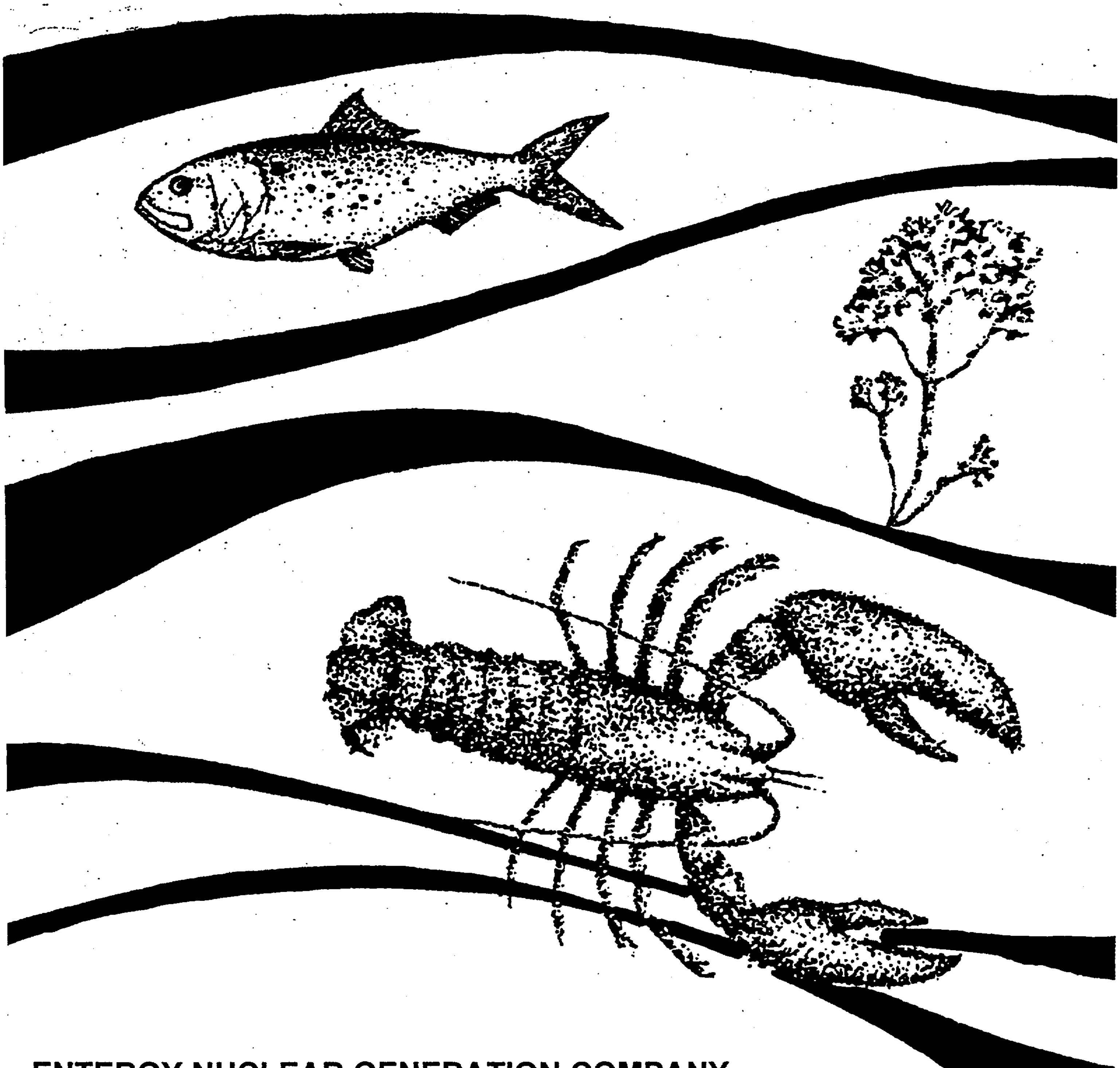
marine ecology studies

Related to Operation of Pilgrim Station

SEMI-ANNUAL REPORT NUMBER 55
JANUARY 1999 - DECEMBER 1999



ENTERGY NUCLEAR GENERATION COMPANY
ENVIRONMENTAL PROTECTION DEPARTMENT

Entergy

MARINE ECOLOGY STUDIES

RELATED TO OPERATION OF PILGRIM STATION

SEMI-ANNUAL REPORT NO. 55

REPORT PERIOD: JANUARY 1999 THROUGH DECEMBER 1999

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Compiled and Reviewed by: Robert D. Anderson
Principal Marine Biologist

Environmental Protection Department
Entergy Nuclear Generation Company
Pilgrim Nuclear Power Station
Plymouth, Massachusetts 02360

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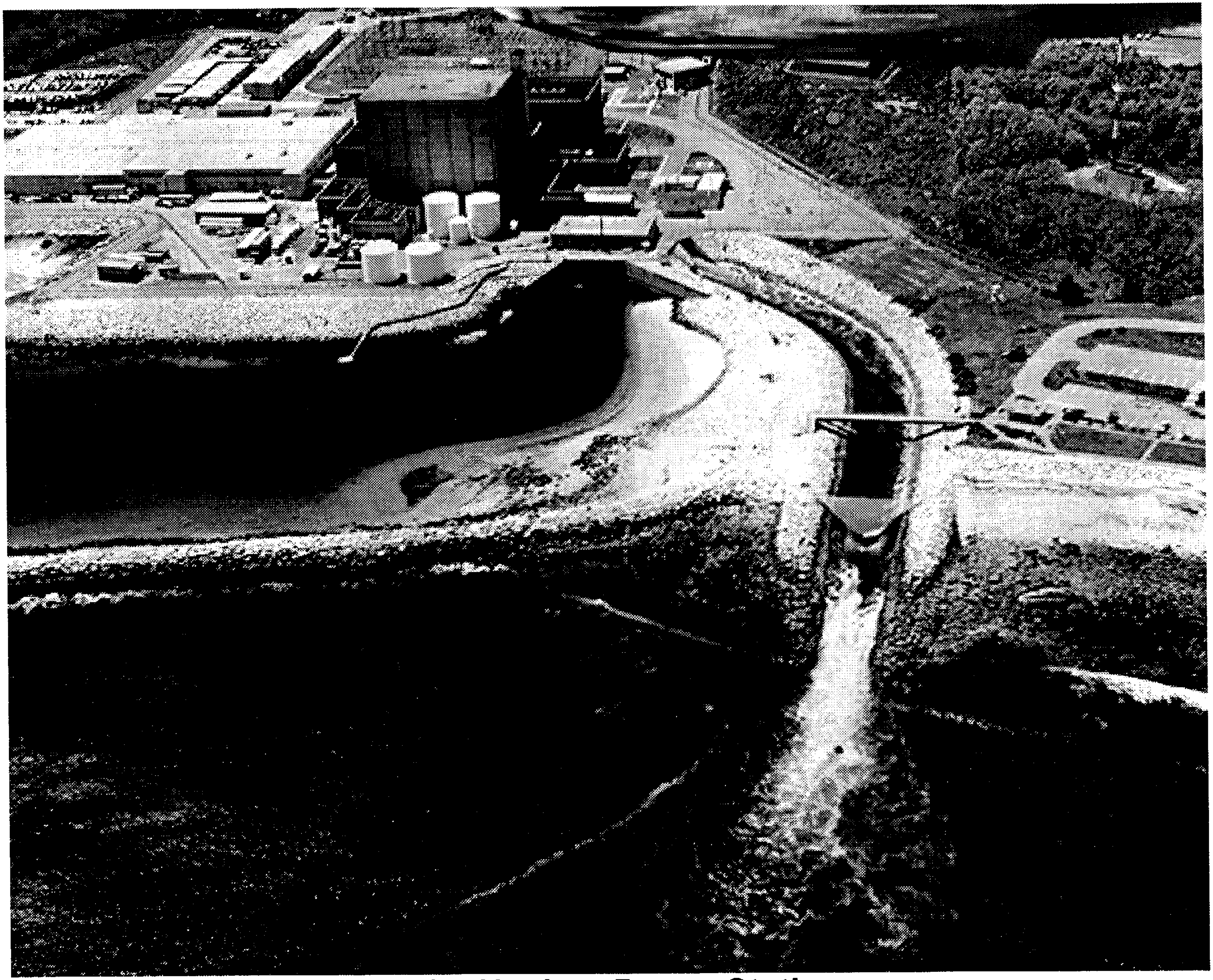

