092 |

[a] Actual flows. Entrainment estimate is based on actual flows.
[b] Design flows of 155,500 gpm for each of two circulating water pumps, and 2,500 gpm for each five service water pumps. Impingement estimates are based on 100% flow capacity.

**Table C-2. Comparison of calculation baseline entrainment and actual entrainment at Seabrook Station.**

| Parameter | Calculation Baseline | Actual Seabrook Data[a] | Design Seabrook Flow |
|---|---|---|---|
| Cooling Water Flow ($10^6$ gallons/year) | 271,743 | 222,372 | 249,660 |
| Entrainment Density (ichthyoplankton/$10^6$ gallons[b]) | 0.0092[b] | 0.0069 | 0.0069 |
| Entrainment Estimate (millions) | 2,500.0 | 1,543.3 | 1,722.7 |

[a] Averages from 2002-2006, See Table C-1.
[b] From Pilgrim Station data, see Table C-1.

Calculation 3. Percent reduction from calculation baseline using average Seabrook station flow: (2500.0-1,543.3)/2,500.0 = 38%

Calculation 4. Percent reduction from calculation baseline using design Seabrook station flows: (2,500.0-1,722.7)/2,500.0 = 31%

# APPENDIX D

## Fish Protection Technologies and Operational Measures

## Proposed Technology and Operational Measures

EPRI has identified many intake technologies for consideration in achieving compliance with the 316(b) performance standards. EPRI has categorized the intake technologies by the methods of operation. They have been categorized as Physical Barriers, Collection Systems, Diversion Systems, and Behavioral Deterrent Systems. The technologies included in each category are as follows.

*Physical Barriers:*

Traveling Screens, Stationary Screens, Drum Screens, Cylindrical Wedgewire Screens, Barrier Nets, Gunderboom, Porous Dike, Radial Wells, Artificial Filter Bed, and Rotary Disc Screens.

*Collection Systems:*

Modified Traveling Screens and Fish Pumps.

*Diversion Systems*

Angled Screens, Modular Inclined Screens, Eicher Screen, Angled Drum Screens, Louvers, Inclined Plane Screen, and Horizontal Traveling Screens.

*Behavioral Deterrent Systems*

Strobe Light, Mercury Light, Sound Systems, Infrasound Generators, Air Bubble Curtains, and Hybrid Systems.

*Other Technologies*

Intake Location (Off-shore intake), Velocity Cap, and Flow Reduction

In addition to the technologies described above, operational measures can be utilized to further reduce intake flow. Flow and annual water use can be reduced by either taking pumps out of service when not required or installing variable frequency drives to reduce flow.

This assessment included an initial screening that evaluated the potential for IM&E reduction technologies at Seabrook (Appendix D). An important consideration in this assessment is biological effectiveness. In addition, for practical considerations, the successful installation and operation of the technology on large cooling water intakes is a prerequisite for passing the initial screening process.

Intake technologies that meet the initial screening criteria noted above include conventional traveling screens with a fish return system, cylindrical wedgewire screens, barrier net (impingement only), aquatic microfiltration barrier (Gunderboom), coarse mesh modified traveling screens with return system (impingement only), fine mesh modified traveling screens with return system, angled screens (impingement only), angled screens, and louvers (impingement only). Further evaluation of each of these technologies for use at Seabrook is provided below.

Due to the effectiveness of the offshore intake at Seabrook, the intake technologies reviewed in this section will be evaluated for use with the existing off-shore intake and not in place of it.

### Conventional Traveling Screens with a Fish Return System

The addition of a fish return system for use with the existing conventional traveling screens is a possible option that could provide some reduction in impingement mortality for some of the more hardy species of fish when other intake design and operating conditions are conducive for fish survival. Although conventional traveling screens do not provide the same level of survival of impinged fish as modified screens, they have been shown to provide some level of impingement mortality reduction when operated continuously and combined with a fish return system.

At the Seabrook Station, any fish entering the off-shore intake structures travel down a vertical shaft to a depth of 160-ft. below MSL and then travel 17,000 feet through the intake tunnel to a depth of 240-ft. below MSL. At that point the fish move up a vertical shaft to the intake transition structure at surface level. If the fish are moving at the same velocity as the water, they will travel from 240-ft. below MSL to the surface elevation in approximately 64 seconds. At a depth of 240-ft., the pressure to which the fish are subjected is approximately eight times greater than at the surface. Due to this rapid and large change in pressure, it is unlikely that there will be a high percentage of surviving fish at the location of the intake screens. Therefore, continuous operation of the screens and the addition of a fish return system will provide little reduction in impingement mortality.

In addition to the anticipated low level of effectiveness in reducing impingement mortality, the installation of an effective fish return system at Seabrook would be difficult, if at all feasible. For a fish return system to be effective, careful consideration must be given to the return point of the system. At Seabrook, the only acceptable return point would be back to the Atlantic Ocean, which is over 8,000 feet from the screen house. Although some of the estuaries, tidal creeks, and Hampton Harbor are closer, the effect of the tide on water depth and salinity levels makes these locations unacceptable as a return point for the fish.

Since the addition of the fish return system along with the continuous operation of the screens will provide very little benefit in reducing impingement mortality and no reduction in entrainment, this alternative shall not be given further consideration.

### Cylindrical Wedge Wire Screens

Submerged cylindrical wedge wire screens is the rule-specified EPA approved design and construction technology for facilities that draw cooling water from freshwater rivers or streams. These screens have also been successfully used in several lake installations. There are not, however, any full scale installations in the United States employing the use of submerged wedge wire screens for an ocean intake or for a nuclear facility.

If wedge wire screens were added to the existing off-shore intake, a slot width of 0.76 mm and through screen velocity of 0.5 fps should be sufficient to physically exclude 60 to 90 percent of the eggs and larval fish. For a cooling water flow of 475,000 gpm, approximately 18, 96-inch diameter wedgewire T-screens would be required to maintain an intake velocity of 0.5 fps. If slot width were increased to 1.75 mm, the quantity of screens required would be reduced to 12. For the two large facilities that utilize cylindrical wedgewire screens, Eddystone and Campbell, the slot widths are ¼" and ⅜" respectively.

For the 96-inch diameter screen, the minimum required water depth is 16 feet. At the location of the current off-shore intake structures the depth is approximately 60 feet, therefore, water depth is not a limiting factor.

An order of magnitude cost estimate for just the installation of wedge wire screens at the existing off-shore intake structures would be approximately $8 million. This estimate was developed using the guidelines provided in the EPA's Technical Development Document (EPA 2004). This cost is just for the installation of the screens and does not include the cost of an air burst system for the cleaning of the screens. For the Eddystone Station, an air burst system is used, but at Campbell, an air burst system was not installed and operating experience has proven that the air burst system is not necessary. The requirement of an air burst system is dependent on the amount of debris present in the vicinity of the screens and the slot opening for the screens. At Seabrook, it is assumed that an air burst system would be required if screens with small slot openings were used and due to the consequences associated with plugging of the screens. The cost of installing an air burst system at Seabrook could far exceed the cost of the wedge wire screens. For an air bust system, a 12-inch air supply line would be required for each 96-inch diameter screen. With the wedge wire screens located approximately 3.25 miles from the screen house, and using the EPA's estimate of $456 per foot for the installation of 12" diameter stainless steel pipe, the cost to install an air burst system for wedge wire screens at the Seabrook offshore intake could exceed $100 million. If a system could be engineered to move the control valves closer to the screens, the cost of the air burst system could possibly be reduced. However, even optimizing the design to the point where only one 12-inch line was required from the onshore location to the intake location, it is anticipated that the minimum cost would be approximately $24 million.

In addition to the high capital cost for wedge wire screens, the additional O&M costs could range from $50,000 to $200,000 per year, depending on screen mesh utilized and the level of debris loading. The O&M costs reflect additional energy requirements for operation of the air compressors, diving costs for cleaning and maintenance of the screens, and additional labor for maintenance of the compressed air system.

While the installation of wedge wire screens at Seabrook may be technically feasible, the addition of these screens significantly increases the probability of a loss of flow through the cooling water intake system due to plugging of the screens. This probability is increased even more with the use of the screens with the smaller slot openings, since screens with the slot openings discussed here for the physical exclusion of eggs and larvae have not been proven in a high flow application such as Seabrook. The use of such screens would require further review to determine if they would conflict with the Nuclear Regulatory Commission safety requirements and with the reliable operation of the station.

Using the order of magnitude costs developed for this technology option, the annual cost could range from $5 million to $16 million. These annual costs do not include the addition of potential pilot testing costs, lost generation costs due to an extended plant outage, and possible performance penalty costs due to a reduction in cooling water flow. It is anticipated that this annual cost will far exceed any incremental benefit and this option will be eliminated from further consideration. In addition, the operational risks associated with the addition of cylindrical wedge wire screens at this site may not be acceptable.

**Barrier Net**

Barrier nets have been successfully applied at several large power plants including the Ludington, Karn-Weadock, Chalk Point, and J. R. Whiting facilities. A typical mesh size for a barrier net is 3/8-inch, therefore, they provide impingement protection only.

The barrier net at Seabrook would have to be located around the existing offshore intake structures. This would be a first of a kind installation since all barrier nets currently in use are either located within or at the entrance to a canal or in front of a shoreline intake structure. A barrier net located around the Seabrook offshore intake structures would have a depth of 60 feet and would not have any protection against wave action. Since barrier nets are very susceptible to damage from waves and storm conditions and since they do not provide any reduction in entrainment, this technology would not be suitable for use at the Seabrook Station and will be eliminated from further consideration.

**Aquatic Microfiltration Barrier**

An aquatic microfiltration barrier system consists of a filter fabric which is installed in the waterbody around the entrance to the intake. The fabric filter is supported by floating booms and extends the full water depth. The openings in the woven fabric are small enough to prevent larval fish and eggs from passing through the fabric and entering the intake. One such system is the Gunderboom Marine Life Exclusion System™ (MLES™).

The microfiltration barrier, as with the barrier net, would have to be located around the existing offshore intake structures. The microfiltration barriers are also very susceptible to damage and failure from waves, storm conditions, and heavy debris loading. In addition, a microfiltration barrier requires an air supply for periodic cleaning of the fabric to remove accumulated debris. Due to these characteristics, a microfiltration barrier is not considered a suitable technology for use at Seabrook and will be eliminated from further consideration.

**Modified Traveling Screens**

Traveling screens with fish handling modifications and fine mesh overlays to reduce impingement and entrainment can be installed in the existing screenwells. In addition to the new screens, this technology requires a fish return system to transport fish and organisms removed from the screens back to the waterbody. It is anticipated that 1 mm mesh screens would be appropriate for the physical exclusion of a high percentage of eggs and larvae, with the potential of reducing entrainment by 60 to 90 percent. It is anticipated that the fine mesh overlays would be utilized during the normal high entrainment months of April, May, June, and July.

In general, an approach velocity of 0.5 to 1.0 fps is recommended when fish protection is the governing criteria for the design of an intake with traveling water screens (ASCE 1982). This is a general rule and can be adjusted to reflect the swimming capabilities and sensitivity of the fish species present. With a typical open area of approximately 50%, this approach velocity range correlates to a through screen velocity of 1.0 to 2.0 fps. This velocity range is in general agreement with research by R. Ian Fletcher, where he drew the general conclusion that the risk of impingement mortality increased sharply when the through screen velocity increased to the range of 1.6 to 2.6 fps (Fletcher 1994). At Seabrook, the calculated through screen velocities at design flow and mean sea level will be approximately 1.0 fps with coarse mesh screens and 2.5 fps with fine mesh screens. If the three additional intake bays that were constructed for the second generating unit could be incorporated into the cooling water intake system for Unit 1, the velocity would be 1.25 fps for the fine mesh screens.

Based on the same reasons discussed for conventional traveling screens, there would be very little reduction in impingement mortality with the conversion to modified screens.

During the time of the year when the fine mesh panels would be in place, there would be a reduction in entrainment. There are several factors, however, that make the feasibility of utilizing fine mesh screens at Seabrook questionable. The primary factor is the through screen velocity. With only three screens, the estimated through screen velocity of 2.5 fps is significantly higher that the normal design velocity of 1.0 fps. This velocity may be acceptable for screen operation, but the survival of any organisms impinged on the screens may be low. In addition, the fine mesh screens will plug with debris much faster than the coarse mesh screens and with a 50 percent clean screen it is estimated that the head loss across the screen would increase to approximately 9 inches, which would be acceptable, but high. Therefore, if fine mesh screen were to be applied at Seabrook, it is likely that additional screens would be required. One possible scenario for the addition of screens would be the use of the three screen wells installed for Unit 2. The feasibility of this option has not been investigated and would require additional investigation.

In addition to the technical issues of high through screen velocities and the feasibility of adding more screens, the fish return system would also present some formidable challenges as discussed under Conventional Traveling Screens. Due to the tendency for fine mesh screens to plug with debris much faster than coarse mesh screens, the probability of a trip of the circulating water system due to high screen differential increases. This is a safety consideration that could eliminate fine mesh screens from further consideration.

Should it be possible to utilize the Unit 2 intake structure, it is estimated that the minimum cost for the installation of six new modified screens with a fish return system would be approximately $9.5 million. With an incremental operation and maintenance cost of $220,000 per year, the total annual cost for the option would be $1.6 million.

Due to their potential effect on the circulating water system reliability, the technical difficulties associated with an extremely long return system, and small incremental benefit as compared to high cost, modified fine mesh screens will be eliminated from further consideration.

**Angled Screens**

With respect to impingement, coarse mesh angled screens have shown potential for impingement mortality reduction. At both the Brayton Point Unit 4 and the Oswego Steam Station Unit 6, installations of angled screens, high diversion capability and impingement mitigation effectiveness was demonstrated. Once diverted to the collection point, it is necessary to either lift or pump the fish back to an appropriate location in the waterbody.

The installation of angled screens at Seabrook would require the construction of a new screening structure. The existing intake structure could not be retrofitted for angled screens. Due to the need for the new intake structure and the need for a fish return system with a pump, the cost to install angled screens at Seabrook would be significantly greater than the cost of installing modified traveling screens with a fish return system. In addition, as is the case with the conventional and modified traveling screens with a fish return system, due to the pressure changes the fish will experience prior to reaching the screens, it is anticipated that fish survival prior to reaching the screens will be low. Since the angled screens would be higher cost than modified traveling screens, would only address impingement, and will provide little reduction in impingement mortality, there is no justification for further consideration of angled screens at Seabrook.

**Louvers**

Louvers consist of a series of panels that are placed across a channel at an angle to the flow. Each panel has a series of evenly spaced vertical rectangular bars that are set with the long side perpendicular to the flow. The panels are placed at an angle of approximately 15 to 20 degrees to the flow and lead to a collection and return system at the end of the panels. The positioning of the bars perpendicular to the flow causes an abrupt change in the flow direction and velocity, which the fish sense and have a tendency to try and avoid. As the fish attempt to swim away from this area where the change in velocity and direction occurs, they move with the current along the face of the louvers toward the point of collection and return. At this location the fish are pumped back to a suitable return point.

Louver systems can be effective in diverting fish to the return system and reducing impingement on the screens. They have been used successfully at several hydroelectric and irrigation facilities in the northwest and northeast and have been applied at one cooling water intake for a nuclear facility in California. Studies have shown that the effectiveness of louvers is very species and life-stage specific due to the technology's dependency on the swimming capability and behavior of the target species. Prior to the implementation of a louver system, studies would be required to evaluate the effectiveness for the target species and to determine the most effective angle of orientation, approach and bypass velocities, bar spacing, and other design characteristics for the site-specific hydraulic conditions.

Due to the use of the offshore intake at Seabrook, louvers, which must be installed at a location before the intake, cannot be applied and are not considered a viable option for further consideration.

**Flow Reduction**

Flow reduction is one method of decreasing impingement and entrainment. Flow reduction can be achieved by removing one circulating pump from service, recirculating water from the discharge back to the intake, or installing variable speed drives.

The potential effects of reducing the circulating water flow are increased turbine backpressure, an increase in circulating water differential temperature, and an increase in circulating water discharge temperature. With the increase in turbine backpressure, comes a reduction in turbine capability and performance.

Seabrook Station currently employs recirculation during the months when the water temperature is low enough. The average recirculation flow for the previous five years has been approximately 47 MGD. This accounts for an overall reduction of 7.3% of the average intake flow.

A previous study has been performed at Seabrook to determine the benefits of flow reduction by periodic operation of two circulating water pumps instead of three. From this analysis, it was determined that an annual flow reduction of 4.3% could be achieved. To achieve this flow reduction it was also necessary to increase the maximum allowable circulating water differential temperature by 5 °F. Under this operating scenario there was not any recirculation of cooling water discharge. Two cooling water pumps was eliminated from consideration due to the increased potential for plant equipment damage if one of the two operating pumps were to trip.

As noted previously, as an alternate source of cooling water for the service water system, a cooling tower was installed to provide shutdown cooling in the event the intake and/or discharge tunnels are blocked due to a seismic event. With a normal service water flow of 23,000 gpm, the potential continuous use of the cooling tower could reduce cooling water intake flow by the full service water flow. This option was investigated and it was determined that it is not practicable to operate the cooling tower on a continuous basis due to the NRC requirements associated with the cooling towers and the significant impact the additional makeup water would have on the Town of Seabrook municipal water supply. In general, the cooling tower is safety related and is strictly controlled by the NRC Operating License Technical Specifications. With continuous operation of the cooling tower it would be extremely difficult, if not impossible, to maintain the cooling tower basin water requirements associated with level and temperature. In addition, the requirement for makeup water, which is supplied by the Town of Seabrook municipal water supply, could increase from a current normal supply of 2 to 4 million gallons per month to 17 million gallons per month. Due to the current water conservation requirements and the low well level concerns that are created when water usage increases to 8 to 10 million gallons per month during refueling outages, it is anticipated that a significant increase in makeup water requirements would create supply problems for the Town of Seabrook.

The use of variable frequency drives (VFD's) for the circulating water pump motors provides the ability to alter the speed of the pumps and therefore, the flow of each pump. The use of VFD's provides more flexibility in the reduction of flow than reducing the number of pumps in operation due to the ability to operate at all flows above the minimum operating threshold. As noted earlier for two pump operation, any reduction in flow will create a higher temperature differential in the circulating water, therefore, one of the limiting factors for flow reduction is the temperature differential limit in the current NPDES Permit. Further study is required to determine if flow reduction with VFD's can achieve a greater flow reduction that is currently obtained with recirculation. An estimated capital cost for the addition of VFD's for the three circulating water pumps at Seabrook is $700,000. This cost was developed in accordance with the guidelines provided in the EPA 2002 Technical Development Document (EPA 2002). The costs presented here also assume that no major modifications are necessary for the pumps, the power supply or controls, and the equipment foundations. This cost will also increase significantly if the motors do not have an appropriate class of insulation or if adequate space is not available in the vicinity of the pumps for the VFD equipment.

Based on the results of the previous flow reduction study and the review of continuous use of the cooling tower, it is apparent that the potential for flow reduction beyond what is currently being achieved with recirculation, is low. However, should the current technologies and operational measures not meet the required performance standards, the potential use of flow reduction and VFD's would be investigated in the CDS.

**Proposed Technologies and Operational Measures for Further Study**

As a result of the screening study and the evaluation of the potential technologies and operational measures, no additional technologies or operational measures were identified for further evaluation in the CDS.

Appendix Table D-1. Evaluation of Fish Protection Technologies and Operational Measures.

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| **Physical Barriers** | | | | | |
| Conventional Traveling Screens - ⅜" Mesh | No | No | Yes – Most common of all intake screening technologies | No entrainment protection beyond baseline. If rotated continuously and with a return system, some reduction in impingement mortality will be realized. Impingement mortality will be high, except for some of the hardiest species of fish. Capable of meeting impingement mortality performance standard if velocity through the screen can be reduced to 0.5 FPS or less. [§ 125.94(a)(1)(ii)] | No - Entrainment<br>Yes - Impingement only with continuous operation and the addition of a fish return system.<br>Station currently has conventional traveling screens with ⅜" mesh in place.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, continuous operation with a fish return system would provide a very small reduction in impingement mortality. |
| Stationary Screens | No | No | Yes - Brunswick Plant – | At Brunswick Plant the screens are installed in a diversion structure at mouth of intake canal. Effective in blocking juvenile and adult menhaden, spot, and croaker at Brunswick. Screen mesh is unknown.<br>No other proven installations. | No.<br>No reduction of impingement mortality or entrainment. |
| Drum Screens | No | No | No | Used primarily at hydroelectric and irrigation facilities. No proven effectiveness in reduction of impingement mortality of entrainment. More effective version is the angled drum screen. | No.<br>No reduction of impingement mortality or entrainment. |
| Cylindrical Wedge-wire Screens | Yes | Yes | Yes – Eddystone (¼" slot), J.H. Campbell (⅜" slot) | EPA approved technology when installed in freshwater river or stream with adequate counter currents, appropriate slot size to reduce entrainment, and velocity at 0.5 FPS or less. | Yes<br>Installation of screens with appropriate slot widths should reduce impingement mortality and entrainment. |
| Barrier Nets | Yes | No | Yes – J.P. Pullman (6 mm mesh), J.R. Whiting (⅜" mesh), Bowline (0.95 cm mesh) | Successfully applied at several power plants to reduce impingement. Mesh size is site specific and must be such that it prevents passage of fish but does not cause fish to become gilled in the net. Impingement reductions between 85 and 99 percent have been realized. | Yes – Impingement Only<br>Barrier nets are effective in reducing impingement mortality but provide no reduction of entrainment. Typically used with a shoreline intake or intake canal. |

## Appendix Table D-1. (Continued)

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| Aquatic Microfiltration Barriers (Gunderboom) | Yes | Yes | Yes – Lovett Gen. Station. | Technology has shown promise for impingement and entrainment reduction. Design and operational problems at only large scale installation. EPA indicates that the technology is still "experimental in nature". | Yes<br>Installation of a Microfiltration Barrier could reduce IM&E. The few existing installations have been with a shoreline intake. |
| Porous Dike | Yes – laboratory and small scale testing only | No | No | No full scale installations for cooling water intakes. All studies were performed in laboratories or were small scale studies. | No<br>Unproven technology |
| Artificial Filter Bed | Yes | Yes | No | Some small scale use only. Reliability problems even at small scale. | No<br>Unproven technology |
| Rotary Disc Screens | No | No | No | For low flow applications with relatively constant water levels. Not appropriate for CWIS application | No<br>Unproven technology |
| **Collection Systems** | | | | | |
| Modified Traveling Screens with Return System (Coarse Mesh) | Yes | No | Yes – Salem, Mystic, Indian Point, Roseton, Surry, Arthur Kill, Dunkirk, Kintigh, Calvert Cliffs, and Huntley. | Installed on many cooling water intakes. Where tested, *impingement mortality* has been significantly reduced for the majority of species. Mortality can be high for some of the more fragile species. Available in either through flow or dual flow configuration. | Yes – Impingement Only<br>Provide reduction in impingement mortality but no reduction of entrainment.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, modified screens with a fish return system would provide a very small reduction in impingement mortality. |
| Modified Traveling Screens with Return System (Fine Mesh) | Yes | Yes | Yes – Very Limited. | Seasonal use of 0.5 mm mesh screens at Big Bend Power Station with good latent survival of drums and bay anchovy eggs and larvae. Some other pilot tests, but very limited data. High maintenance to avoid biofouling and clogging | Yes<br>Installation of screens with fine mesh should reduce IM&E.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, continuous operation with a fish return system would provide a very small reduction in impingement mortality. |

Appendix Table D-1. (Continued)

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| **Diversion Systems** | | | | | |
| Angled Screens | Yes | No | Yes – Brayton Point and Oswego Steam Station | Have shown potential to meet impingement standard. Large bypass flow and fish pump are required. Higher cost than modified traveling screens with return system. | Yes – Impingement Only<br>Potential reduction in impingement mortality but no reduction of entrainment. It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, modifying the intake with angled screens would provide a very small reduction in impingement mortality. |
| Modular Inclined Screens | Yes – Laboratory and pilot tests only | No | No | Laboratory test showed diversion efficiency between 47 and 88 percent for most species. Only one pilot test at a hydroelectric facility that also showed high diversion and survival rates. | No<br>No proven full scale installation |
| Angled Drum Screens | Yes – Juvenile salmonids at hydro & irrigation facilities | No | No | Used at hydroelectric and irrigation facilities. Never applied to a generating station CWIS. Require relatively constant submergence | No<br>No proven full scale installation |
| Louvers | Yes – for juvenile and adult fish | No | Yes – San Onofre – no effectiveness data | Successfully applied at several hydroelectric and irrigation facilities. Diversion efficiency is very species, life stage, and site specific. | Yes – Impingement Only<br>Potential reduction in impingement mortality but no reduction of entrainment. |
| **Behavioral Systems** | | | | | |
| Strobe Light | Yes – on some species | No | No – only installations for testing. | Testing has been inconclusive and any results have been species specific. | No<br>No reduction of entrainment and unproven technology for species of concern at Seabrook. |
| Sound Barriers | Yes – on some species | No | Yes | Some demonstration studies have been successful in reducing alewife impingement. Site specific design is required for targeted species. | No<br>No reduction of entrainment and unproven technology for species of concern at Seabrook. |

## Appendix Table D-1. (Continued)

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| Air Bubble Curtains | No | No | No – no permanent installations | Conclusions from past studies are that this technology is ineffective. | No<br>No reduction of entrainment and unproven technology for impingement reduction. |
| **Other Technology** | | | | | |
| Flow Reduction | Yes | Yes | Yes | Level of flow reduction must be determined from effect on turbine performance and discharge temperature limitations. Percent entrainment reduction is approximately equal to percent flow reduction. Impingement can be reduced with a reduction in flow or performance standards can be satisfied by reducing through screen velocity to less than 0.5 FPS. | Yes<br>Flow reduction will reduce IM&E. Potential level of flow reduction should be evaluated. |
| Closed Loop Cooling | Yes | Yes | Yes | 90 percent or greater reduction in intake flow | Yes |
| Intake Location | Yes | Yes | Yes | Intake can be located to an area of decreased biological productivity. Offshore intakes can be located in these areas of reduced biological productivity and achieve reduced levels of impingement and entrainment from baseline conditions. | Yes<br>An off-shore intake is currently in use at Seabrook. |
| Velocity Cap | Yes | No | Yes – El Segundo, Redondo Beach, San Onofre, Huntington Beach, Edgewater, and Seabrook | Used to create a horizontal flow at off-shore intake. Fish tend to avoid this rapid change in horizontal flow. Effectiveness has exceeded 90 percent on West Coast offshore intakes. Appropriate velocity is species specific, therefore, site specific testing is required. Not effective on eggs, larvae, and early life stage fish. | Yes – Impingement only<br>A velocity cap is currently installed at Seabrook. |

# APPENDIX E

## Quality Control and Quality Assurance Methods for the Seabrook Station Environmental Monitoring Program

# SECTION VA
# PLANKTON SAMPLE PROCESSING

## 1.0 INTRODUCTION

The Plankton Department analyzes several types of samples taken for the Seabrook Environmental Studies (Appendix IIA,Table 2.0-1). For the most part, procedures described in the Technical Procedures Manual (TPM), No. 14, Section VI, are applicable to the processing of Seabrook Environmental Studies samples. Any deviations from these procedures specific to the Seabrook Environmental Study are described in the following sections.

## 2.0 SAMPLE PROCESSING

Refer to Section VI,2.0 of the TPM, No. 14, for sample processing procedures.

### 2.1 MACROZOO-ICHTHYOPLANKTON SAMPLES

Macrozoo-ichthyoplankton samples collected four times per month at Seabrook Stations P2, and P7 will be analyzed according to the following schedule: Ichthyoplankton will be analyzed from one of the two tows at each station (tow A); macrozooplankton will be analyzed from one of the two tows (tow A) at each station for sample periods one and three when samples have been collected in all four weeks of the month. Samples not analyzed will be archived. Procedures described in the TPM, No. 14, Section VI,2.1 shall apply to the processing of Seabrook Environmental Studies macrozoo-ichthyoplankton samples. Ichthyoplankton entrainment samples are collected with a mesh size of 0.333 mm during four sample events per month. Each sampling event consists of four replicates of a duration of about 2 hours and a sample volume of 100 $m^3$ representing each of the six hour diel periods (night: 2215-0415; morning: 0415-1015; day: 1015-1615; evening 1615-215). These samples will be analyzed using the same procedures as described for ichthyoplankton samples.

***Exceptions/Cautions:***

1. Ichthyoplankton will be identified to the lowest practical taxon. Larvae include entire specimens, heads and bodies of fish larvae. In filling larval quotas, only entire specimens and heads will be counted.
2. The minimum count criteria for ichthyoplankton analyses are as follows:
   a. Samples will be split so that a minimum of 200 eggs and 100 larvae (total of all species) are removed, not necessarily from the same size split.
   b. A maximum of approximately 400 ml settled plankton volume will be examined, regardless of whether the criteria in 2a are met, using a Folsom plankton splitter to obtain an aliquot in which the settled plankton volume is between 200 and 400 ml.
3. Fish eggs will not be staged.
4. Lengths of all measurable fish larvae, up to a maximum of 20 per sample, will be measured from two samples per station per sampling period for the following species: American sand lance (*Ammodytes americanus*), Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), yellowtail flounder (*Limanda ferruginea*), pollack

(*Pollachius virens*), winter flounder (*Pseudopleuronectes americanus*), Atlantic mackerel (*Scomber scombrus*), cunner (*Tautogolabrus adspersus*), and hake (*Urophycis* sp.). Lengths measured will be notochord length (or standard length if the hypurals are fully formed) to the nearest 0.5 mm. Variation is determined by dividing the third highest of the 20 lengths by the third lowest. If the variation among lengths for a species in a sample exceeds 2.0, an additional 10 larvae of that species (if present) will be measured from that sample.

5. Macrozooplankton will be identified to the lowest taxonomic level listed in Table VA,2.1-1 for each taxonomic group. Fourteen copepod taxa (designated by * in Table VA,2.1-1) will be enumerated from the Stempel pipette subsamples (TPM, No. 14, Section VI,2.1.1), seven other copepod taxa (** in Table VA,2.1-1) will be enumerated from the Folsom splitter aliquots along with the other macrozooplankters (TPM, No. 14, Section VI,2.1.3). When hydrozoans appear in high densities, preventing an even distribution of copepods, the sample will be split into aliquots using the Folsom splitter. One hydrozoan taxon (*** in Table VA,2.1-1) will be noted as present but not enumerated from the folsom splitter aliquots along with the other macrozooplankters (TPM, No. 14, Section VI,2.1.3).
6. *Calanus finmarchicus, Cancer* species, *Crangon septemspinosa, Neomysis americana* and *Carcinus maenas* will be staged in all samples, using the stages listed in Table VA,2.1-1. Other macrozooplankton taxa will not be staged.
7. The volume of water filtered by the 1.0-m diameter macrozoo-ichthyoplankton net will be calculated using 0.785 $m^2$ as the net mouth area.
8. Data coding specifications for the Copepod and Macrozooplankton Analysis Data Sheet (Figure VA,2.1-1) are listed in Table VA,2.1-2. Data coding specifications for the Ichthyoplankton Egg Data Sheet and Ichthyoplankton Larval Data Sheet (Figure VA,2.1-2 and Figure VA,2.1-3, respectively), are listed in Table VA,2.1-3. Data coding specifications for the Ichthyoplankton Entrainment Egg Data Sheet and Ichthyoplankton Entrainment Larval Data Sheet (Figure VA, 2.1-4 and Figure VA, 2.1-5, respectively), are listed in Table VA, 2.1-4.
9. For the copepod analysis a minimum of 150 total copepods and a minimum of 30 of the most abundant species will be counted.
10. For macrozooplankton analysis approximately 30 organisms per taxon will be counted with the following exceptions.
    a. A minimum of 30 organisms will be counted for the dominant taxon.
    b. A maximum of 1/4 of the sample will be examined for macrozooplankton. Process 1/2 or the total sample, depending on time constraints, if the sample contains an unusually low number of organisms.
    c. If the settled plankton volume of a sample is greater than approximately 400 ml, then the sample will be split, using a Folsom plankton splitter, to obtain an aliquot in which the settled plankton volume is between 200 and 400 ml. A maximum of 1/4 of this aliquot will be analyzed for macrozooplankton.
    d. Enumeration of small rare organisms in a dense sample may be terminated at the discretion of an experienced taxonomist. The terminating aliquot will be determined based on the taxonomist's ability to reasonably expect to locate all of

the rare organisms in the aliquot. The taxa subject to the cutoff may vary seasonally and spatially and will be designated on a sample-by-sample basis.

e. Enumeration of the lifestages of a species will be terminated when the count of the dominant lifestage of that species is approximately 30.

## 2.4 BIVALVE LARVAE SAMPLES

Duplicate bivalve larvae samples are collected by plankton tows at Seabrook Plankton Stations P2, P7 and Estuarine Station P1; and by a barrel sampling device at the intake forebay at the Seabrook Station (entrainment samples). Sampling frequency is once per week, commencing the third week of April through the end of October. All samples will be analyzed for all bivalve taxa. Procedures described in the TPM, No. 14, Section VI 2.4, shall apply to the processing of Seabrook Environmental Studies bivalve larvae samples. Bivalve larvae entrainment samples will be analyzed using the same procedures as described for bivalve larvae samples from plankton tows.

**Exceptions/Cautions**:

1. Data coding specifications for the Bivalve Larvae Analysis Data Sheet (Figure VA,2.4-1) are listed in Table VA,2.4-1.

2. The volume of water filtered by the 0.5-m diameter bivalve larvae net will be calculated using 0.196 $m^2$ as the net mouth area, and will be both low-speed and high-speed calibration data (refer to TPM No. 14, Section VI,4.1, Step 6(b)).

3. Straight-hinge larvae will not be counted.

4. Only the following taxa will be identified separately; all other taxa present will be enumerated as Bivalvia:

| | |
|---|---|
| *Heteranomia squamula* | *Mytilus edulis* |
| *Hiatella* sp. | *Placopecten magellanicus* |
| *Macoma balthica* | Solenidae |
| *Modiolus modiolus* | *Spisula solidissima* |
| *Mya arenaria* | *Teredo navalis* |
| *Mya truncata* | |

Page 1 Of 1

## ICHTHYOPLANKTON - EGG

Analyzed By: ______________________ Date: ____________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | STATION | REP | SAMPLE CONTROL No. |
|---|---|---|---|---|---|---|
| | I E | | | | | |

| SCALING RATIO | SPLIT FOR VOLUME |
|---|---|
| 0 | |

| SPECIES NAME | SPECIES CODE | LIFE STAGES | COND. | COUNT/PCNT |
|---|---|---|---|---|
| Empty Sample | 1 | | E | |
| Windowpane flounder | 2,8,1,2,0,1 | | | |
| Atlantic Menhaden | 5,2,0,2,0,4 | | | |
| Four-beard rockling | 7,7,0,5,0,1 | | | |
| Atlantic Cod | 7,7,0,6,0,2 | | | |
| Silver hake | 7,7,0,9,0,1 | | | |
| Pollock | 7,7,1,2,0,1 | | | |
| Hake species | 7,7,1,5,0,0 | | | |
| Tautog | 9,5,1,0,0,1 | | | |
| Cunner | 9,5,1,1,0,1 | | | |
| Witch Flounder | 1,3,7,0,4,0,1 | | | |
| Plaice | 1,3,7,0,5,0,2 | | | |
| Yellowtail flounder | 1,3,7,1,0,0,2 | | | |
| Atlantic Mackerel | 1,5,7,0,6,0,2 | | | |
| Pleuronectidae/Labridae | 9,9,9,0,0,0,1 | | | |
| Cod/Haddock | 9,9,9,0,0,0,2 | | | |
| Cod/Haddock/Witch | 9,9,9,0,0,1,0 | | | |
| Rockling/Hake | 9,9,9,0,0,1,2 | | | |
| Osteichthyes | 2,0,0,0,0,0,0 | | | |
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Figure VA, 2.1-2. Icthyoplankton Egg.

## ICHTHYOPLANKTON LARVAE

Page 1 Of 1

Analyzed By: ______________________ Date: __________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | STATION | REP | SAMPLE CONTROL No. |
|---|---|---|---|---|---|---|
| | I L | | | | | |

| SCALING RATIO | SPLIT FOR VOLUME |
|---|---|
| 0 | |

| SPECIES NAME | SPECIES CODE | LIFE STAGES | COND | COUNT | LENGTH |
|---|---|---|---|---|---|
| Empty Sample | 1 | | E | | |
| Alligator fish | 3,0,4,0,2 | | X | | |
| American eel | 1,1,0,1,0,1 | | X | | |
| Windowpane flounder | 2,8,1,2,0,1 | | X | | |
| Grubby sculpin | 5,6,2,5,0,1 | | X | | |
| Longhorn sculpin | 5,6,2,5,0,4 | | X | | |
| Shorthorn sculpin | 5,6,2,5,0,8 | | X | | |
| Lumpfish | 5,8,0,5,0,1 | | X | | |
| Seasnail (L. atlanticus) | 5,8,0,7,0,1 | | X | | |
| Gulf seasnail (L. coheni) | 5,8,0,7,1,0 | | X | | |
| Four-beard rockling | 7,7,0,5,0,1 | | X | | |
| Silver hake | 7,7,0,9,0,1 | | X | | |
| Smelt | 1,2,7,0,4,0,1 | | X | | |
| Rock gunnell | 1,3,6,0,2,0,5 | | X | | |
| Witch Flounder | 1,3,7,0,4,0,1 | | X | | |
| Plaice | 1,3,7,0,5,0,2 | | X | | |
| Redfish | 1,5,9,0,6,0,0 | | X | | |
| Radiated shanny (Ulvaria) | 1,6,9,1,8,0,1 | | X | | |
| Osteichthyes | 2,0,0,0,0,0,0 | | X | | |
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Figure VA,2.1-3. Ichthyoplankton Larvae.

## TABLE VA,2.1-3. DATA CODING SPECIFICATIONS

YEAR: * PROJECT NAME: Seabrook DATA TYPE: Ichthyoplankton
MAJOR: * LABOR ACTIVITY: 261 CODING FORM: PL-1 (Eggs), PL-3 (Larvae)

| FIELD | PRECODED | BLANK | CODED | ACCEPTABLE CODES | COMMENTS |
|---|---|---|---|---|---|
| Project | | | x | Integers | Seabrook Laboratory current year project number |
| Method (Ichthyoplankton only) | | | x | IE, IL | Ichthyoplankton eggs, Ichthyo-plankton Larvae (oblique, 1-m net, 505 μm mesh) |
| Sample Period Date | | | x | 01-48 Integers | 4 times per month Month/Day/Year |
| Station (Ichthyoplankton only | | | x | P2, P7 | Seabrook Plankton Stations |
| Replicate (Ichthyoplankton only) | | | x | Integers | Only A is processed; B is a contingency replicate |
| Sample Control No. | | | x | Integers | NAI Sample Control Number |
| Scaling Ratio | | | x | | Reciprocal of fraction analyzed (first split sorted), in tenths (if ⅛ of sample is analyzed then split sorted=8.0). Repeat for last split sorted. If no additional splits are sorted, draw a line through last split sorted box. Scaling ratio=first split sorted (if last split sorted is blank) or scaling ratio=1/2 last split sorted (if more than one split was sorted). |
| Split for volume | | | x | 1, blank | 1 = sample split for volume due to large amount of sample quotas not filled, scaling ration ≠ 1.0<br><br>blank = sample processed in the normal way. |

**TABLE VA,2.1-3. DATA CODING SPECIFICATIONS** (Continued)

YEAR: * PROJECT NAME: Seabrook DATA TYPE: Ichthyoplankton
MAJOR: * LABOR ACTIVITY: 261 CODING FORM: PL-1 (Eggs), PL-3 (Larvae)

| FIELD | PRECODED | BLANK | CODED | ACCEPTABLE CODES | COMMENTS |
|---|---|---|---|---|---|
| Species | | | x | Alphabetic | For QC purposes, not keypunched |
| Species Code | | | x | Integers | NNAS Code |
| Lifestage | | | | | E = no eggs, V = void sample |
| Condition (eggs only) | | | x | E, V | |
| Condition (larvae only) | | | x | E, V, D, X | E = no larvae, V = void sample, D = no length due to damage, X = no length for other reason (>30 in sample, or lengths not required for this species or sample) |
| Count | | | x | | Blank if condition = V |
| Length (larvae only) | | | x | | SL in tenths of millimeters (e.g., 5.6 mm = 56) for selected species only, blank if condition = V, E, D or X |

*Refer to current year project code as specified by project management.

Page 1 Of 1

## ENTRAINMENT ICHTHYOPLANKTON - EGG

Analyzed By: ______________________ Date: __________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | STATION | REP | SAMPLE CONTROL No. |
|---|---|---|---|---|---|---|
| | E E | | | | | |

| SCALING RATIO | SPLIT FOR VOLUME |
|---|---|
| .0 | |

| SPECIES NAME | SPECIES CODE | LIFE STAGES | COND. | COUNT/PCNT |
|---|---|---|---|---|
| Empty Sample | 1 | | E | |
| Windowpane flounder | 281201 | | | |
| Atlantic Menhaden | 520204 | | | |
| Four-beard rockling | 770501 | | | |
| Atlantic Cod | 770602 | | | |
| Silver hake | 770901 | | | |
| Pollock | 771201 | | | |
| Hake species | 771500 | | | |
| Tautog | 951001 | | | |
| Cunner | 951101 | | | |
| Witch Flounder | 1370401 | | | |
| Plaice | 1370502 | | | |
| Yellowtail flounder | 1371002 | | | |
| Atlantic Mackerel | 1570602 | | | |
| Labridae/Limanda | 9990001 | | | |
| Cod/Haddock | 9990002 | | | |
| Cod/Haddock/Witch | 9990010 | | | |
| Rockling/Hake | 9990012 | | | |
| Osteichthyes | 2000000 | | | |
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Figure VA, 2.1-4.

## ENTRAINMENT ICHTHYOPLANKTON LARVAE

Page 1 Of 1

Analyzed By: ____________________ Date: ____________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | STATION | REP | SAMPLE CONTROL No. |
|---|---|---|---|---|---|---|
| | E L | | | | | |

| SCALING RATIO | SPLIT FOR VOLUME |
|---|---|
| .0 | |

| SPECIES NAME | SPECIES CODE | LIFE STAGES | COND | COUNT | LENGTH |
|---|---|---|---|---|---|
| Empty Sample | 1 | | E | | |
| Alligator fish | 3,0,4,0,2 | | X | | |
| American eel | 1,1,0,1,0,1 | | X | | |
| Windowpane flounder | 2,8,1,2,0,1 | | X | | |
| Grubby sculpin | 5,6,2,5,0,1 | | X | | |
| Longhorn sculpin | 5,6,2,5,0,4 | | X | | |
| Shorthorn sculpin | 5,6,2,5,0,8 | | X | | |
| Lumpfish | 5,8,0,5,0,1 | | X | | |
| Seasnail (L. atlanticus) | 5,8,0,7,0,1 | | X | | |
| Gulf seasnail (L. coheni) | 5,8,0,7,1,0 | | X | | |
| Four-beard rockling | 7,7,0,5,0,1 | | X | | |
| Silver hake | 7,7,0,9,0,1 | | X | | |
| Smelt | 1,2,7,0,4,0,1 | | X | | |
| Rock gunnell | 1,3,6,0,2,0,5 | | X | | |
| Witch Flounder | 1,3,7,0,4,0,1 | | X | | |
| Plaice | 1,3,7,0,5,0,2 | | X | | |
| Redfish | 1,5,9,0,6,0,0 | | X | | |
| Radiated shanny (Ulvaria) | 1,6,9,1,8,0,1 | | X | | |
| Osteichthyes | 2,0,0,0,0,0,0 | | X | | |
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Figure VA, 2.1-5.

