MARINE ECOLOGY STUDIES

PILGRIM NUCLEAR POWER STATION

REPORT No. 65

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Compiled and Reviewed by:

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Section 1

Introduction

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

INTRODUCTION

A. Scope and Objective

This is the sixty-fifth (65) report, provided semi-annually, on the status and results of environmental surveillance and monitoring programs related to the operation of Pilgrim Nuclear Power Station (PNPS). The monitoring efforts discussed in this report relate specifically to the Western Cape Cod Bay ecosystem with particular emphasis on the Rocky Point area. This report is submitted in accordance with the environmental monitoring and reporting requirements of the PNPS NPDES Permit from the U.S. Environmental Protection Agency (#MA0003557) and Massachusetts Department of Environmental Protection (#359).

The objectives of the Environmental Surveillance and Monitoring Program are to determine whether the operation of PNPS results in measurable effects on the marine ecology and to evaluate the significance of any observed effects. If an effect of potential significance is detected, corrective steps are taken to address the issue.

The efforts described in this report represent a continuation of monitoring conducted at PNPS in the past by Entergy (and before that, by Boston Edison Company). This program was submitted to U.S. EPA and MA DEP for review in December 2003 and was subsequently approved. Note that in March 2002, Entergy Nuclear Operations, Inc. became the operator of Pilgrim Station, although Entergy Nuclear Generation Co. is still the owner. This change had virtually no effect on the Marine Environmental Monitoring Programs at PNPS or the personnel associated with them.

B. Marine Biota Studies

1. Marine Fisheries Monitoring

Marine Fisheries studies in 2004 focused on winter flounder population parameters to develop an understanding of any PNPS impact on this indicator species. Population estimates and adult equivalency analyses are conducted on this key species to help assess the impact of PNPS entrainment.

Results of the marine fisheries monitoring during the reporting period are presented in Section 3.1. Winter flounder are studied by trawling techniques.

Entergy has conducted efforts to support fisheries enhancement starting in 2000 and continuing through 2004. Winter flounder were spawned and reared in a hatchery from January to May, and then released near the Plymouth Harbor Yacht Club in mid-May 2004.

Field results have been very favorable. In 2004, 312 tagged fish were recaptured. Long-term survival experiments (pen studies) were conducted from June to October. The results of these studies are presented in Section 3.4.

2. Entrainment Monitoring

PNPS has been monitoring entrainment of fish eggs and larvae, and lobster larvae in the plant's cooling water for more than twenty-five years (in 1973-1975 phytoplankton and zooplankton were also studied). Information generated through these studies has been utilized to make periodic modifications in the sampling program to more efficiently address the question of the effect of entrainment. These modifications have been developed by Marine Research, Inc. (MRI) in conjunction with Pilgrim environmental personnel, and reviewed and approved by U.S. EPA and MA DEP on the basis of the program results.

Plankton monitoring in 2004 emphasized consideration of ichthyoplankton entrainment and selected species adult equivalency analyses. The software program RAMAS Metapop was also used to further explore the potential effects of entrainment on the winter flounder population. Model runs were completed with fishing mortality and with and without entrainment losses.

Results of the ichthyoplankton entrainment monitoring for 2004 are discussed in Section 3.2.

3. Impingement Monitoring

The PNPS impingement monitoring and survival program identifies, quantifies and determines viability of the organisms carried onto the four intake traveling screens. Results of the impingement monitoring conducted in 2004 by Marine Research, Inc. are discussed in Section 3.3.

4. Larval Transport Study

In spring 2004, a modified larval transport study was conducted in coastal Cape Cod Bay. The program was designed to update similar studies conducted in 2000 and 2002, based on the suggestions and comments of federal and state agency reviewers. The results of the 2004 Larval Transport Study are discussed in Section 3.5

5. Benthic Monitoring

No benthic monitoring was performed during this period.

C. Station Operation History

The annual capacity factor for 2004 was 98.53%, the best annual capacity factor in Pilgrim's history. Monthly average capacity factors (mean electric generation) for 2004 are shown in Figure 1.

In 2004, there were five (5) minor power reductions associated with thermal backwashes (March 22, June 4, July 30, September 21 and November 16), during which heat-treatment of the intake structure was performed for biofouling control.

The monthly average amount of sea water used for plant cooling water as well as the average discharge water temperatures are given in Figure 2. Discharge flow is shown as percent of total possible flow volume – based on pump run times – from both the circulating water and salt service water systems.

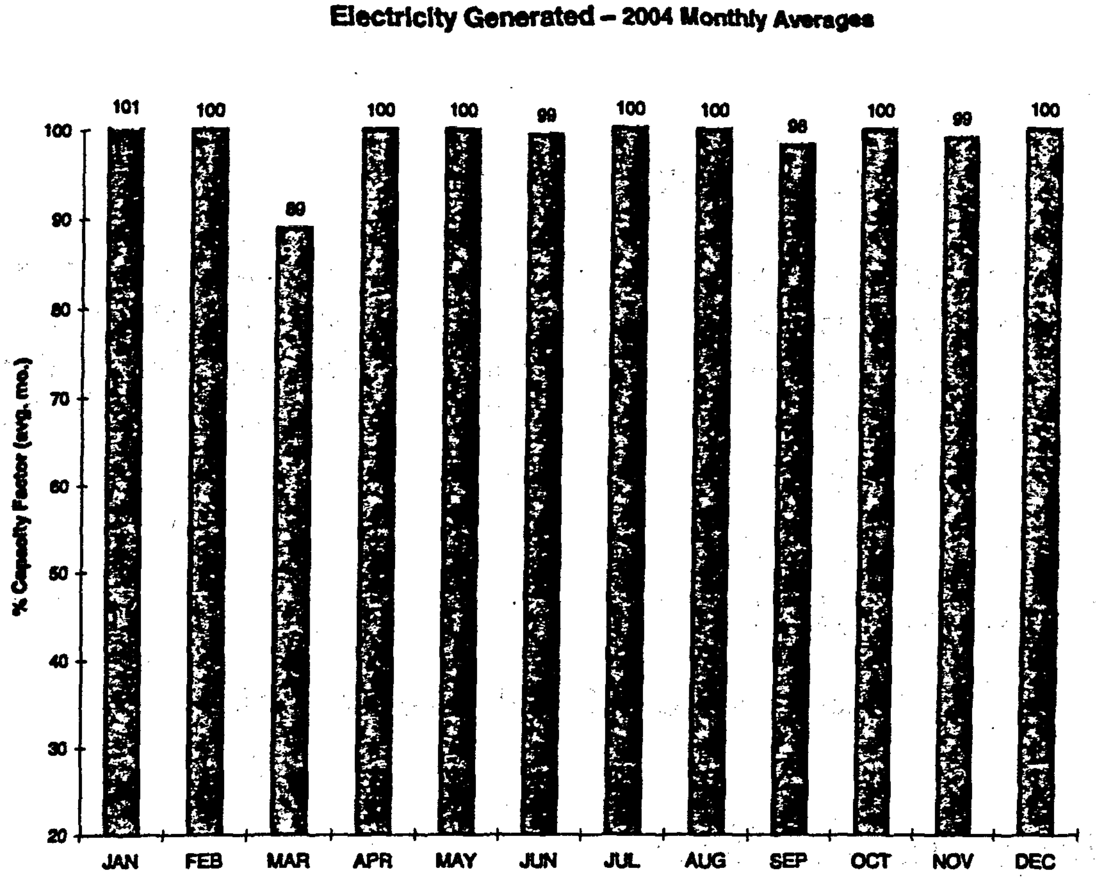

Figure 1. Monthly Electrical Output from Pilgrim Station for 2004 (avg. percent capacity factor).

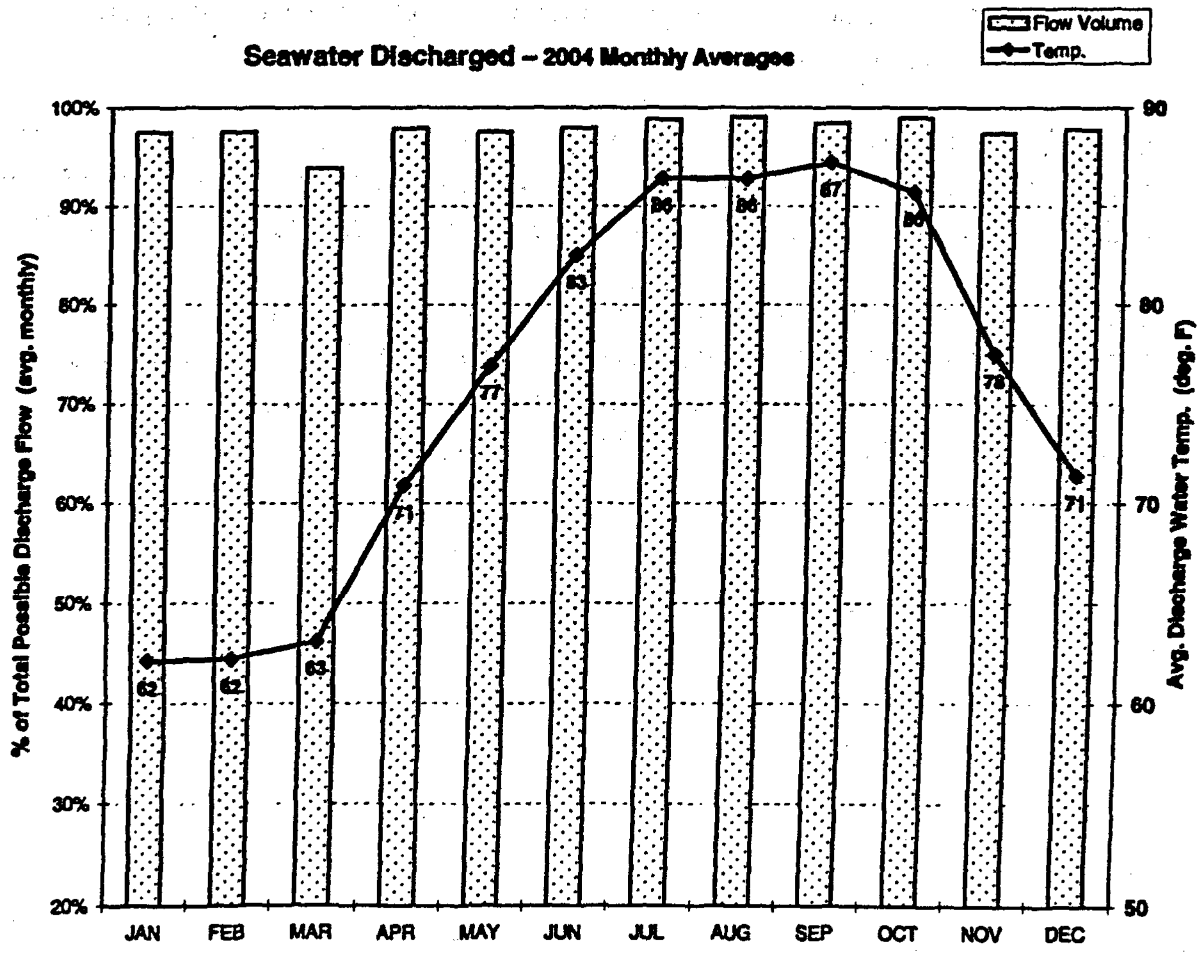

Figure 2. Seawater Discharged from Pilgrim Station - 2004 (temperature and flow).

MARINE ECOLOGY STUDIES

Pilgrim Nuclear Power Station

Section 2

Summary

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

SUMMARY

Results of the January-December 2004 Environmental Surveillance and Monitoring Program at Pilgrim are highlighted below.

Section 3.1 – Marine Fisheries Monitoring:

1. Trawls for winter flounder stock assessment were performed for the tenth consecutive year. The "area-swept" study consisted of 84 tows in northwestern Cape Cod Bay to estimate this species' population (instantaneous abundance).

2. Winter flounder population size (instantaneous abundance) was estimated using an area/density approach, based on the area-swept densities over the entire study area.

3. Adjusted estimates of winter flounder abundance in the study area for 2004 were 157,532 adults and 247,411 total winter flounder.

Section 3.2 – Entrainment Monitoring:

1. A total of 39 species of fish were represented in the January-December 2004 samples, equal to the 29-year mean.

2. Winter-early spring samples were dominated by Atlantic cod, American plaice eggs along with sand lance, rock gunnel and grubby larvae.

3. Late spring-summer collections, taken from May through July, were dominated by the *Labridae-Pleuronectes*, Atlantic mackerel, and *Paralichthys-Scophthalmus* eggs along with radiated shanny, winter flounder, and *Labridae-Pleuronectes* larvae.

4. Late summer-autumn collections (August-December) were dominated by the *Labridae-Pleuronectes*, and *Paralichthys-Scophthalmus* eggs, along with cunner, Atlantic herring, tautog and northern pipefish larvae.

5. Nine (9) lobster larvae were collected in entrainment samples for the January-December 2004 period.

6. Comparisons of ichthyoplankton densities over the 1975-2004 time series suggested that, in most cases, numbers in 2004 were consistent with those recorded since sampling began at PNPS.

Section 3.3 – Impingement Monitoring:

1. In 638.3 collection hours, a total of 33,591 fish consisting of 35 species were collected off the screens in 2004.

2. The impingement rate for 2004 was 2.85 fish per hour.

3. Atlantic silverside, Atlantic menhaden, grubby, blueback herring, winter flounder, and rainbow smelt accounted for 39, 31, 7, 6, 6, and 3%, respectively, of the annual total.

4. From January to December 2004, 20,566 invertebrates representing 12 species were sampled yielding an impingement rate of 2.63 invertebrates per hour. Sevenspine bay shrimp (*Crangon septemspinosa*) were dominant accounting for 78% of the annual total.

Section 3.4 – Hatchery Release & Collection Study

1. A total of 312 tagged hatchery winter flounder were collected in the beach seine survey in 2004. These fish were collected over 17 sampling events, following release on May 10 and May 11.

2. Fish were successfully maintained in the pens from May 12 until September 2, a total of 114 days.

3. The 2004 monthly (84%) and cumulative (80%) survival rates were higher than the 2003 survival rates.

4. Assessments from 2000 through 2004 demonstrated that released hatchery fish survival approximates wild fish survival.

Section 3.5 – Larval Transport Study

1. This was the third larval transport study performed in Cape Cod Bay to examine the key conditions (net water flow and density of winter flounder larvae) affecting the entrainment of winter flounder larvae.

2. The results of the 2004 study are similar to those of the previous studies performed in 2000 and 2002.

3. There is a consistent net flow of water and winter flounder larvae to the south along coastal Cape Cod Bay in the vicinity of Pilgrim Station.

4. Less than 0.1% of the net volumetric flow of water in Cape Cod Bay passes through Pilgrim Station.

5. The amount of winter flounder larvae in northwestern Cape Cod Bay that is entrained by Pilgrim Station is conservatively estimated at less than 1% of the net larval transport.

MARINE ECOLOGY STUDIES

Pilgrim Nuclear Power Station

Section 3.1

Marine Fisheries Monitoring

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

WINTER FLOUNDER

AREA-SWEPT ESTIMATE

WESTERN CAPE COD BAY 2004

Submitted to

Entergy Nuclear Operations, Inc.

Pilgrim Nuclear Power Station

Plymouth, Massachusetts

by

Marine Research, Inc.

Falmouth, Massachusetts

October 20, 2004

Introduction

Field studies around Pilgrim Nuclear Power Station (PNPS) have demonstrated the water withdrawal aspects of plant operations, i.e., entrainment of fish eggs and larvae, and impingement of adult and juvenile fish. The environs around PNPS serve as spawning, nursery, and feeding grounds for winter flounder (*Pseudopleuronectes americanus*) and this species is valuable both commercially and recreationally. From 1995 through 1999 the Massachusetts Division of Marine Fisheries estimated the size of the winter flounder population in waters off Pilgrim Station. This study has been continued by Marine Research, Inc. (MRI) since 2000, the 2004 work being presented here.

Methods and Materials

The study area, sampling methodology, and analytical calculations were the same as those used in the Massachusetts Division of Fisheries (MDMF) studies conducted in 1999 and by Marine Research, Inc. (MRI) from 2000 through 2003. Consistent with the past four years, tow duration was 30 minutes and tows less than 20 minutes were not included in calculations. Eight-four tows were planned for 2004. The sampling area extended from Humarock, Marshfield southeastward to the Mary Ann buoy, Manomet, from nearshore (9.2 m MLW) out to the 36.6 m (MLW) depth contour (Figure 1; Lawton et al. 2000). Since there is spatial variation in winter flounder abundance by depth (Lawton et al. 1995), stratified estimates of abundance were used to improve precision.

The 55-foot F/V *Frances Elizabeth* was contracted to sample winter flounder using a Yankee otter trawl with 18.3 m sweep and 14.6 m headrope with 15.2 cm stretch mesh body and a 7.6 cm square mesh cod end with a 4.5 cm mesh liner; it was fished with 12.8 m legs and 73.2 m ground cables. The trawl doors were steel measuring1.8 m x 1.2 m and weighing 205 kg each.

Beginning and end latitude and longitude, start and end times, and boat speed were recorded during each tow. Tow tracks were plotted with Nobeltec Visual Navigation Suite. All winter flounder were measured to the nearest centimeter total length (TL), sexed by assessing the reproductive state and maturity. This included checking for the presence of ripe eggs or sperm and for the presence of ctenoid scales on the left (blind) side of the caudal peduncle. Ctenoid scales often occur on mature males. Prior to being released all fish were examined for tags (MDMF tagging study 1994 to 1998; Lawton et al. 2000).

Winter flounder population size (instantaneous absolute abundance) was estimated using an area/density approach, based on the area-swept densities over the entire study area. Calculations were completed using the same procedures employed in 1999 by Lawton et al. (2000). Trawl gear efficiency was unknown and assumed to be 50% consistent with previous estimates. Density was determined by dividing the number of winter flounder per tow by the area of bottom covered. Bottom area was based on tow length and tow width. Tow length was taken from the tracks generated by the Nobeltec

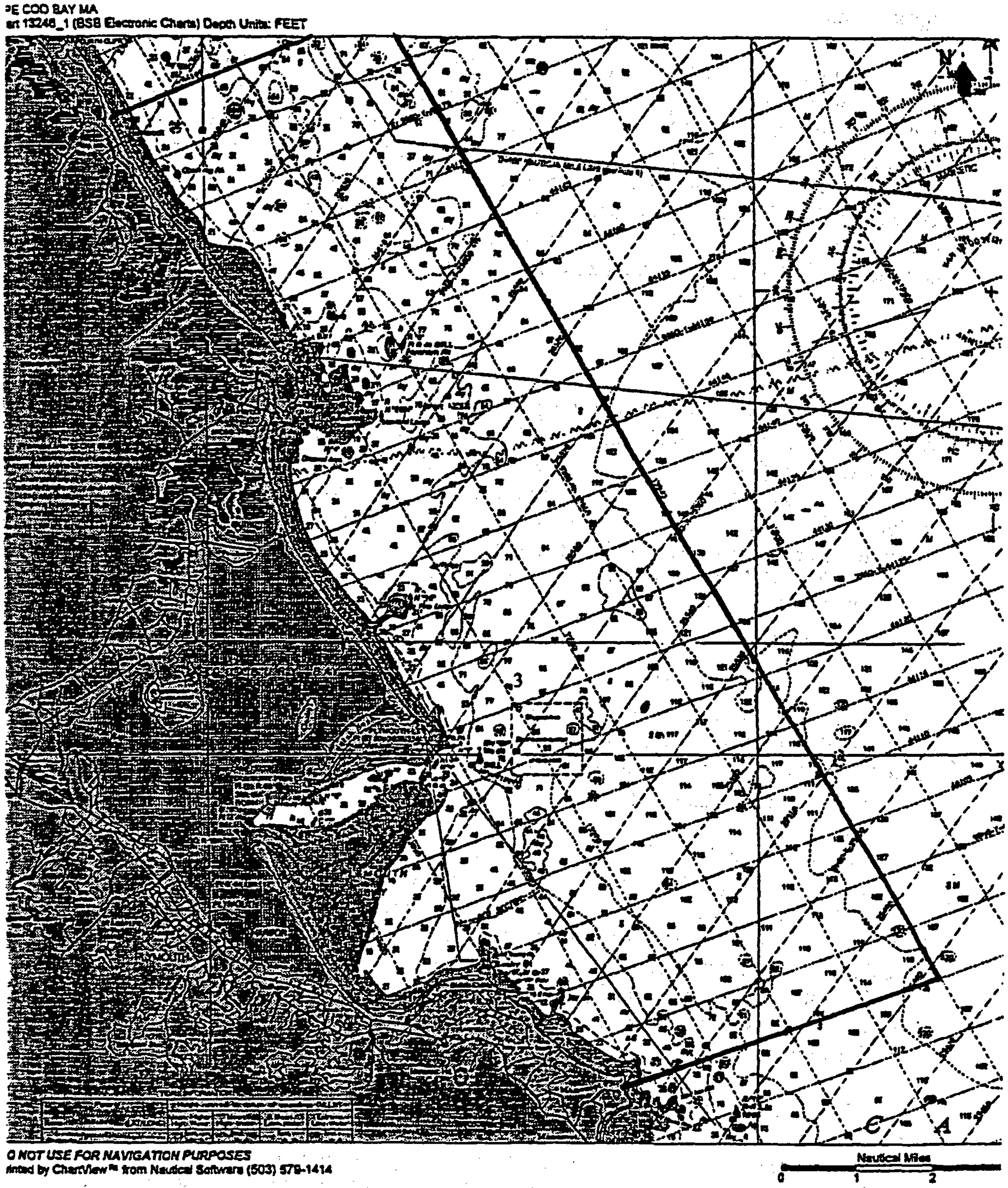

Figure 1. "Area-Swept" sampling boundary, Northwest Cape Cod Bay.

software. Tow width was estimated using the trawl doors' spread on the bottom. Spread was determined by measuring the between-wire width at the blocks and at six feet aft of the blocks and extrapolated to account for the wire out (usually 450 feet) yielding a typical door spread of 175 feet (54 meters). Door spread was used because of the "herding" action caused by the sediment cloud generated by the doors and legs while towing (Somerton 2003, Somerton and Weinberg 2001, Lawton et al. 2000, Ramm and Ziao 1995, Dickson 1993a and Dickson 1993b). Catch per unit area was calculated for each tow. Computed estimates for adult winter flounder (≥280 mm TL; Witherell and Burnett 1993) and for all sizes pooled were doubled to account for assumed catch efficiency. Density estimates were multiplied by total acreage (2.674×10^8 m^2) in the study area to calculate absolute abundance.

Results and Discussion

In 2004, 7,387 winter flounder were taken in 84 tows completed between April 19 and May 13 yielding a mean catch of 88 fish per tow (catch per unit effort, CPUE). The CPUE for 2004 was lower than the previous four years but greater than 1995, 1996, and 1999 (Figure 2). The lower relative abundance prior to 2000 may be attributed to the use of a different fishing vessel with possibly different catch efficiencies (Figure 3).

Unadjusted estimates of winter flounder abundance in the study area for 2004 were 78,766 adults and 123,706 total winter flounder. These estimates were doubled to account for trawl efficiency (assumed to be 50%); the adjusted numbers were 157,532 and 247,411, respectively (Table 1). Winter flounder absolute abundance estimates for adults and total winter flounder were below average in 2004 based on the 1995 - 2003 time series, 80% and 65% of their respective means of 328,284 and 615,222.

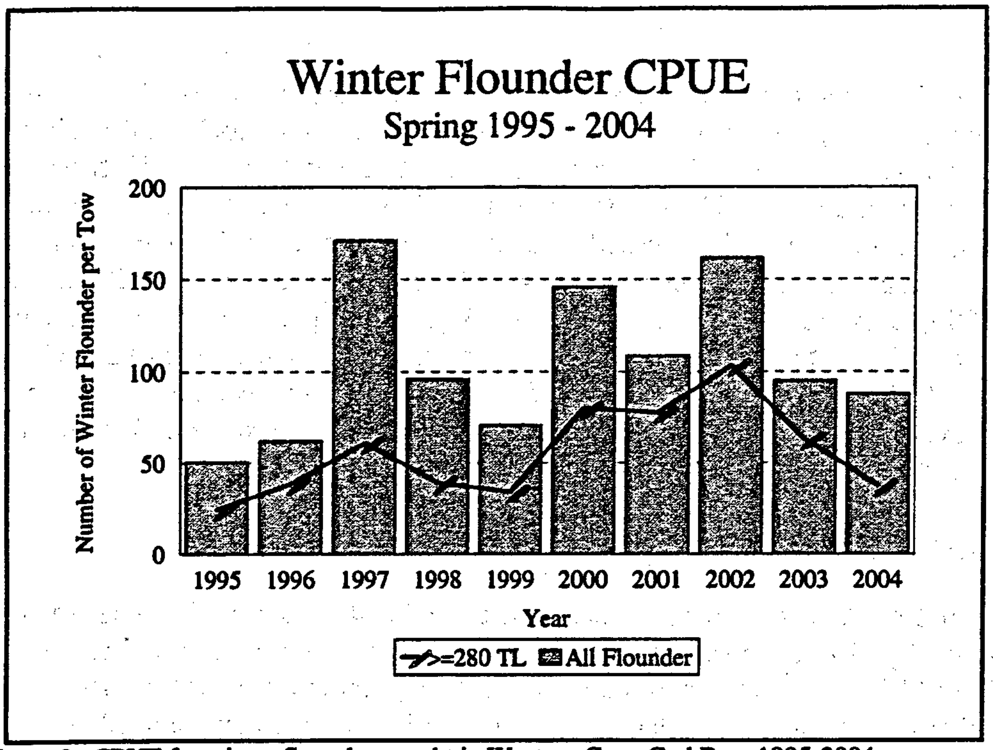

Figure 2. CPUE for winter flounder caught in Western Cape Cod Bay, 1995-2004.

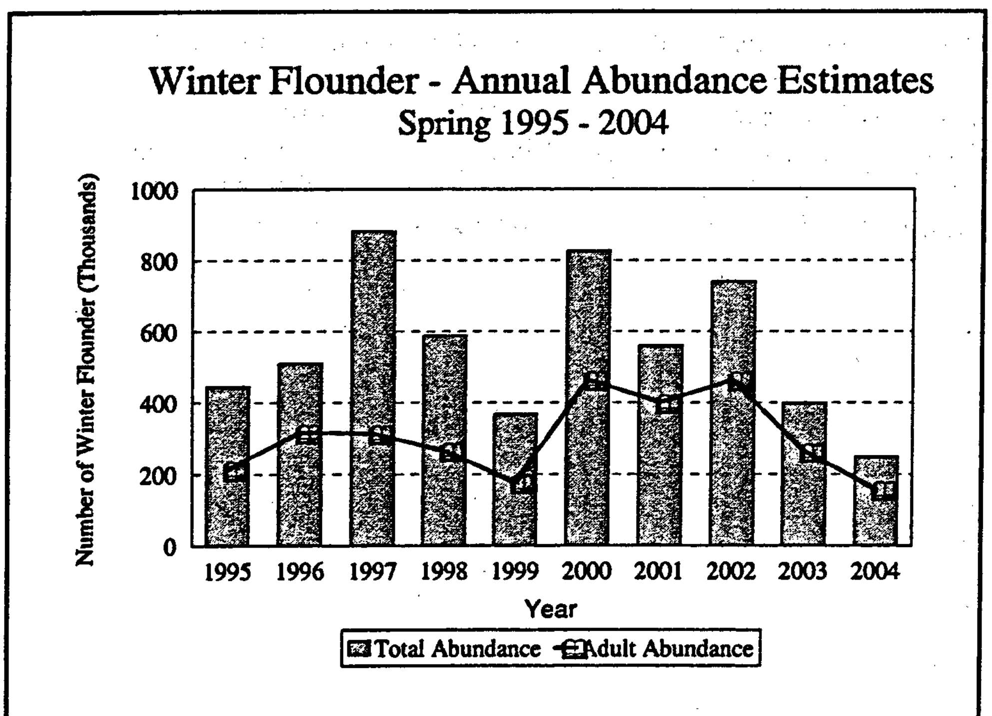

Figure 3. Estimated annual abundance of winter flounder in Western Cape Cod Bay, 1995-2004.

Recent estimates of fishing mortality suggest that it is relatively low with an estimated exploitation rate of 12% in 2001 and 2002. The Gulf of Maine stock is not considered to be in an overfished state and overfishing is not believed to be taking place at the present time (NEFSC 2003). The lower 2004 area swept estimate relative to 2000 and 2002 is likely the result, at least in part, to the natural and fishing induced decline in the strong 1997 and 1998 year classes. A review of the MDMF resource assessment program has shown a steady decline in the northern stock of winter flounder from 2000 to 2003 consistent with trends found in this study. The MDMF defines the northern stock as extending from the New Hampshire border to Cape Cod (Howe et al. 1994).

It is important to note that the assumed trawl efficiency value of 50% almost certainly varies from year to year and was selected to be conservative. It is probably lower than 50% particularly for small fish which would result in higher population estimates than those presented. For example, Kuipers (1975) reported efficiency of 28% for a beam trawl which is typically more efficient than an otter trawl. Harden-Jones et al. (1977) cited in Gunderson (1993) used sonar to estimate that 44% of plaice positioned between the trawl doors were captured. Mearns and Allen (1978) reported efficiencies of 10 to 50% for a small otter trawl. Kjelson and Colby reported a range of efficiencies from 9 to 51%, Grosslien and Laurec (1982) efficiencies of 26 to 38%, and Walsh (1992) values that ranged from as low as 5% for small flounder to 75% for adults.

The Coastal Lobster Investigations Project of the Massachusetts Division of Marine Fisheries maintains temperature monitors in the vicinity of Plymouth at three depth strata (40, 60 and 110 feet). These data along with surface water temperature from National Buoy Data Center Station 44013 (Boston Buoy; available at http://www.ndbc.noaa.gov/station_page.php?station=44013) were plotted from April 1 through May 15 for 2000 to 2004 (Figure 4). Included on these plots was the daily catch per tow for each sampling day. Boston Buoy water temperature data for 2004 was plotted along with the 2000 to 2003 mean in Figure 5. These figures show that 2004 was colder than the previous four years. From April 29 to May 3 there was a 2 degree drop in temperature at the 40-foot and 60-foot monitors. Strong winds on May 3 and 4 were probably responsible for the 2 degree C drop in surface temperature that occurred from May 3 to May 5. This reduction in water temperature may have delayed the inshore migration of mature winter flounder.

Length frequency data for 2004 exhibited a bimodal distribution (Figure 6). The majority of fish sampled were age 2 (Witherell and Burnett 1993). The second mode was age 3 and 4 fish. As in previous years, due to the selectivity of the net and the 4.5 mm cod-end liner, the number of age 2 and younger fish was probably under sampled (Lawton et al. 2000).

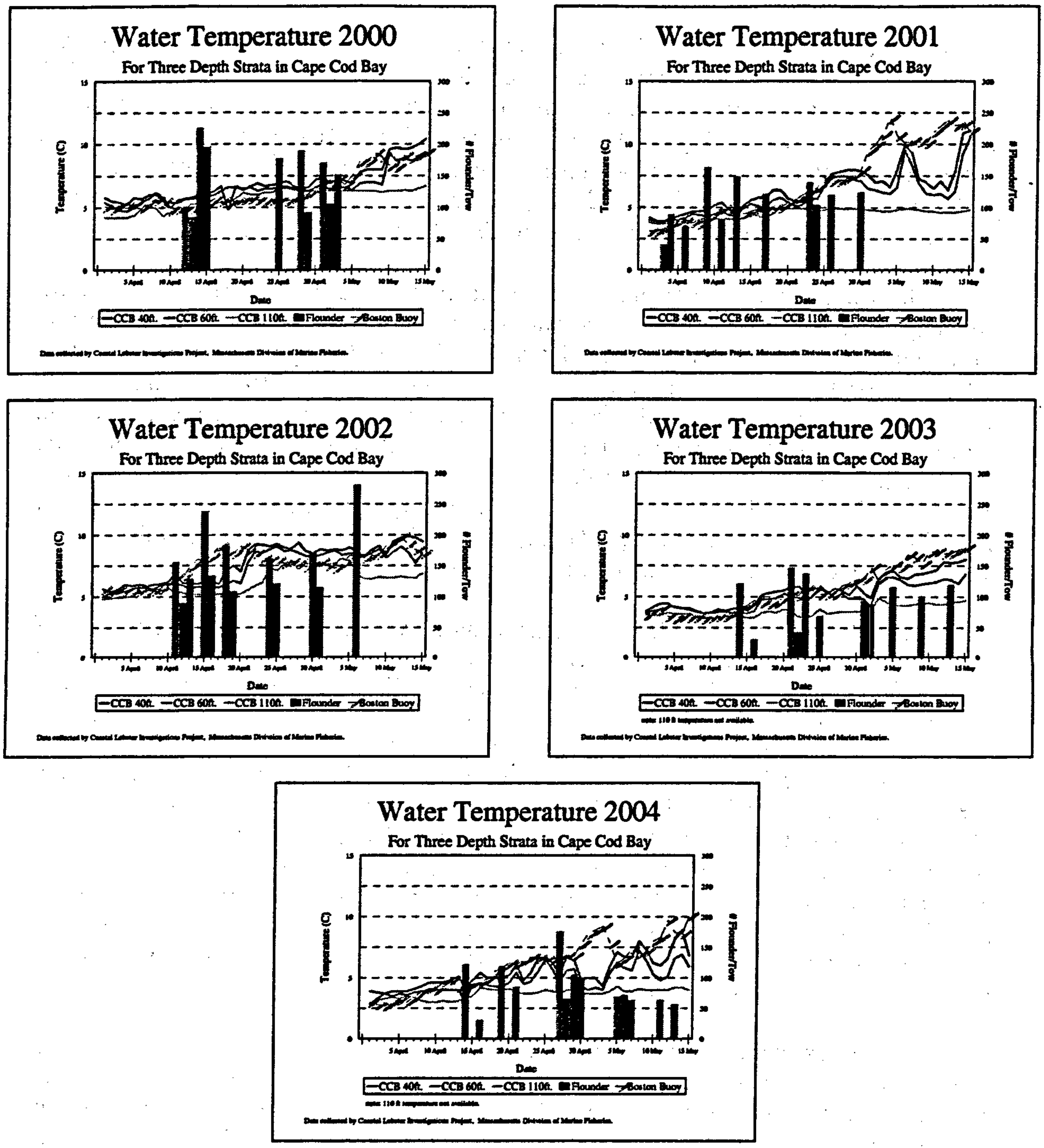

Figure 4. Mean daily water temperatures (April 1 to May 15) for three depth strata, Boston Buoy surface and daily catch per tow, 2000 to 2004.

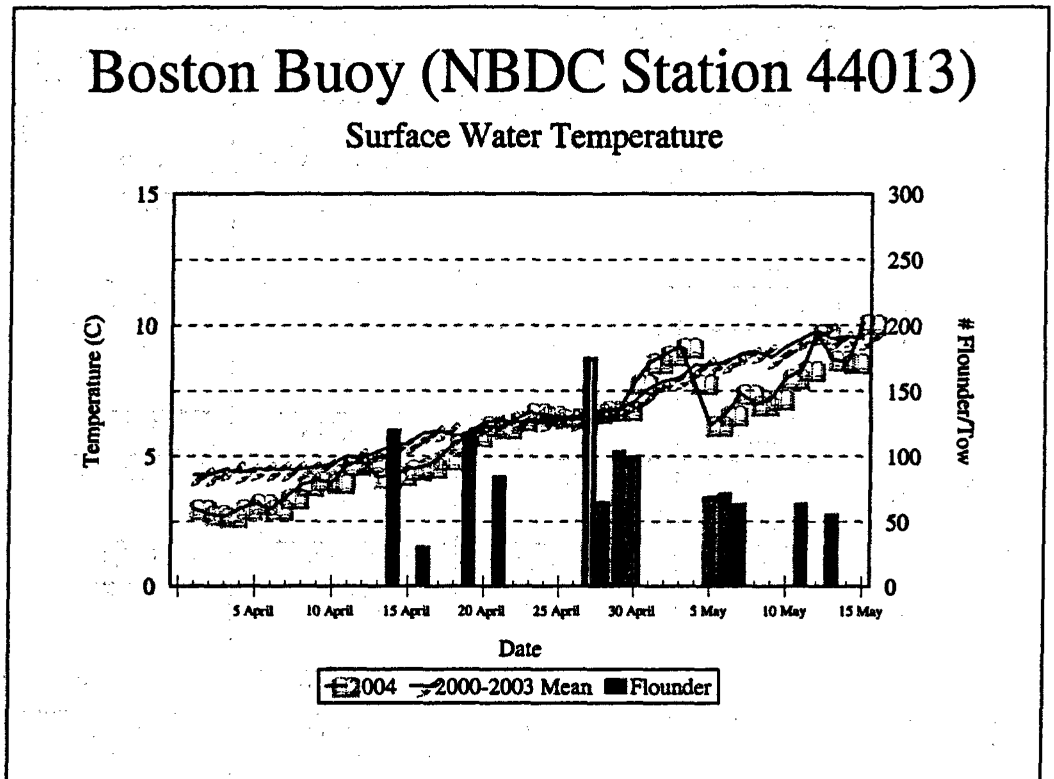

Figure 5. Boston Buoy 2004 surface water temperature and 2000 to 2003 mean with 2004 daily catch per tow.

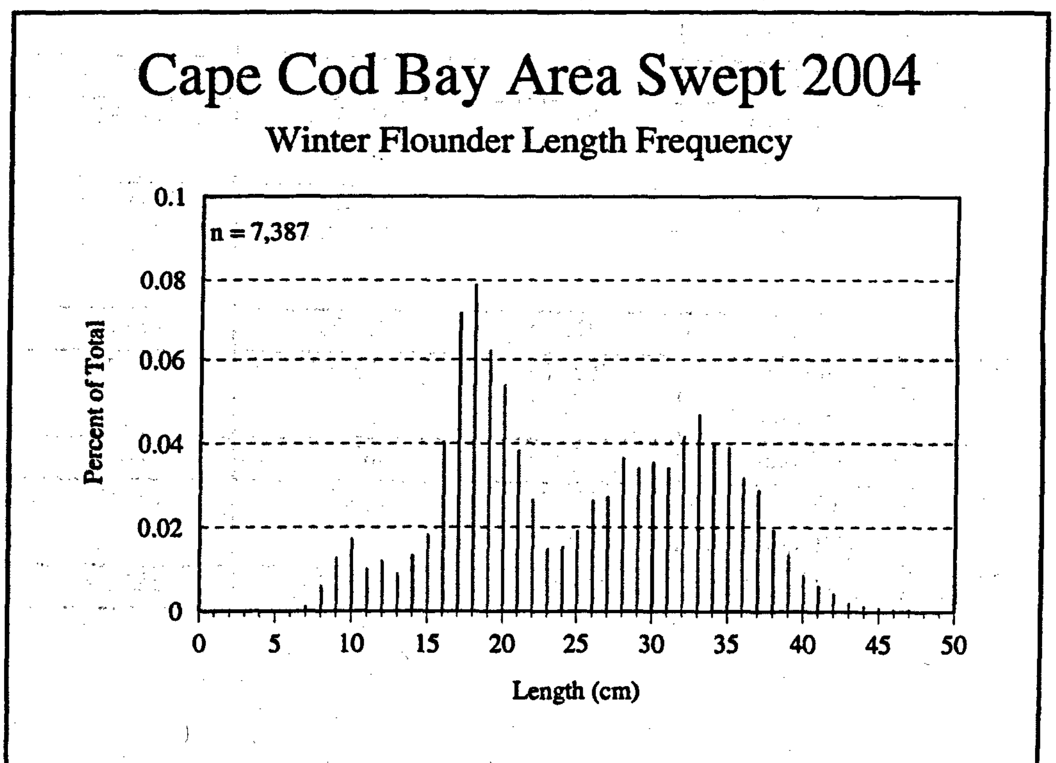

Figure 6. Length frequency for winter flounder caught in Western Cape Cod Bay, 2004.

Table 1. Estimated abundance (stratified by depth) of winter flounder in the study area (2.674×10^8 m^2 at MLW) with 95% confidence limits, Spring 1995-2004.

Year	Category	Number of flounder	Lower 95% CL	Upper 95% CL
1995	Flounder ≥280 mm TL	212,989	210,637	215,341
	All Flounder	444,850	437,438	452,261
1996	Flounder ≥280 mm TL	316,986	314,365	319,607
	All Flounder	510,306	506,378	514,235
1997	Flounder ≥280 mm TL	313,959	308,896	319,021
	All Flounder	882,889	887,834	887,945
1998	Flounder ≥280 mm TL	264,812	242,779	286,825
	All Flounder	588,450	553,330	623,570
1999	Flounder ≥280 mm TL	176,271	172,306	180,236
	All Flounder	367,908	360,826	374,989
2000	Flounder ≥280 mm TL	464,176	450,222	478,126
	All Flounder	826,548	807,952	845,144
2001	Flounder ≥280 mm TL	400,812	330,709	470,914
	All Flounder	559,713	471,109	648,316
2002	Flounder ≥280 mm TL	476,263	429,430	523,096
	All Flounder	741,108	725,285	756,932
2003	Flounder ≥280 mm TL	262,604	223,957	301,247
	All Flounder	398,528	387,156	409,898
2004	Flounder ≥280 mm TL	157,532	154,555	160,509
	All Flounder	247,411	242,226	252,596

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MARINE ECOLOGY STUDIES

Pilgrim Nuclear Power Station

Section 3.2

Entrainment Monitoring

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

ICHTHYOPLANKTON ENTRAINMENT MONITORING

AT PILGRIM NUCLEAR POWER STATION

JANUARY - DECEMBER 2004

Submitted to

Entergy Nuclear Generation Company

Pilgrim Nuclear Power Station

Plymouth, Massachusetts

by

Marine Research, Inc.

Falmouth, Massachusetts

April 2005

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SECTION I
SUMMARY

Sampling of entrained ichthyoplankton at PNPS in 2004 followed the revised protocol initiated in April 1994. In January, February, and October through December three samples were taken every other week each month, weather permitting, for a total of six per month. From March through September single samples were taken three times every week in conjunction with the impingement monitoring study.

A total of 39 species of fish were represented in the January-December samples, equal to the 29-year mean. Winter-early spring samples were dominated by Atlantic cod and American plaice eggs along with sand lance, rock gunnel, and grubby larvae. Late spring-summer collections, taken from May through July, were dominated by the *Labridae-Pleuronectes*, Atlantic mackerel, and *Paralichthys-Scophthalmus* eggs along with radiated shanny, winter flounder, and *Labridae-Pleuronectes* larvae. Late summer-autumn collections (August-December) were dominated by *Labridae-Pleuronectes* and *Paralichthys-Scophthalmus* eggs, along with cunner, Atlantic herring, tautog, and northern pipefish larvae.

Comparisons of ichthyoplankton densities over the 1975-2004 time series suggested that, in most cases, numbers in 2004 were consistent with those recorded since sampling began at PNPS. Species that appeared abundant in 2004 compared with past years included Atlantic cod and American plaice eggs, and larval radiated shanny and winter flounder. In contrast, Atlantic mackerel eggs, and larval Atlantic menhaden and rock gunnel densities were relatively low. No consistent trends were identified for any species over the complete time series.

Unusually high entrainment densities, as defined under PNPS's sampling plan, were identified on 41 occasions in 2004 and involved four species of eggs and six species of larvae. Episodes of high abundance were generally scattered among species and over time and of short duration.

Entrainment and impingement of winter flounder, cunner, Atlantic mackerel, Atlantic menhaden, Atlantic herring, and Atlantic cod were examined in some detail dating back to 1980 using the equivalent adult (EA) procedure. These estimates were compared to commercial and recreational landings and local stock size estimates where available. Equivalent adult estimates

for winter flounder eggs and larvae lost to entrainment in 2004 were 29,019 age 3 adults compared with a time series average of 8,336 based on three sets of survival values. An average of 99 age 3 equivalent adults (range = 5 to 271) weighing 48 pounds (range = 2 to 132 pounds) was also estimated to have been lost to impingement dating back to 1980. The software program RAMAS Metapop was used to explore further the potential affects of entrainment on the local winter flounder population. Model runs were completed with fishing mortality and with and without entrainment losses. Results indicated that a 1% decrease in age 0 survival attributable to entrainment could reduce the local adult population by less than 1% to 3% depending on the rate of fishing. Larval entrainment rates as high as 20 and 30%, equivalent to more than 20 or 30 times the rate suggested by the empirical data have little affect on adult stocks when fishing mortality is low (F = 0.12 to 0.25).

The EA estimate for cunner lost to entrainment in 2004 was 188,107 fish. A total of 206 cunner was impinged in 2004 amounting to 206 additional equivalent adults. Atlantic mackerel equivalent adult losses attributable to entrainment for 2004 amounted to 740 age 1 fish weighing 148 pounds or 304 age 3 fish weighing 213 pounds. Corresponding age 1 values over the 1980 through 2003 time series ranged from 808 (1982) to 19,667 (1989) fish with an average of 5,777. Age 3 values ranged from 332 to 8,086 with an annual average of 2,375 individuals. Atlantic mackerel are swift swimmers and are not often impinged at PNPS. Mean equivalent adult totals for mackerel amounted to 0.4% of the estimated area 514 commercial and recreational landings. EA values for menhaden were 50 age 2 fish in 2004, with an additional 749 age 2 equivalents estimated to have been lost to impingement in 2004. These totals appear very low when compared with commercial landings or an estimate of the number of menhaden that spawned in Cape Cod Bay. For Atlantic herring entrainment of larvae in 2004 was equivalent to the loss of 6,922 age 1 sardines or 3,107 age 3 adults. With the exception of one year (1991) impingement contributed little to losses of herring at PNPS. Lastly, EA values for Atlantic cod in 2004 were very small at 63 age 2 fish which compared with a time series mean of 47. Few Atlantic cod are impinged at PNPS.

Nine lobster larvae were found during the January-December 2004 entrainment sampling period. Previously, a total of 37 lobster larvae have been collected at PNPS dating back to 1974.

SECTION II
INTRODUCTION

This report summarizes results of ichthyoplankton entrainment sampling conducted at the Pilgrim Nuclear Power Station (PNPS) from January through December 2004 by Marine Research, Inc. (MRI) for Entergy Nuclear Generating Company, under Contract No. 4500528757, in compliance with environmental monitoring and reporting requirements of the PNPS NPDES Permit (U.S. Environmental Protection Agency and Massachusetts Department of Environmental Protection). Included here is a brief summary of the dominant taxa collected over the course of the year, a review of long-term time trends for the dominant fish eggs and larvae, and an assessment of numbers entrained for six key species, winter flounder (*Pleuronectes americanus*), cunner (*Tautogolabrus adspersus*), Atlantic mackerel (*Scomber scombrus*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic herring (*Clupea harengus*), and Atlantic cod (*Gadus morhua*).

SECTION III
METHODS AND MATERIALS

Monitoring

Entrainment sampling at PNPS, begun in 1974, was originally completed twice per month during January and February, October-December; weekly during March through September; in triplicate at low tide. Following a PNPS fisheries monitoring review workshop in early 1994, the sampling regime was modified beginning in April 1994. The revised program exchanged replication for improved temporal coverage and has been followed every year since then. In January, February, and October through December during two alternate weeks each month single samples were taken on three separate occasions. Beginning with March and continuing through September single samples were taken three times every week. During autumn and winter months when sampling frequency was reduced, sampling was postponed during onshore storms due to heavy detrital loads. The delayed sample was taken during the subsequent week; six samples were ultimately taken each month.

To minimize costs, sampling was linked to the impingement monitoring program so that collections were made Monday morning, Wednesday afternoon, and Friday night regardless of tide (see Impingement Section). All sampling was completed with a 60-cm diameter plankton net streamed from rigging mounted approximately 30 meters from the headwall of the discharge canal (Figure 1). Standard mesh was 0.333-mm except from late March through late May when 0.202-mm mesh was employed to improve retention of early-stage larval winter flounder. Sampling time in each case varied from 8 to 30 minutes depending on tide, higher tide requiring a longer interval due to lower discharge stream velocities. In most cases, a minimum quantity of 100 m^3 of water was sampled although at astronomically high tides it proved difficult to collect this amount even with long sampling intervals since the net would not inflate in the low current velocity near high tide. Exact filtration volumes were calculated using a General Oceanics Model 2030R digital flowmeter mounted in the mouth of the net. Near times of high water a 2030 R2 rotor was employed to improve sensitivity at low velocities.

All samples were preserved in 10% Formalin-seawater solutions and returned to the laboratory for microscopic examination. A detailed description of the analytical procedures appears in MRI (1988). As in past years, larval winter flounder were enumerated in four developmental stages as follows:

Stage 1 - from hatching until the yolk sac is fully absorbed (2.3-2.8 mm TL).

Stage 2 - from the end of stage 1 until a loop or coil forms in the gut (2.6-4 mm TL).

Stage 3 - from the end of stage 2 until the left eye migrates past the midline of the head during transformation (3.5-8 mm TL).

Stage 4 - from the end of stage 3 onward (7.3-8.2 mm TL).

Similarly larval cunner *(Tautogolabrus adspersus)* were enumerated in three developmental stages:

Stage 1 - from hatching until the yolk sac is fully absorbed (1.6-2.6 mm TL).

Stage 2 - from the end of stage 1 until dorsal fin rays become visible (1.8-6.0 mm TL).

Stage 3 - from the end of stage 2 onward (6.5-14.0 mm TL).

Samples were examined in their entirety for larval American lobster (*Homarus americanus*). When collected these were staged following Herrick (1911).

Unusual Entrainment Levels

When the Cape Cod Bay ichthyoplankton study was completed in 1976, provisions were added to the entrainment monitoring program to identify unusually high densities of fish eggs and larvae. Once identified and, if requested by regulatory personnel, additional sampling could be conducted to monitor the temporal and/or spatial extent of the unusual occurrence. An offshore array of stations was established which could be used to determine whether circumstances in the vicinity of Rocky Point, attributable to PNPS operation, were causing an abnormally large percentage of ichthyoplankton populations there to be entrained or, alternatively, whether high entrainment levels simply were a reflection of unusually high population levels in Cape Cod Bay. The effect attributable to any large entrainment event would clearly be greater if ichthyoplankton densities were particularly high only close to the PNPS shoreline. In past years when high densities were identified, additional entrainment sampling was requested by regulatory personnel and the unusual density in most cases was found to be of short duration (<2 days). With the change in 1994 to Monday, Wednesday, Friday sampling the temporal extent of any unusual density can be more clearly discerned without additional sampling effort.

Until 1994 "unusually abundant" was defined as any mean density, calculated over three replicates, which was found to be 50% greater than the highest mean density observed during the same month from 1975 through to the current year. Restricting comparisons to monthly periods damped the large seasonal variation so readily apparent with ichthyoplankton and allowed tracking densities as each species' season progressed. Starting with 1994 "unusually abundant" was redefined. On a month-by-month basis for each of the numerically dominant species all previous mean densities over three replicates (1974-1993) were examined and tested for normality following logarithmic transformation. Single sample densities obtained from 1994-2003 were added to the pool within each month. Where data sets (for example, mackerel eggs taken in June) fit the lognormal distribution, then "unusually large" was defined by the overall log mean density plus 2 or 2.58 standard deviations.[1] Log densities were back-transformed to make them easier to interpret thus providing geometric means. In cases where data sets did not fit the lognormal distribution (generally months when a species was frequently but not always absent, i.e., many zeros occurred), the mean and standard deviation was computed using the delta-distribution (see for example Pennington 1983). The same mean plus standard deviation guideline was applied.

The decision to rely on 2 standard deviations or 2.58 standard deviations was based on the relative importance of each species. The more critical criterion was applied to species of commercial, recreational, or biological interest, the less critical to the remaining species (i.e., relatively greater densities were necessary to flag a density as unusual). Species of commercial, recreational, or biological interest include Atlantic menhaden, Atlantic herring, Atlantic cod, tautog and cunner (the labrids; *Tautoga onitis* and *Tautogolabrus adspersus),* sand lance *(Ammodytes* sp.), Atlantic mackerel, windowpane (*Scophthalmus aquosus),* American plaice *(Hippoglossoides platessoides),* and winter flounder. Table 1 provides summary data for each species of egg and larva by month within these two categories showing the 2004 "unusually high" levels.

A scan of Table 1 will indicate that, in cases where the long-term mean amounts to 1 or 2 eggs or larvae per 100 m^3, the critical level is also quite small. This situation occurred during months when a given species was obviously uncommon and many zeros were present in the data set with an inherent small standard deviation. The external reference distribution methodology of Box et al. (1975) was also employed. This procedure relies on a dotplot of all previous densities for a species within each month to produce a reference distribution. Densities exceeding either 97.5 or 99.5% of the reference set values were considered unusually high with this procedure.

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[1]Normal distribution curve theory states that 2.5% of the measurements in a normally distributed population exceed the mean plus 1.96 standard deviations (= s, we rounded to 2 for simplicity), 2.5% lie below the mean minus 1.96 standard deviations. Stated another way 95% of the population lies within that range and 97.5% lies below the mean plus 1.96s. Likewise 0.5% of measurements exceed the mean plus 2.58s, 99% lie within the range of the mean ± 2.58s, 99.5% lie above the mean + 2.58s.

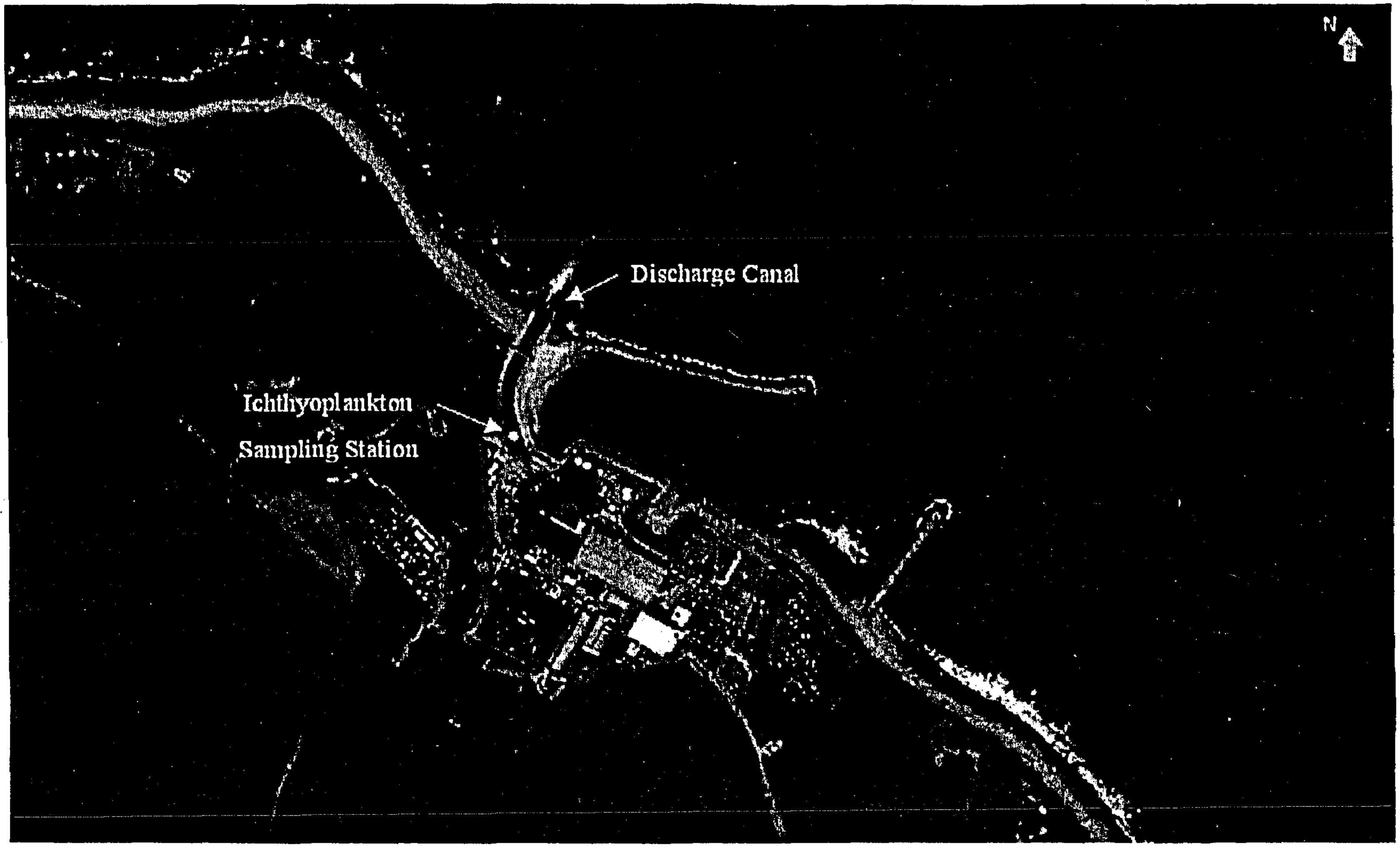


Figure 1. Aerial photograph of the entrainment sampling station in PNPS discharge canal.

Table 1. PNPS ichthyoplankton entrainment values for 2004 by species category and month used to determine unusually high densities. See text for details.

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous High (Year)
January				
LARVAE				
Atlantic herring[2]	0.2	1		38.0 (1999)
Sculpin	0.9		2	9.7 (1999)
Rock gunnel	4.0		7	78.1 (2002)
Sand lance[2]	5	11		337.0 (1996)
February				
LARVAE				
Atlantic herring[2]	0.5	0.7		8.0 (2002)
Sculpin	2		65	183.1 (1998)
Rock gunnel	5		177	133.0 (1999)
Sand lance[2]	16	29		372.9 (1995)
March				
EGGS				
American plaice[2]	2	3		19.0 (1977)
LARVAE				
Atlantic herring[2]	1.4	2		28.5 (1997)
Sculpin	17		608	454.1 (1995)
Seasnails	0.6		1	14.4 (1980)
Rock gunnel	10.7		723	882.2 (1997)
Sand lance[2]	7	164		511.4 (1994)
Winter flounder[2]	0.4	0.7		16.2 (1997)
April				
EGGS				
American plaice[2]	3	32		70.3 (1978)
LARVAE				
Atlantic herring[2]	2	3		38.3 (1999)
Sculpin	15		391	386.2 (1985)
Seasnails	6		10	98.1 (1974)
Radiated shanny	5		7	59.6 (1974)
Rock gunnel	4		142	121.1 (1992)
Sand lance[2]	21	998		2590.6 (1994)
Winter flounder[2]	7	12		198.3 (1994)
May				
EGGS				
Labrids[2]	36	3514		34050.0 (1974)
Atlantic mackerel[2]	18	4031		19203.0 (1995)
Windowpane[2]	9	147		319.0 (2000)
American plaice[2]	2	15		52.6 (1998)

Table 1 (continued).

Densities per 100 m^3 of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous High (Year)
May				
LARVAE				
Atlantic herring	0.7	1.1		10.5 (1975)
Fourbeard rockling	4.1		8	104.5 (1997)
Sculpin	3		4	78.3 (1997)
Seasnails	7		208	164.4 (1974)
Radiated shanny	7		236	266.9 (1998)
Sand lance[2]	37	59		639.1 (1996)
Atlantic mackerel	2	4		377.6 (1998)
Winter flounder[2]	9	123		573.8 (1998)
June				
EGGS				
Atlantic menhaden[2]	14	22		799.7 (1998)
Searobins	2		3	128.0 (1987)
Labrids[2]	958	21599		37282.0 (1995)
Atlantic mackerel[2]	63	3515		8193.2 (1990)
Windowpane[2]	27	261		355.5 (1998)
American plaice[2]	1	3		35.0 (1980)
LARVAE				
Atlantic menhaden[2]	6	10		495.9 (1981)
Fourbeard rockling	9		634	224.0 (1992)
Hake 0.3		1		50.6 (1998)
Cunner[2]	54	87		2215.6 (1998)
Radiated shanny	7		10	262.2 (1996)
Atlantic mackerel[2]	91	155		2700.0 (1981)
Winter flounder[2]	10	106		813.5 (1998)
July				
EGGS				
Atlantic menhaden[2]	2	4		59.1 (1978)
Labrids[2]	615	13349		12917.0 (1981)
Atlantic mackerel[2]	9	16		119.0 (1981)
Windowpane[2]	12	156		257.1 (1978)
July				
LARVAE				
Atlantic menhaden[2]	2	3		124.2 (1974)
Fourbeard rockling	6		9	115.8 (1999)
Hake	0.7		1	248.4 (1998)
Tautog[2]	2	2		268.6 (1998)
Cunner[2]	7	318		2162.5 (1981)
Atlantic mackerel[2]	2	3		60.1 (1996)

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous High (Year)
August				
EGGS				
Searobins	4		6	89.2 (1995)
Labrids[2]	23	936		3500.0 (1984)
Windowpane[2]	15	136		194.0 (1989)
LARVE				
Atlantic menhaden[2]	0.4	1		47.0 (1997)
Fourbeard rockling	6		10	204.6 (1983)
Silver hake	1	2		78.0 (1999)
Hake	2		4	196.1 (1995)
Tautog[2]	1.6	2.2		41.5 (1997)
Cunner[2]	10	15		254.0 (1997)
September				
EGGS				
Atlantic menhaden[2]	42	112		73.2 (1993)
Labrids[2]	2	3		112.8 (1993)
Windowpane	11	159		288.8 (1993)
LARVAE				
Atlantic menhaden[2]	1	2		81.0 (1999)
Fourbeard rockling	4		6	68.6 (1993)
Silver hake[2]	1	2		46.2 (1999)
Hake	5		9	327.2 (1997)
Tautog[2]	1	2		19.3 (1996)
Cunner[2]	1	2		42.1 (1993)
October				
EGGS				
Atlantic menhaden[2]	2	6		163.6 (2002)
Windowpane[2]	1	2		30.3 (1997)
LARVAE				
Atlantic menhaden[2]	2.3	4		70.3 (1997)
Fourbeard rockling	1		16	67.9 (1994)
Hake	1		2	13.7 (1985)
November				
LARVAE				
Atlantic menhaden[2]	0.4	1		57.1 (1997)
Atlantic herring[2]	4	8		124.8 (1995)
December				
LARVAE				
Atlantic herring[2]	2	3		216.7 (1995)

[1]Geometric or Delta Mean.
[2]Species of commercial, recreational, or biological interest for which more critical unusual event level will be used.

SECTION IV
RESULTS

A. Ichthyoplankton Entrained - 2004

Population densities per 100 m^3 of water for each species listed by date, station, and replicate are presented for January-December 2004 in Appendix A (available upon request). The occurrence of eggs and larvae of each species by month appears in Table 2. Ichthyoplankton collections are summarized below within the three primary spawning seasons observed in Cape Cod Bay waters: winter-early spring, late spring-early summer, and late summer-autumn.

Winter-early spring spawners (January-April)

Ichthyoplankton entrained during January through April generally represent winter-early spring spawning fishes. Many of these species employ a reproductive strategy that relies on demersal, adhesive eggs not normally entrained. As a result, more species are typically represented by larvae than by eggs during the early portion of the year. Over both life stages the number of species represented in the catch increased from 5 in January to 17 in April. Egg collections in winter-early spring were numerically dominated by the Atlantic cod and witch flounder egg group (gadidae-*Glyptocephalus*), and American plaice eggs (Figure 2). These species accounted for 45 and 41% of the total egg catch during this period, respectively. Eggs in the Atlantic cod and witch flounder group were entrained each month from January through April with monthly geometric mean densities of 0.7, 0.5, 0.05, and 6.9 eggs per 100 m^3 of water, respectively. American plaice eggs were found only in April with a monthly geometric mean density of 8.7 eggs per 100 m^3 of water.

In the winter-early spring 16 species of larval fish were collected from the discharge canal. The sand lance, grubby (*Myoxocephalus aenaeus*), and rock gunnel (*Pholis gunnellus*) made up the majority of the larval fish collected at this time, contributing 63, 24, and 9% of the seasonal total, respectively. Sand lance, the predominant larval species throughout the time period, were most abundant during March and April, with monthly geometric mean densities of 9.8 and 45.7 larvae per 100 m^3 of water, respectively. At their peak in April they accounted for 74% of the monthly larval total. The grubby also had peak numbers in April with a monthly mean density of 12.5 per 100 m^3 comprising an additional 17% of the monthly total. For rock gunnel, collected each month, peak density occurred in March with a geometric mean density of 6.1 fish per 100 m^3 accounting for 13.5% of the monthly total.