Pilgrim Nuclear Power Station

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I. SUMMARY

SUMMARY

Highlights of the Environmental Surveillance and Monitoring Program results obtained over this reporting period (January -December 1999) are presented below. (Note: PNPS was in an outage (RFO #12) from May 8 - July 7, 1999)

Marine Fisheries Monitoring:

1. In the April - November 1999 shorefront sportfish survey at Pilgrim Station there were 1,993 angler visits and 1,446 fishes recorded for a catch rate of 0.73. Striped bass (55.0%) and bluefish (44.5%) dominated the sportfish catch. The presence of a strong thermal discharge component attracted fish during most of 1990 - 1999 which resulted in good sportfishery success compared with outage and low power years.

2. During July - December 1999 fish observational dive surveys, fish species were observed in the thermal effluent area. Striped bass were the most commonly seen fish, being abundant in the Pilgrim discharge current. Striped bass observations peaked in early Fall, with some individuals noted in the discharge canal in December. Cunner and tautog were consistent throughout the summer into early Fall. Data from the dive and sportfish surveys reveal that certain species are attracted to either the elevated water temperatures (spring and fall) and/or current. This places them at risk of impact from temperature aberrations, chemical releases, and potential gas bubble disease mortalities. As such, some form of direct visual monitoring is useful.

3. Winter flounder tagging in the Plymouth Bay vicinity to estimate adult population size and fidelity has accounted for 22,476 fish with 883 (3.9%) tag returns from 1993-1998. The 1999 population estimate based on an Area Swept Method (trawling) for the Plymouth Bay area was 176,271 adult winter flounder (age 3+). This equates to roughly a 0.5% adult population impact from the 1999 PNPS entrainment of 3,500,000 flounder larvae (912 equivalent adults) although area - swept estimate variability is high. This lower impact rate than recent years reflects, in part, a refueling outage and minimal circulation pump operators from May 10 - June 10, 1999. Continuation of this study may not yield a more accurate or precise estimate of population size.

4. Rainbow smelt egg restocking of the Jones River (Kingston) to mitigate the high PNPS smelt impingements in December 1993 (5,100 fish) /1994 (5,300 fish) accounted for 1,800,000 fertilized eggs being transplanted in 1994/1995. Once hatched, these eggs supplemented those smelt produced by the river's spawning population of this species. Smelt impingement has the potential of impacting the local smelt population and was further mitigated in 1996-1999 by improving the smelt spawning habitat in the Jones River to enhance egg survival, through the use of several dozen specially designed egg collecting trays. These efforts may at least partially account for 1998 and 1999 smelt spawning runs being the largest in over a decade on the Jones River.

Impingement Monitoring:

1. The mean January - December 1999 impingement collection rate was 7.20 fish/hr. The rate ranged from 0.00 fish/hr (June) to 36.31 fish/hr (September) with Atlantic menahden comprising 63.9% of the catch, followed by Atlantic silverside 21.9%, rainbow smelt 2.3% and winter flounder 2.1%.

2. The September/November 1999 Atlantic menhaden impingement accounted for 76% of this species' annual collection, with a large incident occurring on 17/18 September when 4,900 were estimated impinged.

3. The mean January - December 1999 invertebrate collection rate was 1.82+/hr with ctenophores and sevenspine bay shrimp dominating. Common starfish and green crabs accounted for 14% of the catch. Eighteen American lobsters were sampled. The invertebrate impingement rates in 1989 - 1999 were similar to those recorded at Pilgrim Station during the 1987 and 1988 outage years, despite much lower circulating water pump availability in these outage years.

4. Impinged fish initial survival in the Pilgrim Station intake sluiceway was approximately 37% during static screen washes and 84% during continuous washes. Six of the dominant species showed greater than 50% survival overall.

Benthic Monitoring

One observation of the discharge, near-shore acute impact zones was performed during this reporting period (October). Denuded, sparse, and stunted zone boundaries were indistinguishable during September 1987 - June 1989 discharge surveys as a result of the PNPS extended shutdown. However, these surveys did note impact zone boundaries in fall 1989 - 1999 primarily because two circulating water pumps were in operation most of the time resulting in maximum discharge current flow. The scouring (denuded) impact area in October 1999 was 1,925 m^2, ~22% less than October 1998 (2,469 m^2). The 1999 denuded and total affected zones were somewhat smaller than the historical baselines established prior to 1996.

Entrainment Monitoring:

1. A total of 41 species of fish eggs and/or larvae were found in the January - December 1999 entrainment collections: 19 eggs, 37 larvae.

2. Seasonal egg collections for 1999 were dominated by yellowtail flounder, fourbeard rockling, American plaice, winter flounder and Atlantic cod (winter - early spring); windowpane and labrids (late spring - early summer); rockling/hake, windowpane and labrids (late summer - autumn).

3. Seasonal larvae collections for 1999 were dominated by sculpin, rock gunnel and sand lance (winter - early spring); fourbeard rockling, Atlantic menhaden and cunner (late spring - early summer); Atlantic menhaden, silver hake, and Atlantic herring (late summer - autumn).

4. Eight lobster larvae were collected in the entrainment samples for 1999.

5. On several occasions in 1999, "unusually abundant" ichthyoplankton densities were recorded including Atlantic menhaden larvae for the most extended time period. This possibly reflects strong annual spawning production for the species involved.