**TABLE VA,2.1-4. DATA CODING SPECIFICATIONS**

YEAR: * PROJECT NAME: Seabrook DATA TYPE: Entrainment Ichthyoplankton
MAJOR: * LABOR ACTIVITY: 521 CODING FORM: PL-1 (Eggs), PL-3 (Larvae)

| FIELD | PRECODED | BLANK | CODED | ACCEPTABLE CODES | COMMENTS |
|---|---|---|---|---|---|
| Project | | | | Integers | Seabrook Laboratory current year project number |
| Method | | | | EE<br>EL | Entrainment eggs, Entrainment Larvae |
| Mesh | | x | | | Oblique, 1-m net, 505 µm mesh; 333 µm mesh |
| Sample Period | | | x | 01-48 | 4 times per month |
| Date | | | x | Integers | Month/Day/Year |
| Station | | | x | EL | |
| Replicate | | | x | 1,2,3,4 | |
| Sample Control No. | | | x | Integers | NAI Sample Control Number |
| Scaling Ratio | | | x | | Reciprocal of fraction analyzed (first split sorted), in tenths (if ⅛ of sample is analyzed then split sorted=8.0). Repeat for last split sorted. If no additional splits are sorted, draw a line through last split sorted box. Scaling ratio=first split sorted (if last split sorted is blank) or scaling ratio=1/2 last split sorted (if more than one split was sorted). |
| Split for Volume | | | x | 1, blank | 1 = sample split for volume due to large amount of sample quotas not filled, scaling ration ≠ 1.0<br><br>blank = sample processed in the normal way. |

**TABLE VA,2.1-4. DATA CODING SPECIFICATIONS (continued)**

YEAR: * PROJECT NAME: Seabrook DATA TYPE: Entrainment Ichthyoplankton
MAJOR: * LABOR ACTIVITY: 521 CODING FORM: PL-1 (Eggs), PL-3 (Larvae)

| FIELD | PRECODED | BLANK | CODED | ACCEPTABLE CODES | COMMENTS |
|---|---|---|---|---|---|
| Species | | | x | Alphabetic | For QC purposes, not keypunched |
| Species Code | | | x | Integers | NNAS Code |
| Lifestage | | | | | |
| Condition (eggs only) | | | x | E,V | E = no eggs, V = void sample |
| Condition (larvae only) | | | x | E,V,D,X | E = no larvae, V = void sample, D = no length due to damage, X = no length for other reason (>30 in sample, or lengths not required for this species or sample) |
| Count | | | x | | Blank if condition = V |
| Length (larvae only) | | | x | | SL in tenths of millimeters (e.g., 5.6 mm = 56) for selected species only, blank if condition = V, E, D or X |

*Refer to current year project code as specified by project management.

## BIVALVE LARVAE

VA-21
Rev. 5
Change 0
4/1/99

Analyzed By: ____________ Project: ____________ Page 1 Of 1

Analyzed On: ____________ Time: ____________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | PHOTO PERIOD | TIDE | STATION | DEPTH CODE | DEPTH | REP |
|---|---|---|---|---|---|---|---|---|---|
| | B L | | | | | P | | | |

| SAMPLE CONTROL No. | TIME | FIELD VOLUME | SUB-SAMPLE OF No. OF SUBSAMPLES | TYPE |
|---|---|---|---|---|
| | | | | A |

| | SPECIES NAME | SCALING RATIO | SPECIES CODE | LIFE STAGES | COND. | COUNT/PCNT |
|---|---|---|---|---|---|---|
| 1/2 | Heteranomia squamula | | 0,0,0,0,1,9,3 | | | |
| | Bivalvia | | 0,0,0,1,2,0,2 | | | |
| | Hiatella sp. | | 0,0,0,0,2,0,7 | | | |
| 1/16 | Macoma Balthica | | 0,0,0,5,2,1,3 | | | |
| | Modiolus modiolus | | 0,0,0,0,1,8,6 | | | |
| | Mya arenaria | | 0,0,0,0,2,0,5 | | | |
| | Mya truncata | | 0,0,0,0,2,0,6 | | | |
| | Mytilus edulis | | 0,0,0,0,1,8,3 | | | |
| 1/128 | Placopecten magellanicus | | 0,0,0,0,1,9,2 | | | |
| | Solenidae | | 9,0,1,7,0,0,1 | | | |
| | Spisula solidissima | | 0,0,0,0,2,0,0 | | | |
| | Teredo navalis | | 0,0,0,4,5,9,9 | | | |
| 1/1024 | | | | | | |

bilarv.ai 12/13/96

Figure VA,2.4-1.

**TABLE VA,2.4-1. DATA CODING SPECIFICATIONS**

Bivalve Larvae and Bivalve
YEAR: * PROJECT NAME: Seabrook DATA TYPE: Larvae Entrainment

MAJOR: * LABOR ACTIVITY: 264/573 CODING FORM: PL-1

| FIELD | PRECODED | BLANK | CODED | ACCEPTABLE CODES | COMMENTS |
|---|---|---|---|---|---|
| Project | | | x | Integers | Seabrook Laboratory current year project number |
| Method | x | | | BL | Bivalve larvae tows |
| Sample Period | | | x | 01-29 | Weekly Apr-Oct |
| Date | | | x | Integers | Month/Day/Year |
| Photoperiod | | x | | | |
| Tide | | x | | | |
| Station | | | x | P2,P7, PE | Bivalve larvae tows Entrainment samples |
| Depth Code | | | x | 3,6 | 3=oblique, 6=vertical |
| Depth | | x | | | |
| Replicate | | | x | A,B | |
| Sample Control | | | x | Integers | NAI Sample Control Number |
| No. | | x | | | |
| Time | | x | | | |
| Field Volume | | x | | | Two aliquots are analyzed (one, if densities are low), but not coded separately |
| Subsample | | | | | |
| | | x | | | |
| # of Subsamples | x | | | A | All taxa |
| Type | | | | | |

*Refer to current year project code as specified by project management.

# SECTION I
# SAMPLE AND DATA MANAGEMENT SYSTEMS

## 2.0 SAMPLE AND DATA MANAGEMENT SYSTEMS

## 2.1 SAMPLE MANAGEMENT SYSTEM

The Biological Laboratory sample management system consists of three phases: 1) receiving of samples as they are delivered from the field; 2) storage of samples prior to, during and immediately after analysis; and 3) archiving of completed samples for a time period specified by the client. The objective of this system is to track a sample through all phases of its processing in order to facilitate efficient analysis of the sample, quality control and budgetary tracking.

### 2.1.1 Receiving of Samples

1. Samples are delivered with a completed and signed "Field Card/Sample Submittal Form" (Figure I,2.1-1).
2. Person receiving samples acknowledges reception of samples on submittal form after checking and approving:
    a. That the submittal form is completely filled out.
    b. That all samples listed have been received.
    c. That the condition of the samples (including preservation, if appropriate) is satisfactory.
    d. That all samples are properly labeled.
3. If the condition of one or more of the samples is unsatisfactory, the project manager is to be notified and a replacement taken as soon as possible.
4. A photocopy of the submittal form is made and filed in the generators file.
5. When a sample or portion of sample is transferred to another department it must be accompanied by the original of the submittal form.
6. The sample information is logged in the appropriate departmental log.

# SECTION VI
# PLANKTON SAMPLE PROCESSING

## 1.0 INTRODUCTION

The Plankton Department routinely analyzes samples from marine, estuarine, and fresh waters. Generally, five categories of samples are processed: 1) Macrozoo-Ichthyoplankton (including epibenthic macrozooplankton); 2) Microzooplankton; 3) Whole Water Phytoplankton; 4) Bivalve Larvae; and 5) Neuston. Macrozoo-ichthyoplankton sample analysis is further separated into three phases: 1) Copepods; 2) Ichthyoplankton and 3) Macrozooplankton. Neuston samples are separately analyzed for lobster larvae and ichthyoneuston. The procedures for these analyses are found in this section.

## 2.0 SAMPLE PROCESSING

### 2.1 MACROZOO-ICHTHYOPLANKTON SAMPLES

Macrozoo-ichthyoplankton samples are processed according to the scheme presented in Figure VI,2.1-1.

#### 2.1.1 Copepod Analysis

The objective of the copepod analysis is to identify and enumerate the calanoid copepods collected in a macrozoo-ichthyoplankton sample. The analysis is performed on a Stempel pipette subsample in the following manner. If, however, the number of copepods is unusually low, subsampling for copepods can be done by Folsom plankton splitter instead (Section 2.1.2.2), and then continuing with Step 6 below.

1. Rinse the 5% formalin from the sample through a clean ≤505-µm mesh net into a holding jar under a working hood.
2. Transfer the complete sample to a calibrated sample jar using a minimal amount of water.
3. Dilute sample by adding water, or concentrate sample to a level indicated on the calibrated jar to yield between 150 and 200 copepods per 1-ml subsample.
   a. Record the (working) sample volume on the data sheet.
4. Mix sample thoroughly by moving a Stempel pipette in a figure-eight pattern.
5. Extract a 1-ml subsample with a Stempel pipette.
6. Put subsample into a Wards® counting wheel.
7. Place counting wheel on a dissecting microscope for identification and enumeration.
8. Count and identify calanoid copepods. Do not count "empty" copepods (exuviae). If minimum count criteria are not met (refer to project SOP), repeat Steps 4 through 8 until these criteria are met and record the number of 1-ml subsamples extracted on the

Plankton Count Form (Figure VI,2.1-2). (A complete subsample must be counted even though the criteria have been met before its completion.)

9. When sample is completed:
   a. Calculate scaling ratio from sample volume and sub-sample size and record on Plankton Count Form (Figure VI,2.1-2). (Scaling ratio = sample volume in ml divided by number of 1-ml subsamples examined.)
   b. Record counts for each taxon (sum for all subsamples examined) on Plankton Count Form.
   c. Transcribe sample identification information from the original sample jar onto the Plankton Count Form, following project coding specifications (refer to project SOP), and initial and date the form. File in the project file with copepod data.
   d. Log completion of each sample in the Quality Control Log (Figure I,3.2-2).
   e. Recombine copepod subsamples with the original sample.
   f. Log completion of each sample in Plankton Sample Control Log (Figure VI,2.1-3), as described in Section I,2.1.1.
   g. Represerve macrozoo-ichthyoplankton sample in 6% buffered formalin and place on shelf to await ichthyoplankton sort.
   h. Notify alternate taxonomist to keep quality control up to date.

### 2.1.2 Ichthyoplankton Analysis

The objective of the Ichthyoplankton analysis is to identify and enumerate the fish eggs and larvae collected in a macrozoo-ichthyoplankton sample. The analysis is performed in the following manner:

#### *2.1.2.1 Ichthyoplankton Sorting*

1. After the sample information has been logged as described in Section I,2.1.1, rinse the 6% formalin from the sample through a clean 0.333 mm mesh net or sieve into a holding jar under a working hood, and retain formalin for future represervation.
2. Replace the rinsed sample back into the original sample jar using enough water to yield a fluid mixture.
3. Split sample in Folsom splitter as described in Section VI,2.1.2.2 so that the smallest split contains the minimum number of eggs or larvae required for the analysis (refer to project SOP for count criteria).
4. Begin sorting with the smallest aliquot:
   a. Place a workable amount of the sample in a gridded petri dish under a dissecting microscope.
   b. Remove eggs and larvae with forceps or pipette and place in vials.
   c. Enumerate eggs and larvae separately on tabulator as they are removed.
   d. Reserve sorted portion of sample.
   e. Repeat Steps 4a through 4d until aliquot is completely sorted.
   f. Label the sorted portion with the size (fraction) of the split.

5. Continue to sort successively larger splits by the procedure in Step 4 removing eggs or larvae or both until the minimum count criteria have been met. When the mini-mum count is reached partway through a split, continue to sort until that split is completely sorted.
6. When sorting is completed, retain the fractions of the sample in separate jars:
   a. Sorted for both eggs and larvae
   b. Sorted for eggs only
   c. Sorted for larvae only
   d. Not sorted
7. Preserve the eggs and larvae with 6% buffered formalin, insert inside label and place outside label on cap.
8. Record date of completion and sorters initials in Plankton Sample Log (Figure VI,2.1-4) and in the Quality Control Log (Figure I,3.2-1).
9. If the sample is a quality control check and cannot be analyzed immediately, preserve the sample fractions from Step 6 with 6% buffered formalin, and label each jar with sample number, station, replicate, split fraction, and life stage(s) removed from that fraction.
10. After quality control check is completed, recombine all split fractions into original sample by rinsing through a .505-mm mesh net.
11. Represerve in original formalin.
12. Place sample on shelf to await further analysis or storage.
13. Place vials of eggs and larvae in temporary storage location for identification at a later time by taxonomists.
14. File plankton count form in the project file with ichthyoplankton data.

*2.1.2.2 Ichthyoplankton and Macrozooplankton Subsampling*

1. Level Folsom plankton splitter.
2. Rinse splitter thoroughly before use.
3. Place approximately 500 ml or less of the sample in splitter.
4. Rotate splitter six or more times to assure equal separation.
5. Pour into two receiving trays being careful not to com-bine any portion of the splits.
6. Repeat Steps 3 through 5 until entire sample is split.
7. With a flip of a coin, determine which half is to be split further. Continue splitting one half until a workable amount of sample is obtained.

   i.e., 1 Ý 1/2 Ý 1/4 Ý 1/8 Ý 1/16 Ý etc.
   1/2 Ý 1/4 Ý 1/8 Ý 1/16
8. Place splits in jars marked 1/2, 1/4, 1/8, 1/16, etc.
9. Rinse splitter thoroughly when finished.

#### 2.1.2.3 *Ichthyoplankton Identification*

1. Transfer eggs and larvae to water in petri dish.
2. Using a dissecting microscope, identify all eggs and larvae to lowest practical taxon and count them. Do not count empty egg membranes.
3. Measure larvae. Refer to project SOP for which species to measure and type of measurement used.
4. Header information: project number, sample number, station, replicate, sample period, method, collection date, split information, scaling ratio and counts (if no eggs or larvae were found enter zero).
5. Record species, length and counts on Ichthyoplankton Lab Data Sheet (Figure VI,2.1-5) along with taxonomist's initials and date completed, following project coding specifications (refer to project SOP).
6. Record completion of sample in Plankton Sample Log (Figure VI,2.1-4) and in Quality Control Log (Figure I,3.2-2). Record Quality Control results on the Quality Control Worksheet (Figure I, 3.2-3).
7. Return larvae and eggs to original vials in 6% buffered formalin.
8. Place vials on shelf to await quality control check.
9. File Plankton Count Form and Count/Length Form in the project file with ichthyoplankton data.

### 2.4 BIVALVE LARVAE SAMPLES

Bivalve larvae are temporarily preserved in approximately 1% formalin and approximately 1 ml (1/8 to 1/4 teaspoon) each of borax and sugar per liter. Since they are in a weak preservative they must be refrigerated until analysis. Since color is a key characteristic and the sample will deteriorate with time, they must be analyzed as soon as possible, but may be held up to a week if necessary.

1. Remove sample jar from refrigerator and pour contents through a ≤76 µm mesh sieve. Discard filtrate into appropriate waste container. Rinse sample from sieve into a 1000-ml beaker.
2. Swirl contents of beaker and allow the bivalve larvae and residue (i.e.: copepods and other plankton) to settle to the bottom. Sand and bivalve larvae will settle first, residue will settle on top of bivalve larvae.
3. Carefully pour supernatant and residue into another 1000_ml beaker. Rinse bivalve larvae and sand (if any) into a petri dish.
4. Remove bivalve larvae remaining in the residue by:
   a. swirling residue and supernatant, allowing bivalve larvae to settle to the bottom of the beaker and removing them with a pipette or;
   b. carefully discarding the supernatant, pouring the residue into a petri dish (by portions as necessary) and swirling the petri dish to concentrate bivalve larvae in the center where they can be removed with a pipette.

Method 4a is generally quicker in samples containing a large amount of debris and residue.

5. Continue removal process until about 99% of the larvae have been extracted. Discard the residue.
6. After all larvae are removed from the residue, swirl dish on a flat surface in a circular motion causing larvae to collect in a circular mass in the center of the petri dish.
7. If there are fewer than 600 larvae, analyze the whole sample.
8. Samples containing more than 600 larvae should be split into equal halves. Each half should then be serially split. To serially split each half sample:
   a. swirl the dish to concentrate larvae in a circular pile;
   b. divide the pile to the 1/2, 1/4 or 1/8 fraction using a bivalve probe (camel hair in a glass pipette) or a razor blade and; if necessary, remove the 1/8 portion to another petri dish and repeat steps a and b until a subsample of 150 to 300 bivalve larvae is attained.
9. Record the split factors by shading the appropriate fraction of the data sheet splitting symbol during each stage of splitting. The scaling ratio represents the fraction of the entire sample that was analyzed; the sum of the two split factors (i.e.; in a sample where each half was split to a 1/32, the scaling ratio would be 1/32 + 1/32 = 1/16).
10. Identify and enumerate the bivalve larvae from each split.
    a. Do not count shells which are empty of cytoplasm.
    b. If two taxonomists are available, it is recommended that each analyze a replicate from each station.
11. After identification of the fractions:
    a. Complete the header information and record the counts and scaling ratios on the Plankton Count Form (Figure VI,2.1-2) following project coding specifications (refer to project SOP) including the taxonomist's initials and date completed. If two counts are made per sample, record in the margin and combine in count column.
    b. Log completion of each sample in the Plankton Sample Control Log (Figure VI,2.1-3) as described in Section I,2.1.1 and in the Quality Control Log.
    c. Determine if sample is a QC. If so, have alternate taxonomists immediately do a QC.
    d. Recombine the sample into a vial containing 3% borax buffered formalin.
    e. File the plankton count form in the project file with bivalve larvae data.

# 3.0 QUALITY CONTROL

Sorting and identification tasks for macrozoo-ichthyoplankton and identification for bivalve larvae (sorting does not apply to bivalve larvae samples) are subject to quality control checks consisting of reanalysis of randomly selected samples. Samples are inspected using a quality control (QC) procedure derived from MIL-STD (military-standard) 1235B (single and multiple level continuous sampling procedures and tables for inspection by attributes) to achieve a 10 percent or better AOQL (Average Outgoing Quality Limit). QC checks are performed by Senior Taxonomists. The QC procedure used is the CSP-1 continuous sampling plan, which is conducted in two modes as follows:

- *Mode 1.* Reinspect one hundred percent of the samples until "i" consecutive samples pass.
- *Mode 2.* After "i" consecutive samples pass QC reinspection, randomly choose (using a random numbers table) the fraction "f" of the samples for reinspection. If any QC sample fails then return to Mode 1.

For this application of CSP-1, **i=10** and **f=1/10**, because the total number of samples analyzed by an individual was more than 500. QC inspections are performed as soon as possible after the original analysis. Keeping the QC program as current as possible insures that problems are detected and remedied quickly, minimizing the additional number of samples that are analyzed before the problem is addressed. Samples for reanalysis are selected using a random number table. The original analyzer does know whether a sample is to be checked before the analysis of that sample has been completed. All quality control checks are performed "blindly" (i.e., the individual performing the QC inspection had no knowledge of the original analyst's results prior to their completion of the reinspection). The QC plan is applied on an individual processor basis, so that each person's work is subjected to the QC plan independently of others, starting at 100% inspection. A resolution (third person) value may be determined for any sample found defective.

For the task of sorting, a sample is considered defective if the sorter fails to remove 10 percent of the total organisms in the sample (or subsample). Percent error is calculated as follows (where "QC count" denotes the number missed by the sorter):

$$\% \text{ error} = 100\% \times \text{QC count}/(\text{sorter's count} + \text{QC count})$$

When the total count (sorter's plus QC) is ≤20, then the sample is considered defective only if the sorter missed more than two organisms.

For the task of identification, a sample is considered defective if an error of 10 percent or more is made in identifying, assigning a life stage, or counting any species. In determining whether a sample is defective, analyzer and QC results are compared within each taxon/life stage combination. For each taxon (or for a life stage within a taxon) the percent error is calculated as follows (except where the QC count is ≤20, the percent error is considered to be zero if analyzer and QC counts differ by no more than two organisms):

$$\% \text{ error} = 100\% \times |\text{analyzer count} - \text{QC count}|/\text{QC count}$$

A sample with a percent error of greater than or equal to 10% for any life stage for any taxon is considered defective.

For each defective sample, a resolution could be determined in which a third person reanalyzes the sample (resolution value). The error for each species and life stage is then calculated using the resolution counts as the divisor. This was done for both identification and QC counts:

$$\% \text{ error} = 100\% \times |\text{identifier count} - \text{resolution count}| / \text{resolution count}$$

$$\% \text{ error} = 100\% \times |\text{QC count} - \text{resolution count}| / \text{resolution count}$$

If the resolution vs. identifier error is <10 percent, the sample passed. If they are not, the sample failed and identifier counts were replaced by QC counts for all cases, provided the QC vs. resolution error is <10 percent.

# FIELD CARD / SAMPLE SUBMITTAL FORM

Project ______ Date ______ Sampling Period ______

Tide ____ Collectors ______________________

| Sample Number | Task | Sample Type | Collect Method | Collect Time | Station | Depth Meters | Rep. No. | Sample Status | Sample Size / # Cont. | Sample Reading | | |
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Delivered by: ____________ Date: ________ Received by: ____________ Date: ________

Received at: ____________

SAM 10_side 1.ai

Figure I.2.1-1. Field card/sample submittal form. side 1 of 2

| PLANKTON PUMP CALIBRATION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pump No | Volume | Time | Pump No | Volume | Time | Pump No | Volume | Time |
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Comments: ______________________________________________

Laboratory Instructions: ______________________________________________

Side 2
Form SAM-10
Rev. 1/7/91

Figure I,2.1-1. (continued)

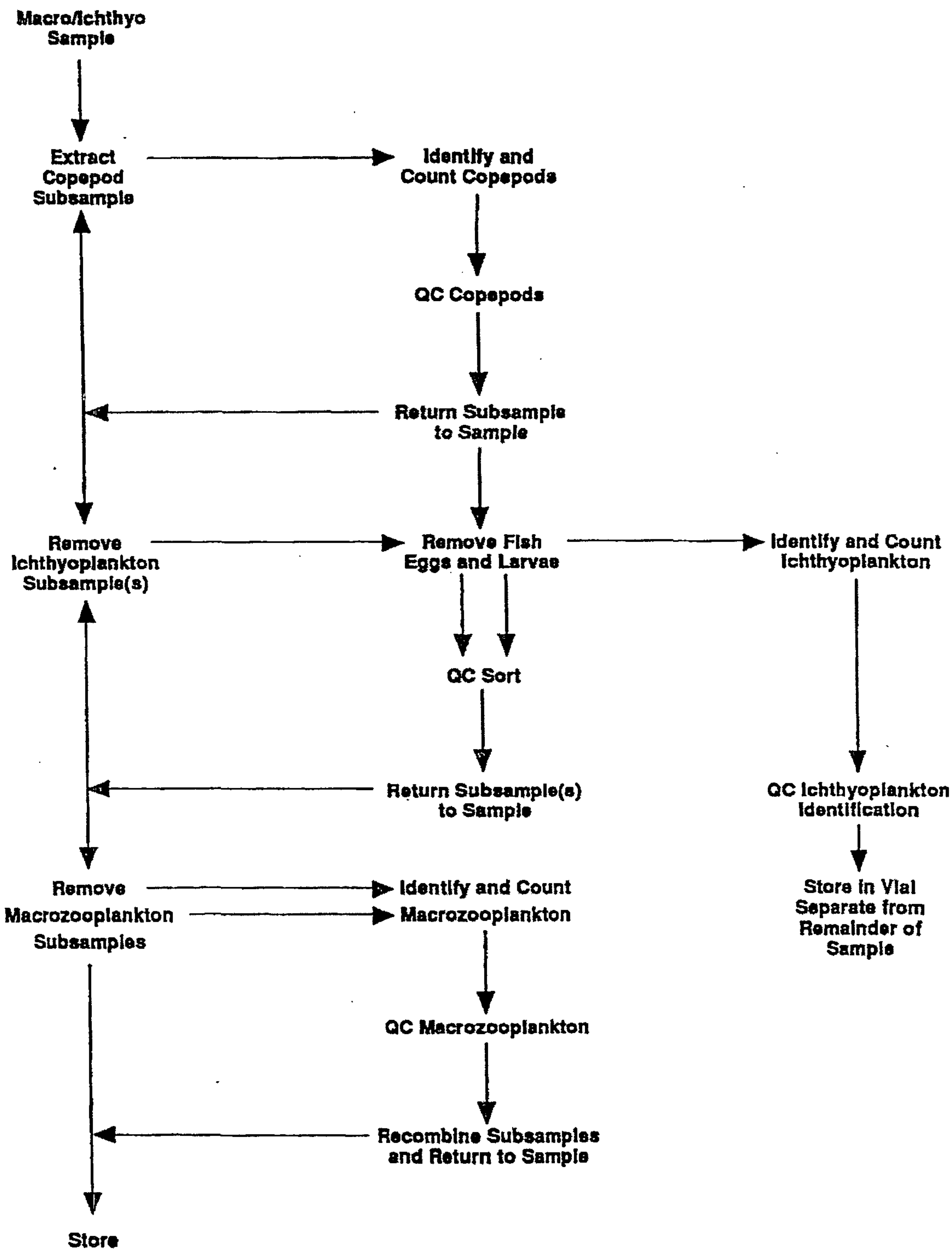


Figure VI,2.1-1. .................................. General Procedure for analysis of macro/ichthyoplankton samples

## PLANKTON COUNT FORM

Analyzed By: ______________ Project: ______________ Page ____ Of ____

Analyzed On: ______________ Time: ______________

| PROJECT | METHOD | SAMPLE PERIOD | DATE | PHOTO PERIOD | TIDE | STATION | DEPTH CODE | DEPTH | REP |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

| SAMPLE CONTROL No. | TIME | FIELD VOLUME | SUB-SAMPLE | OF | No. OF SUBSAMPLES | TYPE |
|---|---|---|---|---|---|---|
| | | | | OF | | |

| SPECIES NAME | SCALING RATIO | SPECIES CODE | LIFE STAGES | COND. | COUNT/PCNT |
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mz1-1.ai 12/10/96

Figure VI,2.1-2. ........................................................................ Plankton count Form.

Page _____

# Quality Control Log: Ident

Project
Name: ____________________
Code: ____________________
Year: ____________________

Taxonomist: ____________________

| Sample No. | | Ident Date | Qc'er | | Results | | Comments |
|---|---|---|---|---|---|---|---|
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QC Log-Ident 9/9/05

Figure I, 3.2-2. ........................................................................................ Quality Control Log: Ident.

## SAMPLE CONTROL SHEET

**SAMPLE TYPE:** ______________________________

| SAMPLE No. | DATE TAKEN | STATION | | | | |
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Figure VI,2.1-3. .................................................................................................... Sample Control Sheet.

Figure VI, 2.1-4........................................ Plankton Count Form (PL)

# Sample Log: Plankton

Page: ______

Project Name: ____________________

Code: ____________________

Year: ____________________

| SP | Sample No. | Collection Date | Station | Sort | | | Scaling Ratio | | | Vol. Split | Vials | | | ID | | | Date to DP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Initials | Date | Hours | E | L | | | E | L | | Initials | Date | Hours | |
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PlanktonSampleLog.a1 10/25/07

## Quality Control Log: Sort

**Project Name:** ____________________

**Code:** ____________________

**Year:** ____________________

**Sorter:** ____________________

| Sample No. | | Qc'er | | Counts | | | Results | | Comments |
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| | | Name | Date | Orig | QC | Total | % Diff | P/F | |
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QC Log-Sort.doc 4/18/05

Figure I,3.2-1. Quality Control Log: Sort.

## Plankton Count Form

PAGE 1 OF ___

**Project Name:** __________ **Project No:** __________ **Plant:** __________

SAMPLE [ ] CARD TYPE [L 1] CATCH_CD [ ] ANALYZED BY: __________ DATE: __________ NO. VIALS: _____

| SPL_FACT | TAXON | STAGE | COUNT | SPECIES NAME |
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STAGE CODES
0 = unknown
1 = egg
2 = yolk-sac larva
3 = post yolk-sac larva
4 = young-of-the-year
5 = yearling or older

SAMPLE [ ] CARD TYPE [L 2] CONVERSION FACTOR [ . ]

| TAXON | | STAGE | | TAXON | | STAGE | | TAXON | | STAGE | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE MEASUREMENT | | SCALE MEASUREMENT | | SCALE MEASUREMENT | | SCALE MEASUREMENT | | SCALE MEASUREMENT | | SCALE MEASUREMENT | |
| 1 | . | 11 | . | 1 | . | 11 | . | 1 | . | 11 | . |
| 2 | . | 12 | . | 2 | . | 12 | . | 2 | . | 12 | . |
| 3 | . | 13 | . | 3 | . | 13 | . | 3 | . | 13 | . |
| 4 | . | 14 | . | 4 | . | 14 | . | 4 | . | 14 | . |
| 5 | . | 15 | . | 5 | . | 15 | . | 5 | . | 15 | . |
| 6 | . | 16 | . | 6 | . | 16 | . | 6 | . | 16 | . |
| 7 | . | 17 | . | 7 | . | 17 | . | 7 | . | 17 | . |
| 8 | . | 18 | . | 8 | . | 18 | . | 8 | . | 18 | . |
| 9 | . | 19 | . | 9 | . | 19 | . | 9 | . | 19 | . |
| 10 | . | 20 | . | 10 | . | 20 | . | 10 | . | 20 | . |

LabL1.ai 7/05

Figure VI,2.1-5. ............................................................ Plankton Count Form, Side One.

## Plankton Count Form

PAGE ___ OF ___

**Project Name:** ____________________ **Project No:** ____________ **Plant:** __________

SAMPLE [ ] CARD TYPE [ L 2 ]

STAGE CODES
0 = unknown
2 = yolk-sac larva
3 = post yolk-sac larva
4 = young-of-the-year
5 = yearling or older

TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
|---|---|---|---|---|---|
| 1 | | | 11 | | |
| 2 | | | 12 | | |
| 3 | | | 13 | | |
| 4 | | | 14 | | |
| 5 | | | 15 | | |
| 6 | | | 16 | | |
| 7 | | | 17 | | |
| 8 | | | 18 | | |
| 9 | | | 19 | | |
| 10 | | | 20 | | |

TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
|---|---|---|---|---|---|
| 1 | | | 11 | | |
| 2 | | | 12 | | |
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| 4 | | | 14 | | |
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| 6 | | | 16 | | |
| 7 | | | 17 | | |
| 8 | | | 18 | | |
| 9 | | | 19 | | |
| 10 | | | 20 | | |

TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
|---|---|---|---|---|---|
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| 3 | | | 13 | | |
| 4 | | | 14 | | |
| 5 | | | 15 | | |
| 6 | | | 16 | | |
| 7 | | | 17 | | |
| 8 | | | 18 | | |
| 9 | | | 19 | | |
| 10 | | | 20 | | |

TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
|---|---|---|---|---|---|
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| 2 | | | 12 | | |
| 3 | | | 13 | | |
| 4 | | | 14 | | |
| 5 | | | 15 | | |
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| 8 | | | 18 | | |
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TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
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| 2 | | | 12 | | |
| 3 | | | 13 | | |
| 4 | | | 14 | | |
| 5 | | | 15 | | |
| 6 | | | 16 | | |
| 7 | | | 17 | | |
| 8 | | | 18 | | |
| 9 | | | 19 | | |
| 10 | | | 20 | | |

TAXON [ ] STAGE [ ]

| | SCALE | MEASUREMENT | | SCALE | MEASUREMENT |
|---|---|---|---|---|---|
| 1 | | | 11 | | |
| 2 | | | 12 | | |
| 3 | | | 13 | | |
| 4 | | | 14 | | |
| 5 | | | 15 | | |
| 6 | | | 16 | | |
| 7 | | | 17 | | |
| 8 | | | 18 | | |
| 9 | | | 19 | | |
| 10 | | | 20 | | |

LabL2.ai 7/05

Figure VI,2.1-5. Plankton Count Form, Side Two

## Quality Control Worksheet

Project Name ______________________ Project Code ____________

Sample ______________________ Date ____________

Sorter/Taxonomist ______________________ Date ____________

QC by ______________________ Date ____________

Resolution by ______________________ Date ____________

- ☐ PASS with no Changes made to original data
- ☐ PASS WITH DISCREPANCIES with Corrections made to original data
- ☐ FAIL with Corrective action taken

Action taken: ______________________

______________________

Signature ______________________ Date ____________

| Categories | | Data | QC | | Resolution | | Results | | | Data Correction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Orig. | QC | % Diff. | Resolv. | % Diff. | Pass | Discrp. | Fail | |
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Quality Control Worksheet.doc 12/11/03

Figure I, 3.2-3. ................................................................ Quality Control Worksheet.

# APPENDIX F

## Results of Annual Impingement and Entrainment Monitoring Programs

**Appendix Table F-1. Annual Estimated Numbers of Fish Eggs Entrained (in millions) by the Cooling Water System at Seabrook Station from 1995 through 2006 (NAI 2007).**

**Eggs**

| TAXON | 1995[f] | 1996[f] | 1997[f] | 1998[f] | 1999[f] | 2000[f] | 2001[f] | 2002[f] | 2003[f] | 2004[f] | 2005[f] | 2006[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American plaice | 14.8 | 78.2 | 15.6 | 13.7 | 24.8 | 16.7 | 26.8 | 22.4 | 37.8 | 33.4 | 11.7 | 5.27 |
| Atlantic cod | 2.2 | 8.1 | 2.9 | 8.4 | 5.3 | 2.9 | 11.0 | 13.4 | 7.9 | 2.9 | 4.4 | 8.23 |
| Atlantic cod/haddock | 2.2 | 1.4 | 0.2 | 0.3 | 0.4 | 1.6 | 0.1 | 0.2 | 0.4 | 0.8 | 0.9 | 0.80 |
| Gadid/witch flounder | 32.6 | 47.2 | 8.9 | 77.3 | 47.2 | 59.0 | 21.0 | 67.4 | 11.2 | 15.6 | 12.8 | 11.10 |
| Atlantic mackerel | 74.5 | 305.1 | 23.1 | 39.3 | 44.6 | 266.9 | 330.4 | 56.7 | 26.4 | 71.3 | 37.7 | 475.60 |
| Atlantic menhaden | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | | | <0.1 | | | |
| Butterfish | | 0.1 | | | <0.1 | | | | | | 0.4 | |
| Cod family | 0.2 | | | | <0.1 | | | | | | | |
| Cunner | | | 35.9 | 9.3 | 21.7 | 207.5 | 18.0 | 2.4 | 15.6 | 208.0 | 1.6 | 4.51 |
| Cunner/yellowtail flounder | 18.6 | 110.2 | 186.1 | 56.2 | 232.4 | 1001.9 | 229.7 | 1396.5 | 128.3 | 939.1 | 254.6 | 486.03 |
| Cusk | 0.2 | 1.8 | 0.2 | 0.1 | <0.1 | 0.1 | 3.0 | 0.3 | | 0.6 | 0.2 | 0.77 |
| Fourbeard rockling | 4.2 | 10.9 | 4.8 | 2.9 | 2.7 | 13.7 | 14.1 | 3.23 | 5.9 | 5.6 | 5.2 | 7.40 |
| Goosefish | | | | 0.9 | | 0.9 | | | | 0.1 | 0.1 | 0.03 |
| Grubby | | | | | 0.1 | | | | | | | |
| Hake | 25.1 | 184.0 | 68.6 | 7.4 | 6.1 | 114.0 | 4.4 | 79.6 | 5.0 | 5.3 | 2.8 | 7.23 |
| Hake/fourbeard rockling | 27.5 | 57.0 | 45.0 | 31.1 | 24.8 | 231.1 | 33.0 | 58.3 | 38.4 | 41.1 | 63.6 | 30.08 |
| Lumpfish | 6.0 | 1.2 | 0.3 | | | | | | <0.1 | | | |
| Pollock | 0.4 | 0.4 | 0.2 | 2.9 | 0.2 | <0.1 | 0.3 | 0.6 | 1.0 | 0.9 | 1.0 | 4.13 |
| Rainbow smelt | | 0.1 | | | | | | | | | | |
| Silver hake | 22.5 | 73.6 | 271.1 | 18.6 | 139.9 | 90.4 | 48.9 | 341.4 | 235.6 | 22.3 | 30.7 | 9.39 |
| Tautog | | 0.3 | 0.1 | 0.1 | | | 0.1 | 3.8 | | 0.1 | 0.2 | |
| Unidentified | 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 | 17.4 | 44.2 | 28.5 | 17.9 | 43.2 | 95.1 | 33.4 | 39.1 | 15.5 | 22.7 | 26.2 | 24.71 |
| Winter flounder | | | | | | 0.3 | | | 0.3 | | | |
| Witch flounder | 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** | **255.9** | **926.4** | **692.7** | **286.7** | **593.9** | **2104.4** | **775.1** | **2086.8** | **529.4** | **1370.1** | **454.4** | **1075.38** |

**Appendix Table F-2. Annual Estimated Numbers of Fish Larvae Entrained (in millions) by the Cooling Water System at Seabrook Station from 1995 through 2006 (NAI 2007).**

**Larvae**

| TAXON | 1995[f] | 1996[f] | 1997[f] | 1998[f] | 1999[f] | 2000[f] | 2001[f] | 2002[f] | 2003[f] | 2004[f] | 2005[f] | 2006[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alligatorfish | 0.3 | 0.1 | 0.1 | 0.2 | 0.1 | | | <0.01 | 0.1 | <0.1 | | 0.03 |
| American eel | | | | <0.1 | 0.1 | | | | | | | 0.03 |
| American plaice | 7.9 | 8.1 | 7 | 2.9 | 4.9 | 1.6 | 8.7 | 11.3 | 9.1 | 2.6 | 1.4 | 0.64 |
| American sand lance | 9.5 | 14 | 10.1 | 10.7 | 7.8 | 1.0 | 5.3 | 10.5 | 27.1 | 107.1 | 28.3 | 14.05 |
| Atlantic cod | 2.3 | 0.3 | 0.7 | 2.2 | 1.0 | 0.4 | 2.5 | 34.6 | 2.5 | 0.5 | 1.6 | 0.27 |
| Atlantic herring | 11.2 | 4.3 | 2.1 | 9.5 | 8.6 | 0.2 | 15.2 | 11.7 | 15.3 | 8.8 | 9.7 | 12.79 |
| Atlantic mackerel | | 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 | | 0.15 |
| Atlantic seasnail | 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 | | | | | | | | | | |
| Cunner | 4.4 | 9.2 | 203.8 | 8.4 | 4.7 | 111.0 | 13.6 | 391.1 | 22.5 | 451.2 | 2.5 | 8.75 |
| Cusk | | | | <0.1 | | | 0.4 | 1.8 | 0.1 | 2.1 | | 0.09 |
| Fourbeard rockling | 3.9 | 11.7 | 22.4 | 13.1 | 21.0 | 8.2 | 19.6 | 176.4 | 19.3 | 61.4 | 2.0 | 4.93 |
| Fourspot flounder | | | 0.1 | <0.1 | | | | <0.01 | | | | |
| Goosefish | | | | | | 2.0 | | | | 0.1 | | |
| Gadidae | | | | | | | | | | | | 0.04 |
| Grubby | 17.4 | 18.6 | 12.8 | 17.3 | 6.4 | 2.2 | 12.4 | 6.6 | 27.5 | 51.8 | 7.8 | 9.32 |
| Gulf snailfish | 0.2 | 2.8 | 0.6 | 1.5 | 0.3 | 0.3 | 0.1 | 4.4 | 2.0 | 9.5 | 2.3 | 1.04 |
| Haddock | | | | | | | | | | | 0.1 | |
| Hake | 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 | 0.4 | 1.3 | 0.7 | 0.8 | 0.6 | 0.3 | 0.3 | 0.6 | 2.0 | 5.2 | 1.2 | 0.97 |
| Lumpfish | 0.6 | 0.1 | 0.2 | 0.5 | 0.1 | 0.3 | 0.6 | 0.1 | 0.1 | 0.3 | 0.2 | 0.50 |
| Moustache sculpin | | 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 | |
| Ocean pout | | | | | | | | | <0.1 | | | |
| Pleuronectidae | | 0.3 | | | | | | | | | | |

(continued)

## Appendix Table F-2. Continued

| TAXON | 1995[f] | 1996[f] | 1997[f] | 1998[f] | 1999[f] | 2000[f] | 2001[f] | 2002[f] | 2003[f] | 2004[f] | 2005[f] | 2006[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pollock | | | | <0.1 | | | | <0.1 | 0.6 | 0.1 | 0.1 | 0.76 |
| Radiated shanny | 2.1 | 2 | 0.3 | 1.7 | 3.5 | 14.0 | 2.4 | 8.3 | 12.3 | 3.6 | 7.0 | 0.76 |
| Rainbow smelt | | | | 0.2 | | 0.3 | 0.1 | | 0.5 | <0.1 | 0.5 | 4.27 |
| Redfish | | | | | | | | | | | <0.1 | |
| Rock gunnel | 15.6 | 33.8 | 25.1 | 16.9 | 18.2 | 3.5 | 4.6 | 12.3 | 56.0 | 109.0 | 54.2 | 30.31 |
| Sea raven | | | | <0.1 | <0.1 | | | | <0.1 | 0.2 | 0.1 | 0.02 |
| Shorthorn sculpin | 0.5 | 0.1 | 1.1 | 2.1 | 1.0 | 0.1 | 0.5 | 0.2 | 3.9 | 11.6 | 2.1 | 0.16 |
| Silver hake | 0.9 | 16.9 | 69 | 0.2 | 0.4 | 33.2 | 0.6 | 5.9 | 0.5 | 0.2 | <0.1 | 0.09 |
| Snailfish | | 0.4 | | | | | | <0.1 | | | 0.2 | |
| Snakeblenny | | | | | | | | | | | | 0.02 |
| Summer flounder | | | | <0.1 | | | | | <0.1 | | | |
| Tautog | | 0.2 | | | | 0.1 | | | 0.1 | | | |
| Unidentified | 30.4 | 2.5 | 4.3 | 0.5 | 1.4 | 0.6 | 1.7 | 4.8 | 1.5 | 4.8 | 1.0 | 0.72 |
| Unidentified sculpin | | 0.6 | 0.05 | | 0.1 | | | <0.1 | 0.5 | 4.4 | 1.2 | 0.42 |
| Unidentified searobin | | 0.1 | | | | 0.1 | | | | | | |
| Windowpane | 2 | 2 | 5.6 | 1.4 | 3.7 | 2.3 | 1.3 | 6.5 | 0.5 | 0.4 | 0.5 | 0.52 |
| Winter flounder | 8 | 10.3 | 2.2 | 4.7 | 7.4 | 14.3 | 14.3 | 4.5 | 20.0 | 34.8 | 4.9 | 7.17 |
| Witch flounder | | 0.8 | 1.2 | <0.1 | 0.1 | 0.5 | | 1.7 | 1.4 | 0.8 | 0.2 | 0.18 |
| Wrymouth | | | | | <0.1 | | | | | <0.1 | | |
| Yellowtail flounder | 0.1 | 1.6 | 0.5 | 0.3 | 0.8 | 0.3 | 0.5 | 0.9 | | 0.1 | <0.1 | 0.02 |
| **TOTAL** | **145.3** | **215.7** | **373.4** | **134.1** | **171.8** | **261.2** | **124.3** | **724.4** | **268.5** | **958.5** | **167.0** | **123.23** |

[f] Represents 12 months.