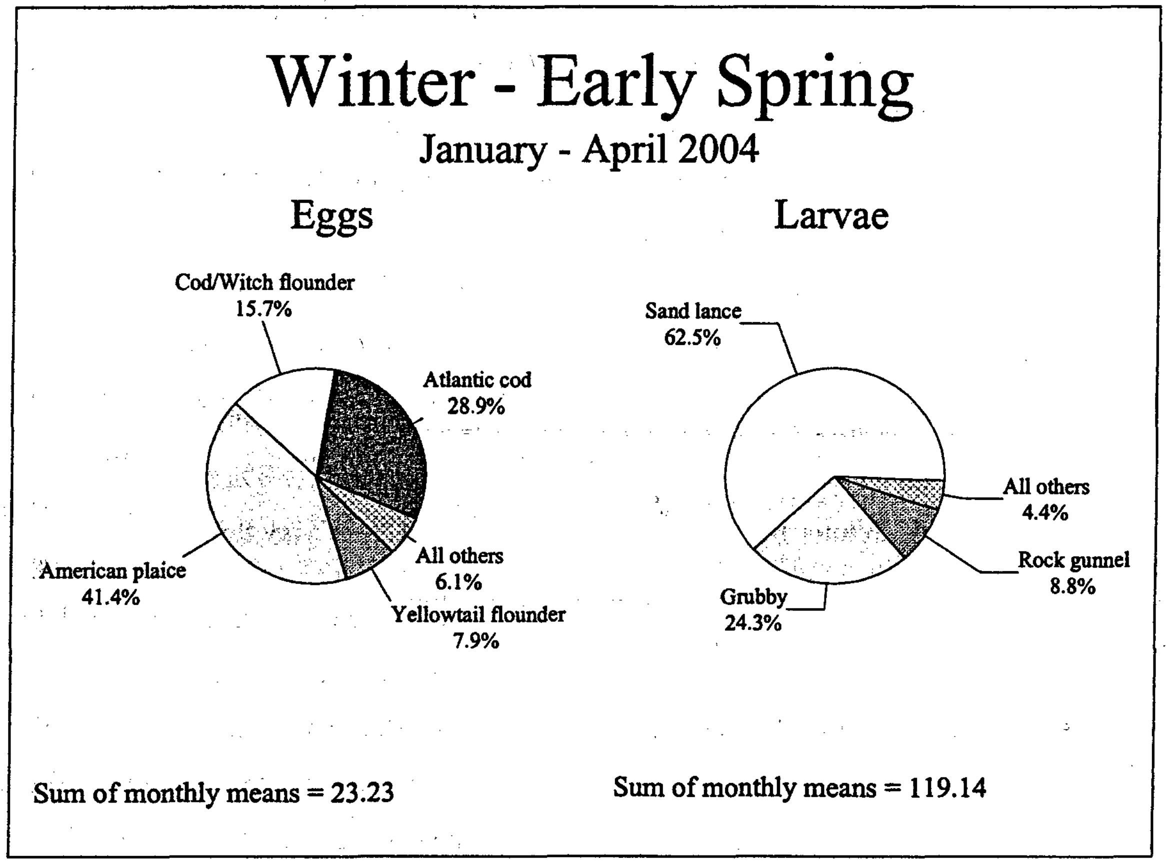


Figure 2: Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the winter-early spring season, 2004. Percent of total and summed monthly mean densities for all species are also shown.

Late Spring-Early Summer (May-July)

May through July represents the late spring-summer ichthyoplankton season, typically the most active reproductive period among temperate fishes. Considering both eggs and larvae, 32 species were represented in the May-July collections, 20 species represented by eggs and 26 species represented by larvae. Numerical dominants represented by eggs included the tautog-cunner-yellowtail flounder egg group (Labridae-*Pleuronectes*), Atlantic mackerel, and fourspot flounder-windowpane egg group (Figure 3). Tautog/cunner/yellowtail flounder eggs accounted for 90% of the late spring-early summer egg catch, peaking in the month of June at a geometric mean density of 730 per 100 m^3. Labrid egg measurement studies completed at PNPS suggested that the majority of labrid eggs collected near PNPS are cunner (Scherer 1984). Labrid eggs far exceed yellowtail eggs during the period when they are indistinguishable from each other. Mackerel eggs accounted for 5% of the seasonal egg collection, peaking in May when they were collected at a mean density of 15.6 eggs per 100 m^3. The fourspot flounder and windowpane egg grouping (*Paralichthys-Scopthalmus*) accounted for 4% of the spring season egg collection with a seasonal peak of 27 per 100 m^3 occurring in June.

Larval collections during late spring-summer contained 26 species with numerical dominants being winter flounder, radiated shanny (*Ulvaria subbifurcata*), fourbeard rockling, Atlantic mackerel, and cunner (Figure 3). Winter flounder accounted for 40% of the seasonal total, radiated shanny for 21%, fourbeard rockling for 11%, mackerel for 8% and cunner for 8% of the three-month total. Winter flounder larvae were observed from May through July (monthly means = 11.3, 5.9, and 0.4 per 100 m^3, respectively), with 69% of the larvae observed in May decreasing to less than 1% in July. Radiated shanny larvae were recorded throughout the late spring-summer season, peaking in May with a mean density of 14.9 per 100 m^3. Fourbeard rockling were most abundant in June (monthly mean =15.7 per 100 m^3) making up 30% of the June larval collections. Atlantic mackerel were found throughout the late spring-summer season; peak seasonal abundance occurred in June with a monthly mean density of 7.6 per 100 m^3. Cunner larvae were observed in June and July (monthly means = 7.0 and 2.5 per 100 m^3, respectively), and accounted for 48% of the July larval total.

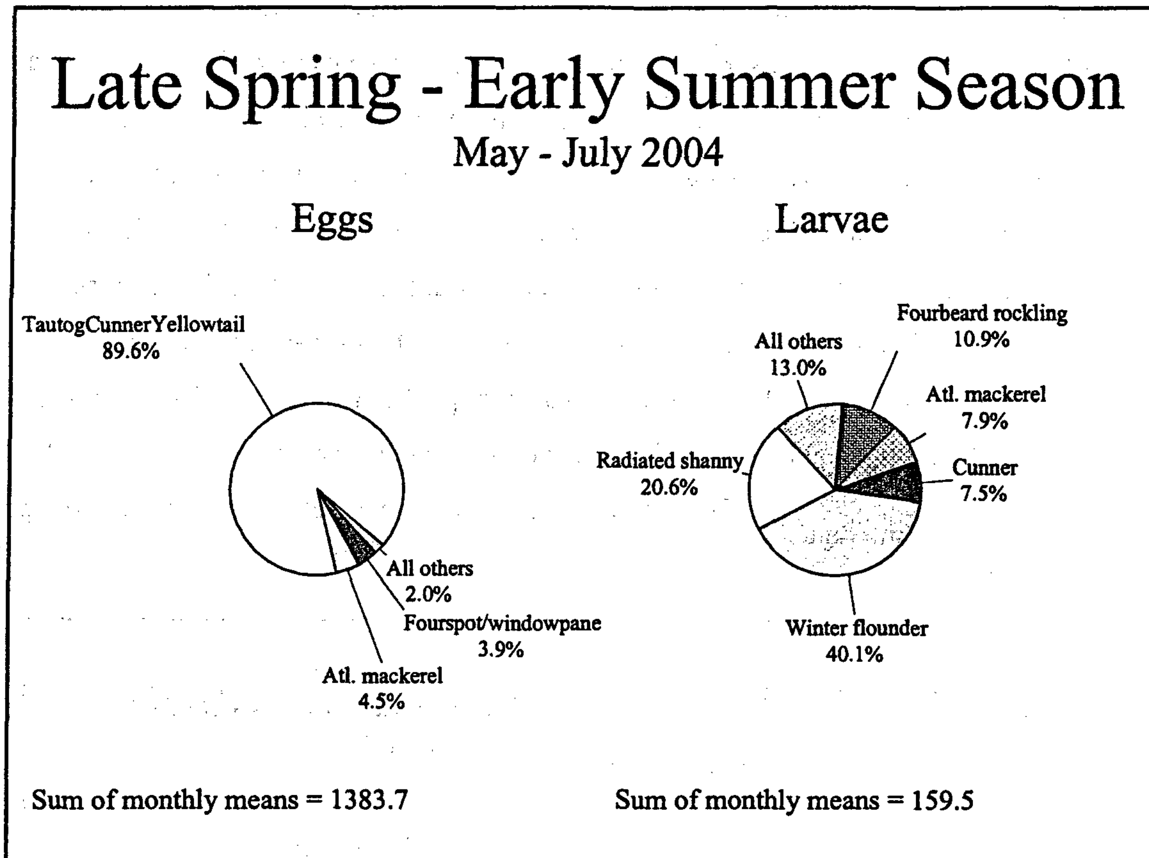


Figure 3. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late spring-early summer season, 2004. Percent of total and summed monthly mean densities for all species are also shown.

Late Summer - Autumn Spawners (August - December)

This season is typically marked by a decline in both overall ichthyoplankton density and in the number of species collected. Considering egg and larval stages combined, 22 species were taken during the August through December period, 19 species in August declining to 2 species in December. Numerical dominants among the eggs included the tautog-cunner-yellowtail, and fourspot flounder-windowpane egg groups. Seasonal percentages for these eggs were 54% and 39%, respectively (Figure 4). Tautog-cunner-yellowtail flounder eggs were present August through October and peaked for the season in August with a mean density of 13.1 per 100 m^3 of water. Fourspot flounder-windowpane eggs were present August through October and peaked in September (monthly mean density = 19.5 per 100 m^3 of water).Larval dominants in this late summer-autumn season were cunner, Atlantic herring, tautog, northern pipefish (*Syngnathus fuscus*), and fourbeard rockling. Seasonal percentages for these species were 36, 17, 17, 12, and 7%, respectively. Cunner larvae were found from June through September with a seasonal peak during August (monthly geometric mean density of 3.3 per 100 m^3 of water). Atlantic herring were present from October through December at geometric mean densities of 0.1, 0.5, and 1.6 per 100 m^3 of water, respectively. The December catch accounted for 41% of this species' annual total. Tautog larvae were present from August through October at geometric mean densities of 1.6, 1.2, and 0.1 per 100 m^3 of water. Northern pipefish were recorded at geometric mean densities of 0.9 and 0.1 per 100 m^3 in August and September, respectively. Fourbeard rockling were observed in August and October with geometric mean densities of 0.7 and 0.1 per 100 m^3, respectively.

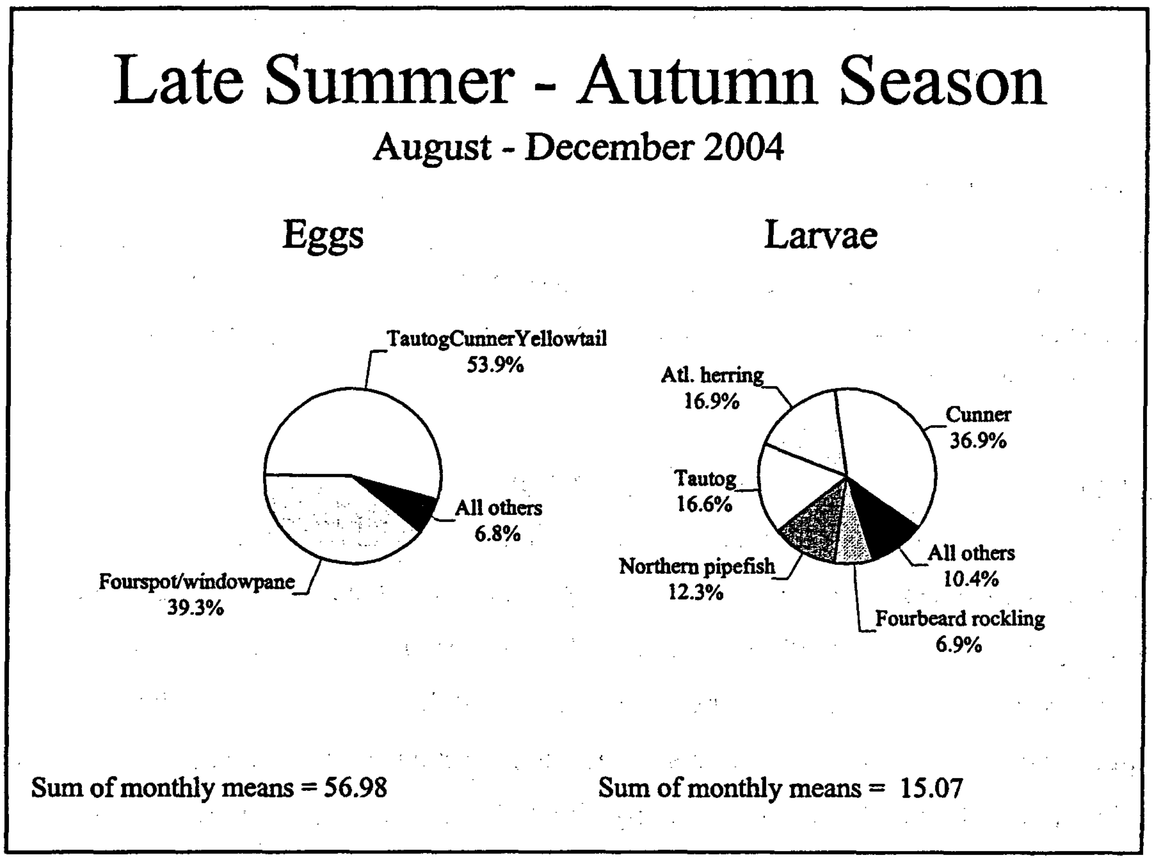


Figure 4. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late summer-autumn season, 2004. Percent of total and summed monthly mean densities for all species are also shown.

B. Unusual Entrainment Values

Ichthyoplankton densities reaching the unusually high level, as defined under Methods, during the 2004 sampling season occurred on several occasions and involved a number of species. These included American plaice, labrid, Atlantic menhaden, and windowpane eggs as well as the larvae of six species - Atlantic herring, sand lance, winter flounder, hake, tautog, and cunner for a total of 10 species of eggs and larvae combined and 41 specific unusual densities (Table 3).

Several species recorded unusually high densities on either several occasions or during more than a single month. For example, Atlantic herring larvae reached unusually high entrainment numbers on eleven occasions in 2004, once in January, five times in April, once in November, and four times in December (Table 3). On January 7, a new high density of 2.9 herring larvae per 100 m^3 was recorded compared with the previous high recorded in 1999 of 1.9 per 100 m^3. This was the only case among the 41 observed that a previous high was exceeded.

Sand lance larvae appeared in unusually high numbers on only one occasion, March 31 (604.1 versus unusual level of 164 per 100 m^3) exceeding 99% of all previous March values for the species (Table 3).

American plaice eggs reached an unusual level on four occasions in May (26.2, 18.0, 69.7, and 31.4 versus the unusual level of 15 per 100 m^3); 69.7 per 100 m^3 exceeded 99% of all previous May values (Table 3).

Winter flounder larvae reached unusual abundance on four occasions, three in May and one in June. These four occasions exceeded 98% of all previous values for May and June (Table 3). The density of 518 winter flounder larvae per 100 m^3 recorded on May 31 approached but did not exceed the previous high of 574 per 100 m^3 recorded in May 1998.

Unusual abundance for hake larvae was recorded on two occasions in July with 4.5 and 1.6 per 100 m^3 of water versus the unusual level of 1.0 per 100 m^3 and previous high of 248 per 100 m^3.

Tautog larvae reached unusually high densities once during the month of July, on five occasions in August, and four occasions in September, none of which exceeded 7 individuals per 100 m^3 or approached previous high values (Table 3). Cunner larvae reached an unusually high density once in August, (32.5 versus the unusual level of 15 per 100 m^3). Labrid eggs attained unusually high densities on five dates in September, (6.8, 37.9, 3.2, 4.3, and 3.3 versus an unusual level of 3 per 100 m^3); 37.9 per 100 m^3 exceeding 98% of all previous September values. The 1993 density of 42 per 100 m^3 of water remains the record high.

Atlantic menhaden eggs were observed in unusual high numbers once in October, 11.6 versus an unusual level of 6 per 100 m^3 but well below the previous high of 164 recorded in 2002.

Lastly, windowpane eggs reached unusually high densities twice in October, 7.0 and 4.9 versus the species' unusual level criterion of 2 per 100 m^3. Both densities were well below the previous high of 30 obtained in 1997.

C. Multi-year Ichthyoplankton Comparisons

A master species list for ichthyoplankton collected from the discharge canal at PNPS appears in Table 4 for the years 1975 through 2004. A total of 39 species was represented in the 2004 collections, the same as the 1975-2003 time series mean (39 species).

Appendix B (available upon request) lists geometric mean monthly densities along with 95% confidence limits for each of the numerical dominants collected over the January-December period dating back to 1981. Geometric means are reported because they more accurately reflect the true population mean when the distribution of sample values are skewed to the right as is commonly the case with plankton data. Generally low values obtained for both eggs and larvae during April-June 1984 and 1987, as well as May-June 1999, were shaded because low through-plant water volumes during those months probably affected densities of ichthyoplankton (MRI 1994). Entrainment data collected from 1975-1980 remain in an outdated computer format requiring conversion before geometric mean densities can be generated. These years were therefore excluded from comparison. To help compare values over the 30-year period, egg data were plotted in Figure 5 for those species whose combined total represented 99% of the 2004 egg catch. For this figure, cod and pollock eggs were combined in the Gadidae-*Glyptocephalus* group; rockling, hake and butterfish made up the *Enchelyopus-Urophycis-Peprilus* group, and labrids and yellowtail flounder were combined in the Labridae-*Pleuronectes* group. For each category shown, the highest monthly geometric means obtained from 1981 through 2003 were joined by solid lines as were the lowest geometric means, and the area between was shaded, indicating the range of these values. Monthly geometric mean values for 2004 were joined by a solid line. Alongside each plot is a bar graph showing annual abundance indices for each year. These were generated by integrating the area under each annual curve using trapezoidal integration[2]. One set of bars was based on geometric monthly means and the other, longer time series, on arithmetic monthly means (1975-2004). Appendix B and Figure 6 contain corresponding data for the 13 numerically dominant species of fish larvae, those accounting for 93% of the 2004 catch as well as total larvae (all species combined). As mentioned for eggs, low values obtained for both eggs and larvae during April through August 1984 and 1987 and May-June 1999 were flagged in these figures and omitted from the following discussion.

In many cases densities of fish eggs and larvae vary considerably from year to year. For example, over the 24-year geometric mean time series for Atlantic menhaden eggs, the highest annual abundance index (1,268 in 1982) divided by the lowest (10 in 1992) amounted to 127. In spite of such pronounced variation, no consistent upward or downward trend is apparent over the time series for many species including menhaden and windowpane eggs, sculpin and rock gunnel larvae. Following are noteworthy observations concerning the multi-year time series. Since densities of each ichthyoplankton species rise and fall to zero over the course of each representative occurrence season, inter-year comparisons are often conveniently made within monthly periods.

<u>Eggs</u>

- Atlantic menhaden eggs were relatively uncommon at PNPS during the month of June, reaching a record low monthly mean density (0.21 per 100 m^3) for the 1981-2003 time series in 2004. The 2004 annual geometric mean index of abundance for menhaden eggs (23) declined from the previous three years (69, 55, and 70 respectively), and ranked the third lowest over the 1981-2003 time series. The arithmetic mean (71) also decreased compared to the previous three years (249, 538, and 370 respectively), and ranked the

[2] Curve integration results in units of (Numbers x days) per 100 m^3 of water.

eighth lowest over the 1975-2003 time series. In contrast menhaden eggs were entrained at an unusually high density on October 6, 2004 when 11.6 eggs per 100 m^3 were obtained. That density exceeded the unusual level of 6 eggs per 100 m^3 and surpassed 97% of all previous October values (Table 3).

The overall seasonal peak abundance periods for menhaden eggs from 1981 to 2003 showed menhaden eggs to be most abundant in June and July followed by a secondary peak in September. The late season, secondary peak extended later in the 2004 season, peaking in October rather than September just as they did in 2002 and 2003. Menhaden eggs collected in October 2004 represented the fourth highest abundance for that month over the time series.

- Atlantic cod eggs were typically collected in low numbers at PNPS during winter months from 1975-1987 (5 per 100 m^3 of water, for example). Following 1987 they became uncommon particularly during January and February. None were taken in either month in 1993 or 1994 and only one was taken in 1995. In 1996 collections rose to three eggs, all taken in February. The gadidae-*Glyptocephalus* group in general showed a significant decline from 1975 to 1993 ($p<0.001$), based on a nonparametric sign test (Sprent 1989), which is consistent with the downward trend reported for Atlantic cod and witch flounder (*Glyptocephalus cynoglossus*) stocks, apparently resulting, at least in part, from overexploitation (NOAA 1998, NFSC 1998). In 1998, the annual geometric mean indices suggested that this decline had ended if not reversed, at least locally, since values for 1994 through 1997 (105, 103, and 112, respectively), appeared stable at about three times the low values recorded in 1993 (39). The 1998 geometric index (149) was the highest since 1989 (158). In 1999 the geometric mean index dipped to 45, indicating a possible reversal in the trend. However, for the years 2000 through 2003 the geometric mean indices increased to 194, 246,196, and 463, respectively. In 2004 the geometric index decreased slightly to 318 but remained relatively strong, with collections representing traditional characteristic peaks for the months of January through February, May, and November. Early-stage Atlantic cod and witch flounder eggs were collected at a record high density of 6.9 eggs per 100 m^3 in April 2004. This is the second year that the April density has set a new record high. Overall an upward trend is apparent in these eggs from 1999 through 2004, which is consistent with an increase in stock biomass and spawning biomass since 1998 for Atlantic cod (NFSC 2001).

- Rockling, hake, and butterfish eggs had two new record lows in July and August of 2004 when 1.1 and 1.0 eggs per 100 m^3, respectively were collected. Eggs of the fourbeard rockling and closely related hake (grouped in the early developmental stages with far less common butterfish as *Enchelyopus-Urophycis-Peprilus*; MRI 1988) have been uncommon in recent years. Trend analysis using the longer-term arithmetic time series indicated that a significant downward trend occurred from 1978 through 1996 ($p = 0.05$) even with a moderate catch in 1995. In spite of relatively high densities in April 1997, the 1997 indices (3,819 and 1,621) represented only a slight improvement over 1996 (2,889 and 1,299). The 1999 (4,715 and 2,366) and 2000 (7,946 and 4,301) indices indicated an upward trend could be underway. Although the 2001 arithmetic and geometric mean indices declined to 1,897 and 641, respectively, the 2002 arithmetic and geometric means improved slightly to 1,980 and 1,199, respectively. However, in 2003 geometric and arithmetic means declined somewhat to 585 and 1,915, respectively, and continued to decline in 2004 to 438 and 953, respectively.

Fourbeard rockling dominate within this egg grouping based on late-stage eggs as well as larval collections. Since they are a small bottom fish with little or no commercial value, stock size data are not available with which to compare trends. Hake on the other hand contribute to the commercial bottom fishery, and stocks in the Gulf of Maine and northern Georges Bank are both considered to be underexploited. Stock abundance of red hake on southern Georges Bank and in Massachusetts waters are relatively low according to the most recent Northeast Fisheries Science Center survey index (NFSC 2001) consistent with the low egg collections.

- Searobin (*Prionotus* spp.) egg abundance indices increased slightly in 2004 (36 and 21) compared to the 2003 time series lows of 1.8 and 1.5, respectively. Searobin egg abundance indices increased in 1999 (258 and 123) and 2000 (452 and 290) suggesting an upward trend. However, abundance declined in 2001 (108 and 62), 2002 (57 and 33), and reached a 1981-2003 time series low in 2003, showing an alternating, intermittent rise and fall in abundance between years since 1987. Massachusetts Division of Marine Fisheries resource survey trawls showed relatively high abundance during the late 1970's through the mid-1980's followed by a sharp decline through the early 1990's (McBride et al. 1998). The decline in the 1990's appears to be reflected in the PNPS egg data.

- Tautog/cunner eggs, believed to be composed primarily of cunner (Scherer 1984) appeared to be in a downward trend from the late 1970's through 1994 although a sign test failed to confirm it using the conventional 95% significance level ($p = 0.055$). In contrast, the arithmetic and geometric indices both showed an increase in density in 1995, the geometric index continuing to rise in 1996. The 1995 arithmetic index appeared exceptionally high and disproportionate to the geometric value due to a single high density in June (37,282 per 100 m^3 of water), which greatly skewed the arithmetic mean for that month. The 1997 arithmetic index (83,356) declined from 1996 (135,791) but remained well above the low values observed in 1990 (58,254), 1991 (36,008), and 1994 (66,078). Indices rose again in 1998, the geometric mean value (50,705) nearly equaling the 1996 (51,652) index. The arithmetic index was disproportionately high due to two high densities in June 1998. The 1999 and 2000 annual values (29,900 and 28,200, respectively) were quite similar to each other but represented a decline from 1998. The 2001 geometric index (40,600) represented an increase from 1999 and 2000 and was comparable to the 1997 value (38,900). However, the 2002 geometric index of 14,709 was the lowest since recording began in 1981 with only the1994 index of 15,263 being nearly as low. The 2003 arithmetic and geometric mean indices (38,755 and 15, 438) rose slightly from 2002 but both were the third lowest values recorded in the time series.

The 2004 abundance indices increased (77,815 and 32,693) compared to the 2002 and 2003 indices, however, they remain below both time series averages, 138,543 and 45,330 respectively. In September, labrid eggs were entrained at an unusually high density on five occasions (Table 3); the 37.9 per 100 m^3 recorded on September 6 exceeded 98% of all previous September values.

The downward trend noted through 1994 is consistent with observations of finfish in the PNPS area as well as impingement collections at the Station (Lawton et al. 1995). Changes in sampling protocols at PNPS have negated the ability to monitor general cunner population trends beyond 1994, which in the past were sampled by gill net, trawl, and diver surveys. Numbers impinged appeared to systematically decline from 1980 through 1992 (annual totals dropped from 116 to as low as 2 in 1988), then increased from 1993 (104) through 1995 (288). They remained high in 1996 (211), which appeared to roughly parallel the egg abundance data. The impingement total for 1997 (39) and 1998 (76) represented a substantial drop relative to the preceding four years and appeared out of step with the ichthyoplankton collections. Cunner impingement in 2000 (294) and 2001 (117) was comparable to impingement numbers from 1993 through 1995 (104-288; see Impingement Section). In 2002, the cunner impingement total dropped to 53 and rose in 2003 to 221.

Cunner larval abundance dropped considerably from 2001(geometric mean index = 1,406) in both 2002 and 2003. The geometric mean index when averaged for 1997-2001 was 2,373 and dropped to 303 (2002) and 115 (2003). Arithmetic mean indices for cunner larvae over the time series (1975-2004) show no apparent trends in entrainment collections, but rather, fluctuate between a few years of relative abundance followed by an occasional year or two in which cunner larvae are less common. For instance, in 1981 the arithmetic mean index for cunner was 10,701 but then declined sharply to 437 in 1982 and climbed to 2,067 in 1983 (Figure 6). This general fluctuation pattern is repeated throughout the time series and likely reflects a localized, dynamic recruitment pattern for this temperate wrasse.

- Eggs of the yellowtail flounder were relatively abundant in April 1999, 2001, and 2002, but declined somewhat in 2003 and 2004. While early stage eggs of this species are similar to and grouped with the labrids, they are believed to account for all eggs of that type collected in April since the labrids are not likely to spawn until May. The geometric mean density for that month in 1999 was 2.4 per 100 m^3, increasing to 4.0 in 2001 and 3.9 in 2002. The April yellowtail flounder eggs' geometric mean index was 1.1 per 100

m^3 in 2003 and 1.6 per 100 m^3 in 2004. Stock assessment information shows a slight increase since 1994, perhaps explaining the increase in egg abundance (NFSC 1998). Spawning stock biomass of yellowtail in southern New England has increased since 1998 and they are now listed as overfished according to a first-ever assessment for yellowtail flounder combining abundance data for both Cape Cod and the Gulf of Maine area (NFSC 2003).

- Mackerel eggs typically display a sharp peak in their seasonal abundance curve often with one or two very high densities. For example, in May 1995 a single density of 19,203 eggs per 100 m^3 was recorded on May 26, dropping to 557 eggs per 100 m^3 on the 29th. The second highest density occurred on June 9 that year with 4,754 eggs per 100 m^3. Due to these brief sharp peaks, arithmetic and geometric indices are often quite far apart (Figure 5). Mackerel eggs were more abundant from 1988 to 1998 when compared to the 1975 through 1987 period. A sign test using the arithmetic index time series supported this upward trend ($p < 0.006$). In 1999 and 2001, however, the numbers decreased significantly to 1,135 and 727, respectively. This is likely due to the fact that the main seawater pumps were off for extended periods during the month of May, the peak season for mackerel eggs. In 2002, the geometric mean index climbed to the second highest value in 10 years (11,850) but in 2003 the index dropped 71% to 3,411. In 2004 the geometric mean index dropped 81% to 661, the lowest value in the 1981-2003 time series. The May 2004 monthly mean of 16 eggs per 100 m^3 ranked below all other years dating back to 1985, and amounted to less than 2% of the peak observed in 1993 (1,042 per 100 m^3). Entrainment of high densities of mackerel eggs over the past decade, 1999 and 2001 aside, is consistent with a dramatic rise in stock biomass attributable to reductions in foreign fishing and underexploitation by U.S. fishermen (Overholtz 1993, NOAA 1998, NFSC 1998).
- Windowpane eggs, assuming based on larval collections, that they predominate within the *Paralichthys-Scophthalmus* egg group, increased from 1994 through 2001 which for 2001 represented the highest geometric mean index (6,377) since 1989 (8,674). In 2002, the same index dropped to 1,396 but rose again in 2003 (1,973) and 2004 (2,843). Over the

entire 30-year time series the arithmetic index for 2004 (5,190) ranked in the middle (13th) and above the 1975-2003 time series average (4,785). Over the 23-year 1981-2003 geometric mean time series 2004 (2,843) ranked 10th overall, slightly below the series average of 2,923. Windowpane eggs were entrained in the highest numbers during the month of June at a geometric mean density of 27 per 100 m^3 of water, consistent with the seasonal peak of past years.

In general these eggs have not shown wide variations in number, at least compared with other species regularly entrained. Massachusetts Division of Marine Fisheries spring and fall trawl surveys, suggest that stocks gradually increased from 1978 to 1995 but then decreased more or less steadily through 2003 (Matthew Camisa, MDMF, personal communication). Over that time series catch did not swing over a very wide range, the low being 2 fish per tow and the high 14 (average of spring and fall surveys).

- American plaice eggs' geometric mean index in 2004 (450) was the highest for the 1981-2003 time series, surpassing the 2001 mean of 414. The 2004 geometric mean index was 2.5 times the series average of 182. American plaice eggs were abundant in April with a mean density of 8.7 per 100 m^3, ranking second behind 2001 (11.8 per 100 m^3). They were also relatively abundant in May with a geometric mean density of 5.9 per 100 m^3 that equaled the 2003 value and exceeded all other May values. American plaice eggs exceeded the level considered to be notable on four occasions in May (Table 3) consistent with the annual ranking.

Plaice egg abundance at PNPS appears to generally follow trends in adult stock size. Entrainment was low in the mid 1980's when stock size was known to be low (NFSC 1998), increased from 1987 through 1992, and decreased slightly through 1996 although remaining above the low of 1990; then rose again through 2001, tapered off in 2002, and increased in 2003 and 2004. A strong year class was produced in 1992 in addition to a subsequent drop in fully recruited fishing mortality from 1992 to 1999 perhaps accounting for the relatively strong egg production near PNPS since then (NFSC 2001). Spawning stock biomass is predicted to increase over the ten-year forecast period from 2000 to 2010 (NEFSC 2001).

- The total eggs collected, all species pooled together in 2004 (Figure 5), reflects normal peak abundance occurring from April to September. The total egg geometric mean abundance index for the 2004 year (44,820) was the eighth lowest for the 1981-2003 time series, and well below the series mean of 84,723. The arithmetic mean index increased in 2004 (88,734) compared to the previous two years, 57,805 in 2002, and 65,881 in 2003. However, the 2004 arithmetic mean was less than half the time series average of 205,290. The relatively low indices in 2004 likely reflect to a large extent below average numbers of cunner and mackerel.

Larvae

- Abundance of menhaden larvae dipped noticeably during 2000 and 2001 after four years of relatively high larval abundance from 1996-1999, climbing slightly in 2002 and dropping again in 2003 and 2004. The 2004 annual geometric mean abundance index (10) was the lowest of all the years sampled, as was the arithmetic mean index (12). The annual geometric mean abundance index for 2000 (21) ranked second for all years sampled as did the arithmetic index (44). During 2001 through 2003, the geometric mean indices rose to 53, 115, and 51, respectively, all below the series average of 240. The arithmetic index rose to 85, 308, and 109, respectively, also below the 1975-2003 time series average of 369.

  Menhaden are coastal migrants that travel in schools that can often be quite dense. The great variability in numbers of eggs taken at PNPS probably reflects not only numbers of adults in the surrounding waters but variability in the distance from PNPS at which spawning takes place. Spawning stock biomass increased from 1993 through 1995 (Cadrin and Vaughan 1997), which is consistent with the observed increase in egg and larval densities in 1997 and larval densities alone in 1997-1999. Currently the stock is believed to be healthy (ASFMC 2004). In addition to traveling in dense schools menhaden are often attracted to both intake and discharge currents at industrial facilities.
- Atlantic herring larval abundance indices have proven valuable in management of herring stocks on Georges Bank, Nantucket Shoals, and in the Northeast Atlantic in general (see for example, Smith and Morse 1993). The stock was seriously depleted by distant-water

fleets during the 1960's and 1970's to the point where no larval herring were found on Georges Bank for a decade (Anthony and Waring 1980, Smith and Morse 1993, Overholtz and Friedland 2002). The stock has increased more or less steadily since 1986 following reductions in fishing pressure to the point where they are abundant on Nantucket Shoals and in the Gulf of Maine-Georges Bank region. Larval collections at PNPS from 1994 through 2002 reflect the general increase in stock size, the geometric mean index for those seven years ranking among the top six. In 2003, however, the geometric mean index (32) fell relative to the 2002 index of 147, and represented a fourteen-year low dating back to 1989. In 2004 the geometric mean index (116) rose relative to the 2003 index, and ranked in the middle (13th) of the 1981-2003 time series. The 2004 arithmetic mean also increased relative to the 2003 index. Atlantic herring larvae reached unusually high levels on 11 occasions in 2004, (Table 3) suggesting that successful spawning occurred. On January 7, a density of 2.9 per 100 m^3 of water set a new January monthly high.

Larval Atlantic herring abundance in 2004 peaked in both April (1.6 per 100 m^3) and December (1.6 per 100 m^3) consistent with the historical pattern. Peak abundance indices shift somewhat from year to year from the long-term trend most likely due to such abiotic factors as water temperature. For example, the major spawning for Atlantic herring in the NW Atlantic traditionally occurs from late August through November (Collette and Klein-MacPhee, 2002), but during unseasonably cold winters this spawning seasonality usually shifts later into December.

- Fourbeard rockling larvae were abundant in 1998 and 1999 particularly in July when the monthly geometric means of 32 and 30 per 100 m^3 respectively exceeded the previous July high of 6 per 100 m^3 dating back to 1981 (Figure 6). In 2000, the annual geometric mean index dropped precipitously (50) and represented the lowest index dating back to 1981. In 2001, the geometric mean index rebounded to 607, the fourth highest since 1990. However, the geometric mean index for 2002 dropped to its third lowest over the 24-year sampling period. In 2003, the geometric mean index dropped to a time series low of 47, under one tenth the series average (509). In 2004, the geometric mean index increased relative to the 2002 and 2003 indices to 528, ranking 10th highest in the time series and above the series average. The September monthly mean (0.0 per 100 m^3) set a new monthly low for the time series, and was the first time that no rockling larvae were collected during this month. In spite of these swings in abundance, no consistent trend over the times series is evident.

As mentioned above under eggs, the rockling is a small bottom fish with little or no commercial value and stock size data are not available with which to compare trends.

- Abundance indices for larval hake increased slightly in 2004 (47 and 23) compared to the 2003 time series lows of 16 and 9, which were far below the series averages of 847 and 229. In spite of generally low abundance hake larvae reached unusually high densities on two occasions in July 2004. The 4.5 per 100 m^3 recorded on July 5 exceeded 91% of all previous July values (Table 3). Data available through 1999 suggest that hake stocks in southern New England have declined by about 50% since the late 1960's, and surveys in Massachusetts waters confirm that, with the possible exception of 1999, abundance is relatively low (NFSC 1998, Robert Johnston, Massachusetts Division of Marine Fisheries, personal communication). Although increased recruitment has helped the southern stocks of red hake (NFSC 2001), the status of white hake is currently listed as overfished (NFSC 2001). Time series highs in larval abundance at PNPS in 1997 (994) and 1998 (932) may indicate production of strong year classes or simply reflect a localized spawning aggregation, especially since the trend did not continue for the last several years.
- Sculpin abundance has remained relatively stable over the 30-year arithmetic mean time series (Figure 6). A slight increasing trend occurred from 1977 through 1989 and a secondary peak in 1997 (geometric mean index = 2,249, arithmetic mean index = 5,058). After dropping in 1998 to 1,086, the geometric mean index climbed to 1,668 in 1999 and 1,528 in 2000 before declining to 958 in 2001. The sculpin geometric mean index for 2002 (2,428) rebounded to the third highest since 1981 and the highest since 1988. In 2003 and 2004, the means fell to 988 and 766, respectively, both below the time series average of 1,393. A new monthly low was set in February when no larvae were collected

for the first time during this month. The major species within this genus entrained at PNPS is the grubby. Since these fish are small and have no commercial or recreational significance, no stock size data are available with which to compare the larval abundance patterns.

- For larval seasnail the geometric mean index rose to a 7-year high in 2004 (233), exceeding the 2002 five-year high of 202. In 2003, these larvae dropped to a 1981-2002 time series low geometric mean index of 27. The arithmetic mean index also reached a 1975-2003 time series low of 30. Since these fish typically reach a length of less than 6 inches and they have no commercial or recreational significance, no stock size data are available with which to compare the larval abundance patterns.
- Tautog abundance in 2004 (geometric mean index = 172) increased relative to the 2003 abundance (64) which declined slightly from that of 2002 (73) and more significantly from the 2001 five-year high of 268. Tautog larvae in 2004 exceeded the unusual density level once in July, five occasions in August, and four occasions in September (Table 3). On two occasions in September, the 1st and 8th, the mean densities of 6.2 and 7.1 respectively, exceeded 96% of all previous densities for September. The arithmetic mean index (1975-2003) extends over a longer time series than the geometric mean index and historically shows peaks and ebbs from year to year with no apparent long-term trend.
- Cunner larvae were more common in 2004 (geometric mean index = 373) than the previous year (115), however their abundance was still below the time series average of 1,144. No consistent long-term abundance trends are apparent for this species. Cunner reached an unusually high abundance in 2004 on August 6th at a mean density of 32.5 per 100 m^3, exceeding 93% of all previous August values (Table 3). Current stock size data for cunner are not available but tautog are believed to be overfished and at very low levels (NFSC 1998). However, recent data indicate that fishing mortality rates have declined from 1993 to 2000 and recreational landings have decreased from 1987-2001 (Stirratt 2002). Hopefully the stock will rebuild.
- Larval radiated shanny were relatively common in 2004 with a geometric mean index of 574 continuing a 4-year increase in abundance since a 12-year low in 1999 (geometric

mean index = 73; Figure 6). Radiated shanny larval abundance rebounded in 2000 (geometric mean index = 239), 2001 (geometric mean index = 604), and in 2002 (651), the highest in seven years and the second highest for the time series. The geometric mean indices for 2001 and 2002 were both above the mean over the 1981-2003 time series average of 395 per 100 m^3. The geometric mean index for shanny in 2003 (452) represented a reversal in the upward trend but remained above the 23-year average. May is typically the month of highest larval abundance for shanny. The monthly geometric mean for May 2004 (14.9 per 100 m^3) was above the time series average for the month of 9.8 per 100 m^3. During June, radiated shanny larval abundance typically ebbs and in 2004 the geometric mean of 3.5 remained above the series average for this month (2.2 per 100 m^3). The June 2004 monthly geometric mean was the fourth highest recorded over the time series 1981-2003; the previous high values were 9.7, 6.3, and 3.6 recorded in 1996, 1994, and 2003, respectively. The arithmetic mean index for 2004 (1,594) was above the 1975-2003 time series mean index of 817. Since this is a small, rather inconspicuous bottom fish, relatively little is known of its habits and data are not available concerning population trends.

- Larval rock gunnel abundance declined in 2003 and 2004 from the previous three years when they were collected in above average numbers. The 2004 annual geometric mean of 289 amounted to 73% of the 1981-2003 time series average (1,073), and was the third lowest value in the time series. The arithmetic mean index (638) was 66% of the 1975-2003 arithmetic mean index time series average of 1,892, and ranked eighth lowest. For 2002, the geometric mean abundance index of 3,040 was appreciably greater than the 23-year average. Overall, however, there was no obvious or statistically significant trend from 1975 to 2004, although there appeared to be intermittent highs in relative abundance followed by one or two-year declines with the peak abundance indices generally increasing over the 1981-2004 time series. The appearance of rock gunnel larvae from February through April, the three months when they typically are most abundant, fell below the time series mean for these months in 2004 consistent with the overall annual index. Because the rock gunnel is a small bottom fish with no commercial or recreational value, abundance data are not available with which to compare the entrainment estimates.

- For sand lance the 2004 geometric mean index (1,824) fell only slightly below the time series average of 1,859. The arithmetic mean index (5,029) remained above the time series average of 3,631 (Figure 6). Sand lance reached an unusually high density on March 31, with 604 per 100 m^3 exceeding 99% of all previous March values. Overall geometric mean indices peaked in 1996 (6,156) and the arithmetic index peaked in 1994. The geometric mean index has increased three-fold in the last 11 years (1994-2004, mean index = 2,820) compared with the first 13 years (1981-1993 mean index = 1,054) indicating a general increase in abundance that began in 1991 after the relatively poor showing of sand lance from 1987-1990.

The 2004 abundance curve generally mirrored the curve for the historical record with highest abundance during the months of March, April, and May. Historically, April represents the peak month for sand lance larval abundance in Cape Cod Bay and data for 2004 follow this trend with an April geometric mean of 46 per 100 m^3. A single sand lance larva was collected in November representing the beginning of the 2005 spawning season. The November appearance of sand lance suggested that the 2005 spawning season may have started earlier than in previous years with larvae typically appearing first in December.

Unfortunately the sand lance has little to no commercial or recreational value, and therefore abundance data are unavailable to compare to the entrainment estimates. However, sand lance do play an important role in community ecology in that they are an important prey source for a number of finfish species including several of the dominant species discussed above: mackerel, cod, hake, plaice, and yellowtail flounder (Winters 1983). Adult sand lance are also an important key prey species in the diet of several baleen whales that migrate to or through Massachusetts and Cape Cod Bays seasonally such as humpback (*Megaptera novaeangliae*) and finback whales (*Balaenoptera physalis*) and influence these whales' seasonal migrations (Weinrich et al 1997; Hain et al 1995). Traditionally, other dominant prey sources for humpback whales have been Atlantic herring and Atlantic mackerel and, as both these prey sources declined in abundance during the late 1970's and early 1980's, humpback whales began targeting sand lance as their main prey source for our region (Kenney et al 1996). The tourism industry generated from commercial whale watching has grown since the end of industrial whaling and has developed to where it plays an important economic role in the New England inshore waters.

- Mackerel larvae and eggs, as mentioned above, typically display a sharp peak in their abundance curve often with one or two very high densities. Due to these brief sharp peaks, arithmetic and geometric indices are often quite far apart (Figure 6). Mackerel larvae geometric mean index reached a 5-year high in the 2004 collections at 251. The geometric mean index for 2003 (36) represented a decline from the previous three years, 2002 (70), 2001 (159), and 2000 (131). The arithmetic mean index was high in 1981 (10,030) and again in 1995 (12,086). In general, the arithmetic mean indices increased from 1975 until 1995 and then declined. The 2004 value (726) ranked in the middle (15^{th}) for the 1975-2003 time series; however, it was well below the time series mean of 1,864. The peak abundance months for larvae over the historical time series are May and June with geometric mean averages of 0.8 and 9.9, respectively. During 2004, the May and June geometric means were below these averages at 0.09 for May and 7.6 per 100 m^3 of water for June.
- Winter flounder larvae, a species of considerable recreational and commercial interest and value, are typically among the numerically dominant members of the larval fish community around PNPS in May and the first part of June. The annual geometric mean index for 2004 (539) increased from the 195 recorded in 2003. The 2003 index was lower than the previous two years, 575 for 2002 and an all-time high of 2,307 for 2001. The 2004 index was slightly higher than the 1981-2003 time series mean of 523. Winter flounder larvae reached unusually high densities on three occasions in May and on one occasion in June (Table 3). On all four occasions the densities exceeded 98% of all previous May and June values. Although the 2004 May collections had unusually-high-density events, the monthly geometric mean of 11.3 per 100 m^3 was below the monthly

time series average of 13 per 100 m^3. The 2004 arithmetic index was 3,047, which ranked fourth over the 1975-2003 times series, and was more than 2.5 times the time series arithmetic mean of 1,107.

The most recent stock assessment for winter flounder in Southern New England/Mid-Atlantic stocks, including offshore Cape Cod catch data through 2001, shows winter flounder are currently overexploited (NFSC 2003). This most recent stock assessment also estimated the 2001 year class to be the smallest in 22 years. However, winter flounder stocks in the Gulf of Maine are doing better than the Southern New England stock, are currently listed as not being overfished, and are considered to have been rebuilding since 1995 (NFSC 2003).

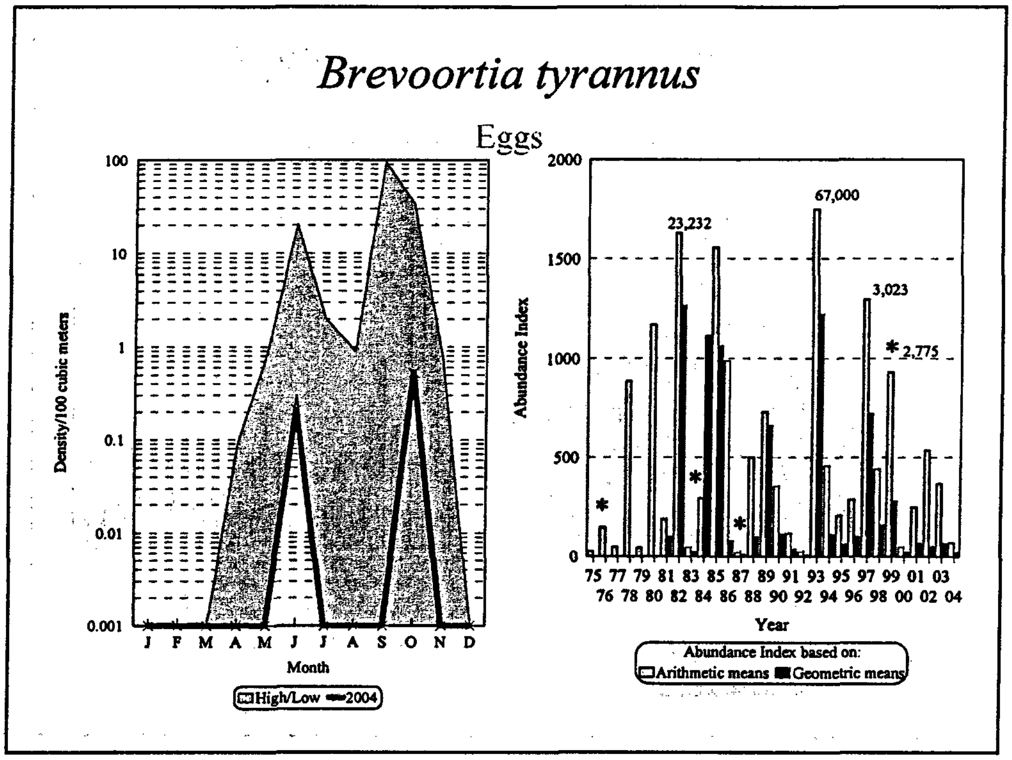
- The total for larvae collected in 2004, all species pooled together (Figure 6), mirrors the time series (1981-2003) abundance curve, showing major peak abundances from April to June. Data collected over the 1981-2003 time series have shown April as the traditional peak in larval abundance (average geometric mean of 90 per 100 m^3) when several species are abundant including: winter flounder sand lance, rock gunnel, seasnail, and sculpin. The 2004 abundance curve differed from the historical curve in February when larval density set a time series low at 1.0 per 100 m^3. The total larval arithmetic and geometric mean indices for 2004 (16,322 and 8,897, respectively) increased from 2003 (10,727 and 6,614), however, both were below the time series averages of 21,629 and 11,827, respectively.

Figure 5. Geometric mean monthly densities per 100 m^3 of water in the PNPS discharge canal for the eight numerically dominant egg species and total eggs, 2004 (bold line). Solid lines encompassing shaded area show high and low values over the 1981-2003 period.

Brevoortia tyrannus	Labridae-*Pleuronectes*
Gadidae-*Glyptocephalus*	*Scomber scombrus*
Enchelyopus-Urophycis-Peprilus	*Paralichtys-Scopthalmus*
Prionotus spp.	*Hippoglossoides platessoides*
	Total eggs

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-2004. An asterix above 1984, 1987 and 1999 marks the three years when values may have been low due to low through-plant water volumes from April-August. An asterix above 1976 indicates abundance value may be low due to absence of sampling during January – late April; see text for clarification. Light bars represent indices based on monthly means arithmetic means, solid bars (1981-2004) indices based on monthly geometric means.

Occasionally bars were rescaled to improve readability. The actual value in those cases is printed above the bar.



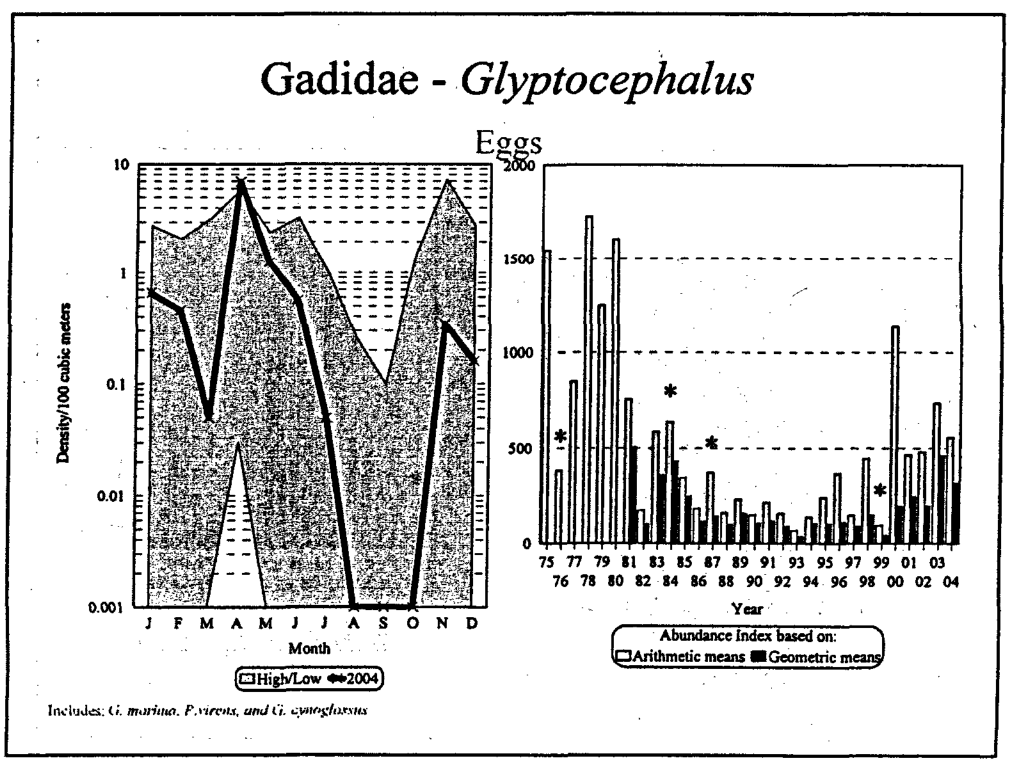
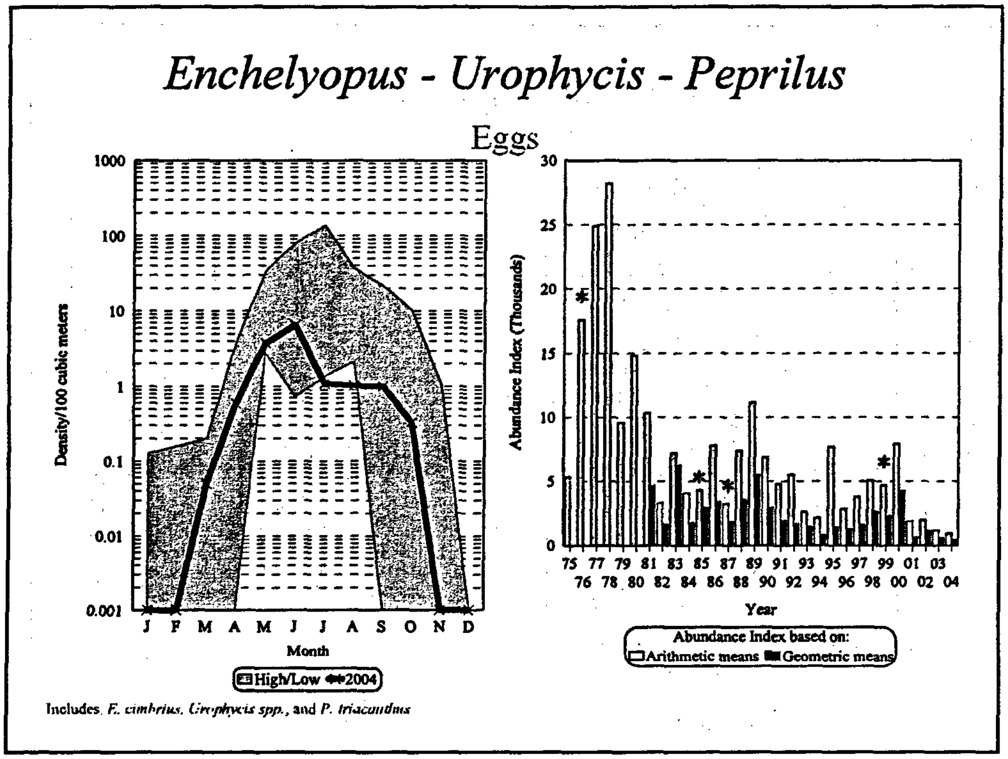
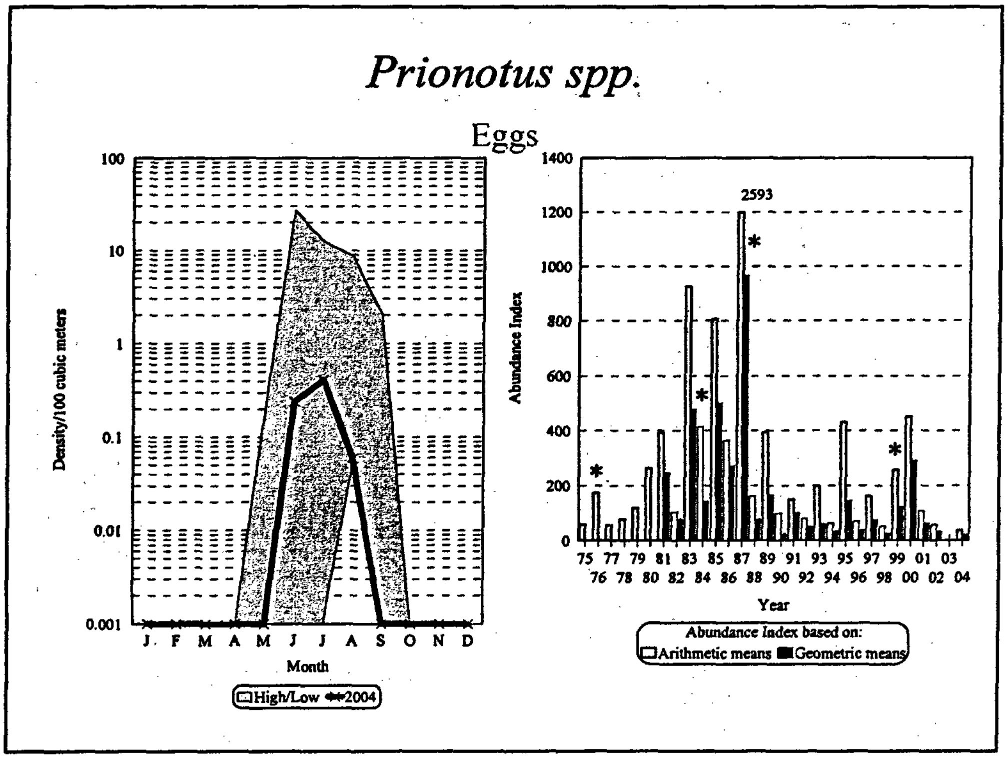


Figure 5 (continued).





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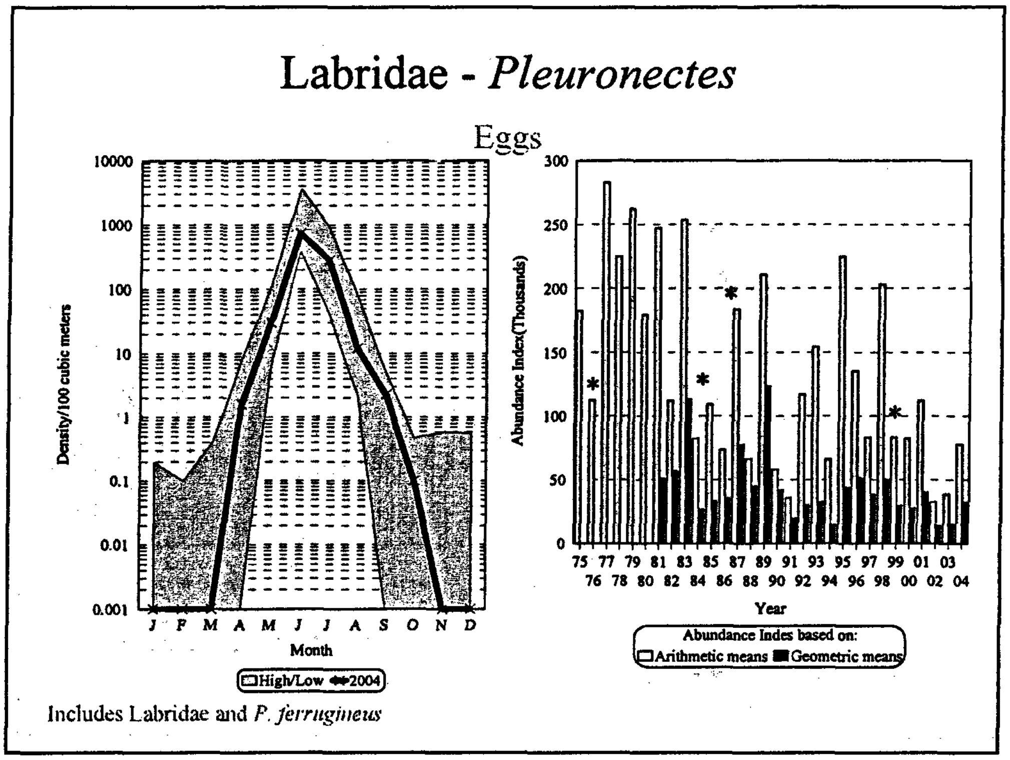

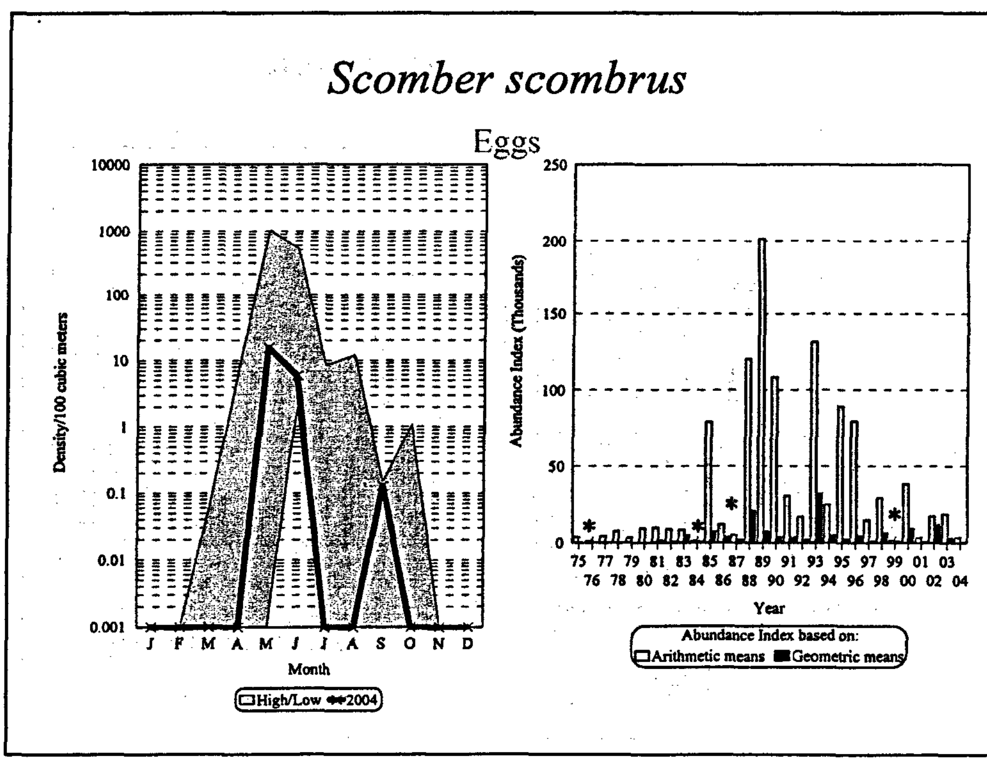

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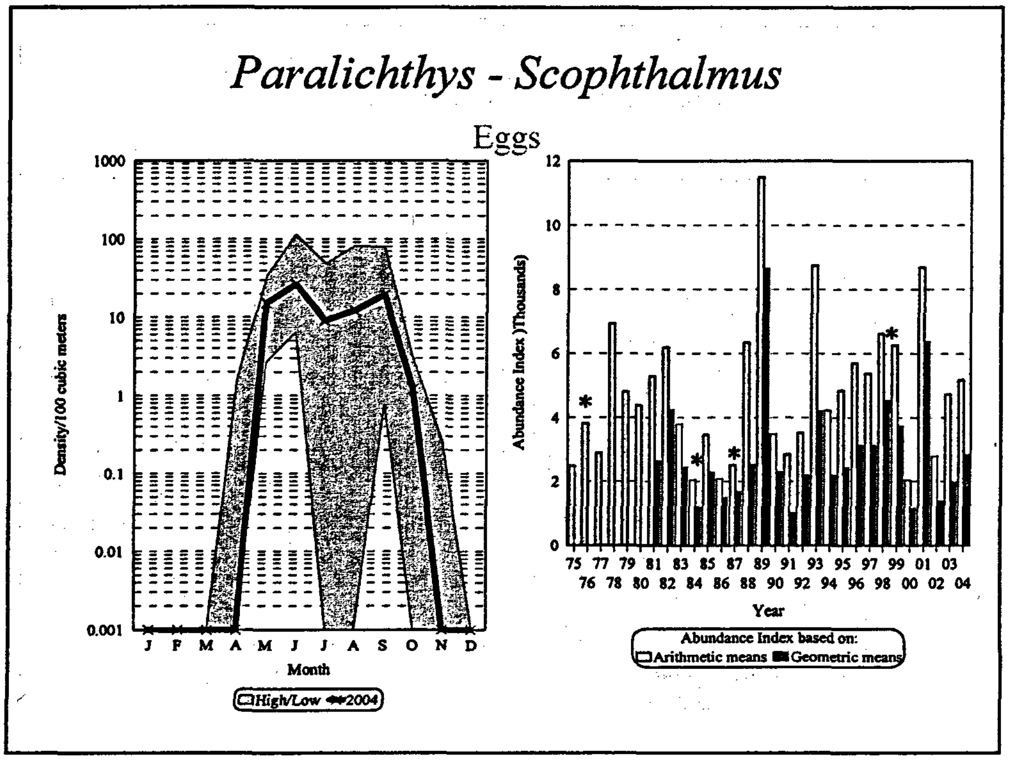


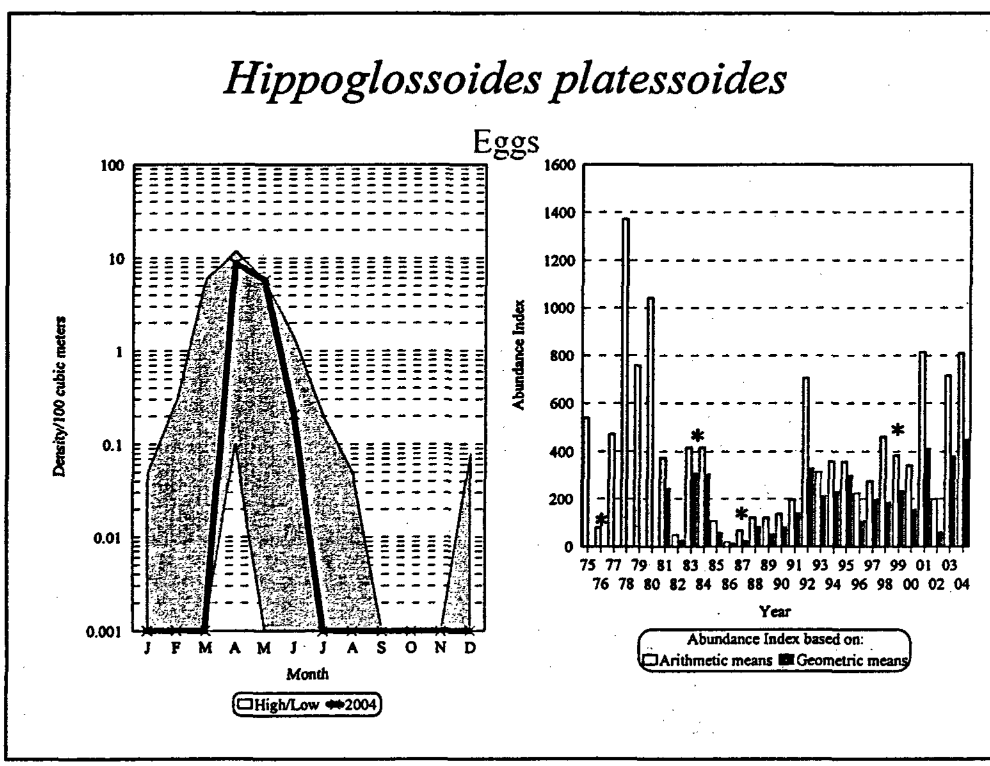


Figure 5 (continued).