6. The mean annual losses attributable to PNPS entrainment (assuming 100% operation) for the adult stage of six abundant species of fish for 1999 were as follows: cunner 242,511; Atlantic mackerel 38; winter flounder 289-2,382; Atlantic menhaden 740; Atlantic herring 11,187; Atlantic cod 6. None of these losses for these species were found to be significant in the context of preliminary population or fishery effects. Comprehensive population impact studies are presently being conducted for winter flounder in the Pilgrim area.

II. INTRODUCTION

INTRODUCTION

A. Scope and Objective

This is the fifty-fifth semi-annual report on the status and results of the Environmental Surveillance and Monitoring Program related to the operation of Pilgrim Nuclear Power Station (PNPS). The monitoring programs discussed in this report relate specifically to the Cape Cod Bay ecosystem with particular emphasis on the Rocky Point area. This is the forty-third semi-annual report in accordance with the environmental monitoring and reporting requirements of the PNPS Unit 1 NPDES Permit from the U.S. Environmental Protection Agency (#MA0003557) and Massachusetts Department of Environmental Protection (#359). A multi-year (1969-1977) report incorporating marine fisheries, benthic, plankton/entrainment and impingement studies was submitted to the NRC in July 1978, as required by the PNPS Appendix B Tech. Specs. Programs in these areas have continued under the PNPS NPDES Permit. Amendment #67 (1983) to the PNPS Tech. Specs. deleted Appendix B non-radiological water quality requirements as the NRC felt they were covered in the NPDES Permit.

The objectives of the Environmental Surveillance and Monitoring Program are to determine whether the operation of the PNPS results in measurable effects on the marine ecology and to evaluate the significance of any observed effects. If an effect of significance is detected steps are taken to correct or mitigate any adverse situation.

These studies are guided by the Pilgrim Administrative-Technical Committee (PATC), which was chaired by a member of the Mass. Department of Environmental Protection in 1999, and whose membership includes representatives from the University of Massachusetts, the Mass. Department of Environmental Protection, the Mass. Division of Marine Fisheries, the National Marine Fisheries Service (NOAA), the Mass. Office of Coastal Zone Management, the U.S. Environmental Protection Agency, and Entergy Nuclear Generation Company.

Copies of the minutes of the Pilgrim Station Administrative-Technical Committee meetings held during this reporting period are included in Section IV.

B. Marine Biota Studies

1. Marine Fisheries Monitoring

Marine Fisheries studies in 1999 focused on winter flounder population parameters to develop an understanding of PNPS impact on this indicator species. Population estimates and adult equivalency analyses were conducted on this key species to help assess the impact of PNPS larval entrainment. Winter flounder were studied by techniques including trawling and population estimation. Cunner population impact efforts were terminated in 1998 and rainbow smelt spawning enhancement continued on the Jones River (Kingston).

Finfish observational dive surveys were performed in 1998 for the Pilgrim Station thermal plume area. This monitoring involves periodic diving from May through October to document fish behavior and condition at various locations in the discharge area, and two discharge dives in late December to record any heated water, overwintering fishes. Results of the marine fisheries monitoring during the reporting period are presented in Section IIIA.

2. Benthic Monitoring

The benthic monitoring described in this report was conducted by ENSR Consulting and Engineering, Woods Hole, Massachusetts. Qualitative transect sampling off the discharge canal to determine the extent of the denuded and stunted algal zones was conducted once in 1999 (September).

Results of the benthic monitoring and impact analysis during this period are discussed in Section IIIB.

3. Plankton Monitoring

Marine Research, Inc. (MRI) of Falmouth, Massachusetts, has been monitoring entrainment in Pilgrim Station cooling water for fish eggs and larvae, and lobster larvae (from 1973-1975 phytoplankton and zooplankton were also studied). Information generated through this monitoring has been utilized to make periodic modifications in the sampling program to more efficiently address the question of the effects of entrainment. These modifications have been developed by the contractor, and reviewed by the PATC on the basis of the program results. Plankton monitoring in 1999 emphasized consideration of ichthyoplankton entrainment and selected species adult equivalency analyses.

Results of the ichthyoplankton entrainment monitoring and impact analysis for this reporting period are discussed in Section IIIC.

4. Impingement Monitoring

The Pilgrim Station impingement monitoring and survival program speciates, quantifies, and determines viability of the organisms carried onto the four intake traveling screens. Marine Research, Inc. has been conducting impingement sampling with results being reported on by Boston Edison - Entergy in 1999.

A new screen wash sluiceway system was installed at Pilgrim in 1979. This new sluiceway system was required by the U.S. Environmental Protection Agency and the Mass. Division of Water Pollution Control as a part of NPDES Permit #MA0003557. Special fish survival studies conducted from 1980-1983 to determine its effectiveness in protecting marine life were terminated in 1984, and a final report on them appears in Marine Ecology Semi-Annual Report #23.

Results of the impingement monitoring and survival program, as well as impact analysis, for this reporting period are discussed in Section IIID.

C. Station Operation History

PNPS was in an outage (RFO#12) form May 8-July 7, 1999 but in a high operating stage during most of this reporting period with a 1999 capacity factor (MDC) of 76.2%. Cumulative capacity factor from 1973-1999 is 56.8%. Capacity factors for the past 15 years are summarized in Table 1.

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Table 1. PILGRIM NUCLEAR POWER STATION UNIT 1 CAPACITY FACTOR USING MDC NET% (Roughly approximates thermal loading to the environment: 100%=32 Degrees F Δ T)

Month	1999 *	1998	1997	1996	1995 *	1994 *	1993	1992	1991	1990	1989	1988 *	1987 *	1986	1985
January	99.2	98.4	92.5	92.1	99.1	98.8	99.0	96.6	95.4	99.4	0.0	0.0	0.0	79.5	54.0
February	98.3	99.5	42.1	99.4	96.3	72.5	96.7	99.4	88.9	97.4	0.0	0.0	0.0	97.7	59.3
March	93.7	99.5	0.0	99.3	74.4	79.5	83.2	80.4	84.6	30.0	10.7	0.0	0.0	26.9	81.8
April	77.1	97.0	21.4	75.9	0.0	63.3	6.4	53.5	92.7	5.4	10.5	0.0	0.0	11.9	90.8
May	17.0	92.5	97.4	98.2	0.0	94.5	0.4	97.8	0.0	77.9	4.6	0.0	0.0	0.0	94.3
June	0.0	99.4	98.1	94.3	65.1	97.2	77.5	97.8	0.0	96.3	16.4	0.0	0.0	0.0	85.0
July	71.3	95.5	95.5	95.3	95.7	97.6	80.3	97.4	0.0	55.1	28.6	0.0	0.0	0.0	96.9
August	87.8	93.0	96.4	92.3	97.7	88.2	86.9	97.4	28.5	94.5	50.8	0.0	0.0	0.0	96.5
September	75.3	93.3	97.4	51.4	96.7	0.0	84.8	94.1	96.4	21.6	52.5	0.0	0.0	0.0	71.4
October	99.0	99.4	98.7	94.0	94.3	0.0	98.0	72.8	94.2	98.7	30.1	0.0	0.0	0.0	95.4
November	96.3	99.6	69.5	94.9	99.5	0.2	80.0	13.7	23.7	96.8	66.0	0.0	0.0	0.0	88.1
December	99.9	98.2	68.8	97.7	98.8	87.7	94.8	65.2	98.1	94.5	77.1	0.0	0.0	0.0	99.1
ANNUAL%	76.2	97.1	73.4	90.5	76.4	65.2	74.0	80.6	58.4	72.3	28.9	0.0	0.0	17.5	84.4