Appendix Table F-3. **Estimated Number of Bivalve Larvae Entrained (X $10^9$) by the Cooling Water System at Seabrook Station 1993, and 1995-2006[a] (NAI 2007).**

| Species | 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] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anomia squamula* | 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 |
| Bivalvia | 334.5 | 797.1 | 671.4 | 71. | 64. | 651.3 | 228.6 | 483.0 | 194.2 | 73. | 89. | 40. | 73 |
| *Hiatella* sp. | 2405.5 | 2598.2 | 4670.2 | 923.7 | 609.7 | 4416.5 | 1920.8 | 1575.2 | 567.3 | 1203.9 | 1024.2 | 352.9 | 604.0 |
| *Modiolus modiolus* | 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. |
| *Mya arenaria* | 22. | 4 | 33. | 53. | 11. | 45. | 23. | 26. | 60. | 5 | 15. | 9 | 11 |
| *Mya truncata* | 2 | 27. | 123.0 | 0 | 8 | 66. | 34. | 26. | 1 | 13. | 5 | 2 | 0 |
| *Mytilus edulis* | 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 |
| *Placopecten magellanicus* | 16. | 6 | 31. | 0 | 0 | 11. | 9 | 8 | 0 | 0 | 0 | 0 | 0 |
| Solenidae | 102.5 | 1092.3 | 241.9 | 49. | 20. | 773.2 | 150.4 | 922.9 | 150.8 | 85. | 113.4 | 57. | 65 |
| *Spisula solidissima* | 48. | 112.5 | 171.1 | 22. | 14. | 175.5 | 33. | 50. | 44. | 3 | 10. | 14. | 20 |
| *Teredo navalis* | 0 | 4 | 7 | 1 | 0 | 29. | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| **Total** | **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** |

[a] No sampling occurred in 1994.
[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

**Appendix Table F-4. Species Composition, Annual Totals, and Nine-Year Total of Finfish, and American Lobster Impinged at Seabrook Station From 1995 to 2006[a] (NAI 2007).**

| Species | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acadian redfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| Alewife | 8 | 1,753 | 2,797 | 14 | 16 | 4 | 35 | 1 | 9 | 212 | 87 | 255 | 5191 |
| American lobster | 16 | 31 | 20 | 4 | 6 | 0 | 1 | 23 | 19 | 0 | 77 | 5 | 233 |
| American plaice | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 5 |
| American shad | 0 | 20 | 21 | 1 | 6 | 10 | 3 | 7 | 10 | 7 | 7 | 0 | 92 |
| American sand lance | 1,324 | 823 | 182 | 708 | 234 | 423 | 114 | 245 | 3396 | 665 | 1029 | 213 | 10571 |
| American eel | 5 | 6 | 42 | 1 | 2 | 0 | 2 | 0 | 0 | 9 | 0 | 0 | 67 |
| Atlantic menhaden | 7 | 97 | 0 | 1 | 957 | 142 | 19 | 1022 | 7 | 361 | 7226 | 94 | 9933 |
| Atlantic hagfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1396 | 0 | 0 | 0 | 1396 |
| Atlantic torpedo | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Atlantic silverside | 1,621 | 1,119 | 210 | 834 | 1,335 | 31 | 282 | 1410 | 20507 | 877 | 2717 | 788 | 37079 |
| Atlantic tomcod | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Atlantic wolffish | 2 | 13 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 21 |
| Atlantic cod | 119 | 94 | 69 | 38 | 66 | 29 | 30 | 199 | 3091 | 467 | 454 | 113 | 4827 |
| Atlantic mackerel | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 4 | 0 | 10 |
| Atlantic herring | 0 | 485 | 350 | 582 | 20 | 5 | 11 | 159 | 198 | 118 | 93 | 189 | 2210 |
| Atlantic moonfish | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 54 |
| Bigeye soldierfish | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Blackspotted stickleback | 0 | 0 | 0 | 2 | 28 | 0 | 0 | 0 | 107 | 12 | 0 | 3 | 152 |
| Black sea bass | 3 | 0 | 0 | 3 | 3 | 17 | 12 | 12 | 10 | 11 | 4 | 0 | 75 |
| Blueback herring | 0 | 111 | 323 | 7 | 53 | 1 | 59 | 475 | 50 | 380 | 130 | 138 | 1740 |
| Bluefish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 7 |
| Butterfish | 14 | 3 | 223 | 9 | 5 | 1 | 28 | 1170 | 4 | 35 | 54 | 44 | 1593 |
| Cunner | 342 | 1,121 | 233 | 309 | 255 | 324 | 341 | 291 | 554 | 625 | 893 | 687 | 6007 |
| Cusk | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| Flounders | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77 |
| Flying gurnard | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Fourbeard rockling | 6 | 0 | 0 | 3 | 1 | 1 | 1 | 0 | 0 | 7 | 3 | 0 | 22 |
| Fourspine stickleback | 0 | 0 | 0 | 23 | 24 | 0 | 6 | 3 | C | 0 | 0 | 0 | 56 |
| Fourspot flounder | 1 | 2 | 3 | 4 | 1 | 11 | 0 | 7 | 0 | 7 | 24 | 0 | 62 |
| Goosefish | 13 | 0 | 0 | 7 | 17 | 15 | 59 | 18 | 10 | 0 | 8 | 0 | 150 |
| Gray triggerfish | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3 | 5 |

(continued)

## Appendix Table F-4 (Continued)

| Species | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grubby | 2,415 | 1,457 | 430 | 3,269 | 3,953 | 1,174 | 549 | 1089 | 2523 | 676 | 531 | 235 | 20979 |
| Haddock | 1 | 397 | 0 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 7 | 3 | 415 |
| Hakes | 2,188 | 156 | 122 | 4 | 68 | 113 | 523 | 1813 | 166 | 35 | 11 | 6 | 8027 |
| Herrings | 231 | 72 | 218 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1035 |
| Killifishes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Lefteye flounder | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Longhorn sculpin | 165 | 84 | 88 | 38 | 127 | 54 | 27 | 73 | 45 | 98 | 268 | 58 | 1230 |
| Lookdown | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 3 |
| Lumpfish | 190 | 51 | 62 | 137 | 344 | 85 | 158 | 84 | 370 | 68 | 61 | 176 | 1968 |
| Mummichog | 0 | 47 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 75 |
| Northern kingfish | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Northern pipefish | 579 | 1,200 | 243 | 268 | 748 | 370 | 714 | 936 | 2716 | 1413 | 1724 | 1288 | 12387 |
| Northern puffer | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 12 | 0 | 3 | 0 | 0 | 20 |
| Northern searobin | 0 | 0 | 11 | 1 | 2 | 0 | 1 | 2 | 564 | 0 | 11 | 0 | 592 |
| Ocean pout | 6 | 1 | 0 | 7 | 3 | 2 | 21 | 1 | 13 | 3 | 3 | 6 | 66 |
| Planehead filefish | 15 | 0 | 0 | 0 | 8 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 27 |
| Pollock | 899 | 1,835 | 379 | 536 | 11,392 | 534 | 405 | 719 | 499 | 80 | 218 | 73 | 19250 |
| Radiated shanny | 92 | 40 | 2 | 39 | 108 | 11 | 53 | 4 | 158 | 18 | 49 | 44 | 618 |
| Rainbow smelt | 213 | 4,489 | 365 | 535 | 100 | 8 | 65 | 323 | 3531 | 2085 | 3314 | 878 | 16451 |
| Red hake | 16 | 1,478 | 371 | 903 | 1,120 | 112 | 155 | 52 | 271 | 892 | 821 | 546 | 6738 |
| Righteye flounder | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| Rock gunnel | 1,298 | 1,122 | 459 | 2,929 | 2,308 | 1,514 | 2,251 | 2066 | 6274 | 4137 | 1752 | 3782 | 30386 |
| Sand tiger shark | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 57 |
| Sculpins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 205 |
| Scup | 14 | 9 | 0 | 3 | 1 | 0 | 3 | 11 | 11 | 0 | 21 | 4 | 77 |
| Sea raven | 125 | 1,015 | 223 | 137 | 132 | 206 | 271 | 166 | 217 | 129 | 221 | 138 | 3058 |
| Sea lamprey | 0 | 1 | 6 | 7 | 2 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 21 |
| Sheepshead | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Shorthorn sculpin | 156 | 282 | 123 | 190 | 296 | 923 | 621 | 642 | 7450 | 876 | 2214 | 1258 | 15045 |
| Silver hake | 49 | 58 | 108 | 13 | 100 | 41 | 5 | 1177 | 22 | 212 | 306 | 31 | 2122 |
| Skates | 157 | 225 | 177 | 41 | 41 | 42 | 17 | 299 | 145 | 60 | 170 | 33 | 1597 |
| Smooth flounder | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

(continued)

## Appendix Table F-4 (Continued)

| Species | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Snailfishes | 165 | 1,013 | 351 | 856 | 2,356 | 690 | 334 | 616 | 451 | 185 | 442 | 330 | 7969 |
| Snakeblenny | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Spotted hake | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Spiny dogfish | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 6 | 8 | 11 | 8 | 0 | 41 |
| Striped bass | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 14 | 0 | 4 | 0 | 25 |
| Striped cusk-eel | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Striped mullet | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Striped searobin | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 8 |
| Summer flounder | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 7 |
| Tautog | 0 | 34 | 0 | 3 | 5 | 1 | 1 | 3 | 0 | 0 | 0 | 3 | 50 |
| Threespine stickleback | 155 | 320 | 174 | 773 | 506 | 10 | 280 | 34 | 1549 | 130 | 307 | 139 | 4444 |
| Unidentified | 40 | 88 | 49 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 198 |
| Whiptail Conger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 |
| White hake | 7 | 967 | 0 | 6 | 19 | 18 | 30 | 16 | 65 | 62 | 103 | 20 | 1314 |
| White perch | 0 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 201 | 0 | 3 | 0 | 210 |
| Windowpane | 943 | 1,164 | 1,688 | 772 | 692 | 251 | 161 | 2242 | 4749 | 936 | 2034 | 572 | 17184 |
| Winter flounder | 1,171 | 3,231 | 468 | 1,143 | 3,642 | 102 | 777 | 897 | 10491 | 783 | 1875 | 767 | 26782 |
| Wrymouth | 9 | 206 | 3 | 21 | 10 | 1 | 135 | 17 | 72 | 7 | 64 | 15 | 615 |
| Yellowtail flounder | 1,149 | 4 | 23 | 11 | 97 | 0 | 8 | 5 | 0 | 0 | 0 | 10 | 1307 |
| **TOTAL** | **15940** | **26825** | **10648** | **15198** | **31239** | **7281** | **8577** | **18413** | **71946** | **16696** | **29368** | **12955** | **284298** |

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

FPL Energy
Seabrook Station

FPL Energy Seabrook Station
P.O. Box 300
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(603) 773-7000

May 4, 2006

SBK-L-06106

United States Environmental Protection Agency
Region I
Office of Ecosystem Protection
One Congress Street, Mail Code CIP
Boston, MA 02114-2023

Attention: Mr. Damien Houlihan

Seabrook Station
CWA § 316 (b) Phase II Regulations, Proposal for Information Collection

FPL Energy Seabrook, LLC has enclosed a Proposal for Information Collection (PIC) as required by CWA § 316 (b) Phase II Regulation, 40 CFR § 125.95 (b)(1). The Seabrook Station PIC is integral to the NPDES Permit renewal application to be filed not later than October 1, 2006.

An EPA Region I letter dated December 30, 2004[1] delineated the schedule for information collection and submission to comply with the Phase II regulations as follows:

- Submit PIC not later than October 7, 2006 (enclosed).
- Submit Comprehensive Demonstration Study not later than January 7, 2008.
- Submit information required by 40 CFR §§ 122.21(r)(2), (3) and (5) not later than January 7, 2008 (enclosed).
- Submit preliminary compliance alternative selection with PIC submittal, and a final compliance alternative selection with the CDS submittal.

The enclosed PIC demonstrates that Seabrook Station has established best technology available through Compliance Alternative 2 (40 CFR § 125.94 (a)(2)). Under Compliance Alternative 2 the existing Seabrook Station Cooling Water Intake Structure (CWIS) design, construction and operational measures are demonstrated to meet the National Performance Standards of 40 CFR § 125.94 (b). The PIC develops a "calculation baseline" level of impingement mortality and entrainment for Seabrook Station through comparison to a shoreline facility located in the same water body and ecological region, a methodology used by EPA in the development of case studies supporting the Phase II regulation. The existing CWIS and the current levels of

[1] EPA Letter dated December 30, 2004, "Supplemental Information Requirements Pursuant to Section 308 of the Clean Water Act for Seabrook Station NPDES Permit Reissuance – [NPDES Permit No: NH0020338]", Linda Murphy, Director, Office of Ecosystem Protection

impingement mortality and entrainment associated with the CWIS as determined through our ongoing environmental monitoring program are significantly reduced in relation to the "calculation baseline" levels of impingement mortality and entrainment. The engineering calculations provided in the PIC identify impingement mortality reductions in the 78 – 81 % range and entrainment reductions in the 55 – 60 % range. FPL Energy Seabrook does not intend to perform any additional sampling other than its current ongoing environmental monitoring program in support of the Compliance Alternative 2 demonstration.

FPL Energy Seabrook intends to submit a Comprehensive Demonstration Study (CDS) subsequent to receiving EPA review comments on the PIC but not later than January 7, 2008. The CDS will address any EPA review comments on the PIC and we anticipate that the CDS will include an additional year (2005) of impingement and entrainment data for Seabrook Station and the shoreline facility in the determination of the "calculation baseline".

In conclusion, we consider the existing Seabrook Station CWIS design and operational measures to be highly effective in reducing impingement mortality and entrainment to those levels established in the National Performance Standard. In particular, the intake location, some 7000 feet from the shoreline reduces the level of biological activity susceptible to impingement mortality and entrainment and reduces the total volume of cooling water flow as compared to a shoreline intake, the velocity caps installed on our three intake structures serve to reduce velocity at their entrance to approximately one half foot per second, and the operational practice of recirculating heated discharge water through the intake also serves to reduce flow.

FPL Energy Seabrook will await your review comments on the Seabrook Station PIC and is prepared to meet with you at your convenience as necessary. Please contact Mr. Allen Legendre, Principal Engineer, at (603) 773-7773 should you have any questions regarding this letter.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Very truly yours,

FPL ENERGY SEABROOK, LLC

James M. Peschel
Regulatory Programs Manager

cc (with enclosures):

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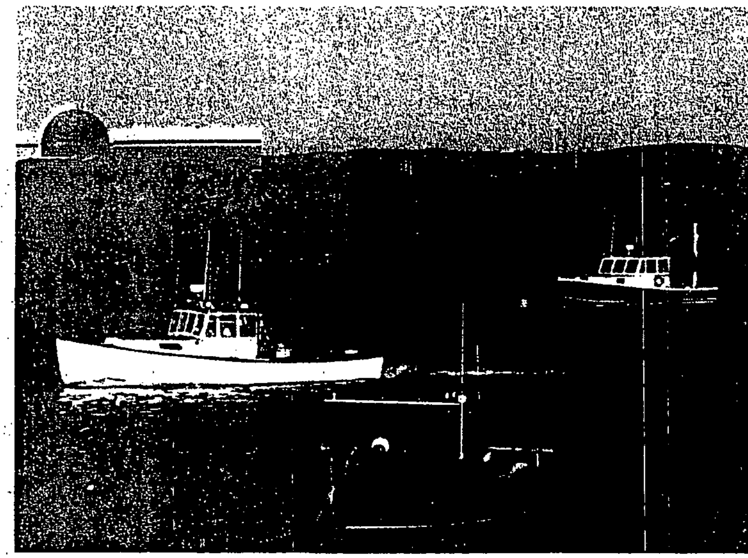
Enclosure to SBK-L-06106

# SEABROOK NUCLEAR POWER STATION
# EPA 316(b) PHASE II RULE PROJECT
# PROPOSAL FOR INFORMATION COLLECTION



MAY 2006

# SEABROOK NUCLEAR POWER STATION
# EPA 316(b) PHASE II RULE PROJECT
# PROPOSAL FOR INFORMATION COLLECTION


**Prepared for**
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**Prepared by**
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**R-20297.000**

**May 2006**

# Table of Contents

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## 1.0 INTRODUCTION

Submittal of a Proposal for Information Collection (PIC) is the first step in compliance with the Phase II rule of Section 316(b) of the Clean Water Act (CWA). This PIC for the FPL Energy Seabrook Nuclear Power Station (Seabrook Station) is submitted to EPA Region I to allow review and comment on Seabrook Station's plan to collect information to support the Comprehensive Demonstration Study (CDS). The CDS is the document that will demonstrate the means of compliance by Seabrook Station with the Phase II rule. The PIC also provides descriptive information on the Cooling Water System (CWS) and the source waterbody for cooling water for Seabrook Station.

This document is intended to document Seabrook Station's compliance with Section 125.95(b)(1) of the Phase II rule. It includes:

- a brief overview of Section 316(b) Phase II regulatory requirements (Section 2.0),
- a description of Seabrook Station and the cooling water system, including the descriptions required in Sections 122.21(r)(2), (3), and (5) of the Phase II rule are presented in Section 3.0.
- a description of existing and potential technology, operational and restoration measures that can be used to demonstrate compliance (Section 4.0),
- a description of historical studies that were used to characterize impingement mortality and entrainment (Section 5.0),
- a description of historical consultations with environmental regulatory agencies, and future impingement and entrainment sampling plans (Section 6.0), and
- a summary of the current environmental monitoring program.

## 2.0 SECTION 316(b) COMPLIANCE REQUIREMENTS

The final Section 316(b) Phase II rule (40 CFR Parts 9, 122, 123, 124, and 125) implements section 316(b) of the Clean Water Act for existing power production facilities that employ a cooling water intake structure and are designed to withdraw 50 MGD or greater from the waters of the United States for cooling purposes. According to Part 125.91, this rule is applicable to Seabrook Station because:

- Seabrook Station's primary activity is to generate electric power,
- Seabrook Station is a point source that uses a cooling water intake structure,
- the cooling water intake withdraws cooling water from waters of the United States and at least 25% is used exclusively for cooling purposes, and
- the cooling water intake structures have a total design flow 50 MGD or more.

The Phase II rule in Part 125.94(a) presents five alternatives for compliance:

**Alternative 1**—Demonstrate facility has reduced flow commensurate with closed-cycle recirculating system or demonstrate facility has reduced design intake velocity to less than 0.5 foot per second (fps).

**Alternative 2**—Demonstrate that existing design and construction technologies, operational measures, and/or restoration measures meet the performance standards.

**Alternative 3**—Demonstrate facility has selected design and construction technologies, operational measures, and/or restoration measures that will, in combination with any existing design and construction technologies, operational measures, and/or restoration measures, meet the performance standards.

**Alternative 4**—Demonstrate facility has installed and properly operates and maintains an approved technology (cylindrical wedgewire screens for intakes in freshwater rivers and streams).

**Alternative 5**—Demonstrate a site-specific determination of BTA is appropriate.

Four of these compliance alternatives require that the station meet the established performance standards and the fifth option allows for a site-specific determination of BTA. These compliance options can potentially be achieved through the implementation of a technological, operational, and/or restoration measures.

# 3.0 SEABROOK NUCLEAR POWER STATION

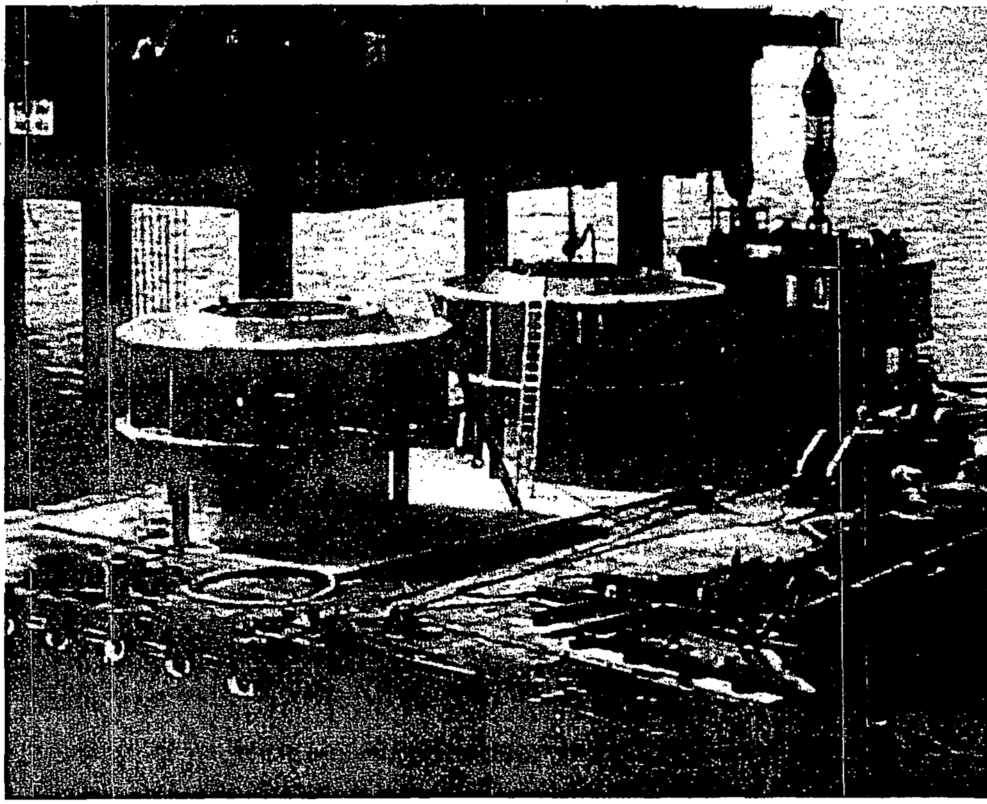
## 3.1 STATION DESCRIPTION

Seabrook Station, a 1,221 MW nuclear power plant located in Seabrook, NH, started commercial operation in August 1990. Cooling water enters the once-through cooling water system through three offshore intake structures equipped with 30 foot diameter velocity caps and nominal 5-inch vertical bar racks. The intakes are located in about 60 feet of water, approximately 7,000 feet offshore in the western Gulf of Maine, an embayment of the North Atlantic Ocean. Each intake rises a total of approximately 18 feet off the bottom and water enters the intakes through 7-foot tall intake bays (Figure 3-1). Water is withdrawn primarily from the middle of the water column and travels down vertical risers to a 19-foot diameter intake tunnel 17,000 feet long that delivers cooling water to traveling screens located in the screenhouse at the plant. Average cooling water flow is 599.5 million gallons per day (MGD) and the maximum design flow is 684 MGD.

The design locations of the intakes were moved several times for environmental concerns during the permitting process. Early proposed intake designs (Ebasco Services Inc. 1969) included:

- an intake pipe withdrawing from the ocean at a depth of 18 feet to a canal dredged across the saltmarsh to the plant,
- an intake pipe withdrawing from the ocean at a depth of 18 feet running directly to the plant, and
- an intake pipe withdrawing water from Hampton Harbor to a canal dredged across the saltmarsh to the plant.

The intake designs that withdrew cooling water from either Hampton Harbor or from the ocean at a depth of 18 feet were eliminated from consideration for environmental reasons. The March 1973 Construction Permit Application to the Nuclear Regulatory Commission included a proposed intake location 3,000 feet offshore in 30 feet of water. The cooling water would be conveyed to the power plant through an intake tunnel bored through the bedrock. In September 1975, the Regional Administrator of the Environmental Protection Agency issued a ruling adding 4,000 feet to the intake



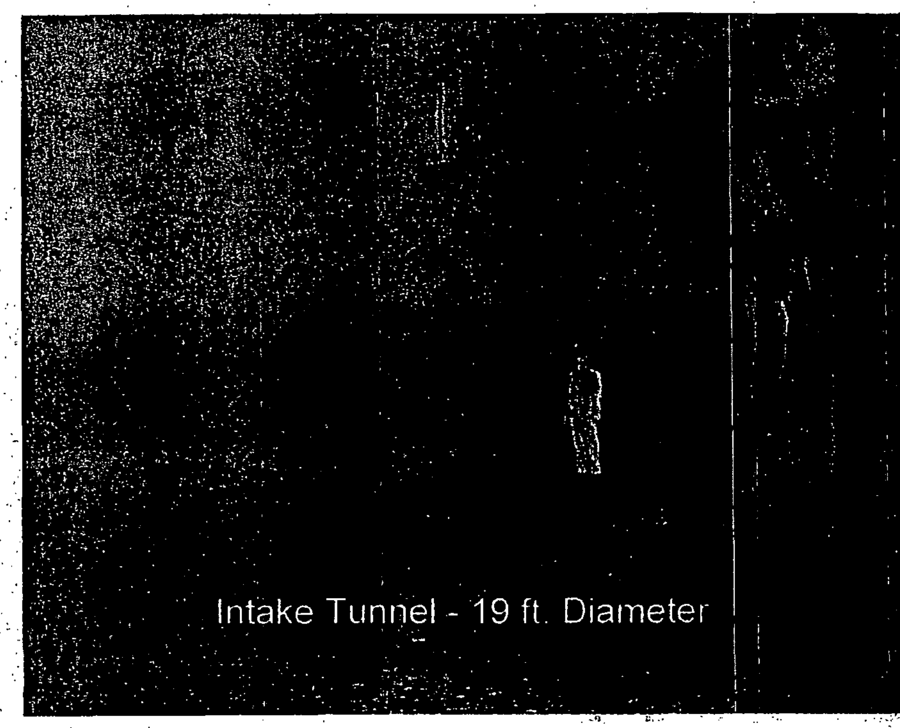



Figure 3-1. Seabrook Nuclear Power Station intake structures on construction barge prior to installation (top) and intake tunnel (bottom).

tunnel for environmental reasons moving the intake location to 60 feet of water. After a series of reversals, reaffirmations, and appeals to the U.S. First Circuit Court of Appeals, an intake tunnel with an intake location 7,000 feet offshore in 60 feet of water was approved and constructed.

## 3.2 SOURCE WATER PHYSICAL DATA

This section will include the information requested in the Phase II rule Sections 122.21(r)(2) source water physical data.

### 3.2.1 Source Water Body

The source water body for Seabrook Station is the western Gulf of Maine, which is an embayment of the North Atlantic Ocean. Therefore, Seabrook Station is subject to the performance standards for marine intakes. Cooling water is withdrawn from the Atlantic Ocean approximately 7,000 feet offshore from water about 60 feet deep. Tidal range is approximately 9 feet and tidal currents flow northward and southward with velocities up to 0.6 kt (USAEC 1974). Superimposed on the tidal currents is the predominantly south to southwesterly current of the counterclockwise gyre of the Gulf of Maine. This net south to southwesterly current can be modified by local weather conditions and winds. In the vicinity of the intakes salinity ranges from 19.6 to 34.7 PSU and water temperature ranges from 0.0 °C to 20.9 °C (NAI 2005).

### 3.2.2 Hydrological and Geomorphological Features

The horizontal flow patterns for the intake structures were determined using a physical model under a two unit scenario with a cooling water flow of 1,177.6 MGD (March and Nyquist 1976). Only one unit was built at Seabrook Station, therefore the modeled flow is about twice the average actual flow. Nevertheless, the modeling exercise provides a conservative upper bound of estimates of the withdrawal zone and flow patterns. At zero ambient current, which would correspond to slack tide, the intakes withdraw from the entire water column. At an ambient current of 0.2 kt, the intakes withdraw from the lower 35 ft (depths of 60-25 ft depth). At an ambient current of 0.4 kt the intakes withdraw from the lower 25 feet (depths of 60-35 ft). The horizontal range of influence was limited to about one intake diameter (30 feet) at 0.2 kt ambient current and about half the intake diameter (15 feet) at 0.4 kt ambient current.

The substrate around the intakes is primarily sand with outcrops of rock. The depths gently slope up from the 60 feet in the vicinity of the intakes to the intertidal zone.

### 3.2.3 Location Maps

Seabrook Station is located in southeastern New Hampshire in the town of Seabrook (Figure 3-2). The Station was built primarily on upland on the edge of the Hampton-Seabrook saltmarsh complex near the tidal portion of the Browns River (Figure 3-3). The Station is located about 2 miles from the open water at Seabrook Beach. Nearby large population centers include Portsmouth, NH, Portland, ME, Manchester, NH, and Boston MA.

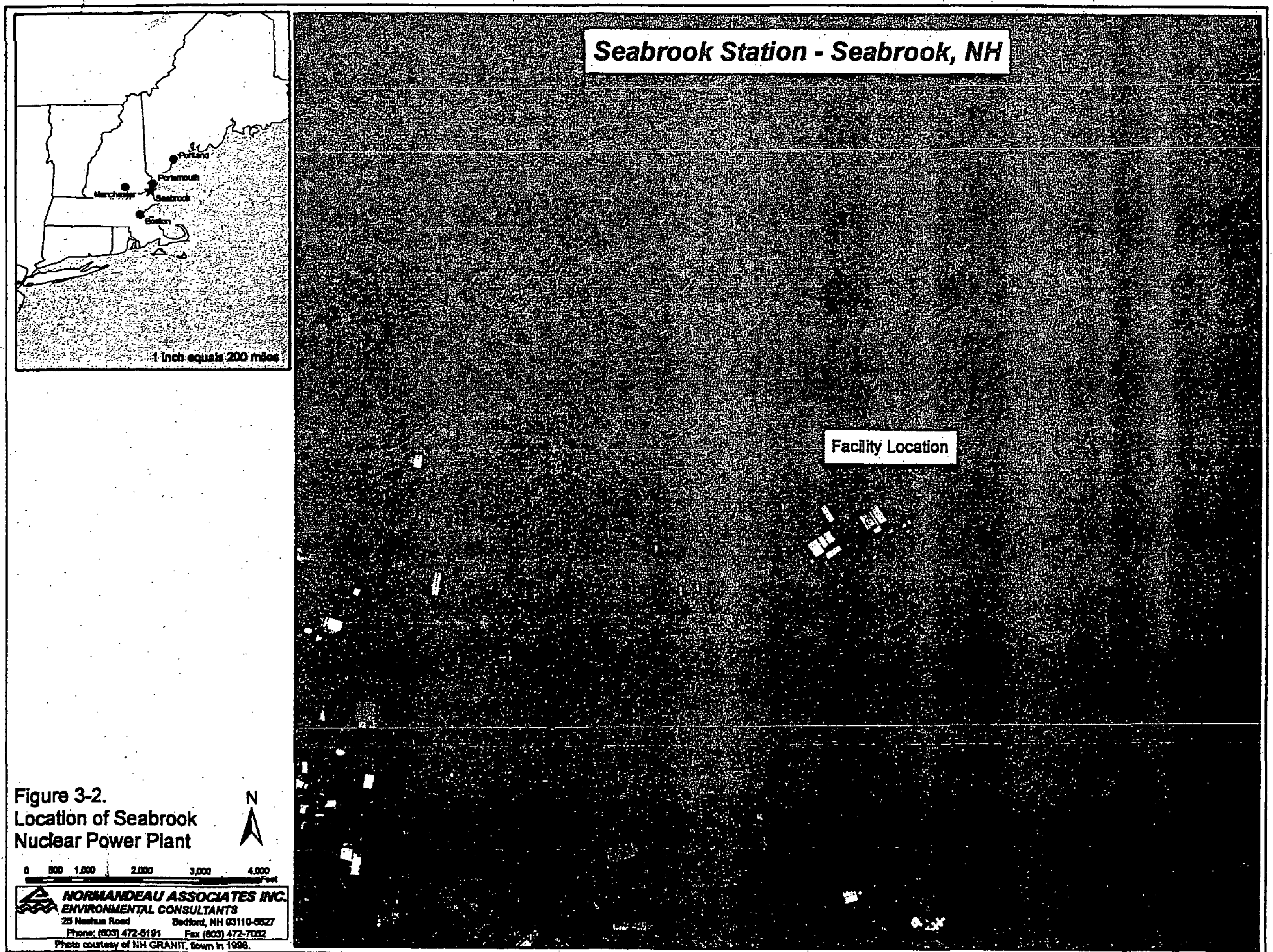



Figure 3-2. Location of Seabrook Nuclear Power Station.

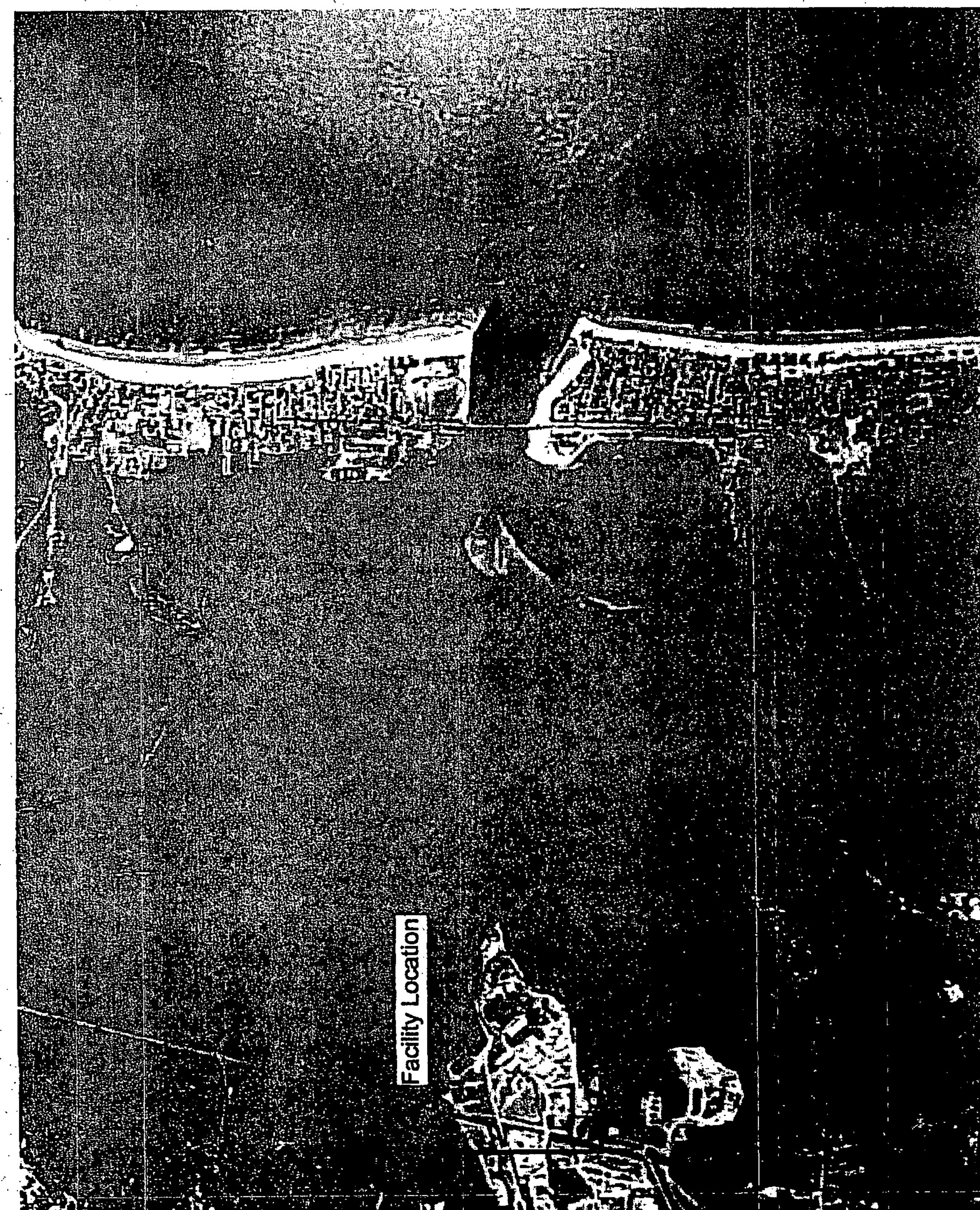



Figure 3-3. Location Seabrook Nuclear Power Station in relation to the Hampton-Seabrook estuary.

### 3.3 Cooling Water Intake Structure

Seabrook Station's CWIS consists of three submerged offshore intake structures, an intake tunnel, a structure to transition the flow from the tunnel to the on-shore intake structure, traveling intake screens, and three circulating water and four service water pumps. The following sections will provide a more thorough discussion of the CWIS and include the information required under 40 CFR 122.21(r)(3).

#### 3.3.1 Cooling Water Intake Structure Description

As defined in the 316(b) regulations, §125.93, the "cooling water intake structure extends from the point at which water is withdrawn from the surface water source up to, and including, the intake pumps".

Seabrook Station makes use of a once-through circulating water system with an offshore cooling water intake for both the condenser cooling water and the plant service water. There are three offshore submerged intake structures which are located approximately 1.3 miles offshore and draw water from the western Gulf of Maine. The three intake structures are approximately 110 feet apart and each has a 9'-10" inside diameter (ID) vertical intake shaft. Each intake shaft connects to the intake tunnel at approximately 160 feet below mean sea level (MSL). The 19-ft ID intake tunnel then conveys the water approximately 3.22 miles to an inland termination point which consists of a 19-ft ID vertical shaft and the transition structure. From the transition structure the water is distributed to the circulating water (CW) and the service water (SW) pumphouses.

As an alternate source of cooling water for the service water system, a cooling tower was installed to provide shutdown cooling in the event the intake and/or discharge tunnels are blocked due to a seismic event. There are two cooling trains provided from the cooling tower to provide water to both trains of the service water system.

Each offshore intake structure consists of a 30-ft. diameter prefabricated reinforced concrete velocity cap with copper-nickel cladding that draws the water in horizontally and directs it to the vertical intake shaft (Figure 3-4). Each velocity cap is located in about 60 feet of water MSL, and extends approximately 18 feet above the ocean floor with the top of the structures approximately 42 feet below MSL. The opening around the periphery of the velocity cap where cooling water enters is approximately 7-feet high. The original design included vertical trash bars placed in the opening around the periphery that was spaced with 17-inch openings between bars. In August of 1999, modifications were made which reduced the openings between bars to 5" to prevent the entrance of seals into the intake structure.

The vertical intake shafts extend from the submerged intake structures to the intake tunnel which is approximately 160 feet below MSL at this location. Each vertical intake shaft is concrete lined, has a finished inside diameter of 9'-10", and has six 2-inch risers for the injection of sodium hypochlorite into the cooling water intake system from the intake tunnel chlorination system.

The concrete lined intake tunnel has an inside diameter of 19-ft. The tunnel slopes downward from a depth of 160-ft. below MSL at the location of the submerged intake structures to a depth of 240-ft. below MSL at the location of the intake transition structure (Figure 3-5). Approximately 1.89 miles of the 3.22 mile long tunnel are inland.

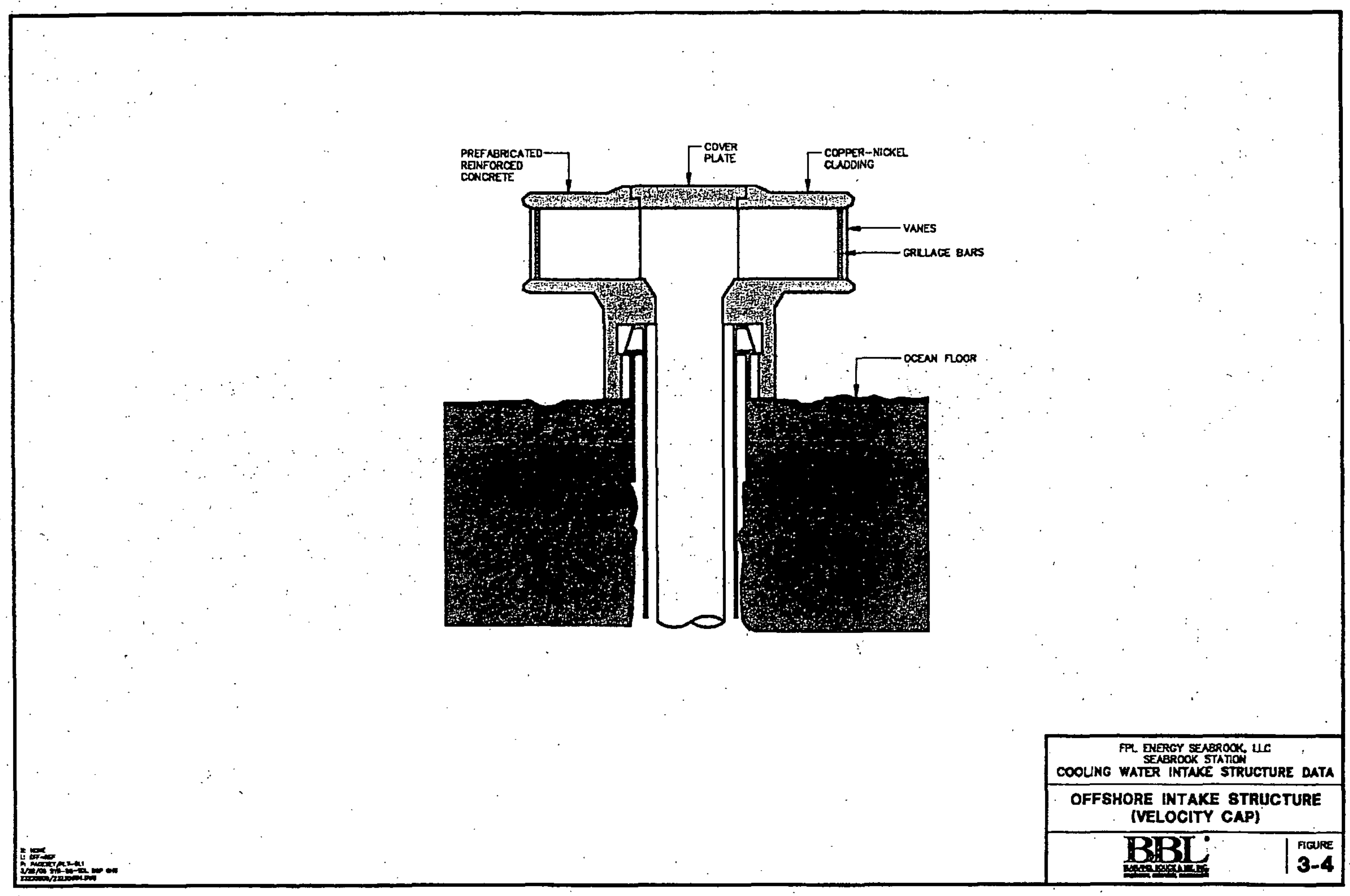



Figure 3-4. Seabrook Nuclear Power Station intake structure.

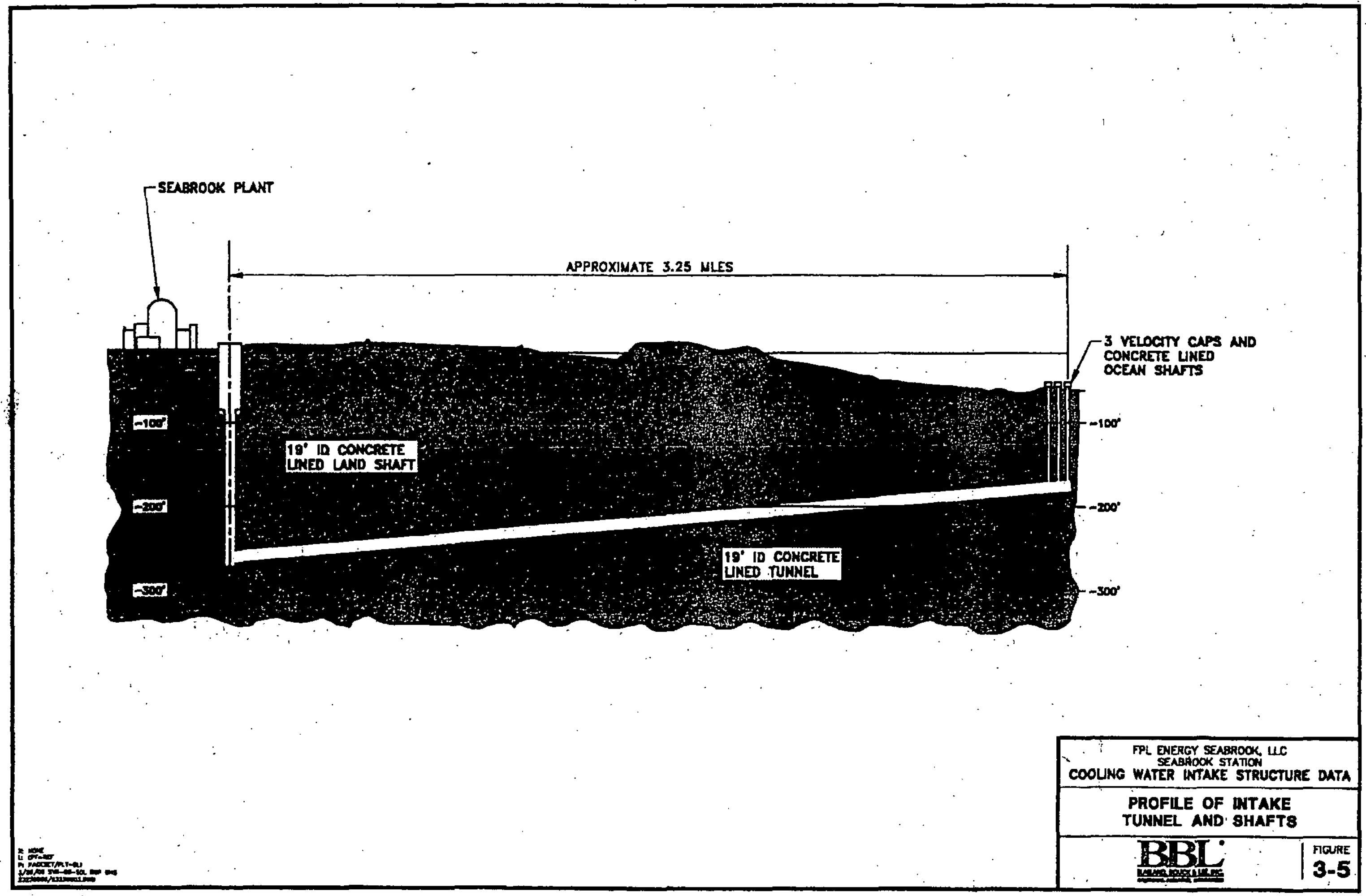



Figure 3-5. Seabrook Nuclear Power Station profile of intake tunnel and shafts.