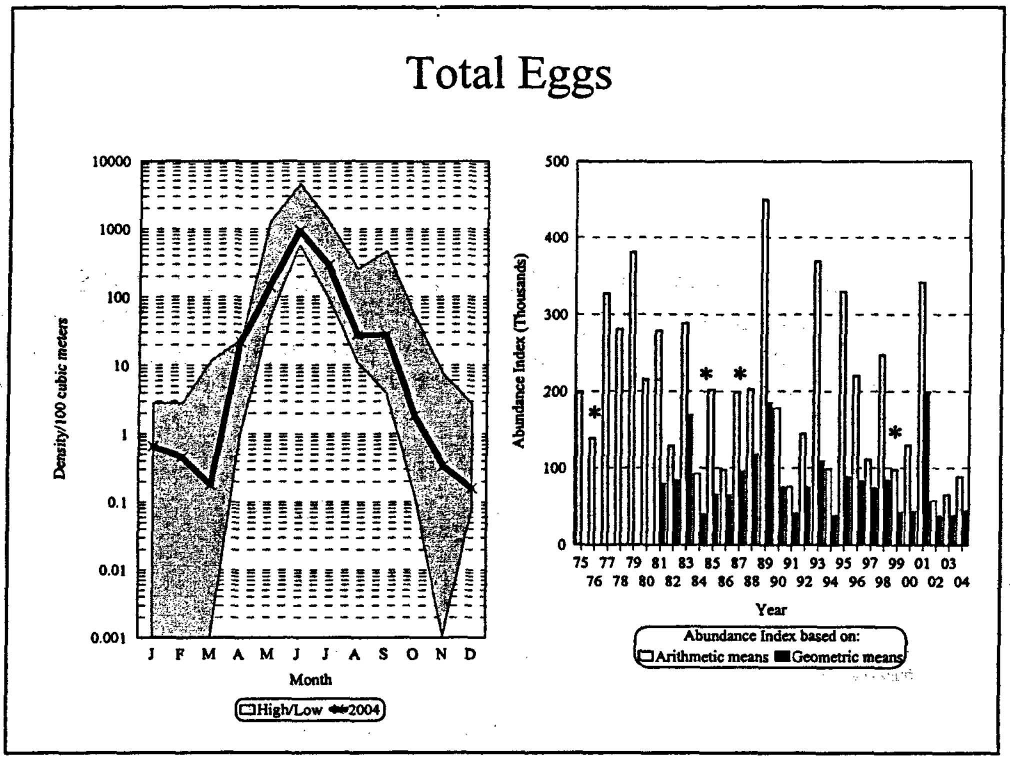


Figure 5 (continued).

Figure 6. Geometric mean monthly densities per 100 m^3 of water in the PNPS discharge canal for the thirteen numerically dominant larval species and total larvae, 2004 (bold line). Solid lines encompassing shaded area show high and low values over the 1981-2003 period.

Brevoortia tyrannus

Clupea harengus

Enchelyopus cimbrius

Urophycis species
Myoxocephalus species

Liparis species

Tautoga onitis

Tautogolabrus adspersus

Ulvaria subbifurcata

Pholis gunnellus

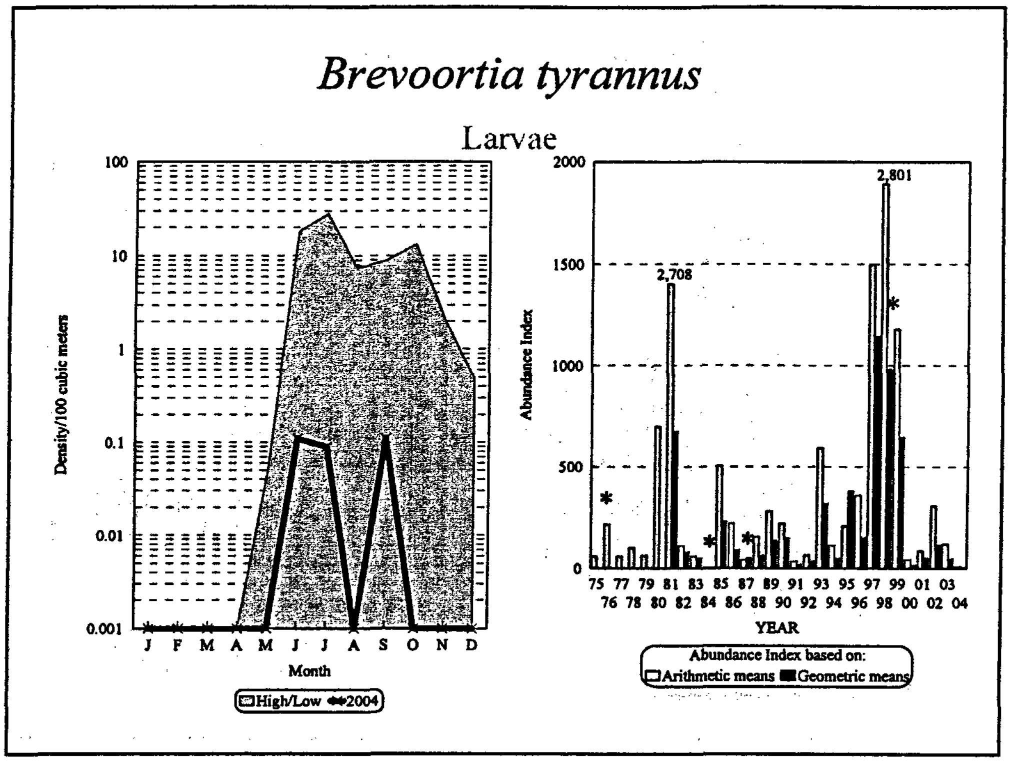
Ammodytes species
Scomber scombrus

Pleuronectes americanus

Total larvae

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-2004. An asterix above 1984, 1987 and 1999 marks the three years when values may have been low due to low through-plant water volumes from April-August. An asterix above 1976 indicates abundance value may be low due to absence of sampling during January – late April; see text for clarification. Light bars represent indices based on monthly means arithmetic means, solid bars (1981-2004) indices based on monthly geometric means.

Occasionally bars were rescaled to improve readability. The actual value in those cases is printed above the bar.



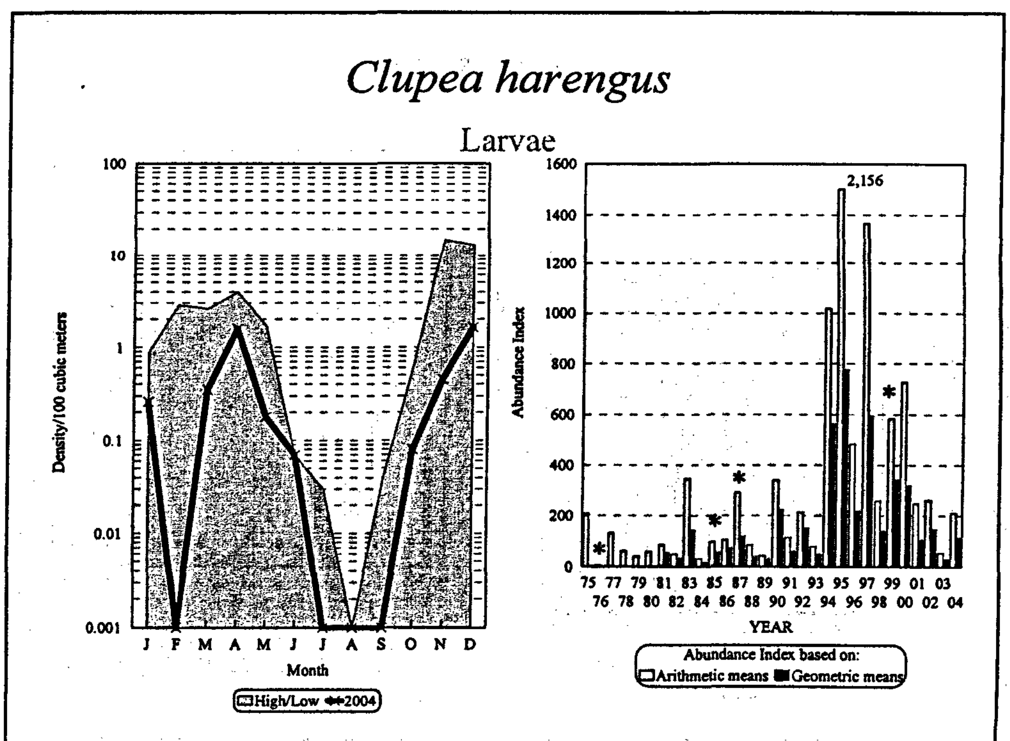
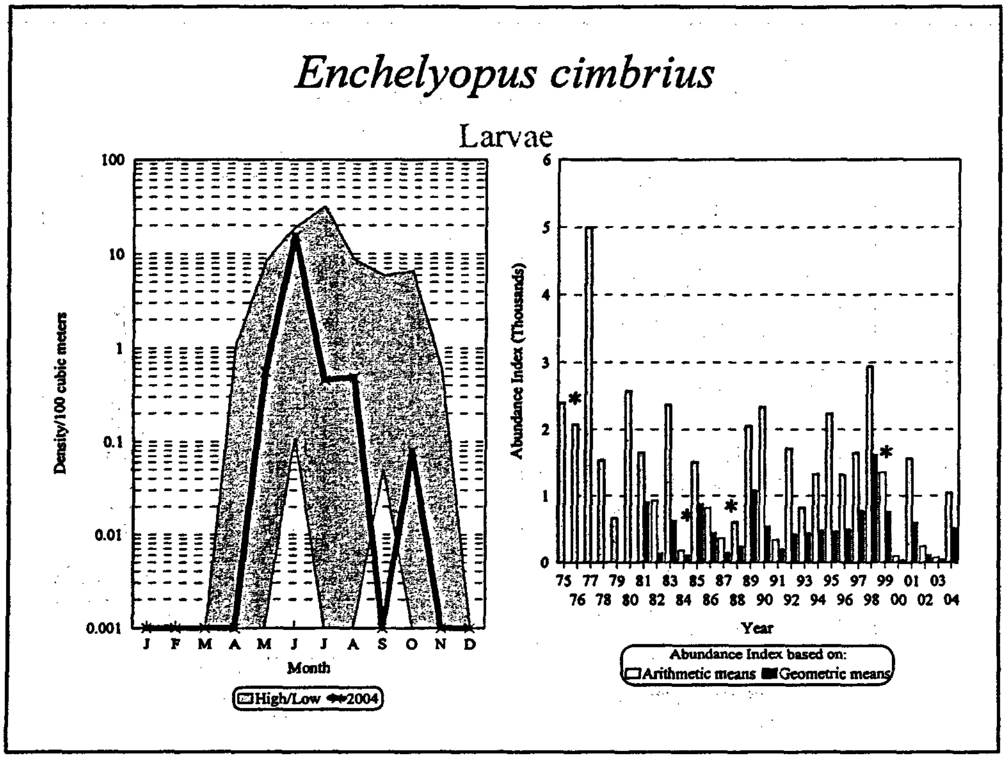


Figure 6 (continued).



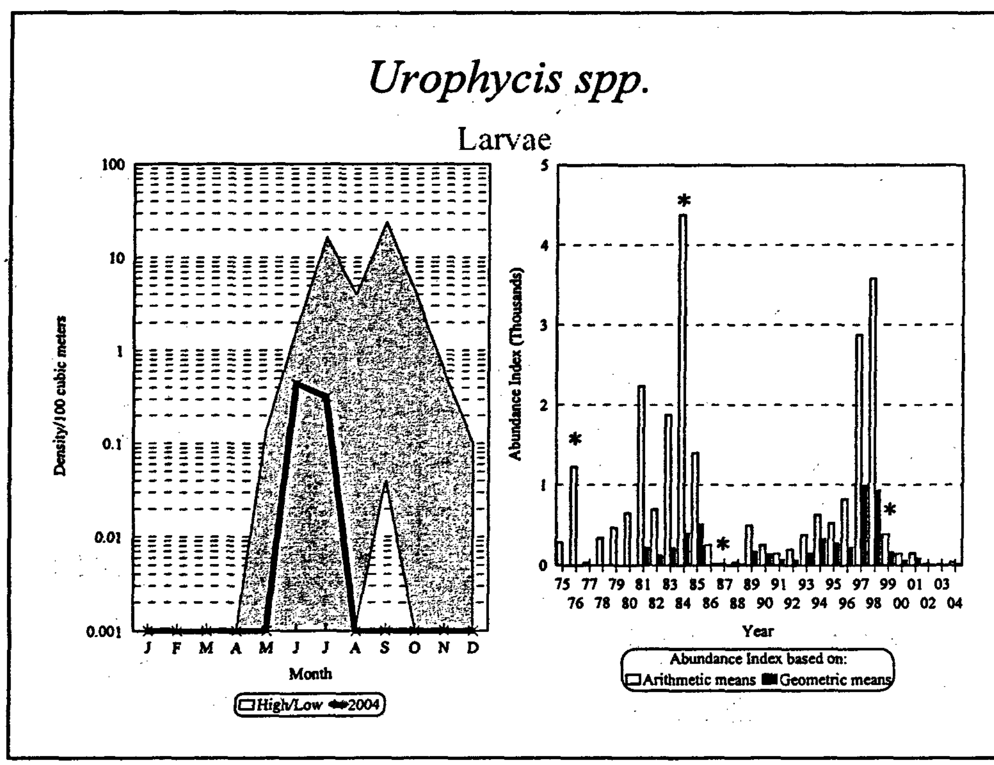
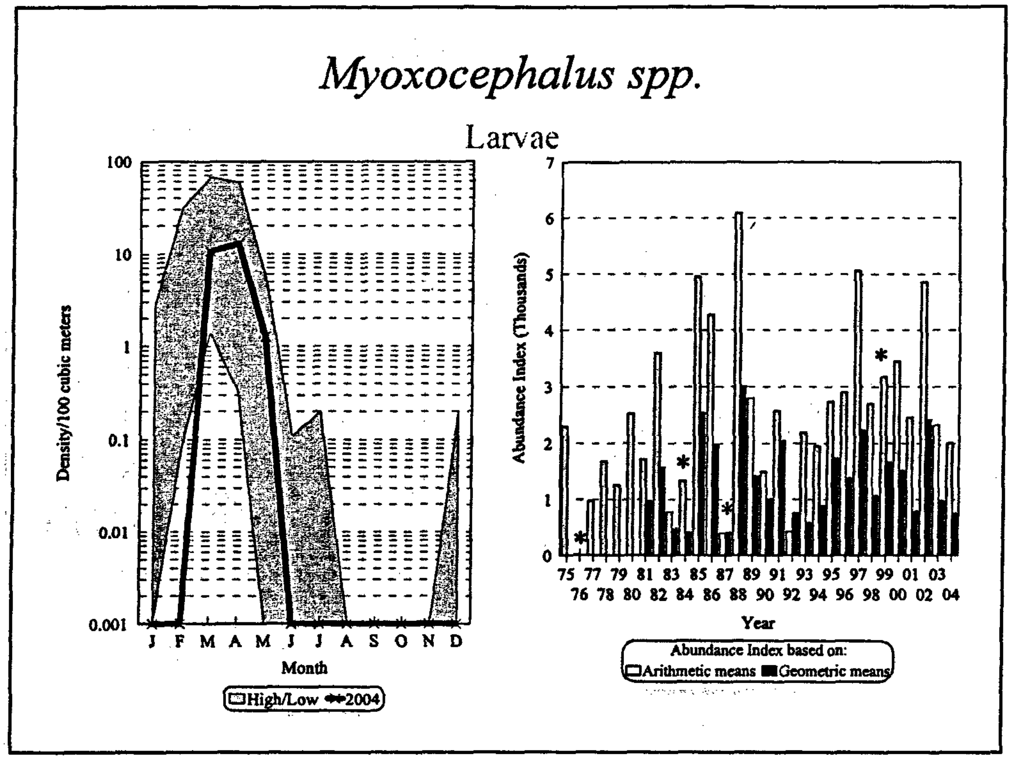


Figure 6 (continued).



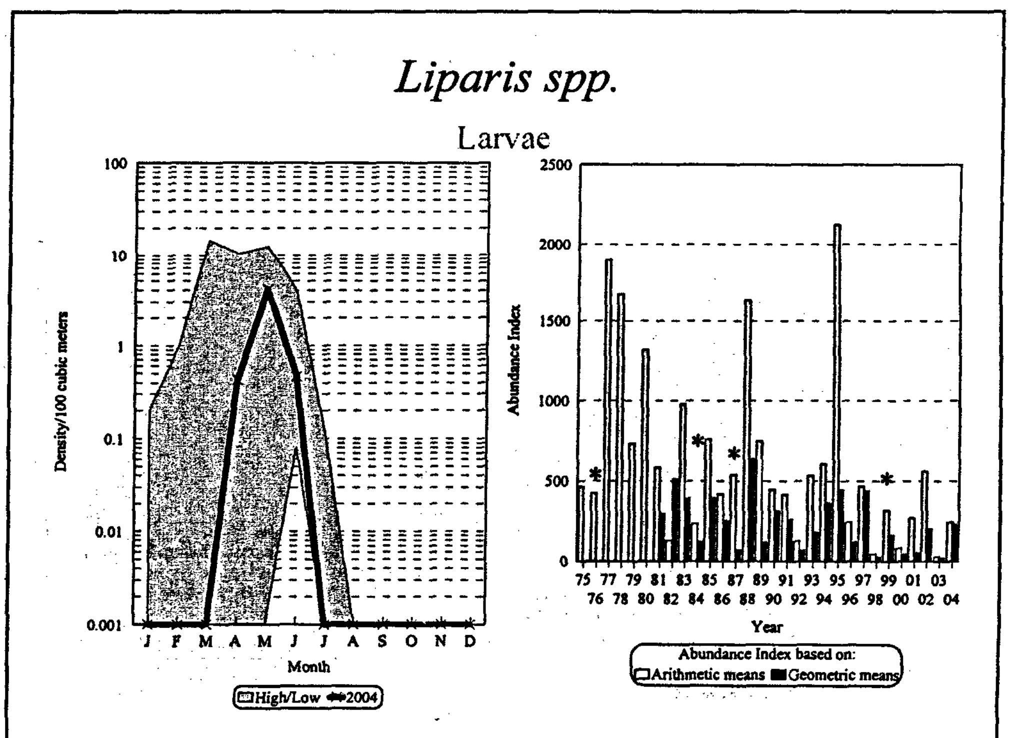
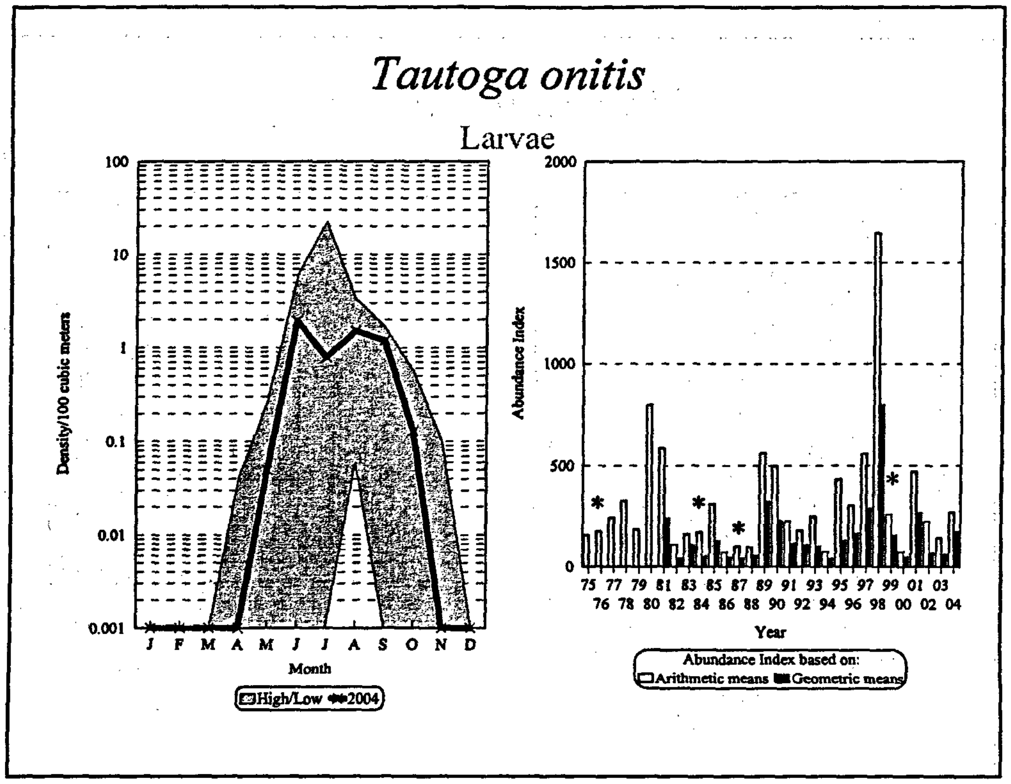


Figure 6 (continued).



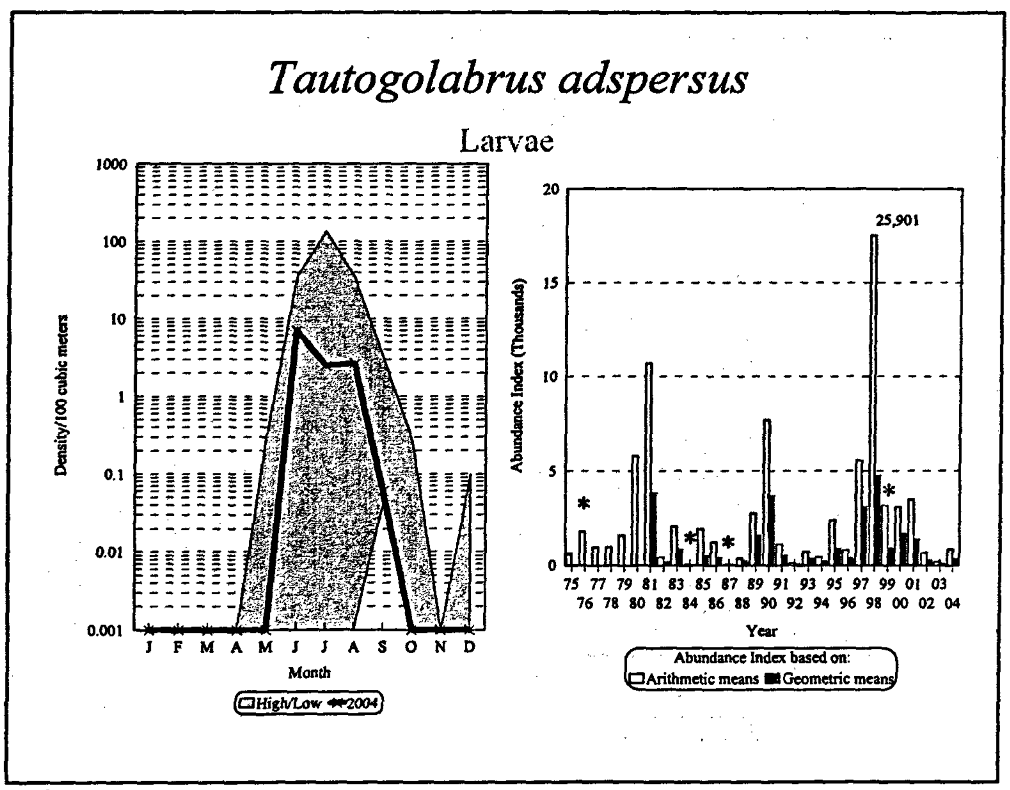
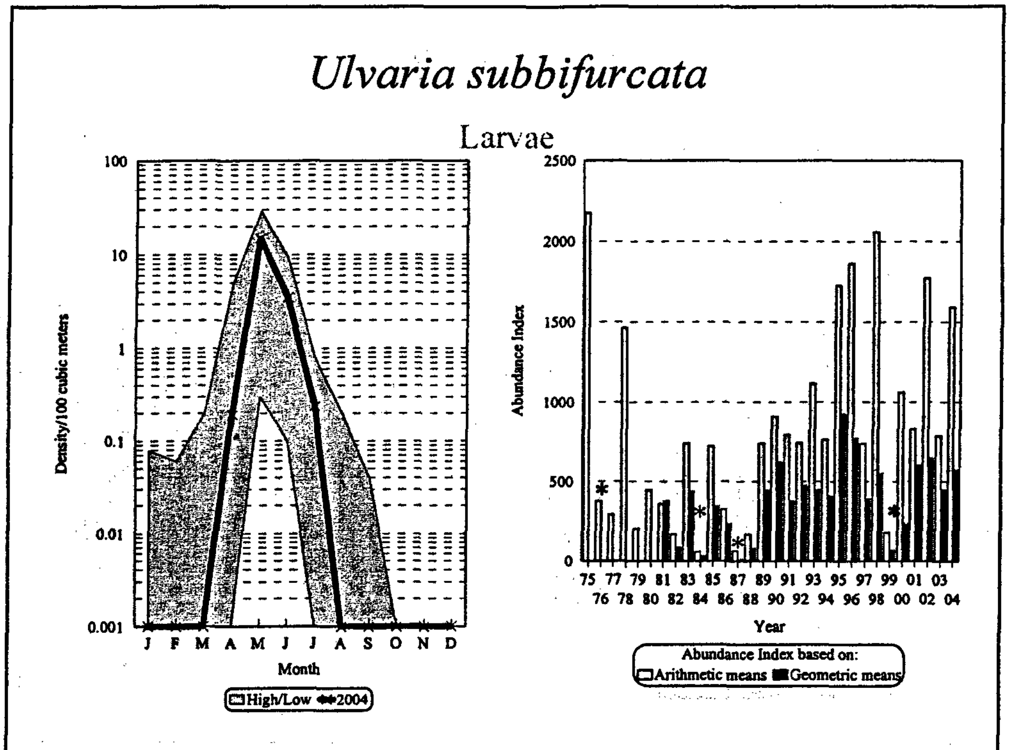


Figure 6 (continued).



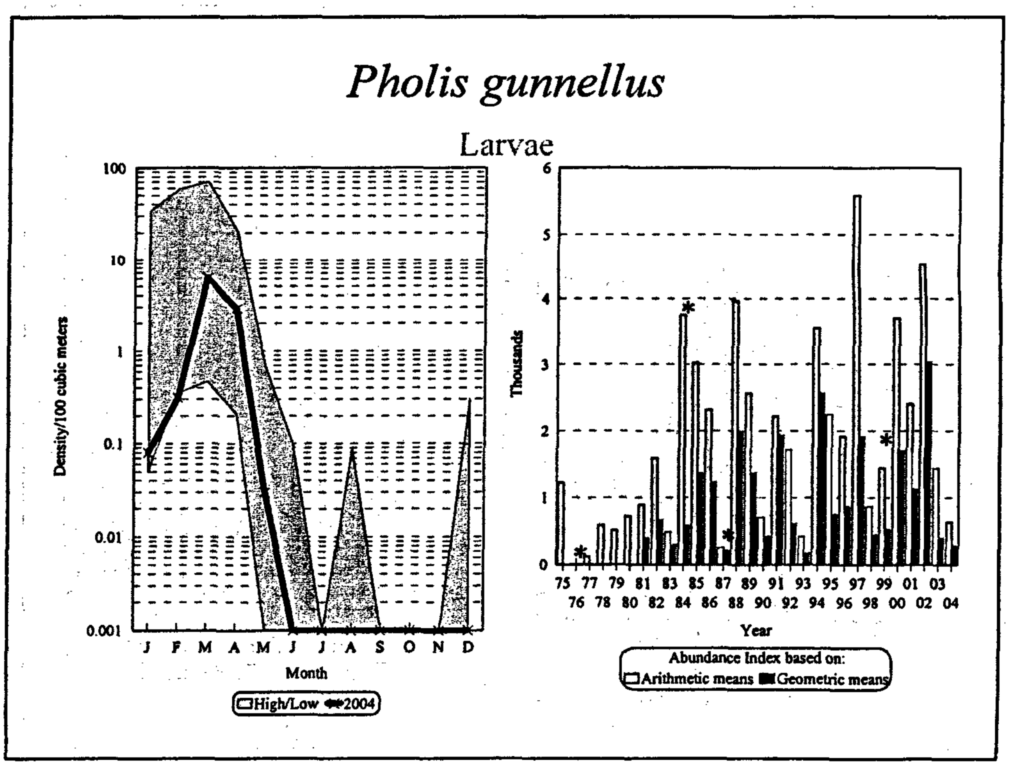
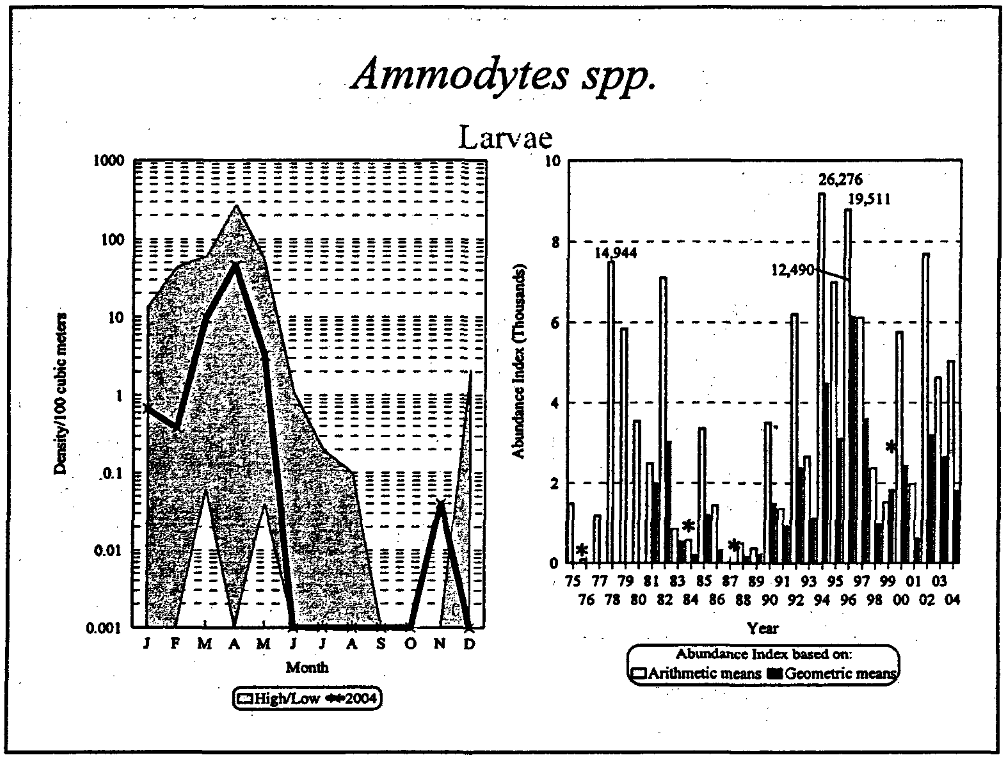


Figure 6 (continued).



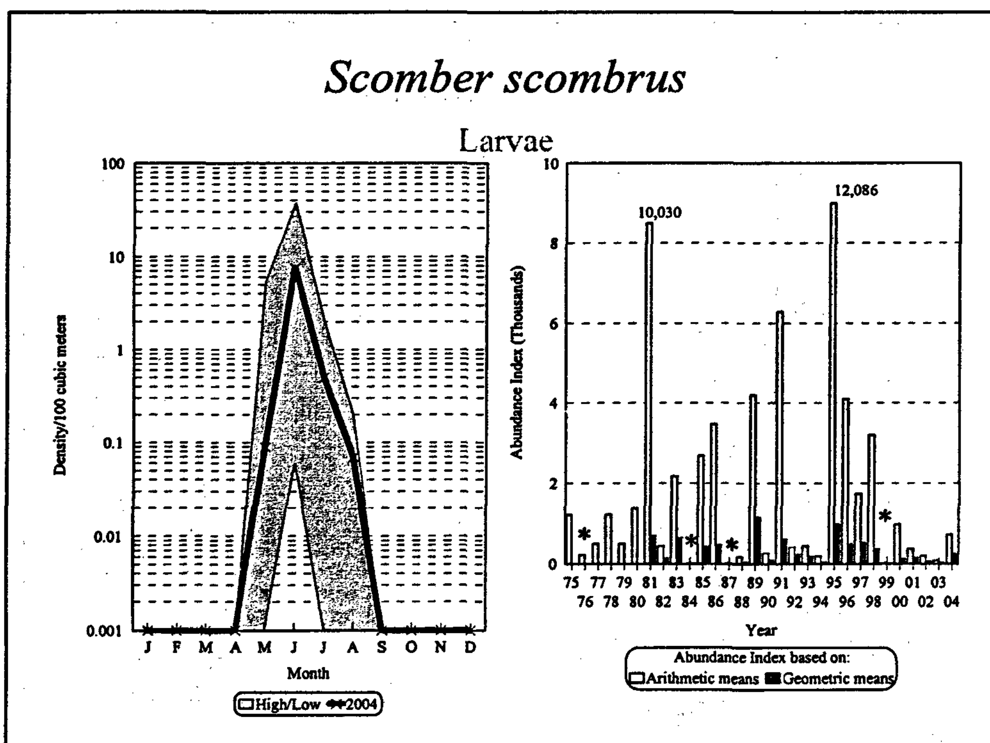
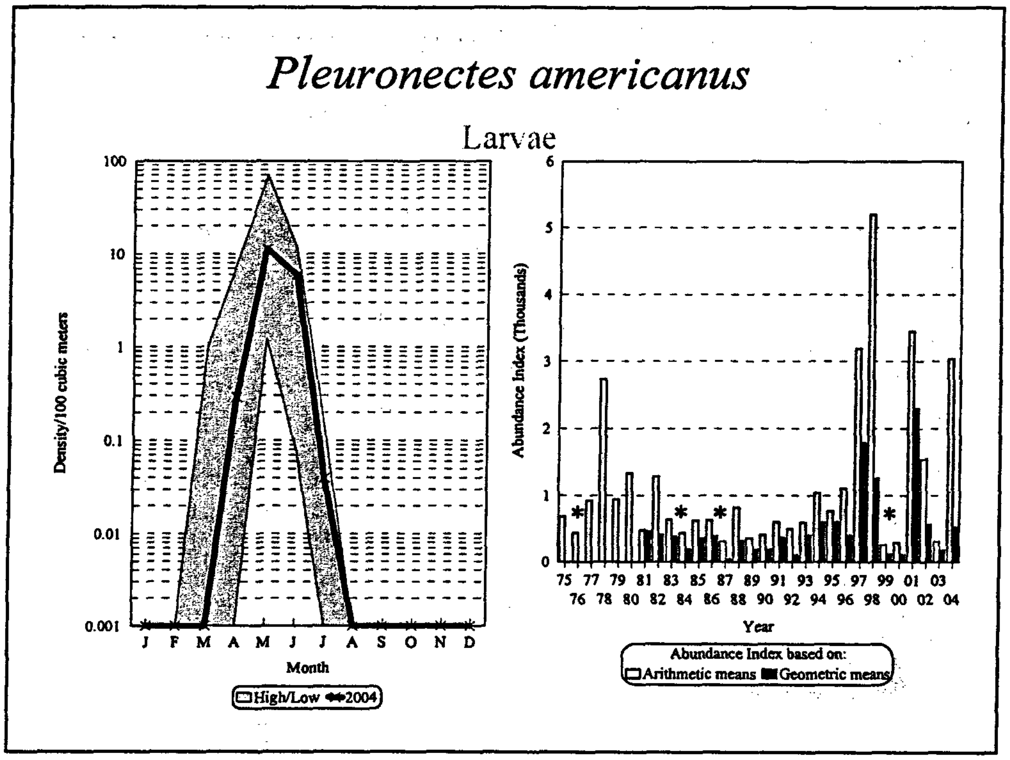


Figure 6 (continued).



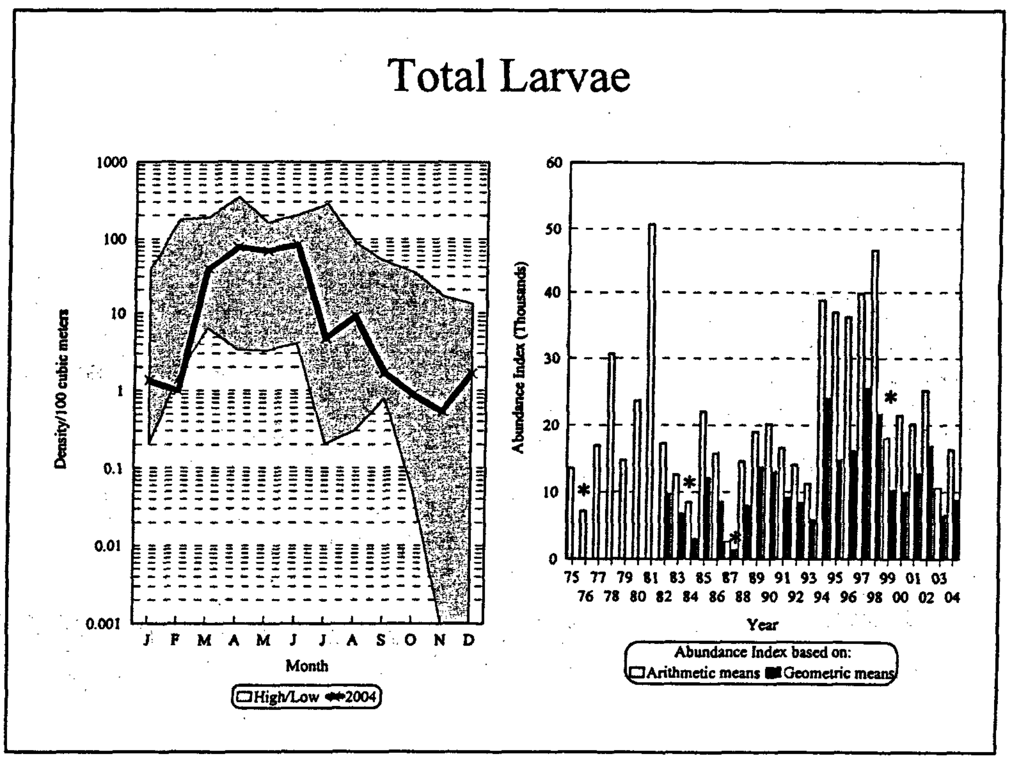


Figure 6 (continued).

Table 2. Species of fish eggs (E) and larvae (L) obtained in ichthyoplankton collections from the Pilgrim Nuclear Power Station discharge canal, January-December 2004.

Species		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2004 Species
American eel	*Anguilla rostrata*													
Atlantic menhaden	*Brevoortia tyrannus*						E/L	L	L	L	E			E/L
Anchovy	*Anchoa spp.*					E	E	E/L	L	L	L			E/L
Atlantic herring	*Clupea harengus*	L		L	L	L	L				L	L	L	L
Rainbow smelt	*Osmerus mordax*													
Cusk	*Brosme brosme*					E			E					E
Fourbeard rockling	*Enchelyopus cimbrius*			E	E	E/L	E/L	E/L	E/L	E	E/L			E/L
Atlantic cod	*Gadus morhua*	E/L	E/L	E/L	E/L	E/L	E/L	E/L				E	E/L	E/L
Pollock	*Pollachius virens*	L			L									L
Haddock	*Melanogrammus aeglefinus*				E/L	E/L	L							E/L
Silver hake	*Merluccius bilinearis*					E	E		E	E	E			E
Atlantic tomcod	*Microgadus tomcod*			L										L
Hake	*Urophycis spp.*					E	E/L	E/L	E/L	E	E			E/L
Goosefish	*Lophius americanus*							E						E
Silversides	*Menidia spp.*						L	L						L
Northern pipefish	*Syngnathus fuscus*						L	L	L	L				L
Searobins	*Prionotus spp.*						E	E	E					E
Grubby	*Myoxocephalus aenaeus*			L	L	L								L
Longhorn sculpin	*M. octodecemspinosus*			L	L									L
Shorthorn sculpin	*M. scorpius*			L	L									L
Alligatorfish	*Asidophoroides monopterygius*													
Seasnail	*Liparis atlanticus*				L	L	L							L
Gulf snailfish	*L. coheni*													
Black sea bass	*Centropristis striata*							L						L
Scup	*Stenotomus chrysops*							L						L
Weakfish	*Cynoscion regalis*							L						L
Wrasses	*Labridae*					E	E	E	E	E	E			E
Tautog	*Tautoga onitis*					E/L	E/L	L	L	L	L			E/L
Cunner	*Tautogolabrus adspersus*						E/L	L	L	L				E/L
Snakeblenny	*Lumpenus lumpretaeformis*													
Radiated shanny	*Ulvaria subbifurcata*				L	L	L	L	L					L
Rock gunnel	*Pholis gunnellus*	L	L	L	L	L								L
Wrymouth	*Crytacanthodes maculatus*			L	L									L
Sand lance	*Ammodytes sp.*	L	L	L	L	L						L		L
Seaboard goby	*Gobiosoma ginsburgi*								L					L
Atlantic mackerel	*Scomber scombrus*					E/L	E/L	L	L	E				E/L
Lumpfish	*Cyclopterus lumpus*													
Butterfish	*Peprilus triacanthus*													
Smallmouth flounder	*Etropus microstomus*							E	E	E				E
Windowpane	*Scophthalmus aquosus*					E/L	E/L	E/L	E/L	E/L	E/L			E/L
Summer flounder	*Paralichthys dentatus*													
Fourspot flounder	*P. oblongus*						E/L	E/L	E/L					E/L
Hogchoker	*Trinectes maculatus*													
Witch Flounder	*Glyptocephalus cynoglossus*				E/L	E	E/L		E					E/L
American plaice	*Hippoglossoides platessoides*				E/L	E/L	E							E/L
Winter flounder	*Pleuronectes americanus*			E	E/L	E/L	L	L	L					E/L
Yellowtail flounder	*P. ferrugineus*				E			L						E/L
Smooth flounder	*P. putnami*											L		L
Number of species		5	3	11	17	20	22	22	19	12	9	4	2	39

Table 3. Ichthyoplankton densities (number per 100 m^3 of water) for each sampling occasion during months when notably high densities were recorded, January - December, 2004. Densities marked by + were unusually high based on values in Table 1. Numbers in the last column indicate percent of all previous values during the month which were lower.

Atlantic Herring Larvae

Month	Day	Density		%
January	2	0		
	7	2.9	+	100
	16	0		
	19	0		
	21	0		
	26	0		
	Previous high:		1.9 (1999)	
	Notice level:		1.0	

Sand Lance Larvae

Month	Day	Density		%
March	1	16.2		
	3	3.4		
	5	3.3		
	8	5.6		
	10	18.4		
	12	26.4		
	15	0.0		
	17	0.8		
	19	9.5		
	22	19.9		
	24	2.2		
	26	42.5		
	29	1.7		
	31	604.1	+	99
	Previous high:		708 (2002)	
	Notice level:		164.0	

Atlantic Herring Larvae

Month	Day	Density		%
April	2	7.3	+	92
	5	1.2		
	7	0.0		
	9	5.8	+	89
	12	9.2	+	95
	14	0.9		
	17	0.0		
	19	4.7	+	85
	21	0.6		
	23	1.3		
	26	2.6		
	28	0.0		
	30	3.3	+	80
	Previous high:		38.3 (1999)	
	Notice level:		3.0	

American Plaice Eggs

Month	Day	Density		%
May	3	12.2		
	5	26.2	+	97
	7	18.0	+	94
	10	7.9		
	12	4.8		
	14	14.3		
	17	13.6		
	19	69.7	+	99
	21	31.4	+	97
	24	0.0		
	26	1.2		
	28	1.3		
	Previous high:		87.2 (2003)	
	Notice level:		15.0	

Winter Flounder Larvae

Month	Day	Density		%
May	3	3.5		
	5	0.6		
	7	0.9		
	10	0.0		
	12	0.5		
	14	18.7		
	17	8.5		
	19	0.6		
	21	0.0		
	24	6.5		
	26	164.8	+	98
	28	289.0	+	99
	31	518.4	+	99
	Previous high:		573.8 (1998)	
	Notice level:		123.0	

Table 3 (continued).

Winter Flounder Larvae

June	2	88.6		
	4	219.9	+	99.5
	7	50.3		
	9	2.1		
	11	12.1		
	14	2.9		
	16	18.2		
	18	9.2		
	21	16.4		
	23	2.7		
	25	17.4		
	28	0.0		
	30	0.7		

Previous high: 814 (1998)
Notice level: 106

Hake Larvae

July	5	4.5	+	91
	7	1.6	+	86
	9	0.0		
	12	0.0		
	14	0.0		
	16	1.0		
	19	0.0		
	21	0.0		
	23	0.0		
	26	0.0		
	28	0.0		

Previous high: 248.4 (1998)
Notice level: 1.0

Tautog Larvae

July	5	1.3		
	7	0.0		
	9	7.6	+	86
	12	0.0		
	14	0.7		
	16	2.0		
	19	0.5		
	21	0.0		
	23	1.6		
	26	0.0		
	28	1.9		

Previous high: 268.6 (1998)
Notice level: 2.0

Tautog Larvae

August	2	0.0		
	4	0.0		
	6	0.0		
	9	3.2	+	85
	11	0.0		
	13	5.3	+	89
	16	5.6	+	89
	18	3.8	+	87.5
	20	3.1	+	85
	23	1.5		
	25	1.2		
	27	0.0		
	30	0.0		

Previous high: 41.5 (1997)
Notice level: 2.2

Cunner Larvae

August	2	11.7		
	4	9.0		
	6	32.5	+	93
	9	14.2		
	11	11.5		
	13	1.8		
	16	4.2		
	18	3.8		
	20	3.1		
	23	1.5		
	25	1.2		
	27	0.0		
	30	0.0		

Previous high: 254.0 (1997)
Notice level: 15.0

Labrid Eggs

September	1	6.8	+	91
	3	0.5		
	6	37.9	+	98
	8	3.2	+	81
	10	1.0		
	13	2.6		
	15	4.3	+	86
	17	3.3	+	81
	22	0.0		
	24	0.0		
	27	0.6		

Previous high: 112.8 (1993)
Notice level: 3.0

Table 3 (continued).

Tautog Larvae

September	1	6.2	+	96
	3	0.0		
	6	1.5		
	8	7.1	+	96
	10	0.0		
	13	0.6		
	15	1.6		
	17	3.3	+	90
	22	0.0		
	24	2.4	+	85
	27	0.0		

Previous high: 19.3 (1996)
Notice level: 2.0

Atlantic Menhaden Eggs

October	4	0.0		
	6	11.6	+	97
	8	0.0		
	18	0.0		
	27	0.0		
	29	0.0		

Previous high: 163.6 (2002)
Notice level: 6.0

Windowpane Eggs

October	4	1.6		
	6	7.0	+	93
	8	4.9	+	88
	18	0.0		
	27	0.0		
	29	0.0		

Previous high: 30.3 (1997)
Notice level: 2.0

Atlantic Herring Larvae

November	3	0.0		
	8	0.0		
	10	0.0		
	12	0.0		
	17	0.7		
	19	1.6		
	22	0.9		
	24	0.0		
	26	9.0	+	76

Previous high: 124.8 (1995)
Notice level: 8.0

Atlantic Herring Larvae

December	3	2.6		
	6	0.0		
	8	11.6	+	90
	10	0.0		
	15	2.2		
	17	10.1	+	89
	20	4.3	+	83
	22	12.0	+	90
	24	0.0		

Previous high: 216.7 (1995)
Notice level: 3.0

Table 4. Species of fish eggs (E) and larvae (L) collected in the PNPS discharge canal, 1975-2004. General periods of occurrence for eggs and larvae combined are shown along the right side; for the dominant species, periods of peak abundance are also shown in parentheses.

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Anguilla rostrata	J[1]	J	J		J	J								J	
Alosa spp.		L	L	J	L						L				
Brevoortia tyrannus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L
Clupeas harengus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Anchoa spp.	L		L	L	L		L	L	L	L	L	L	L	L	L
A. mitchilli			E	E	E		E	E/L			E	E			E
Osmerus mordax	L	L	L	L	L		E/L	L	L		L	L	L	L	E/L
Brosme brosme	E/L	E/L	E/L		E/L	E/L	E	E	E						
Enchelyopus cimbrius	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Gadus morhua	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Melanogrammus aeglefinus	L	E/L	E/L	E/L	L				L		E			E	
Merluccius bilinearis	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Microgadus tomcod			L	L		L	L	L	L	L	L	L	L	L	L
Pollachius virens	E/L	E/L	E	E/L	E/L	E/L	L			L	E/L	L	E/L	L	L
Urophycis spp.	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L
Ophidion marginatum	L														
Lophius americanus	E/L	E	E/L	E/L	E/L	L	E/L	E/L	E/L	E/L	E/L	E	E	E	E/L
Strongylura marina			L												
Fundulus spp.		E	E												
F. heteroclitus					E										
F. majalis					J										
Menidia spp.		L	L	L	L	E/L	E/L	E	E/L	L	L	L	L	L	L
M. menidia	E/L	E/L	E						L						
Syngnathus fuscus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Sebastes norvegicus															L
Prionotus spp.	E/L	E		E	E	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L	E
Hemitripterus americanus															
Myoxocephalus spp.	L	L	L	L	L	L	L	L	E/L	L	E/L	L	L	L	E/L
M. aenaeus					L	L	L	L	L	L	L	L	L	L	L
M. octodecemspinosus						L	L	L	L	L	L	L	L	L	E/L
M. scorpius						L	L	L		L	L	L	L	L	L
Aspidophoroides monopterygius					L	L	L								L
Cyclopterus lumpus		L	L				L	L	E		L		L	L	L
Liparis spp.	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
L. atlanticus							L	L	L	L	L	L	L	L	L

Table 4 (continued).

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
L. coheni							L	L	L	L	L	L	L	L	L
Centropristis striata	L					L			L	L	L	L	L	L	L
Cynoscion regalis						L					L	L			
Stenotomus chrysops	L		L											L	E
Menticirrhus saxatilis	L				L										
Labridae	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Tautoga onitis	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Tautogolabrus adspersus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Lumpenus lumpretaeformis	L						L			L	L	L		L	L
Ulvaria subbifurcata	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Pholis gunnellus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Cryptacanthodes maculatus				L	L		L	L	L	L	L	L			L
Ammodytes sp.	L	L	L	L	E/L	L	L	L	L	L	L	L	L	L	L
Gobiosoma ginsburgi	L		L					L						L	
Scomber scombrus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Peprilus triacanthus	E/L	E/L	E/L	E	E	E/L	E/L	L	E/L	E/L	L		E	E/L	E/L
Etropus microstomus	L								L		E	E/L	E		E
Paralichthys dentatus	E/L								E/L		L		E/L	E	
P. oblongus[3]		E/L	E/L		E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Scophthalmus aquosus[3]	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Glyptocephalus cynoglossus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L
Hippoglossoides platessoides	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
Pleuronectes americanus	E/L	E/L	L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L
P. ferrugineus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L
P. putnami							L	E/L							
Trinectes maculatus			E	E			E	E				E		E	E/L
Sphoeroides maculatus			L								L				
Number of Species[4]	**41**	**36**	**43**	**35**	**37**	**35**	**40**	**38**	**37**	**34**	**42**	**37**	**36**	**41**	**40**

[1]J = juvenile.

[2]Absent August and September; peaks = March-May and November-December.

[3]Although these eggs were not identified specifically, they were assumed to have occurred as shown based on the occurrence of larvae.

[4]For comparative purposes three species of Myoxocephalus were assumed for 1975-1978 and two species of Liparis for 1975-1980.

Table 4 (continued).

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Period of Occurrence
Anguilla rostrata	J				J	J	J	J	J		L	L	L	L		Feb - Sep
Conger oceanicus												L				Jul
Alosa spp.	J						L									May - Jul
Brevoortia tyrannus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (Oct)Dec
Clupeas harengus	L	L	L	L	L	L	L	L	L	L	L	E/L	L	L	L	Jan - Dec2
Anchoa spp.	L	L	L	L	L	L	L	L	L	L			E/L	E	E/L	Jun - Sep
A. mitchilli	E	E	E	E			L		E	E/L	E/L					Jun - Sep
Osmerus mordax			L	L	L	L		L	L	E/L	L	E	L	L		Mar-Jul
Brosme brosme											E/L				E	Apr - Jul
Enchelyopus cimbrius	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (Sep)Dec
Gadus morhua	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Nov) - (Dec)Dec
Melanogrammus aeglefinus	E					E	E		L	E/L	E/L	E/L	E	E/L	E/L	Mar - Jul
Merluccius bilinearis	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	May(May) - (Jun)Nov
Microgadus tomcod	L		L	L	L	L	L	L	L	L	L	L	L	L	L	Jan - Jun
Pollachius virens	L	L	E/L	L	L			E			L		E		L	Jan-Jun,Nov,Dec
Urophycis spp.	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Aug) - (Sep)Nov
Ophidion marginatum						L		L	L	L	L					Aug - Sep
Lophius americanus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E	May - Oct
Strongylura marina																Jul
Fundulus spp.																Jul
F. heteroclitus																Jun
F. majalis			E													Oct
Menidia spp.	L	L	L	L	L	L	L		L	L	E/L	L	E/L	L	L	May - Sep
M. menidia		E		E							E/L					May - Sep
Syngnathus fuscus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Apr - Nov
Sebastes norvegicus												L				Jun
Prionotus spp.	E	E	E	E/L	E	E	E	E/L	E/L	E/L	E/L	E	E/L	E/L	E	May(Jun) - (Aug)Sep
Hemitripterus americanus					L	L			L							Feb - Mar
Myoxocephalus spp.	L	E/L	L	L	L	L	L	L	L	L						Dec(Mar) - (Apr)Jul
M. aenaeus	L	E/L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (Apr)Jul
M. octodecemspinosus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (Apr)May
M. scorpius	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Feb - Apr
Aspidophoroides monopterygius														L		Mar - Apr
Cyclopterus lumpus	E/L		E/L	L	L	L	L				L			L		Apr - Jul
Liparis spp.	L	L	L	L	L	L	L	L	L	L	L					Jan(Apr) - (Jun)Jul
L. atlanticus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Mar(Apr) - (Jun)Jul
Number of Species[4]	**27**	**22**	**25**	**26**	**24**	**26**	**23**	**24**	**27**	**25**	**28**	**23**	**24**	**25**	**22**	

Table 4 (continued).

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Period of Occurrence
L. coheni	L	L	L	L	L			L	L	L	L	L	L	L		Jan(Feb) - (Mar)Apr
Centropristis striata	L			L		L		L	L	L	L	L	L	L	L	Jul - Oct
Cynoscion regalis													L	E/L	L	May - Sep
Stenotomus chrysops	L	L	L	L		L		L	L	E/L	E/L	L	L	E/L	L	Jun - Oct(Sep)
Menticirrhus saxatilis																Jul - Aug
Labridae	E	E	E	E	E	E	E	E	E	E/L	E	E/L	E	E	E	Mar(May) - (Aug)Nov
Tautoga onitis	L	L	L	L	L	L	L	L	L	L	E/L	E/L	L	E/L	E/L	May(Jun) - (Aug)Oct
Tautogolabrus adspersus	L	L	L	L	L	L	L	L	L	L	E/L	E/L	L	E/L	E/L	May(Jun) - (Aug)Oct
Lumpenus lumpretaeformis	L				L		L			L			L			Jan - Jun
Ulvaria subbifurcata	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Feb(Apr) - (Jun)Oct
Pholis gunnellus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Feb) - (Apr)Jul
Cryptacanthodes maculatus	L	L	L	L	L	L	L	L	L				L	L	L	Feb - Apr
Ammodytes sp.	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (May)Dec
Gobiosoma ginsburgi					L	L				L	L	L	L	L	L	Jul - Sep
Scomber scombrus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(May) - (Jul)Sep
Peprilus triacanthus	L	E/L		L	L	E/L	L	L	E/L	L	E/L			E/L		May - Oct
Etropus microstomus		E	E	E		E/L	E/L	E/L	E/L	E/L			E/L		E	Jul - Oct
Paralichthys dentatus	L			E/L	E	E/L	L		L		L	E/L	E	E/L		May - Nov
P. oblongus[3]	E/L	E/L	E\L	E\L	E/L	E/L	E/L	E/L	E/L	L	E/L	E/L	L	E/L	E/L	May - Oct
Scophthalmus aquosus[3]	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(May) - (Sep)Oct
Glyptocephalus cynoglossus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L			E/L	E	E/L	E/L	Mar(May) - (Jun)Nov
Hippoglossoides platessoides	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Mar) - (Jun)Nov
Pleuronectes americanus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Apr) - (Jun)Sep
P. ferrugineus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Feb(Apr) - (May)Nov
P. putnami						L									L	Mar - Jun
Trinectes maculatus	E/L	E								E/L			E	E/L		May - Sep
Sphoeroides maculatus											L					Jul - Aug
Number of Species[4]	**42**	**34**	**36**	**38**	**39**	**42**	**37**	**37**	**40**	**38**	**41**	**37**	**42**	**43**	**39**	

D. Ichthyoplankton Entrainment - Specific

Estimated numbers of eggs and larvae entrained annually at PNPS were examined in some detail for six species of fish using the equivalent adult (EA) procedure (see Horst 1976, Goodyear 1978, Saila et al 1997, for example). Numbers potentially lost to impingement were also considered. This review dates back to 1980 so that, with the addition of 2004, 25 years of analyses are included. The adult equivalent methodology applies estimated survival rates to numbers of eggs and larvae lost to entrainment and numbers of fish lost to impingement to obtain a number of adult fish which might have entered the local population had entrainment not occurred. The consequences, if any, of the loss can then be considered if the size of the extant population is known or numbers can be compared with commercial or recreational landings.

Many assumptions are associated with the EA procedure. The fish population is assumed to be in equilibrium, therefore in her lifetime each female will replace herself plus one male. It is assumed that no eggs or larvae survive entrainment. In assessing potential losses the assumption is also made that no density-dependent compensation occurs among non-entrained individuals, i.e. the approach assumes that non-entrained individuals do not benefit from reduced competition as a direct result of lower densities. The later two assumptions result in an overestimation of plant impacts. Survival has been demonstrated for some species of fish eggs at PNPS such as the labrids (45%; MRI 1978a) and winter flounder (73%, n = 11; MRI 1982) and among larvae at other power plants (0-100% initial survival depending on species and size; Ecological Analysts 1981). More recently LMS (2001) used induced-flow larval sampling tables to assess initial and latent survival among entrained winter flounder and other species. They determined that larval flounder mortality was high and statistically similar in both intake and discharge samples. In spite of high natural mortality they reported that survival increased with increasing larval length and decreasing through-plant temperature change.

Numbers of eggs and larvae entrained were determined using the full-load-flow capacity of Pilgrim Station. This value was used even if the station was out of service and less than full capacity was being circulated. In those cases the adult equivalents are overestimated further. Assuming full-load flow for each year was a particular exaggeration for 1984 and 1987 because both circulating seawater pumps were shut down from April through August yet sampling continued using the salt service water system. Estimated numbers entrained for species present during those months often appear low for those two years because there is some indication that estimates of ichthyoplankton entrainment is disproportionately low when only the salt service water pumps were in operation (MRI 1994). Using estimates obtained with only salt service water pumps operating to predict what entrainment would have been with the plant operating at capacity would probably be heavily biased on the low side. During an outage in 1999 extending from May 9 to June 11 sampling also occurred only with salt service water pumps running so a similar, but less extensive, bias resulted.

Since plankton densities are notorious for deviating from a normal distribution but do generally follow the lognormal, geometric mean densities more accurately reflect the true population mean. The geometric mean is always less than the arithmetic mean particularly for data which are skewed to the right such as plankton densities (see Figures 5 and 6). In calculating total entrainment values for the adult equivalent methodology we chose to use the larger arithmetic mean for all sampling dates preceding April 1994 when three replicate samples were taken per sampling occasion to lend additional conservatism to the assessments. Beginning with April 1994 each individual sample density was utilized so that no averaging was necessary.

In summary, four opportunities were chosen to overestimate the impact of PNPS

- All eggs and larvae were assumed killed by plant passage regardless of thermal load.
- No density-dependent survival compensation was assumed to occur.
- PNPS was assumed to operate at full-flow capacity year round.
- Mean entrainment densities were overestimated by the arithmetic mean for sampling dates when three replicates were taken.

The six species selected for review were winter flounder, cunner, Atlantic mackerel, Atlantic menhaden, Atlantic herring, and Atlantic cod. Flounder were chosen because of their commercial and recreational value as well as their importance in PNPS ecology studies. Cunner were selected because they are abundant in entrainment samples and in the local nearshore area potentially subject to thermal effects. Mackerel and menhaden were included because they are abundant among the ichthyoplankton entrained, both eggs and larvae being removed from the local population, and they are commercially and recreationally valuable. Atlantic herring and cod are not entrained in great numbers but they are valuable species in New England waters.