CUMULATIVE CAPACITY FACTOR (1973-1999) -= 56.8%

________________ = outages >2 months

* = NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 18 FEBRUARY - 8 SEPTEMBER, 1987
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 14 APRIL - 5 JUNE, 1988
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 9 OCTOBER - 16 NOVEMBER, 1994
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 30 MARCH - 15 MAY, 1995
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 10 MAY – 10 JUNE, 1999

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III. MARINE BIOTA STUDIES

III. A. MARINE FISHERIES MONITORING & IMPACT

ANNUAL REPORT ON ASSESSMENT AND MITIGATION OF IMPACT OF THE PILGRIM NUCLEAR POWER STATION ON FINFISH POPULATIONS IN WESTERN CAPE COD BAY

Project Report No. 68 (January to December 1999)

By
Robert Lawton, Brian Kelly,
John Boardman, and Matthew Camisa

April 2000
Massachusetts Department of Fisheries,
Wildlife, and Environmental Law Enforcement
Division of Marine Fisheries
100 Cambridge Street
Boston, Massachusetts 02202

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I. EXECUTIVE SUMMARY

The following are the 1999 highlights of study findings for selected species. Additional information can be found in the Conclusions section of this report.

Rainbow Smelt

- Rainbow smelt (*Osmerus mordax)* impingements of different magnitudes have occurred at Pilgrim Nuclear Power Station (PNPS) over the years of station operation. The smelt is considered an "Important Representative Species" due to its abundance and recreational importance in the Plymouth, Kingston, Duxbury Bay (PKDB) area. The Massachusetts Division of Marine Fisheries (MDMF) has undertaken remediation efforts to compensate for these impingement mortalities. Our overall goal has been to increase the number of adult smelt in the local population and thus offset power plant impact. Overall, efforts have included augmenting natural egg production and enhancing spawning habitat to optimize egg hatchout.
- During the springs of 1994 and 1995, ca. 1.8 million smelt eggs obtained from two genetically isolated, wild, anadromous Massachusetts populations, were transplanted into the Jones River, a tributary to PKDB. Eggs were collected using our portable sphagnum moss-filled incubation trays, which provide ideal habitat for egg development and survival. Larvae were expected to imprint on the waters of PKDB and return to the Jones River and/or its other tributaries to spawn when sexually mature. The stocking portion of our project had to be discontinued because of reduced egg production in our "source" streams, with no other accessible supply of eggs to be found.
- To address spawning habitat enhancement, we continued to use egg-collecting trays. During each spawning season from 1994 to 1999, a number of trays have been placed in the Jones River on the smelt spawning grounds, where spawning activity has consistently been greatest in past years. The

trays are emplaced in the river before smelt spawning commences and are removed after egg hatching is completed.

- O Improving water quality in the Jones River and other tributaries to PKDB has been an ongoing goal of our agency. The MDMF will continue to place trays into the river during the smelt spawning period to continue husbandry practices. We also will monitor spawning activity and egg production densities, while conducting periodic checks to make sure the river is free of obstacles, such as fallen trees, that could hinder fish passage.

Winter Flounder

- O The PKDB and surrounding coastal waters are important spawning and nursery areas for winter flounder (*Pseudopleuronectes americanus*). In the environs of PNPS, winter flounder exhibit fairly high fidelity to natal spawning grounds. In general, they undertake only local seasonal movements.
- O In 1999, an estimated 3.5 million winter flounder larvae were entrained at PNPS. This represents a low level of flounder larval entrainment at the plant and was directly related to the scheduled plant outage during the winter flounder spawning season. Entrainment was markedly down from last year, when 88.8 million winter flounder larvae were entrained.
- O An estimated 1,353 winter flounder - mostly age 0 and age 1 - were impinged at PNPS in 1999.
- O Only four winter flounder reportedly were caught by anglers at the PNPS Shorefront in 1999.
- O Winter flounder tag returns (fish at large at least one year) by area and recovered during the non-spawning period (June-February) from 1993-1998 and (June-December) of 1999 suggest that a large proportion of the winter flounder do not move far afield from the overall tagging area (Areas 1-3) after the spawning season (March-May). Tag returns by area recovered during the spawning period from 1993-1999 were primarily from Area 2 (77%). Our tag data reveal that most movements of winter

flounder in the Plymouth area are restricted to relatively short distances, and there appears to be a fairly high fidelity to the Plymouth area in the local population.

- Density extrapolation, using the Area/Density Method, provides an estimate of the adult winter flounder population size (absolute abundance) for the study area of fish $\geq$ 280 mm total length (TL), i.e., age 3 and older adults, which was 176,271 for 1999. This is down from 1998, when adults in the study area were estimated at 264,872. The data suggest that total annual mortality was high between years.

- The future equivalent age-3 adult loss (staged approach) because of entrainment mortality in 1999 is estimated to represent approximately only 0.5% of the number of adults present in the local population in 1999, estimated by Area /Density methodology.

<u>Other Species</u>

- Atlantic silverside (*Menidia menidia*) is typically impinged annually at PNPS in high numbers (estimated to be 13,811 in 1999), but no compensatory action has been taken because the species is short-lived and prolific.

- Alewife (*Alosa pseudoharengus*) impingement should continue to be monitored, as a large impingement incident of 13,100 juvenile alewives did occur in 1995.

- Striped bass (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*), winter flounder, pollock (*Pollachius virens*), and bonito (*Sarda sarda*) were the species reported in the recreational catch at the PNPS Shorefront in 1999.

- Striped bass dominated the SCUBA finfish sightings off PNPS, with small aggregations of cunner (*Tautogalabrus adspersus)* also observed. Striped bass (up to 100 individuals) over-wintered in the discharge canal at PNPS.

- Data from the sportfish and underwater visual surveys reveal that some finfish species are attracted to the thermal discharge current at PNPS. This places them at risk from temperature aberrations, chemical releases, and potential gas bubble disease problems. As such, direct visual monitoring in the discharge area has been helpful.

II. INTRODUCTION

The Massachusetts Division of Marine Fisheries (MDMF) power plant team conducted field investigations to assess environmental effects of the operation of Pilgrim Nuclear Power Station (PNPS). In some instances, mitigative or remedial measures have been instituted to offset adverse impacts. This work was funded by Boston Edison Company under Purchase Order No. LSP010846 in 1999.

In 1999, we focused on winter flounder (*Pseudopleuronectes americanus*) and rainbow smelt (*Osmerus mordax*), employing trawl gear, equipment, and techniques to sample and, when appropriate, to undertake restorative measures. Descriptive statistics are summarized in tables or displayed in figures.