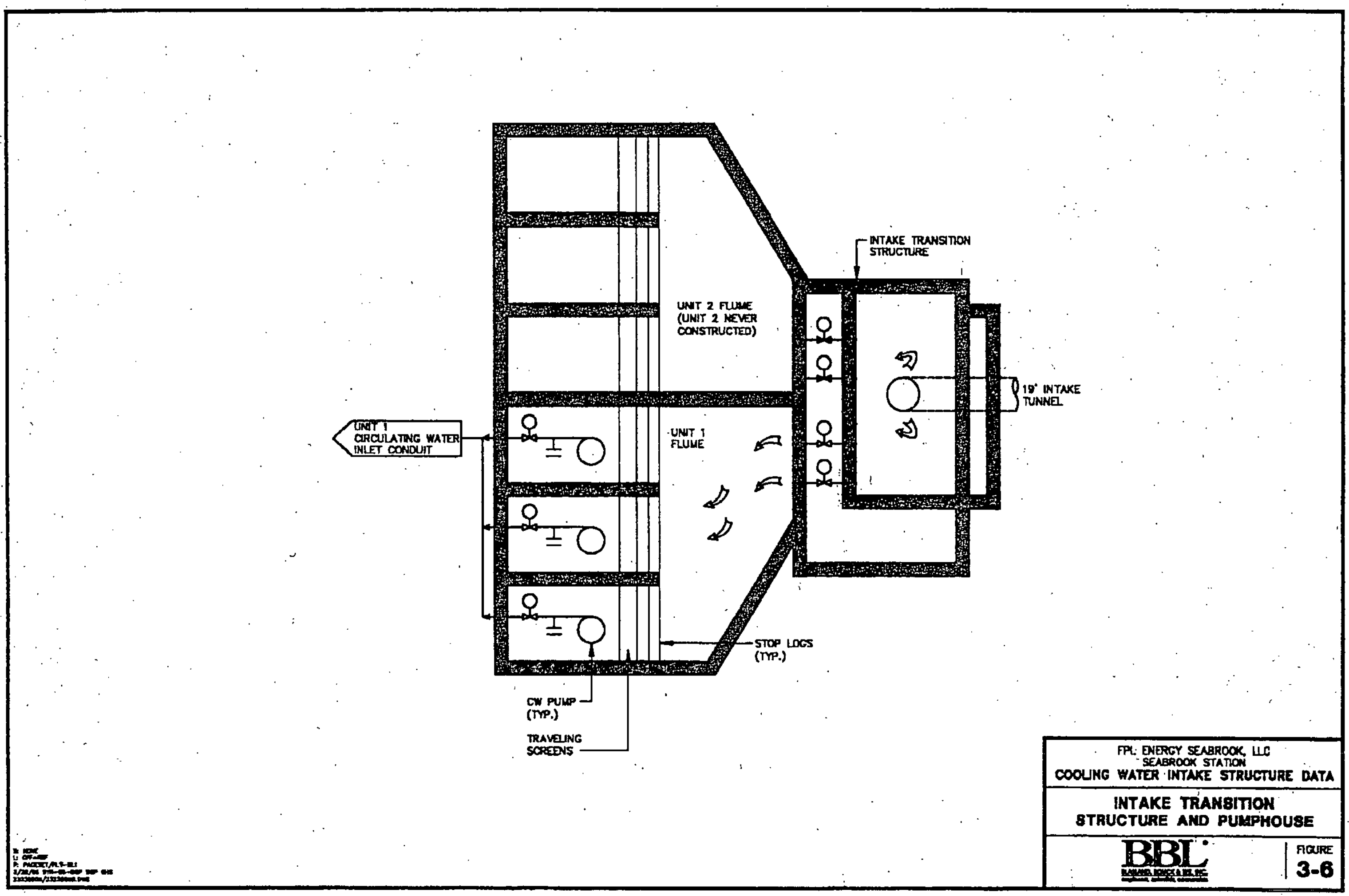



Figure 3-6. Seabrook Nuclear Power Station intake transition structure and pumphouse.

The vertical shaft at the plant end of the intake tunnel is also concrete lined and has an inside diameter of 19-ft. The vertical shaft terminates at a ground-level transition structure, which is a large surge chamber open to the atmosphere (Figure 3-6). At the transition structure are four 102-inch diameter valved connections for circulating water supply, two 42-inch diameter valved connection for service water supply, two 120-inch valved connections for the return of heated circulating water, and one 38-inch diameter valved connection for the return of heat treated service water. Two of the circulating water connections, one of the service water connections, and one of the heated circulating water return connections were installed for Unit 2, which was planned, but never constructed.

Adjacent to the transition structure is the circulating water pumphouse. The water from the two 102-inch diameter circulating water connections at the transition structure enter a below-grade flume and the flow then separates into three screenwells (Figures 3-6 and 3-7). Each screenwell contains stop log guides, a flow-through traveling screen and a 130,000 gpm circulating water pump that supplies circulating water to the condensers. The three screens are designated as 1-CW-SR-1A, 1B, and 1C. Each screen is 14-ft. wide and has ⅜-in. mesh baskets. The water depth at the screens is approximately 43-ft. below MSL. The screens have two operating speeds which are 5 feet per minute (fpm) and 20 fpm. Debris is removed from the upstream (ascending) side of the screens with water sprays and is sluiced via a trough to a metal collection basket, where the debris is removed and the water drains into the intake transition structure. The screen wash water is supplied from two screen wash pumps which draw water from the discharge of circulating water pumps 1-CW-SR-1A and 1-CW-SR-1B.

Normally all three circulating water pumps are operated at full load conditions. As noted above, the rated design flow for each pump is 130,000 gallons per minute (gpm). Each pump has a 3,400 hp electric motor drive which operates at 400 revolutions per minute (rpm). The pumps are designated as P-39A, P-39B, and P-39C. The plant can also be operated at full load with two circulating water pumps, however the NPDES Permit only authorizes this condition for 15 days per year to support online pump maintenance.

An associated subsystem of the CWIS is the chlorination system which provides sodium hypochlorite to several locations within the CWIS. The system has the ability to inject sodium hypochlorite in the vertical shafts below the submerged intakes, the intake transition structure, circulating water pump bays, and service water pump bays. The sodium hypochlorite prevents the growth of microorganisms on the inside of the system piping, structures, and equipment. Should this growth of microorganisms occur in the condenser tubes, the resultant fouling would prevent efficient heat transfer and reduce the condensers capability to effectively remove the heat from the turbine exhaust steam. The chlorination system is located in the chlorination building adjacent to the discharge transition structure. The major components in this system are the metering pumps and three sodium hypochlorite storage tanks.

### 3.3.2 Cooling Water Intake Structure Location

The three offshore submerged intake structures are located in the Gulf of Maine (Atlantic Ocean) east of Hampton Beach, New Hampshire, approximately 1.3 miles offshore. The three structures are aligned in an east-west direction and are separated by approximately 110 feet. The water depth at the intake location is approximately 60 feet at MSL and the tops of the intake structures are located 42 feet below the water surface. The intake structures are located at 42° 54′ 17" N Latitude and 70° 47′ 12" W Longitude.

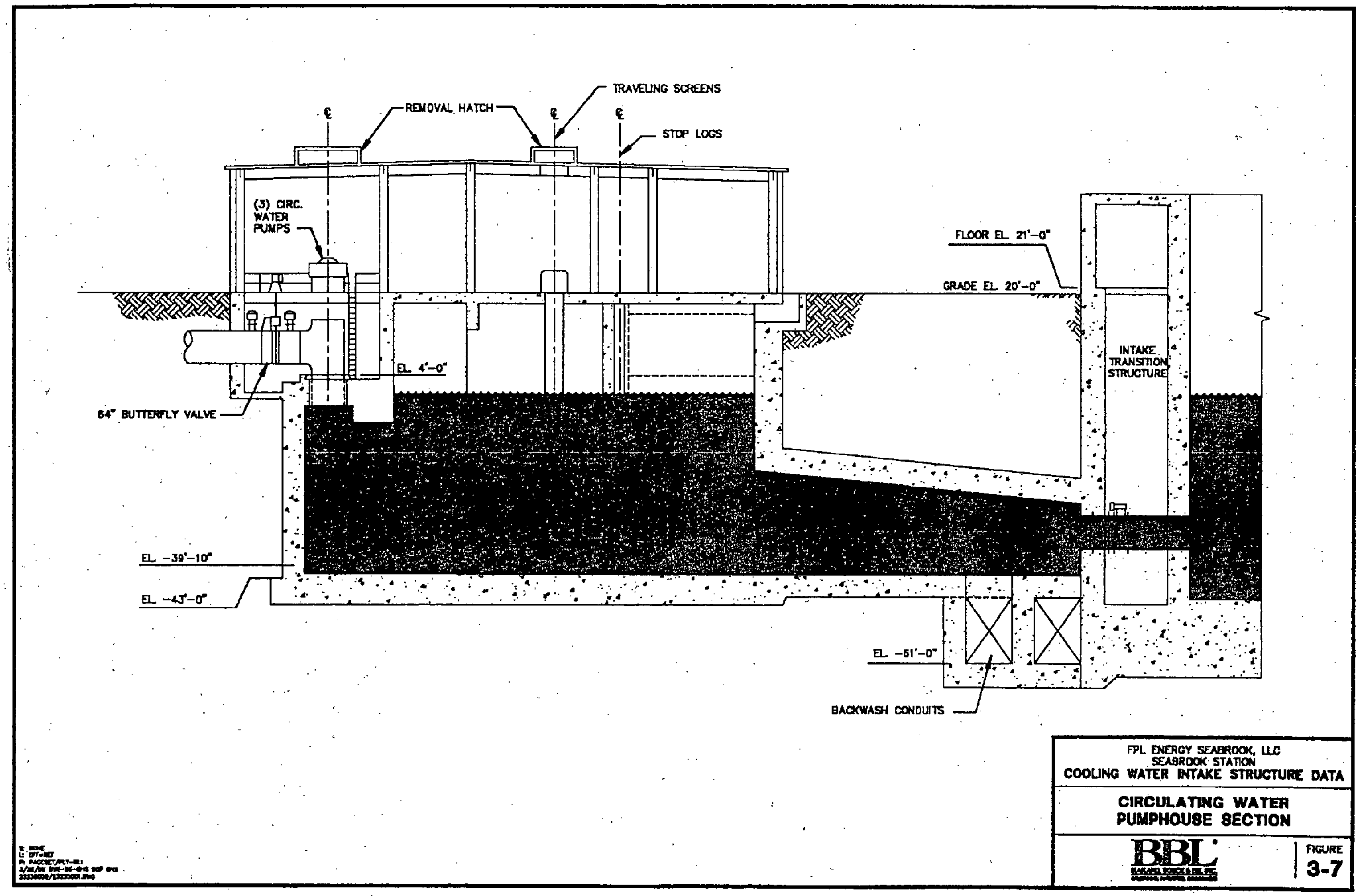
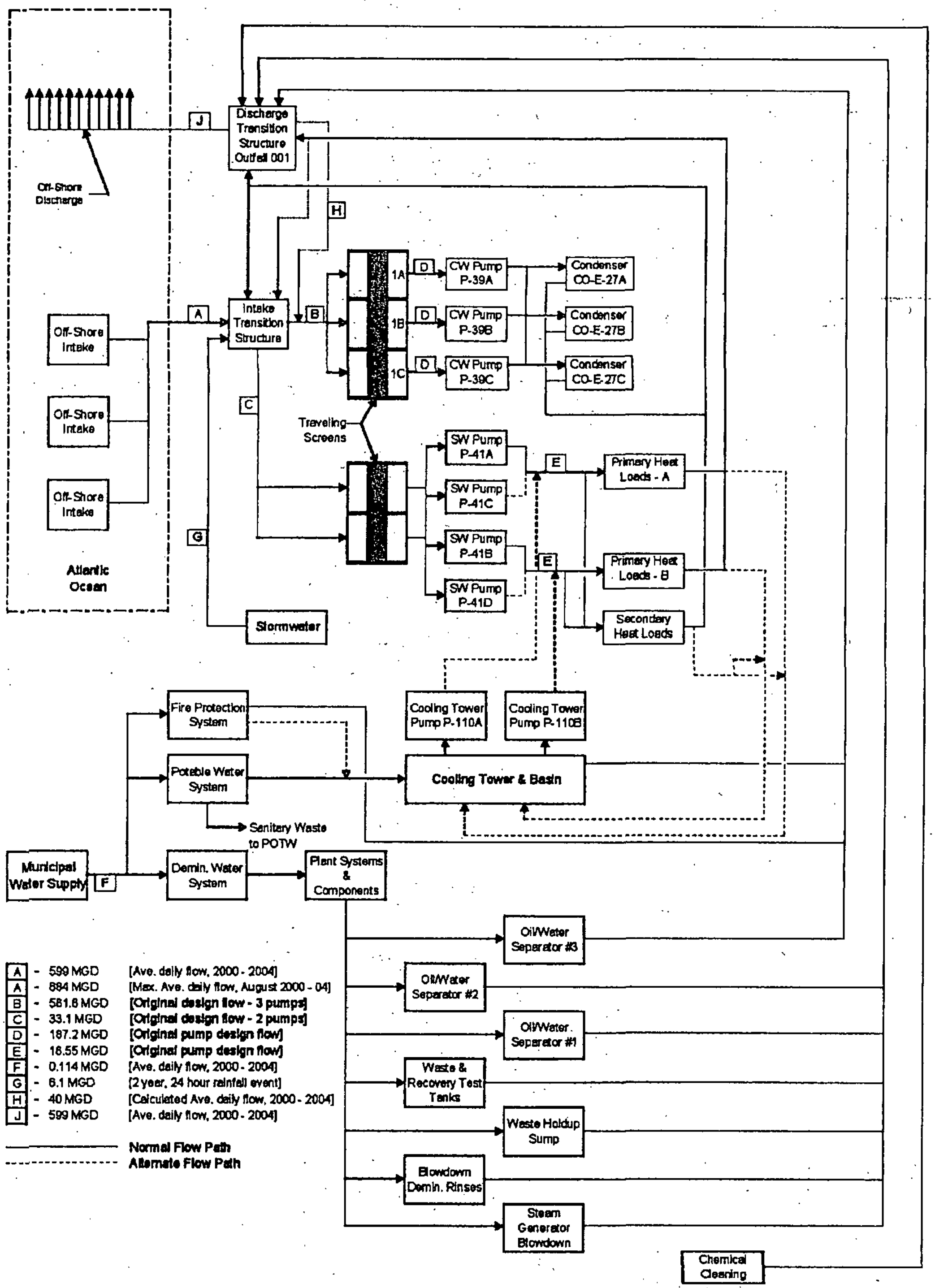



Figure 3-7. Seabrook Nuclear Power Station circulating water pumphouse section.




| | | |
|---|---|---|
| A | 599 MGD | [Ave. daily flow, 2000 - 2004] |
| A | 884 MGD | [Max. Ave. daily flow, August 2000 - 04] |
| B | 581.6 MGD | [Original design flow - 3 pumps] |
| C | 33.1 MGD | [Original design flow - 2 pumps] |
| D | 187.2 MGD | [Original pump design flow] |
| E | 18.55 MGD | [Original pump design flow] |
| F | 0.114 MGD | [Ave. daily flow, 2000 - 2004] |
| G | 6.1 MGD | [2 year, 24 hour rainfall event] |
| H | 40 MGD | [Calculated Ave. daily flow, 2000 - 2004] |
| J | 599 MGD | [Ave. daily flow, 2000 - 2004] |

Normal Flow Path
Alternate Flow Path

**FPL Energy**
**Seabrook Station**
**Coling Water Intake Structure Data**
**Flow Distribution and Water Balance Diagram**
**Figure 3-8**

Figure 3-8. Seabrook Nuclear Power Station flow distribution and water balance diagram.

### 3.3.3 Cooling Water Intake System Operation

The CWIS provides water for condenser cooling and the plant service water system and the service water system that cools a number of primary and secondary heat loads. The CWIS is the only system for providing condenser cooling water, however service water for shutdown cooling can be provided with the closed loop cooling tower system. A flow diagram of the CWIS and the systems it serves are presented in Figure 3-8.

The CWIS at Seabrook was designed with the necessary capacity for two operating units, therefore, the intake was designed for a flow of 854,000 gpm (1,230 MGD), which would support full load operation of the two units. Only one generating unit was constructed at Seabrook, therefore, the CWIS is operating under the flow requirements of a single unit only. With the three circulating water pumps (130,000 gpm each) and the two service water pumps (11,500 gpm each) operating at their design points, the CWIS flow would be 413,000 gpm (595 MGD). At actual operating conditions, the highest average daily cooling water intake flow (circulating water and service water) during full load operation for the years 2000 through 2004 occurred during the month of August and was 475,000 gpm (684 MGD: 5 year average for 2000 – 2004). Therefore, this flow (475,000 gpm) is representative of total CWIS flow for full load operation at maximum annual water temperature. Since the Seabrook CWIS operates at a flow considerably less than the original design of 854,000 gpm, the head loss under the current operating conditions is less than design, causing the pumps to operate at a lower total head loss and higher flow than their original design point.

At a flow of 475,000 gpm, the approach velocity at the intake (velocity cap) is approximately 0.5 feet per second (fps). As the water passes through the vertical bars, the velocity increases to 0.8 fps. It is not possible to isolate any of the submerged intakes, therefore, all three intakes are in operation at all times. It is a NPDES Permit requirement that the velocity at the velocity caps be less than 1.0 fps.

Within the 19-ft diameter intake tunnel, the velocity is 3.7 fps at 475,000 gpm. With the water level at MSL in the screen wells, the velocity through the traveling screens is approximately 1.0 fps.

Seabrook Station is a base loaded facility and the average capacity utilization rate for the last five years has been 89.7%. Over this same time period, the generator operated for 90.3% of the available hours. Therefore, when the generating unit is operating, it typically runs at full load (1221 MW). Net generation increased from 1151 MW to 1221 MW after the April 2005 refueling outage. Figure 3-9 demonstrates that there is not any seasonal pattern to the level of generation. For each month where the capacity utilization rate was down to 80% or less, it was the result of an outage during that month in one of the five years.

Since the circulating water system must be in operation whenever the steam turbine/generator is operating and may also be operated for some period of time when the steam turbine/generator is idle, the CWIS is in operation over 90% of the time. The normal operation is to run all three circulating water pumps to provide the necessary cooling for full load operation, which as noted above, is where the generating unit typically operates. Operating with only two circulating water pumps running is limited due to the resulting performance penalty and due to the limitations within the NPDES Permit. Seabrook is limited to an average monthly temperature differential of 39°F and maximum daily temperature differential of 41°F. The NPDES Permit does allow for these maximum

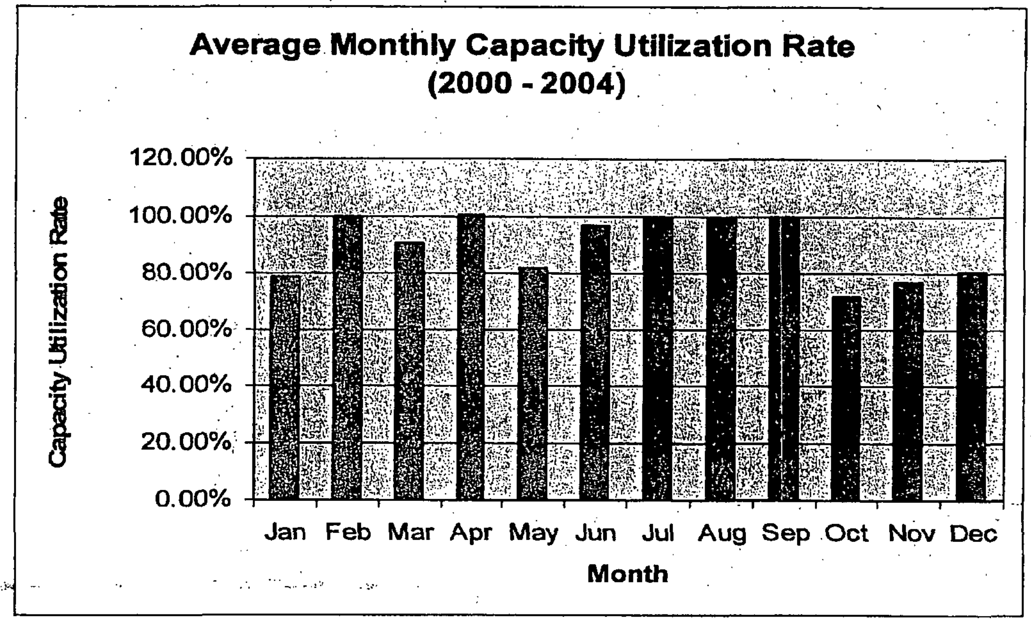



Figure 3-9. Average monthly utilization rate at Seabrook Nuclear Power Station from 2000-2004.

differential temperatures to be exceeded for a "maximum of 15 days per year and only when one circulating water pump has been taken out-of-service for corrective or preventative maintenance".

Historical operating data for the Seabrook CWIS is presented in the chart below (Figure 3-10). The flow values represent the actual amount of water drawn into the intake from the source waterbody. The data is presented as actual average daily flow on a monthly basis for the years 2000 through 2004 and the daily average flow for the same time period when the generating unit is operating at full load. What this chart indicates is that CWIS flow is not only affected by the station capacity factor or hours of operation, but there is also a seasonal trend in flow due to the variations in water temperatures throughout the year. During full load operation, the average flow entering the intake in February (lowest) is 16.4% lower than the average flow in August (highest). The reduced intake flow at full load in the winter months is due to the recirculation of discharge water into the intake. As circulating water temperatures drop, subcooling of the condensate will begin to occur. The subcooling of the condensate has a negative effect on the unit performance, therefore, discharge water is recirculated back to the intake to increase the intake water temperature and prevent the subcooling of the condensate. The recirculation provides the added benefit of reducing the actual water intake flow. See Appendix A for a more detailed development of the recirculation flow.

The traveling intake screens can be operated in either a manual or automatic mode. In the manual mode, the operator will place the selector switch in the run position, which starts the screen wash pumps and then the screens. If the water level differential pressure across the screens is greater than 12-inches, the screen will operate at fast speed, which is 20 feet per minute (fpm). If the screen differential pressure is greater than 6-inches, but less than 12-inches, the screen will operate at slow speed, which is 5 fpm. In the automatic mode, the starting of the screen wash pumps and the rotation of the screens are initiated by a screen differential pressure of 6-inches. The operating speeds are

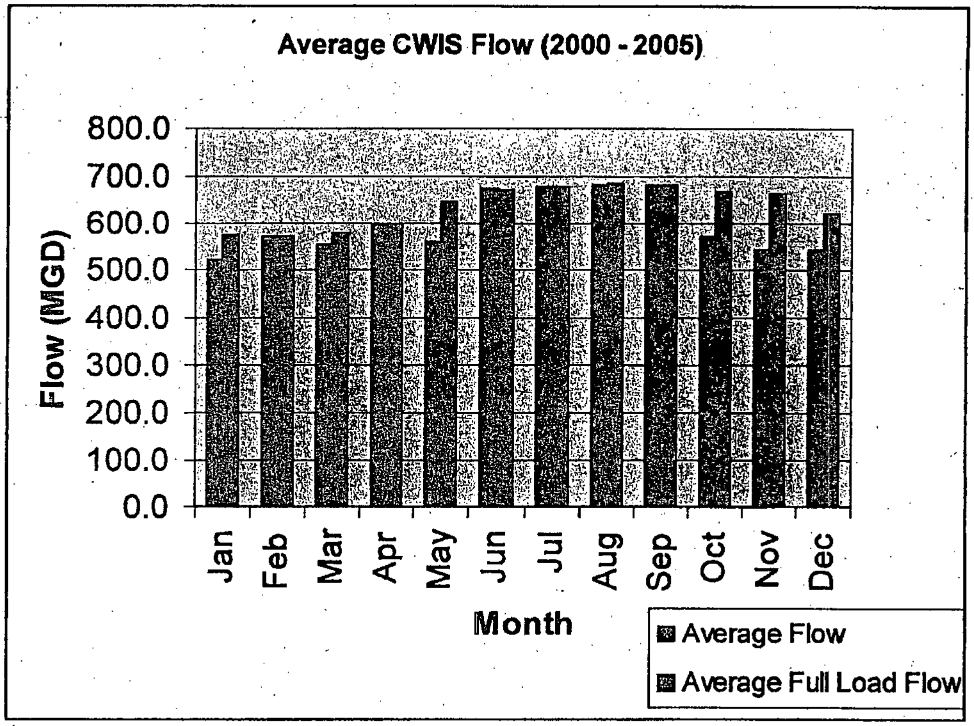



Figure 3-10. Average cooling water intake structure flow 2000-2005 at Seabrook Nuclear Power Station.

similar to the manual mode and the screens stop when the differential pressure drops below 4-inches. In the automatic mode the screens will also start once every 8 hours and run for approximately ½ hour, regardless of the screen differential. Should the differential pressure across any screen reach 60-inches, the associated circulating water pump will trip.

## 3.4 Cooling Water System Data

Seabrook Station has two cooling water systems which utilize the CWIS as a source of cooling water. The condenser circulating water system (circulating water) supplies cooling water to the steam surface condensers, and the service water system supplies cooling water to miscellaneous plant equipment, which are classified as primary and secondary heat loads. The following sections will provide a more thorough discussion of the operation of the plant cooling water systems as required by 40 CFR 122.21(r)(5).

### 3.4.1 Description of Operation

Seabrook Station has two cooling water systems that use cooling water supplied by the CWIS. The two systems are the circulating water system and the service water system. Both systems draw water through the three off-shore intakes, the intake tunnel, and the intake transition structure. After the intake transition structure, each system has an independent set of traveling screens. There are three traveling screens for the circulating water system and two traveling screens for the service water system.

The majority of all water entering the CWIS is for the circulating water system, which provides cooling water to the steam surface condenser for the condensing of the steam after it leaves the steam turbine. After the steam is condensed, the condensate can then be pumped back through the condensate and feedwater heating systems and then to the steam generator, where it is converted back to steam. The following paragraphs provide a description of the circulating water system, which is the primary use of cooling water, and the service water system, which provides cooling water to considerably smaller heat loads.

The circulating water system has three vertical, electric motor driven, circulating water pumps. Each pump is located in a separate pump well, each with a dedicated traveling intake screen. The discharge lines from each of the three pumps combine into a common line, which provides water to the steam surface condenser (three separate shells). The water exiting the condensers combines in a common line that flows into the discharge transition structure (Outfall 001). From the transition structure the water flows to the off-shore discharge.

In addition to supplying water to the condenser, a small portion of the circulating water pump discharge supplies water to the screen wash pumps. The water used for screen wash purposes is directed back to the intake transition structure after fish and debris are removed.

Each circulating water pump has a rated design flow of 130,000 gpm and the system was designed for all three pumps to be utilized for full load operation. The circulating water system was designed to operate with an average ocean temperature of 55° F and, at full load heat rejection, to maintain a circulating water temperature differential within the requirements of the NPDES Permit, which are 39° F maximum monthly average and 41° F maximum daily average.

The service water system provides cooling water for the plant's primary and secondary heat loads. The primary heat loads include the heat exchangers for the Primary Component Cooling Water System, the Diesel Generator Water Jacket, and the Auxiliary Spent Fuel Pool Cooling system. The secondary heat loads include the heat exchangers for the Secondary Component Cooling Water System and the Condenser Water Box Priming Pump. The service water system includes two trains of components with two Service Water Pumps for each train. Under normal full load operation both trains are required with one pump operating from each train. The Service Water Pumps are rated at 11,500 gpm each.

The off-shore intake is the primary source of water for the service water system. Should the intake tunnel fail or become blocked to the point where adequate flow for the service water system cannot be achieved, the cooling tower system is the alternate source of cooling for the service water system.

All intake water entering the CWIS flows through either the circulating water pumps or the service water pumps. Therefore, essentially 100% of the intake flow is for cooling purposes. At original design conditions, with three circulating water pumps and two service water pumps operating, the total intake flow would be 413,000 gpm (595 MGD). The highest average daily cooling water intake flow (circulating water and service water) during full load operation for the years 2000 through 2004 occurred during the month of August and was 475,000 gpm (684 MGD). Therefore, the total CWIS flow for full load operation at maximum annual water temperature is approximately 475,000 gpm.

Since the Seabrook Station operates at such a high capacity factor (average capacity factor for the last five years has been 89.7%), the cooling water system is in operation a very high percentage of the time. Over a four year period from 2000 through 2003, the condenser circulating water system and/or the service water system operated with the cooling water intake system as the primary source of water for an average of 362 days per year.

Seabrook Station operates as a base load unit throughout the year, therefore, there is not a fluctuation in the cooling water flow associated with reduced power output. There are however, seasonal flow fluctuations during the colder months of the year when some water from the discharge transition structure is recirculated back to the intake transition structure, therefore, reducing the flow through the off-shore intakes. However, the overall cooling water flow through the circulating water system and the service water system remains unchanged when recirculation occurs.

Several operational and permit limitations also prevent major fluctuations on the cooling water flow. Within the current NPDES Permit[1], the average monthly and maximum daily circulating water discharge flow (includes condenser circulating water, service water, and some miscellaneous discharge streams which are supplied from the municipal water system) is limited to 720 MGD. In addition, the maximum temperature differential between the intake and discharge transition structures is limited to 39° F on an average monthly basis and 41° F on a daily basis. These temperatures can be increased to 45° F and 47° F respectively for a maximum of 15 days per year.

### 3.5 Regulatory Requirements And Performance Standards

The Phase II rule in Part 125.94(b) specifies performance standards for the reduction of impingement mortality and entrainment (IM&E). These standards are based on the operating characteristics of the plant, the design of the cooling water system, and the source water body for cooling water. Seabrook Station is baseload plant with a five-year capacity factor of 89.7%, and a once-through cooling water system with marine intakes. Based on these characteristics, Seabrook Station is required to meet the performance standards for both impingement mortality and entrainment.

## 4.0 Existing and Proposed Technology, Operational and/or Restortation Measures

### 4.1 Applicable Performance Standards

The performance standard specified in the Phase II rule calls for a reduction of impingement mortality of 80-95%, and a reduction in entrainment of 60-90% from the calculation baseline for plants with ocean intakes and capacity utilization factors over 15%. The calculation baseline is defined in Part 125.93 as an estimate of IM&E that would occur assuming:

- A once-through cooling water system,
- the opening of the cooling water intake structure is located at, and the face of the standard 3/8 inch mesh traveling screen is oriented parallel to, the shoreline near the surface of the source water body, and

[1] National Pollutant Discharge Elimination System Permit No. NH0020338, FPL Energy Seabrook, LLC, Effective date of April 1, 2002.

- the baseline practices, procedures, and structural configuration are those that would be maintained in the absence of any structural or operational controls, including flow or velocity reduction implemented in whole or in part for the purposes of reducing impingement mortality and entrainment.

In practice, this means the calculation baseline is the theoretical level of IM&E that would occur at a facility assuming there were no controls that reduced IM&E. IM&E controls at Seabrook Station include at a minimum:

- The offshore location of the intakes,
- The design of the intakes which includes velocity caps,
- The reduced volume of cooling water withdrawn due to the colder water at the offshore location of the intakes compared to an inshore location, and
- Recirculation of heated discharge water to the intake.

## 4.2 Existing Technology, Operational and/or Restoration Methods

For compliance under Alternative 2 in the regulations, it is required that the facility demonstrate that it has existing design and construction technologies, operational measures, and/or restoration measures that will meet the performance standards. Seabrook does have an intake technology that significantly reduces IM&E and also employs at least one operational measure that also reduces IM&E. These include the use of offshore intakes with velocity caps and the recirculation of cooling water discharge to reduce total intake flow.

The level of IM&E at Seabrook Station that occurs with the offshore intake with the velocity cap is substantially less than the calculation baseline. There are three specific reasons for the success of the offshore intake in reducing IM&E. These are the location of the intake in an area of reduced biological activity, the tendency of fish to avoid the changes in horizontal flow created by the velocity cap, and the reduced cooling water flow requirements due to cooler water temperatures. For Seabrook Station, the baseline flow was calculated to be 744.5 MGD, as compared to the current average cooling water flow of 599.5 MGD (Appendix A).

The reduction in IM&E at Seabrook Station due to reduced biological activity associated with the intake location and the effectiveness of the velocity cap is quantified by a comparison of the actual impingement and entrainment at Seabrook to the density (no./unit volume) of organisms impinged and entrained at Pilgrim Station, which has a shoreline intake and is located on the same waterbody and in close proximity to where a shoreline intake would be located for Seabrook.

The comparison of IM&E between Seabrook and Pilgrim Stations follows a precedent set by EPA in their case studies (USEPA 2002). In the case study, EPA states that both "…facilities are located in the same ecological region, but differ in the locations of their CWIS…". Comparisons between similar stations are expressly allowed in the Phase II rule Section 125.93. Environmental conditions are similar between stations. Both are located in the western Gulf of Maine, and north of Cape Cod, which forms a zoogeographic boundary between a boreal fish community to the north, and a southern fish community. Further evidence of the similarity in fish communities comes from a calculation of similarity indices for the impingement and entrainment communities at the two plants (Table 4-1). Similarity coefficients (100 = complete similarity) ranged from 53 for the Jaccard Index for the egg entrainment community to 79 for the Sorenson index for the larval entrainment community. These coefficients generally indicated a high degree of similarity between the stations. However, because the intake structures are so different with regard to location and portion of water column from which they withdraw water, it can be assumed that the similarities would be even greater if the plants had similar intake structures.

**Table 4-1. Similarity coefficients between Seabrook and Pilgrim Stations for the egg and larval entrainment communities and the impingement community.**

| | Similarity Coefficient | | |
|---|---|---|---|
| Similarity Index[a] | Egg Entrainment Community | Larval Entrainment Community | Impingement Community |
| **Jaccard** | 53 | 61 | 56 |
| **Sorenson** | 69 | 76 | 72 |
| **McConnaughey** | 73 | 79 | 72 |

[a] Clarke and Warwick (1994)

The EPA case studies concluded that: "...I&E at Seabrook's offshore intake is substantially lower than I&E at Pilgrim's nearshore intake." Furthermore, the case studies stated that impingement losses of Age 1 equivalents were 68% less at Seabrook and entrainment losses were 58% less. The EPA comparison between stations did not take into account any reductions in cooling water flow at Seabrook due to the offshore intake but did rely on two monitoring programs that have achieved a degree of credibility with regulators.

A more detailed and updated comparison shows that the impingement rate at Pilgrim is 0.468 fish per million gallons, while the impingement rate at Seabrook is 0.111 fish per million gallons (Appendix Table B-1). This is a reduction of 76% due solely to the location and design of the Seabrook intake.

The primary factor that allows for the reduction in cooling water flow at Seabrook Station from the baseline calculation is the lower temperature water at the offshore intake location. Appendix A contains a discussion of the affect of cooler intake waters on cooling water flow.

Further reduction of cooling water flow is achieved through the recirculation of cooling water discharge back to the intake transition structure. At Seabrook Station, the average recirculation flow is approximately 47.0 MGD. When these two factors are considered, and using average flows for the past five years, the overall reduction in impingement from baseline conditions increases to 81% (Calculation 1, Appendix B). Using design flows only, the percent reduction is 78% (Calculation 2, Appendix B). When using design flows less recirculation, the reduction in impingement decreases to 80% and the Station meets the standard (Calculation 3, Appendix B).

A similar substantial reduction in entrainment is also realized through the reduced cooling water flow at Seabrook Station (Appendix C). The average density of entrained ichthyoplankton at Pilgrim Station is 0.0161 organisms/million gallons while the density at Seabrook Station is 0.0079 organisms/million gallons (Appendix Table C-1). Therefore, there is a reduction of 50% due solely to the design and location of the Seabrook Station intakes.

Using average flows, there is a 60% reduction in entrainment from the calculation baseline (Calculation 4, Appendix C), and a 55% reduction using design flows (Calculation 5, Appendix C). A 58% reduction is achieved using design flows less recirculation (Calculation 6, Appendix C).

Based on the levels of reduction in impingement mortality and entrainment achieved with the current intake design, Seabrook Station meets the performance standards with the current intake technology and operational measures currently in place under the current assumptions.

## 4.3 PROPOSED TECHNOLOGY, OPERATIONAL, AND/OR RESTORATION MEASURES

EPRI has identified many intake technologies for consideration in achieving compliance with the 316(b) performance standards. EPRI has categorized the intake technologies by the methods of operation. They have been categorized as Physical Barriers, Collection Systems, Diversion Systems, and Behavioral Deterrent Systems. However, most, if not all, of these technologies have been developed and tested for inshore type intakes constructed at the shoreline. We are not aware of a single technology in the Physical Barrier, Collection Systems, or Diversions Systems categories that has been installed at an offshore intake. Velocity caps, which are installed at Seabrook Station, and behavioral deterrents have been used at offshore intakes. The primary reason for the lack of installation of physical barriers, collection and diversion systems at offshore intakes is the excessive cost associated with designing and constructing these technologies in an open water environment. At Seabrook Station, the location of the intakes in 60 feet of water, 1.33 miles offshore, compounds these costs, especially when coupled with the nuclear safety concern with reducing flow to safety related systems. Therefore, we do not consider that any physical barriers, collection or diversion systems are practical for Seabrook Station. These technologies and restoration are discussed in more detail in Appendix D.

## 4.4 COST ESTIMATES FOR COMPLIANCE

In Appendix A of the Phase II rule, the EPA provided cost estimates for "the most appropriate compliance technology" for many plants to meet the appropriate performance standards. These cost estimates can then be used in the cost-cost benefit test specified in compliance alternative 5. EPA's cost estimates were based on, among other factors, the actual facility design intake flow and the EPA assumed facility design flow. However, EPA did not estimate the design flow for many plants including Seabrook Station as indicated by the notation N/A in the "EPA assumed design intake flow" in column 3 of Appendix A". In the preamble to the final Phase II rule on page 41646, EPA states:

> "...some entries in Appendix A have NA indicated for the EPA assumed design intake flow in column 2 (sic). These are facilities for which EPA projected that they would already meet otherwise applicable performance standards based on existing technologies and measures. EPA projected zero compliance costs for these facilities..."

Furthermore in the same paragraph EPA states:

> "These facilities should use $0 as their value for the costs considered by EPA for a like facility in establishing the applicable performance standard."

EPA's estimate of $0 dollars for compliance costs suggests that Seabrook Station already meets the applicable performance standards based on existing installed technologies and operational measures.

## 5.0 ECOLOGICAL STUDIES AND HISTORICAL IMPINGEMENT MORTALITY AND ENTRAINMENT STUDIES

Preconstruction environmental evaluation began at Seabrook Station in 1969. A comprehensive environmental monitoring program has been in place for some parameters (softshell clam) since 1974 providing 15 years of preoperational data. Monitoring for most parameters began in the late 1970s or early 1980s and provide approximately 10 years of preoperational data, and as of 2005, 15 years of operational data. Ecological parameters monitored included water quality and nutrients, phytoplankton, zooplankton, ichthyoplankton and fish, macroflora and macrofauna (including estuarine benthos and offshore fouling panels), *Cancer* sp. crabs and lobsters, and softshell clams and bivalve larvae. A summary of the present environmental monitoring program is presented in Table 5-1. Further information can be found in NAI (2005).

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).

A previous Summary Report (NAI 1977) concluded that the balanced indigenous community in the Seabrook study area should not be adversely influenced by loss of individuals due to entrapment in the Circulating Water System (CWS), exposure to the thermal plume, or exposure to increased particulate material (dead organisms) settling from the discharge. The current study continues to focus on the likely sources of potential influence from plant operation, and the sensitivity of a community or parameter to that influence within the framework of natural variability. 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.

Several changes have occurred in the environmental monitoring program since its inception. Table 5-2 summarizes the various ecological parameters monitored and the current status of these monitoring programs. 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.

**Table 5-1. Summary of the Study Design for the Environmental Monitoring Program at Seabrook Station.**

| Program | Parameter | Number of Stations | Sampling Frequency |
|---|---|---|---|
| Water Quality | Discharge Temperature | 1 Farfield<br>1 Nearfield | Continuous. |
| | Water Temperature | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Salinity (S and B) | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Dissolved Oxygen (S and ) | 1 Farfield<br>1 Nearfield<br>(1-m increments) | 4/month. |
| | Estuarine water Temperature | 1 | Weekly at high and low tides. |
| | Estuarine Salinity | 1 | Weekly at high and low tides |
| Zooplankton | Bivalve larvae | 1 Farfield<br>1 Nearfield | Paired tows weekly April-Oct. |
| | Macrozooplankton | 1 Farfield<br>1 Nearfield | Paired tows 2/month. |
| Fish | Ichthyoplankton | 1 Farfield<br>1 Nearfield | Paired tows 4/month. |
| | Fish (otter trawl) | 2 Farfield<br>1 Nearfield | Replicate tows 2/month. |
| | Estuarine fish (seine) | 3 Farfield | 1/month, April-Nov. |
| Macrobenthos | Macroflora and fauna | 2 Farfield<br>2 Nearfield | 3/year destructive sampling. |
| | Macroflora and fauna | 2 Farfield<br>2 Nearfield | 3/year nondestructive sampling. |
| | Settling organisms (panels) | 1 Nearfield<br>1 Farfield | 3/year. |
| Epibenthic Crustaceans | Lobsters and *Cancer* sp. crabs | 1 Nearfield<br>1 Farfield | 3/week, June-Nov. |
| | Lobster larvae | 1 Nearfield<br>2 Farfield | 1/week, May-Oct. |
| Softshell clams | Adults and spat | Hampton Harbor (Farfield) | Annual population survey. |
| Impingement | Adult fish | 1 in-plant | 2/week, year round |
| Entrainment | Ichthyoplankton | 1 in-plant | 4 diel periods, 1/week, year round. |
| | Bivalve larvae | 1 in-plant | 1/week, mid April-Oct. |

Table 5-2. **Summary of Biological Communities and Taxa Monitored for Each Potential Impact Type (NAI 2005).**

| 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 |
| | | Subsurface fouling community | x | x |
| | Turbidity (Detrital Rain) | Mid-depth macrofauna and macroalgae | x | x |
| | | Deep macrofauna and macroalgae | * | *<br>x |
| | | Demersal fish | x | x |
| | | Bottom fouling community | * | * |
| | | 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

Intensive ecological monitoring in the nearfield and farfield environments of almost all trophic levels from 1990 through 2004 has not detected any significant impact due to the operation of the Seabrook Station CWIS (NAI 2005). Direct impacts due to operation of the CWIS are limited to impingement and entrainment. An impingement and entrainment monitoring program has been in place since Seabrook Station began operation in 1990. Appendix E contains a summary of the results of the annual impingement and entrainment monitoring programs. Fish egg and larvae entrainment estimates averaged 898 million eggs and 337 million larvae for the period 1995 through 2004 when sampling occurred year round (Appendix Table E-1). The primary fish eggs entrained were cunner/yellowtail flounder which were about 99% cunner (NAI 2005), silver hake, and Atlantic mackerel. The primary fish larvae entrained were cunner, Atlantic seasnail, and American sand lance.

Entrainment of bivalve larvae has been monitored at Seabrook Station since 1990 (Appendix Table E-2). Consistent sample collection during the bivalve larvae season (third week of April through October) occurred in 1993, and 1995 through 2004. The primary bivalve larvae entrained were *Anomia squamula*, *Mytilus edulis*, *Hiatella* sp., and *Modiolus modiolus*. Larvae of *Mya arenaria* were also entrained, but their entrainment did not appear to affect the set of young-of-the year (NAI 2005).

At Seabrook, Station mean annual impingement for 1994 through 2004 was 22,277 fish/year, and annual estimates ranged from 7,281 (2000) to 71,950 (2003; Appendix Table E-3). The most common fish impinged were Atlantic silverside (3,050/year), rock gunnel (2,260/year), and winter flounder (2,190/year).

Mean annual impingement estimates for other plants ranged from 33,219 fish/year at Pilgrim Station to 65,927 fish at Millstone 2. Based on impingement data from the end of 1994 through 2004, it appears that the majority of the fish impinged are young-of-the-year 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.

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 and pollock.

Equivalent Adult analyses 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 to1995 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 2004). 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 2005). Entrainment and impingement of seven species of commercially-important fishes in 2004 resulted in the estimated loss of less than 1 (yellowtail flounder) to 989 (Atlantic herring) fish in 2004 (Table 5-3). Losses due to entrainment were larger than impingement losses for most species evaluated.

**Table 5-3. Mean Annual Equivalent Adult Losses of Seven Commercially Important Species Impinged and Entrained at Seabrook Station in 2004. Seabrook Operational Report (NAI 2005).**

| | Equivalent Adults | | |
|---|---|---|---|
| **Species** | **Impingement** | **Entrainment** | **Total** |
| Atlantic Cod | 24 | 664 | 688 |
| Atlantic Herring | 8 | 981 | 989 |
| Atlantic Mackerel | NA[a] | 359 | 359 |
| Pollock | 25 | 8 | 33 |
| Red Hake[b] | 342 | 230 | 572 |
| Winter Flounder | 7 | 354 | 361 |
| Yellowtail Flounder | NA[a] | 1 | NA |

[a] Impingement equivalent adult losses are assumed to be 0 in 2004, based on total impingement estimates of less than 10 individuals.
[b] Includes red and white hake.