Winter Flounder

In 2004 an estimated total of 246,468 eggs and 62,178,004 winter flounder larvae were entrained by PNPS (Table 5). The number of larvae ranked second among the 25 totals recorded over the 1980 - 2004 time series ahead of all past years except 1998. The high ranking in 2004 resulted from high densities over a brief period at the end of May and the beginning of June. The brief period of high abundance is reflected in the annual indices discussed above. Based on monthly mean densities, 2004 ranked 4th and 7th, respectively. The average number entrained from 1980-2003 excluding 1984, 1987, and 1999 when the main pumps were out of service for a month or more during the egg and larval flounder season amounted to 4,599,422 eggs and 22,493,023 larvae (s.e. = 4,412,756). Values ranged from 28,600 in 2002 to 32,717,500 in 1985 for eggs and 5,595,000 in 2000 to 86,850,000 in 1998 for larvae.

The relatively high number entrained in 2004 was consistent with recent trends in the northern winter flounder stock (see USGen New England, Inc. 2004, for example) and the cold winter that likely promoted production of a strong year class (NUSCO 1988, Buckley et al. 1990, Keller et al. 1999, Keller and Klein-MacPhee 2000). The 1997 and 1998 year classes appeared to be large ones also based on the PNPS ichthyoplankton results, and subsequent area-swept surveys completed in 2000 and 2001 suggested that increased numbers of reproductive age fish resulted (see Section III, this volume). These fish would have entered the reproductive age pool in 2000 and would have fully recruited to the adult stock by 2002. While the area-swept estimates dropped in 2003 and again in 2004, these fish would have been six and seven years old in 2004 and highly fecund.

The annual larval entrainment estimates were converted to equivalent numbers of age 3 adults, the age at which flounder become sexually mature (Witherell and Burnett 1993, NOAA 1995). Numbers of eggs collected from 1980 - 1994 when 0.333-mm mesh was used on all sampling occasions were scaled upward by 1.24 to correct for mesh extrusion. While no direct mesh extrusion information is available for winter flounder eggs in the PNPS discharge stream, the value for similar sized cunner eggs was used. Numbers of stage 1 and 2 larvae collected prior to 1995 were likewise scaled upward by 1.62 to adjust for mesh extrusion (MRI 1995). Three sets of survival values were used. The first set followed NEP (1978) using data from Pearcy (1962) and Saila (1976). Briefly, this consisted of dividing the total number of entrained larvae by 0.09 to estimate the number of eggs which hatched to produce that number of larvae. NEP (1978) did not specifically account for entrained winter flounder eggs. While they are demersal and adhesive, numbers of them are entrained each year. A survival rate of 0.058 for entrained winter flounder eggs was assumed based on Rose et al (1996) and assuming that the entrained eggs were 15 days from hatching. The number of newly hatched eggs derived from the number of eggs entrained was then added to the number of hatched eggs derived from the larvae entrained. The combined number of eggs was then multiplied in succession by 0.004536, an estimate of survival from a newly hatched egg to day 26; 0.2995, survival from day 27 to metamorphosis; 0.03546, survival of juveniles from 3 to 12 months; 0.3491, survival from 13 to 24 months; and finally 0.33, survival from 24 to 36 months.

The second approach followed larval stage-specific survival rates (S) derived from Niantic River data (Crecco and Howell 1990) as modified by Gibson (1993). These are as follows:

S (stage 1) = 2.36E-01
S (stage 2) = 1.08E-01
S (stage 3) = 0.154
S (stage 4) = 0.623
S (age 0) = 0.0730
S (age 1) = 0.250
S (age 2) = 0.477

A survival rate of 0.058 was assumed for winter flounder eggs as indicated for the unstaged approach. In using the stage-specific rates it is recognized that NUSCO employs different morphological stage criteria than those used at PNPS (NUSCO 2001). However a comparison of samples from both studies showed stages to be quite comparable until larvae approach metamorphosis, a size not often collected because these individuals begin to assume a benthic life style.

The third set of survival values obtained from PG&E (2001) was as follows:

Eggs = 0.75
S (stage 1) = 0.1286
S (stage 2) = 0.0328
S (stage 3) = 0.0296
S (stage 4) = 0.8377
S (age 0) = 0.0927
S (age 1) = 0.3291
S (age 2) = 0.3654

Numbers of age 3 fish were converted to weight based on 0.49 pounds per fish. This was derived from the length-weight equation presented in NEFSC (1998) using mean length at age 3 for males (262 mm TL) and females (267 mm TL). Mean length at age was obtained using the gender specific, north of Cape Cod growth equations provided by Witherell and Burnett (1993). These relationships gave mean weights of 0.47 and 0.50 pounds for males and females, respectively; these were averaged.

The general, unstaged larval survival values produced an adult equivalent value of 3,834 age 3 fish for 2004. The stage-specific values produced EA totals that were higher at 53,153 and 32,373 age 3 individuals, respectively. Based on a weight of 0.485 pounds per fish, these values convert to 1,859, 24,663, and 15,701 pounds, respectively and average 14,074 pounds. Comparable values for 1980 - 2003 ranged from 262 to 5,356 fish (mean = 1,388 fish, 680 pounds) for the general approach, 2,632 to 77,394 (mean = 14,663 fish and, 7,112 pounds) for the Niantic staged approach and 1,040 to 62,171 (mean = 8,956 fish, 4,343 pounds) for the USGen staged approach (Figure 7, Table 5).

EA totals for 1984, 1987, and 1999 based on full load flow were omitted from the estimated means because both circulating seawater pumps were off for much of the larval winter flounder seasons during maintenance outages. As mentioned above there is strong evidence indicating that estimates of ichthyoplankton entrainment are disproportionately low when the salt service water pumps are on but the circulating seawater pumps are not. Based on that, entrainment sampling was not conducted during the portion of the 2001 and 2003 outage periods in which both main seawater pumps were shut down. Based on actual flow rates entrainment was understandably low during those three years with staged EA values ranging from 53 to 447 and 12 to 141, pounds respectively and unstaged values ranging from 10 to 107 pounds.

The differences between unstaged and staged EA totals clearly show how relatively small variations in survival values when applied to large numbers of larvae can result in relatively large variations in adult numbers (see Vaughan and Saila 1976 for example). The USGen survival rates were greater for eggs and stage 4 larvae than the Niantic based rates therefore years when eggs and or stage 4 larvae were prevalent reflected higher EA values.

In addition to entrainment losses small numbers of winter flounder were impinged on the intake screens each year (Table 6, see also the impingement section). Annual totals ranged from 42 in 1984 to 2,301 in 2001 and averaged 838 fish over the time series. The 2004 estimated total was above average at 1,647. Based on mean length data most impinged fish each year were young-of-the-year. Assuming all fish would have completed their first year and applying the average age 1 and age 2 survival rates from the entrainment EA procedures, these totals would be equivalent to an annual average of 99 age 3 adults (range = 5 to 276) weighing 48 pounds (range = 2 to 134 pounds). Although winter flounder typically survive impingement quite well, particularly under continuous screen wash operation (see for example MRI 1982, 1984, 1997), no further adjustment was made to the equivalent adults resulting from impingement.

Over the 1982 through 2003 period an annual average of 1,136,454 pounds (s.e. = 248,639 pounds) of flounder were landed commercially from NOAA statistical area 514 which covers Cape Cod Bay and Massachusetts Bay. Based on a weight of 0.485 pounds per fish, the average estimated loss of 4,091 pounds of equivalent adults due to PNPS entrainment and impingement over a similar time frame based on the three sets of survival calculations (720, 7,161, 4,392, Table 5,6) represents 0.4% of those landings. Area 514 commercial landings declined sharply after 1993 from 1,057,211 pounds that year to 16,788 pounds in 1995, 1,798 pounds in 1997, and only 221 pounds in 1999. Catch rebounded in 2000 to 40,000 pounds but dropped again each of the next three years to 4,742 pounds in 2003. The precipitous drop from 1993 to 1999 is attributable to increased fishing restrictions and stock declines. EA values for 1994 through 1998 and 2001 alone appear quite high compared to the reduced commercial landings and in fact the lower unstaged values for both 1997 and 1998 exceeded the commercial landings for those two years indicating that commercial landings are no longer a realistic measure of the scale of equivalent adult values for heavily fished and regulated stocks.

Winter flounder also have considerable value as a recreational species. Based on NOAA records[1] an annual average of 783,062 fish (s.e. = 246,525) weighing an average of about 0.9 pound each were landed from Massachusetts inland waters and within 3 miles of shore over the 1981-2003 period. Over the course of the past decade or so (1990-2003) recreational landings were well below 1980's levels because of stock declines and catch limits consistent with commercial landings; an annual average of 113,882 fish (s.e. = 10,433) were reported landed in the state from inland waters and within 3 miles of shore since 1993. These fish were also apparently smaller, weighing an average of 0.6 pounds each. Unfortunately recreational landings are compiled by state within distance from shore areas (inland, <3 miles from shore, > 3 miles from shore) and the number of fish taken from a more appropriate area such as Cape Cod Bay are not available. Arbitrarily adding 20,000 pounds of recreationally-caught flounder to the depressed 1994-2003 Area 514 commercial landings would bring the respective totals for those ten years to an average of 63,440 pounds (s.e. = 31,970). The average PNPS EA entrainment and impingement values based on the three parameter sets for the same years (6,434) would amount to 10%. Clearly the decline in commercial landings after 1994 considered along with the stick abundance data suggest that those values even when combined with the recreational landings are no longer a realistic measure of PNPS EA losses.

Massachusetts Division of Marine Fisheries (DMF) personnel made estimates of the number of adult winter flounder (>280 mm TL - age 3+) in a 106 square mile area in the vicinity of PNPS using area swept by a commercial trawl each year from 1997-1999 (Lawton et al. 2000). In 1997 and 1998 they also completed estimates of stock size using several mark and recapture models. Marine Research, Inc. completed comparable surveys from 2000 through 2004 (see section 3.1 of this volume). While reliable estimates of local population size are difficult to make, they can provide more realistic numbers with which to compare EA values relative to commercial and recreational landings which are difficult if not impossible to pinpoint

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[1] Recreational landings data were obtained via the internet at http://remora.ssp.nmfs.gov/mrfss.

to the actual impact area. Landings data typically represent numbers caught over a very large area or as displayed by the most recent commercial landings can be subject to catch restrictions or changes in fishing effort which make them less useful.

The MRI area swept estimate for 2004 equaled 157,532 adults based on gear efficiency of 50% with confidence limits ranging from 154,555 to 160,509 fish. Over the past three years estimates averaged 298,800. The relatively high estimates over the previous three years are consistent with the large numbers of larval flounder entrained in 1997, 1998, and 2004. Members of the 1997-1998 year classes would have reached ages 6 and 7, respectively in 2004. Natural and fishing mortality would be expected to reduce their numbers over time consistent with the drop observed in 2003 and 2004. Comparing the age 3 equivalent adults estimated for 1997 through 2001 with the corresponding area-swept estimates provided the following percentages:

Equivalent Age 3 Adults (Number of Fish) Entrainment and Impingement		Area-Swept Estimate 3 Years Hence	Percent Of Area-Swept Estimate
1997	27,398	464,176	5.9
1998	48,483	400,812	12.1
1999	1,615	476,263	0.3
2000	2,275	262,604	0.9
2001	16,883	157,532	10.7
Note that equivalent adult totals shown are averages of the three sets of survival rates.			

The current 2004 estimated equivalent adult loss of 29,214 fish based on the three sets of survival rates amounted to 9.8% of the average area-swept estimate for the previous three years.

RAMAS Winter Flounder Model

The computer software program entitled RAMAS (Risk Analysis Management Alternative System; Ferson 1993) was used from 1999 - 2001 to further assess the possible effects of PNPS on the western Cape Cod Bay winter flounder population (MRI 2000, NAI 2001, MRI 2002). A stage-structured model was developed using an empirically derived Ricker stock-recruitment (s-r) function for winter flounder. Each model run included 50 time steps and 500 to 750 replications. Results obtained with the RAMAS\Stage model, suggested stock reductions from 2.3 to 5.2% might occur as the direct result of entrainment at PNPS. The model based on mean numbers entrained suggested population reductions of 4.3 or 4.5% depending upon the size of the existing adult population. To simulate one possible future with biannual outage periods during the winter flounder larval period suggested modest population reductions of 2.1 to 3.4% might be expected.

During 2002 RAMAS Metapop (version 4.0, Akcakaya 2002) was used to explore possible consequences of entrainment. Like RAMAS Stage, Metapop utilizes matrix algebra to simulate changes in population size but, in addition to being MS- Windows based, it is a more versatile program. A model was established to represent a winter flounder population near its carrying capacity. Carrying capacity for adults (K) was defined by the relationship K = 12387.9366A^0.9440498 where A represents habitat area in square kilometers (ASFMC 1992, LMS 2001). Using the area of western Cape Cod Bay from the winter flounder area-swept study (267.4 km^2; see this volume, Section 3.1) a carrying capacity of 1,463,000 adult flounder would be expected from the bottom area relationship. Since Metapop was modeled with females only and an even sex ratio was assumed the expected virgin population size was 730,300 adult females.

Initial simulations were performed with an unfished population. Entrainment was accounted for using the dispersal feature in Metapop. Three identical populations were simulated, numbers of larvae entrained were "grown" to age 0 using stage-specific mortality rates and these individuals emigrated from population 1 to population 2. Emigration in the reverse direction was set to zero. Population 3 did not experience emigration or immigration and so represented a virgin stock. Numbers of age 0 fish and numbers of adults (age 3+) were compared between population 1 and 3 to measure the effects of entrainment.

The dispersal rate corresponding to numbers removed from the population as a result of entrainment at PNPS was calculated using the stage-specific survival rates. Each year from 1980 through 2002 numbers of winter flounder eggs and larvae entrained were equated to age 0 juveniles consistent with the first time step in Ramas. The average of these values (48,862 females) along with the observed coefficient of variation (0.26) amounted to 1.9% of the number of age 0 female fish in the model population (2.622 million). This was the dispersal value. Density dependence was included in the model using the Beverton and Holt (1957) function. The modeled virgin population responded to the withdrawal of 1.9% of its age 0 individuals with a compensatory increase in vital rates consistent with density dependence. As a result the increase in fecundity and survival produced somewhat more adult fish than the population with no entrainment loss since plant losses affected only age 0 individuals. Multiple model runs with intrinsic rates of increase ranging from 1.0 to 1.6 indicated that a notable decrease in adult stock would not begin as a result of entrainment unless the intrinsic rate of increase was 1.20 or less. Results suggested that with even small intrinsic rates of increase a winter flounder population can readily compensate for entrainment losses on early life history stages of 2% or more in the absence of fishing.

Model runs completed with varying dispersal rates indicated that a population with density-dependent survival and reproductive rates along with intrinsic rates of increase equal to 1.57 can thrive with the removal of most of its age 0 individuals. The adult population does not begin to decline in the absence of fishing until entrainment reaches 0.9. Without density dependence the population steadily declines since there is no biological mechanism to compensate for losses to entrainment or fishing. With density dependence, as the number removed increases, survival and fecundity of the remaining individuals increase to offset the loss.

Model runs were next completed with various levels of fishing effort. A four-population model was used to simultaneously compare a population with dispersal or entrainment maintained at 1.9% (coefficient of variation = 0.26), a population with fishing, a population with entrainment and fishing, and a virgin population. To determine the level of fishing mortality necessary to reduce the virgin population to around 240,000 adult females, consistent with area swept estimates of the local adult population (see Section 3.1). Runs were made with fishing mortality between 10 and 45% (instantaneous fishing mortality F = 0.11 to 0.58). Under fishing pressure alone an annual harvest rate of 0.43 (F = 0.56) reduced the average number of adults at the end of the simulation to 244,100. With fishing mortality and entrainment the average number of adults at the end of the simulation was 241,700 consistent with the most recent area swept estimate and 1% below the adult population size without entrainment. These runs suggested that the intrinsic rate of increase and fishing mortality have a much more dramatic influence on population size since both act upon all adult age classes while entrainment acts upon only the first month or two of early life.

Ramas metapop was used in 2003 to further explore potential effects of PNPS on local winter flounder. The ability of Ramas to incorporate trends in vital rates was used to examine more closely the role of fishing mortality. Since Ramas cannot incorporate both trends in vital rates and density dependence in the form of Ricker or Beverton and Holt relationships, a simpler "ceiling" density dependence function was used with a carrying capacity of 3,000,000 total female fish. The model population could therefore grow to a maximum of 370,000 adult females. While that was lower than the area-based carrying capacity defined above, population size was consistent with the area-swept estimates obtained by bottom trawl (see Section 3.1). These rates provided an annual growth rate of 1.25, less than the maximum rate of 1.57 (Rmax) but consistent with a heavily fished stock. A heavily fished stock should have relatively high natural survival rates because of reduced competition but since the population is not at extremely low levels growth at the maximum rate would not be expected.

Gulf of Maine fishing mortality rates from 1982 to 2002 were incorporated with and without entrainment losses. Fishing mortality rates were available for 1982-2002 (NFSC 2003). The simulation began with 1976 and ran for 30 years, a reasonable length of time for a power station. During the first five years no fishing or entrainment mortality was applied so the population remained around 367,000 adult females. Incorporating actual fishing mortality beginning with 1982 resulted in a decline in the population particularly since fishing pressure increased rapidly in the mid 1980's and early 1990's.

Entrainment losses were also incorporated based on information obtained from the 2000 and 2002 larval flux studies. Based on the average proportion of winter flounder larvae passing by PNPS that were estimated to be entrained (0.004925, ENSR and MRI 2001, 2003) age 0 survival was reduced by a conservative1% each year or approximately twice the estimated value. The 1% rate change also overstated entrainment because it was applied to age 0 fish when in fact entrainment only influences flounder during the first three months of their first year (small rates of impingement not withstanding). Entrainment reduced the number of adult females by from less than 1% to 3% depending on the prevailing fishing mortality rate. The greater the losses to fishing the greater the reduction in population size due to entrainment because winter flounder or any fish population has a diminishing ability to compensate for losses to both adults and larvae.

The 2003 and 2004 area swept estimates suggest that the number of adult winter flounder in the survey area has declined recently consistent with stock assessment estimates for the Gulf of Maine (Paul Nitschke, personal communication). The larval flux study completed in 2004 suggested that the proportion of winter flounder drifting based PNPS that was entrained in 2004 was consistent with estimates made in 2000 and 2002 i.e, less than 1%. The most recent stock assessment data indicates that fishing mortality rates are far below peak estimates observed in the 1990's. That raises the question of why the local adult stock appears to be declining at least short term.

There are a great number of variables operating on the winter flounder stock and it is not possible to pinpoint a single parameter or even a subset of variables to explain the lack of correspondence between the trawl data and the estimates of entrainment and fishing mortality. Those variables having the largest potential affect would be underestimated fishing mortality (F) and under estimated area-swept trawl efficiency because they influence all age classes. As indicated in Figure 8 using the Ramas model larval entrainment rates as high as 20 and 30%, equivalent to more than 20 or 30 times the rate suggested by the empirical data have little affect on adult stocks when fishing mortality is low (F = 0.12 to 0.25). Model parameters for the 2004 runs were the same as the ones used in 2003 (MRI 2004) with the exception that age 1 survival was reduced by 5% starting with 2002 to reflect cormorant predation (French-McKay and Rowe 2003). These results suggest that local fishing mortality rates are likely higher than the Gulf of Maine in general consistent with ASMFC (2005).

Cunner

As described above, cunner eggs are among the most abundant fish eggs in PNPS entrainment samples and in the waters surrounding the Station (Scherer 1984). Total numbers entrained ranged from 675,000,000 in 1991 to 6,576,000,000 in 1981 with a time series mean of 2,608,806,000 (s.e. = 331,760,000). For cunner larvae annual totals ranged from 2,792,000 in 1992 (1984 excluded) to 576,300,000 in 1981 with a time series average of 78,331,000 (s.e. = 26,934,000). Totals for 2004 increased relative to 2003 but were relatively low amounting to 1,452,433,000 eggs and 16,759,000 larvae. These values equaled 56% of the times series mean for eggs and 21% of the times series mean for larvae.

Goodyear's (1978) basic procedures were used to estimate equivalent adult values for cunner. This method converts numbers of eggs and larvae to numbers of fish at age of sexual maturity which occurs for approximately half the population at age 1 (P. Nitschke, University of Massachusetts, Amherst, personal communication). Assuming all labrid eggs were cunner eggs in PNPS entrainment samples (Scherer 1984), cunner larva/egg ratios were determined from PNPS samples to provide an estimate of survival from spawned egg to entrained larva. Mesh correction values were first applied to both eggs and larvae. Presented in MRI (1998) these were 1.24 for eggs taken from 1980-1995, 1.14 for eggs taken in 1995, and 1.10 for eggs taken in 1997. The mean of 1995 and 1997 values was used for 1998 through 2004 except in early-season cases where cunner eggs occurred in 0.202-mm mesh samples. Larval cunner mesh values applied were 1.16 for stage 1 and 1.28 for stage 2, irrespective of year. From 1980 to 2004 the larva/egg ratio ranged from 0.001284 to 0.128812 and averaged 0.029184; 1984, 1987, and 1999 were excluded because of extended circulating seawater pump shutdown during the cunner spawning season. Average lifetime fecundity was calculated from fish collected in the PNPS area by Nitschke (1997) and Nitschke et al. (2001a, b). He provided numbers of eggs produced at age in the second order form:

$$\text{Log } F = [2.891 \log A] - [1.355 \log A^2] + 3.149 \text{ where}$$

F = fecundity at age A

Age-specific instantaneous mortality necessary for calculation of average lifetime fecundity was calculated from fish trap collections made from 1992 - 1997 (Brian Kelly, Massachusetts Division Of Marine Fisheries, personal communication, MRI 1998). Average instantaneous mortality rates for the PNPS area collections from 1992 through 1997 using this approach were as follows:

Age 3 = 0.286	Age 7 = 0.653
Age 4 = 0.342	Age 8 = 1.463
Age 5 = 0.645	Age 9 = 0.728
Age 6 = 1.260	

Utilizing data from Serchuk and Cole (1974) for age 1 through 5 cunner collected with assorted gear, a survival rate of S = 0.605 was obtained (Z = 0.5025) which appears comparable to the PNPS values. Age 1 and 2 fish appeared less abundant in the PNPS collections than age 3 fish (MRI 1998), suggesting they were not fully recruited to the trap collections, perhaps due to their small size or behavior. Fish older than age 10 were rarely taken both because they are uncommon and because they can exceed the maximum size susceptible to the fish traps. In the absence of additional information an overall mean value of Z = 0.831 was substituted for age 2 and age 10.

Based on the PNPS area fecundity study (Nitschke 1997, Nitschke et al. 2001), 50% of age 1 females were assumed to be mature; complete recruitment was assumed by age 2. Following Goodyear (1978), an average lifetime fecundity of 21,656 eggs per female at age 1 was calculated (MRI 1998). Utilizing the survival estimate for eggs to larvae assuming most eggs were recently spawned and average lifetime fecundity, a survival estimate for larvae to adult of 3.084E-3 was obtained. Converting numbers of eggs to larvae utilizing the larva/egg ratio and then converting numbers of larvae to adults produced an estimate of 188,107 cunner potentially lost to entrainment effects in 2004. Comparable values for 1980-2003 ranged from 113,960 in 1991 to 2,384,804 adults in 1981 averaging 482,537 (s.e. = 103,699) over the 24-year period (Figure 9, Table 7). The high value of 2,308,039 recorded in 1981, attributable to high egg and exceptionally high larval densities skewed the mean EA value. As mentioned for winter flounder, estimates made in 1984 and to a lesser extent those made in1987 and 1999 were biased on the low side apparently due to reduced flow during outage periods. Table 8 presents estimates for 1984, 1987, and 1999 based on both full-load flow rates and those actually recorded. Without those three values and without the 1981 extreme a mean of 407,913 (s.e. = 73,997) was obtained.

In addition to numbers of eggs and larvae entrained cunner were impinged on the intake screens (see impingement section). Annual estimated totals ranged from 33 in 1988 to 1,683 in 1980 with a time series average of 295 fish. A total of 206 fish was impinged in 2004 somewhat below average. Since cunner mature at a young age no equivalent adult adjustment was made to the number impinged. No adjustment was made for impingement survival although numbers of cunner do survive being impinged at PNPS (MRI 1984).

Cunner have no commercial value and little recreational importance (although many may be taken unintentionally by shore fishermen) so that current landing records are not available. To shed some light on their abundance in the PNPS area, calculations were performed to estimate the number of adult cunner which would be necessary to produce the number of eggs found there. The PNPS area was defined by Cape Cod Bay sampling stations 2,3,4,7,8 (MRI 1978b), the half-tide volume of which was estimated by planimetry from NOAA chart 1208 at 22,541,000 100 m^3 units. Labrid egg densities were obtained at those stations on a weekly basis in 1975 and they were integrated over time (April-December) using the mean density of the five stations. The integrated values were multiplied by 1.40 to account for extrusion through the 0.505-mm mesh used in that survey (MRI unpublished data), then by the sector volume. Based on the 0.333/0.202-mm mesh data collected from the PNPS discharge stream from 1994 through 1997, additional upward scaling might be appropriate; however specific data for towed samples with 0.202-mm mesh are not available and an estimated value was not applied. Omitting this step likely led to an underestimate of the number of eggs produced and therefore to an underestimate of the number of adults spawning in the area. The resulting value was divided by 2.2, the estimated incubation time in days for cunner eggs (Johansen 1925), then divided by 30,230, an estimate of mean annual fecundity per female derived from Nitschke (1997) and Nitschke et al. (2001); see also MRI (1998). Lastly the resulting value was multiplied by 2 assuming an even sex ratio. These calculations resulted in an estimated production of 6.899E12 eggs by an estimated 207,473,000 adult fish. The loss of 188,313 adults in 2004 due to PNPS operation represents 0.09% of the estimated spawning stock. The annual mean loss of 482,832 fish to entrainment and impingement, including all years, represents 0.2% of the stock estimate.

In earlier studies MDMF personnel chose cunner as an indicator species for PNPS impact investigations. Tagging studies were conducted during the 1994 and 1995 seasons to estimate the size of the cunner population in the immediate PNPS area. Minimum tagging size and therefore the minimum size fish enumerated was 90 mm TL. Estimates were highly localized since individual cunner have a very small home range measured on the order of 100 m^2 or less (Pottle and Green 1979). Very young cunner may spend their first year within a single square meter (Tupper and Boutilier 1995, 1997). Estimated population size for the outer breakwater and intake areas combined were 7,408 and 9,300 for the two respective years. Combining upper 95% confidence limits for breakwater and intake produced totals of 10,037 and 11,696 fish, respectively. Since the upper confidence limit total is only 0.003% of the egg based population estimate, it is clear that eggs must arrive at PNPS from areas removed from the immediate vicinity of the Station. A hydrodynamic modeling study completed by Eric Adams of MIT predicted that 90% of the cunner eggs and larvae entrained at PNPS come from within about 5.5 miles of PNPS to the north down to White Horse Beach, about one mile to the south of PNPS. This area extends further to the north than the area 2,3,4,7,8 used in the above egg estimates and would presumably provide an even greater adult population estimate. The number of eggs entrained indicated that cunner must be very abundant in these waters.

Atlantic Mackerel

Numbers of mackerel eggs entrained at PNPS ranged from 81,599,000 in 1981 to 4,674,000,000 in 1989 with an average of 996,572,500 (s.e. = 254,943,000; excluding 1984, 1987, and 1999). Totals for larval mackerel ranged from 2,790,400 in 2003 (again 1984, 1987, and 1999 were omitted) to 320,135,596 in 1981 with an average of 49,310,700 (s.e. = 16,643,900). Corresponding values for 2004 were 70,228,000 for eggs and 10,895,000 for larvae based on actual station flow, both well below time series average values.

Procedures outlined by Vaughan and Saila (1976) were used to derive a survival rate for spawned mackerel eggs to age 1 fish. This procedure utilizes the Leslie matrix algorithm to estimate early survival from proportion mature, fecundity, and survival within each age class assuming a stable population. Fecundity for Atlantic mackerel was obtained from Griswold and Silverman (1992) and Neja (1992). Age-specific instantaneous natural mortality (M = 0.20) was obtained from Overholtz et al. (2000) and NOAA (1995). A low fishing mortality rate of F = 0.02 was used consistent with the current low exploitation rate. A maximum age of 14 and maturity schedules were obtained from NFSC (1996). Since two fecundity profiles provide two egg to age 1 survival values: 2.2772E-6 for Griswold and Silverman, 2.3039E-6 for Neja, values were averaged (2.2906E-6).

To account for the fact that all eggs entrained were not recently spawned and the Vaughan and Saila estimate begins at time of spawning an estimate of daily mortality was derived from Pepin (1991). Based on an average late-spring summer water temperature of 15 C daily mortality was estimated to be $M_e = 0.074$. At 15 C mackerel eggs require approximately 4 days to hatch assuming an average diameter of 1.15 mm (Colton and Marak 1969, Pepin 1991). Entrained eggs were therefore assumed to average one day old with a corresponding mortality rate of M = 0.446 (survival rate S = 0.640). The number of entrained eggs was therefore divided by 0.640 to estimate the equivalent number of newly spawned eggs entrained.

To back calculate from entrained larvae to spawned eggs so the spawned egg to age 1 survival rate could be applied the observed average ratio of eggs to larvae for PNPS of 0.07984 (1980-2004) was used. In calculating larvae/egg ratios 1981, 1984, 1987, and 1999 were omitted, 1981 because larvae were more abundant then eggs, 1984, 1987, and 1999 because both circulating seawater pumps were off for all or an important portion of the mackerel egg and larval seasons during maintenance outages. A mesh adjustment factor of 1.12 was applied to the egg data obtained with 0.333-mm mesh nets based on mesh comparison collections completed from 1994 through 1997 (MRI 1998). No mesh adjustment was justified for larvae. Numbers of entrained larvae were divided by 0.07984 then by the age adjustment factor of 0.640 and the back calculated total was then added to the age-adjusted egg total. The age 0 survival rate of 2.2906E-6 was then applied to the combined egg total to derive the number of age 1 fish

According to NOAA (1995, 1998) and Overholtz (2000) stock biomass consists of fish age 1 and older while fish completely recruit to the spawning stock by age 3. Therefore, juvenile and adult equivalent values are shown for both respective age groups (Figure 10, Table 8). Age 3 individuals were estimated using an instantaneous mortality rate of M = 0.52 for age 1 fish and M = 0.37 for age 2 fish (Overholtz et al. 1988). These values provided annual survival rates of S = 0.595 and 0.691, respectively. Numbers of age 1 and 3 mackerel were expressed on a weight basis using 0.2 and 0.7 pounds per fish, respectively (Clayton et al. 1978).

PNPS equivalent age 1 juveniles attributable to entrainment for 2004 amounted to 740 age 1 fish weighing 148 pounds or 304 age 3 fish weighing 213 pounds. Corresponding age 1 values over the 1980 through 2003 time series ranged from 808 (1982) to 19,667 (1989) fish with an average of 5,777 (s.e. = 1,185). Age 3 values ranged from 332 to 8,086 with an annual average of 2,375 (s.e. = 487) individuals. Data from 1984, 1987, and 1999 were omitted here because values were unusually low as described above for the larvae/egg ratio calculations. Converting numbers of fish to weight resulted in an estimated average annual loss through 2003 of 1,155 pounds (s.e. = 237 pounds) or 1,663 pounds (s.e. = 341), respectively (1984, 1987, and 1999 excluded). The number of eggs and larvae entrained in 2004 and therefore the number of equivalent juveniles and equivalent adults was quite low amounting to 11% of the time series mean (Table 9). This follows 2001, 2002, and 2003 when numbers ranged from only about 13 to 23% of the time series average. The below average totals suggest that mackerel egg and larval production in the waters near PNPS were not particularly high during the last four years. The last stock assessment for mackerel was completed in 1999 (Overholtz 2000). At that time stock biomass was believed to be at historic high levels. Whether recent entrainment data reflect a recent downward trend in abundance or a shift in spawning location is unknown at this time.

Atlantic mackerel are swift swimmers and are not often impinged at PNPS. They occurred during only six years from 1980 to 2004 with an average of five individuals annually. Based on their mean size most were adult fish and therefore included with the EA totals.

According to NOAA statistical records, an annual average of 272,900 pounds (s.e. = 73,265) of mackerel were taken commercially from statistical area 514 over the years 1982-2003. For PNPS the loss of an average of 1,155 pounds of age 1 fish (1980-2003; 1984, 1987, and 1999 omitted) amounts to 0.4% of those landings and the loss of an average of 1,666 pounds of age 3 fish, 0.6%. In addition to commercial landings, mackerel have considerable recreational value. For example, over the years 1981-2003 an average of 879,863 fish (s.e. = 124,833) were landed in Massachusetts by fishermen working inland waters and within three miles of shore. These fish had an average weight of about one pound. Unfortunately these landings are available only by state and therefore the portion attributable to Cape Cod Bay is not known. Arbitrarily adding 200,000, 1 pound fish to the commercial landings brings the harvest total to 472,900 pounds. The mean PNPS age 1 loss estimate amounts to 0.2% of those landings and the mean age 3 equivalent adult total to 0.4% of the landings.

Calculations performed to estimate the number of adult cunner which would be necessary to produce the number of eggs found in the PNPS area were also completed for Atlantic mackerel. Mackerel eggs occurred at Cape Cod Bay stations 2, 3, 4, 7, and 8 from early May through early July in 1975. Integration over time using the mean density of the five stations produced an estimate of 1.3529E12 eggs. This total included a mesh correction factor of 1.95 to account for extrusion through 0.505-mm mesh (MRI unpublished data). The resulting value was divided by 4, the estimated incubation time in days for mackerel eggs (Sette 1950), then divided by 319,978, an estimate of mean annual fecundity per female for age 3 fish from Griswold and Silverman (1992) and Neja (1992). Lastly the resulting value was multiplied by 2 assuming an even sex ratio. These calculations resulted in an estimated production of 3.382E11 eggs by an estimated 2,114,052 adult fish. The annual mean loss (1980-2003; 1984, 1987, 1999 omitted) of 2,048 age 3 fish due to PNPS entrainment represents 0.1% of that value.

Atlantic Menhaden

Total numbers of Atlantic menhaden eggs entrained at PNPS dating back to 1980 ranged from 393,000 in 1992 (1984, 1987, and 1999 omitted) to 947,800,000 in 1993, with an overall average of 74,620,700 (s.e. = 46,859,000). Corresponding totals for menhaden larvae ranged from 512,000 in 1991 (1984, 1987, and 1999 omitted) to 48,300,000 in 1997 averaging 9,976,467(s.e. = 2,957,894) over the 1980 - 2003 time series. Totals for 2004 amounted to 613,682 eggs and 176,011 larvae 0.8% and 2% of the respective time series means (Table 9).

Numbers of eggs and larvae entrained each year at PNPS were converted to numbers of equivalent adults using the Vaughan and Saila (1976) approach. This procedure requires an estimate of the ratio of larvae to eggs plus fecundity and mortality for each age class. To provide an estimate of survival from spawned egg to entrained larva (Se) the ratio of larvae to eggs at PNPS was calculated. In some years more larvae were entrained then eggs so that estimates were not obtained for all cases. Estimates ranging from 0.005 to 0.890 were obtained in 1980, 1982, 1985, 1986,1988-1991,1993, 1994, 1998, and 2001-2004. A geometric mean of 0.224 was obtained over those 16 estimates. In the Mount Hope Bay section of Narragansett Bay from 1973-1991 a geometric mean ratio of 0.066 was obtained providing a second estimate based on extensive data. An average of the two estimates, 0.145 was used to approximate survival from egg to larva. Since Se is defined as survival from spawned egg to entrained larva an adjustment to the average larvae/egg ratio was necessary. To derive this estimate, collected menhaden eggs were estimated to average one day old, one-quarter their incubation period at 15C, assuming that spawning takes place near by. A 4-day incubation period was obtained from Pepin (1991) who related incubation duration to water temperature and egg diameter. A mean diameter of 1.6 mm was obtained from Colton and Marak (1969). Pepin (1991) also related daily egg mortality to water temperature ($M_e = 0.030e^{0.18T}$). Assuming an average spring-early summer water temperature of 15C menhaden eggs would experience a daily mortality rate of Me = 0.4464. The mean egg/larvae ratio of 0.145, equivalent to an instantaneous mortality rate of 1.931 was added to 0.4464 to derive the mortality rate from spawned egg to entrained larva of Ze = 2.3774 (Se = 0.093).

The procedure of Vaughan and Saila (1976) using the Leslie matrix algorithm provided an estimate of survival from spawned egg to age 1 of 5.419E-05. Fecundity for ages 3 through 5 was obtained from Dietrich (1979). All females were assumed to spawn first at age 3 based on Ahrenholz et al. (1987) who reported that all age 2 fish mature by the fourth quarter. Since fall spawning does occur but is uncommon in Cape Cod Bay (Scherer 1984), we assumed initial spawning at age 3. Dietrich's (1979) age 5 fecundity was assumed for ages 6 through 9 as well since direct counts were not available. Instantaneous natural mortality rates (M) were obtained from ASFMC (2004); these were 0.98, 0.56, and 0.55 for ages 1, 2, and 3-9, respectively.

Fishing mortality (F) of 0.14 for age 1 and 0.79 for older individuals was also used (ASFMC 2004). To account for the fact that all eggs entrained were not recently spawned and the Vaughan and Saila estimate begins at time of spawning the estimate of daily mortality rate for menhaden eggs described above was used. Numbers of entrained larvae were back calculated to spawned eggs using Se and that total added to the number of entrained eggs.

These parameters provided an estimate of 155 age 1 individuals potentially lost as a result of egg and larvae entrainment in 2004. Since menhaden enter the fishery at age 2 (Durbin et al. 1983), the annual natural mortality rate of M = 0.98 and F = 0.14 (S = 0.376) was applied to the age 1 value to arrive at an estimate of 50 age 2 fish potentially lost to the fishery. Based on a wet weight of 0.6 pound for age 2 individuals (ASFMC 2005), this estimate equals 30 pounds. Corresponding age 2 values for the 1980-2003 time series ranged from 107 pounds in 2000 to 17,063 pounds in 1993 with an average value of 2,375 (s.e. = 853).

Age 2 natural (M = 0.56) and fishing mortality (F = 0.79) rates were then applied to the numbers of age 2 fish to estimate the number of age 3 adults potential lost to the population. For 2004 the estimate was 13 adults. Corresponding age 3 values for the 1980-2003 time series ranged from 46 to 7,371 with an average value of 1,026 (s.e. = 369; Figure 11, Table 9).

In addition to numbers entrained 4,597 young menhaden were estimated to have been impinged in 2004 (see impingement section). That compares with an average of 11,604 annually from 1980-2003 (s.e. = 6,501) and a range from 0 in 1981 and 1987 to 149,390 in 2003. The majority of fish were impinged from late summer through autumn. Since menhaden are sensitive to impingement and handling in general (see for example Tatum et al. 1977, MRI 1984) all were assumed to have died. Assuming conservatively that 50% would have survived to the end of their first year and 32.6% would then survive to age 2 an additional 749 fish might have been lost to the fishery and 194 adults might have been lost to the spawning stock from impingement losses in 2004. This compares with a time series average of 1,891 age 2 and 490 age 3 fish potentially lost to impingement. Combined potential entrainment and impingement losses totaled 799 age 2 and 207 age 3 fish in 2004 and averaged 5,807 age 2 and 1,505 age 3 fish over the 1980-2003 time series.

The Atlantic menhaden resource has supported one of the largest fisheries in the United States since colonial times and is believed to consist of a single population based on tagging studies (Dryfoos et al. 1973; Nicholson 1978, ASMFC 2004). The menhaden fishery has two components, a reduction fishery that produces fishmeal and fish oil and a bait fishery. As bait, menhaden are collected in pound nets, trawls, haul seines, purse seines and gill nets. Obtaining data from the bait fishery is difficult to obtain but the bulk of the landings in New England are used by the lobster fishery. Bait landings along the Atlantic coast averaged approximately 81,364,500 pounds from 1985-2002 and that represented only about 9% of the total landings from 1985 to 1997, 16% since 1998 (ASMFC 2004). The potential loss of an average of 3,484 pounds of menhaden to entrainment and impingement at PNPS would represent a very small portion of the fishery landings.

Numbers of menhaden eggs were re-examined from 1975 when ichthyoplankton sampling was completed through out Cape Cod Bay (see for example Scherer 1984). At that time menhaden eggs were found from late May into July and again in October. To determine an approximation of the number of menhaden which might have spawned in the Bay that year mean densities were integrated over time. The integrated total was multiplied by 2.0 to adjust for extrusion through the 0.505-mm mesh used in those studies (MRI unpublished), then divided by 3 an estimate of the incubation period for menhaden eggs. This value was then divided by the mean fecundity for menhaden used in calculation of average lifetime fecundity (493,343 eggs) and assuming an even sex ratio, multiplied by 2 to account for males. The resulting value was then multiplied by the volume of Cape Cod Bay (4.5E10 $m^{3;}$ Collings et al. 1981). This procedure produced an estimate of 3.4 million adults spawning in the Bay at that time. To be conservative that number was divided in half assuming that eggs were present in only half the volume of Cape Cod Bay. Using this rough approximation and assuming that numbers of menhaden spawning in the Bay in 1975 were similar to current levels the average loss of 1,505 age 3 menhaden (1980-2003, 1984, 1987, 1999 omitted) would amount to 0.04% of the estimated spawning stock in Cape Cod Bay.

MRI completed estimates of the number of menhaden eggs and larvae passing through the Cape Cod Canal during the 1999 spawning season (TRC 2000). Estimates were based on ichthyoplankton sampling completed in the Canal near the eastern end as well as a near-canal station in Buzzard's Bay and in Cape Cod Bay. The seasonal total passing through the Canal amounted to 520 million eggs and 258 million larvae. The number of menhaden eggs and larvae entrained by PNPS in 1999 amounted to 2.8 and 4.6% of those estimates, respectively.

Atlantic Herring

Since Atlantic herring spawn demersal, adhesive eggs primarily on offshore banks they are not subject to entrainment at PNPS. Larvae entrainment based on full load circulating water flow at the station ranged from 468,800 in 1984 to 43,248,000 in 1995 and averaged 6,797,414 (s.e. = 2,248,644) over the 1980-2003 period. For the 2004 season the number entrained was estimated to be 4,722,708 larvae. Since they are relatively large, no mesh adjustment factor was applied to the estimated values. Larval herring have typically been entrained from autumn to early spring so total numbers entrained in 1987 when no sampling was conducted in April during an outage period and in 1984 when sampling occurred but the circulating water system was shutdown in April may have been underestimated slightly as mentioned earlier (Table 10).

The Vaughan and Saila procedure was used to derive an estimate of survival from spawned egg to age 1. For this estimate fecundity was obtained from Messieh (1976); age-specific mortality of M = 0.2 was obtained from NOAA (1998) and NFSC (1998). A maximum age of 11 was assumed following (NFSC 1998) and fishing mortality was set at F = 0.2 beginning at age 1. These values provided an estimated survival rate of 5.1004E-5 for a spawned herring egg to age 1. To estimate the number of eggs which must have been spawned to produce the number of larvae entrained, individuals were assumed to average 45 days of age. This was based on their relatively long larval period (see for example Jones et al. 1978, Folkvord et al. 1997) and the fact that spawning occurs on offshore banks. Over that 45-day period larvae were assumed to experience a mortality rate of 5.75% per day.. This value equals the median summarized from various authors by Dragesund (1970). A mortality rate of 50% was assumed among spawned eggs (Lough et al. 1985). The mortality rate among eggs coupled with a 5.75% daily mortality rate over 45 days provided a mortality rate of Se = 0.034804 from spawned egg to entrained larva.

Dividing the number of entrained larvae by the egg to larva mortality rate and multiplying by 5.1004E-5 provided an estimate of 6,922 age 1 herring potentially lost to entrainment effects in 2004; these might have entered the sardine fishery. Based on an annual survival rate of 0.67 (M = 0.20, F = 0.20, see above), 6,922 age 1 fish would produce 3,107 age 3 adults, the age at which 50% of fish recruit to the spawning stock (NOAA 1995, Overholtz 2000). Assuming age 1 (sardines) weigh 0.03 pounds and age 3 adults, 0.4 pounds, 212 pounds of sardines or 1,268 pounds of adults would have been lost due to entrainment in 2004. These values are 58% of the long-term average for age 1 (366 pounds) and age 3 (2,191 pounds) equivalent fish based on the 1980-2003 time series (Figure 12, Table 10).

In addition to numbers entrained an estimated annual total of 137 young herring were impinged in 2004. That compares with an average of 2,239 annually from 1980-2003 (s.e. = 1,967) and a range from 0 in 1984 and 1996 to 41,419 in 1991. Over the time series fish were most often impinged from late winter to spring although a relatively large number were impinged in July 1991. While some adults appeared in the catch from time to time the majority of fish were small, ranging in length from 25 to 75 mm total length. Converting to equivalent age 3 adults using the annual mortality rate given above would add an annual average of 1,005 age 3 fish.

Atlantic herring have long been an important component of the commercial fishery off the northeast coast of the United States (see for example Matthiessen 2004) They were severely overfished by distant-water fleets during the 1960's and 1970's to the point where no larval herring were found on Georges Bank for a decade (Overholtz and Friedland 2002). They have since recovered and are currently abundant on Nantucket Shoals and in the Gulf of Maine-Georges Bank region. Although likely to increase, landings remain low. For example, while 1.1 million pounds were landed from Statistical Area 514 in 1997, none were reported for that area from 1999 through 2003. Based on the most recent assessment (1997; Overholtz 2002a) spawning stock biomass in the northeast was estimated at 1.8 metric tons or 4 billion pounds of adult fish. Based on the recovery status it is likely that subsequent estimates will show similar or greater abundance then in 1997. If spawning stock biomass in the 514 statistical area equals only one percent of the northeast stock, then the 2004 equivalent adult losses to entrainment and impingement at PNPS (1,268 pounds) would amount to about 0.003%. The time series average of 2,191 pounds would amount to about 0.006%.

Atlantic Cod

Estimated numbers of Atlantic cod eggs entrained at PNPS dating back to 1980 ranged from 1,268,748 in 1993 to 20,388,850 in 1980 averaging 6,062,556 (s.e. = 1,039,155) over the 24-year time series from 1980-2003. For cod larvae corresponding estimates ranged from 119,436 in 1989 to 4,215,642 in 2001 averaging 1,058,475 (s.e. = 200,264) over the time series. Corresponding estimates for 2004 amounted to 5,231,113 eggs and 1,550,052 larvae 86 and 146% of the long term mean, respectively (Table 11). Using the Vaughan and Saila procedure numbers of eggs and larvae were converted to equivalent age 2 fish, the age at which 50% of the stock reaches maturity and the age at which they enter the fishery. To calculate age 0 survival using the Vaughan and Saila procedure fecundity at age was obtained by averaging values from May (1967) and Kjesbu (1996). A natural mortality rate of M= 0.20 was obtained from NOAA (1998) along with a fishing mortality rate of F = 0.2 beginning at age 2. A maximum age of 6 was assumed based on their high exploitation rate (Serchuk et al 1994). Using these variables an age 0 survival rate of 1.5506E-6 was obtained.

Survival from spawned egg to entrained larva (Se) was estimated by averaging three values:

- The average larvae/egg ratio obtained at PNPS from 1980-2004 following adjustment for the average age of entrained eggs; this equaled 0.0900. To derive this estimate, cod eggs were assumed to average 6 days old, half their incubation period at 5C. A 12-day incubation period was obtained from Pepin (1991) who related incubation duration to water temperature and egg diameter. A mean diameter of 1.5 mm was obtained from Colton and Marak (1969). Pepin (1991) also related daily egg mortality to water temperature. Assuming an average winter water temperature of 5C cod eggs would experience a daily mortality rate of Me = 0.074 or 0.443 over six days. The observed geometric mean egg/larvae ratio at PNPS from 1980-2004 of 0.1402, equivalent to an instantaneous mortality rate of 1.9648 was added to 0.443 to derive the mortality rate from spawned egg to entrained larva of Ze = 2.4078 (Se = 0.090).

- The second estimate relied on daily mortality rates given for the closely related pollock by Saila et al (1997; 0.0068). They estimated egg mortality for pollock eggs from spawning to hatch to be Ze = 0.922 and larval mortality at Z = 1.358 per mm of growth. Assuming cod larvae entrained at PNPS average 6 mm in length and that they hatch at 3 mm (Colton and Marak 1969) they would be expected to experience a mortality rate of Z = 4.074. Combined these estimates equal 2.4184 = Z corresponding to a survival rate from spawned egg to entrained larva of S = 0.0068.
- The third value (Se = 0.0077) was derived as follows. Larvae entrained at PNPS were assumed to average 10 days old. Eggs were assumed to require 20 days to hatch with a daily mortality rate of 10% per day (Serchuk et al. 1994). Larval mortality from hatch to day 10 was assumed to be 4% per day (Serchuk et al. 1994) providing a survival rate of 0.0077 from spawned egg to entrained larva.

The average of those three values, Se = 0.0348, was used to estimate the number of eggs necessary to yield the number of entrained larvae at PNPS.

Applying the average Se value to the number of larvae entrained each year, adding the result to the number of eggs entrained and applying the value of age 0 survival to the total provided estimated equivalent adult values of 63 age 2 fish in 2004. This compared with the time series mean of 47 (s.e. = 8). Numbers of fish were converted to weight in pounds using an estimate of 2.0 pounds per fish (Bigelow and Schroeder 1953). For 2004 a weight of 126 pounds was obtained which compares with the overall mean of 94 pounds (s.e. = 16 pounds; Figure 13, Table 11).

In addition to the numbers entrained 137 Atlantic cod were estimated to have been impinged on the PNPS intake screens in 2004. That compares with an average of 25 annually from 1980-2003 (s.e. = 7) and a range from zero to 122 in 1991; no cod were impinged during 12 years (see impingement section). Based on size the majority of impinged cod were young fish ranging in size from 50 to 100 mm total length. Assuming most were age 1 fish the number impinged would account for an additional 112 equivalent adults in 2004 and an average of 20 additional adults over the 1980-2003 time series.

These totals were considered low relative to any recent landings information for the Cape Cod Bay area. For reference Area 514 landings averaged 41,339 pounds (s.e. = 13,742) over the past nine years and Massachusetts inland and near shore (< 3 miles) recreational landings averaged 535,409 pounds (s.e. = 212,670) over the same period.

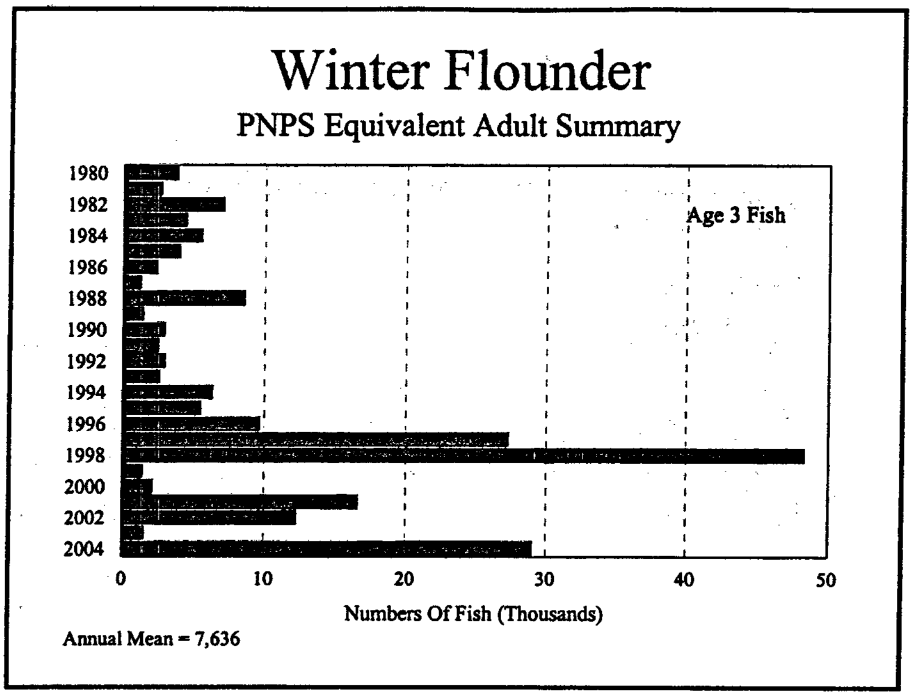

Figure 7. Numbers of equivalent adult winter flounder estimated to have been lost to entrainment at PNPS, 1980-2004.

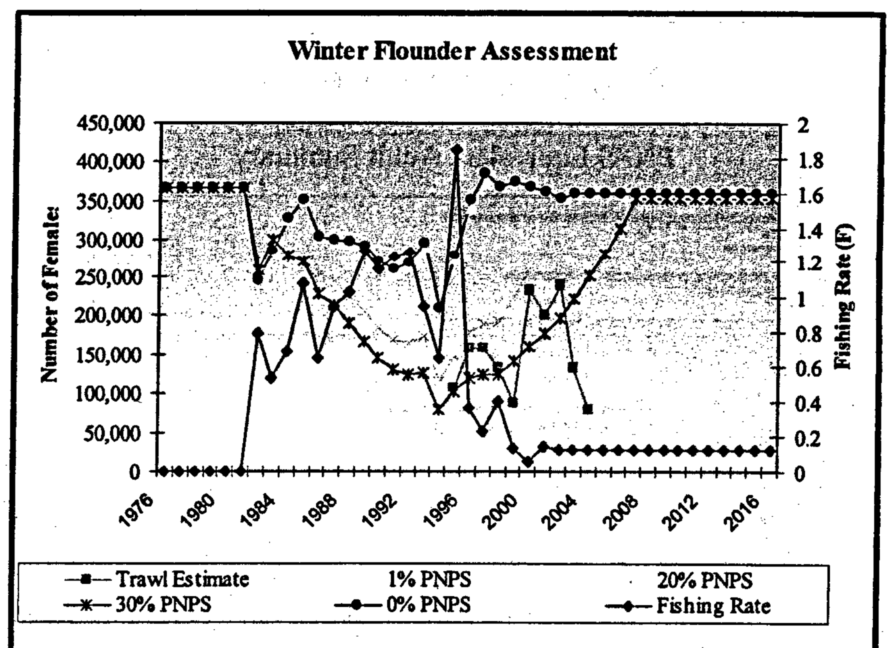

Figure 8. Population size estimated by a Ramas model with and without PNPS entrainment, fishing mortality rates, and population size estimated by bottom trawl in western Cape Cod Bay.

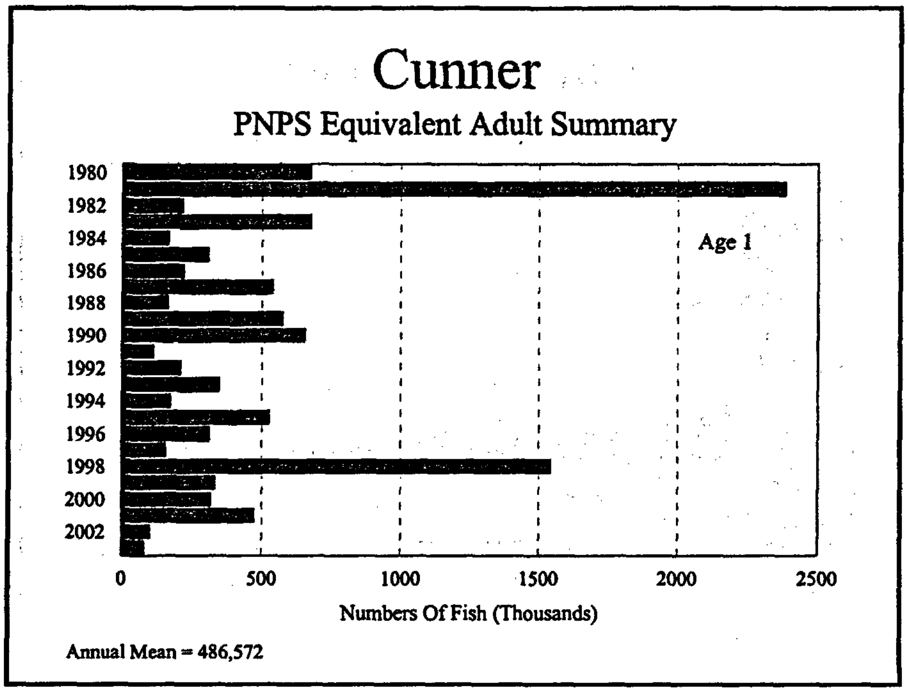

Figure 9. Numbers of equivalent adult cunner estimated to have been lost to entrainment at PNPS, 1980-2004.

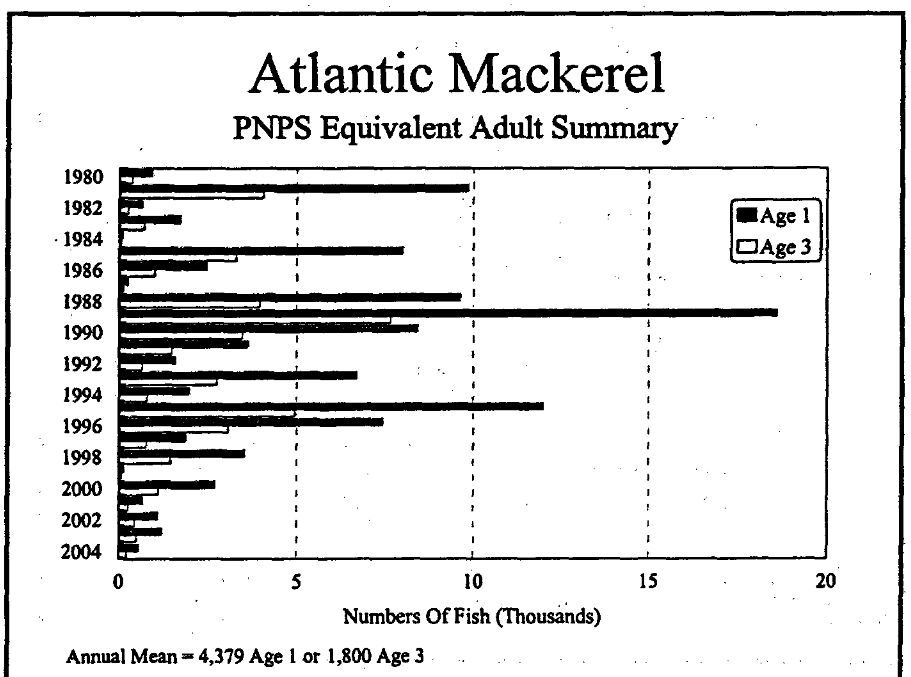

Figure 10. Numbers of equivalent adult Atlantic mackerel estimated to have been lost to entrainment at PNPS, 1980-2004.

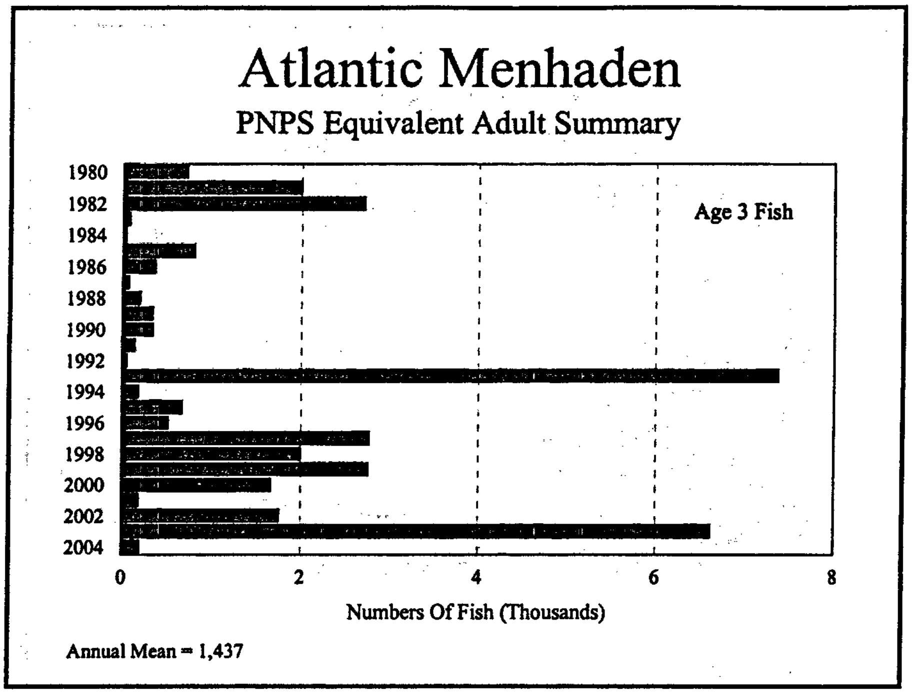

Figure 11. Numbers of equivalent adult Atlantic menhaden estimated to have been lost to entrainment at PNPS, 1980-2004.

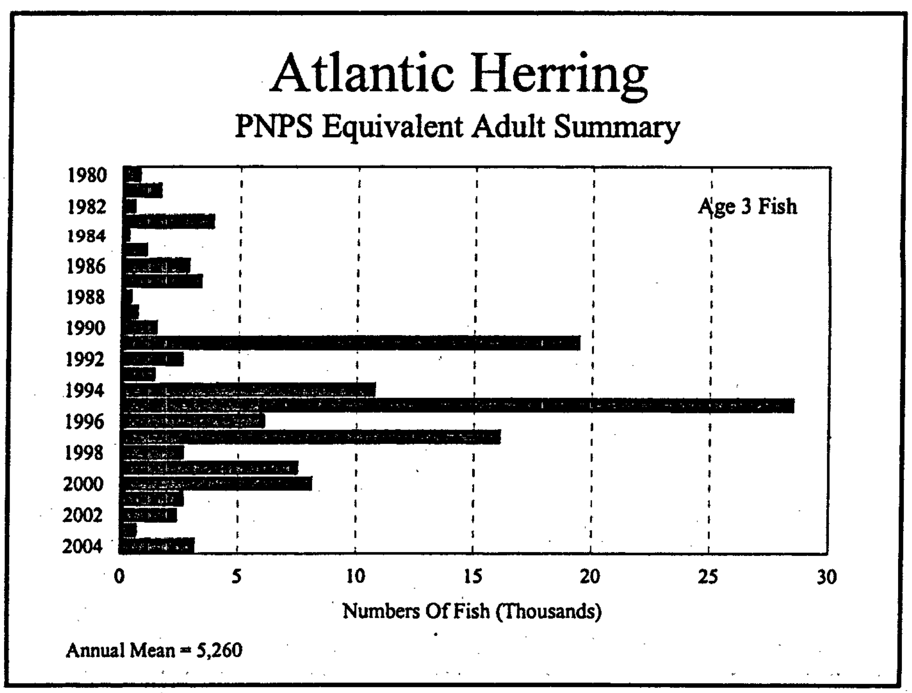

Figure 12. Numbers of equivalent adult Atlantic herring estimated to have been lost to entrainment at PNPS, 1980-2004.

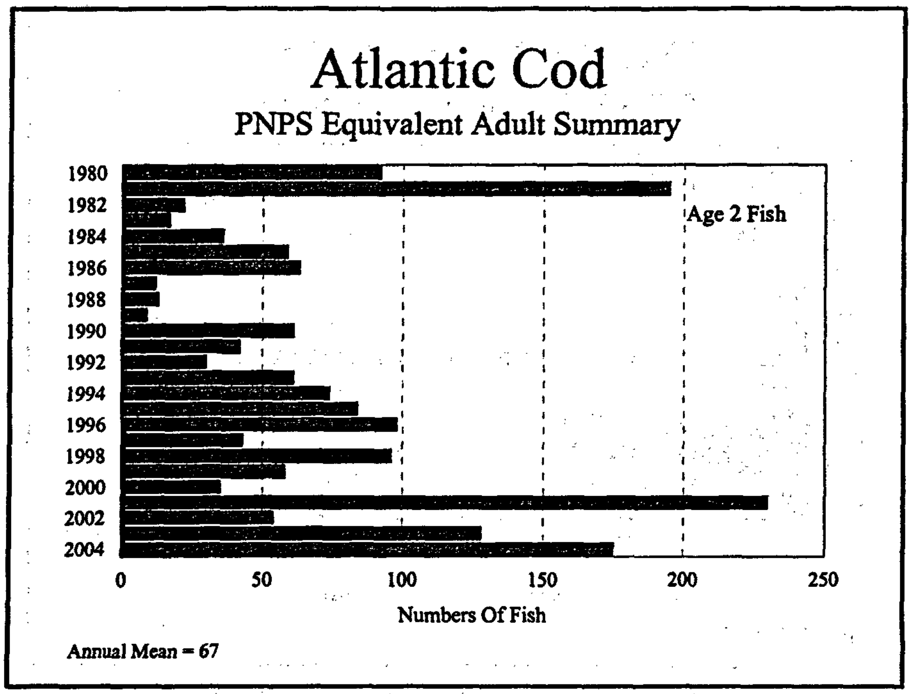

Figure 13. Numbers of equivalent adult Atlantic cod estimated to have been lost to entrainment at PNPS, 1980-2004.