From extensive field studies off PNPS, it is evident that water withdrawal aspects of this station's operations, i.e., entrainment of fish eggs and larvae, and to a lesser extent, impingement of juvenile and adult fish, pose greater environmental threats than does the release of waste heat into the receiving waters.

The two finfish species given particular attention at present in the PNPS area are winter flounder and rainbow smelt (Table 1). The PNPS area serves as winter flounder spawning, nursery, and feeding grounds. This flatfish is highly valued both commercially and recreationally. Winter flounder larvae have been entrained in relatively high numbers over the years of station operations. Rainbow smelt is valued recreationally in the nearby Plymouth, Kingston, Duxbury Bay (PKDB) estuary. Several incidents of relatively high smelt impingement have occurred at PNPS over the years of station operations.

Our objectives in 1999 were: (1) for winter flounder, to affirm discreteness of the local population and estimate its abundance (relative and absolute); and (2) for rainbow smelt, to enhance the quality of spawning habitat in the nearby Jones River, a tributary to PKDB, where most of the local smelt population originates, by providing ideal substrate to maximize egg survival to hatching. This annual report includes a description of sampling design and methodology, together with findings, conclusions, and recommendations. Progress achieved in assessment surveys and ongoing restorative projects was highlighted for these indicator species in the PNPS area.

Table 1. Important indicator species off the Pilgrim Nuclear Power Station.*

Species	Background History	Basis for Selection as an Indicator Species	Possible Sources of Impact	Most Significant Source of Impact (Based on Results to Date)
Rainbow Smelt	RIS	r, s	I, T/C	Impingement - large incidents in December of '78, '93, '94
Winter Flounder	RIS	d, r, c, s	I, E, T/C	Entrainment - large number of larvae collected (April-May)

RIS - representative important species selected in the original 316 (a and b) Demonstration Document and Supplement to assess Pilgrim Station impact (Stone and Webster 1975 and 1977).

d - a dominant species in the Pilgrim area.
r - a local resident
c - commercial importance
s - recreational importance

I - impingement
E - entrainment
T/C - discharge current effects: thermal/current

* Note: Indicator species selection rationale: these two species were selected because they have shown the most potential for impact off Pilgrim Station and may be indicative of power plant induced stresses to other marine fish species.

III. METHODS AND MATERIALS

The study area for 1999 is bounded in Figure 1.

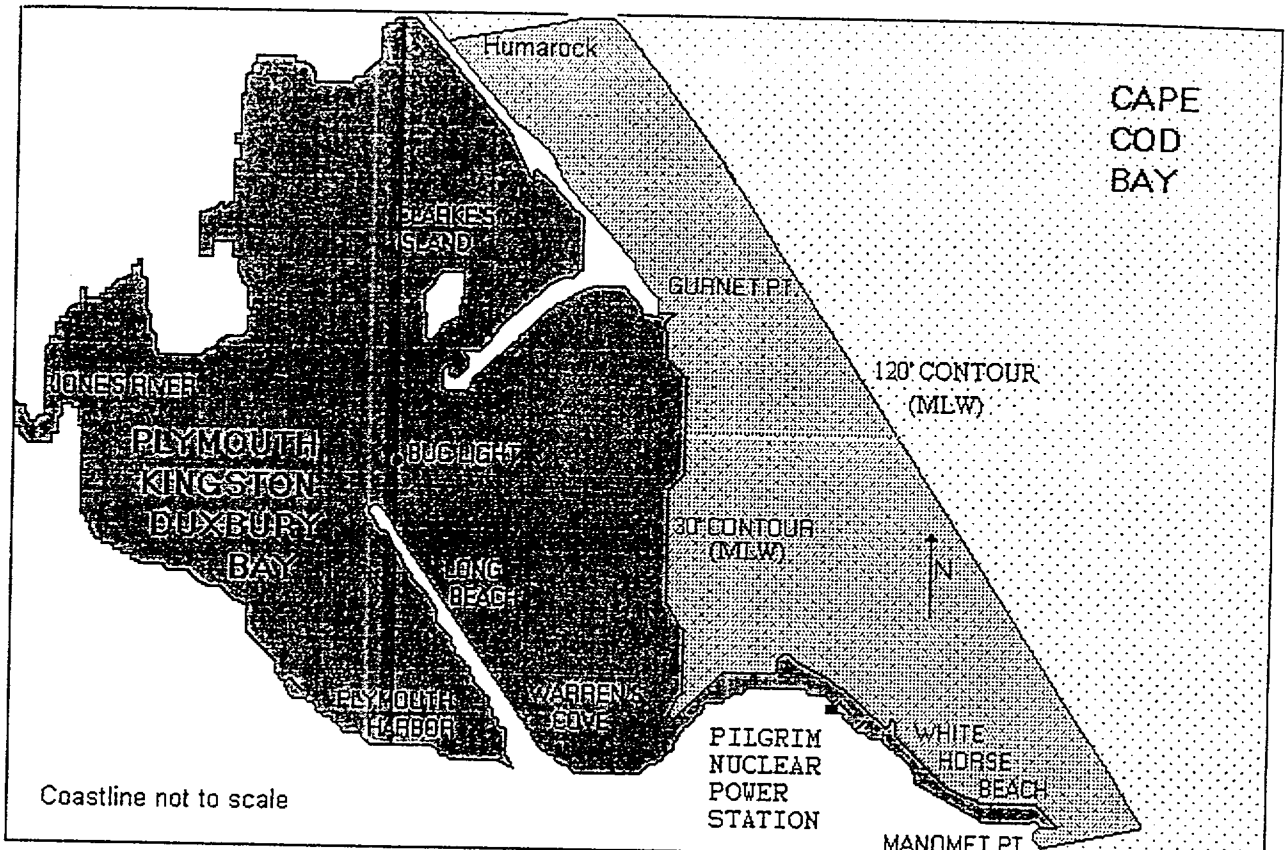

Figure 1. PNPS investigative area for rainbow smelt and winter flounder, January-December, 1999. Depth strata are shaded differently.

Rainbow Smelt

Eggs and Larvae. We allowed rainbow smelt to spawn naturally over egg collecting units placed in the Jones River. Each collection unit (35.6 x 45.7 cm) was a weighted wooden frame, enclosed with chicken wire, and filled with unprocessed sphagnum moss which served as substrate for egg deposition (Figure 2). We deployed the egg trays in selected riffle areas of the upper Jones River smelt spawning ground. We inspected, serviced, and monitored these units every few days for egg deposition, development, and survival. Fouling macro-algae were removed and discarded downstream of the spawning area. We endeavored to minimize egg disturbance and mortality on the riverbed and on our trays during this process. Following egg hatchout, larvae are carried downstream and into the waters of PKDB as they develop. When adults, they should home back to this estuary, ascending the Jones River and possibly other tributaries in this complex to spawn.

Juveniles. Three unusually large rainbow smelt impingement incidents have occurred at PNPS, in December, of 1978, '93, and '94. The majority of smelt impinged were age-0 fish (juveniles). Impingement sampling data were collected by Marine Research, Inc. (see Impingement section, this report).