# 6.0 Agency Consultations

## 6.1 Ongoing Consultations

Seabrook Station is not engaged in any ongoing agency consultations

## 6.2 Historic Consultations

Consultations with the National Oceanic and Atmospheric Administration, National Marine Fisheries Service were initiated in 1997 after a number of seals were taken in the Seabrook Station cooling water system. A Limited Take Permit application was filed by Seabrook Station in June 1997. Subsequently a Limited Take Permit and Letter of Authorization were issued by NMFS in July 1999. The provisions of the Limited Take Permit and LOA included enhanced monitoring, reporting and the requirement to design and install a mitigation device to minimize or eliminate seal takes. Design and installation of a mitigation device was completed in August 1999. Additional vertical bars were installed on the intake velocity caps to reduce the bar spacing from approximately fourteen inches to five inches. The reduced bar spacing mitigation design has been completely successful in eliminating seal takes. In light of the proven effectiveness of the mitigation device design the Limited Take Permit was allowed to expire in June 2004. A copy of the Limited Take Permit and Letter of Authorization (as renewed 11/1/03) are enclosed.

Consultations with various federal agencies were initiated in April 1974 by the United States Atomic Energy Commission upon publication of the "Draft Environmental Statement" for the proposed construction of Seabrook Station Units 1 and 2. The environmental statement was prepared in accordance with the AEC regulations at 10 CFR 50 Appendix D which implemented the requirements of the National Environmental Policy Act of 1969. Letters from the following federal agencies are enclosed:

***Department of the Army (June 7, 1974)***: Comment letter identifies the requirement for a Department of the Army Permit for dredging and disposing of dredged material for installation of intake and discharge facilities. The requisite Army Corps of Engineers Permits were subsequently obtained.

***Department of Commerce (June 28, 1974)***: Comment letter identifies that the location of the intake structures in relation to the Hampton Harbor inlet and natural rock outcroppings could make significant numbers of organisms vulnerable to loss through impingement and entrainment. The location of the intake structures was substantially revised during the Environmental Protection Agency review and public proceeding relative to 316 (b) during the January 1975 to August 1978 time period. The initial proposed intake location 3000 feet from the shoreline was revised during the 316 (b ) proceeding to a location 7000 feet from the shoreline.

***Department of the Interior (June 10, 1974)***: Comment letter identifies that an intake velocity of less than 1 cfs may be necessary to adequately protect aquatic life. The intake velocity originally proposed for two Seabrook Station units was approximately 1 foot per second. The velocity associated with operation of a single unit is approximately .5 foot per second at the velocity caps.

***Department of Transportation (June 14, 1974)***: Comment letter identifies the requirement for a Private Aid to Navigation for the intake and discharge structures due to the possible hazard to navigation. The requisite Private Aids to Navigation are installed and maintained at the intake and discharge locations.

Consultations with various federal agencies were initiated in May 1982 by the United States Nuclear Regulatory Commission upon publication of the "Draft Environmental Statement" for the proposed operation of Seabrook Station Units 1 and 2. The environmental statement was prepared in accordance with the NRC regulations at 10 CFR 51 which implemented the requirements of the National Environmental Policy Act of 1969. Letters from the following federal agencies are enclosed:

***Department of Commerce (July 6, 1982):*** Comment letter identifies that since the agency's initial comments were filed on June 28, 1974, changes in plant design and operation have been instituted which will minimize impacts on fisheries resources and associated habitats.

## 7.0 SAMPLING PLANS

Seabrook Station is not planning any sampling in addition to its current environmental monitoring program as part of the 316(b) Phase II compliance effort as we believe we presently are in compliance.

## 8.0 LITERATURE CITED

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# APPENDIX A

## Calculation Baseline
## Cooling Water Flow at Seabrook Station

**A-1. Effect of Offshore Intakes at Seabrook Station**

The Seabrook once through cooling system currently draws water through the intake structure from approximately 7,000 feet offshore from Hampton Beach in the Gulf of Maine. The water enters through three separate offshore intake structures and travels through a 19 ft diameter tunnel approximately 3.22 miles long to the screen house location.

The existing cooling water intake system at Seabrook differs from the design of the cooling water intake structure identified in the regulations for use in determining the calculation baseline for IM&E. As defined in § 125.93, the "calculation baseline means an estimate of impingement mortality and entrainment that would occur at your site assuming that: the cooling water system had been designed as a once-through system; the opening of the cooling water intake structure is located at, and the face of the standard ⅜-inch mesh traveling screen is oriented parallel to, the shoreline near the surface of the source waterbody; and the baseline practices, procedures, and structural configuration are those that your facility would maintain in the absence of any structural or operational controls, including flow or velocity reductions, implemented in whole or in part for the purposes of reducing impingement mortality and entrainment".

To determine what the IM&E would be with the baseline intake configuration, it is first necessary to determine the cooling water flow requirements if that configuration were utilized. Since the baseline configuration would draw water from the waterbody surface at the shoreline, the intake water would have a higher maximum temperature than the water drawn into the existing off-shore intake. Therefore, a higher circulating water flow would be required to maintain the same discharge temperature. At the Seabrook Station the actual construction of a shoreline intake matching the description above would be faced with many technical and environmental issues that would be extremely difficult, if not impossible, to address. For this reason, any discussion of this baseline intake design is theoretical in nature only.

For this analysis it is assumed that the baseline intake would be located at the Gulf of Maine shoreline near the inlet to Hampton Harbor. At this location the temperature of the water drawn into the intake would be considerably higher than the temperature of the water drawn into the existing offshore intake structures. At the current intake location the monthly average daily water temperature ranges from a minimum of 36.9 °F in February to a maximum of 55.4 °F in September. At the theoretical baseline intake location, where water temperatures will be affected due to the proximity to the estuary and shallower water, the monthly average mean daily water temperature ranges from a minimum of 35.8 °F in February to a maximum of 62.0 °F in July. This temperature data represents the five year average from 2000 through 2004.

To determine the required cooling water flow with the baseline intake configuration, it is necessary to establish criteria for the discharge temperature. It will be assumed here that the discharge temperature will not be allowed to exceed the current discharge temperatures. In the current NPDES Permit for Seabrook, the maximum monthly average difference between the intake temperature and discharge temperature is 39 °F. If the maximum intake temperature is 55.4 °F at the current intake location, then the discharge temperature at the maximum allowable differential of 39 °F is 94.4 °F. Using 94.4 °F as the maximum monthly average discharge temperature for the theoretical baseline intake, the maximum allowable monthly average differential temperature with the baseline intake design must be reduced to 32.4 °F. This maximum temperature rise is similar to the limit in the

NPDES Permit for the Pilgrim Nuclear Station, which has a shoreline intake and a temperature increase limit of 32 °F.

Using the criteria established above and the current design heat load rejection of 8,000 MMBtu/hr, the required circulating water flow rate must increase to 494,000 gpm. If the current service water flow rate of 23,000 gpm is kept unchanged, the total baseline flow would be 517,000 gpm (744.5 MGD). Therefore, the current total cooling water flow rate, including circulating water and service water, at full load operation of 475,000 gpm (684.0 MGD) is 8.1% less than the baseline flow.

**A-2. Effect of Recirculation Flow at Seabrook Station**

The design of the circulating water system at the Seabrook Station allows for the recirculation of heated discharge water back to the condenser inlet. This is accomplished by partially opening the butterfly valve in the backwash conduit to the intake transition structure. Recirculation is performed to increase inlet water temperature when condenser backpressure begins to drop below the optimum level. Using the recirculation of heated discharge water to adjust the inlet water temperature allows the station to maintain the optimum condenser pressure and, therefore, maximize turbine efficiency.

In addition to maximizing turbine efficiency, the recirculation of discharge water provided the station with a method to reduce cooling water intake flow from the source waterbody. Since the flow to the station does not change with the recirculation, the flow through the cooling water intakes is reduced by the amount of water recirculated.

To estimate the amount of recirculation, it is first necessary to determine the full load flow for Seabrook Station. This is accomplished by compiling the flow information for only those months when the unit operated 100 percent of the available hours and the capacity factor was at or above 100 percent. Under these operating conditions, all three circulating water pumps and two service water pumps would be operating continuously. The data that represents full load operation for each month is presented in Table A-1 below.

If it is assumed that no recirculation takes place during the month of August, when water temperatures are the highest, then full load flow without recirculation is 684 MGD. The difference between the full load flow in August and the full load flow during the other months of the year is the estimated recirculation flow. The estimated recirculation flow is an average flow during full load operation. The data is provided in Table A-2 and shown graphically in Figure A-1.

As expected, the amount of recirculation is essentially zero during the summer months and is at a maximum during the month of February, when the intake water temperature is the coldest. The threshold temperature under which recirculation can occur is approximately 46 to 47 °F. The intake water temperature falls below this threshold temperature on a consistent basis between mid and late November and does not go above this temperature until mid to late May.

This reduction in cooling water intake flow accomplished through the recirculation of condenser discharge water is an operational measure that effectively reduces both impingement and entrainment at the Seabrook cooling water intake structure.

Table A-1. **Average Monthly Operating Data, 2000 - 2004 (Months with Capacity Factor ≥ 100%)**

| Date | Days | Hours | Reactor Hours | Generator Hours | Net mw Generation | Capacity Factor | Ave. CW Flow (MGD) | Total CW Flow ($x10^6$ Gal.) |
|---|---|---|---|---|---|---|---|---|
| Jan | 31.0 | 744.0 | 744.0 | 744.0 | 861,297.6 | 100.20% | 575.3 | 17,835.3 |
| Feb | 28.4 | 681.6 | 681.6 | 681.6 | 788,790.1 | 100.17% | 571.8 | 16,238.6 |
| Mar | 31.0 | 744.0 | 744.0 | 744.0 | 861,611.2 | 100.24% | 578.5 | 17,933.5 |
| Apr | 30.0 | 719.0 | 719.0 | 719.0 | 832,977.3 | 100.28% | 596.8 | 17,903.4 |
| May | 31.0 | 744.0 | 744.0 | 744.0 | 862,067.9 | 100.29% | 645.0 | 19,995.0 |
| Jun | 30.0 | 720.0 | 720.0 | 720.0 | 834,767.7 | 100.35% | 672.7 | 20,180.0 |
| Jul | 31.0 | 744.0 | 744.0 | 744.0 | 861,329.4 | 100.21% | 680.2 | 21,086.2 |
| Aug | 31.0 | 744.0 | 744.0 | 744.0 | 860,876.8 | 100.16% | 684.0 | 21,204.0 |
| Sep | 30.0 | 720.0 | 720.0 | 720.0 | 833,336.2 | 100.18% | 682.5 | 20,475.0 |
| Oct | 31.0 | 745.0 | 745.0 | 745.0 | 862,180.6 | 100.17% | 667.5 | 20,692.5 |
| Nov | 30.0 | 720.0 | 720.0 | 720.0 | 833,528.2 | 100.21% | 666.0 | 19,980.0 |
| Dec | 31.0 | 744.0 | 744.0 | 744.0 | 862,172.3 | 100.31% | 623.0 | 19,313.0 |

Table A-2. **Recirculation Flow Estimate**

| Month | Daily Average CW Flow (MGD) | | | Total Recirculation ($x10^6$ Gal.) | Percent Recirculation |
|---|---|---|---|---|---|
| | Full Load - No Recirculation | Actual Full Load | Recirculation | | |
| Jan | 684.0 | 575.3 | 108.7 | 3,369 | 15.89% |
| Feb | 684.0 | 571.8 | 112.2 | 3,254 | 16.40% |
| Mar | 684.0 | 578.5 | 105.5 | 3,271 | 15.42% |
| Apr | 684.0 | 596.8 | 87.2 | 2,617 | 12.75% |
| May | 684.0 | 645.0 | 39.0 | 1,209 | 5.70% |
| Jun | 684.0 | 672.7 | 11.3 | 340 | 1.66% |
| Jul | 684.0 | 680.2 | 3.8 | 118 | 0.56% |
| Aug | 684.0 | 684.0 | 0.0 | 0 | 0.00% |
| Sep | 684.0 | 682.5 | 1.5 | 45 | 0.22% |
| Oct | 684.0 | 667.5 | 16.5 | 512 | 2.41% |
| Nov | 684.0 | 666.0 | 18.0 | 540 | 2.63% |
| Dec | 684.0 | 623.0 | 61.0 | 1,891 | 8.92% |
| **Total** | | | | **17,164** | **7.37%** |

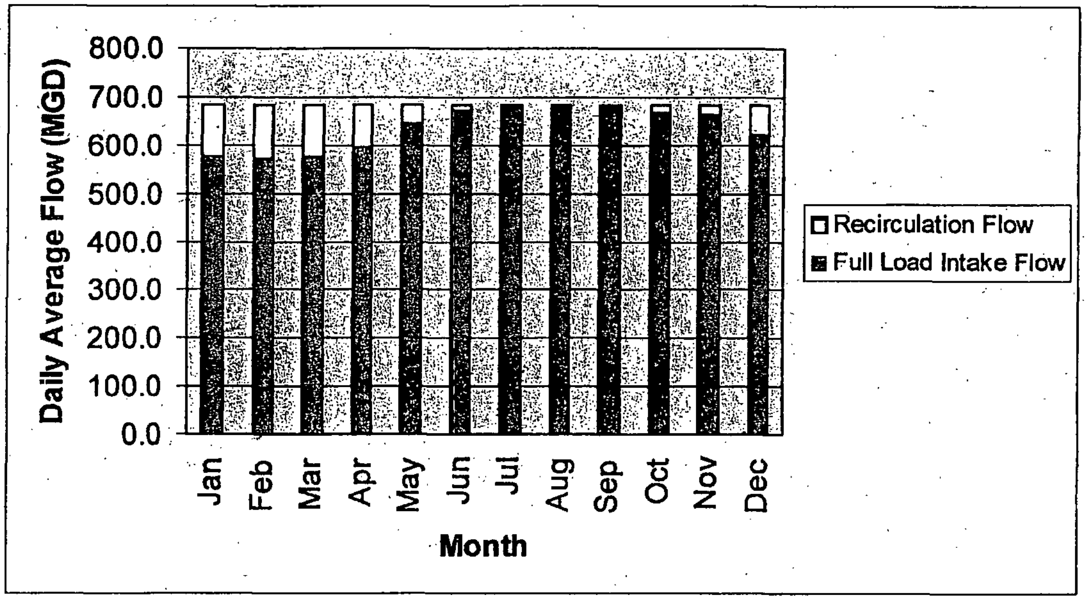



**Figure A-1.** **Average Full Load and Recirculation Flow**

# APPENDIX B

## Calculation Baseline of Impingement Mortality

**Table B-1. Comparison of fish impinged per unit of cooling water flow between Seabrook and Pilgrim Stations.**

| | Seabrook[a] | | | Pilgrim[b] | | |
|---|---|---|---|---|---|---|
| Year | Annual Flow ($10^6$ gallons) | Fish Impinged | Fish/$10^6$ gallons | Annual Flow ($10^6$ gallons) | Fish Impinged | Fish/$10^6$ gallons |
| 2004 | 229,373 | 16,696 | 0.073 | 170,032 | 33,591 | 0.198 |
| 2003 | 220,792 | 71,946 | 0.326 | 170,032 | 224,122 | 1.318 |
| 2002 | 223,066 | 18,413 | 0.083 | 170,032 | 43,180 | 0.254 |
| 2001 | 219,789 | 8,577 | 0.039 | 170,032 | 15,559 | 0.092 |
| 2000 | 201,159 | 7,281 | 0.036 | 170,032 | 81,031 | 0.477 |
| Average | 218,836 | 24,583 | 0.111 | 170,032 | 79,497 | 0.468 |

[a] Actual flows. Impingement estimate is based on actual flows.
[b] Design flows of 155,500 gpm for each of two circulating water pumps, and 2,500 gpm for each five service water pumps. Impingement estimates are based on 100% flow capacity.

**Table B-2. Comparison of calculation baseline impingement and actual impingement at Seabrook Station.**

| Parameter | Calculation Baseline | Actual Seabrook Data[a] | Design Seabrook Flow | Design Flow Less Recirculation |
|---|---|---|---|---|
| Cooling Water Flow ($10^6$ gallons/year) | 271,743 | 218,836 | 249,660 | 232,496 |
| Impingement Density (fish/$10^6$ gallons[b] | 0.468 | 0.111 | 0.111 | 0.111 |
| Impingement Estimate | 127,175 | 24,583 | 27,712 | 25,807 |

[a] Averages from 2000-2004, see Table B-1.
[b] From Pilgrim Station data, see Table B-1.

Calculation 1. Percent reduction from calculation baseline using average Seabrook Station flows: (127,175-24,583)/127,175 = 81%

Calculation 2. Percent reduction from calculation baseline using design Seabrook Station flows: (127,175-27,712)/127,175 = 78%

Calculation 3. Percent reduction from calculation baseline using design Seabrook Station flows less recirculation: (127,175-25,807/127,175 = 80%

# APPENDIX C

## Calculation Baseline for Entrainment

**Table C-1. Comparison of ichthyoplankton entrained per unit of cooling water flow between Seabrook and Pilgrim Stations**

| | Seabrook[a] | | | Pilgrim[b] | | |
|---|---|---|---|---|---|---|
| Year | Annual Flow ($10^6$ gallons) | Ichthyoplankton Entrained (millions) | Ichthyoplankton entrained/$10^6$ gallons | Annual Flow ($10^6$ gallons) | Ichthyoplankton Entrained (millions)[c] | Ichthyoplankton entrained/$10^6$ gallons |
| 2004 | 229,373 | 1,682.5 | 0.0073 | 170,032 | 1,846.9 | 0.0109 |
| 2003 | 220,792 | 797.9 | 0.0036 | 170,032 | 1,338.1 | 0.0079 |
| 2002 | 223,066 | 2,811.2 | 0.0126 | 170,032 | 1,460.2 | 0.0086 |
| 2001 | 219,789 | 899.4 | 0.0041 | 170,032 | 6,348.3 | 0.0373 |
| 2000 | 201,159 | 2,365.6 | 0.0118 | 170,032 | 2,662.8 | 0.0157 |
| Average | 218,836 | 1,711.3 | 0.0079 | 170,032 | 2,731.2 | 0.0161 |

[a] Actual flows. Entrainment estimate is based on actual flows.
[b] Design flows of 155,500 gpm for each of two circulating water pumps, and 2,500 gpm for each five service water pumps. Impingement estimates are based on 100% flow capacity.
[c] Entrainment estimate is derived from index of entrainment for Pilgrim Station. Units for the index are (no.of organisms enrained/100 $m^3$) x days. Entrainment is estimated as the index/365.

**Table C-2. Comparison of calculation baseline entrainment and actual entrainment at Seabrook Station.**

| Parameter | Calculation Baseline | Actual Seabrook Data[a] | Design Seabrook Flow | Design Flow Less Recirculation |
|---|---|---|---|---|
| Cooling Water Flow ($10^6$ gallons/year) | 271,743 | 218,836 | 249,660 | 232,496 |
| Entrainment Density (ichthyoplankton/$10^6$ gallons[b]) | 0.0161 | 0.0079 | 0.0079 | 0.0079 |
| Entrainment Estimate (millions) | 4,375.1 | 1,728.8 | 1,972.3 | 1,836.7 |

Calculation 4. Percent reduction from calculation baseline using average Seabrook station flow: (4,375.1-1,728.8)/4,375.1 = 60%

Calculation 5. Percent reduction from calculation baseline using design Seabrook station flows: (4,375.1-1,972.3)/4,375.1 = 55%

Calculation 6. Percent reduction from calculation baseline using design Seabrook station flows less recirculation: (4,375.1-1,836.7)/4,375.1 = 58%

# APPENDIX D

## Fish Protection Technologies, Operational Measures and/or Restoration

## PROPOSED TECHNOLOGY, OPERATIONAL, AND/OR RESTORATION MEASURES

EPRI has identified many intake technologies for consideration in achieving compliance with the 316(b) performance standards. EPRI has categorized the intake technologies by the methods of operation. They have been categorized as Physical Barriers, Collection Systems, Diversion Systems, and Behavioral Deterrent Systems. The technologies included in each category are as follows.

***Physical Barriers:***

Traveling Screens, Stationary Screens, Drum Screens, Cylindrical Wedgewire Screens, Barrier Nets, Gunderboom, Porous Dike, Radial Wells, Artificial Filter Bed, and Rotary Disc Screens.

***Collection Systems:***

Modified Traveling Screens and Fish Pumps.

***Diversion Systems***

Angled Screens, Modular Inclined Screens, Eicher Screen, Angled Drum Screens, Louvers, Inclined Plane Screen, and Horizontal Traveling Screens.

***Behavioral Deterrent Systems***

Strobe Light, Mercury Light, Sound Systems, Infrasound Generators, Air Bubble Curtains, and Hybrid Systems.

***Other Technologies***

Intake Location (Off-shore intake), Velocity Cap, and Flow Reduction

***Restoration Measures***

Restoration initiative at Browns River Marsh

In addition to the technologies described above, operational measures can be utilized to further reduce intake flow. Flow and annual water use can be reduced by either taking pumps out of service when not required or installing variable frequency drives to reduce flow.

This assessment included an initial screening that evaluated the potential for IM&E reduction technologies at Seabrook (Appendix D). An important consideration in this assessment is biological effectiveness. In addition, for practical considerations, the successful installation and operation of the technology on large cooling water intakes is a prerequisite for passing the initial screening process.

Intake technologies that meet the initial screening criteria noted above include conventional traveling screens with a fish return system, cylindrical wedgewire screens, barrier net (impingement only), aquatic microfiltration barrier (Gunderboom), coarse mesh modified traveling screens with return system (impingement only), fine mesh modified traveling screens with return system, angled screens (impingement only), angled screens, and louvers (impingement only). Further evaluation of each of these technologies for use at Seabrook is provided below.

Due to the effectiveness of the offshore intake at Seabrook, the intake technologies reviewed in this section will be evaluated for use with the existing off-shore intake and not in place of it.

### Conventional Traveling Screens with a Fish Return System

The addition of a fish return system for use with the existing conventional traveling screens is a possible option that could provide some reduction in impingement mortality for some of the more hardy species of fish when other intake design and operating conditions are conducive for fish survival. Although conventional traveling screens do not provide the same level of survival of impinged fish as modified screens, they have been shown to provide some level of impingement mortality reduction when operated continuously and combined with a fish return system.

At the Seabrook Station, any fish entering the off-shore intake structures travel down a vertical shaft to a depth of 160-ft. below MSL and then travel 17,000 feet through the intake tunnel to a depth of 240-ft. below MSL. At that point the fish move up a vertical shaft to the intake transition structure at surface level. If the fish are moving at the same velocity as the water, they will travel from 240-ft. below MSL to the surface elevation in approximately 64 seconds. At a depth of 240-ft., the pressure to which the fish are subjected is approximately eight times greater than at the surface. Due to this rapid and large change in pressure, it is unlikely that there will be a high percentage of surviving fish at the location of the intake screens. Therefore, continuous operation of the screens and the addition of a fish return system will provide little reduction in impingement mortality.

In addition to the anticipated low level of effectiveness in reducing impingement mortality, the installation of an effective fish return system at Seabrook would be difficult, if at all feasible. For a fish return system to be effective, careful consideration must be given to the return point of the system. At Seabrook, the only acceptable return point would be back to the Atlantic Ocean, which is over 8,000 feet from the screen house. Although some of the estuaries, tidal creeks, and Hampton Harbor are closer, the effect of the tide on water depth and salinity levels makes these locations unacceptable as a return point for the fish.

Since the addition of the fish return system along with the continuous operation of the screens will provide very little benefit in reducing impingement mortality and no reduction in entrainment, this alternative shall not be given further consideration.

### Cylindrical Wedge Wire Screens

Submerged cylindrical wedge wire screens is the rule-specified EPA approved design and construction technology for facilities that draw cooling water from freshwater rivers or streams. These screens have also been successfully used in several lake installations. There are not, however, any full scale installations in the United States employing the use of submerged wedge wire screens for an ocean intake or for a nuclear facility.

If wedge wire screens were added to the existing off-shore intake, a slot width of 0.76 mm and through screen velocity of 0.5 fps should be sufficient to physically exclude 60 to 90 percent of the eggs and larval fish. For a cooling water flow of 475,000 gpm, approximately 18, 96-inch diameter wedgewire T-screens would be required to maintain an intake velocity of 0.5 fps. If slot width were increased to 1.75 mm, the quantity of screens required would be reduced to 12. For the two large facilities that utilize cylindrical wedgewire screens, Eddystone and Campbell, the slot widths are ¼" and ⅜" respectively.

For the 96-inch diameter screen, the minimum required water depth is 16 feet. At the location of the current off-shore intake structures the depth is approximately 60 feet, therefore, water depth is not a limiting factor.

An order of magnitude cost estimate for just the installation of wedge wire screens at the existing off-shore intake structures would be approximately $8 million. This estimate was developed using the guidelines provided in the EPA's Technical Development Document (EPA 2004). This cost is just for the installation of the screens and does not include the cost of an air burst system for the cleaning of the screens. For the Eddystone Station, an air burst system is used, but at Campbell, an air burst system was not installed and operating experience has proven that the air burst system is not necessary. The requirement of an air burst system is dependent on the amount of debris present in the vicinity of the screens and the slot opening for the screens. At Seabrook, it is assumed that an air burst system would be required if screens with small slot openings were used and due to the consequences associated with plugging of the screens. The cost of installing an air burst system at Seabrook could far exceed the cost of the wedge wire screens. For an air bust system, a 12-inch air supply line would be required for each 96-inch diameter screen. With the wedge wire screens located approximately 3.25 miles from the screen house, and using the EPA's estimate of $456 per foot for the installation of 12" diameter stainless steel pipe, the cost to install an air burst system for wedge wire screens at the Seabrook offshore intake could exceed $100 million. If a system could be engineered to move the control valves closer to the screens, the cost of the air burst system could possibly be reduced. However, even optimizing the design to the point where only one 12-inch line was required from the onshore location to the intake location, it is anticipated that the minimum cost would be approximately $24 million.

In addition to the high capital cost for wedge wire screens, the additional O&M costs could range from $50,000 to $200,000 per year, depending on screen mesh utilized and the level of debris loading. The O&M costs reflect additional energy requirements for operation of the air compressors, diving costs for cleaning and maintenance of the screens, and additional labor for maintenance of the compressed air system.

While the installation of wedge wire screens at Seabrook may be technically feasible, the addition of these screens significantly increases the probability of a loss of flow through the cooling water intake system due to plugging of the screens. This probability is increased even more with the use of the screens with the smaller slot openings, since screens with the slot openings discussed here for the physical exclusion of eggs and larvae have not been proven in a high flow application such as Seabrook. The use of such screens would require further review to determine if they would conflict with the Nuclear Regulatory Commission safety requirements and with the reliable operation of the station.

Using the order of magnitude costs developed for this technology option, the annual cost could range from $5 million to $16 million. These annual costs do not include the addition of potential pilot testing costs, lost generation costs due to an extended plant outage, and possible performance penalty costs due to a reduction in cooling water flow. It is anticipated that this annual cost will far exceed any incremental benefit and this option will be eliminated from further consideration. In addition, the operational risks associated with the addition of cylindrical wedge wire screens at this site may not be acceptable.

**Barrier Net**

Barrier nets have been successfully applied at several large power plants including the Ludington, Karn-Weadock, Chalk Point, and J. R. Whiting facilities. A typical mesh size for a barrier net is 3/8-inch, therefore, they provide impingement protection only.

The barrier net at Seabrook would have to be located around the existing offshore intake structures. This would be a first of a kind installation since all barrier nets currently in use are either located within or at the entrance to a canal or in front of a shoreline intake structure. A barrier net located around the Seabrook offshore intake structures would have a depth of 60 feet and would not have any protection against wave action. Since barrier nets are very susceptible to damage from waves and storm conditions and since they do not provide any reduction in entrainment, this technology would not be suitable for use at the Seabrook Station and will be eliminated from further consideration.

**Aquatic Microfiltration Barrier**

An aquatic microfiltration barrier system consists of a filter fabric which is installed in the waterbody around the entrance to the intake. The fabric filter is supported by floating booms and extends the full water depth. The openings in the woven fabric are small enough to prevent larval fish and eggs from passing through the fabric and entering the intake. One such system is the Gunderboom Marine Life Exclusion System™ (MLES™).

The microfiltration barrier, as with the barrier net, would have to be located around the existing offshore intake structures. The microfiltration barriers are also very susceptible to damage and failure from waves, storm conditions, and heavy debris loading. In addition, a microfiltration barrier requires an air supply for periodic cleaning of the fabric to remove accumulated debris. Due to these characteristics, a microfiltration barrier is not considered a suitable technology for use at Seabrook and will be eliminated from further consideration.

**Modified Traveling Screens**

Traveling screens with fish handling modifications and fine mesh overlays to reduce impingement and entrainment can be installed in the existing screenwells. In addition to the new screens, this technology requires a fish return system to transport fish and organisms removed from the screens back to the waterbody. It is anticipated that 1 mm mesh screens would be appropriate for the physical exclusion of a high percentage of eggs and larvae, with the potential of reducing entrainment by 60 to 90 percent. It is anticipated that the fine mesh overlays would be utilized during the normal high entrainment months of April, May, June, and July.

In general, an approach velocity of 0.5 to 1.0 fps is recommended when fish protection is the governing criteria for the design of an intake with traveling water screens (ASCE 1982). This is a general rule and can be adjusted to reflect the swimming capabilities and sensitivity of the fish species present. With a typical open area of approximately 50%, this approach velocity range correlates to a through screen velocity of 1.0 to 2.0 fps. This velocity range is in general agreement with research by R. Ian Fletcher, where he drew the general conclusion that the risk of impingement mortality increased sharply when the through screen velocity increased to the range of 1.6 to 2.6 fps (Fletcher 1994). At Seabrook, the calculated through screen velocities at design flow and mean sea level will be approximately 1.0 fps with coarse mesh screens and 2.5 fps with fine mesh screens. If the three additional intake bays that were constructed for the second generating unit could be incorporated into the cooling water intake system for Unit 1, the velocity would be 1.25 fps for the fine mesh screens.

Based on the same reasons discussed for conventional traveling screens, there would be very little reduction in impingement mortality with the conversion to modified screens.

During the time of the year when the fine mesh panels would be in place, there would be a reduction in entrainment. There are several factors, however, that make the feasibility of utilizing fine mesh screens at Seabrook questionable. The primary factor is the through screen velocity. With only three screens, the estimated through screen velocity of 2.5 fps is significantly higher that the normal design velocity of 1.0 fps. This velocity may be acceptable for screen operation, but the survival of any organisms impinged on the screens may be low. In addition, the fine mesh screens will plug with debris much faster than the coarse mesh screens and with a 50 percent clean screen it is estimated that the head loss across the screen would increase to approximately 9 inches, which would be acceptable, but high. Therefore, if fine mesh screen were to be applied at Seabrook, it is likely that additional screens would be required. One possible scenario for the addition of screens would be the use of the three screen wells installed for Unit 2. The feasibility of this option has not been investigated and would require additional investigation.

In addition to the technical issues of high through screen velocities and the feasibility of adding more screens, the fish return system would also present some formidable challenges as discussed under Conventional Traveling Screens. Due to the tendency for fine mesh screens to plug with debris much faster than coarse mesh screens, the probability of a trip of the circulating water system due to high screen differential increases. This is a safety consideration that could eliminate fine mesh screens from further consideration.

Should it be possible to utilize the Unit 2 intake structure, it is estimated that the minimum cost for the installation of six new modified screens with a fish return system would be approximately $9.5 million. With an incremental operation and maintenance cost of $220,000 per year, the total annual cost for the option would be $1.6 million.

Due to their potential effect on the circulating water system reliability, the technical difficulties associated with an extremely long return system, and small incremental benefit as compared to high cost, modified fine mesh screens will be eliminated from further consideration.

**Angled Screens**

With respect to impingement, coarse mesh angled screens have shown potential for impingement mortality reduction. At both the Brayton Point Unit 4 and the Oswego Steam Station Unit 6, installations of angled screens, high diversion capability and impingement mitigation effectiveness was demonstrated. Once diverted to the collection point, it is necessary to either lift or pump the fish back to an appropriate location in the waterbody.

The installation of angled screens at Seabrook would require the construction of a new screening structure. The existing intake structure could not be retrofitted for angled screens. Due to the need for the new intake structure and the need for a fish return system with a pump, the cost to install angled screens at Seabrook would be significantly greater than the cost of installing modified traveling screens with a fish return system. In addition, as is the case with the conventional and modified traveling screens with a fish return system, due to the pressure changes the fish will experience prior to reaching the screens, it is anticipated that fish survival prior to reaching the screens will be low. Since the angled screens would be higher cost than modified traveling screens, would only address impingement, and will provide little reduction in impingement mortality, there is no justification for further consideration of angled screens at Seabrook.

**Louvers**

Louvers consist of a series of panels that are placed across a channel at an angle to the flow. Each panel has a series of evenly spaced vertical rectangular bars that are set with the long side perpendicular to the flow. The panels are placed at an angle of approximately 15 to 20 degrees to the flow and lead to a collection and return system at the end of the panels. The positioning of the bars perpendicular to the flow causes an abrupt change in the flow direction and velocity, which the fish sense and have a tendency to try and avoid. As the fish attempt to swim away from this area where the change in velocity and direction occurs, they move with the current along the face of the louvers toward the point of collection and return. At this location the fish are pumped back to a suitable return point.

Louver systems can be effective in diverting fish to the return system and reducing impingement on the screens. They have been used successfully at several hydroelectric and irrigation facilities in the northwest and northeast and have been applied at one cooling water intake for a nuclear facility in California. Studies have shown that the effectiveness of louvers is very species and life-stage specific due to the technology's dependency on the swimming capability and behavior of the target species. Prior to the implementation of a louver system, studies would be required to evaluate the effectiveness for the target species and to determine the most effective angle of orientation, approach and bypass velocities, bar spacing, and other design characteristics for the site-specific hydraulic conditions.

Due to the use of the offshore intake at Seabrook, louvers, which must be installed at a location before the intake, cannot be applied and are not considered a viable option for further consideration.

**Flow Reduction**

Flow reduction is one method of decreasing impingement and entrainment. Flow reduction can be achieved by removing one circulating pump from service, recirculating water from the discharge back to the intake, or installing variable speed drives.

The potential effects of reducing the circulating water flow are increased turbine backpressure, an increase in circulating water differential temperature, and an increase in circulating water discharge temperature. With the increase in turbine backpressure, comes a reduction in turbine capability and performance.

Seabrook Station currently employs recirculation during the months when the water temperature is low enough. The average recirculation flow for the previous five years has been approximately 47 MGD. This accounts for an overall reduction of 7.3% of the average intake flow.

A previous study has been performed at Seabrook to determine the benefits of flow reduction by periodic operation of two circulating water pumps instead of three. From this analysis, it was determined that an annual flow reduction of 4.3% could be achieved. To achieve this flow reduction it was also necessary to increase the maximum allowable circulating water differential temperature by 5 °F. Under this operating scenario there was not any recirculation of cooling water discharge. Two cooling water pumps was eliminated from consideration due to the increased potential for plant equipment damage if one of the two operating pumps were to trip.

As noted previously, as an alternate source of cooling water for the service water system, a cooling tower was installed to provide shutdown cooling in the event the intake and/or discharge tunnels are blocked due to a seismic event. With a normal service water flow of 23,000 gpm, the potential continuous use of the cooling tower could reduce cooling water intake flow by the full service water flow. This option was investigated and it was determined that it is not practicable to operate the cooling tower on a continuous basis due to the NRC requirements associated with the cooling towers and the significant impact the additional makeup water would have on the Town of Seabrook municipal water supply. In general, the cooling tower is safety related and is strictly controlled by the NRC Operating License Technical Specifications. With continuous operation of the cooling tower it would be extremely difficult, if not impossible, to maintain the cooling tower basin water requirements associated with level and temperature. In addition, the requirement for makeup water, which is supplied by the Town of Seabrook municipal water supply, could increase from a current normal supply of 2 to 4 million gallons per month to 17 million gallons per month. Due to the current water conservation requirements and the low well level concerns that are created when water usage increases to 8 to 10 million gallons per month during refueling outages, it is anticipated that a significant increase in makeup water requirements would create supply problems for the Town of Seabrook.

The use of variable frequency drives (VFD's) for the circulating water pump motors provides the ability to alter the speed of the pumps and therefore, the flow of each pump. The use of VFD's provides more flexibility in the reduction of flow than reducing the number of pumps in operation due to the ability to operate at all flows above the minimum operating threshold. As noted earlier for two pump operation, any reduction in flow will create a higher temperature differential in the circulating water, therefore, one of the limiting factors for flow reduction is the temperature differential limit in the current NPDES Permit. Further study is required to determine if flow reduction with VFD's can achieve a greater flow reduction that is currently obtained with recirculation. An estimated capital cost for the addition of VFD's for the three circulating water pumps at Seabrook is $700,000. This cost was developed in accordance with the guidelines provided in the EPA 2002 Technical Development Document (EPA 2002). The costs presented here also assume that no major modifications are necessary for the pumps, the power supply or controls, and the equipment foundations. This cost will also increase significantly if the motors do not have an appropriate class of insulation or if adequate space is not available in the vicinity of the pumps for the VFD equipment.

Based on the results of the previous flow reduction study and the review of continuous use of the cooling tower, it is apparent that the potential for flow reduction beyond what is currently being achieved with recirculation, is low. However, should the current technologies and operational measures not meet the required performance standards, the potential use of flow reduction and VFD's would be investigated in the CDS.

**Restoration Measures**

The use of restoration measures to meet, or partially meet the compliance standards allowed in Part 125.94 of the Phase II rule under Alternative 3. However, this aspect of the rule is subject to a suit by the Attorneys General of six northeastern states. Therefore, it is not known if this aspect of Alternative 3 will remain in the rule.

Assuming that restoration remains part of the compliance alternatives, the restoration of the Browns River marsh provides an excellent opportunity to mitigate some of the losses of fish due to IM&E with restored habitat. The tidal Browns River, north of the Seabrook Station peninsula is restricted in flushing a 40 acre salt marsh west of the Boston & Maine Railroad embankment by the existing 150 year old culvert beneath the embankment. A new pre fabricated box culvert with dimensions 8' wide x 6' tall x 62' long was installed in April 2006 just south of the old culvert, which will be left in place. The improved flushing provided by the new culvert will help control the growth of invasive plants and provide improved fish habitat in the 40 acre marsh.

The greater tidal exchange may promote the development of more *Spartina* marsh and greater fish production. The increase in the amount of *Spartina* marsh can be estimated by pre and post restoration vegetation surveys. Presently, a pre construction survey has been completed and a post restoration survey will be necessary to evaluate the change in vegetation. Potential increases in fish production can be estimated based on the amount of habitat that is restored to a *Spartina* marsh.

If compliance alternative 2 results in Seabrook Station falling just short of the performance standards, the marginal increase in fish production caused by the restoration of the Browns River marsh could be used to make up the additional reductions in IM&E needed to achieve compliance.

**Proposed Technologies, Operational and Restoration Measures for Further Study**

As a result of the screening study and the evaluation of the potential technologies and operational measures, no additional technologies or operational measures were identified for further evaluation in the CDS.