Table 5. Numbers of winter flounder eggs and larvae entrained at PNPS annually by stage, 1980 - 2004. Numbers and weight of equivalent age 3 adults calculated by three methods is also shown. Estimates based on full-load flow except where indicated.

Year	Number Of Eggs Entrained	Number Of Larvae Entrained Stage 1	2	3	4	Total	Equivalent Age 3 Adults General Number	General Pounds	Staged Suite 1 Number	Staged Suite 1 Pounds	Staged Suite 2 Number	Staged Suite 2 Pounds	Average Number	Average Pounds
1980	3,513,717	8,694,456	12,714,822	7,317,129	0	28,726,407	1,773	860	7,448	3,612	2,151	1,043	3,791	1,838
1981	9,674,954	7,606,942	19,133,121	3,073,126	43,304	29,856,494	1,844	894	4,701	2,280	1,445	701	2,663	1,292
1982	7,001,776	2,706,834	6,724,795	11,583,134	425,011	21,439,774	1,324	642	12,652	6,136	7,241	3,512	7,072	3,430
1983	1,305,735	1,933,453	2,246,172	7,558,534	260,350	11,998,508	740	359	7,970	3,865	4,544	2,204	4,418	2,143
1984	341,424	248,082	0	7,570,145	516,247	8,334,475	514	249	9,128	4,427	6,914	3,353	5,519	2,677
1985	32,717,535	1,039,001	2,312,789	8,025,452	130,786	11,508,028	720	349	7,683	3,726	3,490	1,693	3,964	1,923
1986	5,118,035	5,397,403	5,783,669	3,963,747	77,005	15,221,823	940	456	4,371	2,120	1,878	911	2,396	1,162
1987	20,857,334	0	437,608	3,088,405	0	3,526,013	224	109	2,644	1,282	876	425	1,248	605
1988	3,494,771	1,995,968	1,656,376	15,079,960	511,009	19,243,314	1,188	576	15,562	7,548	8,961	4,346	8,570	4,157
1989	6,423,987	1,668,823	5,755,240	2,224,675	39,114	9,687,851	599	291	2,632	1,277	1,040	504	1,424	691
1990	48,501	643,683	1,155,404	6,846,718	33,002	8,678,807	535	260	6,016	2,918	2,212	1,073	2,921	1,417
1991	1,217,178	3,471,022	3,908,488	5,188,056	37,717	12,605,283	778	377	4,967	2,409	1,827	886	2,524	1,224
1992	4,124,308	873,660	876,914	7,034,690	26,192	8,811,456	545	264	6,119	2,968	2,202	1,068	2,955	1,433
1993	3,078,941	1,595,700	3,540,750	4,934,952	88,617	10,160,019	627	304	4,962	2,407	2,228	1,081	2,606	1,264
1994	2,530,707	1,034,617	6,433,716	13,060,373	172,606	20,701,312	1,277	620	12,450	6,038	5,284	2,563	6,337	3,073
1995	2,766,716	1,632,907	2,820,023	8,826,496	375,857	13,655,283	843	409	9,703	4,706	5,979	2,900	5,508	2,672
1996	4,896,687	504,810	5,818,499	11,329,855	995,127	18,648,292	1,151	558	15,401	7,469	12,482	6,054	9,678	4,694
1997	3,609,393	2,225,634	9,537,788	41,484,016	2,126,280	55,373,718	3,416	1,657	47,091	22,839	31,415	15,236	27,307	13,244
1998	1,035,001	3,111,891	20,282,772	58,546,916	4,904,482	86,846,061	5,356	2,597	77,394	37,536	62,171	30,153	48,307	23,429
1999	1,409,453	2,031,988	588,974	1,936,648	123,103	4,680,713	289	140	2,383	1,156	1,694	822	1,455	706
2000	1,693,672	33,482	170,475	5,391,088	0	5,595,045	346	168	4,521	2,193	1,493	724	2,120	1,028
2001	330,283	4,638,546	13,093,697	37,019,304	263,144	55,014,691	3,393	1,645	33,626	16,309	12,814	6,215	16,611	8,056
2002	28,637	1,389,319	6,911,151	14,802,848	1,232,865	24,336,183	1,501	728	19,703	9,556	15,669	7,599	12,291	5,961
2003	1,977,333	722,030	480,190	2,966,524	76,394	4,245,138	262	127	2,951	1,431	1,540	747	1,584	768
Mean	4,966,503	2,300,010	5,515,976	12,035,533	519,092	20,370,612	1,258	610	13,420	6,509	8,231	3,992	7,636	3,704
s.e.	1,498,148	460,591	1,171,783	2,842,935	215,744	4,026,136	248	120	3,501	1,698	2,727	1,323	2,141	1,038
Minimum	28,637	0	0	1,936,648	0	3,526,013	224	109	2,383	1,156	876	425	1,248	605
Maximum	32,717,535	8,694,456	20,282,772	58,546,916	4,904,482	86,846,061	5,356	2,597	77,394	37,536	62,171	30,153	48,307	23,429
1984, 1987, 1999 Omitted														
Mean	4,599,422	2,520,009	6,255,088	13,155,123	562,803	22,493,023	1,388	673	14,663	7,112	8,956	4,343	8,336	4,043
s.e.	1,503,601	503,594	1,259,228	3,174,721	245,079	4,412,756	272	132	3,927	1,905	3,085	1,496	2,409	1,168
2004	246,468	159,859	10,431,901	49,597,823	1,988,421	62,178,004	3,834	1,859	50,851	24,663	32,373	15,701	29,019	14,074
Plant outage years recalculated with actual circulating water flow.														
1984	341,424	166,925	0	164,036	15,729	346,690	21	10	226	111	193	94	45	22
1987	20,782,324	0	5,613	23,555	0	3,534,685	218	107	109	53	25	12	6	3
1999	1,409,453	2,030,743	496,056	977,373	1,345	3,505,517	216	106	912	447	291	141	68	33

Notes: Mesh factor = 1.24 applied to eggs prior to 1995. Mesh factor = 1.62 applied to Stages 1 and 2 prior to 1995.
Larval densites recorded in 1984, 1987, and 1999 are believed to be low relative to densities in surrounding waters. See text for details.

Table 6. Numbers of winter flounder impinged at PNPS annually, 1980 - 2004. Number and weight of equivalent age 3 adults calculated by two methods is also shown.

	Estimated Annual Number Impinged	Equivalent Adults General Number	Equivalent Adults General Pounds	Equivalent Adults Staged Number	Equivalent Adults Staged Pounds
1980	218	25	12	26	13
1981	229	26	13	27	13
1982	344	40	19	41	20
1983	230	26	13	28	13
1984	42	5	2	5	2
1985	735	85	41	88	43
1986	653	75	36	78	38
1987	166	19	9	20	10
1988	184	21	10	22	11
1989	595	69	33	71	35
1990	295	34	16	35	17
1991	1,171	135	65	140	68
1992	817	94	46	98	48
1993	1,171	135	65	140	68
1994	1,069	123	60	128	62
1995	1,326	153	74	159	77
1996	866	100	48	104	51
1997	770	89	43	92	45
1998	1,493	172	83	179	87
1999	1,353	156	76	162	79
2000	1,313	151	73	157	77
2001	2,301	265	129	276	134
2002	1,347	155	75	161	79
2003	1,435	165	80	172	84
Mean	838	97	47	100	49
s.e.	116	13	7	14	7
Min	42	5	2	5	2
Max	2,301	265	129	276	134
2004	1647	190	92	197	96

Values shown for the staged survival suite are the average of both parameter sets. They did not differ by more than one fish.

Table 7. Numbers of cunner eggs and larvae entrained at PNPS annually, 1980 - 2004. Numbers and equivalent adults are also shown. Estimates based on full-load flow except where indicated.

Cunner	Eggs	Larvae				Equivalent Adults		
		Stage 1	Stage 2	Stage 3	Total	Entrainment Number	Impingement Number	Combined Pounds
1980	3,257,891,776	76,282,260	40,480,032	4,229,248	120,991,540	674,056	1,683	81,089
1981	6,576,294,915	316,245,739	256,567,950	3,508,876	576,322,566	2,384,804	839	286,277
1982	2,010,779,150	6,351,445	3,187,760	597,356	10,136,561	216,988	803	26,135
1983	5,895,329,347	10,961,646	27,571,530	3,955,802	42,488,978	675,563	184	81,090
1984	1,766,764,864	0	176,682	1,029,352	1,206,034	166,908	50	20,035
1985	2,021,886,071	17,182,039	20,392,615	2,307,617	39,882,271	309,750	509	37,231
1986	1,493,653,289	4,419,092	22,197,318	297,368	26,913,778	220,965	224	26,543
1987	4,465,564,080	40,247,222	314,474	248,738	40,810,434	538,325	233	64,627
1988	1,539,089,318	2,290,972	2,624,077	2,461,452	7,376,502	164,908	33	19,793
1989	4,469,416,004	34,100,052	15,224,141	2,863,938	52,188,130	573,769	241	68,881
1990	1,336,048,112	65,705,970	62,378,298	44,014,528	172,098,797	654,158	210	78,524
1991	675,000,390	5,790,172	3,701,490	7,243,966	16,735,627	113,960	402	13,723
1992	2,174,661,078	0	1,186,819	1,605,055	2,791,875	209,474	34	25,141
1993	3,235,317,207	148,674	7,178,133	7,923,303	15,250,109	345,864	104	41,516
1994	1,558,253,667	0	5,545,977	4,440,095	9,986,072	174,726	83	20,977
1995	4,116,491,874	7,961,638	29,910,748	9,257,792	47,130,178	525,573	288	63,103
1996	2,807,124,109	3,765,455	8,094,509	5,558,849	17,418,813	313,002	211	37,586
1997	1,718,289,720	6,444,923	51,895,511	41,294,559	99,634,994	465,986	39	55,923
1998	4,341,664,826	104,908,332	211,248,501	54,060,618	370,217,451	1,542,772	76	185,142
1999	1,717,578,656	36,934,878	11,960,388	7,510,427	56,405,693	332,601	117	39,926
2000	1,349,685,330	22,411,361	39,293,994	1,388,620	63,093,975	319,247	294	38,345
2001	2,744,377,803	1,044,260	34,542,919	35,707,859	71,295,038	473,361	143	56,820
2002	580,954,607	537,068	4,771,751	10,257,985	15,566,804	101,668	53	12,207
2003	759,226,058	352,721	1,783,511	1,865,231	4,001,463	82,467	221	9,923
Mean	2,608,805,927	31,836,913	35,926,214	10,567,860	78,330,987	482,537	295	57,940
s.e.	331,759,579	13,600,872	13,020,383	3,198,732	26,934,282	103,699	75	12,447
	1981, 1984, 1987, 1999 Omitted.							
Mean	2,404,256,987	18,532,904	29,660,482	12,066,562	60,259,948	407,913	292	48,985
s.e.	321,292,270	6,603,902	10,386,253	3,750,942	19,062,766	73,997	84	8,880
2004	1,452,433,321	462,728	7,927,232	8,369,181	16,759,141	188,107	206	22,598

Outage years recalculated with actual circulating water flow.

1984	56,209,029	0	33,596	10,105	43,701	5,324	50	639
1987	1,122,803,794	118,232	119,740	1,868	239,840	104,423	233	12,531
1999	1,098,618,436	30,161,622	8,878,633	7,510,427	46,550,682	242,511	117	29,101

Notes:
Mesh adjustment factors incorporated as necessary.
Egg and larval densities recorded in 1984, 1987, and 1999 are believed to be low relative to densities in surrounding waters.
Applying full load flow values to those densities likely underestimates the numbers which would have been entrained.
1981 omitted from second block because entrainment was unusually high.
Weight based on 0.12 pound per fish.

See text for details.

Table 8. Numbers of Atlantic mackerel eggs and larvae entrained at PNPS annually, 1980 - 2004. Numbers of equivalent age 1 and age 3 fish are also shown. Estimates based on full-load flow.

Year	Total Number Entrained Eggs	Total Number Entrained Larvae	Equivalent Juveniles Age 1 Entrainment Number	Equivalent Juveniles Age 1 Entrainment Pounds	Equivalent Adults Age 3 Entrainment Number	Equivalent Adults Age 3 Impingement Number	Equivalent Adults Total Pounds
1980	81,599,432	22,293,108	1,291	258	531	0	372
1981	183,959,791	320,135,596	15,009	3,002	6,171	46	4,352
1982	108,234,931	9,388,143	808	162	332	0	232
1983	148,616,621	41,333,673	2,385	477	981	11	694
1984	22,486,619	78,315	84	17	35	0	25
1985	1,867,648,438	45,711,343	8,734	1,747	3,591	0	2,514
1986	219,488,066	58,333,520	3,401	680	1,398	0	979
1987	71,222,294	215,561	265	53	109	0	76
1988	2,663,608,568	3,401,489	9,686	1,937	3,982	17	2,799
1989	4,673,915,938	65,562,469	19,667	3,933	8,086	14	5,670
1990	2,313,416,455	4,627,282	8,487	1,697	3,490	10	2,450
1991	479,761,865	66,009,482	4,676	935	1,923	0	1,346
1992	377,610,764	8,086,393	1,714	343	705	0	494
1993	1,801,378,418	8,325,789	6,820	1,364	2,804	0	1,963
1994	520,917,221	3,419,299	2,018	404	830	12	589
1995	1,767,609,278	197,689,693	15,188	3,038	6,245	0	4,372
1996	1,507,370,682	70,947,053	8,575	1,715	3,526	0	2,468
1997	316,969,390	25,778,062	2,290	458	942	0	659
1998	530,017,006	56,622,648	4,435	887	1,824	0	1,277
1999	34,498,141	483,595	145	29	60	0	42
2000	619,863,003	16,496,664	2,958	592	1,216	0	851
2001	150,613,190	4,868,686	756	151	311	0	218
2002	280,852,511	3,704,444	1,171	234	482	0	337
2003	314,571,725	2,790,425	1,251	250	514	0	360
Mean	877,342,931	43,179,280	5,076	1,015	2,087	5	1,464
s.e.	231,910,160	14,906,955	1,104	221	454	2	318
1984, 1987, 1999 Omitted							
Mean	996,572,538	49,310,727	5,777	1,155	2,375	5	1,666
s.e.	254,943,108	16,643,887	1,185	237	487	2	342
2004	70,227,928	10,894,804	740	148	304	0	213

Outage years recalculated with actual circulating water flow.

Year	Eggs	Larvae	Age 1 Number	Age 1 Pounds	Age 3 Entrainment Number	Age 3 Impingement Number	Total Pounds
1984	570,854	2,480	2	0	1	0	1
1987	2,397,224	107,727	12	2	5	0	4
1999	6,182,166	311,394	31	6	13	0	9
2001	134,385,477	4,839,176	698	140	287	0	201

Notes:
Egg and larval densities recorded in 1984, 1987, and 1999 are believed to be low relative to densities in surrounding waters. Applying full load flow values to those densities likely underestimates the numbers which would have been entrained.

See text for details.

Table 9. Numbers of Atlantic menhaden eggs and larvae entrained at PNPS annually, 1980-2004. Numbers of equivalent age 2 and 3 fish are also shown including impingement losses. Estimates based on full-load flow.

Year	Total Number Entrained		Equivalent Adults				
			Age 2			Age 3	
	Eggs	Larvae	Entrainment Number of Fish	Impingement Number of Fish	Weight (lbs)	Entrainment Number of Fish	Impingement Number of Fish
1980	16,468,408	12,060,791	2,748	47	1,677	712	12
1981	3,473,080	40,076,799	7,716	0	4,630	2,000	0
1982	365,091,471	1,845,849	10,439	31	6,282	2,706	8
1983	869,580	1,227,190	257	62	191	67	16
1984	4,751,607	0	131	3	80	34	1
1985	41,131,470	9,190,654	2,884	233	1,870	748	61
1986	21,112,802	3,654,854	1,278	158	862	331	41
1987	311,687	1,560,529	305	0	183	79	0
1988	9,273,771	2,713,857	772	11	470	200	3
1989	11,212,165	4,411,807	1,149	189	803	298	49
1990	7,057,041	3,263,718	816	536	811	211	139
1991	5,744,115	512,319	256	322	347	66	83
1992	392,533	1,117,881	223	4	136	58	1
1993	947,815,345	11,833,443	28,439	8	17,069	7,371	2
1994	10,221,752	2,361,834	732	10	445	190	2
1995	3,280,481	12,419,886	2,452	171	1,574	636	44
1996	4,861,265	8,660,874	1,781	258	1,224	462	67
1997	48,899,715	48,283,152	10,531	176	6,424	2,730	46
1998	44,730,447	33,280,806	7,564	161	4,635	1,961	42
1999	14,395,648	19,324,314	4,072	6,582	6,393	1,055	1,706
2000	882,086	809,127	178	6,255	3,860	46	1,621
2001	4,025,648	1,251,898	349	405	453	91	105
2002	14,464,446	5,164,308	1,382	5,421	4,082	358	1,405
2003	6,027,864	5,364,766	1,187	24,351	15,322	308	6,312
Mean	66,103,934	9,599,611	3,652	1,891	3,326	947	490
s.e.	41,145,547	2,667,901	1,259	1,060	923	326	275
1984, 1987, 1999 Omitted.							
Mean	74,620,737	9,976,467	3,959	1,848	3,484	1,026	479
s.e.	46,859,009	2,957,894	1,422	1,186	1,023	369	307
2004	613,682	176,011	50	749	479	13	194
Plant outage years recalculated with actual circulating water flow.							
1984	300,943	0	8	3	7	2	1
1987	135,755	731,741	143	0	86	37	0
1999	10,385,304	18,939,526	3,888	6,582	6,282	1,008	1,706

Notes:
Egg and larval densities recorded in 1984, 1987, and 1999 are believed to be low relative to densities in surrounding waters. Applying full load flow values to those densities likely underestimates the numbers which would have been entrained.
Weight conversion based on 0.5 pound per fish.
See text for details.

Table 10. Numbers of Atlantic herring larvae entrained at PNPS annually 1980-2004.
Numbers of equivalent age 1 and 3 fish are also shown.

Year	Total Number Larvae Entrained	Equivalent Juveniles\Adults Number Of Fish Entrainment Age 1	Impingement Age 1	Combined Age 3	Weight(lbs) Age 1	Weight(lbs) Age 3
1980	1,068,466	1,566	116	755	50	302
1981	2,471,492	3,622	30	1,640	110	656
1982	732,857	1,074	115	534	36	214
1983	5,880,315	8,618	23	3,879	259	1,552
1984	468,840	687	0	308	21	123
1985	1,580,435	2,316	38	1,057	71	423
1986	1,811,101	2,654	3,760	2,879	192	1,152
1987	5,142,045	7,536	17	3,391	227	1,356
1988	639,089	937	33	435	29	174
1989	911,487	1,336	227	702	47	281
1990	2,079,483	3,048	333	1,518	101	607
1991	1,280,273	1,876	41,419	19,435	1,299	7,774
1992	3,970,208	5,819	34	2,627	176	1,051
1993	2,098,952	3,076	130	1,439	96	576
1994	16,351,765	23,966	36	10,774	720	4,310
1995	43,247,883	63,385	144	28,518	1,906	11,407
1996	9,265,826	13,580	0	6,096	407	2,438
1997	24,445,056	35,827	19	16,091	1,075	6,436
1998	4,026,783	5,902	107	2,697	180	1,079
1999	11,379,446	16,678	70	7,518	502	3,007
2000	12,306,502	18,035	52	8,120	543	3,248
2001	4,062,977	5,955	61	2,701	180	1,080
2002	3,468,890	5,084	319	2,425	162	970
2003	1,045,853	1,533	25	699	47	280
Mean	6,655,668	9,755	1,963	5,260	352	2,104
s.e.	1,990,463	2,917	1,722	1,433	96	573
1984,1987, and 1999 Omitted						
Mean	6,797,414	9,962	2,239	5,477	366	2,191
s.e.	2,248,644	3,296	1,967	1,618	108	647
2,004	4,722,708	6,922	137	3,169	212	1,268

Notes:
Outage periods in 1984 and 1987 may have affected entrainment estimates at the end of the spring larval herring period.
The outage in 1999 occurred after the larval herring season.
Separate averages are shown for consistency with the other species analyzed.
Weight conversion based on 0.03 for age 1, 0.4 pound per age 3 fish.

See text for details.

Table 11. Numbers of Atlantic cod eggs and larvae entrained at PNPS annually, 1980-2004. Numbers of equivalent age 2 fish are also shown.

Year	Total Number Entrained		Equivalent Adults		
			Number Of Fish		Combined Weight (lbs)
	Eggs	Larvae	Entrainment Age 2	Impingement Age 2	Age 2
1980	20,388,850	1,450,522	79	12	183
1981	11,620,588	2,173,076	95	100	389
1982	2,582,984	222,721	11	11	44
1983	9,349,728	142,136	17	0	34
1984	11,726,579	587,054	36	0	73
1985	5,071,151	1,441,442	59	0	119
1986	2,788,767	1,035,987	42	21	126
1987	5,623,282	122,579	12	0	23
1988	2,747,034	254,239	13	0	26
1989	3,395,726	119,436	9	0	17
1990	2,406,536	1,566,291	61	0	121
1991	3,668,649	239,746	13	29	84
1992	2,819,673	469,713	21	9	60
1993	1,268,748	446,489	18	43	121
1994	3,119,312	1,904,519	74	0	148
1995	2,549,370	602,594	25	59	169
1996	8,542,922	2,369,255	98	0	196
1997	1,800,711	1,101,118	43	0	86
1998	4,971,621	735,301	33	62	191
1999	1,932,894	464,125	20	38	116
2000	18,525,824	325,095	35	0	71
2001	6,869,977	4,215,642	164	66	460
2002	4,698,000	1,299,393	54	0	108
2003	7,032,420	2,114,930	88	40	256
Mean	6,062,556	1,058,475	47	20	134
s.e.	1,039,155	200,264	8	6	22
Min	1,268,748	119,436	9	0	17
Max	20,388,850	4,215,642	164	100	460
2004	5,231,113	1,550,052	63	112	350

Notes:
Weight conversion based on 2.0 pounds per fish.

See text for details.

Lobster Larvae Entrained

Nine lobster larvae were found in the entrainment samples collected during 2004. This represents the second highest number of lobster larvae collected in a single year, the record number collected of 16 occurred in 2003. Previously, only 37 larvae were collected at PNPS in total dating back to 1974 including more intensive sampling directed specifically toward lobster larvae in 1976.

No direct relationship between prevailing winds or tide at the time of sampling and the number of entrained larval lobster is apparent. However, since night sampling was added to the protocol in 1995, 91% of the lobster larvae captured were collected during the Friday evening sampling period. That represents 67% of the total larvae captured over the 30-year time period. The addition of a nighttime sample period has likely contributed to the increase in the observed number of lobster larvae entrained since adult female lobsters release larvae at night (Ennis 1975, Charmantier et al. 1991). Additionally, Pilgrim Station established a protection zone around the plant extending seaward from the shorefront for a distance of approximately 1000 feet on September 11, 2001. Within this zone no lobster harvesting is permitted; as a result there may be an increase in nearshore lobster reproductive activity and successful larvae release.

Following is a tabulation of previous collections:

2004: **9 larvae**: 2 stage 1, June 4; 2 stage 1, June 11; 1 stage 1, July 5; 1 stage 1, July 23; 1 stage 1, August 13; 1 stage 3, September 3; 1 stage 4, September 3.

2003: **16 larvae**: 1 stage 2, June 2; 1 stage 3, June 6; 1 stage 3, June 13; 7 stage 3, June 20; 5 stage 3, July 4; 1 stage 1, July 11.

2002: none found

2001: none found.

2000: none found.

1999: **8 larvae:** 4 stage 1, June 18; 1 stage 1, July 3; 1 stage 1, July 5; 1 stage 1, August 6, 1 stage 4, 26 August.

Lobster Larvae (continued).

1996 - 1998: none found.

1995: **1 larva** – stage 4-5, July 28.

1994: none found.

1993: **1 larva** –stage 4-5, July 21.

1991-1992: none found.

1990: **2 larvae** – 1 stage 1, June 26; 1 stage 4, August 23.

1983-1989: none found.

1982: **1 larva** – stage 1 on June 14.

1981: **1 larva** – stage 4 on June 29.

1980: none found.

1979: **1 larva** – stage 1 on July 14.

1978: none found.

1977: **3 larvae** – 1 stage 1, June 10; 2 stage 1, June 17.

1976: **2 larvae** – 1 stage 1, July 22; July 22; 1 stage 4-5, August 5.

1975: **1 larva** – stage 1, date unknown.

1974: none found.

SECTION V

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MARINE ECOLOGY STUDIES

Pilgrim Nuclear Power Station

Section 3.3

Impingement Monitoring

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

IMPINGEMENT OF ORGANISMS on the INTAKE SCREENS

at PILGRIM NUCLEAR POWER STATION

JANUARY - DECEMBER 2004

Submitted to

Entergy Nuclear Generation Company

Pilgrim Nuclear Power Station

Plymouth, Massachusetts

MARINE RESEARCH, INC.

By

Marine Research, Inc.

Falmouth, Massachusetts

April 2005

Introduction

Pilgrim Nuclear Power Station (PNPS) is located on the northwestern shore of Cape Cod Bay (Figure 1) with a licensed capacity of 670 megawatts. The unit has two circulating water pumps with a capacity of approximately 345 cfs (155,500 gallons per minute) each and five service water pumps (2,500 gallons per minute each) with a combined capacity of 23 cfs. Water is drawn under a skimmer wall, through vertical bar racks spaced approximately three inches on center, and finally through vertical traveling screens of ½ x ¼ inch mesh (Figure 2). There are four vertical screens, two for each circulating water pump.

This report provides documentation of environmental monitoring and reporting requirements of NPDES Permit No. 0003557 (USEPA) and No. 359 (MA DEP) at PNPS. This report describes the monitoring of impinged organisms at Pilgrim Station based on screen wash samples taken from January to December 2004.

Methods and Materials

Three scheduled screen wash periods were monitored each week from January to December 2004. These included the 0830 wash on Monday, the 1630 wash on Wednesday, and the 0030 wash on Saturday. Each sampling period thus represented a separate, distinct eight-hour period. Prior to each sampling period, the time of the previous screen wash was obtained from a strip chart recorder located in the screen house to permit the current sampling interval to be calculated. Whenever the screens were static upon arrival, a 30-minute sample was collected and, whenever the screens were operating continuously, a 60-minute sample was obtained.

Water nozzles directed at the screens washed impinged organisms and debris into a sluiceway which was sampled by inserting a collection basket made of stainless steel mesh. All fauna were identified and noted as being alive, dead, or injured. Fish were determined to be alive if they showed opercular movement and no obvious signs of injury. Fauna determined to be alive were measured for total length (mm), then released. Those determined to be dead or injured were preserved. In the lab, the weights (grams) and total lengths (mm) were recorded for up to 20 specimens of each species. The impingement rate was calculated by dividing the number of fish collected by the number of hours in the collection period. Counts made at each collection during a month were extrapolated to estimate a monthly total ($\sum$ number of fish $\div \sum$ sample hours) $\times$ 24 hours $\times$ number day per month) These monthly totals were summed to derive an annual total adjusted for number of collection hours.

If an impingement rate of 20 fish per hour was obtained for static washes, an additional one-hour sample was taken. If at least 20 fish were taken in the extra 60-minute period or immediately following a continuous wash, the Operator and Shift Manager were immediately informed and advised to leave the screens operating until further notice. In the interim, other communication typically occurred in order to keep all appropriate individuals updated. The contractor then collected two additional one-hour screenwash periods at four-hour intervals. If 20 or more fish/hour were taken in the fourth sample, screenwashes were monitored for one hour at eight-hour intervals until impingement rates declined to less than 20 fish per hour.

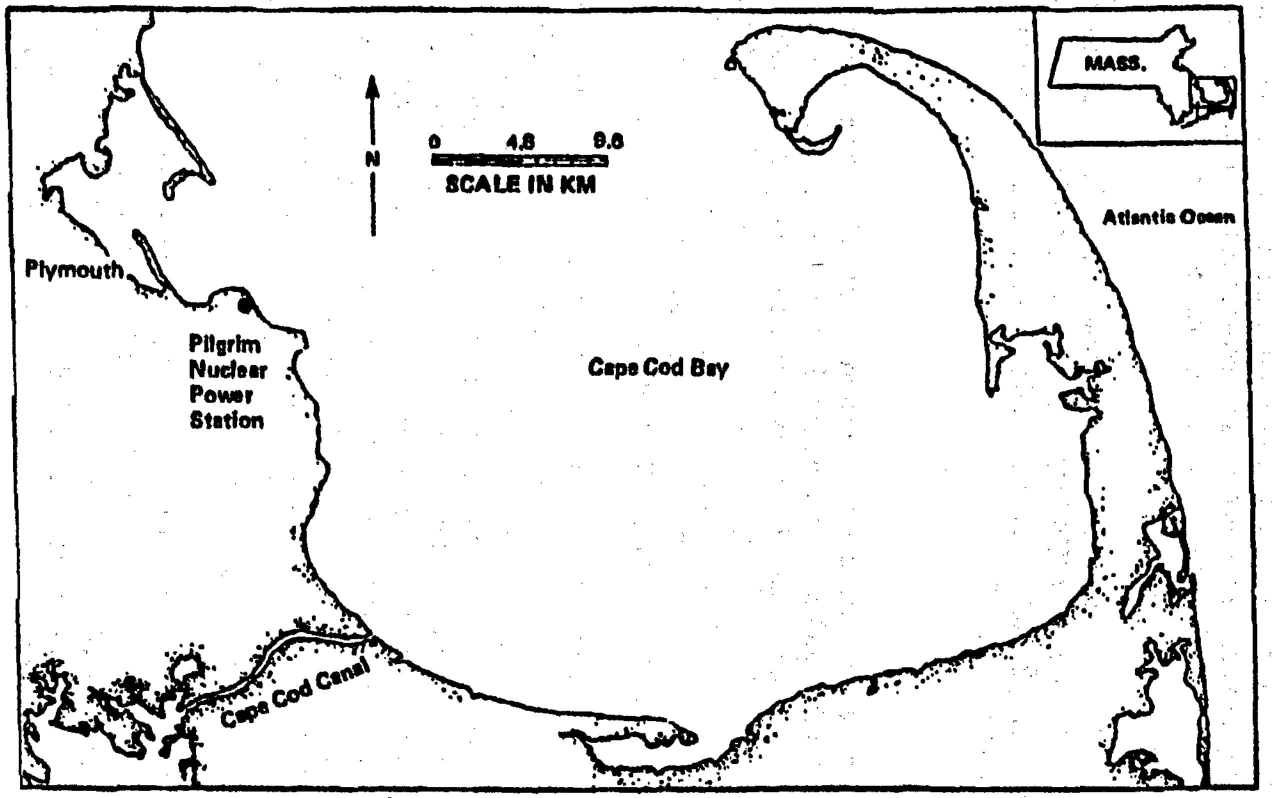

Figure 1. Location of Pilgrim Nuclear Power Station

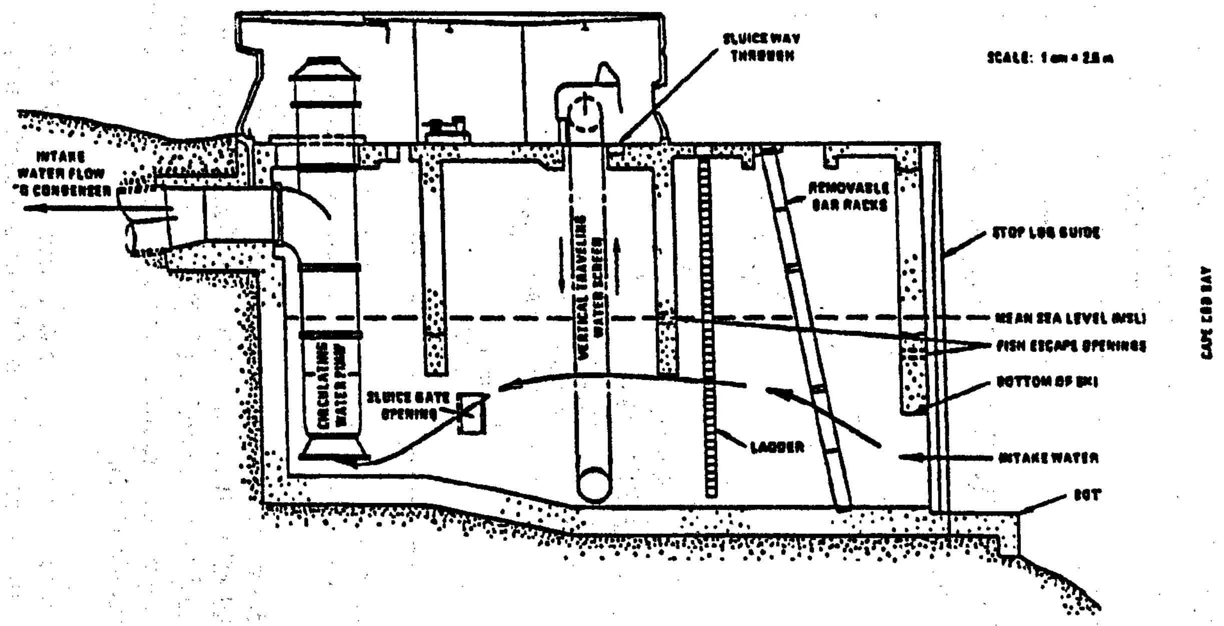

Figure 2. Cross-section of intake structure of Pilgrim Nuclear Power Station.

Results and Discussion

Fish

In 638.3 collection hours, an estimated total of 33,591 fish consisting of 35 species was collected during sampling from January - December 2004 (Table 1, Figure 3). Atlantic silversides (*Menidia menidia*), Atlantic menhaden, (*Brevoortia tyrannus*), grubby (*Myoxocephalus aenaeus*), blueback herring (*Alosa aestivalis*), winter flounder (*Pseudopleuronectes americanus*), and rainbow smelt (*Osmerus mordax*) accounted for 92% of the annual total. The impingement rate for 2004 was 2.85 fish per hour (Table 1). Impingement of all fish was highest in November (17.79 fish/hour) and lowest in June (0.04 fish/hour).

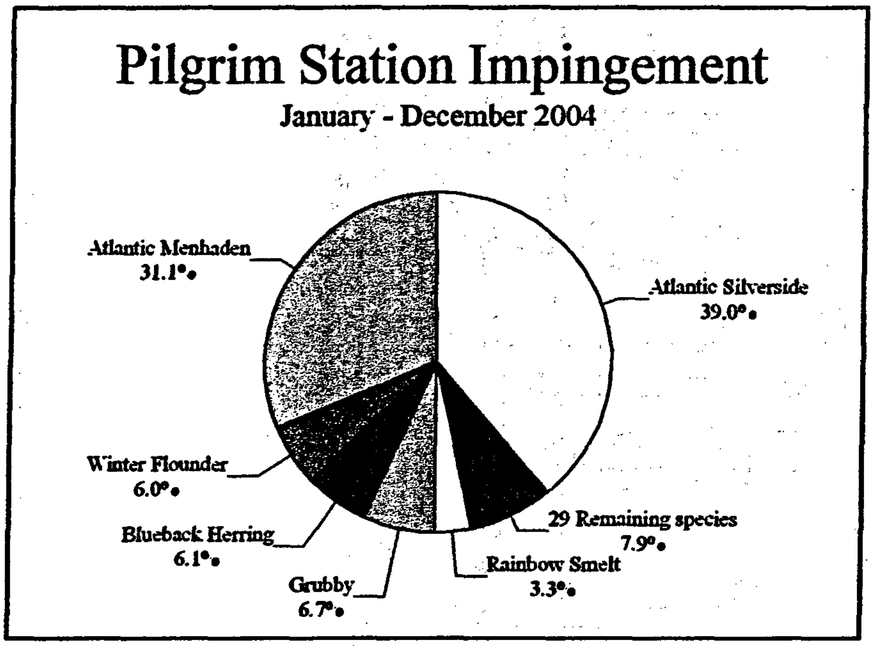

Figure 3. Percent of total for numerically dominant species of fish impinged on the Pilgrim Nuclear Power Station intake screens, January to December 2004.

Atlantic silversides, historically one of the most numerous fish impinged at PNPS, ranked first with an estimated annual total of 13,107 fish, Silversides were most abundant in April (7,393 fish), when 56% of the annual total was collected (Table 1). Impinged silversides were young-of-the-year and age 1 fish ranging in size from 52 to 175 mm, and had a mean length of 94 mm (Table 2; Conover and Murawski 1982).

Atlantic menhaden ranked second in the 2004 catch with 10,431 extrapolated total fish collected and were most abundant in November when 58% of the annual total was impinged (Table 1). Most of the menhaden impinged were young-of-the-year between 30 and 97 mm, averaging 65 mm in length (Table 2).

Grubby ranked third accounting for 6.7% of the annual catch (2,257 fish, Table 1). Grubby were most abundant in November and ranged in size from 39 to 120 mm with a mean length of 70 mm.

Blueback herring ranked fourth with 2,045 fish and were most abundant in December (1,552 fish) when 76% of the annual estimated total was obtained (Table 1). Blueback herring averaged 89 mm in length and ranged from 56 to 137 mm suggesting they were young-of-the-year (Table 2).

Winter founder ranked fifth accounting for 6% of the annual catch (2,021 fish; Table 1). Young-of-the-year winter flounder dominated the catch which ranged in size from 35 to 340 mm with a mean of 70 mm (Table 2). There were only three fish greater than 150 mm (age 2 and older) sampled Winter flounder were most abundant in November with 36% of the estimated annual catch.

Rainbow smelt (1,092 fish) ranked sixth in 2004. Smelt were most abundant in November and ranged from 40 to 220 mm and averaged 105 mm total length.

Annual extrapolated totals for typical dominants impinged from 1980 to 2004 along with their respective 1980 to 2003 long-term means are shown in Table 3 and Figure 4. These fish typically account for greater than 90% of the annual total collected on the screens, averaging 91% from 1990 to 2003. In 2004, these species accounted for 95% of the annual total. The 2004 impingement total for all fish was 61% of the 14-year mean of 3,329 fish collected.

Atlantic silverside were impinged in numbers slightly greater than their 24-year mean of 11,306 fish collected while Atlantic menhaden were taken in numbers just below their long-term mean of 11,226 fish. These two species typically ranked either first or second each year from 1980 to 2004 (Table 3). Grubby, blueback herring and winter flounder were also sampled in numbers 4, 2.6 and 2.3 times their respective 24-year means of 558, 777, and 871 fish. All other species except Atlantic tomcod (*Microgadus tomcod*) and hakes (*Urophycis spp.*) were sampled in below average numbers (Table 3 and Figure 4).

Impingement Rates

In 2004 there was one impingement event (≥ 20 fish/hour) which occurred on November 1. The impingement rate for that event was 145 fish/hour and the dominant species was young of the year menhaden (mean total length = 62 mm; range 48 to 97 mm). Three additional samples were taken yielding impingement rates between 0 and 3 fish/hour; demonstrating that the event lasted only a short period.

Previous large impingement events (≥1,000 fish) at PNPS since 1973 are documented in Table 4. There were no large impingement events in 2004. These events often occur in the late summer and autumn when young fish are abundant, actively moving offshore for the winter and water temperatures are declining. As water temperatures decline metabolism declines along with swimming ability.

Impingement rates (number of fish collected divided by number of collection hours) for each species and their respective estimated annual totals are presented in Table 5. Silverside and menhaden yielded the highest impingement rates (1.51 and 0.52 fish/hour, respectively). For all species combined, the impingement rates were 2.85 fish/hour and 34,485 fish/year, ranking eighth over the 25-year time series from 1980 to 2004 (Table 6). The average annual impingement total for 1980 to 2003 was 34,485 fish per year, ranging from 1,112 (1984) to 179,608 (2003) fish per year.

Since 1980, 73 species of fish have been collected on the PNPS intake screens (Table 7). Nine species of fish (alewife (*Alosa pseudoharengus*), Atlantic silverside, Atlantic tomcod, blueback herring, cunner (*Tautogolabrus adspersus*), grubby, hakes, rainbow smelt, and winter flounder) were collected every year from 1980 to 2004. Six other species (Atlantic herring, Atlantic menhaden, lumpfish (*Clyclopterus lumbus*), rock gunnel (*Pholis gunnellus*), tautog (*Tautoga onitis*), and windowpane (*Scophthalmus aquosus*) were present at least 90% of the time (≥23 annual occurrences).

Invertebrates

From January to December 2004, 20,566 invertebrates representing 12 taxa (Table 8) were sampled yielding an impingement rate of 2.63 invertebrates per hour. Sevenspine bay shrimp (*Crangon septemspinosa*) were dominant accounting for 78% of the annual estimated total. They were primarily impinged in February and April when 64% of the 16,056 estimated total were collected. Rock crab (*Cancer irroratus*) was sampled every month except June, and ranked second (2,485 crabs) accounting for 12% of the annual total of all invertebrates impinged. Twenty-two American lobsters (*Homarus americanus*) were impinged during sampling periods in 2004 ranging in size from 34 to 98 mm, yielding an annual total of 434 lobsters. Of the 22 lobsters collected the largest was of legal size (≥ 82 mm) and the rest were less that 75 mm and likely juveniles.

Fish Survival

Initial survival among fish impinged was recorded immediately upon removal from the collection basket (Table 9). Initial survival rates (number of fish alive/number of fish collected) for continuous wash periods (34%) were greater than those for static wash periods (19%). This reduced survival for the static washes could be attributed to the poor survivability for the large numbers of Atlantic silverside impinged. Among the four most abundant fishes impinged, Atlantic silverside, Atlantic menhaden, winter flounder, and blueback herring, survival during continuous wash periods was higher than in static wash periods. As in previous years, initial survival rates were typically higher during continuous wash periods presumably due to the reduced exposure time on the screens (MRI 1983, Anderson 2000).

Combined initial survival rates for static and continuous wash periods for each species in which more than 20 fish were sampled in 2004 was greater than 50% in each case except for Atlantic silverside Atlantic menhaden, blueback herring, and rainbow smelt (7, 11, 30 and 8%, respectively). These four species are generally sensitive to impingement effects. The high combined survival rates for winter flounder and grubby (85 and 83%, respectively) were not surprising since their respective static survival rates (83 and 82%) indicated their high tolerance of impingement. That is consistent with observations at other surface water intake structures (MRI 1997, and 1982).

Conclusions

1. The average hourly impingement rate for 2004 at Pilgrim Station from January to December was 2.85.

2. Thirty-five species of fish were sampled in 638.3 collection hours in 2004.

3. Atlantic silverside, Atlantic menhaden, grubby, blueback herring, winter flounder, and rainbow smelt accounted for 39, 31, 7, 6, 6, and 3%, respectively, of the extrapolated annual total of 33,591 fish.

4. The estimated annual impingement total of 33,591 fish was 97% of the 1980 to 2003 mean of 34,485 fish, ranking eigth for the 25-year time series.

5. Invertebrates were impinged at a rate of 2.63 per hour. Sevenspine bay shrimp and rock crabs accounted for 78 and 12% of the 2004 estimated annual total of 16,056 invertebrates.

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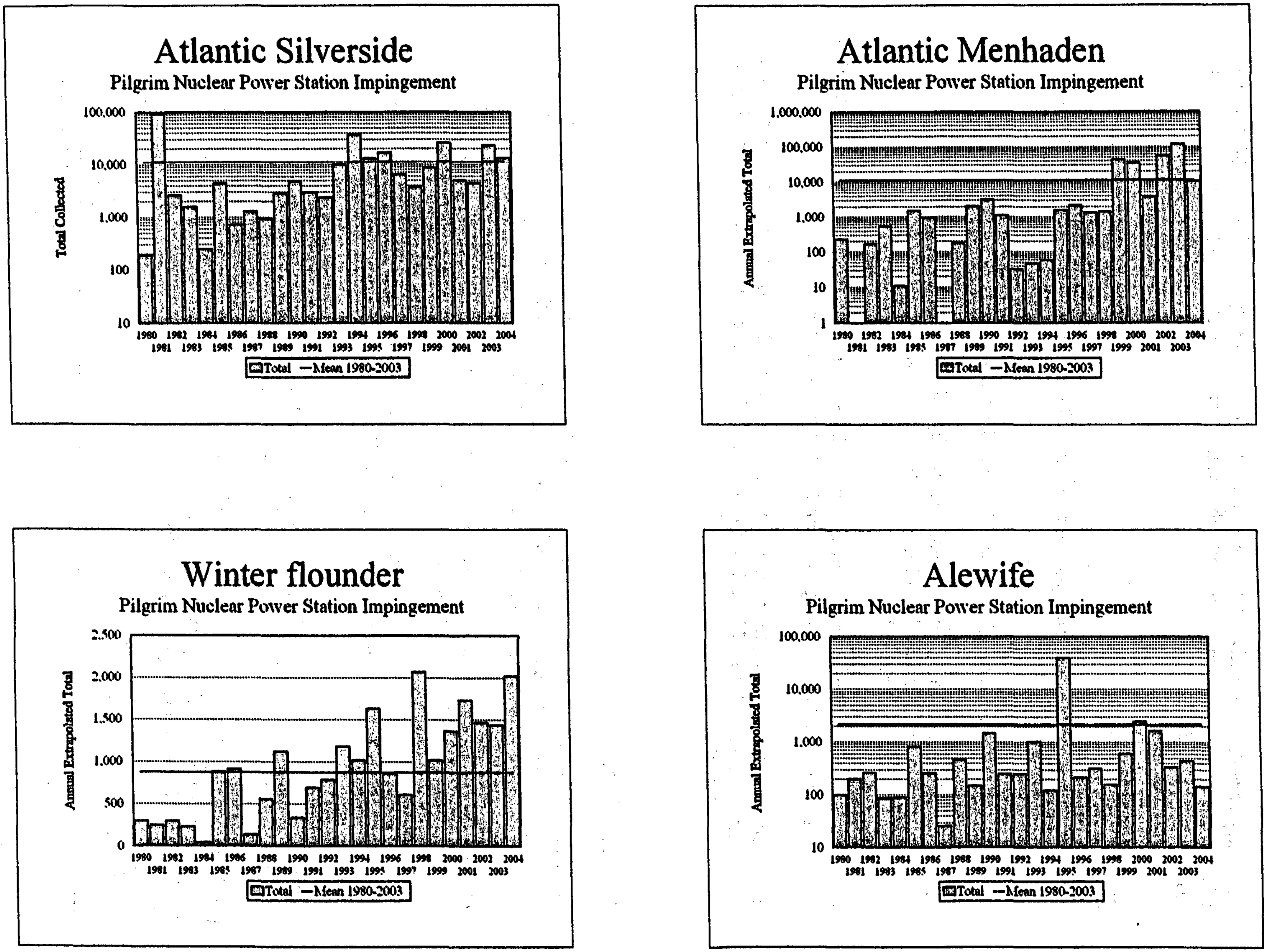
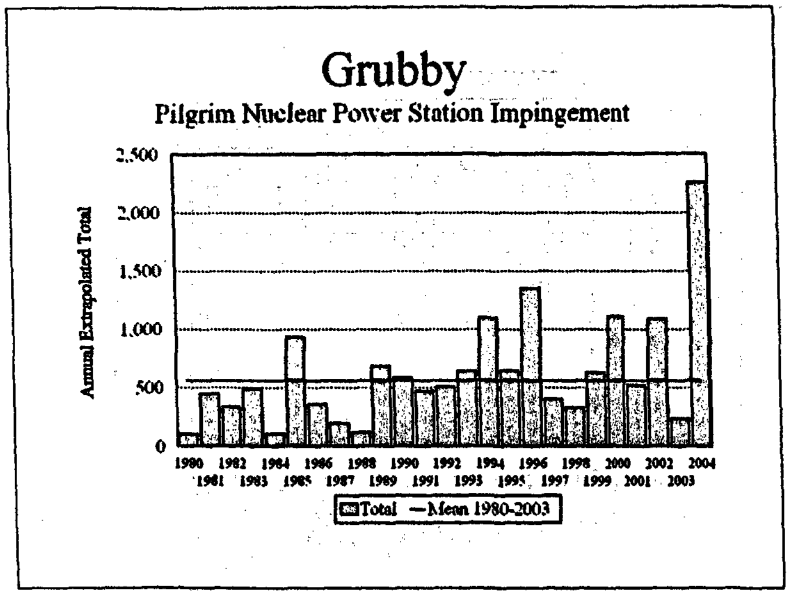
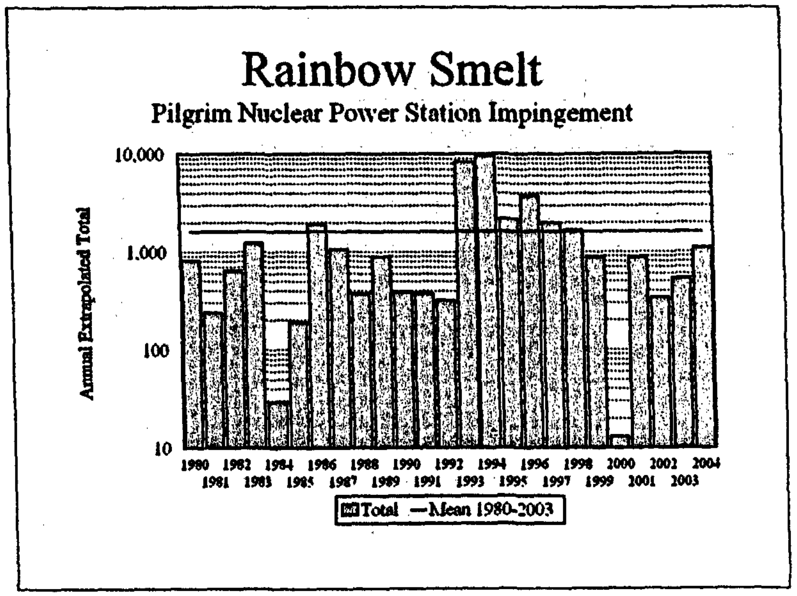
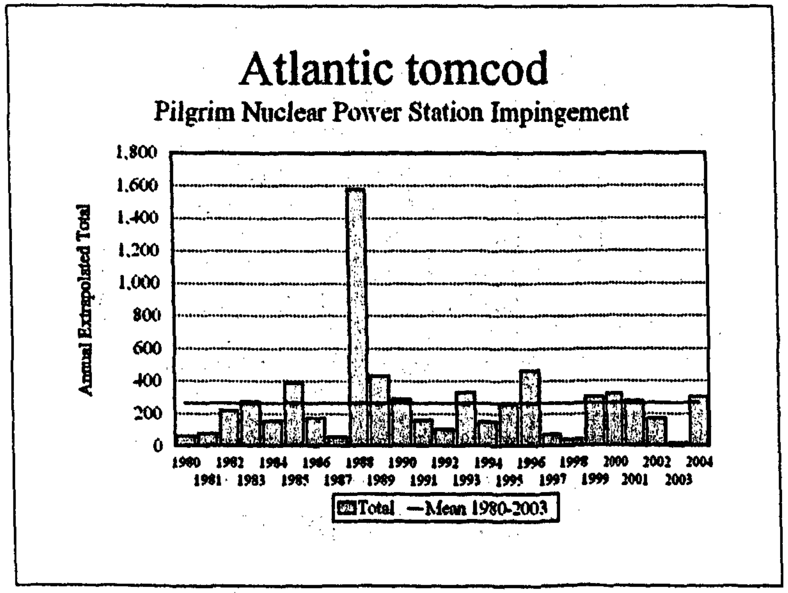
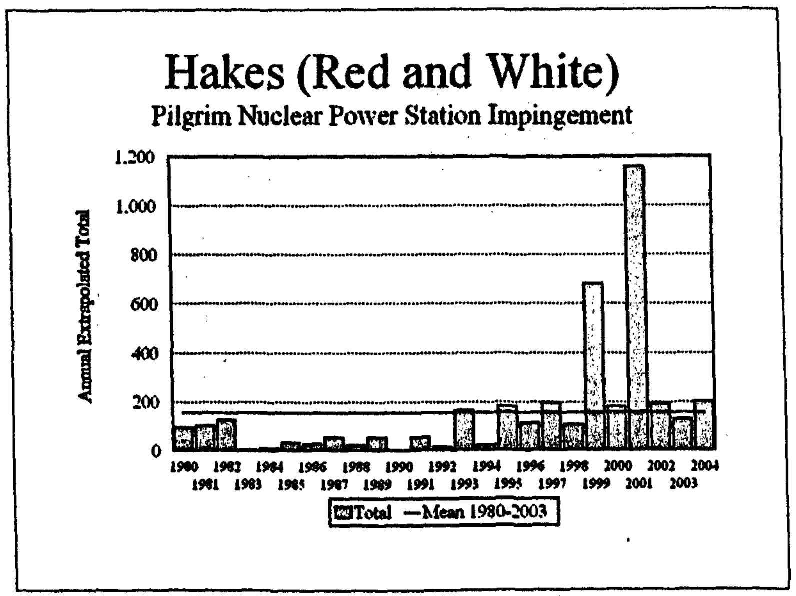


Figure 4. Extrapolated annual totals for typical numerical dominants impinged at Pilgrim Nuclear Power Station, 1980-2004.









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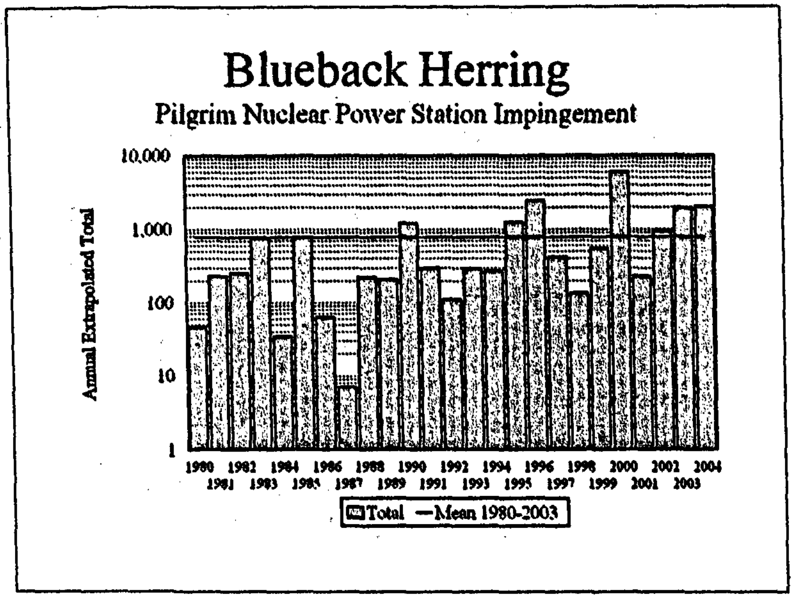

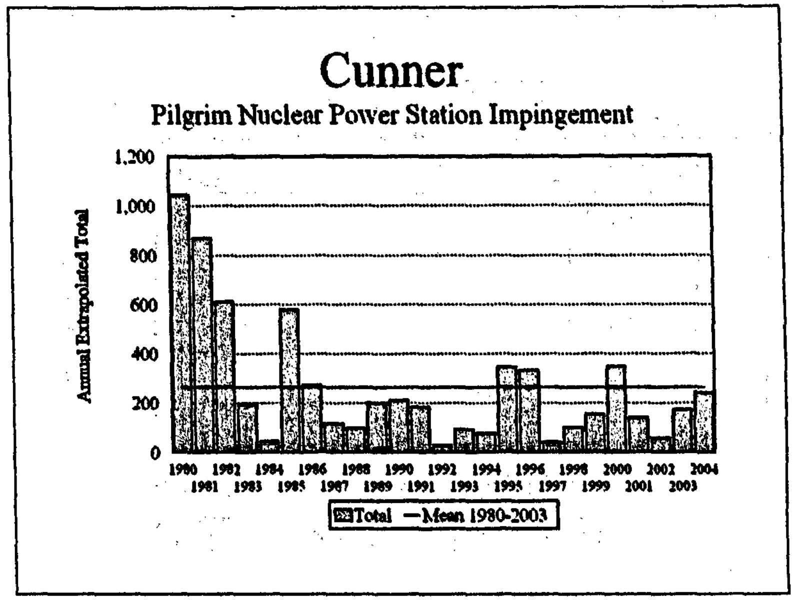

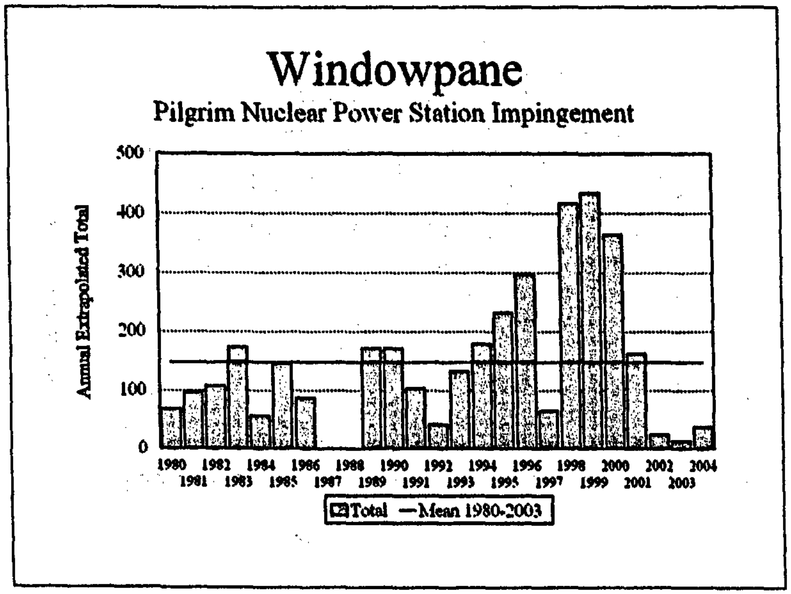

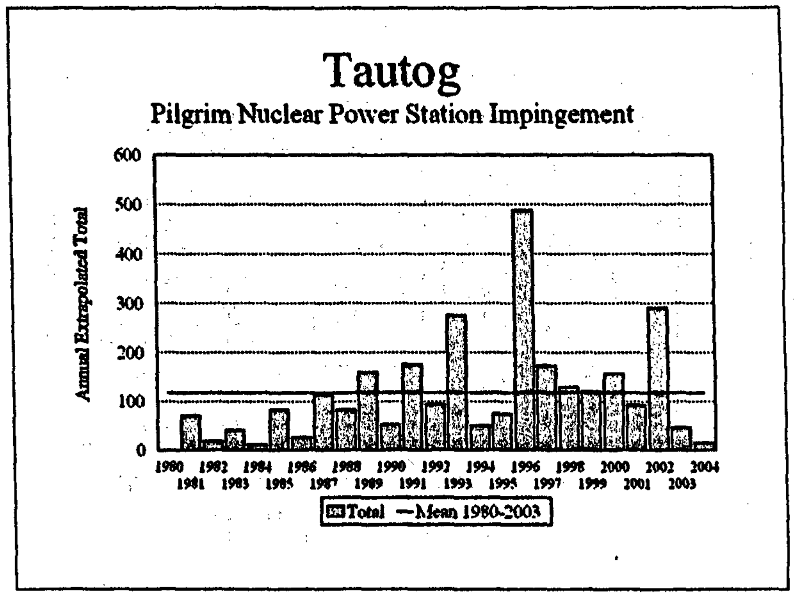

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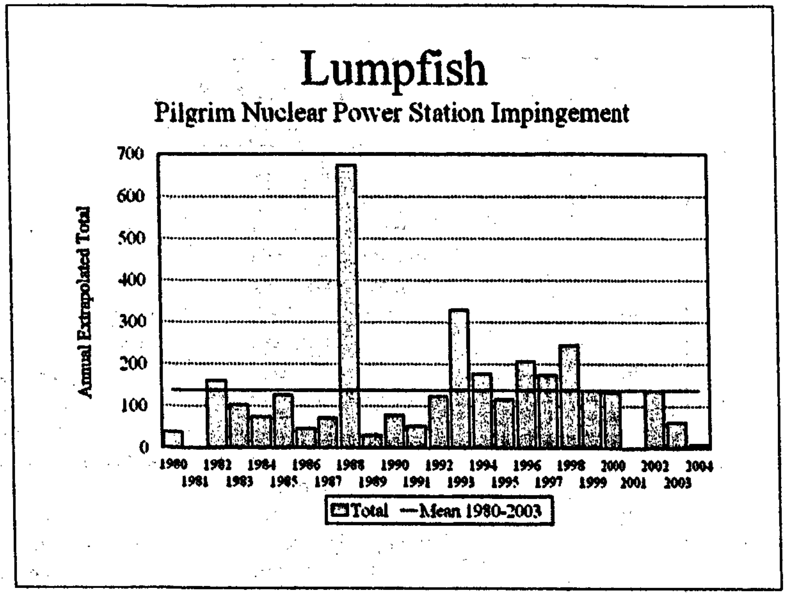

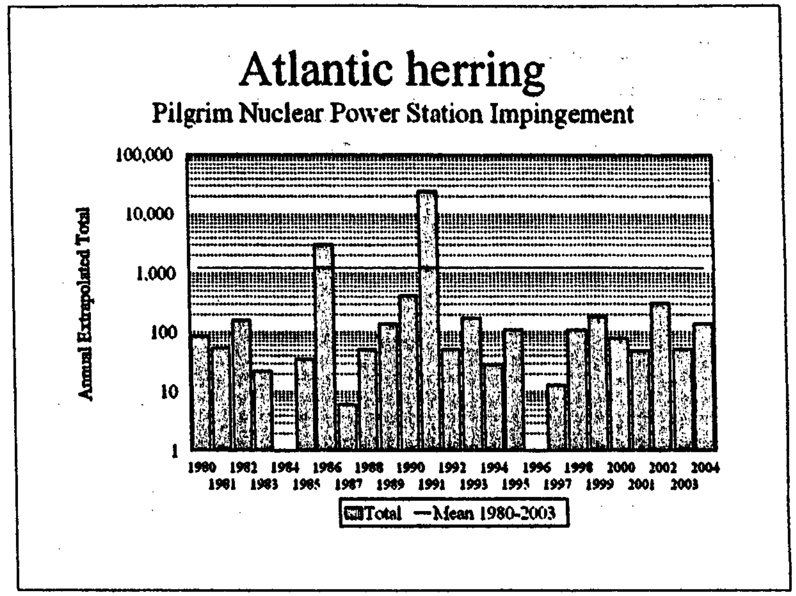

Figure 4. (continued).

Table 1. Monthly extrapolated totals for all fishes collected from Pilgrim Station intake screens, January-December 2004.