Adults. Adult rainbow smelt (Figure 2) also have been impinged at PNPS (see Impingement section).

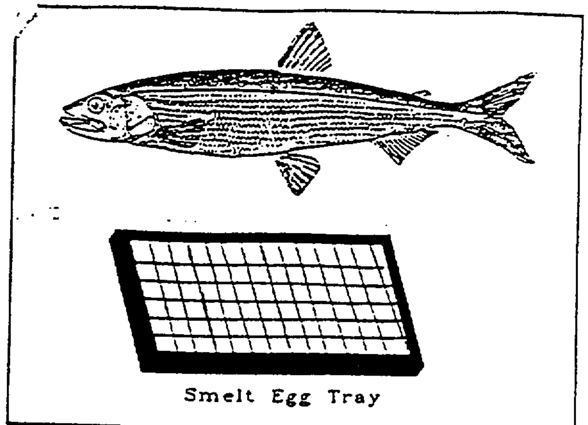

Figure 2. A sphagnum moss filled collecting unit of the type used to collect and incubate smelt eggs (smelt shown above) in the Jones River.

Winter Flounder

Eggs and larvae. Data on these two life stages (primarily larvae) were collected by Marine Research, Inc. in their entrainment sampling program at PNPS (see Entrainment section, this volume).

Juveniles. Juvenile winter flounder are impinged at PNPS, with monitoring data also collected by Marine Research, Inc. (see Impingement section, this volume).

Adults. Our objectives have been to determine the discreteness (fidelity) of the local winter flounder population and to estimate population abundance. This information is being used to assess the magnitude of adverse impact of flounder entrainment and impingement at PNPS.

During the winter flounder spawning season north of Cape Cod (March-May), some flounder may move in and/or out of PKDB (Figure 1), with evidence of spawning both inside and outside this estuary. Flounder may aggregate in pre-spawning staging areas out in deeper water, with some moving into the estuary at night on a flood tide to spawn in the shallows.

We again contracted a commercial fishing vessel in 1999 to sample winter flounder. The F/V *Alosa* was employed to estimate winter flounder density and to sample for winter flounder tag recaptures. The tagging study area was the same as last year and included the waters 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).

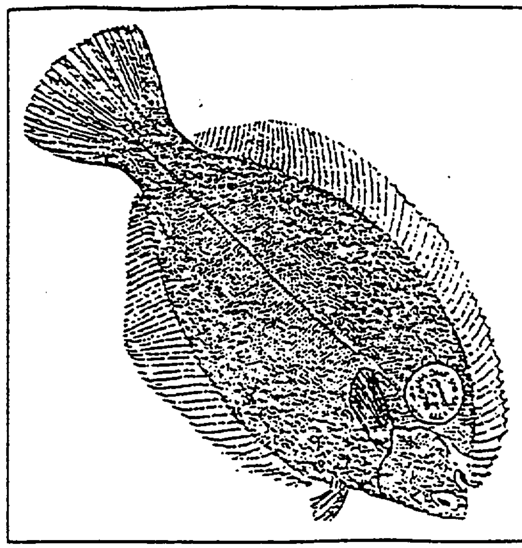

Figure 3. Winter flounder with Petersen disc tag attached (tag not to scale).

Trawl gear on the F/V *Alosa* consisted of a Yankee otter trawl (18.3-m sweep and 12.2-m headrope, which had a 15.2-cm stretch mesh and a 4.5-cm mesh liner); it was fished with 12.8-m legs and 73.2-m ground cables. The trawl doors (#63 Thiboron doors) were of steel (1.5 m x 0.9 m and 181 kg each).

Winter flounder were enumerated, measured (TL), sexed, assessed for maturity and reproductive state, and examined for tags before being released near capture sites. Within the tagging area, winter flounder had been marked (Figure 3) from 1993-1998 at locations selected on the basis of known local flounder concentrations (staging areas) primarily during the spring flounder spawning season (March-May). Data also were collected on net geometry and the trawl distance of each tow. Tow duration and distance averaged 30 minutes and 1.2 km, respectively.

We estimated winter flounder population size (instantaneous absolute abundance) for 1999 using an area/density approach, based on density extrapolation over the total defined study area from trawl area-swept sampling aboard the F/V *Alosa*. As trawl gear efficiency in our sampling was unknown, we assumed it to be at least 50% for winter flounder and is probably higher. To estimate density, the number of winter flounder by tow (data transformed via $\ln(x+1)$) was divided by the area of bottom covered. Tow length was determined, and tow width was estimated from the trawl doors' spread on the bottom. Door spread is used as a measure of width because of the "herding" action caused by the sediment cloud generated by the doors and legs while towing. Catch per unit area was calculated for individual tows. The estimates computed for adult winter flounder (≥280 mm TL) and for all sizes pooled were doubled to reflect the assumed catch efficiency, which likely overestimates absolute abundance. Density estimates (number per m^2) were multiplied by the total bottom acreage in the study area to obtain estimates of absolute abundance. Bottom area was determined using a dot grid and navigational charts. Acreage was converted to square meters.

Other Fish Species

Eggs and Larvae. Egg and larval information for other finfish species entrained at Pilgrim Station were obtained by Marine Research, Inc. (see Entrainment section, this volume).

Juveniles. We also collected data on juveniles of a few finfish species using SCUBA diving. Impingement data were obtained from Marine Research, Inc.

Adults. (Same as for juveniles)

IV. RESULTS AND DISCUSSION

A. PHYSICAL FACTORS

1. Power Output-Thermal Capacity

Pilgrim Nuclear Power Station's capacity factor (MDC net percent) is an index of operational status that approximates thermal loading into the nearshore receiving waters of western Cape Cod Bay. This factor is relevant when assessing long-term thermal impact on marine organisms. By permit regulation, PNPS is allowed a maximum discharge temperature of 38.9°C and an effluent ΔT of 18°C above ambient. For the 27-year history of plant operations, the annual mean MDC at PNPS has ranged from 0.0% (outage years) to 97.1% in 1998. The power output at PNPS averaged 76.2% for 1999, for there was a scheduled refueling outage (10 May-10 June) in the spring.

2. Pump Operations

Once-through, open-cycle cooling at PNPS induces a localized water current flow just off the plant. Two circulating seawater pumps [586.7 kl/min each (155,000 gals/min)] withdraw water from an artificially created intake embayment that is bounded by breakwaters and rip-rap. The cooling water circulates through the plant condenser tubes before being discharged back into the receiving waters of western Cape Cod Bay with waste heat. At ebb tide, effluent velocities can exceed 2.1 m/sec (7 ft/sec) at the egress of the discharge canal. This results in scouring of the benthos and concomitant erosion of substrate along the bottom path of the discharge plume.