## Appendix Table D-1. Evaluation of Fish Protection Technologies and Operational Measures.

| Technology | Proven Effectiveness: Impingement Mortality Reduction | Proven Effectiveness: Entrainment Reduction | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| **Physical Barriers** | | | | | |
| Conventional Traveling Screens - ⅜" Mesh | No | No | Yes – Most common of all intake screening technologies | No entrainment protection beyond baseline. If rotated continuously and with a return system, some reduction in impingement mortality will be realized. Impingement mortality will be high, except for some of the hardiest species of fish. Capable of meeting impingement mortality performance standard if velocity through the screen can be reduced to 0.5 FPS or less. [§ 125.94(a)(1)(ii)] | No - Entrainment<br>Yes - Impingement only with continuous operation and the addition of a fish return system.<br>Station currently has conventional traveling screens with ⅜" mesh in place.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, continuous operation with a fish return system would provide a very small reduction in impingement mortality. |
| Stationary Screens | No | No | Yes - Brunswick Plant – | At Brunswick Plant the screens are installed in a diversion structure at mouth of intake canal. Effective in blocking juvenile and adult menhaden, spot, and croaker at Brunswick. Screen mesh is unknown.<br>No other proven installations. | No.<br>No reduction of impingement mortality or entrainment. |
| Drum Screens | No | No | No | Used primarily at hydroelectric and irrigation facilities. No proven effectiveness in reduction of impingement mortality of entrainment. More effective version is the angled drum screen. | No.<br>No reduction of impingement mortality or entrainment. |
| Cylindrical Wedge-wire Screens | Yes | Yes | Yes – Eddystone (¼" slot), J.H. Campbell (⅜" slot) | EPA approved technology when installed in freshwater river or stream with adequate counter currents, appropriate slot size to reduce entrainment, and velocity at 0.5 FPS or less. | Yes<br>Installation of screens with appropriate slot widths should reduce impingement mortality and entrainment. |
| Barrier Nets | Yes | No | Yes – J.P. Pullman (6 mm mesh), J.R. Whiting (⅜" mesh), Bowline (0.95 cm mesh) | Successfully applied at several power plants to reduce impingement. Mesh size is site specific and must be such that it prevents passage of fish but does not cause fish to become gilled in the net. Impingement reductions between 85 and 99 percent have been realized. | Yes – Impingement Only<br>Barrier nets are effective in reducing impingement mortality but provide no reduction of entrainment. Typically used with a shoreline intake or intake canal. |

**Appendix Table D-1. (Continued)**

| Technology | Proven Effectiveness: Impingement Mortality Reduction | Proven Effectiveness: Entrainment Reduction | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| Aquatic Microfiltration Barriers (Gunderboom) | Yes | Yes | Yes – Lovett Gen. Station. | Technology has shown promise for impingement and entrainment reduction. Design and operational problems at only large scale installation. EPA indicates that the technology is still "experimental in nature". | Yes<br>Installation of a Microfiltration Barrier could reduce IM&E. The few existing installations have been with a shoreline intake. |
| Porous Dike | Yes – laboratory and small scale testing only | No | No | No full scale installations for cooling water intakes. All studies were performed in laboratories or were small scale studies. | No<br>Unproven technology |
| Artificial Filter Bed | Yes | Yes | No | Some small scale use only. Reliability problems even at small scale. | No<br>Unproven technology |
| Rotary Disc Screens | No | No | No | For low flow applications with relatively constant water levels. Not appropriate for CWIS application | No<br>Unproven technology |
| **Collection Systems** | | | | | |
| Modified Traveling Screens with Return System (Coarse Mesh) | Yes | No | Yes – Salem, Mystic, Indian Point, Roseton, Surry, Arthur Kill, Dunkirk, Kintigh, Calvert Cliffs, and Huntley. | Installed on many cooling water intakes. Where tested, impingement mortality has been significantly reduced for the majority of species. Mortality can be high for some of the more fragile species. Available in either through flow or dual flow configuration. | Yes – Impingement Only<br>Provide reduction in impingement mortality but no reduction of entrainment.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, modified screens with a fish return system would provide a very small reduction in impingement mortality. |
| Modified Traveling Screens with Return System (Fine Mesh) | Yes | Yes | Yes – Very Limited. | Seasonal use of 0.5 mm mesh screens at Big Bend Power Station with good latent survival of drums and bay anchovy eggs and larvae. Some other pilot tests, but very limited data. High maintenance to avoid biofouling and clogging | Yes<br>Installation of screens with fine mesh should reduce IM&E.<br>It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, continuous operation with a fish return system would provide a very small reduction in impingement mortality. |

**Appendix Table D-1. (Continued)**

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| **Diversion Systems** | | | | | |
| Angled Screens | Yes | No | Yes – Brayton Point and Oswego Steam Station | Have shown potential to meet impingement standard. Large bypass flow and fish pump are required. Higher cost than modified traveling screens with return system. | Yes – Impingement Only<br>Potential reduction in impingement mortality but no reduction of entrainment. It is the current opinion that fish mortality occurs prior to impingement on screens, therefore, modifying the intake with angled screens would provide a very small reduction in impingement mortality. |
| Modular Inclined Screens | Yes – Laboratory and pilot tests only | No | No | Laboratory test showed diversion efficiency between 47 and 88 percent for most species. Only one pilot test at a hydroelectric facility that also showed high diversion and survival rates. | No<br>No proven full scale installation |
| Angled Drum Screens | Yes – Juvenile salmonids at hydro & irrigation facilities | No | No | Used at hydroelectric and irrigation facilities. Never applied to a generating station CWIS. Require relatively constant submergence | No<br>No proven full scale installation |
| Louvers | Yes – for juvenile and adult fish | No | Yes – San Onofre – no effectiveness data | Successfully applied at several hydroelectric and irrigation facilities. Diversion efficiency is very species, life stage, and site specific. | Yes – Impingement Only<br>Potential reduction in impingement mortality but no reduction of entrainment. |
| **Behavioral Systems** | | | | | |
| Strobe Light | Yes – on some species | No | No – only installations for testing. | Testing has been inconclusive and any results have been species specific. | No<br>No reduction of entrainment and unproven technology for species of concern at Seabrook. |
| Sound Barriers | Yes – on some species | No | Yes | Some demonstration studies have been successful in reducing alewife impingement. Site specific design is required for targeted species. | No<br>No reduction of entrainment and unproven technology for species of concern at Seabrook. |

Appendix Table D-1. (Continued)

| Technology | Proven Effectiveness | | Full Scale Power Plant CWIS Installation | Comments (EPRI 1999, EPA 2004) | Potential Impingement & Entrainment Reduction Technology for Seabrook |
|---|---|---|---|---|---|
| | Impingement Mortality Reduction | Entrainment Reduction | | | |
| Air Bubble Curtains | No | No | No – no permanent installations | Conclusions from past studies are that this technology is ineffective. | No<br>No reduction of entrainment and unproven technology for impingement reduction. |
| **Other Technology** | | | | | |
| Flow Reduction | Yes | Yes | Yes | Level of flow reduction must be determined from effect on turbine performance and discharge temperature limitations. Percent entrainment reduction is approximately equal to percent flow reduction. Impingement can be reduced with a reduction in flow or performance standards can be satisfied by reducing through screen velocity to less than 0.5 FPS. | Yes<br>Flow reduction will reduce IM&E. Potential level of flow reduction should be evaluated. |
| Closed Loop Cooling | Yes | Yes | Yes | 90 percent or greater reduction in intake flow | Yes |
| Intake Location | Yes | Yes | Yes | Intake can be located to an area of decreased biological productivity. Offshore intakes can be located in these areas of reduced biological productivity and achieve reduced levels of impingement and entrainment from baseline conditions. | Yes<br>An off-shore intake is currently in use at Seabrook. |
| Velocity Cap | Yes | No | Yes – El Segundo, Redondo Beach, San Onofre, Huntington Beach, Edgewater, and Seabrook | Used to create a horizontal flow at off-shore intake. Fish tend to avoid this rapid change in horizontal flow. Effectiveness has exceeded 90 percent on West Coast offshore intakes. Appropriate velocity is species specific, therefore, site specific testing is required. Not effective on eggs, larvae, and early life stage fish. | Yes – Impingement only<br>A velocity cap is currently installed at Seabrook. |

# APPENDIX E

## Results of Annual Impingement and Entrainment Monitoring Programs

Appendix Table E-1. **Annual Estimated Numbers of Fish Eggs and Larvae Entrained (in millions) by the Cooling Water System at Seabrook Station from June 1990 Through December 2004 (NAI 2005).**

**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] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| Atlantic menhaden | | 0.5 | 1.4 | 0.1 | | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | | | <0.1 | |
| Butterfish | | | | | | | 0.1 | | | <0.1 | | | | | |
| 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 |
| 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 |
| 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 |
| 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 |
| Goosefish | | | | | | | | | 0.9 | | 0.9 | | | | 0.1 |
| 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 |
| 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 |
| Lumpfish | | | | 9.5 | 0.1 | 6.0 | 1.2 | 0.3 | | | | | | <0.1 | |
| 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 |
| 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 |
| Tautog | | 0.2 | | | | | 0.3 | 0.1 | 0.1 | | | 0.1 | 3.8 | | 0.1 |
| 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 |
| 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 |
| Winter flounder | | | | | | | | | | | 0.3 | | | 0.3 | |
| Witch flounder | 0.4 | | | | | 0.7 | 0.1 | 0.9 | 0.1 | 0.1 | 0.2 | | | | |
| Yellowtail flounder | | | | | | 0.2 | 1.6 | | | | 0.1 | 0.2 | 0.7 | | |
| 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 |

(Continued)

## Appendix Table E-1. 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] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alligatorfish | | 0.1 | 0.2 | | 0.2 | 0.3 | 0.1 | 0.1 | 0.2 | 0.1 | | | <0.01 | 0.1 | <0.1 |
| American eel | | | | | | | | | <0.1 | 0.1 | | | | | |
| 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 |
| 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 |
| 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 |
| 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 |
| Atlantic mackerel | 0.2 | 4.7 | | | | | 0.1 | 0.4 | 0.0 | 0.1 | 0.3 | 0.1 | 0.4 | | 20.2 |
| Atlantic menhaden | 0.1 | | | | | | | | 0.1 | 0.1 | | | 0.1 | | <0.1 |
| 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 |
| Atlantic silverside | | | | | | | | | | | | | | <0.1 | |
| Bluefish | | | | | | | | 0.1 | | | | | | | |
| Butterfish | | | | | | 0.3 | 0.1 | | | | | | | | |
| 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 |
| Cusk | | | | | | | | | <0.1 | | | 0.4 | 1.8 | 0.1 | 2.1 |
| 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 |
| Fourspot flounder | 0.2 | | | | | | | 0.1 | <0.1 | | | | <0.01 | | |
| Goosefish | 0.1 | | | | | | | | | | 2.0 | | | | 0.1 |
| 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 |
| 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 |
| Haddock | | | 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 |
| 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 |
| 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 |
| Moustache sculpin | | 0.1 | 0.3 | 0.4 | 2.2 | | 0.6 | 0.3 | <0.1 | | | | | | |
| Northern pipefish | | | | | | | 0.1 | | | 0.1 | | 0.1 | 0.1 | | 0.1 |
| Ocean pout | | | | | | | | | | | | | | <0.1 | |
| Pleuronectidae | | | | | | | 0.3 | | | | | | | | |
| Pollock | 0.2 | | 0.1 | | | | | | <0.1 | | | | <0.1 | 0.6 | 0.1 |
| 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 |
| Rainbow smelt | 0.2 | | 0.1 | | | | | | 0.2 | | 0.3 | 0.1 | | 0.5 | <0.1 |
| Redfish | | | 0.4 | | 0.05 | | | | | | | | | | |

(Continued)

## Appendix Table E-1. 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] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| Sea raven | | | | | | | | | <0.1 | <0.1 | | | | <0.1 | 0.2 |
| 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 |
| 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 |
| Snailfish | 0.1 | 0.3 | | 0.2 | | | 0.4 | | | | | | <0.1 | | |
| Summer flounder | | | | | | | | | <0.1 | | | | | <0.1 | |
| 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 |
| Unidentified sculpin | | | 0.1 | | | | 0.6 | 0.05 | | 0.1 | | | <0.1 | 0.5 | 4.4 |
| 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 |
| 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 |
| Witch flounder | 0.3 | | | | | | 0.8 | 1.2 | <0.1 | 0.1 | 0.5 | | 1.7 | 1.4 | 0.8 |
| 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 |
| 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 |

[a] Represents only 7 months, August - December.
[b] Represents only 8 months, January - July, December.
[c] Represents only 8 months, January - August.
[d] Represents only 8 months, January - August.
[e] Represents only 8 months, January - March, September - December.
[f] Represents 12 months.

Appendix Table E-2. **Estimated Number of Bivalve Larvae Entrained (in billions) by the Cooling Water System at Seabrook Station 1990 Through 1993, and 1995 Through 2004[a] (NAI 2005).**

| 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] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *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 |
| 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 |
| *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 |
| *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 |
| *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 |
| *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 |
| *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 |
| *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 |
| 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 |
| *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 |
| *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 |
| **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** |

[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.

**Appendix Table E-3. Species Composition, Annual Totals, and Nine-Year Total of Finfish, and American Lobster Impinged at Seabrook Station From 1994 to 2004[a] (NAI 2005).**

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alewife | 0 | 8 | 1,753 | 2,797 | 14 | 16 | 4 | 35 | 1 | 9 | 212 | 4849 |
| American lobster | 31 | 16 | 31 | 20 | 4 | 6 | 0 | 1 | 23 | 19 | 0 | 151 |
| American plaice | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| American shad | 0 | 0 | 20 | 21 | 1 | 6 | 10 | 3 | 7 | 10 | 7 | 85 |
| American sand lance | 1,215 | 1,324 | 823 | 182 | 708 | 234 | 423 | 114 | 245 | 3396 | 665 | 9329 |
| American eel | 0 | 5 | 6 | 42 | 1 | 2 | 0 | 2 | 0 | 0 | 9 | 67 |
| Atlantic menhaden | 0 | 7 | 97 | 0 | 1 | 957 | 142 | 19 | 1022 | 7 | 361 | 2613 |
| Atlantic hagfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1396 | 0 | 1396 |
| Atlantic torpedo | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Atlantic silverside | 5,348 | 1,621 | 1,119 | 210 | 834 | 1,335 | 31 | 282 | 1410 | 20507 | 877 | 33574 |
| Atlantic tomcod | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Atlantic wolffish | 0 | 2 | 13 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 17 |
| Atlantic cod | 58 | 119 | 94 | 69 | 38 | 66 | 29 | 30 | 199 | 3091 | 467 | 4260 |
| Atlantic mackerel | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 6 |
| Atlantic herring | 0 | 0 | 485 | 350 | 582 | 20 | 5 | 11 | 159 | 198 | 118 | 1928 |
| Atlantic moonfish | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 50 | 0 | 0 | 54 |
| Bigeye soldierfish | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Blackspotted stickleback | 0 | 0 | 0 | 0 | 2 | 28 | 0 | 0 | 0 | 107 | 12 | 149 |
| Black sea bass | 0 | 3 | 0 | 0 | 3 | 3 | 17 | 12 | 12 | 10 | 11 | 71 |
| Blueback herring | 13 | 0 | 111 | 323 | 7 | 53 | 1 | 59 | 475 | 50 | 380 | 1495 |
| Bluefish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 7 |
| Butterfish | 3 | 14 | 3 | 223 | 9 | 5 | 1 | 28 | 1170 | 4 | 35 | 1460 |
| Cunner | 32 | 342 | 1,121 | 233 | 309 | 255 | 324 | 341 | 291 | 554 | 625 | 4427 |
| Cusk | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| Flounders | 77 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77 |
| Flying gurnard | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Fourbeard rockling | 0 | 6 | 0 | 0 | 3 | 1 | 1 | 1 | 0 | 0 | 7 | 19 |
| Fourspine stickleback | 0 | 0 | 0 | 0 | 23 | 24 | 0 | 6 | 3 | 0 | 0 | 56 |
| Fourspot flounder | 2 | 1 | 2 | 3 | 4 | 1 | 11 | 0 | 7 | 0 | 7 | 38 |
| Goosefish | 3 | 13 | 0 | 0 | 7 | 17 | 15 | 59 | 18 | 10 | 0 | 142 |
| Gray triggerfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Grubby | 2,678 | 2,415 | 1,457 | 430 | 3,269 | 3,953 | 1,174 | 549 | 1089 | 2523 | 676 | 20213 |
| Haddock | 0 | 1 | 397 | 0 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 405 |
| Hakes | 2,822 | 2,188 | 156 | 122 | 4 | 68 | 113 | 523 | 1813 | 166 | 35 | 8010 |
| Herrings | 514 | 231 | 72 | 218 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1035 |
| Killifishes | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Lefteye flounder | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Longhorn sculpin | 105 | 165 | 84 | 88 | 38 | 127 | 54 | 27 | 73 | 45 | 98 | 904 |

(continued)

## Appendix Table E-3 (Continued)

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lookdown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Lumpfish | 182 | 190 | 51 | 62 | 137 | 344 | 85 | 158 | 84 | 370 | 68 | 1731 |
| Mummichog | 0 | 0 | 47 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71 |
| Northern kingfish | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Northern pipefish | 188 | 579 | 1,200 | 243 | 268 | 748 | 370 | 714 | 936 | 2716 | 1413 | 9375 |
| Northern puffer | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 12 | 0 | 3 | 20 |
| Northern searobin | 0 | 0 | 0 | 11 | 1 | 2 | 0 | 1 | 2 | 564 | 0 | 581 |
| Ocean pout | 0 | 6 | 1 | 0 | 7 | 3 | 2 | 21 | 1 | 13 | 3 | 57 |
| Planehead filefish | 0 | 15 | 0 | 0 | 0 | 8 | 1 | 0 | 3 | 0 | 0 | 27 |
| Pollock | 1,681 | 899 | 1,835 | 379 | 536 | 11,392 | 534 | 405 | 719 | 499 | 80 | 18959 |
| Radiated shanny | 0 | 92 | 40 | 2 | 39 | 108 | 11 | 53 | 4 | 158 | 18 | 525 |
| Rainbow smelt | 545 | 213 | 4,489 | 365 | 535 | 100 | 8 | 65 | 323 | 3531 | 2085 | 12259 |
| Red hake | 1 | 16 | 1,478 | 371 | 903 | 1,120 | 112 | 155 | 52 | 271 | 892 | 5371 |
| Righteye flounder | 0 | 3 | 4 | 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 | 2066 | 6274 | 4137 | 24852 |
| Sand tiger shark | 0 | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 57 |
| Sculpins | 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 205 |
| Scup | 0 | 14 | 9 | 0 | 3 | 1 | 0 | 3 | 11 | 11 | 0 | 52 |
| Sea raven | 78 | 125 | 1,015 | 223 | 137 | 132 | 206 | 271 | 166 | 217 | 129 | 2699 |
| Sea lamprey | 0 | 0 | 1 | 6 | 7 | 2 | 0 | 2 | 0 | 0 | 0 | 18 |
| Sheepshead | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Shorthorn sculpin | 14 | 156 | 282 | 123 | 190 | 296 | 923 | 621 | 642 | 7450 | 876 | 11573 |
| Silver hake | 0 | 49 | 58 | 108 | 13 | 100 | 41 | 5 | 1177 | 22 | 212 | 1785 |
| Skates | 190 | 157 | 225 | 177 | 41 | 41 | 42 | 17 | 299 | 145 | 60 | 1394 |
| Smooth flounder | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Snailfishes | 180 | 165 | 1,013 | 351 | 856 | 2,356 | 690 | 334 | 616 | 451 | 185 | 7197 |
| Snakeblenny | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Spotted hake | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Spiny dogfish | 1 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 6 | 8 | 11 | 33 |
| Striped bass | 0 | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 14 | 0 | 21 |
| Striped cusk-eel | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Striped mullet | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Striped searobin | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 8 |
| Summer flounder | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Tautog | 0 | 0 | 34 | 0 | 3 | 5 | 1 | 1 | 3 | 0 | 0 | 47 |
| Threespine stickleback | 67 | 155 | 320 | 174 | 773 | 506 | 10 | 280 | 34 | 1549 | 130 | 3998 |
| Unidentified | 6 | 40 | 88 | 49 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 198 |
| Whiptail Conger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 6 |

(continued)

## Appendix Table E-3 (Continued)

| Species | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| White hake | 1 | 7 | 967 | 0 | 6 | 19 | 18 | 30 | 16 | 65 | 62 | 1191 |
| White perch | 0 | 0 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 201 | 0 | 207 |
| Windowpane | 980 | 943 | 1,164 | 1,688 | 772 | 692 | 251 | 161 | 2242 | 4749 | 936 | 14578 |
| Winter flounder | 1,435 | 1,171 | 3,231 | 468 | 1,143 | 3,642 | 102 | 777 | 897 | 10491 | 783 | 24140 |
| Wrymouth | 55 | 9 | 206 | 3 | 21 | 10 | 1 | 135 | 17 | 72 | 7 | 536 |
| Yellowtail flounder | 0 | 1,149 | 4 | 23 | 11 | 97 | 0 | 8 | 5 | 0 | 0 | 1297 |
| **TOTAL** | **19212** | **15940** | **26825** | **10648** | **15198** | **31239** | **7281** | **8577** | **18413** | **71946** | **16696** | **241975** |

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

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

MAY 7 2004

Mr. Allen L. Legendre
FPL Energy Seabrook, LLC
Seabrook Station
Lafayette Road
Seabrook, New Hampshire 03874

Dear Mr. Legendre:

We are in receipt of your application for renewal of National Marine Fisheries Service (NOAA Fisheries) regulations governing takes of marine mammals incidental to the operation of Seabrook Station nuclear power plant. Based on NOAA Fisheries' review of the application and monitoring reports submitted over the last five years, we have determined it is our opinion that an incidental take authorization is no longer necessary under current operating conditions.

NOAA Fisheries first issued regulations to authorize incidental takes of marine mammals at Seabrook Station in June 1999, after seal remains were discovered in either Seabrook Station's forebays or the condenser intake screens between 1993 and 1997. While not observed, it was determined that seals were swimming into the offshore intake structures and becoming trapped once inside conditions likely prevented the seals from exiting. The accelerating, downward turning flow of the water transported them to the forebay over a period of approximately 80 minutes, during which time the seals probably drowned during this period.

In August 1999, Seabrook installed a Seal Deterrent Barrier (SDB) on each of the three bars at the intake structures, which reduced the width of the openings to less than five inches. Since the SDB was installed over four years ago, the incidental take of seals has been reduced to zero. In other words, no seals or seal remains have been found during twice-daily monitoring of the circulating water and service water forebays, daily inspections of the intake transition structure (from April to December), and regular screen washings at Seabrook's cooling station. Accordingly, it appears that the cause of the earlier incidental takes has been eliminated completely and that the potential for injury or mortality has been significantly reduced.

In light of the foregoing, and as discussed in a telephone conversation between Kimberly Skrupky of NOAA Fisheries and Ron Sher of Seabrook Station, we have determined that Seabrook Station currently does not require an incidental take authorization and therefore are treating your application as withdrawn. This determination is premised on Seabrook Station's continued proper maintenance of the SDB. In the future, if conditions at Seabrook Station should change or if evidence of a marine mammal take becomes apparent in the future, an incidental take authorization may be warranted. In that case, please promptly contact Dana Hartley at (508) 459-2090 in NOAA Fisheries' Northeast Region for input regarding the appropriate course of action.

If you have any questions, please feel free to contact Kimberly Skrupky, NOAA Fisheries, at (301) 713-2322 x163.

Sincerely,

Donna Wieting

(for) Laurie K. Allen
Director
Office of Protected Resources

New Hampshire
**Yankee**

**Ted C. Feigenbaum**
President and
Chief Executive Officer

NYE- 91013

June 18, 1991

Mr. Edward K. McSweeney
Chief, Wastewater Management Branch
United States Environmental Protection Agency
John F. Kennedy Building
Boston, Massachusetts 02203

Reference: NPDES Permit No. NH0020338

Subject: Comparative Evaluation of Thermal Plume Model and Field Data

Dear Mr. McSweeney:

New Hampshire Yankee (NHY) has enclosed pursuant to NPDES Permit No. NH0020338, Part IA.1.n.(3), a report entitled "Comparative Evaluation of Hydraulic Model and Field Thermal Plume Data, Seabrook Nuclear Power Station". This report was prepared by Alden Research Laboratory, Inc. for NHY.

In the fall of 1990, field surveys were conducted to measure the thermal plume associated with Seabrook Stations' cooling water discharge under varying tidal and ambient conditions. The field survey data was compared with the corresponding plumes predicted by the earlier hydraulic model studies conducted at the Alden Research Laboratory. Overall, a satisfactory agreement between the model and field data in terms of surface temperature rise isotherms, thermocline depths and plume pattern, was observed. Differences in plume orientation and the maximum local temperature rises were explainable and consistent with expected trends.

Should you have any questions regarding this letter, please contact Mr. James M. Peschel, Regulatory Compliance Manager, at (603) 474-9521 extension 3772.

Very truly yours,

Ted C. Feigenbaum

TCF:ALL/act

Enclosure

cc: Mr. Jeffery Andrews
Supervisor, Industrial Permits Section
Department of Environmental Services
Water Supply & Pollution Control Division
6 Hazen Drive
Concord, NH 03302

New Hampshire Yankee
June 18, 1991

ENCLOSURE TO NYE-91013

# COMPARATIVE EVALUATION OF HYDRAULIC MODEL AND FIELD THERMAL PLUME DATA SEABROOK NUCLEAR POWER STATION

By

Mahadevan Padmanabhan

George E. Hecker

Sponsored by

New Hampshire Yankee Division

of Public Service Company of New Hampshire

May 1991

ALDEN RESEARCH LABORATORY, INC.

30 Shrewsbury Street

Holden, MA 01520

Printed at ARL - May 1991.

TABLE OF CONTENTS

TABLES

## ABSTRACT

Data from field surveys conducted by Aquatec to measure the thermal plumes from Seabrook Station cooling water discharge with one unit operating were compared with the corresponding plumes predicted by the earlier hydraulic model study conducted at the Alden Research Laboratory. Five field data sets with similar tidal and other ambient conditions were selected for comparison with model data.

Overall, a satisfactory agreement between the model and field data in terms of surface temperature rise isotherms, thermocline depths and plume pattern, was observed. Differences in plume orientation and the maximum local temperature rises were explainable and consistent with expected trends.

## ACKNOWLEDGEMENTS

The valuable suggestions, reviews, and discussions provided during this study by Mr. John Snooks and Mr. John Jacobson of Yankee Atomic Electric company (YAEC), are acknowledged. The cooperation extended by Aquatec, Inc. in providing the field data and associated isotherm plots is appreciated.

This study was sponsored by the New Hampshire Yankee (NHY) Division of the Public Service Company of New Hampshire (PSNH).

## 5.0 REFERENCES

1. Teyssandier, R.G., Durgin, W.W., and Hecker, G.E., "Hydro-thermal Studies of Diffuser Discharge in the Coastal Environment: Seabrook Station", Alden Research Laboratory Report No. 86-74, August, 1974.

2. Nyquist, R.G., Durgin, W.W., and Hecker, G.E., "Hydrothermal Studies of Bifurcated Diffuser Nozzles and Thermal Backwashing", Alden Research Laboratory Report No. 101-77, July, 1977.

3. Aquatec Inc., Data Report: "Dye Concentration and Environmental Data Associated with the 25 October 1990 Dye Study of Seabrook's Outfall Diffuser", November, 1990.

4. Aquatec Inc., Data Report: "Dye Concentration and Environmental Data Associated with the 29 November 1990 Dye Study of Seabrook's Outfall Diffuser", January, 1991.

5. Aquatec Inc., Data Report: "Dye Concentration and Environmental Data Associated with the 12 December 1990 Dye Study of Seabrook's Outfall Diffuser", January, 1991.

- The plume orientation indicated by the field data was somewhat more offshore than shown by the model, presumably due to differences in magnitude and direction of currents.

- The surface temperature rise decay along the plume centerline was greater in the field compared to the model data. Hence, model data on plume surface temperature decay is more conservative for the lower temperature rises.

## 4.0 SUMMARY AND CONCLUSIONS

Data from field surveys conducted by Aquatec to measure the thermal plumes from Seabrook Station cooling water discharge with one unit operating were compared with the corresponding plumes predicted by the earlier hydraulic model study conducted at the Alden Research Laboratory. Five field data sets with similar tidal and other ambient conditions were selected for comparison with model data.

Overall, a satisfactory agreement between the model and field data in terms of surface temperature rise isotherms, thermocline depths and plume pattern, was observed. Differences in plume orientation and the maximum local temperature rises were explainable and consistent with expected trends.

Specific conclusions drawn from this comparative evaluation are summarized below:

- The model and field data sets showed comparable 1 and 2 degree surface temperature isotherm widths and indicated no significant temperature rises at the outer sunk rocks nor at the intake location.

- The three degree surface temperature rise isotherms were generally small, less than 32 acres, for both model and field data.

- The field data indicated that maximum local (instantaneous) surface temperature rises in the immediate vicinity of the diffuser were about 20% to 40% higher than the corresponding values in the model. However, the model values were time averaged over about 12 minutes prototype time.

- The vertical temperature rises at selected points in the plume showed excellent agreement between the model and prototype, indicating thermocline depths of about 15 to 20 ft.

temperature profiles, and plume centerline temperature rise decay, as shown in Figures 2 through 11. The vertical temperature rise profiles show excellent agreement of the thermocline position, and thus of the heater layer depth.

lower and irregular compared to model currents and this could have resulted in reduced entrainment of ambient water in the field, leading to the higher field temperature rises.

### 3.2.6 Vertical Temperature Profiles

The vertical temperature profiles at selected points are included in Figures 2 through 6. The field vertical temperature profiles corresponded to a time other than (between) the surface temperature survey duration indicated in the figures. The field vertical temperature profiles used herein were selected so that the currents were similar to those during the plume survey duration, and so the field and model profiles were near the plume center. Both model and field data show excellent agreement, and indicate similar thermocline depths of about 15 to 20 ft. This indicates the vertical density stratification was predicted well by the physical model.

### 3.2.7 Plume Centerline Surface Temperature Decay

Figures 7 through 11 show the comparison of plume centerline surface temperature decay derived from the field and model data sets corresponding to those presented in Figures 2 through 6. The plume centerlines were approximated from the surface temperature rise data. Except for one data set (Figure 9), the model and field temperature rises at distances 500 to 2000 ft from the diffuser along the plume centerline were within $\pm 0.5°$ F. In general, the field data is seen to indicate a larger temperature rise decay along the plume compared to model data and, at longer distances from the diffuser, the model data predicted higher temperature rises. Thus, the model is conservative for the lower temperature rises.

### 3.2.8 Overall Comparison

This comparative study substantiates the model data. Taking into account the differences discussed in the above sections, an overall agreement is indicated between the model predicted and field thermal patterns in terms of surface temperature rises near the diffuser, vertical local (instantaneous) surface temperature rises about 20% to 40% higher than the corresponding values for the model, see listed values in Figures 2 through 6.

3.2.4 Plume Orientation

The plume orientation indicated by the field data was somewhat more offshore than the model plume. The reasons for this difference are apparent by examining the magnitude and direction of currents pertaining to the model and field data sets.

In most cases, especially for the first and second data set of the December 12 survey (Figures 3 and 4), and the data set of the November 29 survey (Figure 2), the field currents showed more variations in magnitude and directions than the model currents, with an average current slightly lower in magnitude than the model simulated currents. Also, for the first and second data sets of the December 12 survey (Figures 3 and 4), the field currents had a higher off-shore component (W-E). These differences in currents suggest that the field plume orientation would be more offshore than the model plume orientation.

3.2.5 Surface Temperature Rises

The model and field data sets showed comparable 1 and 2 degree temperature rise isotherm widths. Areas of the 1 and 2 degree isotherms cannot be compared as the isotherms are not closed within the survey area. Both model and field data sets, however, showed no significant temperature rises at the outer sunk rocks nor at the intake location.

The 3 degree temperature rise isotherm areas generally are small, less than 32 acres. Except for Figure 4, the 3 degree isotherm areas indicated by the model and field data are not significantly different. The data of Figure 4 show a small 4 degree isotherm in the field and a larger 3 degree isotherm than the model data. For this data set, the field currents were generally

The model data corresponded to an ambient temperature of 68° to 70°F (peak summer conditions), whereas the field data corresponded to an ambient temperature of about 45° F (early winter conditions). Available model data [2] for two-unit operation for similar S-N and N-S currents at summer and winter ambient temperatures (about 58° F summer and 47° F winter temperatures) indicated that under winter conditions, the plume temperature rises averaged 12% to 15% higher than those under summer ambient temperatures. Lower buoyancy forces under winter ambient conditions may result in more bottom interference for the jets, and reduce buoyant spreading of the plume, both factors resulting in less entrainment and higher temperature rises. The one-unit model tests corresponded to peak summer temperatures of 68° to 70° F. Hence, the maximum temperature rises indicated by the field data are expected to be higher by more than 15% due to the low ambient water temperatures.

The model temperature rise data used in drawing isotherms are the average of three readings of each thermocouple taken over a total duration of 66 seconds in the model, equivalent to about 12 minutes in the prototype. Hence, the isotherms from the model data are based on 12-minute average temperature rises at each measurement point. The field data based on dye concentrations represent instantaneous readings and, consequently, the isotherms from the field data are based on instantaneous values. Considering the above, some differences can be expected between the maximum measured temperatures indicated by the model and field data, even under identical ambient conditions. Due to time averaging of data, the model is expected to yield somewhat lower peak temperatures than the instantaneous field measurements.

### 3.2.3 Comparison of Maximum Temperature Rises

Considering the difference in field and model ambient temperatures, condenser temperature rises, and data gathering techniques, one could expect somewhat higher values of maximum temperature rises (and perhaps areas under isotherms of the larger temperature rises) in the field data compared to the model data. This seems to be the trend, the field data indicating maximum

## 3.2 Results of Evaluation

### 3.2.1 Presentation of Data for Comparison

Figure 2 shows the model and field surface temperature rise isotherms and vertical profiles for a case with a generally North to South current. One field data set from the November 29, 1990, survey and an appropriately selected scan from the model data from test No. 310 [2] are used in this figure.

Figures 3 to 6 show the model and field data of surface temperature rise isotherms and vertical temperature rise profiles for cases with predominantly South to North currents. Four field data sets from the December 12, 1990 survey and model data from model test No. 311 [2] with an average South to North (S-N) current of about 0.15 knots are used. The model data in each figure corresponds to a scan (as indicated in the figure) for which the tidal current (magnitudes and directions) and tide level are similar to the corresponding field conditions.

The tidal water levels and current magnitudes and directions for each data set considered are included in the corresponding figure (Figures 2 through 6). The maximum temperature rises measured are also indicated.

### 3.2.2 Comparison of Ambient and Thermal Discharge Conditions and Temperature Averaging

The model data given in Figures 2 through 6 correspond to a condenser temperature rise of about 39.5° F, while the field condenser temperature rise (data provided by YAEC) was in the range of 36° to 38° F. This means the field data may indicate about 7% lower temperature rises than the model, assuming no effects on plume dilution due to the change in initial temperature rise.

# 3.0 COMPARATIVE EVALUATION

## 3.1 Selection of Field and Model Data for Comparison

To compare the model and field data, it is necessary to select data sets with similar conditions. Most attention was given to the current magnitudes and directions, since this has the primary influence on plume direction and dilution, and then to the tidal water depths. After carefully studying the eleven data sets from the field surveys, listed in Table 1, five data sets giving a reasonable match of hydrologic conditions were selected for the model to field data comparison. Reasons for rejection/selection of each field data set for model comparison are noted under the "Remarks" column in Table 1.

The selected data sets included the four data sets of December 12, 1990 survey, and one data set of November 29, 1990 survey. These plume measurements were made during essentially the same "steady" current condition as the model tests for one-unit operation. Table 2 provides a summary of conditions for the selected field and corresponding model data sets for easy comparison.

As seen from Table 2, for the five selected data sets, some differences in the ambient water temperature and plant condenser temperature rises existed. The model data corresponded to summer ambient water temperatures of about 68° to 70° F, whereas the field data were obtained in late fall with ambient water temperatures ranging from about 44° to 48° F. This was required to obtain field data without any natural temperature stratification, as was the case for the model tests. The model thermal discharge corresponded to a 39.5° F condenser temperature rise, compared to the field condenser temperature rises of about 37° to 38° F for the selected data sets. The cooling water discharge for all the surveys was within 2% of the plant discharge of 911 cfs simulated in the model. It is necessary to consider effects on the surface temperature rise isotherms and plume characteristics resulting from the above ambient and discharge temperature rise differences when comparing the model and field data.

locations along a 3000 ft x 3000 ft boundary, water from several depths along a vertical axis (up to about 30 ft depth) was analyzed. The dye concentrations were used to calculate equivalent temperature rises and plot the plume isotherms and vertical temperature rise profiles. Dye samples for the vertical temperature rise profiles were collected after the measurement of dye concentration for surface temperature rises were completed.

Three surveys, one each on October 25, 1990, November 29, 1990, and December 12, 1990, were conducted with three or four plume data sets covering different times on the date of each survey.

A summary of the details of ambient and tidal conditions corresponding to each data set is included in Table 1. An in-situ current meter at a location between the intake and discharge was used to describe the current magnitudes and directions at 15-minute intervals. Data on tidal water depths, ambient temperatures, intake temperatures, and condenser temperature rise during each of the surveys were also available.

Details of the surveys and all results are available in the corresponding Aquatec reports [3, 4, 5].

# 2.0 BACKGROUND INFORMATION

## 2.1 Hydraulic Model Study

The hydraulic model study conducted at ARL from 1973 to 1977 used a 1:115 undistorted scale hydraulic model of a 9000 ft x 9000 ft area of the Atlantic ocean containing both the intake and diffuser discharge structures. Several submerged diffuser designs were tested to develop the final bifurcated nozzle design presently at Seabrook, consisting of 11 riser shafts spaced 100 ft apart, each with a pair of nozzles. The diffuser is oriented along a NW-SE line, with the discharge directed in the offshore (East) direction. Figure 1 shows the location and arrangement of the diffuser, and the model boundary.

The two-unit thermal discharge case, being the worst case in terms of temperature rises was studied for several types of tidal cycles. Two tidal cycles with more or less steady currents (one N-S and one S-N) and four tidal cycles with reversing currents were tested for two-unit operations. Only the two tidal cycles with essentially steady currents were tested for one-unit operation. Hence, the comparisons between the field and model data is for those field data indicating a more or less steady N-S or S-N currents for the duration of the data set, including a few hours preceding the plume measurements.

Details of the model study and results are available in the previous ARL reports [1, 2], and only the temperature rise isotherms used for comparative evaluations are included in this report.

## 2.2 Field Surveys

The field hydro-thermal surveys were conducted by Aquatec using Rhodamine WT dye as a tracer to indicate thermal diffusion. The dye was injected with the cooling water discharge. Water was pumped through the on-board fluorometer from about one foot below the water surface along transects covering the survey area defined by the plume. Also, at selected

## 1.0 INTRODUCTION

A few years ago, hydrothermal studies of thermal plumes, resulting from the cooling water discharge through submerged diffuser nozzles of the Seabrook Station nuclear power plant, were conducted at the Alden Research Laboratory (ARL), using a 1:115 geometric scale hydraulic model, [1, 2]. At that time, Seabrook Station was planned to operate with two units, and most of the tests corresponded to two-unit operations. Tests simulated both steady and unsteady (reversing) tidal currents and tidal variations of water depths. A few tests were also conducted for one-unit operation, but were limited to more or less steady tidal currents with tidal water level variations.

Presently, Seabrook Station has one unit operating with a design cooling water thermal discharge to the Atlantic ocean of about 911 cfs and a nominal condenser temperature rise of 39° F. Field surveys to obtain data of the surface temperature rises in the ocean over an area of about 6000 x 6000 ft in the vicinity of the diffuser, and vertical temperature rise profiles at selected locations within this area, were conducted by Aquatec, Inc., under a contract from the New Hampshire Yankee (NHY) Division of Public Service Company of New Hampshire (PSNH).

The purpose of this study, conducted by ARL under contract from NHY, is to provide a comparison of the field and model data for cases with similar tidal and other ambient conditions.

TABLE 1. SUMMARY OF FIELD SURVEYS

| Date of Survey & Time | Ambient Temp. F & Flow (cfs) | Condenser Rise (°F) | Tidal Current | Tide Height (ft) | Remarks on Comparing with Model Data |
|---|---|---|---|---|---|
| 10/25/90 7:48-9:40 | 50.9 F 922 cfs | 37.1 | Irregularly varying mostly zero | 2.5-3 Low Ebb | Insufficient waiting period after dye injection; Data not good; No 2 & 3 °F isotherms; NOT selected for comparison |
| 10/25/90 10:37-12:36 | 50.9 F 922 cfs | 37.4 | Preceded by 2 hours of almost zero current; Zero to 0.55 fps N-S with a W-E component | 2.5-3, Low Ebb | No suitable model data with similar currents; NOT selected for comparison |
| 10/25/90 14:00-15:45 | 50.9 F 922 cfs | 36.5 | Changing from S-N to N-S with a strong E-W component | 6.5-7 near high flood | No suitable model data with similar currents; NOT selected for comparison |
| 10/25/90 16:17-19:44 | 50.9 F 922 cfs | 36.5 | Nonperiodic changing currents from S-N to N-S with strong E-W components | 7.0 near high flood | No suitable model data with similar currents; NOT selected for comparison |

TABLE 1. SUMMARY OF FIELD SURVEYS (continued)

| Date of Survey & Time | Ambient Temp. F & Flow (cfs) | Condenser Rise (°F) | Tidal Current | Tide Height (ft) | Remarks on Comparing with Model Data |
|---|---|---|---|---|---|
| 11/29/90 6:58-8:15 | 47.6 F 911 cfs | 36.7 | Almost zero current preceded by nonperiodic irregular N-S and S-N currents | 9.0 Max. flood | No suitable model data available; NOT selected for comparison |
| 11/29/90 9:55-11:34 | 47.5 F 911 cfs | 37.1 | N-S currents with E-W components; 0.1-0.4 fps | 5.0 slack after flood | Model Test #310, Hr. 11 SELECTED for comparison |
| 11/29/90 13:00-14:20 | 47.6 F 911 cfs | 38.3 | S-N with strong E-W components | 0.5 near max. ebb | No suitable model data available; NOT selected for comparison |
| 12/12/90 7:18-8:40 | 44.8 F 911 cfs | 36.8 | S-N currents 0.17-0.34 fps with small W-E components | 9.0 Max. flood | Model Test #311, Hr. 3 SELECTED for comparison |
| 12/12/90 9:56-11:40 | 44.3 F 911 cfs | 37.5 | S-N currents 0.18-0.33 fps with small W-E components | 5.5 slack after flood | Model Test #311, Hr.5 SELECTED for comparison |

TABLE 1. SUMMARY OF FIELD SURVEYS (continued)

| Date of Survey & Time | Ambient Temp. F & Flow (cfs) | Condenser Rise (°F) | Tidal Current | Tide Height (ft) | Remarks on Comparing with Model Data |
|---|---|---|---|---|---|
| 12/12/90 13:08-14:53 | 44.2 F 911 cfs | 38.1 | S-N currents 0.3-0.4 fps with small W-E components | 1.0 Max. Ebb | Model Test #311, Hr. 8 SELECTED for comparison |
| 12/12/90 16:18-17:58 | 44.3 F 911 cfs | 37.5 | S-N currents 0.2-0.5 fps with small W-E components | 3.5 slack after Ebb | Model Test #311, Hr. 1 SELECTED for comparison |

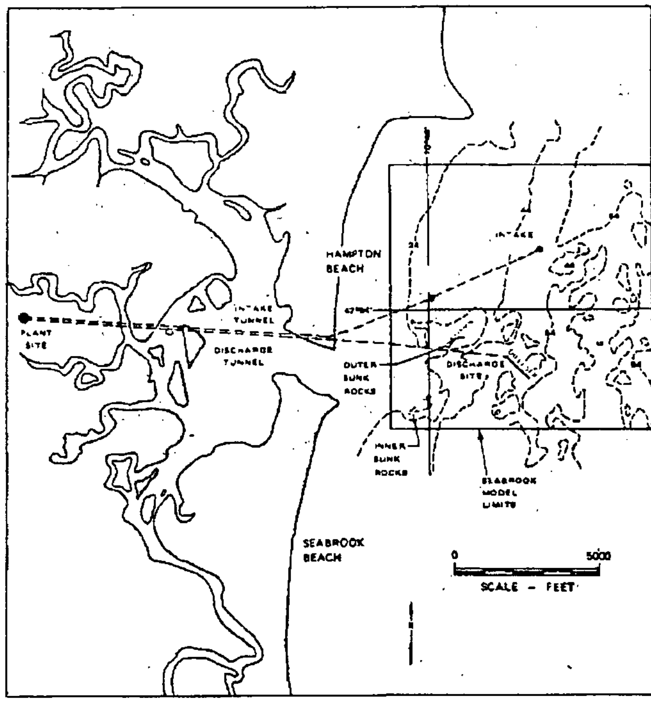
TABLE 2. AMBIENT CONDITIONS OF THE MODEL AND FIELD DATA SETS SELECTED FOR COMPARISON

| No. | Data Set Source | Data ID | Ocean Ambient Temp. | Condenser Flow | Condenser Rise | Current Speed and Direction | Tide Water Level |
|---|---|---|---|---|---|---|---|
| 1. | Field | 11/29/90 9:55-11:34 | 47.5 F | 911 cfs | 37.1 F | 0.1-0.4 fps N-S with E-W components | Slack |
| | Model | Test #310 Hr. 11 | 68.4 F | 911 cfs | 39.5 F | 0.25 fps N-S with E-W component | Slack |
| 2. | Field | 12/12/90 7:18-8:40 | 44.8 F | 911 cfs | 36.8 F | 0.17-0.34 fps; S-N currents small W-E components | Max. flood |
| | Model | Test #311 Hr. 3 | 69.9 F | 911 cfs | 39.7 F | 0.25 fps S-N currents; small W-E components | Max. flood |
| 3. | Field | 12/12/90 9:56-11:40 | 44.3 F | 911 cfs | 37.5 F | 0.18-0.33 fps; S-N currents with small W-E components | Slack |
| | Model | Test #311 Hr. 5 | 69.9 F | 911 cfs | 39.7 F | 0.18 fps S-N; small W-E comp. | Near Slack |

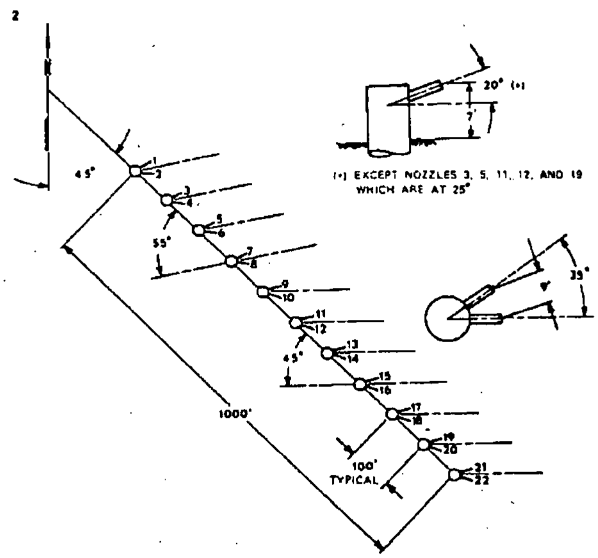
TABLE 2. AMBIENT CONDITIONS OF THE MODEL AND FIELD DATA SETS SELECTED FOR COMPARISON (Continued)

| No. | Data Set Source | Data ID | Ocean Ambient Temp. | Condenser Flow | Condenser Rise | Current Speed and Direction | Tide Water Level |
|---|---|---|---|---|---|---|---|
| 4. | Field | 12/12/90 13:08-14:53 | 44.2 F | 911 cfs | 38.1 F | 0.3-0.4 fps; S-N with small W-E components | Max. Ebb |
| | Model | Test #311 Hr. 8 | 69.9 F | 911 cfs | 39.7 F | 0.35 fps S-N with W-E component | Near Max. Ebb |
| 5. | Field | 12/12/90 16:18-17:58 | 44.3 F | 911 cfs | 37.5 F | 0.2-0.5 fps; S-N with small W-E components | Slack |
| | Model | Test #311 Hr. 1 | 69.9 F | 911 cfs | 39.7 F | 0.3 fps; S-N with W-E component | Near Slack |