Common Name	Species	2004 Summary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Atlantic Silverside	*Menidia menidia*	13,107	127	287	3,011	7,393	1,113					75	953	146
Atlantic Menhaden	*Brevoortia tyrannus*	10,431	93			41			15	848	247	786	8,309	91
Grubby	*Myoxocephalus aenaeus*	2,257	51	39	43	178	42		15			37	1,542	310
Blueback Herring	*Alosa aestivalis*	2,045	17		43	123	53						257	1,552
Winter Flounder	*Pseudopleuronectes americanus*	2,021	119	147	57	383	138		15	12		75	728	347
Rainbow Smelt	*Osmerus mordax*	1,092	8	15	43	137					27		514	347
Atlantic Tomcod	*Microgadus tomcod*	304	17			14	53					19	128	73
Cunner	*Tautogolabrus adspersus*	240		8	14		42		59			37	43	37
Little Skate	*Leucoraja erinacea*	237					42		30	61		19	86	
Hakes (Red and White)	*Urophycis spp.*	202								12		19	171	
Threespine Stickleback	*Gasterosteus aculeatus*	158			128	14		16						
Black Sea Bass	*Centropristis striata*	147										19	128	
Alewife	*Alosa pseudoharengus*	145				41							86	18
Striped Bass	*Morone saxatilis*	139		93		27								18
Atlantic Herring	*Clupea harengus*	138				110	11							18
Fourspot Flounder	*Paralichthys oblongus*	122	25	8	43	27								18
Striped Killifish	*Fundulus majalis*	121				14					27	37	43	
Atlantic Cod	*Gadus morhua*	99	34	8			42		15					
White Perch	*Morone americana*	86											86	
Scup	*Stenotomus chrysops*	72	8							36	27			
Pollock	*Pollachius virens*	53					11						43	
Northern Searobin	*Prionotus carolinus*	51		8									43	
Tautog	*Tautoga onitis*	43											43	
Summer Flounder	*Paralichthys dentatus*	41				41								
Sand Lance	*Ammodytes sp.*	38				27	11							
Windowpane	*Scophthalmus aquosus*	37		15			21							
Yellowtail Flounder	*Limanda ferruginea*	37												37
Butterfish	*Peprilus triacanthus*	31								12		19		
Rock Gunnel	*Pholis gunnellus*	24				14	11							
Smooth Dogfish	*Mustelus canis*	16						16						
Radiated Shanny	*Ulvaria subbifurcata*	14			14									
Northern Pipefish	*Syngnathus fuscus*	14				14								
Ocean Pout	*Zoarces americanus*	14				14								
Lumpfish	*Cyclopterus lumpus*	8	8											
Atlantic Seasnail	*Liparis atlanticus*	8		8										
Species Count		35	11	11	9	18	13	2	6	6	4	11	17	13
Extrapolated Totals		33,591	509	635	3,397	8,612	1,591	31	148	981	329	1,142	13,203	3,013
Number of "Collection Hours"		638.3	87.7	89.8	52.1	54.3	70.2	47.5	50.3	61.4	27.1	39.8	17.4	40.8
Impingement Rate (# fish/hour)		2.85	0.68	0.91	4.57	11.91	2.14	0.04	0.20	1.32	0.44	1.53	17.79	4.05

Marine Research, Inc.

Table 2. Species, number, length and weight for all fish impinged at Pilgrim Station, January - December 2004.

Common Name	Species	Number Collected	Length (mm) n	Length (mm) Mean	Length (mm) Min	Length (mm) Max	Weight (g) n	Weight (g) Mean	Weight (g) Min	Weight (g) Max
Atlantic Silverside	*Menidia menidia*	961	331	94	52	175	268	4	1	9
Atlantic Menhaden	*Brevoortia tyrannus*	335	189	65	30	97	126	3	0	8
Winter Flounder	*Pseudopleuronectes americanus*	120	120	70	35	340	22	2	1	8
Blueback Herring	*Alosa aestivalis*	110	68	89	56	137	52	4	1	15
Grubby	*Myoxocephalus aenaeus*	87	56	70	39	120	8	5	1	9
Rainbow Smelt	*Osmerus mordax*	48	47	105	40	220	40	8	1	62
Atlantic Tomcod	*Microgadus tomcod*	16	16	103	51	196	1	11	11	11
Striped Bass	*Morone saxatilis*	15	15	460	315	538	0			
Cunner	*Tautogolabrus adspersus*	15	14	102	47	210	4	7	1	14
Little Skate	*Leucoraja erinacea*	14	14	398	200	501	0			
Threespine Stickleback	*Gasterosteus aculeatus*	11	11	56	47	65	1	2	2	2
Atlantic Herring	*Clupea harengus*	10	10	91	30	290	1	121	121	121
Atlantic Cod	*Gadus morhua*	10	10	111	54	165	3	11	2	26
Fourspot Flounder	*Paralichthys oblongus*	10	10	64	47	103	1	1	1	1
Alewife	*Alosa pseudoharengus*	6	6	99	59	172	5	10	1	37
Red Hake	*Urophycis chuss*	6	5	113	74	190	2	4	4	5
Striped Killifish	*Fundulus majalis*	5	5	77	67	94	0			
Scup	*Stenotomus chrysops*	5	5	49	32	80	4	2	1	6
Black Sea Bass	*Centropristis striata*	4	4	70	51	88	2	5	2	8
Windowpane	*Scophthalmus aquosus*	4	4	120	103	140	2	10	10	11
Sand Lance	*Ammodytes sp.*	3	3	140	129	147	0			
Summer Flounder	*Paralichthys dentatus*	3	3	57	46	63	0			
Pollock	*Pollachius virens*	2	2	134	74	193	0			
Northern Searobin	*Prionotus carolinus*	2	2	72	47	97	1	2	2	2
White Perch	*Morone americana*	2	2	164	92	236	1	8	8	8
Rock Gunnel	*Pholis gunnellus*	2	2	123	110	136	0			
Butterfish	*Peprilus triacanthus*	2	2	61	60	61	2	2	2	3
Yellowtail Flounder	*Limanda ferruginea*	2	2	143	66	220	1	74	74	74
Smooth Dogfish	*Mustelus canis*	1	1	166	166	166	1	20	20	20
Northern Pipefish	*Syngnathus fuscus*	1	2	149	147	150	0			
Lumpfish	*Cyclopterus lumpus*	1	1	93	93	93	0			
Atlantic Seasnail	*Liparis atlanticus*	1	1	63	63	63	1	3	3	3
Tautog	*Tautoga onitis*	1	1	86	86	86	0			
Ocean Pout	*Zoarces americanus*	1	1	165	165	165	0			
Radiated Shanny	*Ulvaria subbifurcata*	1	1	78	78	78	1	3	3	3

Table 3. Annual extrapolated totals for typical dominants found on the Pilgrim Station intake screens, 1980-2004.

Species	1980	1981	1982	1983	1984[1]	1985	1986	1987[2]	1988	1989	1990	1991	1992	1993	1994[3]	1995[4]	1996	1997	1998	1999[5]	2000	2001[6]	2002	2003[7]	Mean 1990-2003	2004
Atantic silverside	191	90,449	2,626	1,586	245	4,417	702	1,298	940	2,838	4,761	2,955	2,381	9,872	36,498	13,085	16,615	6,303	6,773	8,577	25,665	4,987	4,430	23,149	11,306	13,107
Atlantic menhaden	226	0	171	522	11	1,491	953	0	177	2,020	3,135	1,117	32	46	58	1,560	2,168	1,329	1,423	42,686	34,354	3,599	53,304	119,041	11,226	10,431
Winter flounder	297	249	297	232	47	884	908	138	556	1,119	336	694	787	1,181	1,018	1,628	857	608	2,069	1,021	1,358	1,729	1,466	1,435	871	2,021
Blueback herring	46	230	251	754	34	791	63	7	222	207	1,194	298	110	295	269	1,244	2,462	424	134	550	5,919	229	943	1,968	777	2,046
Grubby	107	448	340	490	114	932	359	200	124	684	585	468	507	640	1,094	648	1,347	405	335	628	1,105	517	1,087	237	558	2,257
Rainbow smelt	814	236	634	1,224	29	189	1,909	1,070	370	886	387	372	317	8,302	9,464	2,191	3,728	1,978	1,656	875	13	879	335	532	1,600	1,092
Atlantic tomcod	63	76	221	276	157	389	174	57	1,578	433	291	159	104	329	153	260	466	72	40	302	323	278	168	19	266	304
Cunner	1,043	870	610	196	45	580	270	115	97	199	210	182	28	93	77	346	332	41	101	153	348	140	59	172	263	240
Atlantic herring	83	53	156	22	0	35	3,009	6	51	138	408	24,238	51	169	28	108	0	13	108	181	77	48	301	51	1,222	138
Alewife	99	201	262	83	88	807	261	26	464	149	1,480	250	247	1,021	123	39,884	216	317	158	610	2,443	1,618	334	438	2,149	145
Hakes (Red and White)	93	101	125	0	8	34	27	53	23	55	0	55	14	166	23	182	113	196	106	682	182	1,158	192	128	155	202
Windowpane	68	96	107	173	56	146	87	0	0	171	171	103	41	133	179	232	296	65	416	434	363	162	24	13	147	37
Tautog	0	69	18	41	11	83	26	113	82	159	52	175	93	275	50	73	488	172	129	119	157	92	289	46	117	14
Lumpfish	38	0	160	103	75	125	46	72	674	30	78	51	122	329	177	116	206	173	244	136	131	0	137	61	137	8
Total above species	3,168	93,078	5,978	5,702	920	10,903	8,794	3,155	5,358	9,088	13,088	31,117	4,834	22,851	49,211	61,557	29,294	12,096	13,692	56,954	72,438	15,436	63,069	147,290	30,795	32,042
Total all fish	4,030	95,336	8,411	6,558	1,112	12,499	9,259	3,782	6,675	10,289	15,939	32,080	5,397	24,105	50,439	62,616	30,264	14,230	14,303	58,318	103,986	15,636	64,606	179,608	34,562	33,591
Percent of total	79%	98%	71%	87%	83%	87%	95%	83%	80%	88%	82%	97%	90%	95%	98%	98%	97%	85%	96%	98%	70%	99%	98%	82%	89%	95%
Collection Time (hrs.)	687	574.8	687	763	1,042	465	806	527	525	618	919.5	930.3	774.0	673.5	737.4	607.7	416	455	575	375.5	507	430.1	494.4	714.1	638	638.3
Impingement Rate (all fish)																										

1 No CWS pumps were in operation April to August 1984.
2 No CWS pumps were in operation August 1987
3 No CWS pumps were in operation 9 October - 14 November 1994.
4 No CWS pumps were in operation 30 March - 15 May 1995.
5 No CWS pumps were in operation 10 May - 10 June 1999.
6 No CWS pumps were in operation 28 April - 9 May 2001.
7 No CWS pumps were in operation 21 April - 11 May 2003.

Table 4. Dominant species and annual estimated number impinged from high impingement events at PNPS, 1973-2004.

Date	Species	Estimated Number for all Species
August-September, 1973	Clupeids	1,600
August 5, 1976	Alewife	1,900
November 23-28, 1978	Atlantic menhaden	10,200
December 11-29, 1978	Rainbow smelt	6,200
March/April, 1979	Atlantic silverside	1,100
September 23-24, 1981	Atlantic silverside	6,000
July 22-25, 1991	Rainbow smelt	4,200
December 15-28, 1993	Atlantic silverside	5,100
November 26-28, 1994	Atlantic silverside	5,800
December 26-28, 1994	Atlantic silverside and Rainbow smelt	11,400
September 8-9, 1995	Alewife	13,100
September 17-18, 1999	Atlantic menhaden	4,910
November 17-20, 2000	Atlantic menhaden	19,900
August/September, 2002	Atlantic menhaden	33,300
November 1, 2003	Atlantic menhaden	2,500
November 12 - 17, 2003	Atlantic menhaden	63,900
November 19 - 21, 2003	Sand lance and Atlantic menhaden	17,900
November 29, 2003	Atlantic silverside	3,900

Table 5. Impingement rates per hour and year for all fishes sampled from Pilgrim Station intake screens, January-December 2004 (assuming 100% operation).

Species	Rate/Hr	Estimated Annual Rate	Dominant month of occurrence	Total Collected
Atlantic Silverside	1.51	13,107	April	961
Atlantic Menhaden	0.52	10,431	November	335
Winter Flounder	0.19	2,021	November	120
Blueback Herring	0.17	2,045	December	110
Grubby	0.14	2,257	November	87
Rainbow Smelt	0.08	1,092	November	48
Atlantic Tomcod	0.03	304	November	16
Striped Bass	0.02	139	April	15
Cunner	0.02	240	July	15
Little Skate	0.02	237	November	14
Threespine Stickleback	0.02	158	March	11
Atlantic Herring	0.02	138	April	10
Atlantic Cod	0.02	99	May	10
Fourspot Flounder	0.02	122	March	10
Alewife	0.01	145	November	6
Red Hake	0.01	202	November	6
Striped Killifish	0.01	121	November	5
Scup	0.01	72	August	5
Black Sea Bass	0.01	147	November	4
Windowpane	0.01	37	May	4
Sand Lance	0.005	38	April	3
Summer Flounder	0.005	41	April	3
Pollock	0.003	53	November	2
Northern Searobin	0.003	51	November	2
White Perch	0.003	86	November	2
Rock Gunnel	0.003	24	April	2
Butterfish	0.003	31	October	2
Yellowtail Flounder	0.003	37	December	2
Smooth Dogfish	0.002	16	June	1
Northern Pipefish	0.002	14	April	1
Lumpfish	0.002	8	January	1
Atlantic Seasnail	0.002	8	February	1
Tautog	0.002	43	November	1
Ocean Pout	0.002	14	April	1
Radiated Shanny	0.002	14	March	1
Total	2.85	33,591		1,817

Table 6. Hourly, daily, and estimated annual impingement rates for all species combined and annual dominants collected on the PNPS intake screens, 1980-2004.

Year	Fish/Hour	Fish/Year	Dominant Species (Number/Year)
1980	0.66	4,030	Cunner (1,043)
1981	10.02	95,336	Atlantic silverside (90,449)
1982	0.93	8,411	Atlantic silverside (2,626)
1983	0.57	6,558	Atlantic silverside (1,586)
1984	0.13	1,112	Atlantic silverside (245)
1985	1.14	12,499	Atlantic silverside (4,417)
1986	1.26	9,259	Atlantic herring (3,009)
1987	0.28	3,155	Atlantic silverside (1,298)
1988	0.27	6,675	Atlantic tomcod (1,578)
1989	0.80	9,088	Atlantic silverside (2,838)
1990	1.70	15,939	Atlantic silverside (4,761)
1991	3.38	32,080	Atlantic herring (24,238)
1992	0.63	5,397	Atlantic silverside (2,381)
1993	2.78	24,105	Atlantic silverside (9,872)
1994	5.97	50,439	Atlantic silverside (36,498)
1995	5.87	62,616	Alewife (39,884)
1996	3.11	30,264	Atlantic silverside (16,615)
1997	1.43	14,230	Atlantic silverside (6,303)
1998	1.30	14,303	Atlantic silverside (6,773)
1999	7.21	58,318	Atlantic menhaden (42,686)
2000	9.25	103,968	Atlantic menhaden (34,354)
2001	1.78	15,636	Atlantic silverside (4,987)
2002	4.93	64,606	Atlantic menhaden (53,304)
2003	25.58	179,608	Atlantic menhaden (119,041)
1980 to 2003 Mean	**3.79**	**34,485**	
2004	2.85	33,591	Atlantic silverside (13,107)

Table 7. Species collected on the Pilgrim Station intake screens, 1980-2004.

Common Name	Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Alewife	*Alosa pseudoharengus*	x	x	x	x	x	x	x	x	x	x	x	x	x
American Eel	*Anguilla rostrata*	x	x	x				x			x			x
American Plaice	*Hippoglossoides platessoides*													
American Shad	*Alosa sapidissima*									x				
Atlantic Cod	*Gadus morhua*	x	x	x				x		x			x	x
Atlantic Herring	*Clupea harengus*	x	x	x	x		x	x	x	x	x	x	x	x
Atlantic Mackerel	*Scomber scombrus*											x		
Atlantic Menhaden	*Brevoortia tyrannus*	x		x	x	x	x	x		x	x	x	x	x
Atlantic Moonfish	*Selene setapinnis*				x	x					x			x
Atlantic Silverside	*Menidia menidia*	x	x	x	x	x	x	x	x	x	x	x	x	x
Atlantic Tomcod	*Microgadus tomcod*	x	x	x	x	x	x	x	x	x	x	x	x	x
Bay Anchovy	*Anchoa mitchilli*	x		x			x	x			x	x		
Bigeye	*Priacanthus arenatus*										x			
Black Ruff	*Centrolophorus niger*											x		
Black Sea Bass	*Centropristis striata*		x					x	x		x		x	x
Black Spotted Stickleback	*Gasterosteus wheatlandi*								x					
Blueback Herring	*Alosa aestivalis*	x	x	x	x	x	x	x	x	x	x	x	x	x
Bluefish	*Pomatomus saltatrix*			x										
Butterfish	*Peprilus triacanthus*		x	x	x	x	x					x		
Cunner	*Tautogolabrus adspersus*	x	x	x	x	x	x	x	x	x	x	x	x	x
Flying Gurnard	*Dactylopterus volitans*						x							
Fourbeard Rockling	*Enchelyopus cimbrius*													
Fourspine Stickleback	*Apeltes quadracus*	x	x											
Fourspot Flounder	*Paralichthys oblongus*	x	x	x	x					x		x	x	
Gizzard Shad	*Dorosoma cepedianum*													
Goosefish	*Lophius americanus*													
Grubby	*Myoxocephalus aenaeus*	x	x	x	x	x	x	x	x	x	x	x	x	x
Gulf Stream Flounder	*Citharichthys arctifrons*													
Hakes	*Urophycis spp.*	x	x	x	x	x	x	x	x	x	x	x	x	x
Hogchoker	*Trinectes maculatus*												x	
Little Skate	*Leucoraja erinacea*		x	x	x	x	x	x	x	x	x		x	x
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*			x	x									
Lumpfish	*Cyclopterus lumpus*	x		x	x	x	x	x	x	x	x	x	x	x
Mummichog	*Fundulus heteroclitus*			x						x		x	x	
Northern Kingfish	*Menticirrhus saxatilis*												x	
Northern Pipefish	*Syngnathus fuscus*	x	x	x	x	x	x	x		x	x	x		x
Northern Puffer	*Sphoeroides maculatus*											x	x	x

Table 7. (continued).

Common Name	Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Northern Searobin	*Prionotus carolinus*	x	x	x	x	x	x		x		x	x	x	
Ocean pout	*Zoarces americanus*													
Orange Filefish	*Aluterus schoepfii*											x		
Weitzman's Pearlside	*Maurolicus weitmani*													
Planehead Filefish	*Monacanthus hispidus*													x
Pollock	*Pollachius virens*	x		x	x	x	x		x	x		x		x
Radiated Shanny	*Ulvaria subbifurcata*	x		x			x	x	x		x	x	x	x
Rainbow Smelt	*Osmerus mordax*	x	x	x	x	x	x	x	x	x	x	x	x	x
Rock Gunnel	*Pholis gunnellus*	x	x	x	x	x	x	x	x	x	x	x	x	x
Round Scad	*Etrumeus teres*										x	x		
Sand Lance	*Ammodytes sp.*	x		x	x		x	x				x		x
Sculpin sp.	*Myaxocephalus spp.*											x	x	
Scup	*Stenotomus chrysops*	x	x	x	x		x				x	x	x	x
Atlantic Seasnail	*Liparis atlanticus*		x		x	x						x		x
Sea Raven	*Hemitripterus americanus*						x							
Shorthorn Sculpin	*Myxocephalus scorpius*			x										
Silver Hake	*Merluccius bilinearus*	x	x		x		x	x	x		x			
Silver-rag	*Ariomma bondi*			x								x		
Smallmouth Flounder	*Etropus microstomus*							x			x	x		
Smooth Dogfish	*Mustelus canis*	x	x		x					x	x	x	x	
Smooth Flounder	*Pleuronectes putnami*													
Spiny Dogfish	*Squalus acanthus*											x	x	
Spot	*Leiostomus xanthurus*													
Striped Bass	*Morone saxatilis*													
Striped Cusk Eel	*Ophidion marginatum*													
Striped Killifish	*Fundulus majalis*		x		x		x	x	x	x	x	x	x	x
Striped Searobins	*Prionotus evolans*					x						x		
Summer Flounder	*Paralichthys dentatus*	x		x				x			x			
Tautog	*Tautoga onitis*		x	x	x	x	x	x	x	x	x	x	x	x
Threespine Stickleback	*Gasterosteus aculeatus*	x	x	x	x	x	x		x	x	x	x	x	x
Weakfish	*Cynoscion regalis*													
White Perch	*Morone americana*		x			x	x						x	
Windowpane	*Scophthalmus aquosus*	x	x	x	x	x	x	x			x	x	x	x
Winter Flounder	*Pleuronectes americanus*	x	x	x	x	x	x	x	x	x	x	x	x	x
Winter Skate	*Leucoraja ocelata*	x		x	x				x					
Yellowtail Flounder	*Limanda ferruginea*							x	x					

Table 7. (continued).

Common Name	Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Alewife	*Alosa pseudoharengus*	x	x	x	x	x	x	x	x	x	x	x	x
American Eel	*Anguilla rostrata*								x				
American Plaice	*Hippoglossoides platessoides*											x	
American Shad	*Alosa sapidissima*												
Atlantic Cod	*Gadus morhua*	x	x	x			x	x		x		x	x
Atlantic Herring	*Clupea harengus*	x	x	x		x	x	x	x	x	x	x	x
Atlantic Mackerel	*Scomber scombrus*		x										
Atlantic Menhaden	*Brevoortia tyrannus*	x	x	x	x	x	x	x	x	x	x	x	x
Atlantic Moonfish	*Selene setapinnis*			x	x			x		x			
Atlantic Silverside	*Menidia menidia*	x	x	x	x	x	x	x	x	x	x	x	x
Atlantic Tomcod	*Microgadus tomcod*	x	x	x	x	x	x	x	x	x	x	x	x
Bay Anchovy	*Anchoa mitchilli*					x				x		x	
Bigeye	*Priacanthus arenatus*												
Black Ruff	*Centrolophorus niger*												
Black Sea Bass	*Centropristis striata*			x						x		x	x
Black Spotted Stickleback	*Gasterosteus wheatlandi*	x	x			x							
Blueback Herring	*Alosa aestivalis*	x	x	x	x	x	x	x	x	x	x	x	x
Bluefish	*Pomatomus saltatrix*						x						
Butterfish	*Peprilus triacanthus*	x	x	x	x	x	x	x		x			x
Cunner	*Tautogolabrus adspersus*	x	x	x	x	x	x	x	x	x	x	x	x
Flying Gurnard	*Dactylopterus volitans*			x						x			
Fourbeard Rockling	*Enchelyopus cimbrius*						x						
Fourspine Stickleback	*Apeltes quadracus*									x			
Fourspot Flounder	*Paralichthys oblongus*	x			x	x	x	x				x	x
Gizzard Shad	*Dorosoma cepedianum*								x				
Goosefish	*Lophius americanus*								x				
Grubby	*Myoxocephalus aenaeus*	x	x	x	x	x	x	x	x	x	x	x	x
Gulf Stream Flounder	*Citharichthys arctifrons*								x				
Hakes	*Urophycis spp.*	x	x	x	x	x	x	x	x	x	x	x	x
Hogchoker	*Trinectes maculatus*												
Little Skate	*Leucoraja erinacea*	x	x	x	x	x	x			x	x	x	x
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*				x		x	x	x				
Lumpfish	*Cyclopterus lumpus*	x	x	x	x	x	x	x	x	x	x	x	x
Mummichog	*Fundulus heteroclitus*	x	x	x				x	x				
Northern Kingfish	*Menticirrhus saxatilis*												
Northern Pipefish	*Syngnathus fuscus*	x	x	x	x	x		x	x	x	x	x	x
Northern Puffer	*Sphoeroides maculatus*	x		x		x						x	

Table 7. (continued).

Common Name	Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Northern Searobin	*Prionotus carolinus*	x	x	x			x	x	x	x		x	x
Ocean pout	*Zoarces americanus*											x	x
Orange Filefish	*Aluterus schoepfii*												
Weitzman's Pearlside	*Maurolicus weitmani*	x										x	x
Planehead Filefish	*Monacanthus hispidus*												
Pollock	*Pollachius virens*	x	x	x				x	x				x
Radiated Shanny	*Ulvaria subbifurcata*	x	x	x	x		x	x	x	x	x	x	x
Rainbow Smelt	*Osmerus mordax*	x	x	x	x	x	x	x	x	x	x	x	x
Rock Gunnel	*Pholis gunnellus*	x	x	x	x		x	x	x	x	x		x
Round Scad	*Etrumeus teres*												
Sand Lance	*Ammodytes sp.*		x				x		x	x		x	x
Sculpin sp.	*Myoxocephalus spp.*	x							x				
Scup	*Stenotomus chrysops*	x	x				x		x			x	x
Atlantic Seasnail	*Liparis atlanticus*				x					x	x	x	x
Sea Raven	*Hemitripterus americanus*												
Shorthorn Sculpin	*Myxocephalus scorpius*												
Silver Hake	*Merluccius bilinearus*											x	
Silver-rag	*Ariomma bondi*												
Smallmouth Flounder	*Etropus microstomus*						x	x					
Smooth Dogfish	*Mustelus canis*											x	x
Smooth Flounder	*Pleuronectes putnami*									x			
Spiny Dogfish	*Squalus acanthus*	x							x	x			
Spot	*Leiostomus xanthurus*	x											
Striped Bass	*Morone saxatilis*				x				x			x	x
Striped Cusk Eel	*Ophidion marginatum*	x					x						
Striped Killifish	*Fundulus majalis*	x	x	x	x		x	x	x	x	x	x	x
Striped Searobins	*Prionotus evolans*	x		x		x		x					
Summer Flounder	*Paralichthys dentatus*		x				x					x	x
Tautog	*Tautoga onitis*	x	x	x	x	x	x	x	x	x	x	x	x
Threespine Stickleback	*Gasterosteus aculeatus*	x	x	x	x		x	x	x	x		x	x
Weakfish	*Cynoscion regalis*											x	x
White Perch	*Morone americana*									x		x	x
Windowpane	*Scophthalmus aquosus*	x	x	x	x	x	x	x	x	x	x	x	x
Winter Flounder	*Pleuronectes americanus*	x	x	x	x	x	x	x	x	x	x	x	x
Winter Skate	*Leucoraja ocelata*												
Yellowtail Flounder	*Limanda ferruginea*	x						x				x	x

Table 8. Monthly extrapolated totals for invertebrates impinged on the PNPS intake screens, January - December 2004.

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Nematode	8												8
Nereis	42	8	143	199									392
Squid					21	15	59	73	27	37	41		274
Sevenspine Bay Shrimp	1,282	3,069	2,512	7,221	1,538						124	310	16,056
American Lobster				40	85	15		12		56	207	18	434
Hermit Crabs										19			19
Spider Crabs											41		41
Rock Crabs	85	70	371	66	42		59	182	27	562	912	110	2,485
Japanese Shore Crab	8			13									22
Green Crabs	8	8	14	66		15	15	36		56	166	55	440
Lady Crabs										19	124		143
Starfish				26				24		19	166	18	254
Total	1,435	3,154	3,040	7,632	1,686	45	133	327	53	767	1,782	511	20,566
Number of Hours	87.65	89.81	52.13	54.34	70.16	47.5	50.3	61.42	27.14	39.75	17.37	40.75	638.3
Impingement Rate (#/hour)	1.93	4.53	4.09	10.60	2.27	0.06	0.18	0.44	0.07	1.03	2.48	0.69	2.63

Table 9. Summary of initial survival rates for fish impinged on the PNPS intake screens, January-December, 2004.

Species	Continuous		Static		Combined	
	Number Collected	Percent Survival	Number Collected	Percent Survival	Number Collected	Percent Survival
Atlantic Silverside	64	35%	897	5%	961	7%
Atlantic Menhaden	165	13%	170	8%	335	11%
Winter Flounder	21	96%	99	83%	120	85%
Blueback Herring	18	65%	92	23%	110	30%
Grubby	11	91%	76	82%	87	83%
Rainbow Smelt	11	18%	37	5%	48	8%
Atlantic Tomcod	5	60%	11	64%	16	63%
Cunner	8	50%	7	43%	15	47%
Striped Bass	12	8%	3	100%	15	27%
Little Skate	5	100%	9	100%	14	100%
Threespine Stickleback	6	100%	5	80%	11	91%
Atlantic Cod	3	33%	7	57%	10	50%
Atlantic Herring	1	100%	9	0%	10	10%
Fourspot Flounder	1	0%	9	78%	10	70%
Alewife	1	0%	5	20%	6	17%
Red Hake	1	100%	5	40%	6	50%
Scup	3	0%	2		5	0%
Striped Killifish	2	100%	3	100%	5	100%
Black Sea Bass	3	33%	1	0%	4	25%
Windowpane			4	75%	4	75%
Sand Lance			3	100%	3	100%
Summer Flounder	3	100%			3	100%
Butterfish	1	0%	1	0%	2	0%
Northern Searobin			2	50%	2	50%
Pollock			2	100%	2	100%
Rock Gunnel			2	100%	2	100%
White Perch			2	0%	2	0%
Yellowtail Flounder			2	50%	2	50%
Atlantic Seasnail	1	100%			1	100%
Lumpfish			1	100%	1	100%
Northern Pipefish	1	100%			1	100%
Ocean Pout	1	100%			1	100%
Radiated Shanny	1	100%			1	100%
Smooth Dogfish			1	0%	1	0%
Tautog			1	100%	1	100%

MARINE ECOLOGY STUDIES

Pilgrim Nuclear Power Station

Section 3.4

Hatchery Release & Collection Study

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

Hatchery Production Study
Young-Of-The-Year Winter Flounder
Post-Release Collections
2000 - 2004

Conducted For
Entergy Nuclear - Pilgrim Station

By
Marine Research, Inc.

MARINE RESEARCH, INC.

February 2005

Introduction

Winter flounder, *Pseudopleuronectes americanus,* is an important commercial, recreational, and estuarine indicator species. Entergy's Pilgrim Nuclear Power Station (PNPS) monitors the local winter flounder population to assess potential impacts of plant operations on the Cape Cod Bay ecosystem. To assess the feasibility of contributing to the local winter flounder stock and mitigating potential entrainment impacts from PNPS tagged young-of-the-year (YOY) winter flounder were released into Plymouth Harbor annually from 2000-2004 and included Duxbury Bay in 2001. This report summarizes follow-up sampling and ancillary studies completed to determine growth and survival of hatchery-reared individuals released into the wild.

Briefly, assessments from 2000 through 2004 demonstrate: 1) released hatchery-reared fish not only survive, but convert to wild food sources and thrive after release; 2) released hatchery fish feeding behavior is similar to wild fish feeding behavior; 3) released hatchery fish survival approximates wild fish survival, consistent with the pen studies discussed herein. In short, the assessments support the continued use of and reasonable reliance on hatchery enhancement as a mitigation tool.

Methods

2000 to 2004 Release Methods

To assess the feasibility of contributing to the local winter flounder stock and mitigating potential PNPS entrainment impacts approximately 104,450 hatchery-produced winter flounder were released to Plymouth Harbor and Duxbury Bay from 2000-2004 (Table 1) by Marine Research, Inc. biologists. Hatchery fish were released in Plymouth Harbor in lots over 2 or 3 days, in the vicinity of the Plymouth Yacht Club (Figure 1, Site 1). This site was selected due the large numbers of wild YOY winter flounder at the location, ensuring suitable habitat for hatchery fish. In 2001, hatchery fish were also released in Duxbury Bay, just south of Powder Point (Figure 2). In general, methods for release and post-release sampling were similar from 2000-2004 although improvements to procedures were employed as experience was gained.

Winter flounder were reared by Llennoco, Inc., Chatham, MA, from Cape Cod Bay spawning stock. Prior to release, hatchery reared fish were implanted with a visible fluorescent implant elastomer mark (Figure 3) at the hatchery. Tag colors varied each year: 2000 tags were red, 2001 tags were green, 2002 tags were yellow, 2003 tags were green, and 2004 tags were orange. Tags were visible with an unaided eye, however, a 7-LED halogen dive light with a blue filter lens and amber glasses were employed to improve tag recognition.

Hatchery fish were transported to the release site in aerated 15-gallon Rubbermaid plastic totes in 2000, 2001, and the first batch released in 2002. The remainder of the 2002 fish and all hatchery fish released in 2003 and 2004 were transported in plastic bags with oxygen added. Fish were released on a low incoming tide. In 2000, fish were allowed to acclimate for 1-2 hours prior to release in a 4 ft by 4 ft by 8 ft, ¼-inch nylon mesh holding pen staked in shallow water at the release site. Hatchery fish were released directly into the water in subsequent years.

Hatchery-reared fish were released when wild YOY winter flounder were present from 2000-2002. In 2000, hatchery-reared flounder were released in late-July, at about half the size of the wild YOY fish collected at that time. Hatchery-reared fish were similar in size to wild YOY fish caught at the time of release in 2001 and 2002 (Table 1). Fish were released earlier in 2003 and 2004 before wild YOY winter flounder had settled and disbursed to nearshore areas, as evidenced by seine collections. (Table 1).

2000 to 2004 Recapture Methods

To gather information on the survival, distribution, and growth of hatchery-reared flounder beach seining was conducted in Plymouth Harbor near the release site (Figure 1, Site 1) from 2000-2004, on the west side of Plymouth Beach (Figure 1, Site 2) from 2002-2004, and at the Duxbury Bay release site (Figure 2) in 2001. Two beach seines were used in 2000 and 2001, each constructed of ¼-inch mesh; one measured 50-ft x 6-ft and the other 100-ft x 6-ft. The hauls encompassed approximately a 214 m^2 area with the 50-ft net or a 400 m^2 area with the larger 100-ft net. From 2002-2004 the larger net was employed exclusively, with one exception in 2004 where the smaller net was used (Tables 2 to 9).

Seine collections were conducted one hour before low tide through the slack and early flooding tide from 2000-2002. In 2003 it was found that large numbers of hatchery and wild fish were collected during the flood tide. Thereafter, seining started at or shortly after low tide and continued during the flooding tide. All winter flounder captured in each seine haul were counted and transferred to plastic buckets with aerated seawater or to floating mesh baskets. After all seine hauls were completed total length was measured to nearest mm on all tagged, wild Age 1+, and up to100 wild YOY fish. As many as 20 fish were occasionally preserved for stomach content analysis, all other fish were released. The number of hauls conducted on each sampling date varied (Tables 2 to 9).

To determine the growth rate of wild YOY, wild Age 1+ and uncaged hatchery-reared flounder the average size of fish collected in seine hauls was calculated and plotted against date using linear regression for each group, where the slope represented the growth rate in millimeters per day.

Dispersal Survey:

To determine how far released fish might move from the release site seine sampling was carried out on one date at 4 stations in Plymouth Harbor (Figure 1, Site 1-4) in 2003 and 5 stations in Plymouth Harbor (Figure 1, Site 1-5) in 2004. Flounder obtained in these seine hauls were checked for marks, counted, and measured as described above (Tables 6 to 9).

Additional Sampling:

To gather information on the survival and distribution of hatchery-reared flounder in bottom areas beyond the reach of seines a beam trawl was used in 2000. The beam trawl measured one meter across the mouth and was constructed of ¼-inch mesh. Beam trawl tows, conducted from a 14-ft, outboard-powered skiff, varied in length but start and end points were recorded with a GPS. Given the effort required to use the beam trawl, the relatively small area it sampled, and its limited results, the approach was discontinued after 2000; instead the effort was directed to holding pen studies.

To obtain insight on the efficiency of the 50-ft beach seine for collecting recently released hatchery fish, marked individuals were released in the path of the seine as it was being deployed in 2001. This was done once in Plymouth Harbor and once in Duxbury Bay. In Plymouth Harbor the marked fish were released as the seine was being hauled while in Duxbury Bay the seine haul was not completed for 25 minutes following release of the marked fish. Flounder obtained in these seine hauls were checked for marks and counted.

Stomach Content Analysis

To determine whether hatchery and wild YOY winter flounder consume the same prey items, as many as 20 fish collected in selected beach seine hauls were preserved in 10% formalin from 2001-2004. Wild and hatchery YOY were preserved on the same day when available so that stomach contents could be compared. In the laboratory winter flounder total length was measured to the nearest mm, the stomachs were removed, sliced open and the contents flushed into a sieve. Prey items were sorted, identified to lowest possible taxonomic group, counted, and the percent stomach volume of each taxonomic group was visually estimated (Stehlik and Meise 2000). Stomach content weights were unable to be obtained since entire stomach contents were less than 0.01 g.

Holding Pen Methods

2001

To provide information on growth and survival wild and hatchery-reared flounder were transferred to holding pens in Plymouth Harbor and in Duxbury Bay under the Powder Point Bridge for various lengths of time (Table 10). With the exception of the first night, the pens used in Plymouth Harbor were cylindrical, constructed of 1-inch wire mesh lined with 1/4-inch plastic mesh, and measured 4 feet in diameter by 1 foot deep. Due to shipment failure, a temporary holding pen was constructed of 1/8-inch nylon mesh, and measured 3 feet in diameter by 4 feet deep for the initial June 4 overnight period. The temporary holding pen was stocked with 50 hatchery flounder and 18 wild YOY winter flounder and staked in subtidal water near shore adjacent to the Plymouth Harbor Yacht Club dock. Seven wire-mesh pens were set on June 19, two pens were placed in shallow water approximately 3 feet deep adjacent to the Yacht Club and four were situated on the eastern side of Plymouth Harbor in water approximately 7.5 feet deep at low water. These pens were stocked with 18 hatchery fish and 18 wild YOY winter flounder. An additional pen was stocked with approximately 200 hatchery fish intended for used in Duxbury Bay pens.

The pens used in Duxbury Bay were circular, constructed of 1/8-inch rigid plastic mesh fitted to a 1-inch polyethylene pipe frame, and measured 36 inches in diameter by 18 inches in height. These pens were deployed on June 22 and June 27. On June 22 two pens were set up containing 12 hatchery fish and 15 wild fish each. These pens were harvested on June 27. The pens were set up again with new fish on June 27, one with 25 hatchery fish and 14 wild YOY, and the other with 18 hatchery fish and 23 wild YOY.

2002

In 2002, wild and hatchery-reared flounder were transferred to holding pens following the same procedures and using the same hardware as in 2001. Seven wire-mesh pens were set in Plymouth Harbor on June 13, four in shallow water approximately 4 feet deep and three in water approximately 10 feet deep at low tide. Each pen was stocked with 15 wild and 15 marked hatchery fish and were maintained for various lengths of time (Table 11).

2003

A new pen design was employed in 2003 for this study, which had proven effectiveness based on studies published by Meng et al. (2000). The pens were constructed of welded metal frames and wood covered with 0.16 inch plastic mesh, measuring 4 feet long by 3 feet wide by 28 inches tall, with 9-inch long steel edges used to dig into the sediment (Figure 4). Edges were pushed into the sediment deep enough to prevent predators from burrowing into the pen from the bottom and fish within the pen from getting out. Pens had open-bottoms and removable tops secured by wing-nuts. The open bottom of these pens was the primary difference between this design and the mesh-bottom design previously used. The open bottom allowed flounder access to benthic food resources and natural substrate to burrow in. Pens were anchored in a silty-sand bottom substrate and rigorously cleared with a dipnet over a period of ten minutes to remove predators and other fish from the pens prior to stocking with young flounder. Naturally-occurring YOY winter flounder were found while clearing the pens for setup (10 flounder/m^2, in one case), confirmed that suitable substrate was selected for the experiment. Once it was determined the pens were clear, hatchery fish were measured and placed in the pens. This procedure was conducted during low tide, when the tops of the pens were exposed.

24-hour survival studies: To provide an estimate of the immediate, short-term survival of hatchery fish after transport and introduction into the bay, a 24-hr survival study was conducted. On each of two dates, May 15 and May 20, 2003, 50 fish were placed in a pen for a 24-hour period then removed and counted. The density of fish in the pen was extremely high and not meant to represent natural conditions.

Long-term (LT) survival studies: Eight growth and survival experiments were conducted from May 20 to September 30. The length of the experiments varied, from 49 to 86 days (Table 12). All pens were maintained just off the beach at Plymouth Yacht Club (Figure 1, Site 1). Pens were cleaned regularly during extreme low tides to prevent fouling. Once a month fish were removed from the pens, measured for total length, and moved to a clean pen placed over fresh substrate. To determine the growth rate of caged hatchery-reared flounder average size of fish was calculated and plotted over time; the slope provided the growth rate (mm/day).

For the first experiment 10 YOY hatchery winter flounder were placed in a 3 foot long by 3 foot wide by 17 inch tall pen, from May 20 to June 17. The pen used for this experiment was smaller than the pens described above used for experiments 2 thru 7. Six pens as described above were maintained from June 17-August 13 (Table 12), each was stocked with 5 hatchery-reared winter flounder. Five fish were used at the beginning of all but the first long-term experiment to prevent overstocking and the potential for reduced growth and survival due to limited food supply. One of the six pens set up on June 17 was stocked using 5 fish from the May 20-June 17 experiment. The remaining five pens were stocked with fish transported directly from the hatchery on June 19 and were maintained from June 19-August 12 or 13 (55+ days). Two pens were maintained from August 13-September 30 (49 days) with 5 fish each, transferred from pens cleaned on August 13. One group of fish (Experiment 1) was held together from May 20 (the second release date) to August 13, and then transferred into another pen (Experiment 7) with fish held since June 19, then kept until September 30; cumulatively, these fish were penned for 134 days. On August 13 a second pen (Experiment 8) was setup with 5 tagged fish taken from experiments harvested on that date (LT#2-6), and was maintained until September 30.

2004

In 2004, hatchery-reared flounder were transferred to holding pens following similar procedures and using the same hardware as in 2003.

24-hour survival studies: To provide an estimate of the immediate survival of hatchery fish transported and introduced into the bay, we placed 50 fish in a pen on the May 10 and May 11 release dates. We returned 24 hours later and counted the survivors. Fish recovered on May 10 were preserved in 10% formalin for size analysis. Thirty fish recovered on May 11 were used in the long-term survival study, all remaining recovered fish were preserved for size analysis.

Long-term survival study: To provide an estimate of the long-term growth and survival of released hatchery fish six pens were set in Plymouth Harbor just off the beach at Plymouth Yacht Club near the release site (Figure 1, Site 1). Each pen was stocked with 5 hatchery winter flounder recovered from the May 11, 24-hr study. To minimize fouling, pens were cleaned once a month on neap tides. The fish were removed, measured for total length, and moved to a clean pen placed over fresh substrate. Pen condition, sediment, and predators were noted. The pens were maintained until September 29 (Table 13) at which time fish were preserved in 10% formalin for gut content analysis. To determine the growth rate of caged hatchery-reared flounder average size of fish was calculated and plotted over time.

Results:

Seine and recapture studies

2000

Table 2 presents a summary of beach seine and beam trawl collections completed in Plymouth Harbor during the summer and autumn of 2000 intended to determine if the hatchery fish survived. While a total of 1,887 wild young-of-the-year winter flounder were collected between July and November, no marked recaptures were identified.

2001

Beach seine collections completed during the summer and autumn of 2001 were tabulated separately below for the Plymouth Harbor and Duxbury Bay release sites (Table 3, 4).

An estimated total of 963 young-of-the-year winter flounder were collected on seven occasions in Plymouth Harbor adjacent to the Yacht Club (Table 3). The number is approximate because on June 18 some 200 young flounder were obtained in a single seine haul. These fish were intended for use in the holding pens and every effort was made to minimize stress by transferring them quickly from the seine to buckets of water. While an accurate count was not obtained, the fish were carefully checked for marks. Overall six recaptures were obtained, four on June 18, 14 days following release, one on August 2, 59 days following release, and the last on September 7, 95 days following release. Recaptured fish exceeded the mean length of wild fish collected on the same respective day. This was particularly true for the individuals collected on August 2 and September 7; they were 70 to 80% larger than the average wild fish (78 vs 43 and 88 vs 52 mm total length, respectively) and exceeded the length of the largest fish (68 and 85 mm, respectively) by 10 millimeters on August 2 and by 3 millimeters on September 7. The number of recaptures (N = 6) was insufficient to calculate growth and survival rates.

In Duxbury Bay 426 young-of-the-year flounder were collected with one recapture being obtained on July 11, 27 days following release, assuming the marked fish was from the June 14 release (Table 4). In this case the recaptured fish was small (39 mm) relative to the average length of wild flounder collected on the same day (mean length = 46 mm), although wild fish as small as 25 mm were collected.

Trials in which marked flounder were released in front of the seine suggested that recapture efficiency at least immediately following release could be very low. On June 4 approximately 50 marked fish were released in the path of the seine in Plymouth Harbor. A total of 19 winter flounder juveniles were captured, only one of which was marked. On June 12 approximately 250 marked individuals were released in the path of the seine at the Duxbury site. Thirty marked fish were recaptured along with 15 wild flounder. These results suggested that upon release young flounder drop to the bottom and likely remain motionless for an undetermined recovery period. With this behavior the seine simply passed over them. This is consistent with repeated field observations where young hatchery flounder were found to drop passively to the bottom after being measured and released. Individuals have been observed landing on their eyed side where they remain inverted for several minutes. In contrast, wild fish appear more likely to rise from the bottom and dart short distances forward in "leap frog" fashion in advance of the lead line of the seine until it reaches shallow water. Others will rise from the bottom and turn into the net to be captured. Since wild flounder were collected in nearly every seine haul completed in both Plymouth Harbor and Duxbury Bay, they would have to be very abundant to account for the numbers taken if they behaved the same as recently released hatchery fish.

2002

Table 5 summarizes information on number and mean total length of YOY winter flounder captured in the seine survey for the summer and autumn sampling period of 2002. A total of 1,815 YOY winter flounder were collected over sixteen sampling events in Plymouth Harbor adjacent to the Yacht Club and one sampling event on the eastern side of the harbor (Figure 1, Site 2). Overall, 32 hatchery fish were recaptured from June 4 to September 12; 4 to 100 days after release. On 6 of the 7 days on which recaptures were collected, hatchery fish exceeded the mean length of wild fish collected on the same day (Figure 5). Although sample size was small, growth among hatchery fish appeared comparable to that of wild fish (hatchery growth rate = 0.30 mm/day, $R^2 = 0.77$, $p < 0.001$; wild growth rate = 0.26 mm/day, $R^2 = 0.98$, $p < 0.001$).

2003

Abundance/density

A total of 144 tagged hatchery winter flounder were collected in the beach seine survey during 2003 (Table 6). These fish were collected over 14 sampling events, following release on May 15 and May 20. Interestingly, hatchery fish were not recaptured during the first three sampling events (May 16-May 21) suggesting an initial, rapid dispersal from the release site perhaps in response to a spring tide. The fish clearly returned to the point of release however. 90% of the recovered hatchery fish were caught within 60 days of release. The remaining 10% were recaptured 64, 73, 78, 119, and 133 days after the May 20 release. The decrease in recaptures over time probably reflects a combination of mortality and dispersal. On August 1 a hatchery fish was recaptured at Site 2, approximately 1,650 m from the release site (Figure 1).

A total of 2,646 wild winter flounder were collected in the beach seine in 2003. Of the total, 2,485 were young-of-the-year (age-0) and 160 were age 1 or 2 (Tables 6, 7). In the initial seine collections completed on May 15, May 16, May 28, June 4 and June 6 age one and age two wild winter flounder were collected, but wild young-of-the-year were not. Wild YOY were first found in the seine on June 12. This is later than the first appearance of YOY in 2001 and 2002 in Plymouth Harbor.

On June 6 seine sampling was carried out at three additional sites in an effort to determine the degree of dispersal of hatchery fish. Hatchery fish were collected at the release site on that date, but were not found at any other station (Table 6). This may have resulted from a relatively low density of fish once dispersed from the release site. Vigorous sampling over a wide area in the days immediately following release would help further clarify this issue.

Size/Growth

Hatchery-raised YOY winter flounder averaged 34 mm (s.e. = 0.5, n = 133) at release. Growth of hatchery fish was rapid, 0.82 mm/day ($p = 0.0000$, $R^2 = 0.97$) from May 15 to August 6 based on linear regression analysis (Figure 6). Growth slowed somewhat later in the season, to 0.43 mm/day from September 16 to September 30. One hatchery fish was recaptured on September 30 measuring 106 mm. Wild YOY were about half that size on that date, averaging 51 mm total length.

Wild YOY winter flounder grew at the rate of 0.21 mm/day ($p = 0.02$, $R^2 = 0.44$) from June 12 to August 6, a slower rate compared to hatchery fish (growth rate = 0.78 mm/day for June 12 to August 6). That represented a conservative estimate of the growth rate of wild YOY winter flounder since the protracted settling period of age-0 wild winter flounder results in small newly recruited fish being averaged with larger previously settled fish, reducing the overall average, and therefore the estimated growth rate.

Hatchery and wild YOY overlapped in size range on three sampling dates in 2003; June 12, June 17, and July 9. However, throughout the study, mean total length of hatchery fish exceeded wild fish, ranging from 55-124% larger than wild YOY (Figure 6).

Age 1 wild winter flounder were caught from May 15 to September 16, 2003. Age 1 flounder grew at the rate of 0.67 mm/day from May 15 to August 6, slightly slower than hatchery fish over the same growth period.

2004

Abundance/density

A total of 312 tagged hatchery winter flounder were collected in 17 sampling events during the 2004 beach seine survey (Table 8). 91% of the recovered hatchery fish were caught within 60 days of release. The remaining 9% were recaptured 72 to 172 days after release. The decrease in recaptures over time probably reflects a combination of mortality and dispersal.

A total of 2,108 wild winter flounder were collected in the 2004 beach seine survey. Of the total, 1,692 were young-of-the-year (age-0) and 416 were age 1 or 2 (Tables 8, 9). In the initial seine collections (May 10 - June 3) only age one and two wild winter flounder were collected; wild young-of-the-year (YOY) were not found in the seine until June 7. This is later than the first appearance of YOY in Plymouth Harbor in 2001 and 2002, but slightly earlier than their appearance in 2003.

On May 13 seine sampling was carried out at four additional sites in an effort to determine the degree of early dispersal of hatchery fish. Hatchery fish (n = 13) were collected at the release site and at Site 3 (n = 3) on that date (Table 8), showing limited dispersal. This result is consistent with the findings of Saucerman and Deegan (1991) which indicated minimum lateral and cross-channel movement of YOY winter flounder.

Size/Growth

Hatchery-raised YOY winter flounder averaged 29 mm (s.e. = 0.5, n = 92) at release between May 10 and May 12. Growth of hatchery fish was most rapid from May 13 to July 6, 0.64 mm/day ($p = 0.00001$, $R^2 = 0.97$). It then slowed to 0.44 mm/day ($p = 0.04$; $R^2 = 0.92$) from July 6 to September 2 based on linear regression analysis (Figure 7).

Wild YOY winter flounder appeared to grow at a much slower rate over the corresponding July 6 to September 2 period - 0.09 mm/day and in fact the slope of the growth line was not significantly different from zero ($p = 0.18$). As indicated for 2003 those rates are likely biased by the continual influx of younger fish during the protracted settlement period. Examining grow using only the 50th and 75th percentile lengths on each sampling date in an effort to focus on the largest fish in the collections resulted in greater apparent growth (0.11 and 0.16 mm/day, respectively) but slope parameters were not significantly different from zero.

Age 1 wild winter flounder were caught from May 10 to October 1, 2004. Age 1 flounder grew at the rate of 0.88 mm/day ($p = 0.00001$, $R^2 = 0.95$) from May 10 to July 6. Growth rate slowed to 0.24 mm/day ($p = 0.07$, $R^2 = 0.86$) from July 6 to August 18. Only 1 Age 1+ flounder was collected after August 18, therefore further growth rates were unable to be calculated.

Stomach Content Analysis

2001

A total of 37 young-of-the-year winter flounder were examined for stomach content analysis including 17 individuals from hatchery stock. None of the stomachs were empty. In general the diet of these fish consisted of a variety of juvenile infaunal and epibenthic species. Polychaete worms were the dominant food item generally comprising 50% or more of the gut contents. Bivalve mollusks and crustacea were also commonly eaten. A wide range of crustacean types were found including copepods, cumacea, ostracods, capellid and gammarid amphipods, and decapod larvae. No indication of selectivity was noted. No remarkable differences in stomach contents were noted between hatchery fish and wild individuals nor between those marked and unmarked recovered from the holding pens and the seine.

2002

A total of 39 young-of-the-year winter flounder were examined for stomach content analysis including 16 individuals from hatchery stock and 23 wild fish. Five of the individuals examined had empty stomachs, four were wild fish. In general, the diet of these fish consisted of a variety of juvenile infaunal and epibenthic species as noted in 2001. Polychaetes constituted the dominant food type consumed by tagged flounder averaging 24% of the volume of material in each gut (Table 14). Unidentifiable insect larvae remains followed accounting for 21%, and unidentified animal remains ranked third at 17%. Other prey items included terrestrial seeds, and a variety of crustaceans.

Gut contents of wild fish were examined from the same dates at approximately the same lengths as tagged fish. Crustaceans formed the dominant prey type for wild fish accounting for an average of 57% of the volume followed by polychaete remains (23%) and polypoid cnidarin larvae (7%). A wide range of crustacean types were found including copepods, isopods, ostracods, amphipods, and decapod larvae.

The primary prey found in the guts of hatchery and wild winter flounder changed over time (Table 15). Given the small number of hatchery guts available for examination, and the absence of concurrent prey abundance data it is difficult to determine if this change represented a change in prey availability or prey choice. Overall, no indication of selectivity was noted consistent with 2001 results.

2003

Gut contents were examined for 37 hatchery YOY winter flounder and 26 wild YOY winter flounder captured in the seine. Two of the hatchery fish examined had empty stomachs. Stomach contents of hatchery fish caught in the seine from May 28 to June 17 were dominated by annelids (mostly polychaetes), averaging 91% of the contents over that time (Table 16). Hatchery fish had a more mixed gut composition from July 3 to the last sampling date on September 30, perhaps reflecting a change in prey availability or improved foraging ability with age and increasing size. Stomach contents of wild YOY winter flounder caught in the seine were also strongly dominated by annelids on June 17 (85% of the gut contents). Gut contents thereafter were more mixed in composition similar to hatchery fish. When averaged for the period during which both hatchery and wild YOY winter flounder co-occurred, gut contents were relatively similar (Table 17). For hatchery YOY annelids made up the majority of the prey species, followed by arthropods, and others and mollusks. Wild YOY guts were mostly composed of annelids, others, arthropods, and mollusks.

2004

Gut contents were examined for 60 hatchery YOY winter flounder, 24 wild YOY, and 34 Age 1+ winter flounder captured in the seine. There were no empty stomachs. Stomach contents of recaptured hatchery fish from May 11 to June 3 were dominated by annelids, averaging 76.5% of the contents over that time (Table 18). Stomach contents of hatchery fish contained a more mixed composition from June 18 to the last sampling date of September 16. Stomach contents of wild Age 1+ captured from May 10 to June 3 were also dominated by annelids (72.4%). Wild YOY stomach contents from June 18 to September 16 contained a mixed composition (Table 18). Gut contents averaged for the period during which both hatchery and wild winter flounder co-occurred were relatively similar (Table 19). Hatchery flounder prey species were dominated by annelids, followed by others, and then arthropods. Wild winter flounder were dominated by annelids, followed by arthropods, others, and then mollusks.

Pen Studies

2001

The temporary holding pen set overnight during the Plymouth Harbor release on June 4 failed due to abrasion between the nylon mesh and the posts used to secure it. Of the 50 hatchery fish released into the pen, 13 (26%) were recovered alive, 4 were found dead, the remainder apparently escaped through tears in the sidewall of the pen. Of the 18 wild flounder released, 5 (28%) were recovered alive and 1 was found dead. In an effort to offer natural bottom to the fish and help anchor the pen, coarse sediment was added before the fish were released. The sediment proved troublesome when trying to recover the fish since individuals were difficult to find. It is also likely that some fish were injured as the pen was moved to shallow water for recovery since gravel in the sediment rolled around in the pen.

The wire and plastic mesh pens set on June 19 were hauled on three different dates (Table 10). One pen contained approximately 200 marked fish intended for use in holding pens in Duxbury Bay. This pen, set in shallow water, was hauled on June 22 only three days after it was set. The number of marked fish found in the pen was surprisingly low; 24 were recovered alive along with 3 partial flounder. Not only were 88% of the fish no longer alive but also all except three were missing. Small sevenspine bay shrimp (*Crangon septemspinosa*) and several periwinkles (*Littorina* spp.) were found in the pen and it is possible they consumed the flounder. The periwinkles apparently originated from two rocks used to weight the pen and the shrimp were small enough to move freely through the mesh. Whether they consumed the flounder before or after they died is unknown. Bay shrimp are known to prey on young winter flounder from the time they metamorphose to approximately 20 mm (Witting and Able 1993, 1995). While the mean length of fish placed in the pen exceeded 20 mm, being confined could have increased their susceptibility to predation.

The second pen set in shallow water was retrieved on June 29, 10 days after it was set. Survival among marked individuals was 67% compared with 11% among wild flounder. Subsequently, two pens were retrieved on July 10, 21 days after being set. Survival of marked fish averaged 61% and survival of wild fish averaged 20%. The remaining three pens were retrieved on August 2, 44 days after being set. Survival of marked hatchery fish averaged 29% compared with 43% among wild fish.

The pens employed in Duxbury Bay were found to be unsatisfactory in design. Additionally, pen location was unsuitable given the large number of people in close proximity to the experimental area and the strong currents found there. When the pens were recovered to check for survivors, they were found opened, flipped over, and one had holes in the mesh allowing fish to escape. No fish were recovered from the pens. These pens were not used after these experiment failures.

2002

The wire and plastic mesh pens set on the 13th of June were hauled on three different dates (Table 11). Two pens were recovered on each of the following dates: July 15, 33 days after deployment; August 13, 62 days after deployment; and August 26, 75 days post-deployment. One of the pens was not recovered because its marker buoy was lost.

Recovery of marked and wild winter flounder juveniles from the pens was low. Of the 90 marked fish placed in retrieved pens, only 3 were recovered. Of the 90 wild fish placed in the six pens, 4 were recovered. In three of the pens, no flounder were recovered. Low survival in the pens may be due to several factors. First, recovered pens were heavily fouled by the accumulation of settling organisms on the pen's top and sides (Figure 8). This accumulation restricted water flow through the pens and could have resulted in mortality if water became stagnant particularly at slack tide, leading to hypoxic conditions. Another source of loss may have resulted from predation within the pens. Several pens contained crabs, shrimp, and other fish species. These animals apparently entered through the mesh as larvae or early stage juveniles and grew to considerable size within the pen. Careful scrutiny of each pen failed to indicate any other way for the predators to have entered other than through the mesh. The flounder in the pens were probably consumed, being more susceptible to predation by confinement. One pen contained 8 green crabs (*Carcinus maenas*), 1 hermit crab (*Pagurus longicarpus*), and 2 cunner (*Tautogolabrus adspersus*). Another pen held 6 spider crabs (*Libinia* spp.), 5 green crabs, and 2 cunner approximately 50 mm total length. The largest crab was 48 mm carapace length. Green crabs are a known predator of YOY winter flounder (Fairchild and Howell 2000).

2003

A major advantage of the new pens employed in the 2003 study was accessibility over the course of the study. Since the pens were set in relatively shallow water they could be examined on spring tide days when the covers were exposed, allowing fish to be recaptured, measured, and moved to a clean pen. Moving the fish was particularly important because the pens fouled quickly, reducing water flow through the mesh. Low water turnover can limit the oxygen available to flounder during slack tides and may reduce prey abundance by decreasing the settlement of benthic organisms. Additionally, moving the fish to pens over 'fresh' sediment probably prevented the flounder from consuming all of the prey resources within the confined area.

A disadvantage to this new design was that the removal of all other fish and large invertebrates proved difficult at the start of each trial even though pens were vigorously cleaned. Invertebrate predators (large crabs) and other fish, including wild YOY winter flounder, were found in some pens (Table 20). The predation or competition of other organisms in the pens may have negatively impacted flounder survival.

Survival results

Survival of hatchery flounder in the new pens employed in 2003 was the highest to date, with fish being successfully maintained in pens from May 20 (the second release date) until September 30, a total of 134 days. The first two experiments were short in duration, where 50 fish were placed in a pen on the first and second release date to determine short-term survival and the effects of transfer and release of the hatchery fish to the Harbor. In the absence of predators, 24-hour survival rates for these experiments were 90% on May 15 and 100% on May 20, indicating that hatchery fish successfully survived the transition to the wild (Table 12).

Survival of hatchery fish in long-term pen experiments varied over time (Table 12). The first experiment conducted from 5/20-6/17 had a relatively low 29-day survival rate (50%) compared to experiments conducted from 6/17-7/16 and 7/15-8/13. The low survival observed in the first experiment is probably the result of overstocking in a smaller pen, where 10 fish were placed in a 3 ft by 3 ft pen. This may have resulted in some density-dependent effects such as food resource shortage. All other experiments were conducted in 4 ft by 3 ft pens. The average survival of hatchery flounder in pens from 6/17-7/16 was 63% (range 40-80%). Those fish that survived to July 16 (day 26-28) were transferred to clean pens and had a high 30-day survival rate, averaging 90%. The survival rate of tagged fish in the experiments conducted from 8/13-9/30 was 70%. The increase in survival from the 6/17-7/15 experiments compared to the later experiments (63% vs. 90% for 7/15-8/13 and 70% for 8/13-9/30) suggests that fish that survived the first month of release have a greater likelihood of continued survival. Cumulatively, survival for one experiment conducted for 86 days was 40% and averaged 52% for the five experiments set up on June 19 ending 55-56 days later on August 12 and 13 (Table 12).

Although efforts were made to remove predators and other fish from the pens at setup, invertebrate predators and other fish were found in some pens (Table 20). The two experiments (LT#2 and LT#6) which had large crabs (>65mm carapace width), wild YOY winter flounder, and other finfish had the lowest survival for the 6/19-7/14 period, with only 40% of the hatchery fish surviving over that time. The survival in LT#4 was comparatively low at 60% from 6/19-7/14 although no predators were found in the pen. With the exception of LT#4, it is likely that predation or competition were responsible for the experiments with the lowest observed survival.

Growth Rate

Growth rate was determined for the first caging experiment conducted from 5/20-6/17, the six experiments that took place from 6/17-8/13, and the two experiments conducted from 8/13-9/30. Focus was placed on comparing growth rate of caged hatchery fish with the uncaged hatchery population.

The growth rate of experiment #1 conducted from 5/20-6/17 was 0.13 mm/day (Table 21). This growth rate was low compared to the 0.76 mm/day growth rate observed for hatchery fish recaptured in the seine over the period of 5/15-6/17. The low growth rate observed in the first experiment is probably the result of overstocking in a smaller pen, where 10 fish were placed in 3-ft x 3-ft pen. This may have resulted in some density-dependent effects such as food resource shortage.

The average growth rate of caged hatchery fish from 6/17-8/13 was 0.43 mm/day (range 0.31-0.52 mm/day, s.e. = 0.03, Table 21). The growth rate of uncaged hatchery fish from 6/17-8/6 (no seine sampling was conducted on 8/13) was 0.74 mm/day. The average growth rate for experiments conducted from 8/13-9/30 was 0.13 mm/day (Table 21). This rate was significantly lower than that observed in cages from 6/17-8/13. The growth rate of hatchery fish collected in the seine from 8/6-9/30 was 0.19 mm/day ($R^2 = 0.88$, $p = 0.06$). This rate was significantly less than that observed in the seine-collected hatchery fish from 6/17-8/6. Therefore, it is not surprising that the growth rate in the cages was reduced between these periods. Again, it is interesting to note that the growth rate of caged flounder was lower than that observed from seine-collected hatchery fish.

Gut Contents

Gut contents were examined from 9 hatchery fish held in pens. The gut contents of these fish were dominated by annelids (58.5% of total gut volume on August 13, and 44% of total gut volume on September 30). Other important taxa included arthropods, mollusks, chordates, and others (Table 16).

2004

Survival results

The two 24-hr experiments were designed to determine short-term survival and the effects of transfer and release of the hatchery fish to Plymouth Harbor. In the absence of predators, 24-hour survival rates for these experiments were 90% on May 10 and 100% on May 11, indicating that hatchery fish successfully survived transport and release (Table 13).

The long-term survival study successfully maintained fish in pens from May 12 (the last release date) until September 2, for a total of 114 days. Survival of hatchery fish in the long-term experiment varied over time and between pens (Table 13). During the first month of the experiment (May 12 - June 7, 27 days) the survival rate was 90% and during the second month (32 days) the survival rate was 84.5% with a cumulative survival rate of 80%. The monthly survival rates continued to hold at 84% or higher until September (Table 13). The 2004 monthly and cumulative survival rates were higher than the 2003 survival rates.