Throughout the operational history of PNPS, there have been station outages, when one or both circulating seawater pumps were not operated. Such periods have occurred periodically and generally have been short-lived; however, extensive outages occurred in 1984 and from 1986-1988. In 1999, both circulating pumps basically were turned off from 10 May - 10 June during a scheduled refueling outage at the plant. This, in turn, greatly reduced entrainment impacts at the plant for this time period of the year.

B. FINFISH SPECIES OF IMPORTANCE

1. Rainbow smelt

Background

The goal of our 1999 rainbow smelt project was to enhance the quantity of quality smelt spawning habitat in the Jones River, a tributary to PKDB. We placed 100 egg collecting trays in the upper smelt spawning area of the Jones River for the period of 25 March through 14 May, 1999. The trays collected the naturally spawned, demersal, adhesive smelt eggs, providing an ideal habitat for egg protection and development. The sphagnum moss filling the trays provides a three dimensional depositional surface for the eggs, and represents a micro-environment that offers protection for the developing embryos, reducing 'egg turnover' loss. Water can flow through the moss, carrying away metabolic wastes and providing a continuous supply of oxygen to the eggs.

The rainbow smelt spawning ground in the Jones River is comprised largely of hard substrate (gravel, sand, and cobble). Natural aquatic vegetation which provides ideal substrate for egg development covers only a small portion of the spawning ground. Sutter (1980) reported smelt egg survival to hatching was about 10% on vegetation but only 1% on hard surfaces. Trays with sphagnum have consistently collected higher egg sets than natural hard abiotic bottom.

Eggs and Larvae

The 1998 rainbow smelt egg set in the Jones River was the best in over a decade. Areas containing more than 50 eggs per square inch were considered to have heavy sets, while 20 to 50 per square inch were considered moderate sets, and < 20 eggs per square inch were light sets. The majority of available spawning habitat in Zone A and upper third of Zone B was utilized for egg deposition (Figure 4). This section of the river generally was covered by moderate to heavy egg sets. Egg patches of varying densities also could be found throughout the lower two thirds of Zone B and even down to the Route 6A bridge.

The 1999 smelt egg deposition, i.e., the number of eggs spawned, in the Jones River was even higher than in 1998. Figure 5 depicts the smelt egg set in the Jones River for 1999. The majority of available spawning habitat in Zone A and upper third of Zone B was covered with eggs. No major storms occurred, and conditions in the Jones River were favorable for another successful spawning year. The river was free of obstructions, and a good flow existed with many riffle areas observed, which dispersed the eggs and prevented their aggregation in one area. The long, filamentous macro-algal blooms, which likely reduce water flow to the developing eggs, was a problem this year.

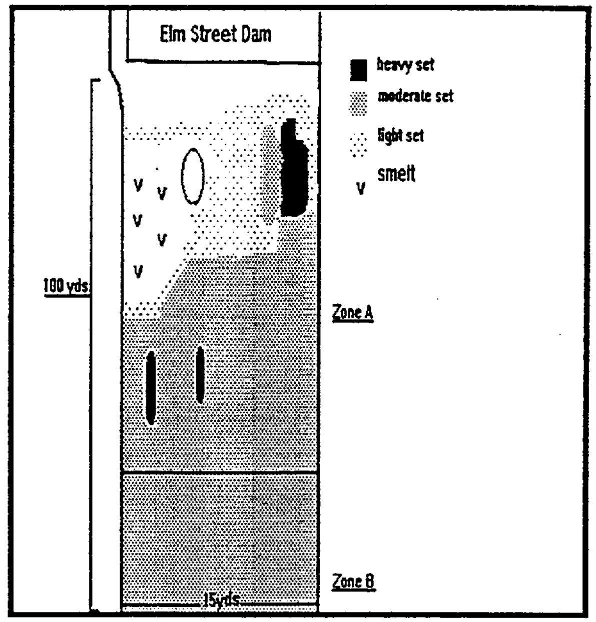

Figure 4. Smelt egg densities within zones A&B of the Jones River habitat enhancement area, 1998.

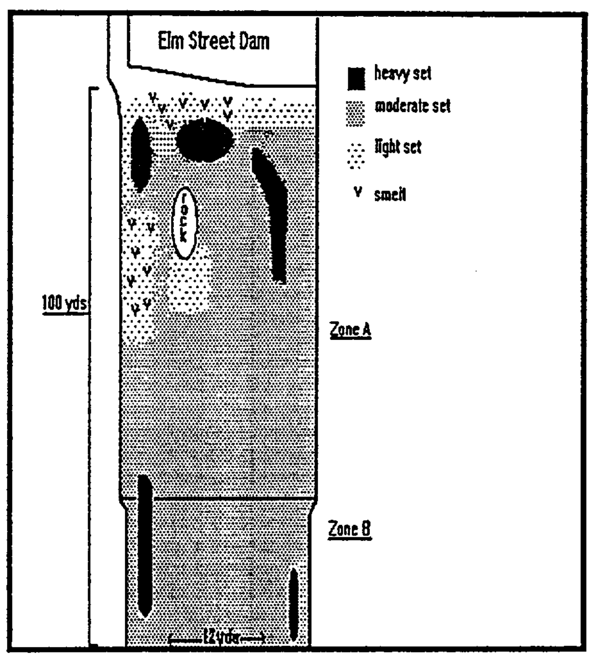

Figure 5. Smelt egg densities within zones A&B of the Jones River habitat enhancement area, 1999.

During the 1999 smelt spawning season, Eel River, Town Brook, and Smelt Brook (other tributaries in the PKDB complex) were inspected for smelt egg deposition. We reconnoitered areas of known spawning activity based on past observations. Town Brook had somewhat better egg production than in years past; however, egg sets were rated as light and patchy. As in years past, Smelt Brook, a tributary to the Jones River, had a small scattering of eggs. We found smelt eggs in the Eel River for the first time in two years. Egg sets of light to moderate density were found there just downstream of the Rt. 3A bridge. The majority of smelt spawning of the local PKDB smelt population, however, still occurred in the Jones River.

Juveniles

For the last seven years (1993-1999), rainbow smelt impingement at PNPS was estimated to total 27,143 fish (1,446 in 1999). A representative sample of impinged fish was measured each year. After comparing lengths of these fish to the mean length at age for smelt from an earlier study of ours in the Jones River, we determined that the majority of impinged fish were juveniles (ages 0+ and 1+ fish). Smelt spawning runs in the Jones River had been depressed for many consecutive years, with the exceptions of 1998 and 1999.

Adults

Large aggregations of adult rainbow smelt were observed in the Jones River on several occasions during daytime trips to the river in 1999. The fish were congregated in a pool in Zone A (Figure 5). Based on past observations, this is indicative of a relatively strong spawning run. As an anecdotal observation, we caught numbers of adult smelt while trawling for winter flounder this spring in western Cape Cod Bay.