FIGURES




A. LOCATION OF DIFFUSER




B. DIFFUSER GEOMETRY - SCHEMATIC

FIGURE 1 LOCATION AND GEOMETRY OF SUBMERGED DIFFUSER FOR THERMAL DISCHARGE

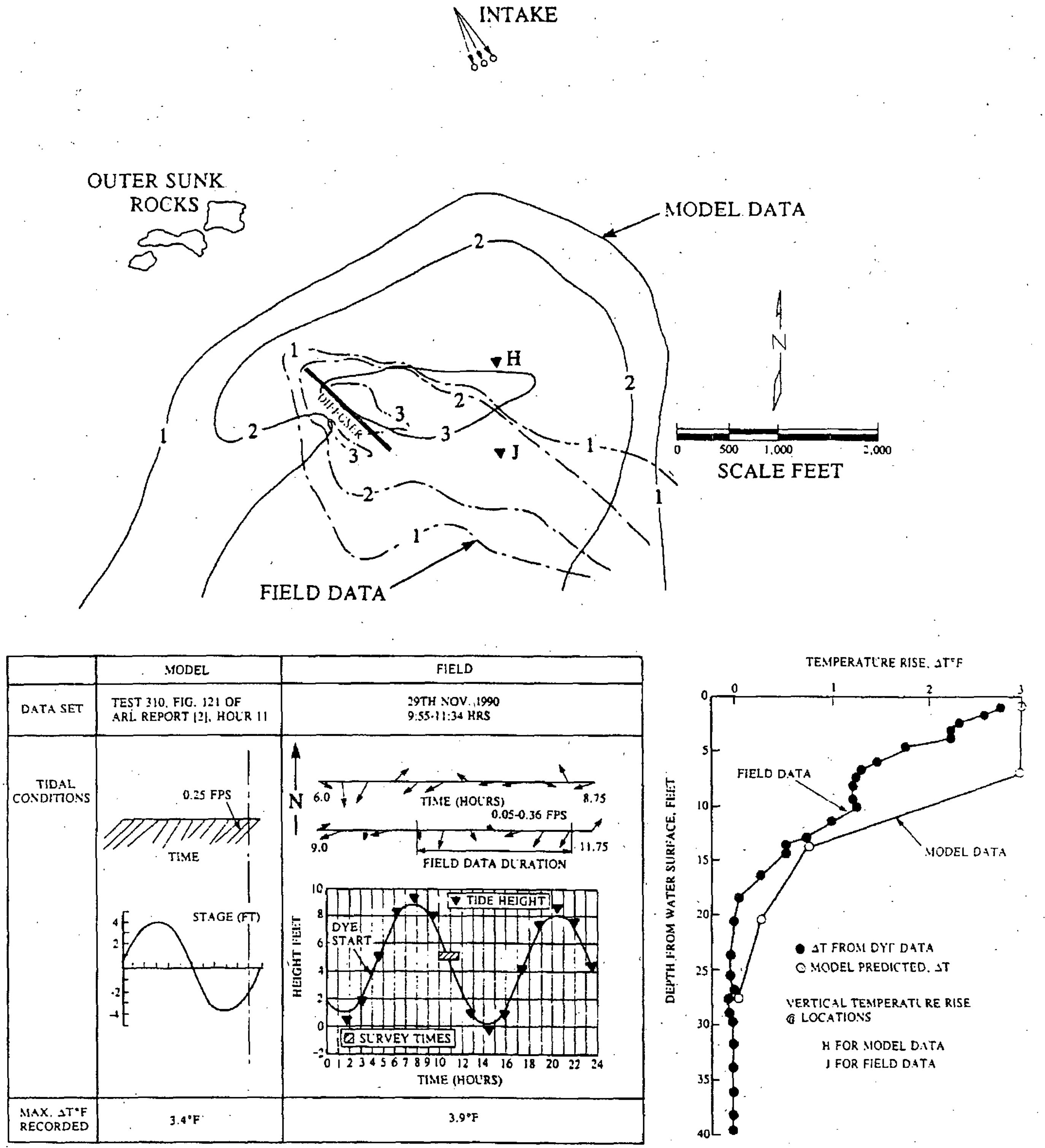
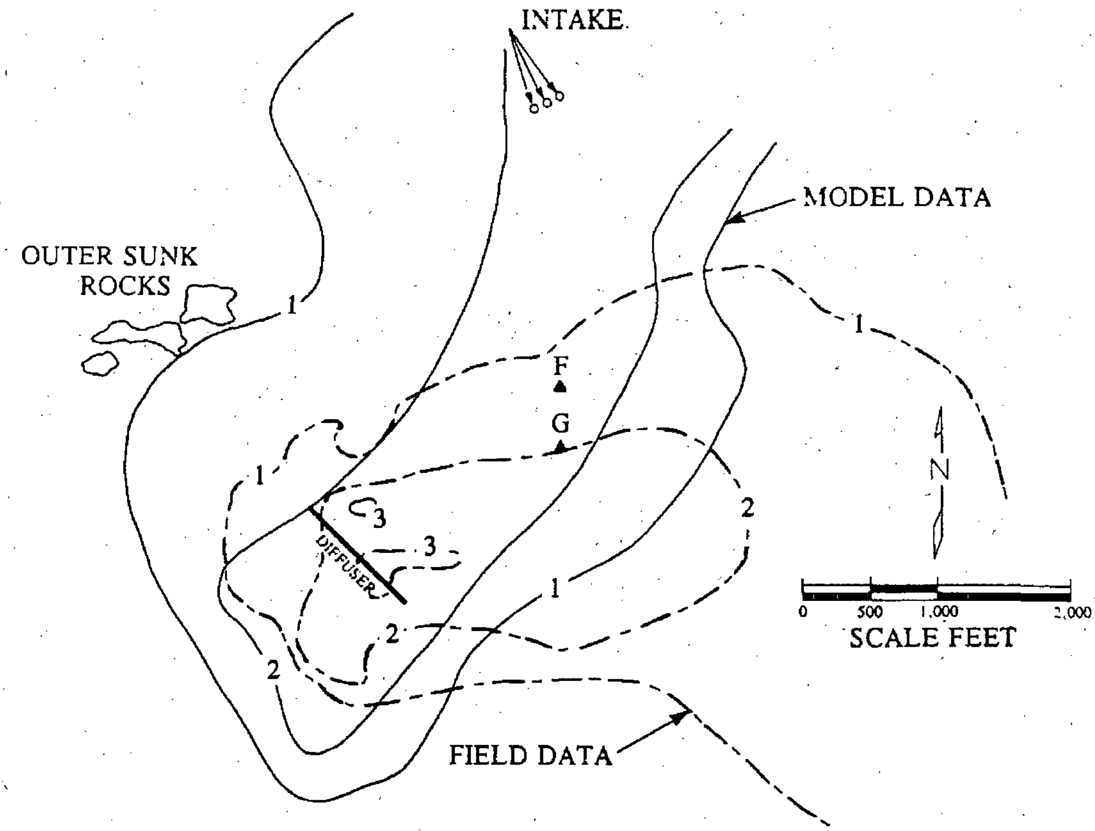
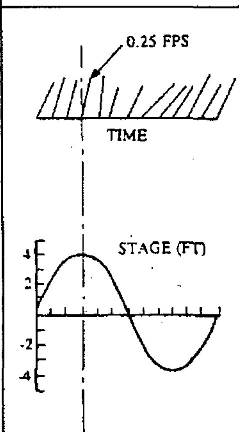
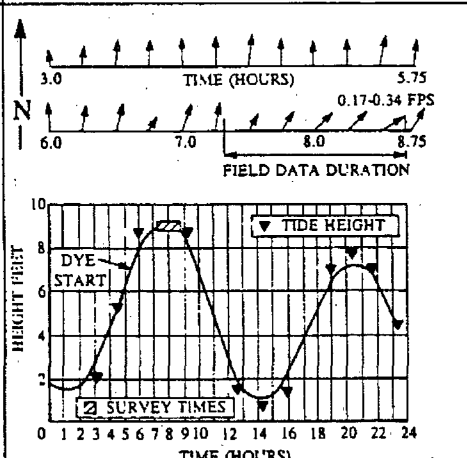



FIGURE 2 COMPARISON OF MODEL AND FIELD ISOTHERMS; FIELD DATA OF 29 NOV. 1990, 9:55-11:34




| | MODEL | FIELD |
|---|---|---|
| DATA SET | TEST 311, FIG. 127 OF ARL REPORT [2], HOUR 3 | 12TH DEC. 1990 7:18-8:40 HRS |
| TIDAL CONDITIONS |  |  |
| MAX. ΔT°F RECORDED | 3.0°F | 3.7°F |





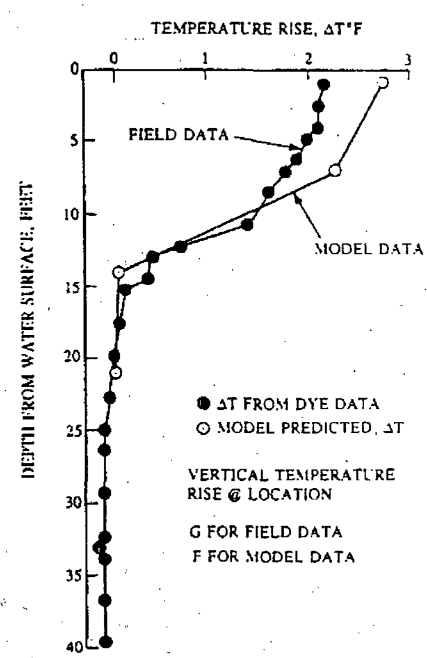
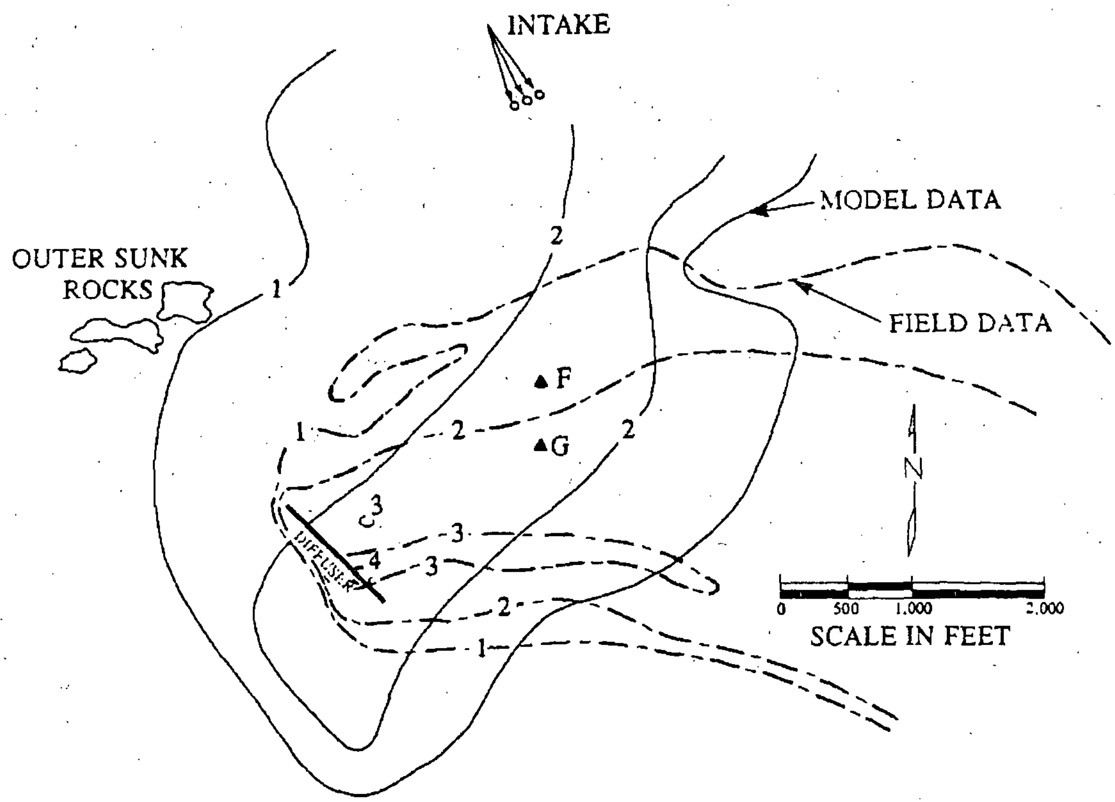
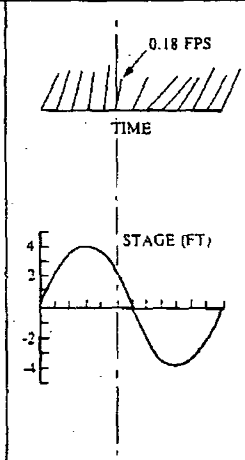
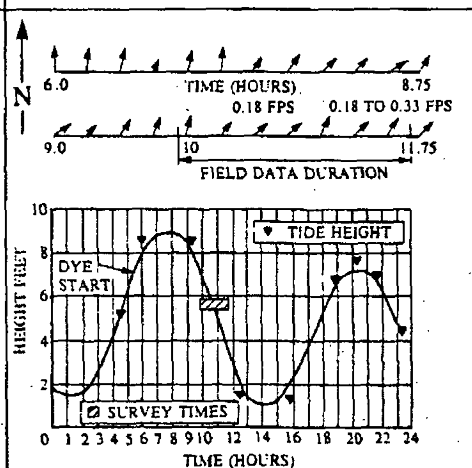



FIGURE 3 COMPARISON OF MODEL AND FIELD ISOTHERMS; FIELD DATA OF 12 DEC. 1990, 7:18-8:40 HRS.

ARL




| | MODEL | FIELD |
|---|---|---|
| DATA SET | TEST 311, FIG. 127 OF ARL REPORT [2], HOUR 5 | 12TH DEC. 1990 9:56 - 11:40 |
| TIDAL CONDITIONS |   |   |
| MAX. ΔT°F RECORDED | 3.0°F | 4.3°F |

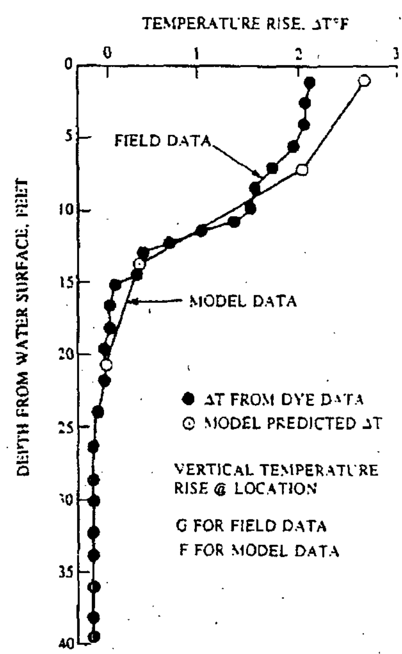
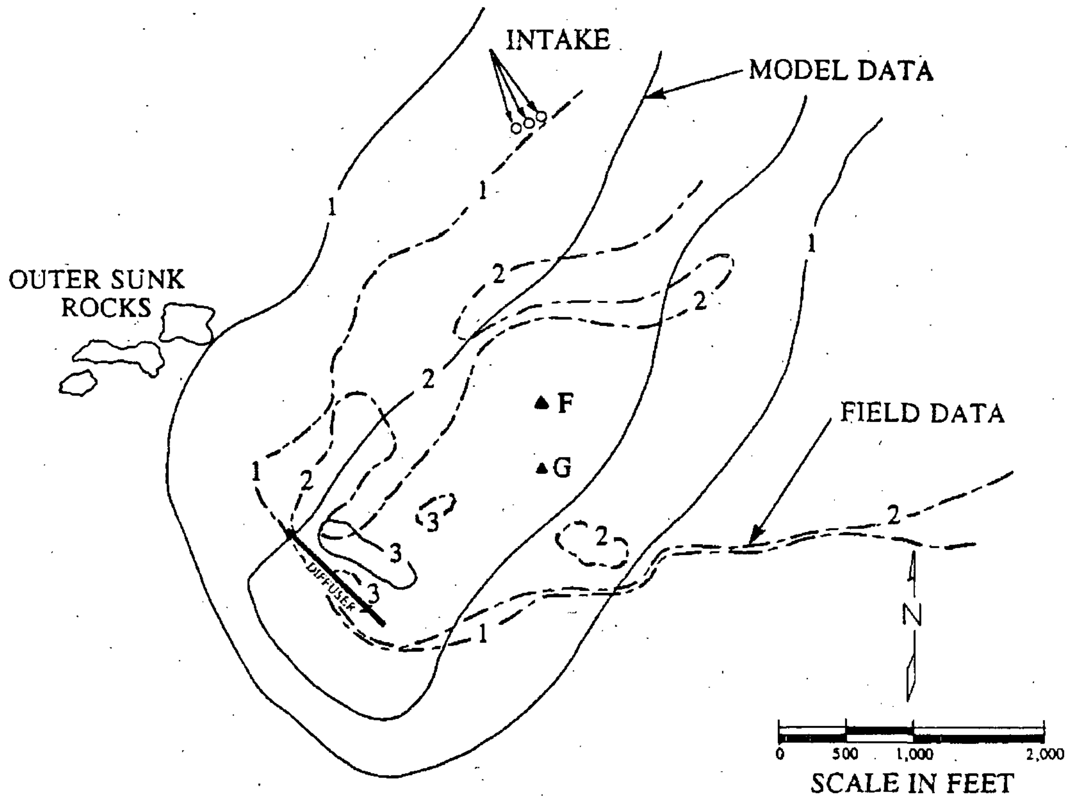
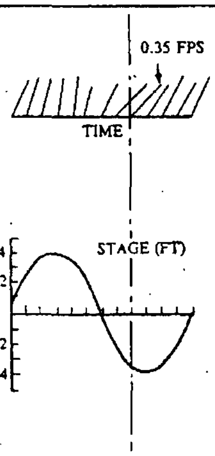
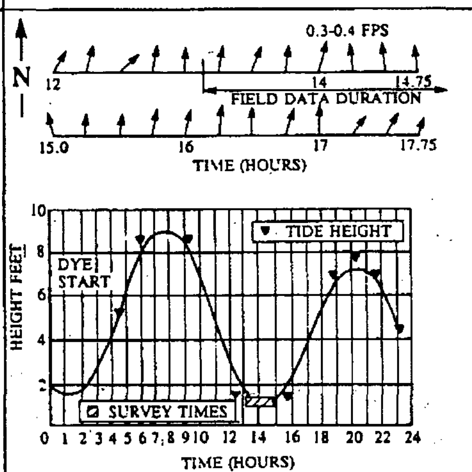



FIGURE 4 COMPARISON OF MODEL AND FIELD ISOTHERMS; FIELD DATA OF 12 DEC. 1990, 9:56-11:40 HRS.

ARL




| | MODEL | FIELD |
|---|---|---|
| DATA SET | TEST 311, FIG. 127 OF ARL REPORT [2], HOUR 8 | 12TH DEC. 1990 13:08-14:53 HRS |
| TIDAL CONDITIONS |  |  |
| MAX. ΔT°F RECORDED | 3.1°F | 3.9°F |





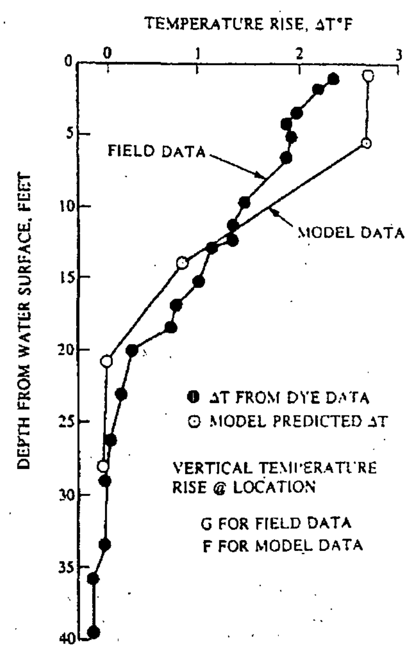
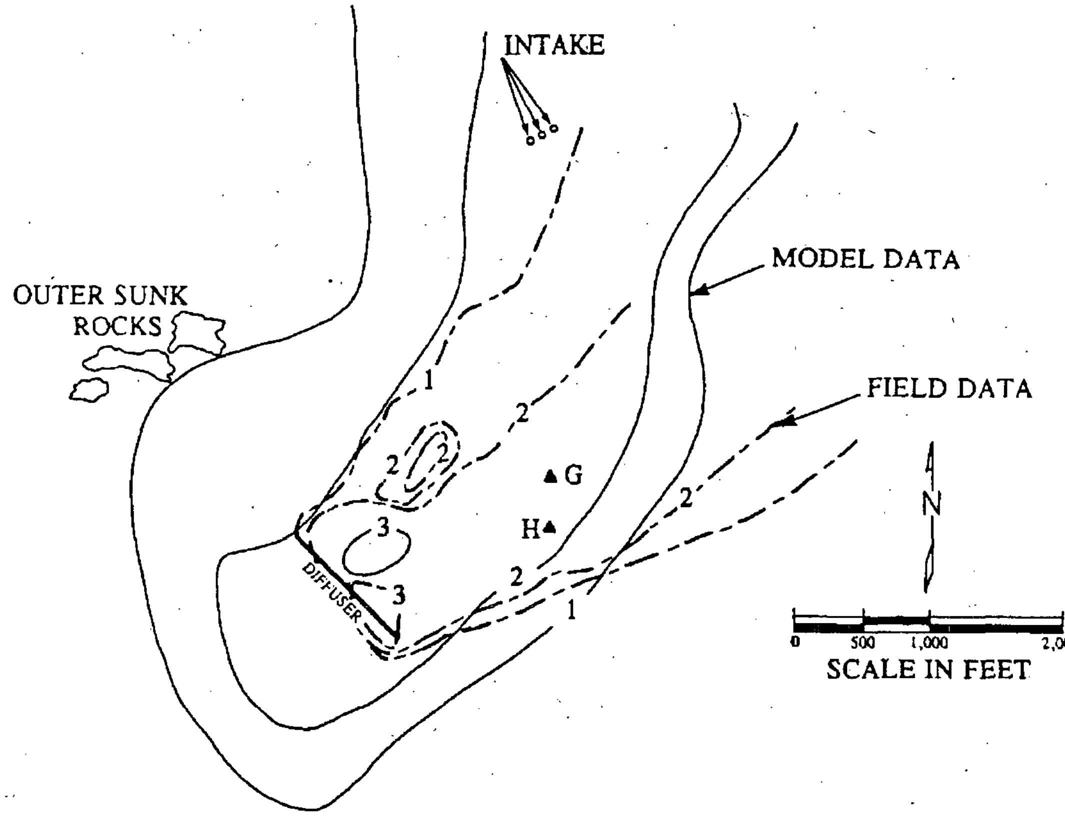
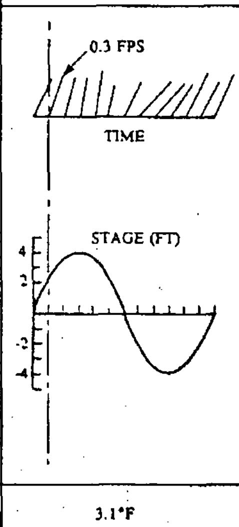
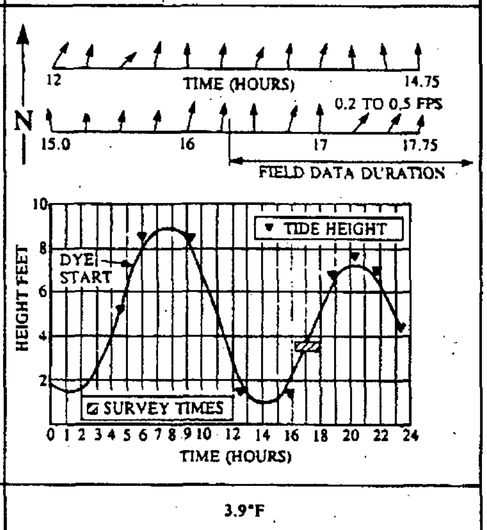



FIGURE 5 COMPARISON OF MODEL AND FIELD ISOTHERMS; FIELD DATA OF 12 DEC. 1990, 13:08-14:53 HRS.

ARL




| | MODEL | FIELD |
|---|---|---|
| DATA SET | TEST 311, FIG. 125 OF ARL REPORT [2], HOUR 1 | 12TH DEC. 1990 16:18 - 17:58 HRS |
| TIDAL CONDITIONS |  |  |
| MAX. ΔT°F RECORDED | 3.1°F | 3.9°F |





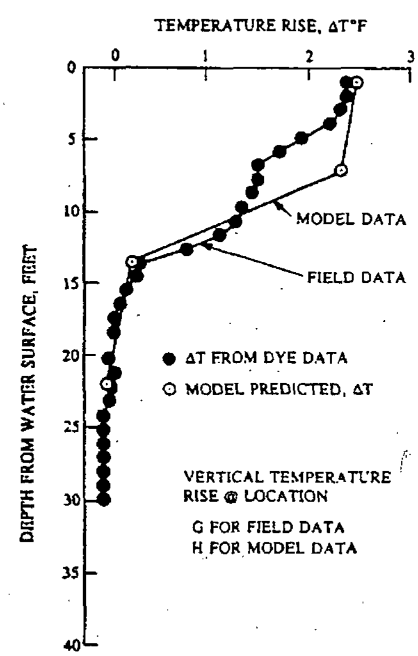



FIGURE 6 COMPARISON OF MODEL AND FIELD ISOTHERMS; FIELD DATA OF 12 DEC. 1990, 16:18-17:58 HRS.

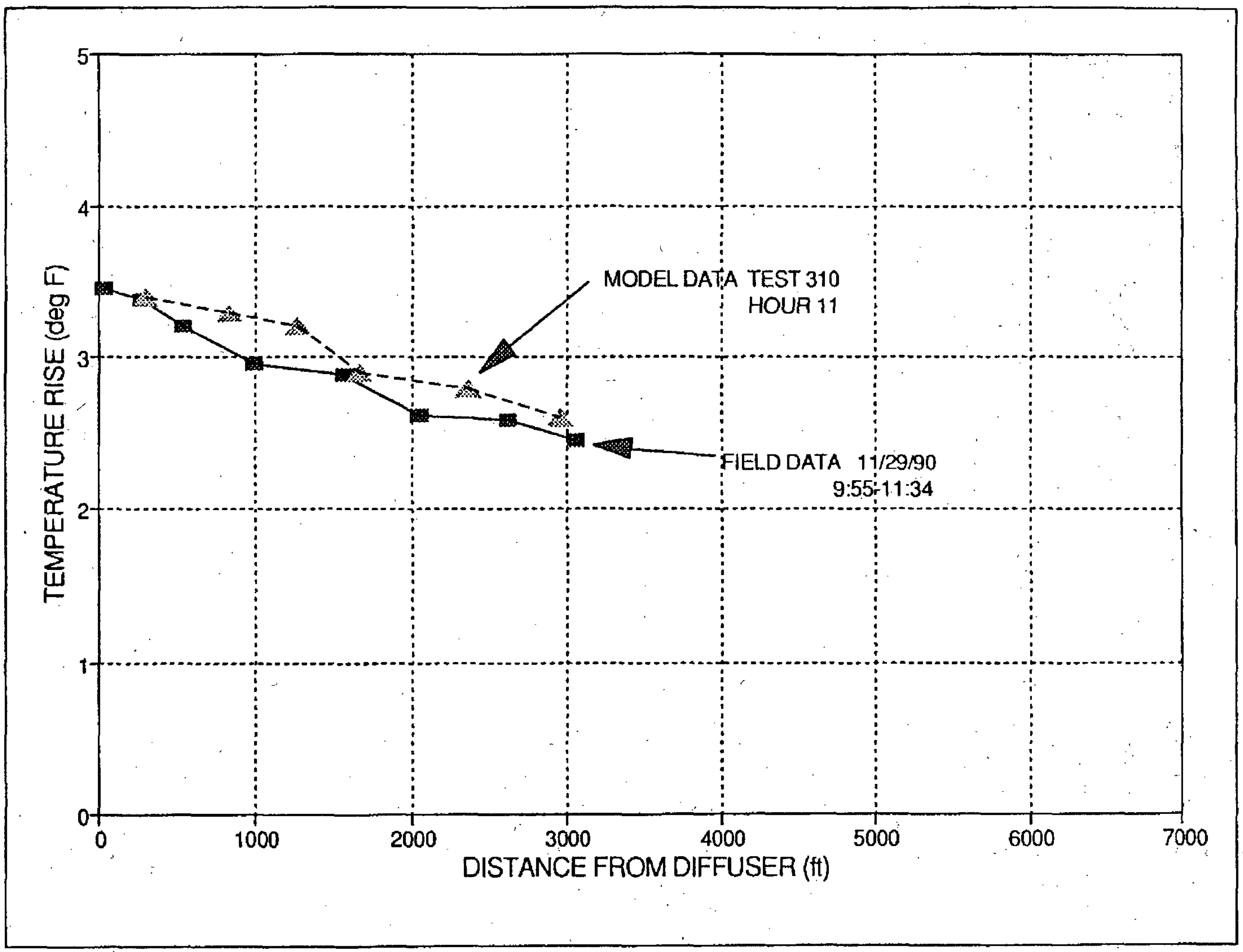



FIGURE 7 COMPARISON OF MODEL AND FIELD PLUME CENTERLINE TEMPERATURE RISE DECAY; FIELD DATA OF NOV. 29, 1990, 9:55-11:34

ARL

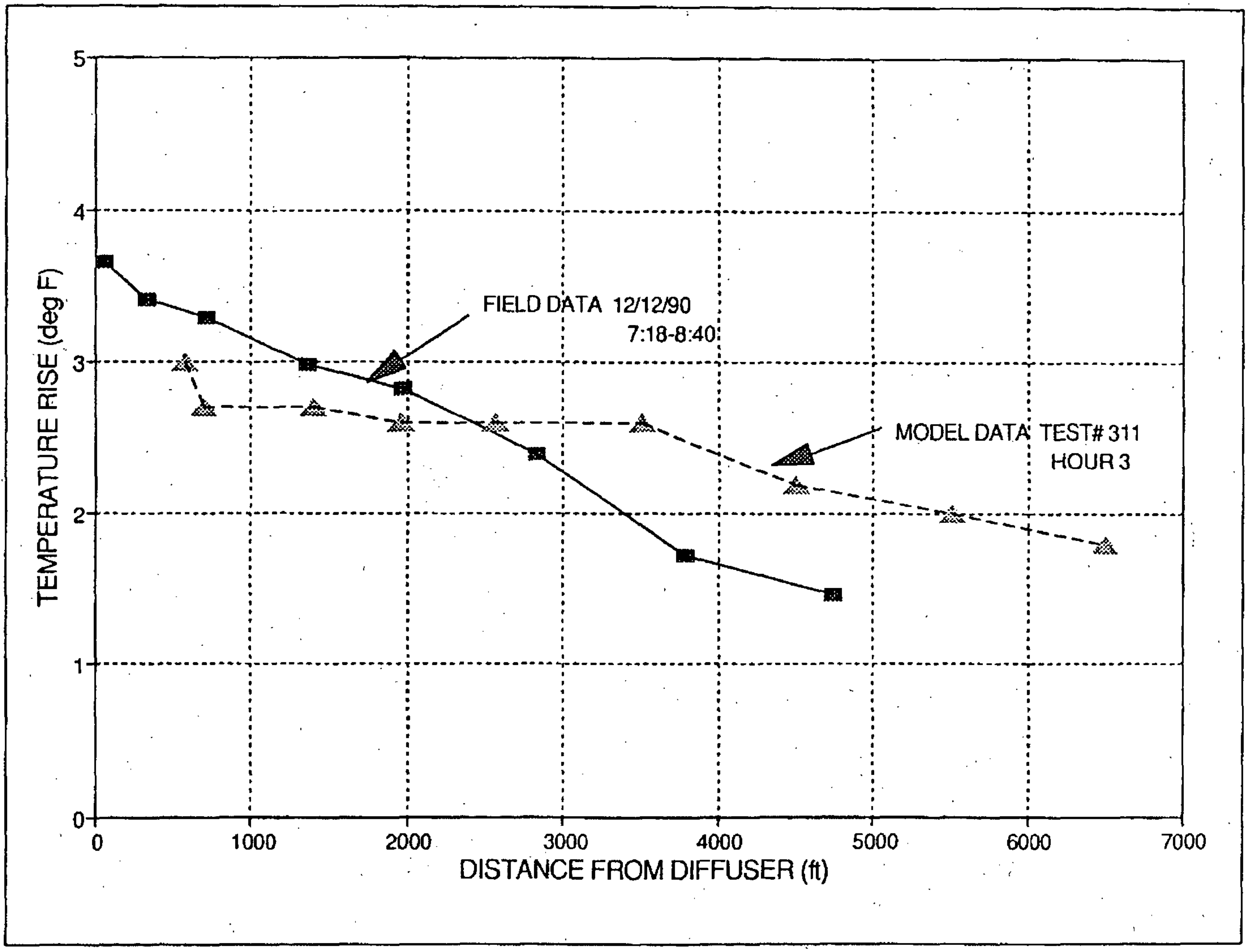



FIGURE 8 COMPARISON OF MODEL AND FIELD PLUME CENTERLINE TEMPERATURE RISE DECAY; FIELD DATA OF DEC. 12, 1990, 7:18-8:40

ARL

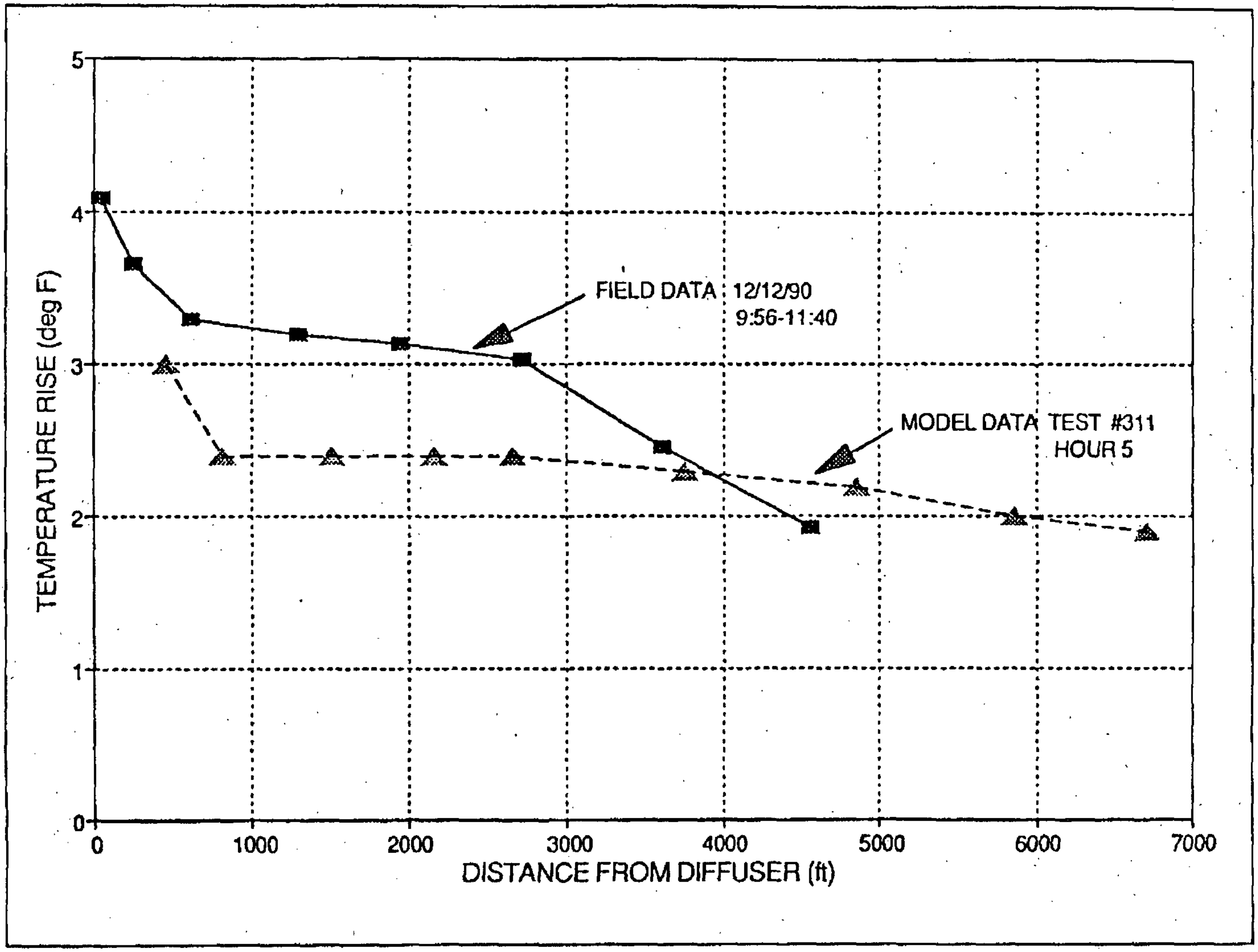



FIGURE 9 COMPARISON OF MODEL AND FIELD PLUME CENTERLINE TEMPERATURE RISE DECAY; FIELD DATA OF DEC. 12, 1990, 9:56-11:40

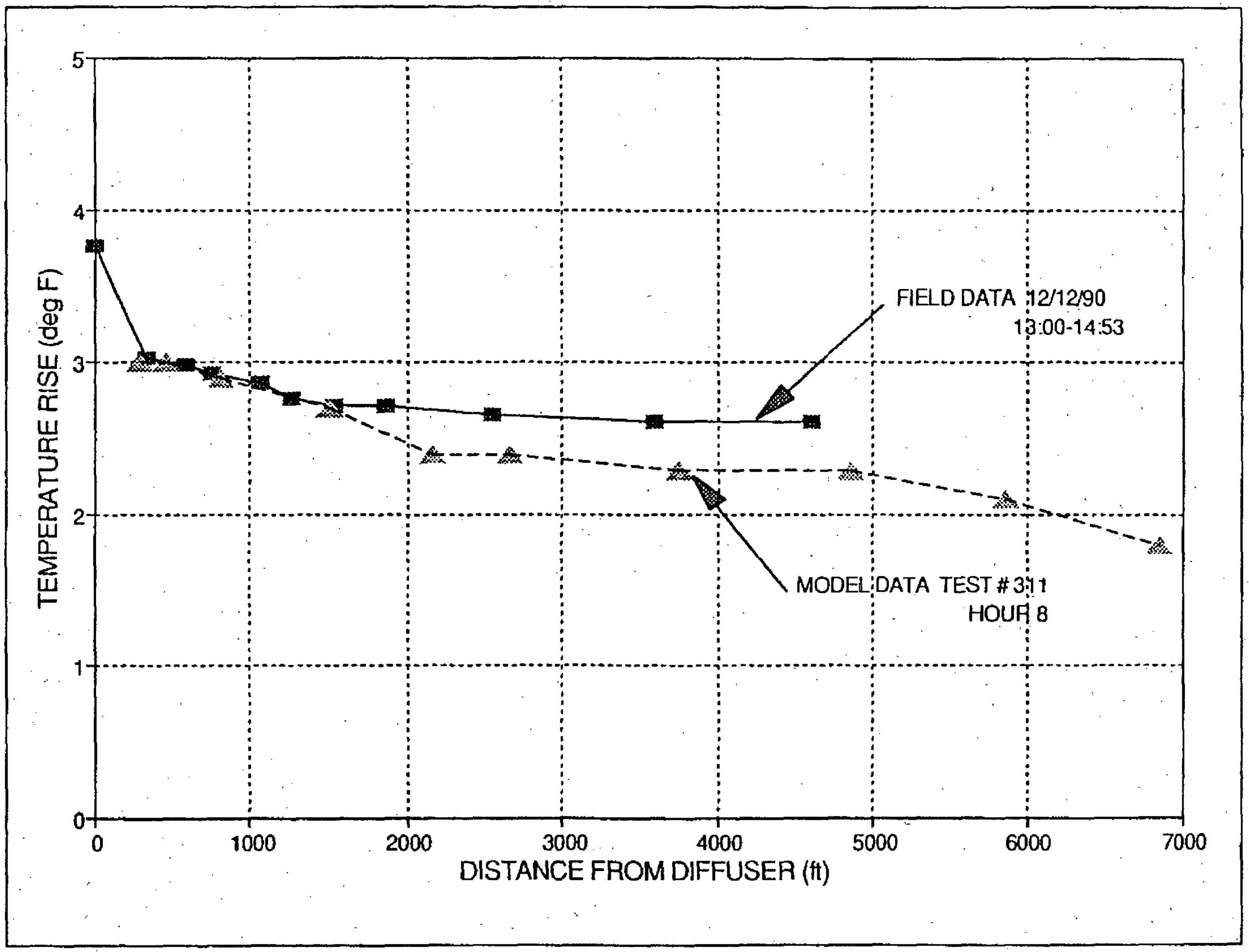



FIGURE 10. COMPARISON OF MODEL AND FIELD PLUME CENTERLINE TEMPERATURE RISE DECAY; FIELD DATA OF 12 DEC. 1990, 13:00-14:53

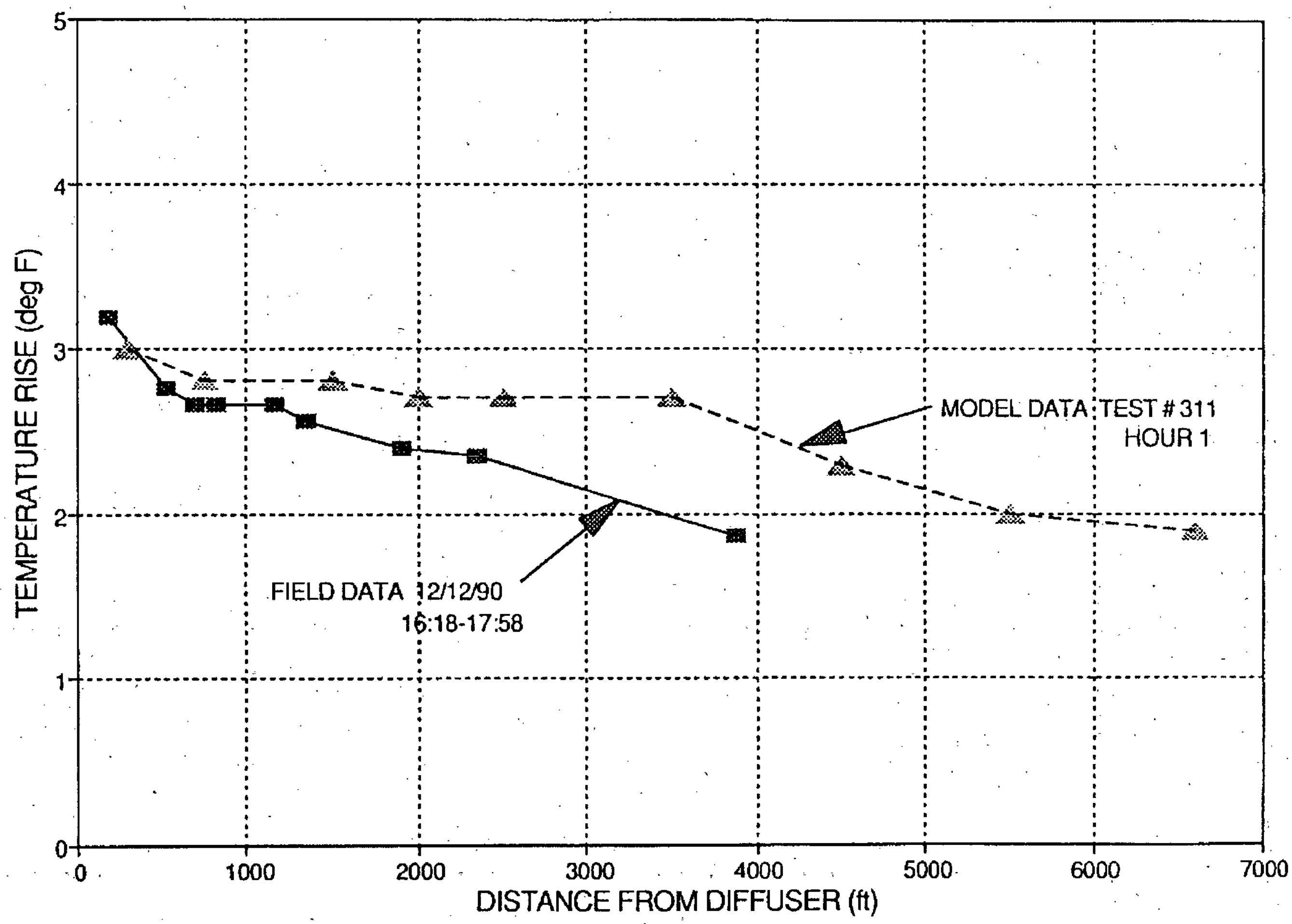



FIGURE 11 COMPARISON OF MODEL AND FIELD PLUME CENTERLINE TEMPERATURE RISE DECAY; FIELD DATA OF DEC. 12 1990, 16:18-17:58

ARL

**SEABROOK STATION**

**Regulatory Compliance Procedure**

# Bivalve Larvae Entrainment Sampling

**ZN1120.02**

**Rev. 00 Chg. 03**

| |
|---|
| Level of Use<br>General |

Procedure Owner:
Regulatory Compliance
Supervisor

## Bivalve Larvae Entrainment Sampling

TABLE OF CONTENTS

1. <u>PURPOSE</u>

### 1.1 Objective

This procedure describes the process for the collection of weekly entrainment samples of bivalve (soft-shell clam) larvae from the Circulating Water System (CWS). Entrainment sampling is a requirement of Seabrook Station's NPDES Permit.

### 1.2 Discussion

Entrainment sampling is part of Seabrook Station's Environmental Studies Program which is a requirement of the Station's NPDES Permit. Environmental studies which evaluate the number of bivalve (soft-shell clam) larvae, entrained by the Station's Circulating Water System (CWS), determine the potential impact to the population of these organisms due to Station entrainment.

Approximately 2,000 gallons of water from the Circulating Water (CW) pump discharges are passed through 0.075 mm mesh bivalve larvae plankton nets. Entrainment sampling equipment is in two trains (A and B). Each train consists of two double-barrel systems. The plankton net is suspended in a 30-gallon drum which, in turn, is suspended in a 55-gallon drum. Water diverted from the CWS enters the 55-gallon drum from the bottom and overflows the 30-gallon drum into the plankton net. After passing through the plankton net, the water discharges through the bottom of both drums. The collected bivalve larvae are washed from the plankton nets into sample collection jars and preserved.

Weekly samples are delivered to the Normandeau Associates Hampton Lab and then to Normandeau Associates Bedford Lab for analysis. Entrainment sampling can be performed only when at least one CW pump is operating when sufficient flow is available to supply ocean water to entrainment sampling equipment. Bivalve larvae entrainment sampling is normally performed before ichthyoplankton entrainment sampling.