Growth Rate

Growth rates in the long-term survival study varied between pens and over time (Table 22). Growth rates from May 12 - July 5 (average: 0.44 mm/day) were notably greater in all six pens than the July 5-August 31 growth rates (average: 0.14 mm/day, Table 21). The growth rates of caged hatchery flounder where lower than the growth rates of hatchery fish collected in the seine from May 12- July 5 (0.64 mm/day) and July 5-August 31 (0.46 mm/day, Table 22). The 2004 average growth rates were very similar to the 2003 average growth rates. Growth rates may have been affected by the presence of anoxic conditions from July until the end of the experiment (Table 23). The pen bottoms and surrounding area sediment (deeper than a cm) was black, fine, and silty during this period. The pens denoted as anoxic in Table 23 had the sediment described above accompanied by a hydrogen sulfide smell.

Although pens were thoroughly cleared at the beginning of each trial some crabs and wild YOY winter flounder were found in them at the end (Table 23). No discernible effects on the survival and growth rates of the hatchery-reared flounder were observed with the presence of the crabs and wild YOY winter flounder in the pens.

Gut Contents

Gut contents were examined from 6 hatchery fish held in pens. The gut contents of these fish were dominated by annelids, 60% of the total stomach volume. The next dominate group was others, followed by arthropods, and mollusks (Table 18).

Discussion:

The scale of the hatchery release provides a useful perspective when evaluating recapture rates particularly those in 2000 and 2001. The area of Plymouth Harbor is approximately 3,824 acres or 15,475,177 m^2 (Frank Germano, Massachusetts Division of Marine Fisheries, personal communication). If 15,000 or 25,000 young flounder were released and dispersed evenly over 10% of the Harbor bottom, 1 to 1.6 individuals would be expected every 100 m^2. Since fish typically demonstrate a contagious or patchy rather than a uniform distribution, it becomes clear that hatchery fish released may be difficult to find once they disperse. An individual recaptured on August 1, 2003 nearly a mile from the release site, indicated that individuals may disperse over a wide area.

The recapture rate in Plymouth Harbor was similar in 2001 and 2002 (0.12 and 0.13% respectively). The rate increased in 2003, when 144 hatchery fish were recaptured (0.58%), and again in 2004, when 312 hatchery fish were recaptured (1.2%), representing large increases in recapture rates compared to previous years. The increased numbers of recaptured hatchery fish with each succeeding year is probably due to a combination of factors but release date was likely important since number of recaptures and initial release date were negatively correlated. The particularly early release dates in 2003 and 2004 (May 15, 2003; May 10, 2004) may have been beneficial to introduced fish due to the relatively low predator abundance observed in the initial seine collections and the lack of wild YOY winter flounder, reducing intraspecific competition for resources. Wild YOY winter flounder were not collected in seine hauls until June 12, 2003 and June 7, 2004, 23 to 28 days after hatchery release. The somewhat later first appearance of wild YOY winter flounder in Plymouth Harbor in 2003 and 2004, compared to 2001 and 2002 can be explained by colder spring water temperatures (Figure 9). Sogard et al. (2001) found that colder temperatures delayed winter flounder larvae occurrence which resulted in corresponding later metamorphosis and settlement. In Plymouth Harbor delayed winter flounder settlement would result in the delayed arrival of wild YOY at sampling locations.

To take advantage of reduced predation and intraspecific competition continued early release may be a good strategic measure. However, it is important to consider that prey resource availability for newly released YOY winter flounder may vary in abundance and timing from year to year. Selecting release dates should consider both predator abundance and prey abundance. Further study of these relationships (release date, prey abundance, predator abundance, and intraspecific competition) would be helpful in defining the best time for release.

Growth rates calculated for hatchery-reared flounder collected in the seine for 2002 to 2004 were higher than the growth rates for wild YOY flounder during the same period. The difference in growth rates may be explained by the protracted settling period of age-0 wild winter flounder. Small newly recruited fish are averaged with larger previously settled fish, reducing the overall average, and therefore the estimated growth rate. Larval winter flounder were collected at PNPS as late as July 4, 2003 and July 9, 2004 suggesting that wild YOY may continue to join the wild population for a very long time.

The stomach contents from 2001-2004 were similar across years and between hatchery and wild YOY winter flounder. The diets consisted of a variety of juvenile infaunal and epibenthic species. Plymouth Harbor young winter flounder appeared to be opportunists feeding upon a wide array of prey items within a suitable size range for their small mouths. This is consistent with information from the literature (Pearcy 1962, Mulkana 1966, Klien-MacPhee 1978, Armstrong 1995, Stehlik and Meise 2000). Stehlik and Meise (2000) found a pronounced dietary shift occurred from calanoid copepods to a wider array of prey items when young winter flounder reached around 50 mm in length consistent with our results.

The winter flounder growth rates observed in the pens in 2003 and 2004 (Tables 21, 22) are comparable to those observed in similar pens in Rhode Island estuaries. Meng et al. (2000) reported mean growth rates of YOY winter flounder ranging from 0.32-0.43 mm/day based on experiments conducted from June 4 to July 7, 1997. The pen experiments conducted in 2003 found cumulative survival of hatchery fish penned for 55+ days ranged from 40 to 80%, averaging 52%. The long-term experiment conducted in 2004 found a cumulative survival of hatchery fish penned for 55+ days ranged from 40 to 100%, averaging 80%, and cumulative survival for 112+ days ranged from 40 to 80%, averaging 64%.

The lower growth rate observed in the 2003 and 2004 long-term pen survival experiments compared to the growth rates of the uncaged hatchery fish (Tables 21, 22) suggested that the caged flounder did not have an optimal habitat for development. While pens may eliminate sources of stress and mortality from predation by piscivores (striped bass, bluefish, cormorants and shore birds), they also limit access to food resources and reduce water exchange potentially decreasing dissolved oxygen, and increasing metabolic wastes. Caged fish may experience suboptimal feeding since they are unable to move to microhabitats that have higher food concentrations. In addition, fouling on the pens could restrict both the recruitment of settling food resources and their survival. These factors may be compounded by increases in water temperature to near the upper lethal temperature for winter flounder, 30° C (Pearcy 1962). Previous caging experiments have indicated that winter flounder growth can be inhibited by increasing water temperatures and low oxygen levels in shallow waters during mid-summer (Sogard et al. 2001, Sogard 1992, Phelan et al. 2000). Olla et al (1969) observed that water temperatures higher than 22.2°C caused winter flounder to bury into the sediment and cease to feed. In spite of these limitations, the pens provided valuable growth and survival information by eliminating dispersion and advection.

Conclusions

Young-of-the-year winter flounder reared in the Chatham hatchery were easily transported to both Plymouth Harbor and Duxbury Bay at high densities. Post-release collections from 2001-2004 indicated that released fish do survive and grow particularly when released early in the season. The 2001 seine trials where hatchery fish were released in the path of the seine suggested that recently handled hatchery fish behave differently from undisturbed fish. They appear to settle to the bottom where they remain inactive for a period of time and during that period they are less susceptible to capture than wild fish. The 2003 dispersal study where 1 tagged flounder was recaptured nearly a mile from the release site indicated that significant dispersal can occur. Dispersion and mortality among hatchery fish may account for absent or low recapture numbers, especially when wild YOY are found in seine collections. Size and growth analysis of uncaged hatchery-reared fish indicate that there was successful growth. Stomach content analysis conducted in 2001 to 2004 suggested that there were not pronounced differences in hatchery fish feeding behavior compared to wild YOY winter flounder. This indicates that hatchery-reared fish successfully converted to wild food resources. The 2001, 2003 and 2004 pen studies further support this.

Pen studies may eliminate some sources of mortality such as predation, however, they may introduce others in the form of reduced water exchange and food resources. These factors were reflected in reduced growth among caged fish relative to free-ranging hatchery fish. In spite of the limitations, pens do provide valuable growth and survival information by eliminating dispersion and advection. Pen studies strongly suggested that the survival rate is greater than the rate determined by seining. Assuming all hatchery fish adjusted quickly to being released, as the 2003 and 2004 pen studies suggested, survival among hatchery and wild fish is likely to be similar.

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Figure 1. Plymouth Harbor release site.

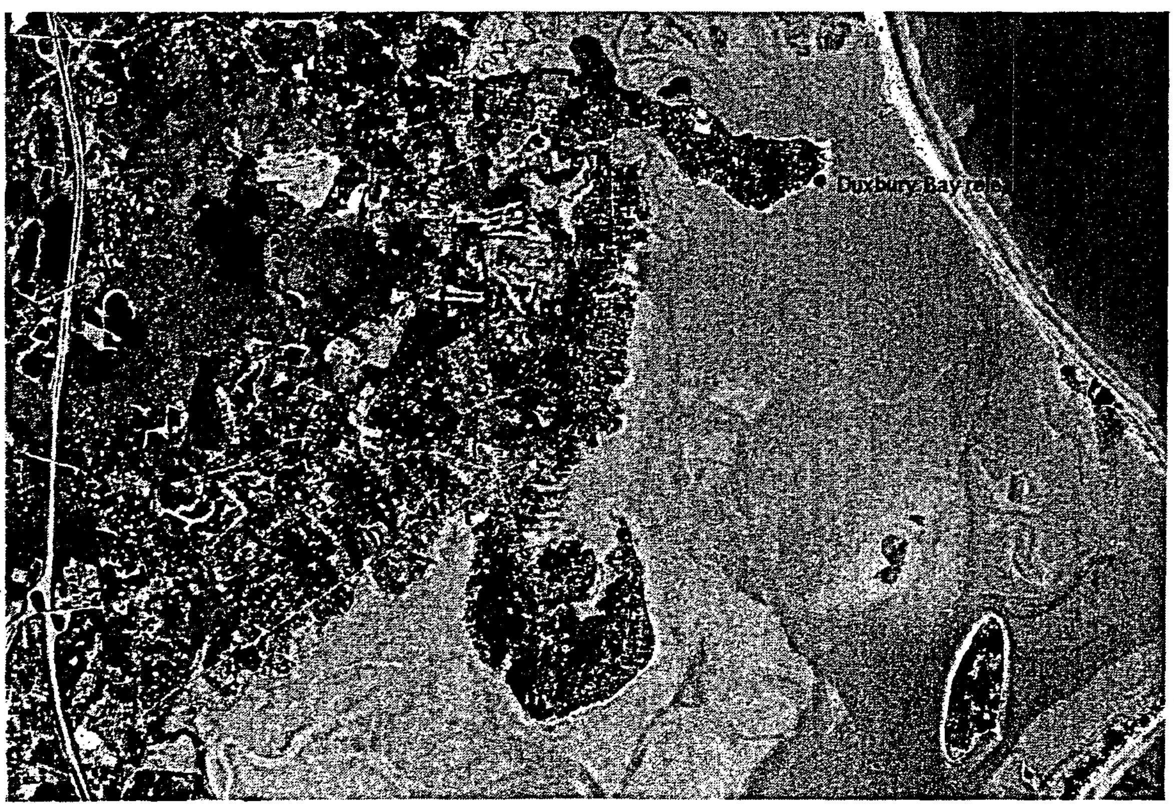

Figure 2. Duxbury Bay release site.

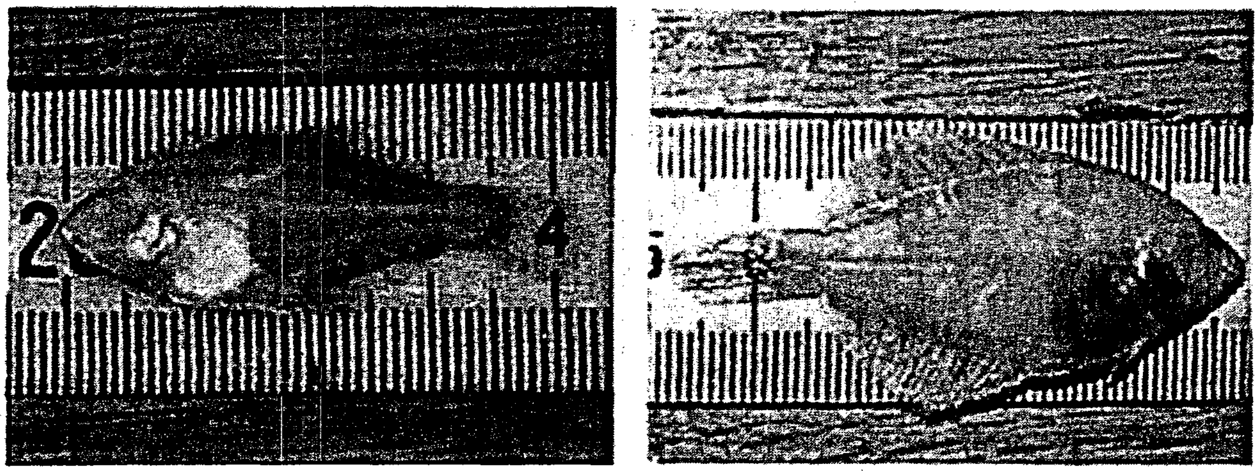

Figure 3. Tagged hatchery winter flounder, left: green tag = 2003 and right: orange tag = 2004. Note the left-eyed variant from the 2004 hatchery stock on the right.

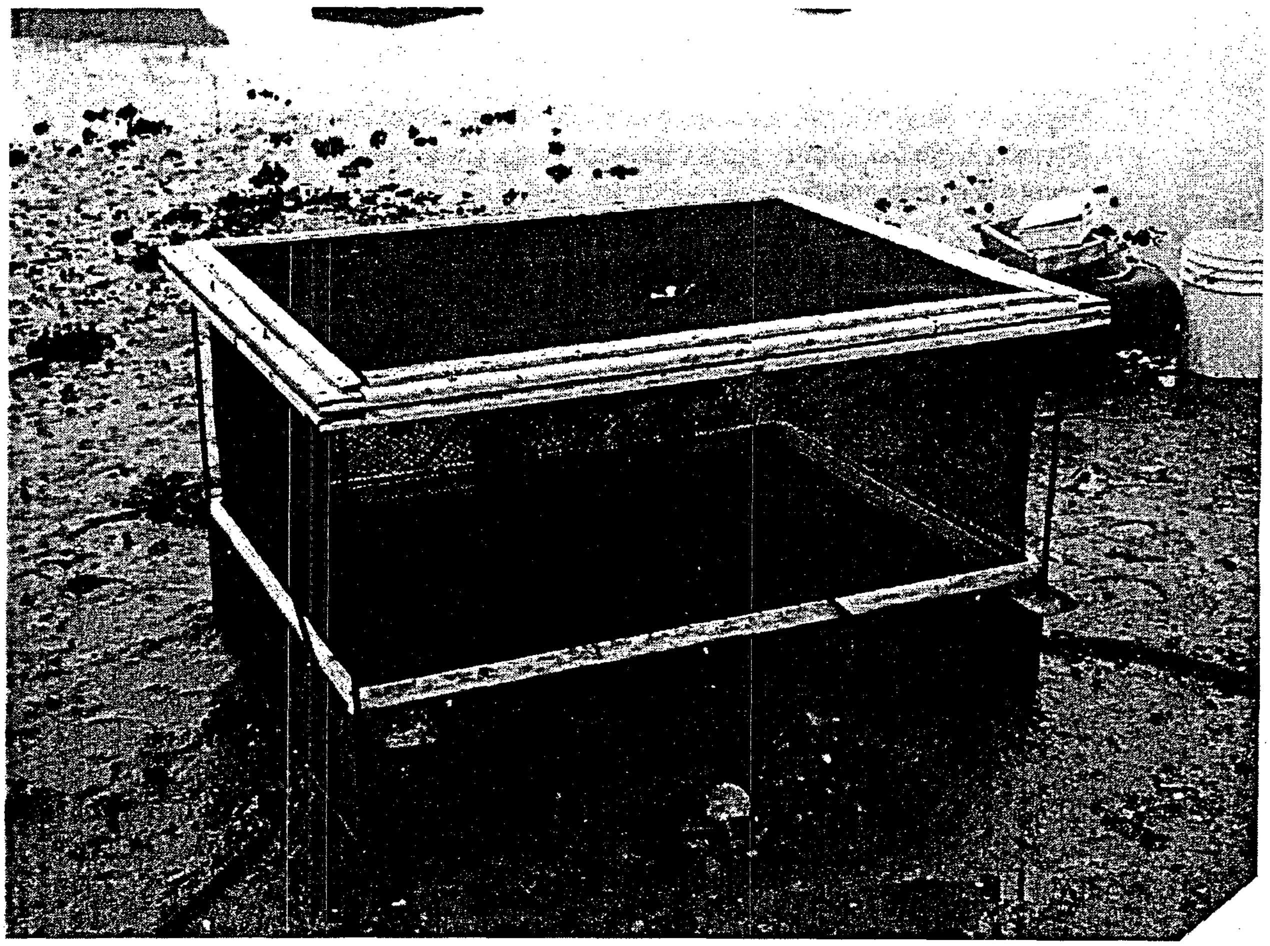

Figure 4. Open-bottom pens employed in 2003 and 2004 growth and survival experiments.

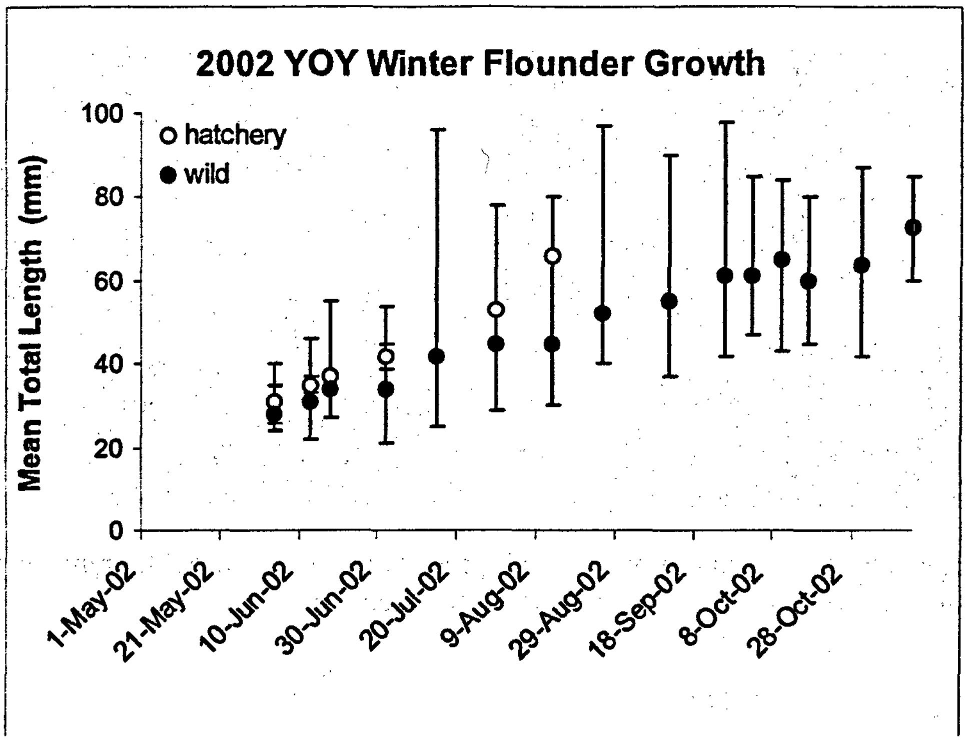

Figure 5. Size of hatchery and wild YOY winter flounder over time, Plymouth Harbor, 2002. Bars represent range (min-max) of size and point represents mean.

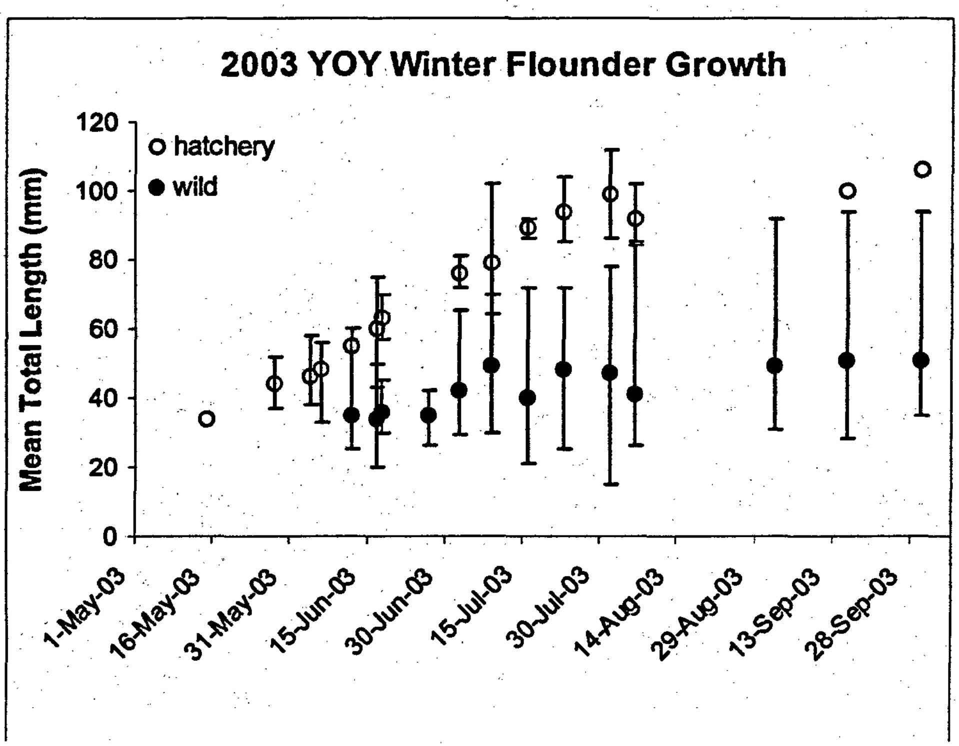

Figure 6. Size of hatchery and wild YOY winter flounder over time, Plymouth Harbor, 2003. Bars represent range (min-max) of size and point represents mean.

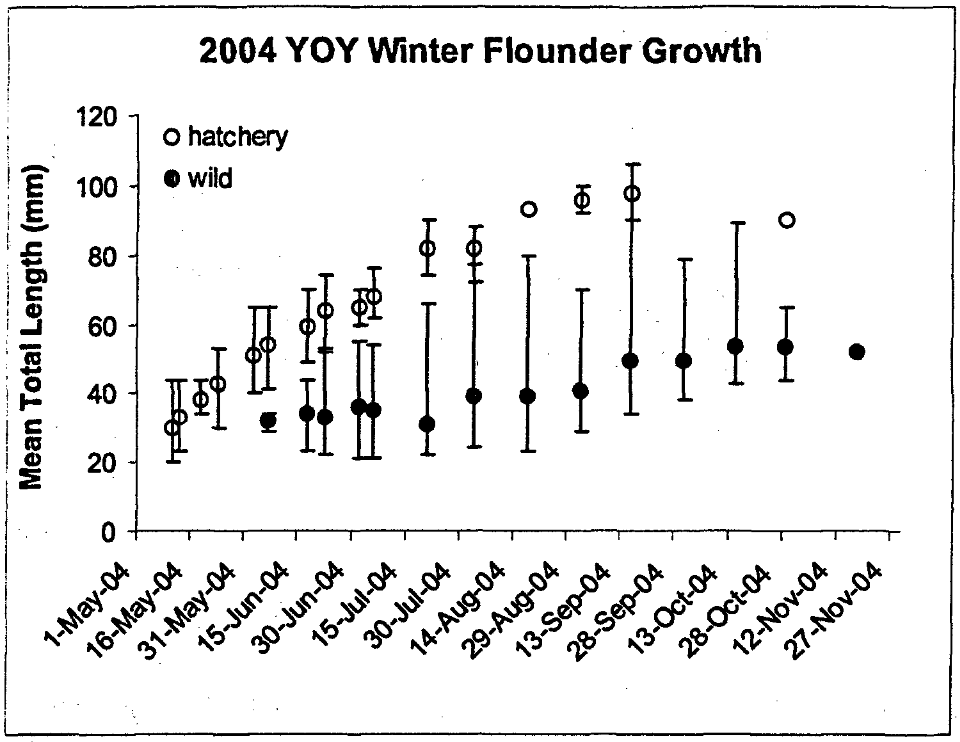

Figure 7. Size of hatchery and wild YOY winter flounder over time, Plymouth Harbor, 2004. Bars represent range (min-max) of size and point represents mean.

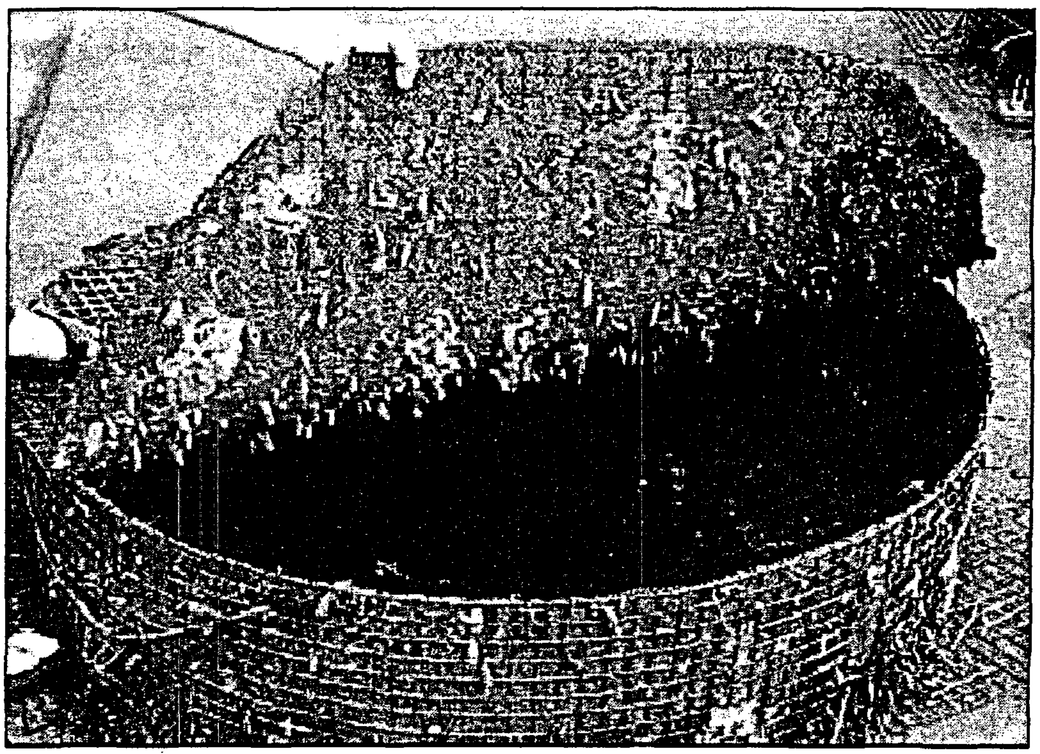

Figure 8. Enclosed pen used in 2002 growth and survival studies showing fouling.

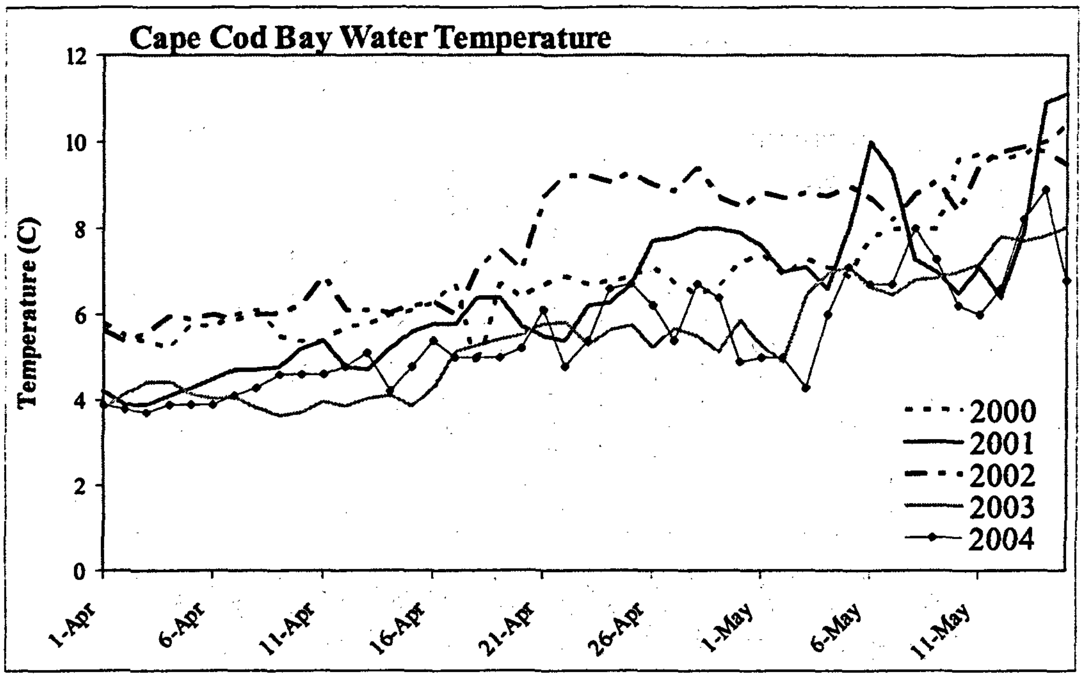

Figure 9. Cape Cod Bay water temperature 2000-2004 at 40-ft depth strata. Coastal Lobster Project of the Massachusetts Division of Marine Fisheries, Rocky Point.

Table 1. Release details for 2000-2004 PNPS winter flounder stock enhancement program.

Year	date of release	# of hatchery fish released	average size (mm) of hatchery fish at release [1]	average size (mm) of wild yoy winter flounder [1]	release location	water temperature (°C)
2000	7/24	4,700	28.1 (0.7)		Plymouth Yacht Club	19.3
	7/28	10,600	29.9 (0.5)		West side of Plymouth Beach	17.9
	7/31			50.1 (1.9)		
	total	**15,300**				
2001	6/4-6/5	4,950	29.7 (1.1)	26.9 (2.2)	Plymouth Yacht Club	15.4
	6/12	1,000			Duxbury Bay	
	6/14	8,000	28.4 (0.9)		Duxbury Bay	23.0
	6/15			37.2 (1.1)		
	total	**13,950**				
2002	5/31	15,000				16.5
	6/4	10,200		28.0 (1.6)	Plymouth Yacht Club	15.4
	6/13		32.6 (0.5)	31.0 (0.6)	Plymouth Yacht Club	
	total	**25,200**				
2003	5/15	16,000	34.0 (0.8)	no wild yoy at release	Plymouth Yacht Club	16.0
	5/20	9,000	33.0 (0.9)	no wild yoy at release	Plymouth Yacht Club	14.0
	total	**25,000**				
2004	5/10	9,900	29.9 (0.4)	no wild yoy at release	Plymouth Yacht Club	14.0
	5/11	10,100	28.39 (0.8)	no wild yoy at release	Plymouth Yacht Club	15.0
	5/12	5,000		no wild yoy at release	Plymouth Yacht Club	15.4
	total	**25,000**				

[1] The standard error is denoted in parentheses.

Table 2. Post-Release Sampling of Young-of-the-Year Flounder - 2000

Sampling date	Location	Gear	number of hauls/tows	surface water temp	number of age-0 winter flounder collectec	mean size (mm)	s.e.	n	range (mm)
7/31	Plymouth Yacht Club	50-ft beach seine	7		184 wild	50	1.9	51	33-87
8/4	Plymouth Yacht Club	50-ft beach seine	7		22 wild	48	2.1	22	34-67
		beam trawl	7		19 wild	56	2.5	19	34-75
8/11	Plymouth Yacht Club	50-ft beach seine	7		267 wild	51	1.4	50	36-74
		beam trawl	8	22.4	36 wild	55	2.5	36	36-90
8/18	Plymouth Yacht Club	50-ft beach seine	12	19.8	95 wild	58	2.0	50	40-97
		beam trawl	14	19.2	14 wild	61	4.8	14	38-102
8/25	Plymouth Yacht Club	50-ft beach seine	9	21.7	66 wild	57	2.1	50	38-100
		beam trawl	9	19.5	14 wild	69	6.2	14	43-131
9/1	Plymouth Yacht Club	50-ft beach seine	7	17.6	238 wild	61	1.6	50	45-95
9/8	Plymouth Yacht Club	50-ft beach seine	13	18.0	237 wild	63	1.8	50	39-102
		beam trawl	3		11 wild	65	4.3	11	45-96
9/18	Plymouth Yacht Club	50-ft beach seine	14	16.0	74 wild	60	1.3	50	44-96
		beam trawl	2		3 wild	64	3.5	2	60-67
9/22	Plymouth Yacht Club	50-ft beach seine	13	17.1	112 wild	68	1.8	50	47-104
10/2	Plymouth Yacht Club	50-ft beach seine	16	14.2	135 wild	63	1.2	81	46-95
		beam trawl	3		10 wild				
10/10	Plymouth Yacht Club	50-ft beach seine	11	13.2	7 wild				
10/18	Plymouth Yacht Club	50-ft beach seine	12	12.7	19 wild	65	2.0	17	55-88

Table 2. Continued

Sampling date	Location	Gear	number of hauls/tows	surface water temp	number of age-0 winter flounder collectec	mean size (mm)	s.e.	n	range (mm)
11/1	Plymouth Yacht Club	50-ft beach seine	9	7.7	120 wild	68	1.4	34	55-85
11/3	Plymouth Yacht Club	50-ft beach seine	11	7.6	46 wild	78	2.0	44	52-101
11/9	Plymouth Yacht Club	50-ft beach seine	*	7.1	101 wild	71	1.9	50	46-98
11/16	Plymouth Yacht Club	50-ft beach seine	*	6.8	57 wild	72	2.6	50	48-115

* long hauls completed to cover similar portions of beach as on earlier dates

Table 3. Plymouth Harbor Post-Release Sampling Young-of-the-Year Winter Flounder - 2001

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collectec	mean size (mm)	s.e.	n	range (mm)
6/5	Plymouth Yacht Club	50-ft beach seine	6	15.6	46 wild	27	2.2	29	20-36
6/18	Plymouth Yacht Club	100-ft beach seine	4		228 wild	30	0.5	64	24-47
					4 hatchery	36	0.4	4	35-37
6/29	Plymouth Yacht Club	100-ft beach seine	4	22.2	154 wild	39	0.4	145	24-50
7/10	Plymouth Yacht Club	100-ft beach seine	7	23.2	215 wild	39	0.7	132	27-67
8/2	Plymouth Yacht Club	100-ft beach seine	3		160 wild	43	1.1	64	30-68
					1 hatchery	78			
8/22	Plymouth Yacht Club	100-ft beach seine	5		59 wild	51	1.6	47	36-82
9/7	Plymouth Yacht Club	100-ft beach seine	7		96 wild	52	1.4	70	38-85
					1 hatchery	88			

Table 3. Plymouth Harbor Post-Release Sampling Young-of-the-Year Winter Flounder - 2001

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
6/5	Plymouth Yacht Club	50-ft beach seine	6	15.6	46 wild	27	2.2	29	20-36
6/18	Plymouth Yacht Club	100-ft beach seine	4		228 wild	30	0.5	64	24-47
					4 hatchery	36	0.4	4	35-37
6/29	Plymouth Yacht Club	100-ft beach seine	4	22.2	154 wild	39	0.4	145	24-50
7/10	Plymouth Yacht Club	100-ft beach seine	7	23.2	215 wild	39	0.7	132	27-67
8/2	Plymouth Yacht Club	100-ft beach seine	3		160 wild	43	1.1	64	30-68
					1 hatchery	78			
8/22	Plymouth Yacht Club	100-ft beach seine	5		59 wild	51	1.6	47	36-82
9/7	Plymouth Yacht Club	100-ft beach seine	7		96 wild	52	1.4	70	38-85
					1 hatchery	88			

Table 4. Duxbury Bay Post-Release Sampling Young-of-the-Year Winter Flounder - 2001

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
6/15	Duxbury Bay	50-ft beach seine	7	25.1	43 wild	37	1.1	22	27-48
6/22	Duxbury Bay	100-ft beach seine	2		95 wild	41	1.0	60	24-60
6/27	Duxbury Bay	100-ft beach seine	10		55 wild	47	1.5	32	29-66
7/11	Duxbury Bay	100-ft beach seine	5	22.9	109 wild	46	1.0	103	25-75
					1 hatchery	39			
7/24	Duxbury Bay	100-ft beach seine	3	25.5	85 wild	48	1.6	67	30-80
9/20	Duxbury Bay	100-ft beach seine	2		38 wild	58	1.9	33	45-80

Table 5. Post-Release Sampling Young-of-the-Year Winter Flounder - 2002

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
6/4	Plymouth Yacht Club	100-ft beach seine	2		177 wild	28	1.6	6	24-35
					18 hatchery				
6/13	Plymouth Yacht Club	100-ft beach seine	3	14.0	261 wild	31	0.6	75	22-46
					6 hatchery	35	1.2	3	33-37
6/18	Plymouth Yacht Club	100-ft beach seine	4		38 wild	34	2.0	15	27-55
					2 hatchery	37			
7/2	Plymouth Yacht Club	100-ft beach seine	3	22.0	180 wild	34	1.0	63	21-54
					2 hatchery	42	3.0	2	39-45
7/2	Site 2	100-ft beach seine	3	22.5	88 wild	36	1.2	60	21-66
7/15	Plymouth Yacht Club	100-ft beach seine	6	23.0	65 wild	42	1.7	65	25-96
7/30	Plymouth Yacht Club	100-ft beach seine	4	21.7	212 wild	45	1.8	50	29-78
					2 hatchery	53	0.0	2	53
8/13	Plymouth Yacht Club	100-ft beach seine	5	23.0	95 wild	45	1.1	104	30-80
					1 hatchery	66			
8/26	Plymouth Yacht Club	100-ft beach seine	4	19.5	34 wild	52	2.5	33	40-97
9/12	Plymouth Yacht Club	100-ft beach seine	5	17.5	79 wild	55	1.0	77	37-90
					1 hatchery	55			
9/26	Plymouth Yacht Club	100-ft beach seine	5	17.0	183 wild	61	1.5	62	42-98
10/3	Plymouth Yacht Club	100-ft beach seine	4	18.0	191 wild	61	1.1	50	47-85

Table 5. Continued

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
10/10	Plymouth Yacht Club	100-ft beach seine	5	14.5	13 wild	65	2.6	13	43-84
10/17	Plymouth Yacht Club	100-ft beach seine	5	15.5	70 wild	60	1.3	50	45-80
10/30	Plymouth Yacht Club	100-ft beach seine	5	8.0	90 wild	64	1.8	30	42-87
11/12	Plymouth Yacht Club	100-ft beach seine	5	13.0	7 wild	73	3.4	7	60-85
11/26	Plymouth Yacht Club	100-ft beach seine	4	7.0	0 wild				

Table 6. Post-Release Sampling Young-of-the-Year Winter Flounder - 2003

Sampling date	Location	Gear	number of hauls	surface water temp	number of yoy winter flounder collected	mean size (mm)	s.e.	n	range (mm)
5/15	Plymouth Yacht Club	100-ft beach seine	2	16.0	0 wild				
5/16	Plymouth Yacht Club	100-ft beach seine	3	10.5	0 wild				
5/20	Plymouth Yacht Club	100-ft beach seine	5	14.0	0 wild				
5/20	Site 2	100-ft beach seine	2	14.0	0 wild				
5/21	Plymouth Yacht Club	100-ft beach seine	5	13.0	0 wild				
5/28	Plymouth Yacht Club	100-ft beach seine	6	14.0	0 wild				
					11 hatchery	44	1.5	11	37-52
6/4	Plymouth Yacht Club	100-ft beach seine	4	15.0	0 wild				
					3 hatchery	46	6.2	3	38-58
6/6	Plymouth Yacht Club	100-ft beach seine	2	16.0	0 wild				
					5 hatchery	48	4.1	5	33-56
6/6	Site 2	100-ft beach seine	2		0 wild				
6/6	Site 3	100-ft beach seine	2		0 wild				
6/6	Site 4	100-ft beach seine	1		0 wild				
6/12	Plymouth Yacht Club	100-ft beach seine	5	18.0	10 wild	35	4.0	10	25-60
6/17	Plymouth Yacht Club	100-ft beach seine	6	16.0	42 wild	34	1.0	41	20-50
					28 hatchery	60	1.3	28	43-75
6/18	Plymouth Yacht Club	100-ft beach seine	3	15.0	10 wild	36	1.5	10	30-45
					10 hatchery	63	1.5	10	57-70

Table 6. Continued

Sampling date	Location	Gear	number of hauls	surface water temp	number of yoy winter flounder collected	mean size (mm)	s.e.	n	range (mm)
6/27	Plymouth Yacht Club	100-ft beach seine	5	20.0	13 wild	35	1.3	13	26-42
7/3	Plymouth Yacht Club	100-ft beach seine	5	18.0	114 wild	42	1.1	46	29-65
					11 hatchery	76	1.2	9	72-81
7/9	Plymouth Yacht Club	100-ft beach seine	5	19.5	335 wild	49	1.2	49	30-70
					33 hatchery	79	1.4	32	64-102
7/16	Plymouth Yacht Club	100-ft beach seine	5	19.0	205 wild	40	1.9	50	21-72
					2 hatchery	89	3.0	2	86-92
7/23	Plymouth Yacht Club	100-ft beach seine	4	18.0	295 wild	48	1.8	48	25-72
					8 hatchery	94	2.8	7	85-104
8/1	Plymouth Yacht Club	100-ft beach seine	3	18.0	279 wild				
					4 hatchery	98	5.4	4	86-112
8/1	Site 2	100-ft beach seine	3	18.0	98 wild	47	1.3	98	15-78
					1 hatchery	102			
8/6	Plymouth Yacht Club	100-ft beach seine	4	18.0	284 wild	41	1.2	100	26-84
					4 hatchery	92	3.7	4	85-102
9/2	Plymouth Yacht Club	100-ft beach seine	4	17.5	509 wild	49	1.3	132	31-92
9/16	Plymouth Yacht Club	100-ft beach seine	5	20.0	290 wild	51	1.3	100	28-94
					1 hatchery	100			
9/30	Plymouth Yacht Club	100-ft beach seine	6	17.0	100 wild	51	2.0	78	35-139
					1 hatchery	106			

Table 7. Post-Release Sampling Age-1 Winter Flounder - 2003

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-1 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
5/15	Plymouth Yacht Club	100-ft beach seine	2	16.0	30 wild	75	2.6	30	47-108
5/16	Plymouth Yacht Club	100-ft beach seine	3	10.5	19 wild	78	2.3	19	64-97
5/20	Plymouth Yacht Club	100-ft beach seine	5	14.0	0 wild				
5/20	Site 2	100-ft beach seine	2	14.0	19 wild	76	3.1	19	56-108
5/21	Plymouth Yacht Club	100-ft beach seine	5	13.0	0 wild				
5/28	Plymouth Yacht Club	100-ft beach seine	6	14.0	54 wild	89	1.8	54	65-138
6/4	Plymouth Yacht Club	100-ft beach seine	4	15.0	6 wild	94	4.8	6	76-110
6/6	Plymouth Yacht Club	100-ft beach seine	2	16.0	3 wild	94	2.1	3	90-97
6/6	Site 2	100-ft beach seine	2		50 wild	90			67-125
6/6	Site 3	100-ft beach seine	2		0 wild				
6/6	Site 4	100-ft beach seine	1		0 wild				
6/12	Plymouth Yacht Club	100-ft beach seine	5	18.0	2 wild	110	10.5	2	99-120
6/17	Plymouth Yacht Club	100-ft beach seine	6	16.0	11 wild	99	2.0	11	88-110
6/18	Plymouth Yacht Club	100-ft beach seine	3	15.0	15 wild	104	2.5	15	85-124
6/27	Plymouth Yacht Club	100-ft beach seine	5	20.0	0 wild				
7/3	Plymouth Yacht Club	100-ft beach seine	5	18.0	4 wild	118	3.5	4	110-125

Table 7. Continued

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-1 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
7/9	Plymouth Yacht Club	100-ft beach seine	5	19.5	1 wild	130			
7/16	Plymouth Yacht Club	100-ft beach seine	5	19.0	0 wild				
7/23	Plymouth Yacht Club	100-ft beach seine	4	18.0	6 wild	131	8.3	4	109-149
8/1	Plymouth Yacht Club	100-ft beach seine	3	18.0	3 wild	127	2.8	3	120-133
8/1	Site 2	100-ft beach seine	3	18.0	7 wild	118	4.5	7	103-133
8/6	Plymouth Yacht Club	100-ft beach seine	4	18.0	1 wild	129			
9/2	Plymouth Yacht Club	100-ft beach seine	4	17.5	1 wild	140			
9/16	Plymouth Yacht Club	100-ft beach seine	5	20.0	1 wild	145			
9/30	Plymouth Yacht Club	100-ft beach seine	6	17.0	0 wild				

Table 8. Post-Release Sampling Young-of-the-Year Winter Flounder - 2004

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
5/10	Plymouth Yacht Club	100-ft beach seine	2	14.0	0 wild				
5/11	Plymouth Yacht Club	100-ft beach seine	6	14.0	0 wild				
					11 hatchery	30	2.1	11	20-44
5/12	Plymouth Yacht Club	100-ft beach seine	1	14.5	0 wild				
5/13	Plymouth Yacht Club	100-ft beach seine	2	15.0	0 wild				
					13 hatchery	33	1.8	11	23-44
5/13	Plymouth Site 2	100-ft beach seine	2	15.0	0 wild				
5/13	Plymouth Site 3	100-ft beach seine	2	15.0	0 wild				
					3 hatchery	36	4.4	3	27-41
5/13	Plymouth Site 4	100-ft beach seine	1	15.0	0 wild				
5/13	Plymouth Site 5	100-ft beach seine	2	15.0	0 wild				
5/19	Plymouth Yacht Club	100-ft beach seine	5	15.5	0 wild				
					5 hatchery	38	1.9	5	34-44
5/24	Plymouth Yacht Club	100-ft beach seine	5	14.5	0 wild				
					43 hatchery	43	0.7	43	30-53
6/3	Plymouth Yacht Club	100-ft beach seine	4	15.5	0 wild				
					48 hatchery	51	0.6	48	40-65
6/7	Plymouth Yacht Club	100-ft beach seine	5	14.5	5 wild	32	0.9	5	29-34
					64 hatchery	54	0.7	64	41-65
6/18	Plymouth Yacht Club	100-ft beach seine	4	16.8	215 wild	34	0.5	99	23-44
					43 hatchery	59	0.8	43	49-70

Table 8. Continued

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-0 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
6/23	Plymouth Yacht Club	100-ft beach seine	5	20.0	171 wild	33	0.7	100	22-52
					31 hatchery	64	1.0	31	53-74
7/2	Plymouth Yacht Club	50-ft beach seine	5	19.0	42 wild	36	1.3	40	21-55
					7 hatchery	65	1.2	7	60-70
7/6	Plymouth Yacht Club	100-ft beach seine	4	19.0	290 wild	35	0.7	104	21-54
					17 hatchery	38	1.1	17	62-76
7/21	Plymouth Yacht Club	100-ft beach seine	4	25.0	184 wild	30	0.8	101	22-66
					6 hatchery	82	2.4	6	74-90
8/3	Plymouth Yacht Club	100-ft beach seine	4	20.5	292 wild	39	1.5	100	24-77
					11 hatchery	82	1.4	11	72-88
8/18	Plymouth Yacht Club	100-ft beach seine	4	20.0	185 wild	39	1.2	125	23-80
					1 hatchery	93			93
9/2	Plymouth Yacht Club	100-ft beach seine	4	18.0	80 wild	41	0.8	78	29-70
					6 hatchery	96	1.1	6	92-100
9/16	Plymouth Yacht Club	100-ft beach seine	4	17.5	127 wild	49	1.3	101	34-90
					2 hatchery	98	8.0	2	90-106
10/1	Plymouth Yacht Club	100-ft beach seine	5	16.5	23 wild	49	2.7	19	38-79
10/15	Plymouth Yacht Club	100-ft beach seine	4	14.0	50 wild	53	2.1	47	43-89
10/29	Plymouth Yacht Club	100-ft beach seine	5	11.0	20 wild	54	1.3	19	44-65
					1 hatchery	90			
11/18	Plymouth Yacht Club	100-ft beach seine	5	8.0	9 wild	52	4.4	9	41-80

Table 9. Post-Release Sampling Age-1 Winter Flounder - 2004

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-1 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
5/10	Plymouth Yacht Club	100-ft beach seine	2	14.0	2 wild	62	8.0	2	54-70
5/11	Plymouth Yacht Club	100-ft beach seine	6	14.0	16 wild	63	1.6	16	54-75
5/12	Plymouth Yacht Club	100-ft beach seine	1	14.5	6 wild	64	3.3	6	50-75
5/13	Plymouth Yacht Club	100-ft beach seine	2	15.0	81 wild	69	1.2	42	56-85
5/13	Plymouth Site 2	100-ft beach seine	2	15.0	84 wild				
5/13	Plymouth Site 3	100-ft beach seine	2	15.0	74 wild	67	0.9	67	51-85
5/13	Plymouth Site 4	100-ft beach seine	1	15.0	0 wild				
5/13	Plymouth Site 5	100-ft beach seine	2	15.0	6 wild	68	3.4	6	58-82
5/19	Plymouth Yacht Club	100-ft beach seine	5	15.5	53 wild	70	1.2	52	55-94
5/24	Plymouth Yacht Club	100-ft beach seine	5	14.5	121 wild	72	0.8	97	60-98
6/3	Plymouth Yacht Club	100-ft beach seine	4	15.5	78 wild	81	1.1	78	55-110
6/7	Plymouth Yacht Club	100-ft beach seine	5	14.5	19 wild	82	1.9	18	68-98
6/18	Plymouth Yacht Club	100-ft beach seine	4	16.8	21 wild	91	1.8	21	70-102
6/23	Plymouth Yacht Club	100-ft beach seine	5	20.0	1 wild	109			
7/2	Plymouth Yacht Club	50-ft beach seine	5	19.0	0 wild				
7/6	Plymouth Yacht Club	100-ft beach seine	4	19.0	6 wild	113	7.4	6	92-141
7/21	Plymouth Yacht Club	100-ft beach seine	4	25.0	4 wild	113	3.0	4	106-119

Table 9. Post-Release Sampling Age-1 Winter Flounder - 2004

Sampling date	Location	Gear	number of hauls	surface water temp	number of age-1 winter flounder collected	mean size (mm)	s.e.	n	range (mm)
8/3	Plymouth Yacht Club	100-ft beach seine	4	20.5	2 wild	117	22.0	2	95-139
8/18	Plymouth Yacht Club	100-ft beach seine	4	20.0	5 wild	123	2.6	5	115-130
9/2	Plymouth Yacht Club	100-ft beach seine	4	18.0	0 wild				
9/16	Plymouth Yacht Club	100-ft beach seine	4	17.5	0 wild				
10/1	Plymouth Yacht Club	100-ft beach seine	5	16.5	1 wild	135			
10/15	Plymouth Yacht Club	100-ft beach seine	4	14.0	0 wild				
10/29	Plymouth Yacht Club	100-ft beach seine	5	11.0	0 wild				
11/18	Plymouth Yacht Club	100-ft beach seine	5	8.0	0 wild				

Table 10. Summary of Pen Studies - 2001

Experiment	Date	Holding Period (days)	Number of tagged age-0 flounder introduced	Number of wild age-0 flounder introduced	Number of tagged age-0 flounder recovered	Number of wild age-0 flounder recovered
LT#1	6/19-6/21	3	~200	0	24 (~12%)	
LT#2	6/19-6/28	10	18	18	12 (67%)	2 (11%)
LT#3	6/19-7/9	21	18	18	10 (55%)	5 (28%)
LT#4	6/19-7/9	21	18	18	12 (67%)	2 (11%)
				average survival 6/19-7/9	61%	20%
LT#5	6/19-8/1	44	18	18	8 (44%)	13 (72%)
LT#6	6/19-8/1	44	18	18	8 (44%)	9 (50%)
LT#7	6/19-8/1	44	18	18	0 (0%)	1 (6%)
				average survival	29%	43%

Table 11. Summary of Pen Studies - 2002

Experiment	Date	Holding Period (days)	Number of tagged age-0 flounder introduced	Number of wild age-0 flounder introduced	Number of tagged age-0 flounder recovered	Number of wild age-0 flounder recovered
LT#1	6/13-7/15	33	15	15	0 (0%)	2 (13%)
LT#2	6/13-7/15	33	15	15	2 (13%)	1 (7%)
				average survival	7%	10%
LT#3	6/13-8/13	62	15	15	1 (7%)	1 (7%)
LT#4	6/13-8/13	62	15	15	0 (0%)	0 (0%)
				average survival	4%	4%
LT#5	6/13-8/26	75	15	15	0 (0%)	0 (0%)
LT#6	6/13-8/26	75	15	15	0 (0%)	0 (0%)
LT#7	6/13	not recovered	15	15		
				average survival	0%	0%

Table 12. Summary of Pen Studies - 2003

Short-term experiments

Experiment	Holding period	Number of tagged fish introduced	Number of tagged fish recovered	Survival (%)
ST#1	24 hours	50	45	90
ST#2	24 hours	50	50	100

Long-term experiments

Experiment	Date	Number of hatchery flounder Start	Finish	Holding period (days)	Survival (%)	Cumulative holding period (days)	Survival (%)
LT#1	5/20-6/17	10	5	29	50		
LT#1	6/17-7/15	5	4	29	80	57	40
LT#2	6/19-7/14	5	2	26	40		
LT#3	6/19-7/15	5	4	27	80		
LT#4	6/19-7/14	5	3	26	60		
LT#5	6/19-7/16	5	4*	28	80		
LT#6	6/19-7/16	5	2	28	40		
				average 6/17-7/15	**63.3**		
LT#1	7/15-8/13	4	4	30	100	86	40
LT#2	7/15-8/13	2	2	31	100	56	40
LT#3	7/15-8/15	4	3	32	75	58	60
LT#4	7/14-8/12	3	2	30	67	55	40
LT#5	7/16-8/12	4	4	30	100	55	80
LT#6	7/16-8/12	2	2	30	100	55	40
				average 7/15-8/13	**90.3**	**cumulative average** 6/19-8/13**	**52.0**
LT#7	8/13-9/30	5	4	49	80		
LT#8	8/13-9/30	5	3	49	60		
				average 8/13-9/30	**70.0**		

* 1 fish lost while measuring

** average of experiments 2-6

Table 13. Summary of Pen Studies - 2004

Short-term experiments

Experiment	Holding period	Number of tagged fish introduced	Number of tagged fish recovered	Survival (%)
ST#1	24 hours	50	45	90
ST#2	24 hours	50	50	100

Long-term experiment

Experiment	Date	Number of hatchery flounder Start	Finish	Holding period (days)	Survival (%)	Cumulative holding period (days)	Cumulative Survival (%)
Pen #1	5/12-6/3	5	4	23	80		
Pen #2	5/12-6/3	5	5	23	100		
Pen #3	5/12-6/4	5	5	24	100		
Pen #4	5/12-6/7	5	5	27	100		
Pen #5	5/12-6/4	5	3	24	60		
Pen #6	5/12-6/7	5	5	27	100		
				average 5/12-6/4	90.0		
Pen #1	6/4-7/5	3*	2	32	67	55	40
Pen #2	6/4-7/5	5	5	32	100	55	100
Pen #3	6/5-7/5	5	5	31	100	55	100
Pen #4	6/8-7/6	5	4	29	80	56	80
Pen #5	6/5-7/6	3	3	32	100	56	60
Pen #6	6/8-7/6	5	3	29	60	56	60
				average 6/5-7/6	84.5	cumulative average 5/12-7/6	80.0
Pen #1	7/6-8/2	2	2	28	100	83	40
Pen #2	7/6-8/2	5	4	28	80	83	80
Pen #3	7/6-8/2	5	4	28	80	83	80
Pen #4	7/7-8/3	4	4	28	100	84	80
Pen #5	7/7-8/3	3	3	28	100	84	60
Pen #6	7/7-8/3	3	2	28	67	84	40
				average 7/7-8/3	87.8	cumulative average 5/12-8/3	68.0
Pen #1	8/3-8/31	2	2	29	100	112	40
Pen #2	8/3-8/31	4	4	29	100	112	80
Pen #3	8/3-9/1	4	4	30	100	113	80
Pen #4	8/4-9/1	4	4	29	100	113	80
Pen #5	8/4-9/2	3	2	30	67	114	40
Pen #6	8/4-9/1	2	2	29	100	113	40
				average 8/4-9/1	94.5	cumulative average 5/12-9/1	64.0

* 1 fish lost while measuring

Table 14. Gut contents expressed as percent volume (the volume of each species expressed as a percentage of the total volume of food from all stomachs) for hatchery and wild fish averaged over 6/4-8/13, 2002, Plymouth Harbor.

	Tagged (n=15)	Wild (n=20)	
Arthropod	**34.0%**	**57.5%**	**Total Arthropod**
Crustacean			
Decapod			
Brachyura decapod juvenile			
General	6.7%	2.5%	
Paguridae juvenile	2.1%	3.5%	
Isopoda	2.3%	5.4%	
Copepod			
General	1.4%	2.6%	
Calanoid	0.1%	38.1%	
Unidentified	0.0%	4.9%	
Insect larvae	21.2%	0.5%	
Annelida	**24.1%**	**23.0%**	**Total Annelida**
Polychaete			
Spionidae	3.5%	5.0%	
Orbiniidae	0.0%	4.5%	
Unidentified	20.6%	13.6%	
Mollusca			
Bivalve	**3.5%**	**2.1%**	**Total Mollusca**
Cnidaria			
Polypoid larvae	**3.5%**	**6.5%**	**Total Cnidaria**
Others	**34.8%**	**10.8%**	**Total Others**
Sand	3.7%	0.5%	
Rock	0.0%	4.8%	
Animal remains	16.9%	5.5%	
Terrestrial seeds	14.2%	0.0%	
Total	100%	100%	

Table 15. Gut contents from seine samples 2002

Hatchery

Average % volume of gut contents

Date	n	Arthopoda	Annelida	Cnidaria	Mollusca	Other
6/4/2002	7	83.9%	16.1%	0.0%	0.0%	0.0%
6/13/2002	2	1.0%	0.0%	0.0%	25.0%	74.0%
6/18/2002	1	60.0%	40.0%	0.0%	0.0%	0.0%
7/2/2002	2	41.0%	9.5%	0.0%	0.0%	49.5%
7/30/2002	2	7.5%	66.5%	0.0%	0.0%	26.0%
8/13/2002	1	0.0%	50.0%	50.0%	0.0%	0.0%
	15					

Wild

Date	n	Arthopoda	Annelida	Cnidaria	Mollusca	Other
6/4/2002	3	38.7%	38.0%	0.0%	0.0%	23.3%
6/13/2002	2	75.0%	25.0%	0.0%	0.0%	0.0%
6/18/2002	4	90.0%	5.3%	0.0%	2.8%	2.0%
7/2/2002	4	99.5%	0.0%	0.0%	0.0%	0.5%
7/30/2002	3	10.0%	63.3%	3.3%	10.0%	13.3%
8/13/2002	4	25.3%	21.3%	29.8%	0.0%	23.8%
	20					

Table 16. Gut contents from seine samples 2003

Hatchery

% volume of gut contents

Date	n	Arthopoda	Annelida	Mollusca	Other
5/28/2003	5	0.6	99.4	0.0	0.0
6/4/2003	3	2.0	98.0	0.0	0.0
6/6/2003	5	30.0	70.0	0.0	0.0
6/12/2003	5	0.0	100.0	0.0	0.0
6/17/2003	7	11.4	87.1	0.0	1.4
7/3/2003	5	32.6	49.4	0.0	18.0
7/24/2003	5	33.7	66.0	0.0	0.3
9/16/2003	1	0.0	0.0	99.0	1.0
9/30/2003	1	95.0	5.0	0.0	0.0
	37				

Wild

Date	n	Arthopoda	Annelida	Mollusca	Other
5/28/2003	0	0	0	0	0
6/4/2003	0	0	0	0	0
6/6/2003	0	0	0	0	0
6/12/2003	0	0	0	0	0
6/17/2003	7	0.1	85.4	0	14.3
7/3/2003	5	38.8	40	0.2	21.4
7/24/2003	4	2.8	72.3	0	25
9/16/2003	5	30	10	10	50
9/30/2003	5	20	22	20	38
	26				

Caged Hatchery

date	n	arthopoda	annelida	mollusca	other
8/13/2003	5	39	58.5	0.5	2
9/30/2003	4	4	44	7	45

Table 17. Gut contents expressed as percent volume (the volume of each species expressed as a percentage of the total volume of food from all stomachs) for hatchery and wild fish averaged over 6/17-9/30, 2003, Plymouth Harbor.

	Hatchery n=17	Wild n=26	
Arthropod			
Crustacean	**25.8%**	**17.6%**	**Total Arthopod**
Decapod	1.5%	0.0%	
Brachyura decapod juvenile	0.0%	0.0%	
Paguridae juvenile	0.0%	3.8%	
Caridea decapod	0.0%	3.8%	
Isopoda	0.6%	0.0%	
Copepoda			
Harpactacoid	0.1%	2.1%	
Amphipod			
Ampeliscidae	2.9%	3.5%	
Gammaridae	1.2%	0.4%	
Lysianassidae	4.7%	0.0%	
Corophium	6.2%	2.5%	
Unidentified	5.6%	1.3%	
Insect larvae	2.9%	0.1%	
Annelida	**62.4%**	**47.8%**	**Total Annelida**
Polychaete			
Spionidae	1.8%	9.2%	
Polydora ligni	9.9%	0.4%	
Cirratulidae	1.2%	0.0%	
Maldanidae	4.0%	4.8%	
Nereidae	0.6%	0.4%	
Phyllodocidae	7.1%	1.0%	
Unidentified	37.9%	32.1%	
Mollusca	**5.8%**	**5.8%**	**Total Mollusca**
Bivalve	5.8%	3.8%	
Mya arenaria	0.0%	1.9%	
Others	**6.0%**	**28.8%**	**Total Others**
Animal remains	5.6%	28.3%	
Total	100%	100%	

The volume of each species is expressed as a percentage of the total volume of food from all stomachs

Table 18. Gut contents from seine samples 2004

Hatchery YOY

% volume of gut contents

date	n	arthopoda	annelida	mollusca	other
5/11/2004	12	60.0	10.0	0.0	30.0
5/19/2004	5	0.2	99.0	0.0	0.8
5/24/2004	10	2.7	97.3	0.0	0.0
6/3/2004	11	0.1	99.9	0.0	0.0
6/18/2004	10	8.7	61.4	0.0	29.9
7/2/2004	5	0.8	74.3	0.0	25.0
9/1/2004	5	0.0	5.0	0.0	95.0
9/16/2004	2	0.0	45.0	0.0	55.0
	60				

Wild YOY

date	n	arthopoda	annelida	mollusca	other
5/10/2004	0				
5/11/2004	0				
5/19/2004	0				
5/24/2004	0				
6/3/2004	0				
6/18/2004	12	96.9	2.1	0.0	1.0
7/2/2004	5	34.0	48.0	0.4	17.6
9/1/2004	5	0.0	20.0	0.0	80.0
9/16/2004	2	2.5	38.0	0.0	59.5
	24				

Wild Age 1+

date	n	arthopoda	annelida	mollusca	other
5/10/2004	2	5.0	0.0	0.0	95.0
5/11/2004	5	8.6	91.4	0.0	0.0
5/19/2004	5	6.6	93.4	0.0	0.0
5/24/2004	10	12.1	78.3	0.0	9.6
6/3/2004	12	0.5	98.7	0.8	0.0
	34				

Caged Hatchery

date	n	arthopoda	annelida	mollusca	other
9/30/2004	6	1.8	60.2	1.3	36.7

Table 19. Gut contents expressed as percent volume (the volume of each species expressed as a percentage of the total volume of food from all stomachs) for hatchery and wild fish averaged over 5/10-9/16, 2004, Plymouth Harbor.