Figure 3 provides a description of Bivalve Larvae Entrainment Analytic Calculation.

### 1.3 Frequency

Bivalve larvae entrainment samples are collected every week. From the third week in April through the end of October, three samples will be collected weekly. From November through the first two weeks of April, only two samples are collected weekly.

## 2. PREREQUISITES

### 2.1 Requirements

2.1.1 Entrainment sampling can be performed only when at least one circulating water system pump is in operation, when sufficient flow is available to supply ocean water to entrainment sampling equipment.

2.1.2 Perform a self-briefing by considering the following:

- Job hazards and safety considerations
- Personnel protective equipment
- Human error prevention techniques
- Configuration Control – Prevent the mispositioning of components by using **D.I.R.T.** What **Directs** the positioning of the component? What prevents **Inadvertent** contact? What **Repositions** the component to its final position? What **Tracks** the position of the component?
- Sequence of steps and duration
- Procedure availability and use
- Conditions to stop work
- Notifications
- House keeping

### 2.2 Initial Conditions

None

### 2.3 Tools and Consumables

2.3.1 Two Plankton nets with 0.075 mm mesh openings

2.3.2 Cod end sample collection cups for end of plankton nets with 0.075 mm mesh openings

2.3.3 16 oz. plastic sample jars for bivalve larvae samples

2.3.4 Table sugar

2.3.5 37% buffered formaldehyde

## 3. PRECAUTIONS

None

## 4. INSTRUCTIONS

> **NOTE**
>
> If for any reason entrainment samples **cannot** be acquired, the Control Room (x-3380 or x-3480) **must** be contacted and an attempt **must** be made to notify Regulatory Compliance.
>
> - Mike O'Keefe (x-7745)
> - Al Legendre (x-7773)

### 4.1 Entrainment Sampling Preparations

4.1.1 NOTIFY the Control Room (x-3380 or x-3480) of the following:

- ☐ you will be starting plankton entrainment sampling
- ☐ you will be opening CW-V-130 and
- ☐ Normandeau Associates personnel will be on-site while CW-V-130 is open.

4.1.2 CHECK OPEN/OPEN CW-V-130, Entrainment Sampling Supply Isolation Valve which is located 20 feet east of the CW Pumphouse entrance door.

**NOTE**

1. Entrainment sampling drum assemblies are set up as two trains (A and B), each with two drums (see Figure 1). Sampling is normally performed using only train A. Train B may be used as a backup. The instructions for sampling with Train B are identical to Train A, with the exception of valve designations which are presented in parentheses.

2. Bivalve larvae entrainment samples are normally collected before ichthyoplankton samples.

### 4.2 Entrainment Sampling Equipment Instructions

4.2.1 CHECK OPEN/OPEN the following valves:

☐ • CW-V-132, Entrainment Sampling Outlet Valve, (Train B: CW-V-135)

☐ • CW-V-133, Entrainment Sampling Outlet Valve, (Train B: CW-V-136)

☐ 4.2.2 CLOSE outer drum assembly drains by inserting the drain plugs on the steel rods at the back of each barrel.

☐ 4.2.3 Slowly THROTTLE OPEN CW-V-131, Entrainment Sampling Inlet Valve, (Train B: CW-V-134).

☐ 4.2.4 FLUSH system for at least 2 minutes or until water is visibly clear.

☐ 4.2.5 Slowly CLOSE CW-V-131, (Train B: CW-V-134).

☐ 4.2.6 ALLOW drums to drain to fish pit.

**NOTE**

Nets should be clean before proceeding. If residue from last sample is evident, nets **must** be rinsed with salt water from salt water supply, CW-V-0211.

**4.3 Bivalve Larvae Sample Net Set-Up**

☐ 4.3.1 SUSPEND the two 0.075 mm bivalve larvae nets from the hooks above each drum. These nets should not be confused with the coarser mesh ichthyoplankton nets (0.333 mm).

☐ 4.3.2 FASTEN a cod end collection cup to the end of the net.

4.3.3 CLOSE the entrainment sampling outlet valves:

☐ • CW-V-132, (Train B: CW-V-135)

☐ • CW-V-133, (Train B: CW-V-136)

☐ 4.3.4 Slowly FILL both drums until the water level is at least 2 inches above the top of the inner drums by throttling OPEN CW-V-131, entrainment sampling inlet valve (Train B: CW-V-134).

☐ 4.3.5 CLOSE CW-V-131, (Train B: CW-V-134) when the water has reached the desired level.

☐ 4.3.6 LOWER the plankton nets into the inner drums, DISPLACE any trapped air and "hoop" the net ring around the outside of the inner drum (See Figure 1).

☐ 4.3.7 RESET (re-zero) flow totalizer CW-FT-6052, (Train B: CW-FT-6053).

## 4.4 Bivalve Larvae Sample Collection

☐ 4.4.1 SLOWLY THROTTLE OPEN CW-V-131, entrainment sampling inlet valve (Train B: CW-V-134).

☐ 4.4.1.1 ALLOW water to rise above the nets and NOTE this as "Sample Start Time."

☐ 4.4.1.2 RECORD start time on Form A.

4.4.2 THROTTLE OPEN the entrainment sampling outlet valves:

☐ • CW-V-132, (Train B: CW-V-135)

☐ • CW-V-133, (Train B: CW-V-136)

**NOTE**

Final flow rate through the drums should be 100 to 400 gpm as read on CW-FT-6052, (Train B: CW-FT-6053), entrainment sampling flow totalizer. Totalizer reading is in gallons.

4.4.3 MAINTAIN water level of drums to about 2 to 6 inches above inner drum by adjusting the following:

☐ • CW-V-132, (Train B: CW-V-135) entrainment sampling outlet valve

or

☐ • CW-V-133, (Train B: CW-V-136) entrainment sampling outlet valve

or

☐ • CW-V-131, (Train B: CW-V-134) entrainment sampling inlet valve

☐ 4.4.4 MONITOR the water level in the drums periodically to prevent overflow.

☐ 4.4.5 When the totalizer displays approximately 2,000 gallons, slowly CLOSE CW-V-131, entrainment sampling inlet valve (Train B: CW-V-134).

☐ 4.4.6 RECORD the following on Form A:

- sample end time
- water volume sampled from the flow totalizer
- approximate average flow

☐ 4.4.7 OPEN the entrainment sampling outlet valves:

- CW-V-132, (Train B: CW-V-135)
- CW-V-133, (Train B: CW-V-136)

### 4.5 Bivalve Larvae Sample Removal from Nets

> **NOTE**
>
> Bivalve larvae can **only** be rinsed into the sample jars with salt water.

☐ 4.5.1 REMOVE the nets from the drums and HANG them on hooks above A Train drums.

☐ 4.5.2 RINSE down the nets into the 0.075 mm cod end collection cup, using a garden hose attached to saltwater supply CW-V-0211 and ENSURE all sample material is washed into cup.

> **STOP W A R N I N G STOP**
>
> Sample **must** be carefully transferred to sample jar containing buffered formaldehyde to avoid inhaling **or** spilling formaldehyde on skin.

> **NOTE**
>
> All bivalve larvae samples **must** be preserved with buffered formaldehyde and sugar.

☐ 4.5.3 TRANSFER the contents of both 0.075 mm cod end collection cups to the 16 oz. sample jar which already contains 3 ml of buffered formaldehyde and sugar (jars are pre-labeled with matching external and internal labels, see Figure 2).

☐ 4.5.4 If collection jar has >50% biomass (by volume) two sample jars **must** be used. PERFORM the following steps for both collection jars after splitting the sample into two sample jars.

4.5.5 Fill out the outside label:

☐ 4.5.5.1 PROJ – enter the current Seabrook project number

☐ 4.5.5.2 METHOD – enter P75

☐ 4.5.5.3 STA – enter E1

☐ 4.5.5.4 REP:

- ENTER "1"for first replicate.
- ENTER "2" for second replicate.
- ENTER "3" for third replicate.

☐ 4.5.6 RECORD the "sample end time" for each replicate collection under TIME on Form A.

☐ 4.5.7 RECORD all information on Form A, and PROVIDE a copy of the data sheet to Regulatory Compliance Department (01-48).

4.5.8 REPEAT steps 4.3.2 through 4.5.7 for the required bivalve larvae samples, and PLACE each sample in a separate 16 oz. sample jar.

☐ 4.5.9 VERIFY that at least one circulating water pump has been operating for the entire sampling period.

## 4.6 Bivalve Larvae Sample Completion

4.6.1 If ichthyoplankton samples are to be collected after bivalve larvae samples, PERFORM the following:

- ☐ ENSURE bivalve samples are kept cool (e.g., samples in a cooler with ice) during 24-hour ichthyoplankton sampling.
- ☐ PROCEED to ZN1120.01, Ichthyoplankton Entrainment Sampling, Section 4.2, Entrainment Sampling Equipment Instructions.

☐ 4.6.2 If ichthyoplankton samples will **not** be collected after bivalve larvae samples, PROCEED to step 4.6.3.

☐ 4.6.3 CLOSE CW-V-130, entrainment sampling supply isolation valve.

☐ 4.6.4 NOTIFY Control Room (x-3380 or x-3480) of the following:

- plankton entrainment sampling is complete
- CW-V-130 is closed.

4.6.5 After completion of sample collection PERFORM the following:

- ☐ REMOVE drain plug from rear of drums to allow drums to drain.
- ☐ RINSE nets and inside of both drums with potable water from PW-V-66.
- ☐ Store nets on left side of train B.

☐ 4.6.6 DELIVER sample jars and sample data sheet to contract laboratory (Normandeau Associates Hampton Lab).

## 5. REFERENCES

5.1 ZN1120.01, Ichthyoplankton Entrainment Sampling

5.2 NPDES Permit NH0020338

5.3 ON1038.07, Circulating Water Chlorination System Operation

5.4 ON1038.01, Circulating Water System Pump Startup

## 6. SUMMARY OF CHANGES

6.1 Rev. 00: Initial Issue.

6.2 Rev. 00 Chg. 01 (October 2004)

- Incorporated into Change 02.
- Valves identified in initial conditions have been removed from the system. Initial conditions are being totally removed from this procedure. As there are no initial conditions that must be completed or verified complete prior to procedure performance the procedure change is non-intent.

6.3 Rev. 00 Chg. 02 (October 2004)

- Incorporated Change 01.
- Incorporates a self-briefing and reformats some procedure steps. Names of notified personnel are updated; instructions for labeling samples are updated.

6.4 Rev. 00 Chg. 03 (January 2008)

- Add Configuration Control to Requirement 2.1.2 for self-briefing.

## Figure 1: Diagram of Entrainment Sampling Equipment

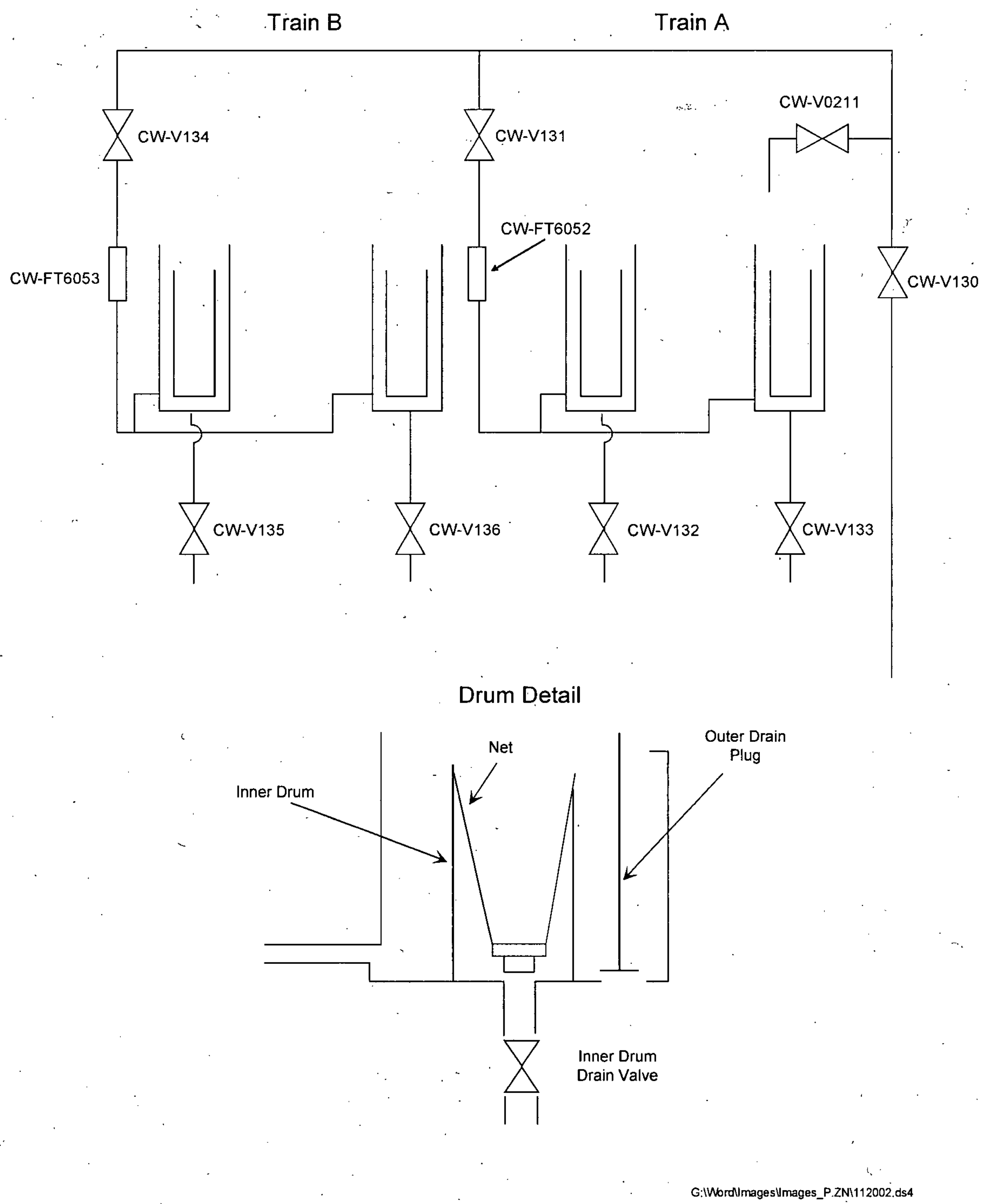
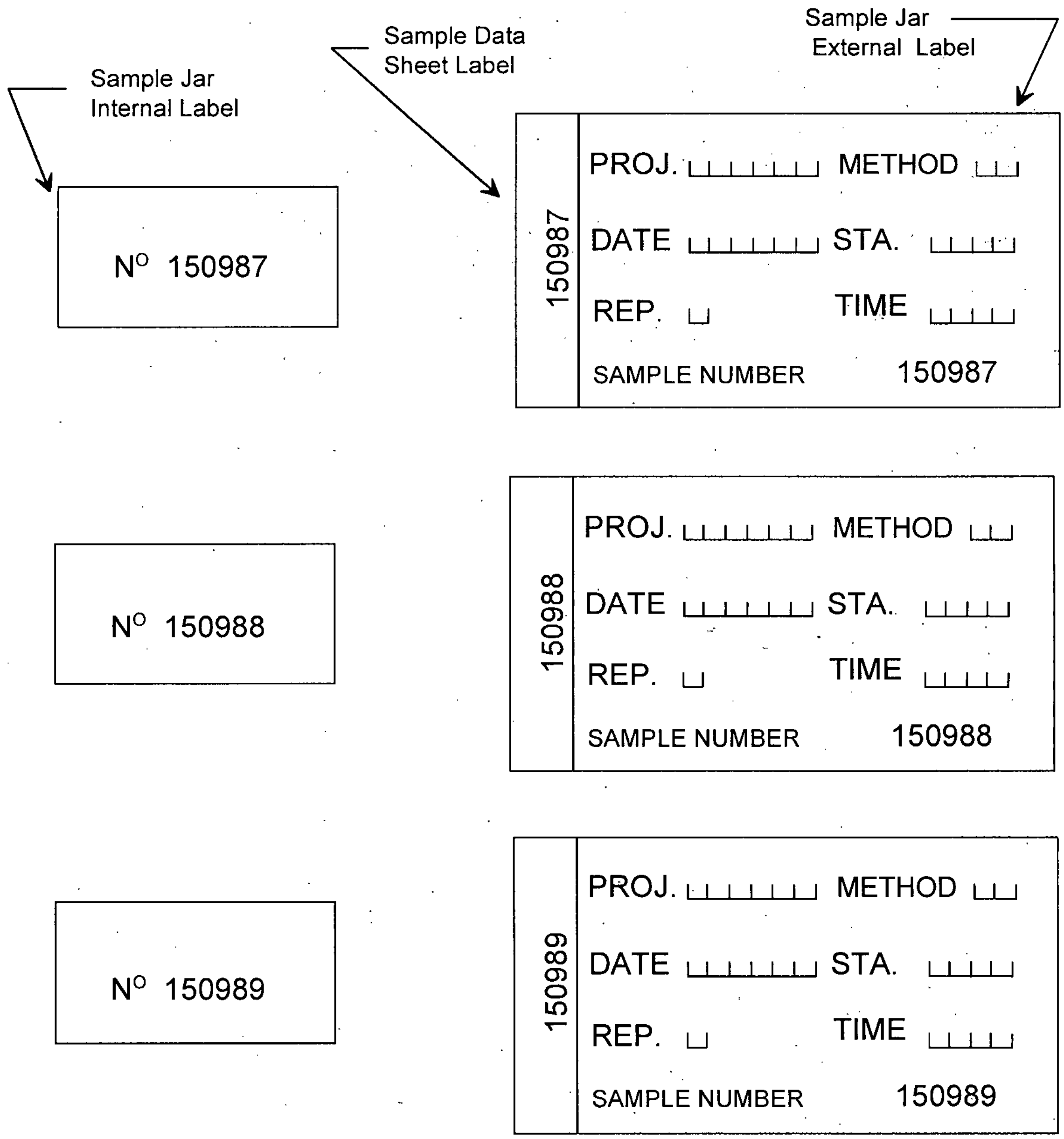


**Figure 2: Example of Sample Jar Internal and External Labels**

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## Figure 3: Bivalve Larvae Entrainment Analytic Calculation

The annual bivalve larvae entrainment estimate will be calculated as follows:

$$E_p = (D_{s,p})\ (V_p)$$

$$E_m = \sum_{p=1}^{4} E_p$$

$$E_a = \sum_{m=4}^{10} E_m$$

where,

$E_p$ = entrainment estimate for a sample period (usually one week),

$D_{s,p}$ = density of bivalve larvae in a sample for period p, units are number of bivalve larvae per gallons of water sampled

$V_p$ = volume of cooling water pumped by the plant in a sample period (usually one week)

$E_m$ = monthly entrainment estimate,

$E_a$ = annual entrainment estimate (mid-April through October).

Sample Period: ___________________

## Form A: Entrainment Sampling Data Sheet

Date Samples Collected _____________________ Collector's Name __________________________________________

| SAMPLE NUMBER (PLACE ADHESIVE LABEL HERE) | SAMPLE START TIME | SAMPLE END TIME | SAMPLE DURATION (MINUTES) | SAMPLE VOLUME (TOTALIZER READING GALLONS) | FLOW RATE (GPM) | FORMALDEHYDE AND SUGAR ADDED |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |

Samples Delivered to Normandeau Associates by: _____________________________ Time: ______________ Date: __________

Samples Received by: _____________________________________ Time: ________________ Date: ______________

**Provide copy of completed form to Regulatory Compliance (mail code 01-48).**

## PROCEDURE BASIS INFORMATION

**Archived information located in the Basis Section, such as revision, change status, table and step references are not updated as the procedure is changed or revised.**

Rev. 00: Initial Issue; procedure was developed in accordance with PR 3.2, Rev. 01.

SEABROOK STATION

Regulatory Compliance Procedure

# Ichthyoplankton Entrainment Sampling

**ZN1120.01**

**Rev. 01 Chg. 03**

Level of Use
General

Procedure Owner:
Regulatory Compliance
Supervisor

TABLE OF CONTENTS

## 1. PURPOSE

### 1.1 Objective

This procedure describes the process for the collection of weekly entrainment samples of ichthyoplankton (fish eggs and larvae) from the Circulating Water System (CWS). Ichthyoplankton entrainment sampling is a requirement of Seabrook Station's NPDES Permit.

### 1.2 Discussion

Entrainment sampling is part of Seabrook Station's Environmental Studies Program which is a requirement of the Station's NPDES Permit. Environmental studies, which evaluate the number of ichthyoplankton (fish eggs and larvae) entrained by the Station's Circulating Water System (CWS), determine the potential impact to the population of these organisms.

About 288,000 gallons of water from the discharge of the Circulating Water (CW) discharge pumps are passed through the 0.333 mm mesh ichthyoplankton nets during a 24-hour sample period. Ichtyoplankton samples are normally collected Wednesday to Thursday of each week.

Weekly Bivalve larvae entrainment samples are collected using 0.075 mm mesh nets, per ZN1120.02.

Each 24-hour sample will be divided into four 6-hour diel strata. Collection of samples from diel periods will allow comparisons of entrainment rates during diel periods and the potential to optimize sampling effort in future years. Four times each month entrainment samples will be collected during the following 6-hour diel strata: 2215-0415 (night, 0415-1015 (morning), 1015-1615 (day) and 1615-2215 (evening) EST. Times of sampling will be delayed one hour when EDT is in effect so that 2215-0015 EST becomes 2315-0115 EDT etc. (Figure 1). Within each of these strata, the entrainment sample will be collected during a 2-hour period. A total CW flow rate of about 600 gallons per minute (gpm) is maintained during sampling in both trains of drum samplers (300 gpm in each drum samplers). Since only two of the possible six hours of a particular diel stratum would be sampled each week, that 2-hour block **must** be scheduled in an unbiased way, either randomly **or** systematically. Systematic sampling has the advantage of insuring that all six hours of a diel strata are equally represented in a year, and that the intervals between successive sampling of any particular 2-hour block are **not** excessively long. Therefore, the first of the three 2-hour intervals of each of the four-diel strata will be sampled in the first week of sampling, and the second 2-hour interval on the second week continuing until all three 2-hour intervals have been sampled. In week four sampling will return to the first 2-hour interval in the diel strata.

Entrainment sampling is performed using both sampling trains (A and B). Four 0.333 mm mesh nets are suspended in the Four drum samplers of Train A and B to collect an entrainment sample. Samples collected in the Four drum samplers from each train, are combined to provide one sample.

The plankton net is placed in a 30-gallon drum which is suspended in a 55-gallon drum. Water diverted from the CWS enters the 55-gallon drum from the bottom and overflows the 30-gallon drum into the plankton net. After passing through the plankton net, the water discharges through the bottom of both drums. The collected ichthyoplankton are washed from the plankton nets into sample collection jars and preserved. Weekly samples are delivered to the Normandeau Associates Hampton lab for analysis. Ichthyoplankton entrainment sampling is performed four times per month. Entrainment sampling is normally performed when two CW pumps are operating, when sufficient flow is available to supply 600 gpm of ocean water to entrainment sampling equipment (300 gpm per train). If only one CW pump is operating **or** if only one of the Seawater Supply Valves is open, it will **not** be possible to achieve a flow of 300 gpm in each Train. Entrainment samples **shall** be collected at the reduced flow rates.

Figure 3 provides a description of the Ichthyoplankton Entrainment Analytic Calculation.

### 1.3 Frequency

Ichthyoplankton entrainment samples are collected four times each month for a total of 48 samples per year. Within each sampling day, the four diel strata will be sampled in 2-hour periods.

## 2. PREREQUISITES

### 2.1 Requirements

2.1.1 Entrainment sampling can be performed only when at least one Circulating Water System pump is in operation, when sufficient flow is available to supply ocean water to entrainment sampling equipment.

2.1.2 Perform a self-briefing by considering the following:

- Job hazards and safety considerations
- Personnel protective equipment
- Human error prevention techniques
- Configuration Control – Prevent the mispositioning of components by using **D.I.R.T.** What **Directs** the positioning of the component? What prevents **Inadvertent** contact? What **Repositions** the component to its final position? What **Tracks** the position of the component?
- Sequence of steps and duration
- Procedure availability and use
- Conditions to stop work
- Notifications
- House Keeping

### 2.2 Initial Conditions

None

### 2.3 Tools and Consumables

2.3.1 Four plankton nets with 0.333 mm mesh openings and Cod end collection cups.

2.3.2 32 oz. plastic sample jars for ichthyoplankton samples, with labels.

2.3.3 37% buffered formaldehyde.

## 3. PRECAUTIONS

None

## 4. INSTRUCTIONS

> **NOTE**
>
> If for any reason entrainment samples **cannot** be acquired, the Control Room (X3380 or X3480) **must** be contacted and an attempt **must** be made to notify Regulatory Compliance.
>
> - Mike O'Keefe (x-7745)
> - Al Legendre (x-7773)

### 4.1 Entrainment Sampling Preparations

4.1.1 NOTIFY the Control Room (x-3380 or x-3480) of the following:

- ☐ you will be starting plankton entrainment sampling
- ☐ you will be opening CW-V-130 and
- ☐ Normandeau Associates personnel will be on-site while CW-V-130 is open.

☐ 4.1.2 CHECK OPEN/OPEN CW-V-130, Entrainment Sampling Supply Isolation Valve which is located 20 feet east of the CW Pumphouse entrance door.

### 4.2 Entrainment Sampling Equipment Instructions

> **NOTE**
>
> Entrainment sampling drum assemblies are set up as two trains (A and B), each with two drums (See Figure 1). Both trains will be used simultaneously for sampling with the 0.333 mm mesh net.

4.2.1 CHECK OPEN/OPEN the entrainment sampling outlet valves:

- ☐ CW-V-132
- ☐ CW-V-133
- ☐ CW-V-135
- ☐ CW-V-136

☐ 4.2.2 CLOSE outer drum assembly drains by inserting the drain plugs on the steel rods towards the back of each drum.

☐ 4.2.3 Slowly THROTTLE OPEN Entrainment Sampling Inlet Valves.

- CW-V-131
- CW-V-134

4.2.4 FLUSH system for at least 2 minutes at a flow rate of about 200 gpm or until water is visibly clear.

☐ 4.2.5 Slowly CLOSE entrainment sampling inlet valves:

- CW-V-131
- CW-V-134

☐ 4.2.6 ALLOW drums to drain to fish pit.

**NOTE**

Nets should be clean before proceeding. If residue from last sample is evident, nets **must** be rinsed clean.

## 4.3 Ichthyoplankton Sample Net Set-Up

☐ 4.3.1 SUSPEND the two 0.333 mm ichthyoplankton nets from the hooks above each drum. These nets should **not** be confused with the finer mesh bivalve nets (0.075 mm).

☐ 4.3.2 FASTEN a 0.333 mm mesh Cod end collection cup to the end of the net.

4.3.3 CLOSE the entertainment sampling outlet valves:

☐ • CW-V-132

☐ • CW-V-133

☐ • CW-V-135

☐ • CW-V-136

☐ 4.3.4 Slowly FILL both drums until the water level is above the top of the inner drums by throttling OPEN Entertainment Sampling Inlet Valves.

☐ • CW-V-131

☐ • CW-V-134

☐ 4.3.5 When water has reached the desired level, slowly CLOSE Entrainment Sampling Inlet Valves.

☐ • CW-V-131

☐ • CW-V-134

4.3.6 LOWER the plankton nets into the inner drums, DISPLACE any trapped air and "hoop" the net ring around the outside of the inner drum and SECURE net with an elastic ring. (See Figure 2).

☐ 4.3.7 RESET (re-zero) flow totalizer CW-FT-6052 (Train B: CW-FT-6053).

### 4.4 Ichthyoplankton Sample Collection

**CAUTION**

Avoid overflowing the drums. The following three steps need to be performed in rapid succession to avoid overflowing the drums and may need to be repeated to maintain the correct water level.

**NOTE**

Final flow through each sample train is about 300 gpm as read on entrainment sampling flow totalizer CW-FT-6052 and CW-FT-6053. A total of 4 subsamples of 2 hours duration are collected on each sampling day. The total volume of ocean water processed is about 288,000 gallons. Section 4.4 is for the collection of one 2-hour subsample. These steps will be repeated three more times in the course of a 24-hour sample. If only one CW pump is operating, it may **not** be possible to achieve a flow of 300 gpm in each Train. If this condition exists, proceed with the collection of a 2-hour sample at the highest flow rate achievable **not** to exceed 300 gpm per Train.

☐ 4.4.1 SLOWLY THROTTLE OPEN entrainment sampling inlet valves, to achieve a flow rate of about 300 gpm per train.

- CW-V-131
- CW-V-134

4.4.1.1 ALLOW water to rise above the nets and NOTE this as "Sample Start Time."

☐ 4.4.1.2 RECORD start time on Form A.

☐ 4.4.2 THROTTLE OPEN the entrainment sampling outlet valves:

- CW-V-132
- CW-V-133
- CW-V-135
- CW-V-136

☐ 4.4.3 MAINTAIN water level of drums above inner drum by adjusting the following valves as necessary while maintaining flow through each train about 300 gpm:

- Train A
  - CW-V-131
  - CW-V-132
  - CW-V-133
- Train B
  - CW-V-134
  - CW-V-135
  - CW-V-136

☐ 4.4.4 MONITOR the water level in the drums periodically to prevent overflow.

> **NOTE**
>
> Totalizer reading is in gallons.

☐ 4.4.5 After 2-hours of collection (about 36,000 gallons of flow per train) SLOWLY CLOSE entrainment sampling inlet valves.

- CW-V-131
- CW-V-134

☐ 4.4.6 REMOVE the nets from the drums and HANG them on the hooks over the drums.

☐ 4.4.7 RECORD the following on Form A:

- "End Time"
- "Sample Volume Totalizer Reading"
- "Flow Rate"

## 4.5 Ichthyoplankton Sample Removal from Nets

STOP **WARNING** STOP

Sample **must** be carefully transferred to sample jar containing buffered formaldehyde to avoid inhaling or spilling formaldehyde on skin.

- [ ] 4.5.1 REMOVE the sample from both nets in the train being used (A or B).
- [ ] 4.5.2 RINSE down the nets into the 0.333 mm mesh collection cup, using a garden hose attached to saltwater supply CW-V-0211.
- [ ] 4.5.3 ENSURE that any material caught in net seams is also rinsed into the sample collection cup.
- [ ] 4.5.4 TRANSFER the contents of both 0.333 mm Cod end collection cups from both trains to the 32 oz. sample jar which already contains buffered formaldehyde solution.
- [ ] 4.5.5 If the jar has >50% biomass (by volume), USE two 32 oz. sample jars. After splitting the sample into two sample jars, PERFORM the following:
- [ ] 4.5.5.1 PLACE a label with sample number that matches the outside label, on the inside of the 32 oz. sample jar(s), and CLOSE the sample collection jar.
- [ ] 4.5.5.2 Fill out the outside label (Figure 3):
- [ ] 4.5.5.2.1 PROJ – enter the current Seabrook project number
- [ ] 4.5.5.2.2 METHOD – enter P33
- [ ] 4.5.5.2.3 STA – enter E1

☐ 4.5.5.2.4 REP:

- ENTER "1" for morning diel period replicate.
- ENTER "2" for day diel period replicate.
- ENTER "3" for evening diel period replicate.
- ENTER "4" for night diel period replicate.

4.5.5.3 RECORD all information on Form A.

### 4.6 Restoration of Entrainment Sampling Equipment

4.6.1 If bivalve entrainment sampling is **not** scheduled to be performed,

- ☐ REMOVE drain plug from rear of drums to allow drums to drain,
- ☐ RINSE nets and inside of both drums with potable water from PW-V-66, and
- ☐ HANG nets from hooks above drums.

4.6.2 CHECK CLOSE/CLOSE CW-V-130, entrainment sampling supply isolation valve.

☐ 4.6.3 CHECK OPEN/OPEN the entertainment sampling outlet valves:

- ☐ CW-V-132
- ☐ CW-V-133
- ☐ CW-V-135
- ☐ CW-V-136

☐ 4.6.4 NOTIFY Control Room (x-3380 or x-3480) of the following:

- plankton entrainment sampling is complete
- CW-V-130 is closed

☐ 4.6.5 ENSURE all information is filled in on the entrainment sampling data sheet (Form A).

☐ 4.6.6 MAKE a copy of data sheet and provide to Regulatory Compliance (mail code 01-48).

☐ 4.6.7 Deliver sample jars and data sheet to the Hampton Lab.

## 5. REFERENCES

5.1 NPDES Permit NH0020338

5.2 ON1038.07, Circulating Water Chlorination System Operation

5.3 ON1038.01, Circulating Water System Pump Startup

5.4 RTS 96RL00002012

## 6. SUMMARY OF CHANGES

6.1 Rev. 01

- Revised to clarify and simplify the procedure.
- Revised to reflect the use of just 0.333 mm mesh nets and the elimination of 0.505 mm nets.
- Revised to reflect that collection of four 2-hour samples during a 24-hour period instead of four 6-hour samples.
- Revised to reflect the flow rate maintained during sampling is increased from about 70 gallons per minute (gpm) to about 300 gpm.
- Revised to reflect that both trains of entrainment sampling equipment (two sets of collection drums) are used to collect samples.
- Deleted old Reference 5.3 and renumbered.
- Updated Form A.
- Corrected title of Figure 3.

6.2 Rev. 01 Chg. 01 (October 2004)

- Incorporated into Change 02.
- Valves identified in initial conditions have been removed from the system. Initial conditions are being totally removed from this procedure. As there are **no** initial conditions that **must** be completed or verified complete prior to procedure performance the procedure change is non-intent.

6.3 Rev. 01 Chg. 02 (October 2004)

- Incorporated Change 01.
- Incorporates a self-briefing and reformats some procedure steps. Names of notified personnel are updated; instructions for labeling samples are updated.

6.4 Rev. 01 Chg. 03 (January 2008)

- Add Configuration Control to Requirement 2.1.2 for self-briefing.

## Figure 1: Proposed Sampling Design for Ichthyoplankton Entrainment Collections at Seabrook Station

| Diel Stratum | Sample Time (EST)[a] | Scheduled Samples (X) by Quarter-Month Sampling Period | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | January | | | | February | | | | March | | | | ....[b] | December | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | .... | 45 | 46 | 47 | 48 |
| Night | 2215-0015 | X | | | X | | | X | | | X | | | | | X | | |
| | 0015-0215 | | X | | | X | | | X | | | X | | | | | X | |
| | 0215-0415 | | | X | | | X | | | X | | | X | | X | | | X |
| Morning | 0415-0615 | X | | | X | | | X | | | X | | | | | X | | |
| | 0615-0815 | | X | | | X | | | X | | | X | | | | | X | |
| | 0815-1015 | | | X | | | X | | | X | | | X | | X | | | X |
| Day | 1015-1215 | X | | | X | | | X | | | X | | | | | X | | |
| | 1215-1415 | | X | | | X | | | X | | | X | | | | | X | |
| | 1415-1615 | | | X | | | X | | | X | | | X | | X | | | X |
| Evening | 1615-1815 | X | | | X | | | X | | | X | | | | | X | | |
| | 1815-2015 | | X | | | X | | | X | | | X | | | | | X | |
| | 2015-2215 | | | X | | | X | | | X | | | X | | X | | | X |

[a]Delay time of sampling by one hour when Eastern Daylight Time is in effect, so that 2215-0015 EST becomes 2315-0115 EDT, etc.

[b]The schedule repeats every three months, so the sampling period 1-12 schedule is repeated for sampling periods 13-24, 25-36, and 37-48.

## Figure 2: Diagram of Entrainment Sampling Equipment

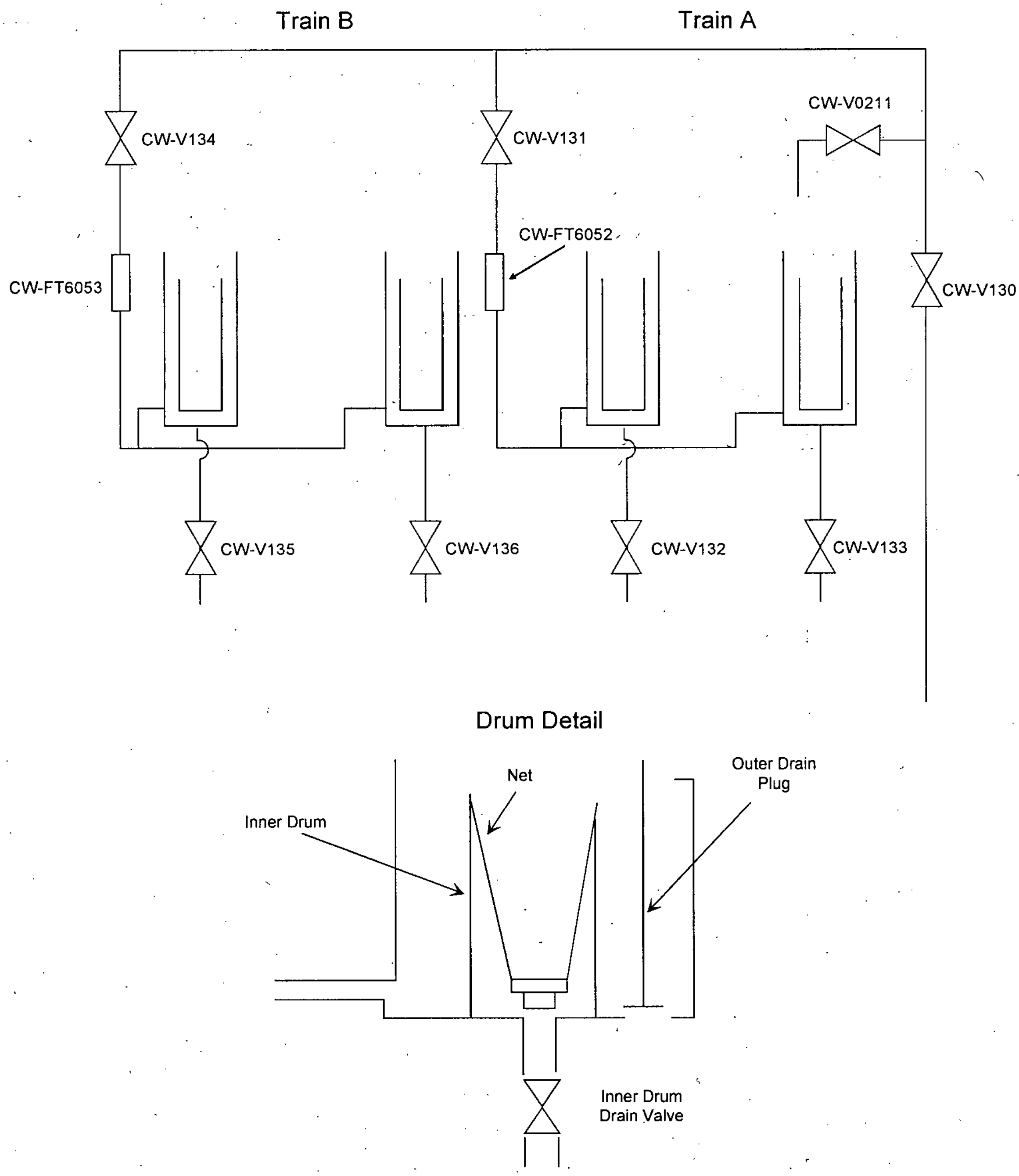


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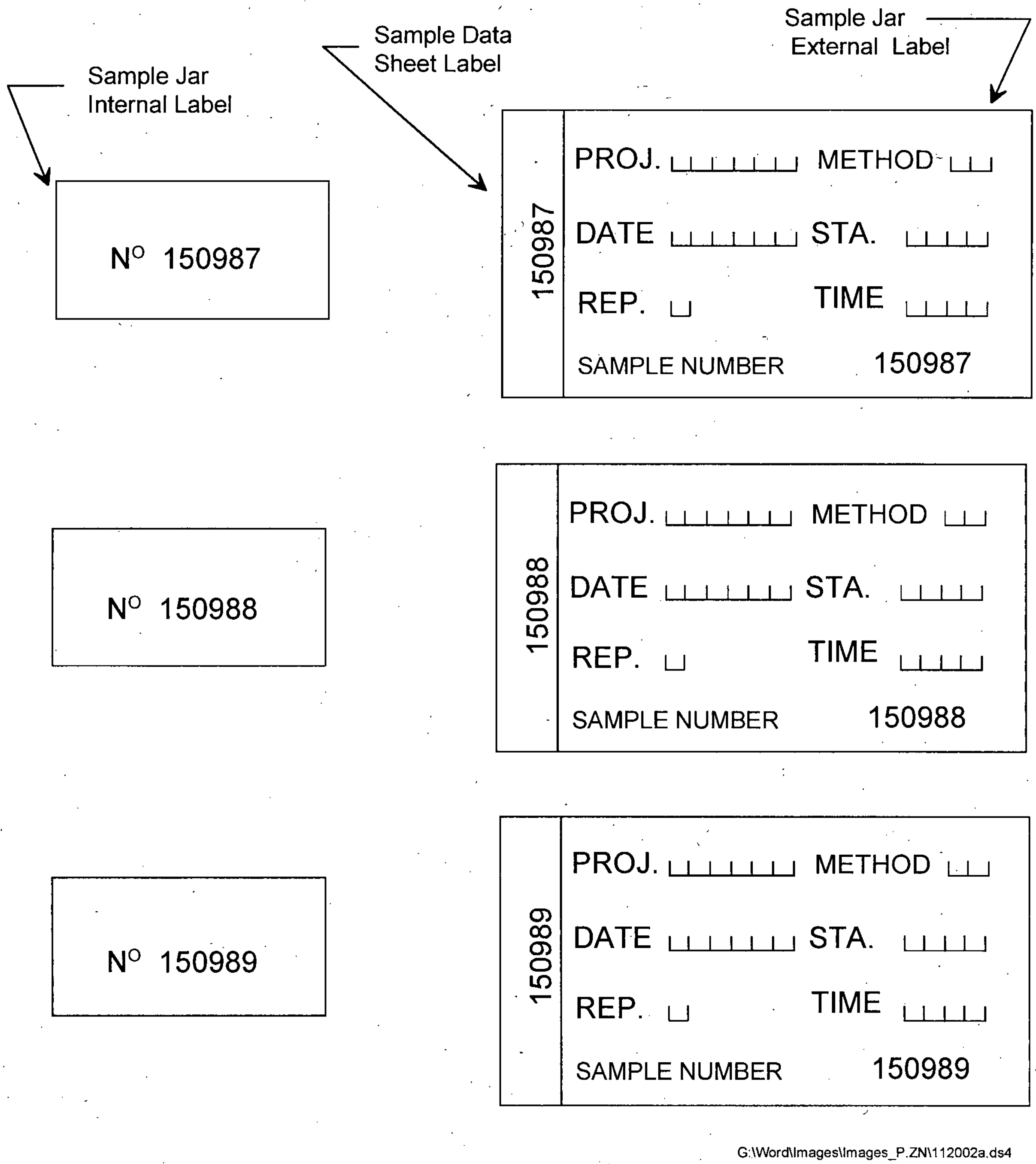
**Figure 3: Example of Sample Jar Internal and External Labels**



## Figure 4: Ichthyoplankton Entrainment Analytic Calculation

The annual entrainment estimate for each mesh size will be calculated as follows:

$$E_p = (D_{s,p})\ (V_p)$$

$$E_m = \Sigma_{p=1..4}\ E_p$$

$$E_a = \Sigma_{m=1..12}\ E_m$$

where,

$E_p$ = entrainment estimate for a sample period (usually one week),

$D_{s,p}$ = density of ichthyoplankton in a sample for period p,

$V_p$ = volume of cooling water pumped by the plant in a sample period (usually one week).

$E_m$ = monthly entrainment estimate,

$E_a$ = annual entrainment estimate.

Analysis of Variance (ANOVA) will be used to determine if there are significant differences in the mean densities of key species between day and night. MANOVA will be used to investigate differences in the species composition between the day and night samples.

## Form A: Seabrook Station Entrainment Sampling Data Sheet

Date Collected ____________________ Collected By: ______________________________ Sample Period: __________________

| Sample Number (affix label) | Diel Period * | Start Time (24 hour) | End Date (mmddyy) | End Time (24 hour) | Sample Duration (minutes) | Sample Volume totalizer reading gallons | Flow Rate (gpm) | Formaldehyde Added (43 ml.) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

Diel Periods*
1 = Morning
2 = Day
3 = Evening
4 = Night

Samples Delivered to Normandeau Associates By: ________________________________ Date: ______________ Time: ______________

Samples Received By: ________________________________ Date: ______________ Time: ______________

**Provide copy of completed form to Regulatory Compliance (mail code 01-48).**

## PROCEDURE BASIS INFORMATION

**Archived information located in the Basis Section, such as revision, change status, table and step references are not updated as the procedure is changed or revised.**

Rev. 00: Initial Issue.