	Hatchery n=60	Wild n=58	
Arthropod	**12.6%**	**25.0%**	**Total Arthopod**
Crustacean			
Decapod			
Brachyura decapod juvenile	0.0%	0.0%	
Paguridae juvenile	0.0%	0.0%	
Caridea decapod			
Crangon septemspinosa	0.0%	0.1%	
Isopoda	0.0%	0.5%	
Copepoda			
Calanoid	12.4%	23.2%	
Ostracod	0.0%	0.1%	
Amphipod			
Ampeliscidae	0.1%	0.6%	
Gammaridae	0.0%	0.1%	
Lysianassidae	0.0%	0.0%	
Corophium	0.0%	0.1%	
Unidentified	0.0%	0.0%	
Insect larvae			
Chironomidae	0.0%	0.4%	
Annelida	**64.8%**	**59.8%**	**Total Annelida**
Polychaete			
Spionidae	6.8%	12.1%	
Polydora ligni	39.2%	31.9%	
Cirratulidae	0.0%	0.5%	
Orbiniidae	0.0%	0.0%	
Maldanidae	3.8%	5.1%	
Nereidae	0.1%	0.0%	
Phyllodocidae	1.1%	1.1%	
Unidentified	13.9%	9.0%	
Mollusca	**0.0%**	**0.2%**	**Total Mollusca**
Bivalve			
Mytilus sp.	0.0%	0.2%	
Mya arenaria	0.0%	0.0%	
Others	**22.6%**	**15.0%**	**Total Others**
Artemia sp. nauplii and eggs	1.8%	0.0%	
Animal remains	15.1%	8.1%	
Barnacle cirri	1.8%	1.5%	
Fecal pellet	1.8%	0.0%	
Hydrozoa	1.8%	4.2%	
Sand	0.4%	1.1%	
Total	100%	100%	

Table 20. Pen experiment details - 2003

Experiment	Date	Hatchery YOY winter flounder Start	Hatchery YOY winter flounder Finish	Wild YOY winter flounder Start	Wild YOY winter flounder Finish	Crabs	Other fish	Hatchery YOY survival	Wild YOY survival
LT#1	5/20-6/17	10	5					50%	
	6/17-7/15	5	4			1	2	80%	
	7/15-8/13	4	4					100%	
LT #2	6/19-7/14	5	2		2*	1	2	40%	
	7/14-8/13	2	2	2	2			100%	100%
LT#3	6/19-7/15	5	4			3	1	80%	
	7/15-8/13	4	3		1			75%	
LT#4	6/19-7/14	5	3		2*			60%	
	7/14-8/12	3	2	2	4			67%	100%
LT#5	6/17-7/16	5	4**		1*			80%	
	7/16-8/12	4	4	1	1***			100%	0%
LT#6	6/19-7/16	5	2		2	4	2	40%	
	7/16-8/12	2	2	2	2			100%	100%
LT#7	8/13-9/30	5	4			2	1	80%	
LT#8	8/13-9/30	5	3		5	7	12	60%	

*wild YOY not found during pen setup
**1 fish lost while measuring
***Wild fish recovered smaller than wild fish introduced

Table 21. Growth rates of caged and uncaged hatchery fish in 2003.

Experiment	date	slope	R^2	p-value		
1	5/20-6/17	0.13				
uncaged hatchery fish	5/15-6/17	0.76	0.97	<0.001		
1	6/17-8/13	0.38	0.99	0.06	Average 6/17-8/13	0.43
2	6/17-8/13	0.52	0.99	0.04	n	6
3	6/17-8/13	0.31	0.90	0.20	st err	0.03
4	6/17-8/13	0.47	0.98	0.01		
5	6/17-8/13	0.39	0.99	0.01		
6	6/17-8/13	0.49	0.99	0.01		
uncaged hatchery fish	6/17-8/6	0.74	0.92	<0.001		
7	8/13-9/30	0.13			Average 8/13-9/30	0.13
8	8/13-9/30	0.13				
uncaged hatchery fish	8/13-9/30	0.19	0.88	0.06		

The p-value represents the probability that the slope is significant different from zero.

Table 22. Growth rates of caged and uncaged hatchery fish in 2004.

Experiment	date	slope	R^2	p-value		
Pen 1	5/12-7/5	0.61	0.99	0.05		
Pen 2	5/12-7/5	0.37	0.99	0.05	Average 5/12-7/5	0.44
Pen 3	5/12-7/5	0.41	0.98	0.09	n	6
Pen 4	5/12-7/5	0.38	0.98	0.1	st err	0.04
Pen 5	5/12-7/5	0.43	0.99	0.02		
Pen 6	5/12-7/5	0.41	0.99	0.03		
uncaged	5/12-7/5	0.64	0.97	<0.001		
Pen 1	7/5-8/31	0.18	0.99	0.02		
Pen 2	7/5-8/31	0.1	0.68	0.38		
Pen 3	7/5-8/31	0.08	0.99	0.01	Average 7/5-8/31	0.14
Pen 4	7/5-8/31	0.26	0.93	0.02		
Pen 5	7/5-8/31	0.01	0.59	0.48		
Pen 6	7/5-8/31	0.23	0.98	0.09		
uncaged	7/5-8/31	0.46	0.99	0.19		

The p-value represents the probability that the slope is significant different from zero.

Table 23. Pen experiment conditions - 2004

Experiment	Date	Hatchery YOY winter flounder Start	Hatchery YOY winter flounder Finish	Anoxic	Wild YOY winter flounder	Crabs	Hatchery YOY survival
Pen 1	5/12-6/3	5	4				80%
	6/3-7/5	3*	2	X	1		67%
	7/5-8/2	2	2	X			100%
	8/2-8/31	2	2	slightly			100%
	8/31-9/30	2	0	X			0%
Pen 2	5/12-6/3	5	5				100%
	6/3-7/5	5	5			2	100%
	7/5-8/2	5	4	X		2	80%
	8/2-8/31	4	4				100%
	8/31-9/30	4	4		1		100%
Pen 3	5/12-6/4	5	5				100%
	6/4-7/5	5	5		1	1	100%
	7/5-8/2	5	4	slightly			80
	8/2-9/1	4	4	slightly		2	100%
	9/1-9/30	4	lost				0%
Pen 4	5/12-6/7	5	5				100%
	6/7-7/6	5	4			2	80%
	7/6-8/3	4	4	slightly	1		100%
	8/3-9/1	4	4	X			100%
	9/1-9/30	4	2				50%
Pen 5	5/12-6/4	5	3				60%
	6/4-7/6	3	3		1	2	100%
	7/6-8/3	3	3				100%
	8/3-9/2	3	2		1		67%
	9/2-9/30	2	lost				0%
Pen 6	5/12-6/7	5	5				100%
	6/7-7/6	5	3			3	60%
	7/6-8/3	3	2				67%
	8/3-9/1	2	2	slightly			100%
	9/1-9/29	2	lost				0%

*1 tag lost while measuring
The X denotes the presence of anoxic conditions
All wild YOY winter flounder were smaller than the hatchery-reared YOY flounder.

MARINE ECOLOGY STUDIES

Related to Operation of Pilgrim Station

Section 3.5

Larval Transport Study

ANNUAL REPORT No. 65

JANUARY 2004 THROUGH DECEMBER 2004

Environmental Protection Group
Entergy Nuclear-Pilgrim Station

Entergy Nuclear Generation Company
Plymouth, MA

Study of Winter Flounder Larval Transport in Coastal Cape Cod Bay and Entrainment at Pilgrim Nuclear Power Station

Spring 2004

ENSR Corporation
Marine Research, Inc.

February 2005
Document Number 10658-001

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LIST OF FIGURES

1.0 INTRODUCTION

Winter flounder (*Pseudo pleuronectes americanus*) are commercially important in Cape Cod Bay and are a dominant species collected by the entrainment monitoring program at Pilgrim Nuclear Power Station (PNPS). The objective of this study was to evaluate the impact of winter flounder larvae entrainment at PNPS through direct field measurements. An approach was applied whereby field measurements were collected to determine the relative amount of net volumetric flow and winter flounder larvae entrained into the PNPS cooling water system compared to the net volumetric flow and amount of winter flounder larvae passing PNPS in offshore Cape Cod Bay waters.

This program was designed to update the similar studies completed in 2000 (ENSR and MRI, 2000) and 2002 (ENSR and MRI, 2003), based on the suggestions and comments of federal and state agency reviewers. The results of this study confirmed those of the prior studies in that:

- PNPS withdraws a relatively small percentage of the available net volumetric flow of water—generally less than 0.1%.
- The number of winter flounder larvae entrained by PNPS is a relatively small percentage of the net larval transport—conservatively estimated at less than one percent.

The field program was designed to collect sufficient measurements to determine the flux of winter flounder larvae moving along the Plymouth coast and the flux of winter flounder entering PNPS. To determine larvae flux, larvae concentration and volumetric flowrate of water were required. The field program featured determination of larval densities and water velocity measurements along the Plymouth coast in Cape Cod Bay and determination of larval densities in the PNPS cooling water system.

The field program was conducted between late May and late June and consisted of the following elements:

- Winter flounder larvae sampling –
  - o in Cape Cod Bay at five offshore stations, and
  - o in the PNPS discharge canal (entrained in the cooling water flow).
- Water velocity measurements –
  - o at four offshore stations in Cape Cod Bay, using bottom-mounted Acoustic Doppler Current Profiler (ADCP) units, and
  - o along transects using boat-based ADCPs.

Larvae and water velocity measurements were collected concurrently in late May and early June 2004 to support determination of larval flux. Larvae sampling was conducted along the Plymouth coast and at

PNPS during two surveys, between May 26 and June 4, 2004. For each survey, larval samples were obtained four times, twice during the day, and twice during the night, during a one-day period. Water velocity measurements were collected continuously from fixed stations between May 20 to June 20, 2004 and from boat-based transects on June 17, 2004.

The ichthyoplankton data were combined with the current measurements to determine the flux of larvae along the coast of Cape Cod Bay, for each of the two daily surveys. These values were then compared to the number of larvae entrained by the PNPS cooling system, as determined from the entrainment study, during the same two daily measurement periods.

Section 2 of this report describes the field sampling program. Section 3 provides the field study results. Section 4 provides an analysis of the study results. Section 5 provides the study conclusion and an overall assessment of the entrainment by PNPS on winter flounder larvae from Cape Cod Bay.

2.0 FIELD SAMPLING PROGRAM

2.1 Sampling Program Design

The field program was designed in part based on the results of the similar studies performed in 2000 and 2002. In particular:

- The sampling stations were deployed in a pattern that would provide the ability to capture currents flowing in any direction, as variable currents were observed during the 2002 study, as well as to perform an alternative analysis of tidal flushing (see Section 4.3).
- Two larvae sampling surveys were performed, as this was deemed sufficient to capture the changes in larval densities observed as the season progressed.

2.2 Winter Flounder Larvae Sampling

2.2.1 Cape Cod Bay

Larval winter flounder were collected at five stations in Cape Cod Bay (Figure 2-1). The stations were established in a diamond-shaped pattern. Three of the five stations (A, E, and D) were established along a single transect extending from just south of Rocky Point northeast into the 120' depth contour of Cape Cod Bay. The total transect length was approximately five nautical miles. Stations B and C were located approximately one nautical mile northwest and southeast, respectively, of Station E. The close proximity of the larvae sampling stations to the hydrodynamic measurements facilitated correlation of the acquired hydrodynamic data with biological sample data to formulate an estimate of the population of winter flounder contained in Cape Cod Bay coastal waters flowing towards and past PNPS.

The five sampling stations were identified as Stations A through E. The approximate low-water depth at each station was as follows: Station A: 25'; Station B: 98'; Station C: 70'; Station D: 123'; Station E: 90'. As shown on Figure 2-1, the stations were positioned such that station E was centrally located between the other stations.

Two field surveys were completed during the spring of 2004: May 26 – 27, and June 3 – 4. Each survey was structured to capture the ebb and flood tides of two tidal cycles on each sampling day (4 sampling events per survey, 2 predominately during the day and 2 predominately during the night). Sampling was conducted at each station using 60-cm diameter "bongo" nets rigged with 0.202-mm and 0.333-mm nylon mesh plankton nets and with an epibenthic bottom sled rigged with a 0.333-mm nylon mesh net. The sled was constructed of PVC pipe identical to the one used for ichthyoplankton sampling near PNPS in 2002 (ENSR and MRI 2003). Tow duration for each sample was approximately six to eight minutes, which provided sample volumes ranging from 85 to 150 cubic meters and an overall average of 120 cubic meters.

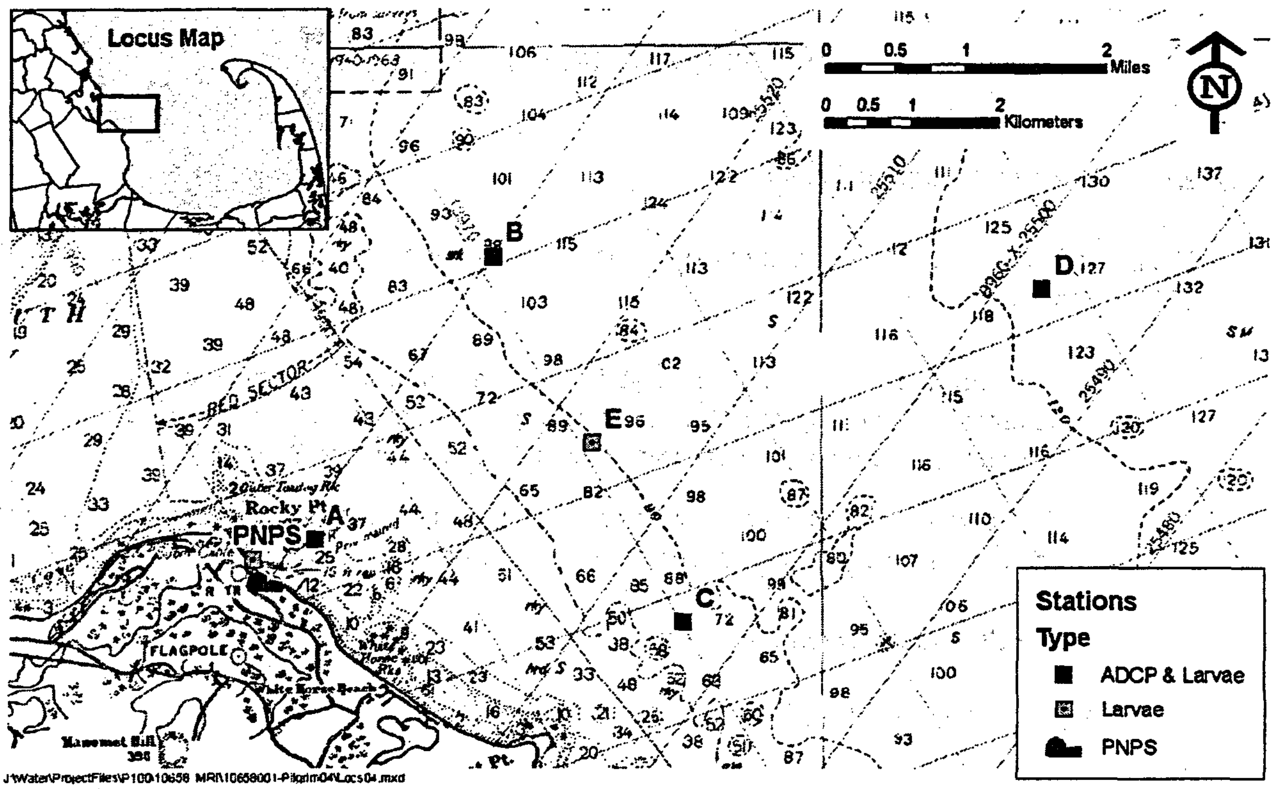

Figure 2-1 Locations of Larvae Sampling and ADCP Deployment Stations

During the first survey, the sled was damaged during the third sampling event. As a consequence, bottom samples with the sled were not obtained for stations B and D in the third event, nor were any bottom samples obtained during the fourth event. The sled was repaired and used to successfully collect samples at all stations and all events during the second survey.

At all five stations (A, B, C, D, E) stratified oblique tows were performed with the bongo net, by partitioning the water column into two equal-depth layers and completing one oblique tow in each layer so that samples were obtained from surface to mid-depth and from mid-depth to the near-bottom layer. Filtration volumes were determined using General Oceanics 2030R flow meters installed in the mouth of each plankton net. In addition to the bongo net tows the epibenthic, bottom sled was used to collect winter flounder larvae closer to the bottom than the bongo net could be towed. Tow distance for the sled averaged 750 m and was determined with GPS bearings and with a General Oceanics 2030R flowmeter mounted on the frame. Distance estimates determined by GPS and flowmeter were averaged.

After the completion of each sample tow, the net was washed down from the outside and the contents were transferred to one-liter bottles containing sufficient Formalin to produce a 10% solution with seawater. Waterproof tags listing the station, date, start and end time of the collection, flow-meter readings, and net were placed into each sample container. Samples were then delivered to the laboratory for microscopic analysis where all winter flounder larvae were identified and counted within four developmental stages (see the entrainment section 3.3 of this document). Only the 0.202-mm mesh samples were analyzed; the 0.333-mm mesh samples were archived. Due to the abundance of zooplankton, 50% of the samples were split in half using a plankton splitter patterned after Motoda 1959 (see also Van Guelpin et al. 1982). Counts were converted to larvae per 100 cubic meters of water (density) based on the flow-meter readings.

2.2.2 PNPS Discharge

In conjunction with each offshore sampling series, ichthyoplankton samples were also taken from the PNPS cooling water discharge to assess the entrainment of winter flounder larvae. Sampling was conducted near the center of the discharge canal, approximately 30 meters downstream from the headwall, which is the same location used for the routine entrainment monitoring. Samples were collected using a 60-cm diameter plankton net constructed of 0.202-mm nylon mesh. On each survey, samples were scheduled to be taken every three hours for a total of eight samples per 24-hour sampling event. A backwash performed at the Station during the night of June 4 resulted in the collection of seven samples instead of eight. Each collection was made by streaming the net for 10 minutes. Exact filtration volumes were determined using a General Oceanics 2030R2 flowmeter mounted in the mouth of the net.

After sample collection, the net was rinsed from the outside using seawater to wash all plankton into the cod end of the net. The sample was then transferred into a 1-liter, wide mouth bottle and preserved using sufficient buffered Formalin to obtain a 10% solution. A waterproof tag listing the station, date, time of collection, and the flow-meter readings was placed into each sample container. Samples were returned to the laboratory and processed as described above for the offshore samples.

2.3 Hydrodynamic Measurements

The hydrodynamic measurement component of the field program was designed to support determination of the total volumetric flowrate of water along the Plymouth coast. The long-term, fixed-base hydrodynamic monitoring program was scheduled to include the time of the two winter flounder larvae sampling surveys.

The hydrodynamic field program consisted of two components, a long-term survey and a synoptic survey. The long-term and synoptic surveys successfully collected the data required to support the study and are described below.

2.3.1 Long-term Hydrodynamic Survey

Hydrodynamic measurements were continuously collected at four locations (A, B, C, and D see Figure 2-1). At each hydrodynamic sampling location, the following measurements were collected for a period of one month.

- Water velocity measurements were recorded throughout the water column using a bottom-based acoustic Doppler current profiler (ADCP). The ADCP measures the magnitude and direction of water movement through transmission of acoustic signals and interpretation of Doppler frequency shifts in acoustic returns. ADCP measurements were acquired at one-meter intervals throughout the full depth of the water column.

- Sea surface elevation using a tide gauge (pressure transducer).

A description of long-term survey deployments, equipment, and data collection is provided in Table 2-1 for each location.

The long-term hydrodynamic survey achieved the 100% data collection goal. Processing, analysis and application of the long-term hydrodynamic measurement data is described in Section 3.

2.3.2 Synoptic Hydrodynamic Survey

Synoptic, boat-based water velocity measurements were collected using an ADCP instrument on 17 June 2004. The boat-based ADCP survey featured measurement of water velocities (direction and magnitude) at one-meter intervals throughout the water column. Two transits of Transect A–D and Transect B–C were performed, once each during an ebb and flood tide. The ADCP unit was rigidly mounted in a frame suspended over the side of the survey vessel. Published tidal information for this date at Gurnet Point indicated low tide at 06:00, high tide at 12:11 and low tide at 18:02.The synoptic survey transits were performed at the times indicated below:

- Flood tide: Transect B-C 08:55 to 09:41 and Transect A-D 10:03 to 11:18

- Ebb tide: Transect A-D 14:04 to 15:19 and Transect B-C 15:42 to 16:20

The synoptic survey achieved the 100% data collection goal. Processing, analysis and application of synoptic hydrodynamic measurement data is described in Section 3.

2.4 Water Column Monitoring

Measurements of water temperature (± 0.1° C), salinity (± 0.1 o/oo), and dissolved oxygen (± 0.1 ppm) were recorded at each station immediately preceding the surface ichthyoplankton tow using a Hydrolab Quanta multiparameter water quality instrument. Readings were recorded at surface, mid-depth and at a depth of within one meter of the bottom (Station A) or up to a maximum depth of 23 meters, the length of cable available. Bottom temperatures were also recorded by both the tide gauges and ADCPs. The water quality instrument failed during the first survey after the first samples were collected at Stations A and B, for 10% data capture during the first survey. All water quality observations were successfully made for the second survey.

Table 2-1 Long-Term Hydrodynamic Survey Deployment Description

		Station A	Station B	Station C	Station D
Deployment	Instrument deployment coordinates	41° 56' 56.50" N 70° 34' 15.20" W	41° 58' 42.19" N 70° 32' 45.40" W	41° 56' 24.00" N 70° 31' 11.40" W	41° 58' 27.94" N 70° 28' 11.13" W
	Instrument deployment depth	27 feet	104 feet	88 feet	132 feet
	Deployment date/time	5/19/2004 at 13:10	5/19/2004 at 12:19	5/19/2004 at 12:45	5/19/2004 at 11:24
	Recovery date/time	6/22/2004 at 09:00	6/17/2004 at 12:23	6/17/2004 at 13:07	6/17/2004 at 11:40
	Deployment duration	34 days, 20 hours	30 days	30 days	30 days
	Data record duration	34 days, 20 hours	30 days	30 days	30 days
Equipment and Data Collection	Water velocity meter specification	RD Instruments, Workhorse Sentinel ADCP, 1200kHz frequency (serial #0256)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #2355)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #1302)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #1301)
	ADCP water velocity data collection	Recorded every 15 minutes throughout the water column	Recorded every 15 minutes throughout the water column	Recorded every 15 minutes throughout the water column	Recorded every 15 minutes throughout the water column
	Tide gauge specification	Coastal Macrowave Non-directional Wave Gauge (serial #10215)	Coastal Macrowave Non-directional Wave Gauge (serial #10377)	Coastal Macrowave Non-directional Wave Gauge (serial #10301)	Coastal Macrowave Non-directional Wave Gauge (serial #10222)
	Tide gauge data collection	Water level measurements recorded every 15 minutes	Water level measurements recorded every 15 minutes	Water level measurements recorded every 15 minutes	Water level measurements recorded every 15 minutes

3.0 STUDY RESULTS

3.1 Winter Flounder Larvae Sampling Results

Densities of larval flounder per 100 m^3 of water by developmental stage for each sample appear in Appendix A. Larval flounder were present on each sampling occasion (Figure 3-1 and Figure 3-2).

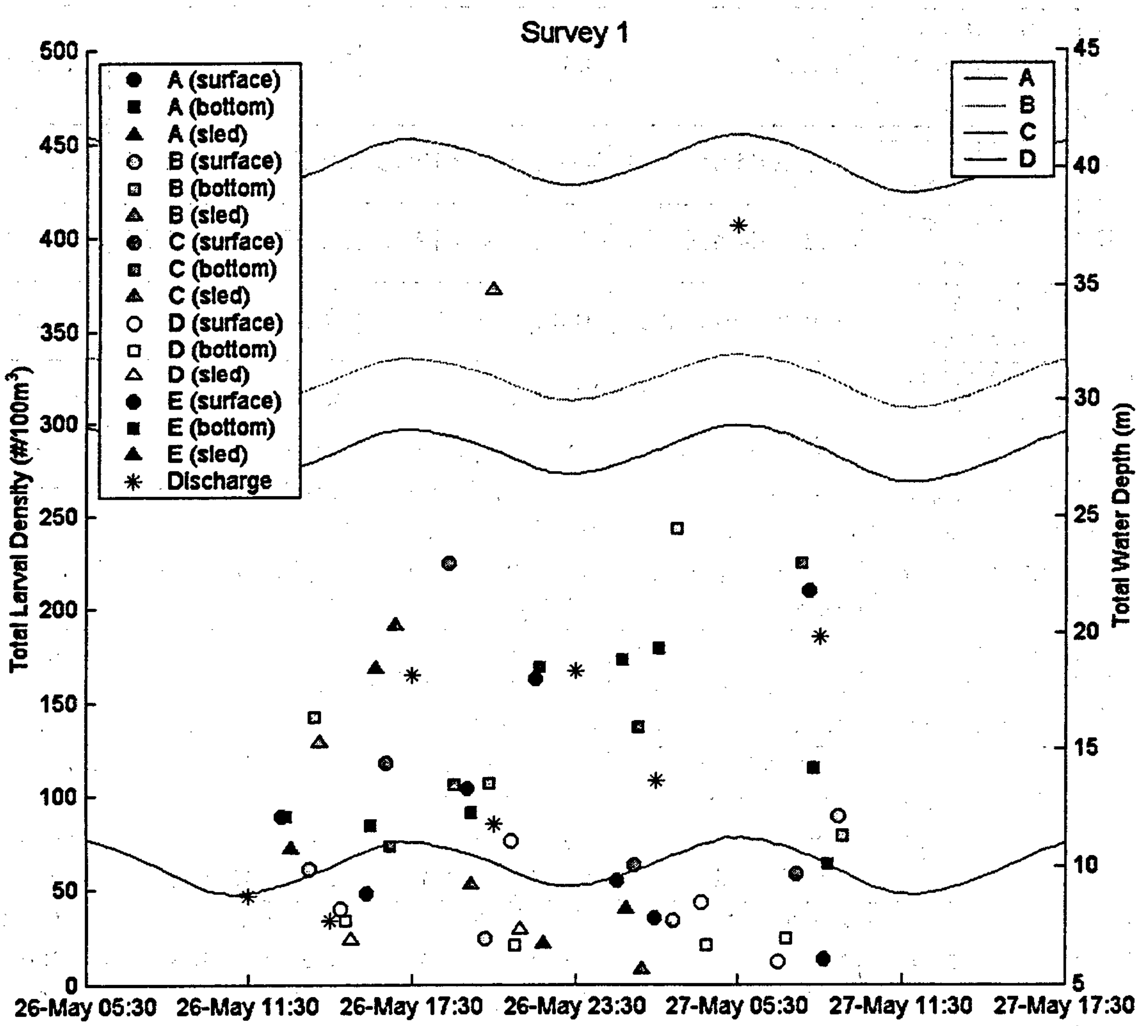

Figure 3-1 Total Larval Densities For Sampling Survey 1

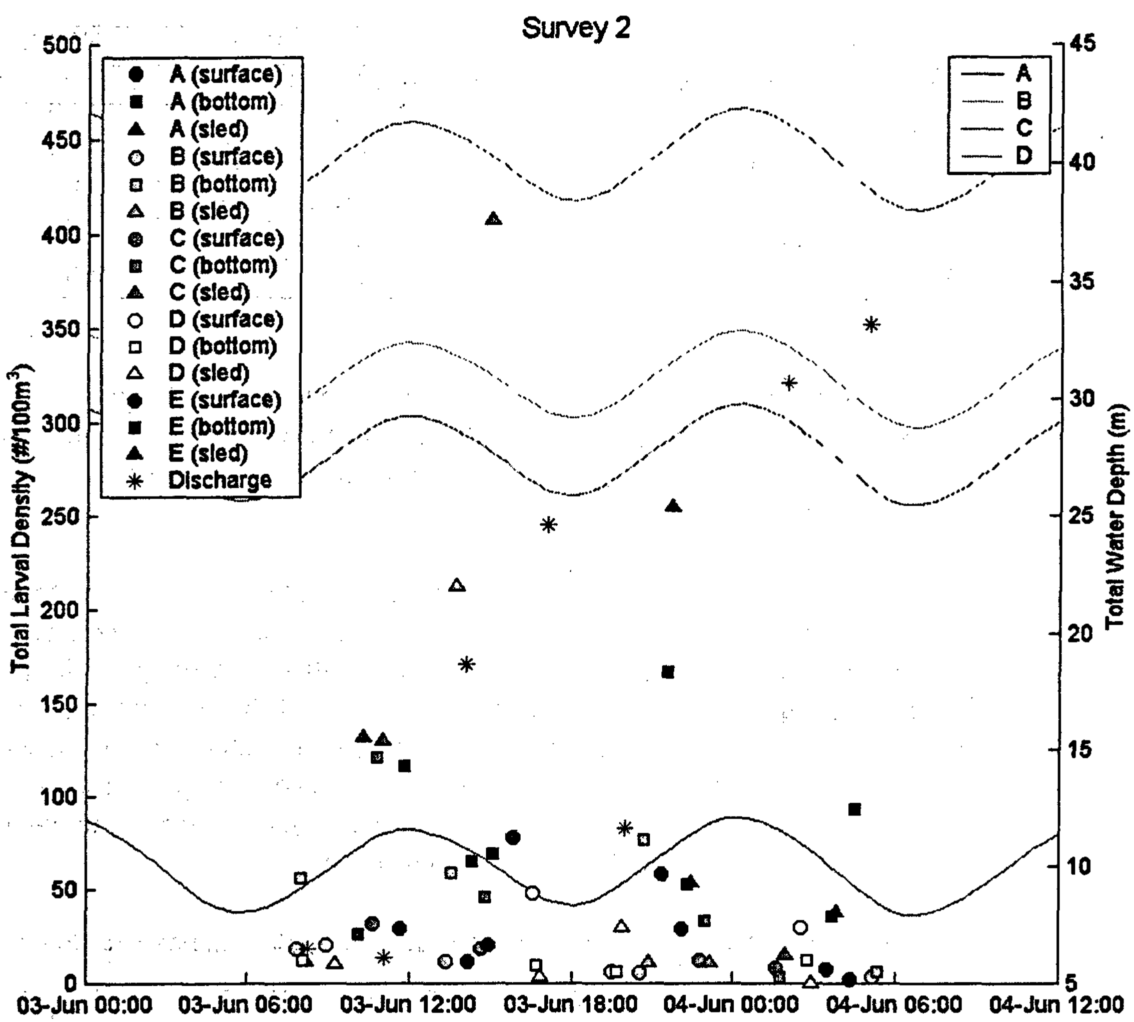

Figure 3-2 Total Larval Densities For Sampling Survey 2

3.1.1 Cape Cod Bay

The distribution of winter flounder larvae among developmental stage is shown in Table 3-1 pooled over both collection dates within sampling strata and including the PNPS discharge. All four developmental stages were found in the collections although stage 2 and 3 larvae accounted for 80 to 90% of the total within each strata. The low contribution of early stage 1 larvae likely reflected, at least in part, the late May, early June sampling dates, relatively late in the spawning season. The low numbers of stage 4 larvae probably reflected their lower numbers in general as a result of natural mortality and gear avoidance as a result of their benthic life style.

Table 3-1 Larval Density and Proportion By Depth Strata

Stage	Upper Strata		Lower Strata		Bottom Strata		PNPS Discharge	
	Density	% of Total	Density	% of Total	Density	% of Total	Density	% of Total
1	7.4	14.8%	9.3	11.5%	8.4	2.0%	1.9	1.2%
2	31.2	61.9%	44.7	55.0%	183.0	43.3%	33.4	20.9%
3	11.7	23.2%	27.1	33.4%	231.3	54.7%	123.7	77.2%
4	0.1	0.2%	0.1	0.1%	0.4	0.1%	1.2	0.8%
Total	50.4		81.2		423.1		160.2	

Overall, larval densities in Cape Cod Bay averaged higher near bottom. Densities in the upper half of the water column collected with the bongo net averaged 50.4 per 100 m3 of water compared with 81.2 per 100 m3 in the lower portion and 423.1 per 100 m3 near bottom as determined with the sled. Densities averaged 160.2 per 100 m3 in the PNPS discharge.

Summarized across stations and events for each survey, the percentages of each larval stage observed are given in Table 3-2. In general, larval densities in Cape Cod Bay were higher near shore and lower farther off shore and in deeper water, and larval densities in the PNPS discharge were within the range observed in the Bay. During the first survey, stage 2 larvae were most abundant in Cape Cod Bay, except at Station A, where like the PNPS discharge, stage 3 larvae were most abundant. In the second survey, stage 2 and 3 larval densities in Cape Cod Bay were found in about equal proportion, except at Station D, where stage 2 was most abundant and stage 1 was still significant. Stage 3 was fully three-quarters of the larvae observed in the PNPS discharge during the second survey.

Table 3-2 Larval Stage Percentages of Total At Each Station Summarized For Each Survey

Stage		Survey 1						Survey 2					
		A	B	C	D	E	PNPS	A	B	C	D	E	PNPS
1	%	3	9	11	16	20	1	1	2	6	16	4	1
2	%	42	63	62	66	60	19	41	43	49	60	53	23
3	%	54	28	27	18	20	79	58	55	45	25	43	75
4	%	0.1	0	0	0	0	1.3	0.2	0	0.2	0.5	0	0.3
Total	Density	431	133	123	31	114	151	514	123	70	16	108	172

3.1.2 PNPS Discharge

Mean densities of flounder larvae observed in the PNPS discharge were 149.8 and 172.0 per 100 m^3 of water for the May 26 and June 3 series, respectively.

The percentages of larval stages observed in the PNPS discharge are summarized above in Table 3-2. Stage 3 larvae were observed at a much higher percentage compared to the three other stages. Stage 1 larvae were approximately one percent of the total observed, suggesting that the spawning season ended earlier in May. Stage 4 larvae made up one percent or less of the total in both surveys.

3.2 Hydrodynamic Monitoring Results

3.2.1 Long-term Hydrodynamic Survey

Hydrodynamic data from each of the three locations were inspected, processed, and exported for further analyses using RD Instruments WinADCP software. The conversion of the water velocity vectors (magnitude and direction) to velocity normal to a transect results in velocities and water flowrates being reported such that positive values are flowing North and/or West, and negative values are flowing South and/or East.

Over the duration of the ADCP deployment, the observed extremes of velocity averaged over the entire water column were, in meters per second:

Station	North	South	East	West
A	0.185	-0.352	0.145	-0.406
B	0.188	-0.282	0.118	-0.172
C	0.320	-0.356	0.140	-0.196
D	0.234	-0.302	0.121	-0.157

Hydrodynamic data are provided in electronic form as Appendix C.

3.2.2 Synoptic Hydrodynamic Surveys

Data from the four boat-based ADCP tows were inspected using RD Instruments WinRiver software, and exported for further analysis. The ADCP transect tows of June 17, 2004 are presented in Figure 3-3 to Figure 3-6. These figures show the velocity normalized perpendicular to the A–D and B–C transects, with positive values flowing northwest, and negative values flowing southeast. The results of the synoptic surveys show that the current profiles vary across the transect, however, the placement of the fixed ADCP stations should capture the major flow regimes. The synoptic survey also shows that the variation in currents is predominantly with depth rather than distance along the transect. As expected flow is mostly to the South (negative velocities across the transect in Figure 3-3) during flood tide and mostly to the North (positive velocities across the transect in Figure 3-4) during ebb tide.

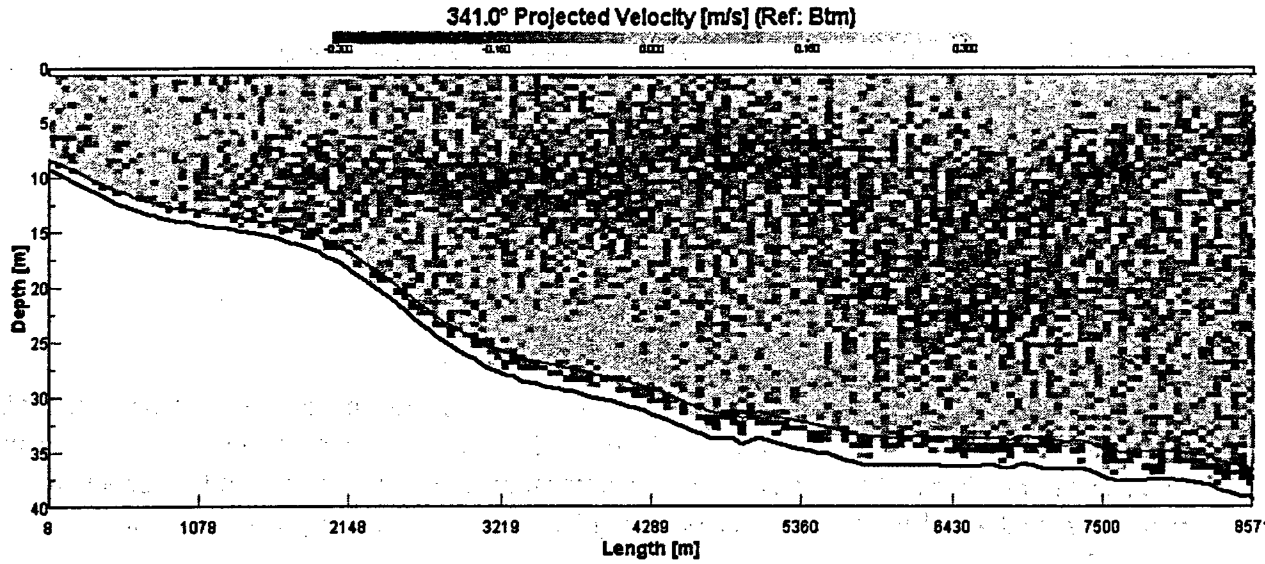

Figure 3-3 Velocity Normal to Transect A–D: Flood Tide June 17, 2004

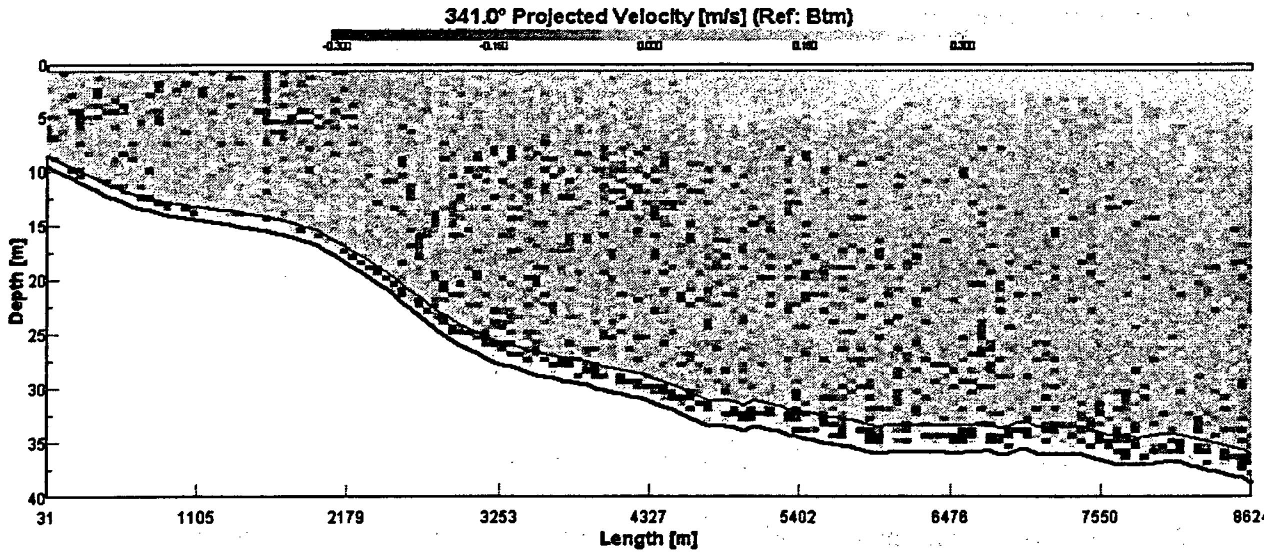

Figure 3-4 Velocity Normal to Transect A–D: Ebb Tide June 17, 2004

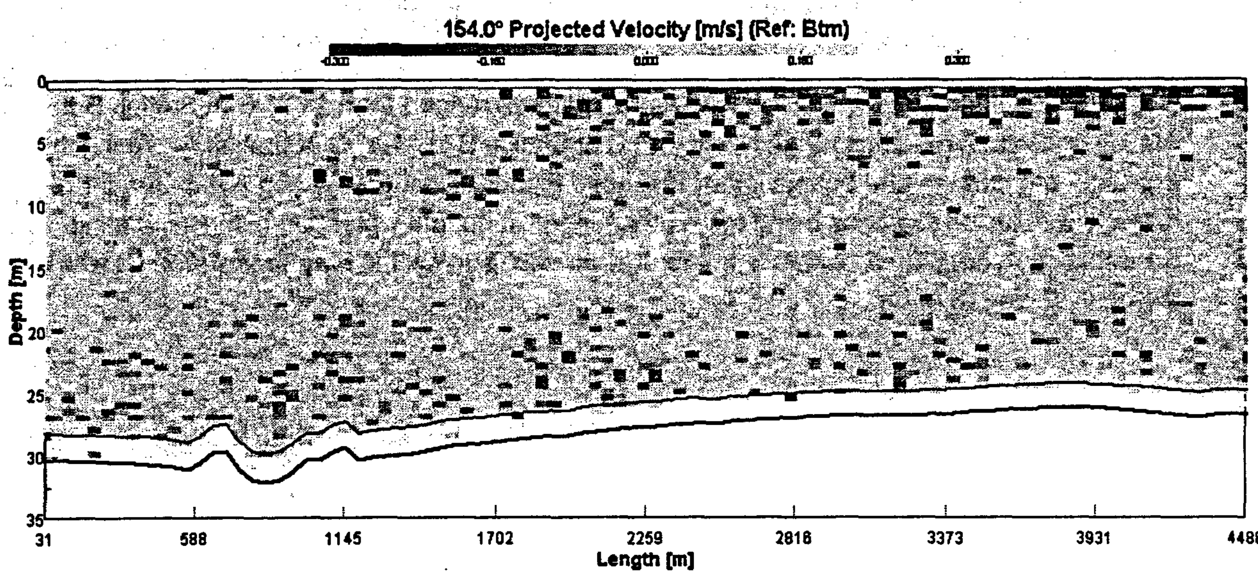

Figure 3-5 Velocity Normal to Transect B–C: Flood Tide June 17, 2004

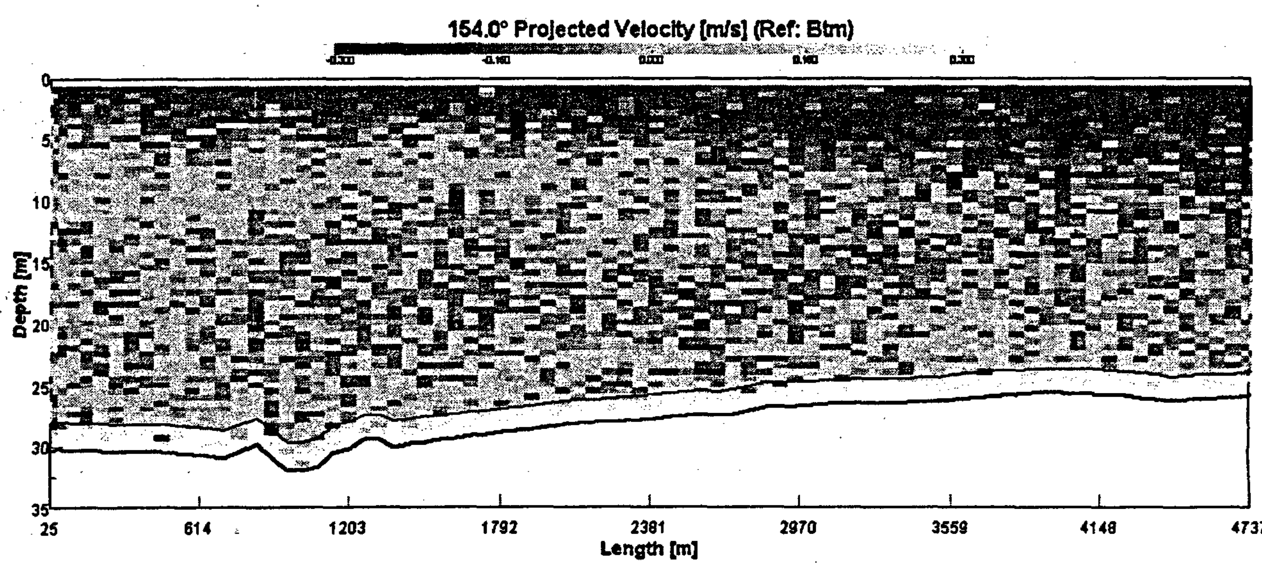

Figure 3-6 Velocity Normal to Transect B–C: Ebb Tide June 17, 2004

3.3 Water Column Monitoring Results

Water temperature, salinity, and dissolved oxygen data recorded at each station are tabulated in Appendix B. A malfunction with the Hydrolab equipment prevented the collection of hydrographic data on the May 26-27 survey for all collections except for 1-A and 1-B. The most significant variation observed during the study was in temperature values. Bottom water temperature obtained from the ADCP instruments for the May survey ranged from 4.2° C at Station B to 10.6° C at Station A. Based on average readings for each station on the June survey, surface water temperatures ranged from 11.3° C at Station B to 15.0° C at Station A. Bottom readings ranged from 4.0° C at Station B to 11.4° C at Station A. Along the sampling transect both surface and bottom water averaged higher at inshore Station A than further offshore, the difference between locations being more pronounced in bottom water due to the increasing depth along the transect. Averaging all bottom temperatures for each survey, the May survey (6.2° C) was cooler than the June survey (6.8° C).

4.0 DATA ANALYSIS AND ASSESSMENT

The data discussed above were analyzed for (1) the percentage of net volumetric flow in nearby coastal Cape Cod Bay waters withdrawn by PNPS and (2) the percentage of winter flounder larvae in the net coastal flow entrained by PNPS. This allows an evaluation of the overall effect of winter flounder larvae entrainment at PNPS.

A separate calculation of the percentage of coastal flow withdrawn and larvae entrained by PNPS was performed for each of the two sampling surveys conducted. In addition, the volumetric flow analysis was performed over the entire monthly period that the hydrodynamic measurements were conducted. The larval analysis was performed for each of the four winter flounder larvae life stages and for total larvae. Details of the analysis procedures and results are discussed below.

4.1 Volumetric Water Flowrate Analysis

In order to correlate the four continuous-depth ADCP stations with the five discrete-depth larvae sampling stations, the ADCP water velocity data was processed in the following manner:

- The flow across the transect A–D (from southwest to northeast) was analyzed. At each ADCP station, the water column was divided into three segments based on total depth at the time of the reading: the upper half, from half to three meters above the bottom, and the bottom three meters. The component of the ADCP velocity normal to the transect was averaged over each depth segment of the water column, for each 15-minute ensemble of data. Figure 4-1 and Figure 4-2 contain plots of water depth and the average velocities normal to the transect for ADCP stations A and D and for each depth interval during the two larvae sampling surveys.
- For larvae sampling station E, velocities were estimated by taking the average of the transect normal velocities at the adjacent stations *i.e.*, E is average of B and C.
- The flowrate of water across the transect was then calculated by multiplying each of the transect velocity series by the estimated cross-sectional area of the transect represented by that value. The cross-sectional areas were determined for each segment by multiplying the appropriate water depth interval at the station for that time by one-half of the combined distance to the two adjacent stations.

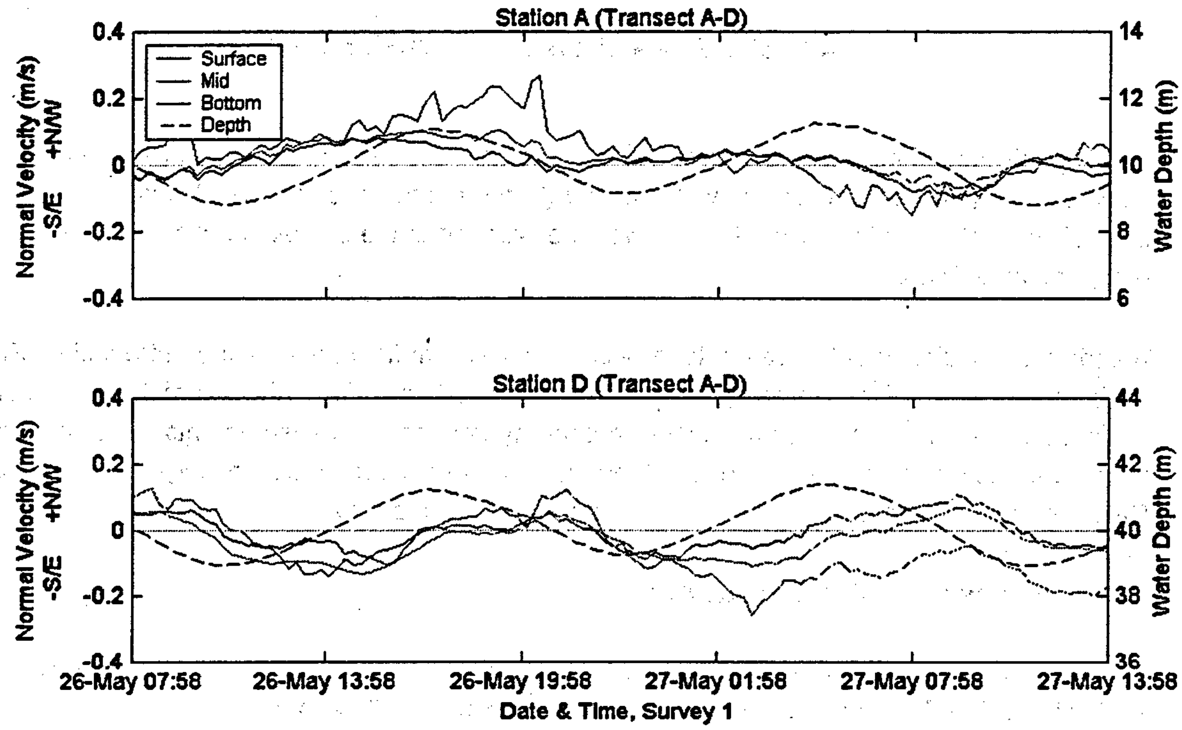

Figure 4-1 Water Velocities During Sampling Survey 1

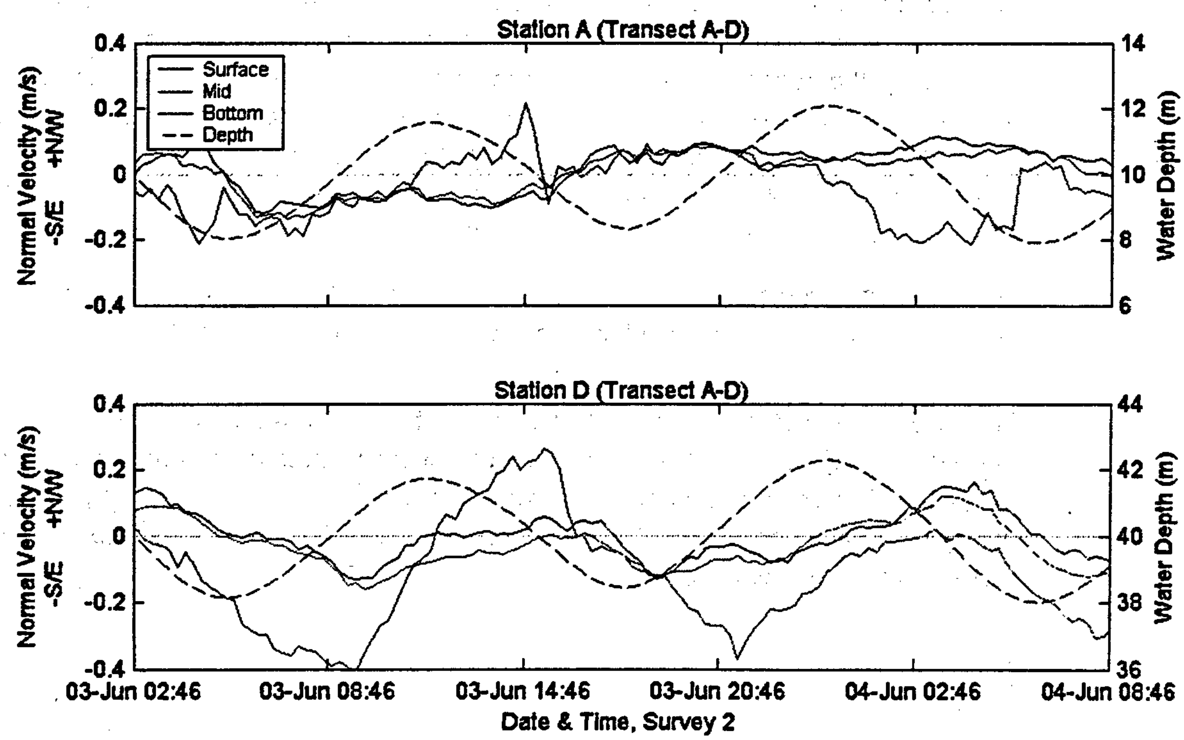

Figure 4-2 Water Velocities During Sampling Survey 2

- In order to correlate the ADCP time series with the discrete larvae sampling events, the ADCP-based water flowrate data was averaged over the duration of each tidal phase. The tidal phase was defined as the time between the maximum and minimum tide heights at the station. The sum of the flowrates during the four tidal phases also was the basis for daily estimates of water flowrate across the study transect.

Table 4-1 compares the daily water flowrates during the sampling events with the average daily water flowrate during the study period. The percentage of the volumetric flow withdrawn by PNPS (with both pumps operating at the rated total maximum of 19.56 m^3/s) ranges from 0.02% to 0.03% for the two larvae sampling days.

Table 4-1 Analysis of Net Volumetric Flowrate in Bay Study Area Compared to PNPS Withdrawal

	May 26-27	June 3-4
Net Volumetric Flowrate (m^3/s) in Bay Study Area	72,587	86,141
% of Volumetric Flowrate in Bay Study Area Withdrawn by PNPS (both pumps operating at the rated total maximum of 19.56 m^3/s)	0.03%	0.02%

4.2 Net Larval Transport and Entrainment Analysis

4.2.1 Larval Transport Analysis

The flux or transport of winter flounder larvae flowing along the coast was determined for each of the two surveys using larvae density and hydrodynamic measurements. This approach integrated current velocity, water depth and larval stage density over the cross-sectional area of the transect during the time of each tidal phase.

The calculation was performed for each of the four winter flounder larval stages and the total winter flounder larval density at each of the four 6-hour tidal periods that constituted one 24-hour "day". The net larval flux over a given 6-hour tidal period was determined by multiplying the density of larvae (larvae/m^3) times the flowrate of water (m^3/s) to yield larvae/second over the 6-hour period. The water column depth intervals were assigned corresponding larvae samples: surface by net, bottom by net, and sled. As noted in Section 2, the sled larvae sampling was incomplete for the first survey, so the bottom net samples were used for the deepest water column interval when sled data was missing. For each study day, the net larval flux was determined by taking the sum of the net larval flux over all the 6-hour tidal periods.

4.2.2 Larval Entrainment Analysis

The number of winter flounder larvae entrained by PNPS during both surveys was determined from the station flow rate and the eight larval entrainment samples collected during the day specifically for this study. The calculation was performed for each of the four winter flounder larval stages, by multiplying the number of larvae for each stage entrained by the station by the station flow rate for the 6-hour tidal cycle over which the ambient flounder samples were collected. The sum of each of the 6-hour periods became the total entrainment per day.

The percentage of each larval stage entrained was determined by dividing the number of larvae entrained during the day by the number of larvae carried past the station in the net longshore current (and then multiplying by 100 to obtain a percentage). The larval entrainment results are presented in Table 4-2. for the major transect in the study area, A-D.

In general, the results in Table 4-2 indicate that PNPS entrains a very small percentage of the winter flounder larvae in the coastal flow of Cape Cod Bay. These results are similar to those of the larvae transport studies performed in 2000 (ENSR and MRI, 2000) and 2002 (ENSR and MRI, 2003).

Table 4-2 Larval Flux and Entrainment Results Transect A–D

		Survey 1	Survey 2
Stage 1	PNPS Larvae/day	31,042	37,634
	Bay Larvae/day	168,609,082	32,366,901
	% Entrained	0.02	0.12
Stage 2	PNPS Larvae/day	492,234	705,010
	Bay Larvae/day	547,780,748	182,815,242
	% Entrained	0.09	0.39
Stage 3	PNPS Larvae/day	2,106,405	2,270,584
	Bay Larvae/day	115,972,069	93,189,196
	% Entrained	1.82	2.44
Stage 4	PNPS Larvae/day	33,259	10,036
	Bay Larvae/day	167,656	2,295,983
	% Entrained	19.84	0.44
Total	PNPS Larvae/day	2,654,071	3,018,245
	Bay Larvae/day	830,355,922	304,399,510
	% Entrained	**0.32**	**0.99**

Based on this analysis, it is concluded that the percentage of winter flounder larvae transported in coastal Cape Cod Bay waters that is entrained by PNPS may be conservatively estimated at less than one percent. Though the results in Table 4-2 indicate higher entrainment percentages for Stages 3 and 4 larvae, it is likely that the actual entrainment rate for these larval Stages is similar to the total larvae entrainment rate of one percent or less. During Survey 1, the loss of the sled meant that two stations were not sampled during two of the four tidal periods, and the rest were not sampled for one of the tidal periods. Since the sled samples routinely yielded the highest larvae counts, results for Survey 1 likely underestimate larval flux in the Bay. Also, for Stage 4, since the densities are so low, the change in count by one individual has a disproportionately high effect on densities, and thus on the percent entrained. For example, in Survey 1, 18 total Stage 4 individuals were counted in the PNPS samples, and two total Stage 4 individuals were counted in the net and sled samples in the Bay.

4.3 Entrainment Analysis by Tidal Flushing

The spatial arrangement of sampling stations used for the 2004 study enabled an alternative method of calculating larval flux and entrainment. This method was used to determine the total amount of larvae transported by tidal currents into and out of an area defined by one tidal excursion near PNPS, thereby providing a measure of the tidally induced flushing of larvae in the region subject to entrainment by the station. The amount of larvae entrained by PNPS was then compared to this value to obtain an assessment of the entrainment rate compared to larval transport by tidal flushing.

The analysis was performed by the following method:

- Determine total volume of water, entering the study area only (*i.e.*, flowing in a southerly direction), across the B–D transect for each of the three depth segments over the two tide cycle "day".
- Apportion this total flow volume to each of the five stations according to the area it represents when Thiessen polygons (borders are equidistant from adjacent points) are constructed about the stations, as shown in Figure 4-3.
- Multiply each station's fraction of the total flow by the larval density to get number of larvae flushed from the area during the day.

Results of this analysis are presented in Table 4-3 and generally are one to two orders of magnitude less than the transect method presented in Section 4.2.

Table 4-3 Larval Flux and Entrainment Results by Tidal Flushing

		Survey 1	Survey 2
Stage 1	PNPS Larvae/day	31,042	37,634
	Bay Larvae/day	5,370,497,708	1,563,085,127
	% Entrained	0.001	0.002
Stage 2	PNPS Larvae/day	492,234	705,010
	Bay Larvae/day	19,950,035,353	6,724,111,167
	% Entrained	0.002	0.01

		Survey 1	Survey 2
Stage 3	PNPS Larvae/day	2,106,405	2,270,584
	Bay Larvae/day	6,525,781,642	6,435,347,196
	% Entrained	0.03	0.04
Stage 4	PNPS Larvae/day	33,259	10,036
	Bay Larvae/day	2,609,868	46,401,085
	% Entrained	1.27	0.02
Total	PNPS Larvae/day	2,654,071	3,018,245
	Bay Larvae/day	31,870,235,653	14,813,167,928
	% Entrained	**0.01**	**0.02**

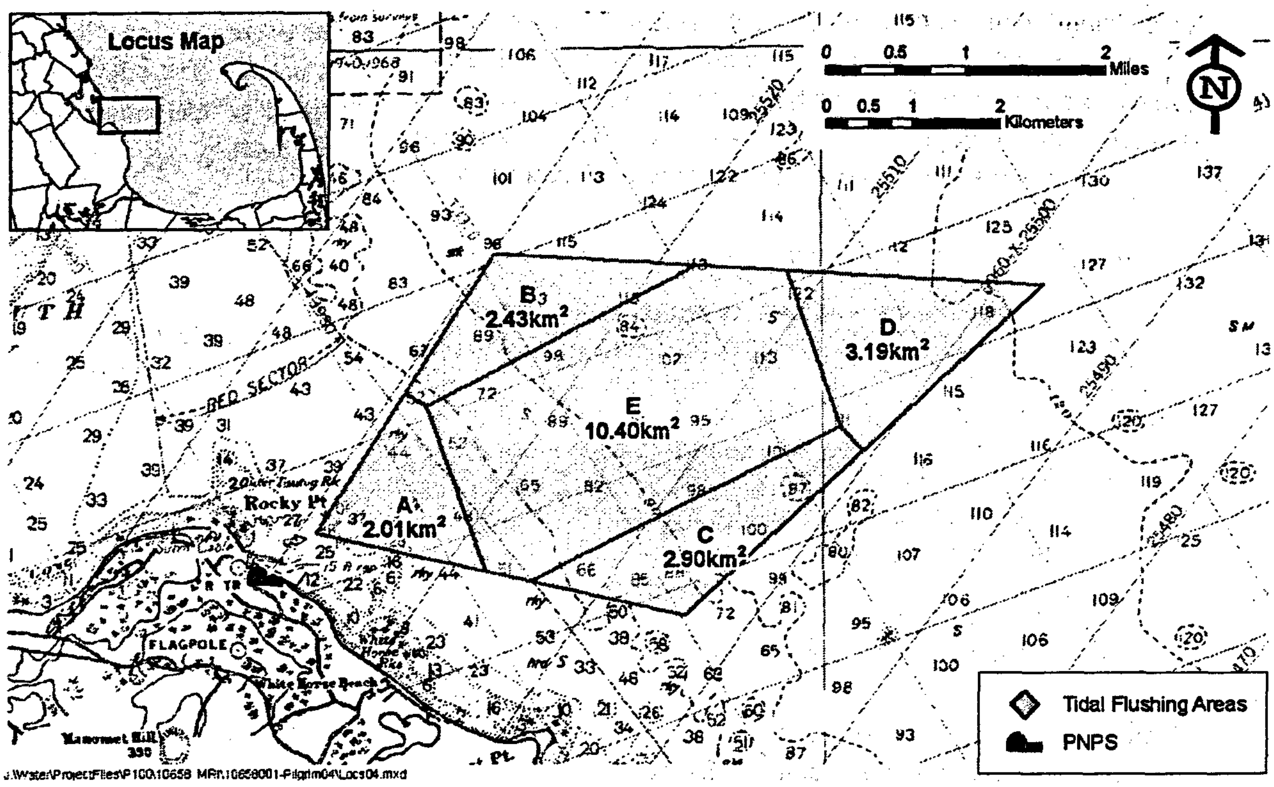

Figure 4-3 Tidal Flushing Analysis Areas

5.0 CONCLUSIONS

This was the third larval transport study performed in Cape Cod Bay to examine the key conditions (net water flow and density of winter flounder larvae) affecting the entrainment of winter flounder larvae. These three studies—conducted adjacent to Pilgrim Station in 2000, 2002 and 2004 by ENSR and MRI—were designed to complement each other and were modified as needed, based on the suggestions and comments of federal and state agency reviewers.

They are intended to provide an empirical basis for the conclusion stated in the March 2000 316 Demonstration Report that "there have been no adverse impacts to the integrity of the winter flounder population due to the PNPS thermal discharge or CWIS." (ENSR, 2000)

The results of the 2004 study are similar to those of the previous studies performed in 2000 and 2002. When viewed together, the significant conclusions are:

- There is a consistent net flow of water and winter flounder larvae to the south along coastal Cape Cod Bay in the vicinity of PNPS.
- A very small amount – less than 0.1% – of the net volumetric flow of water in Cape Cod Bay passes through PNPS.
- The amount of winter flounder larvae in northwest Cape Cod Bay that is entrained by PNPS is conservatively estimated at less than 1% of the net larval transport.

These findings are consistent with the 316 Demonstration Report, which stated that Pilgrim's potential entrainment impact to the winter flounder population is less than 5%. In fact, based on these results, the potential impact to the winter flounder population (less than one percent) is even smaller than the assessment provided in the 316 Demonstration Report. The clear conclusion is that entrainment at PNPS is minimal, and does not adversely impact the integrity of the winter flounder population.

6.0 REFERENCES

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