2. Winter Flounder

Background

Winter flounder range the northwest Atlantic from Labrador to Georgia (Bigelow and Schroeder 1953), being found in water temperatures between 0 and 27°C and salinities from 10 to 35‰. They can form discrete, resident populations which undertake localized seasonal movements (Perlmutter 1947; Saila 1961; Howe and Coates 1975). Flounder movement and migration are apparently temperature driven (Pearcy 1962; McCracken 1963; Scarlett 1988; Powell, R.I. DEM, unpublished data). Some adults emigrate from shoal waters when water temperatures rise above 15°C and return as waters cool below this level. Other groups of winter flounder are resident, and, although an avoidance temperature of 24.4°C was reported by Meldrim and Gift (1971), their year-round occurrence has been documented in some estuaries (Olla et al. 1969; Wilk et al. 1977) at water temperatures around 24°C. In addition, Phelan (1992) found adult winter flounder throughout the year in an offshore area of New York and New Jersey.

Based on a meristics' study, Pierce and Howe (1977) concluded that estuarine groups of winter flounder do not necessarily constitute separate genetic, biological units. A group may be comprised of an assemblage of adjacent estuarine spawning units that intermix, of which some may be more geographically isolated than others. Homing patterns have been documented to some estuaries (NUSCO 1986; Black et al. 1988; Scarlett 1988; Phelan 1992; Powell, RIDEM unpublished data), and several tagging studies (Lobell 1939; Perlmutter 1947; Saila 1961; Howe and Coates 1975) have provided evidence of high fidelity to specific embayments for spawning following offshore migrations in consecutive years. At the same time, some winter flounder disperse to distant locations (Saila 1961; McCracken 1963; Howe and Coates 1975; Phelan 1992), and there may be a random search back for the natal spawning grounds (Saila 1961), following random food searches (McCracken 1963). Phelan (1992) speculated that populations may be discrete only during the spawning period, with random temperature-related seasonal movements resulting in an intermix at other times of the year. If the search for natal spawning grounds has a random component to it, then some winter flounder may be found in non-natal locations during the spawning season. From mark and recapture work in the inner New York Bight, Phelan (1992) purported that winter flounder there formed a dynamic assemblage, consisting of three reproductively discrete spawning sub-populations: one that "homes" to natal spawning grounds in the Navesink and Shrewsbury Rivers, a second consisting of an aggregation of generally sedentary fish found in Sandy Hook and Raritan Bays, and a third group found offshore, with all three capable of intermixing.

In Massachusetts, Lux et al. (1970), Howe and Coates (1975), and Pierce and Howe (1977) concluded from meristic and tagging work that, for management purposes, winter flounder consist of three stocks - one north of Cape Cod, another south and east of Cape Cod, and the third on Georges Bank. A comprehensive winter flounder mark and recapture program (more than 12,000 fish tagged at 21 locations) was conducted in Massachusetts during the 1960's by Howe and Coates (1975), who found that flounder migration generally encompassed relatively short distances; although, extensive movements of some tagged fish did occur. Flounder dispersal, overall, was greater south of Cape Cod, where many areas are shoal (<18.3 m) with waters warming considerably during the summer. Returns from release sites north of Cape Cod revealed that movement generally was more limited, with many tagged fish recovered in respective sub-area release sites, even years later.

Winter flounder spawn principally at night when water temperatures are at or near the lowest (0 - 5°C) for the year, occurring during late winter and early spring. Spawning occurs in estuaries (bays, rivers, harbors), over shoals outside estuaries, and on offshore banks. It usually takes place in the shallows over firm bottom, e.g., gravel, sand, eelgrass, and pelagic algae. The eggs are demersal and adhesive, and those that fall onto soft, fine sediments or onto algal mats are less likely to develop. Hatching occurs in about two to three weeks at water temperatures of 3-5°C. Larval stage duration is up to 2 months, and the pelagic larvae, which are relatively non-buoyant, can move vertically in the water column, thus somewhat offsetting the effects of a diffusive environment. Age-0 fish (juveniles) are more tolerant of higher water temperatures than are the adults, and they often remain in estuarine nursery areas throughout their first year; age-1 fish may do the same (Buckley 1982).

The PKDB estuary, not far from PNPS, is a local spawning ground for winter flounder, although spawning also can occur outside this estuary. The adult segment of the local population is exploited prior to the spawning season by a regulated commercial otter trawl fishery that is open from 1 November to 31 January, with a minimum legal fish size of 305 mm TL. In past years, this fishery was open into the spring, but declining flounder abundance prompted a mandated reduction in temporal effort to reduce fishing mortality.

Spawning success, recruitment, and population coherence are maintained where physiography and oceanographic circulation enhance larval retention in specific geographic areas. Size of the spawning grounds and larval retention areas are limiting factors to absolute population abundance. Winter flounder population size is a function of the size of the physical system underlying larval retention. Large populations generally are found in large bays and on large offshore banks; whereas, smaller populations are associated with coastal ponds (lagoons) and smaller estuarine river systems (Howell et al. 1992). Clearly, the magnitude of impact of a given mortality (power plant related or otherwise) is inversely related to the absolute abundance of the population (pool source) affected.

Habitat and water quality are important issues regarding inshore winter flounder spawning and nursery grounds because these areas typically are subject to anthropogenic alterations and environmental degradation. The various winter flounder life stages can be affected by dredging, filling of wetlands, toxicants, disease infestation, hypoxic conditions, and power plant-induced mortality. Direct mortality, permanent loss of habitat or habitat exclusion, along with the loss of reproductive and growth potential can result. In addition to natural and fishing mortality, impingement and entrainment of winter flounder by power plants can substantially add to total mortality. Losses may be especially problematic when power plant intakes are located in or near spawning and/or nursery grounds (Normandeau 1979), e.g., at PNPS.

All life stages of winter flounder, at least seasonally, inhabit the artificial intake embayment at PNPS, which simulates a small cove.

Eggs and Larvae

The larvae of winter flounder are much more susceptible to power plant entrainment than are their eggs, which are demersal and adhesive. The benthi-pelagic larvae, especially the later stages, generally are more abundant near the bottom of the water column during the daytime and, thus, are vulnerable to entrainment as bottom water is drawn into the intake structure. At PNPS, entrainment of winter flounder larvae has ranged from an estimated 3.5 to 88.8 million annually over the last 20 years (1980 to 1999); the 1998 estimate was, by far, the highest recorded during this entire period. Larval entrainment also was relatively high in 1997 (55.4 million larvae), which represents the second highest annual entrainment of the time series. The third highest value of this period was 29.8 million larvae, which was recorded in 1981, when abundance of the winter flounder stock last peaked. We pondered the cause for the large increases in larval entrainment in 1997 and 1998, even though the local population is far from being at a high in overall abundance. From the Massachusetts Division of Marine Fisheries' (MDMF) coastwide spring trawl-survey time series, we found that the survey biomass index for the Gulf of Maine winter flounder stock did not substantially increase in either year, suggesting that population numbers were not particularly high. Overall, however, MDMF's spring surveys have revealed record high indices of recruitment of age-2 flounder since 1992. We found no correlation between the number of larvae entrained at PNPS and the surveyed number of age-2 fish, using a two year lag, however.

Larval mortality due to entrainment at PNPS in 1999, assuming no survival and using the Adult Equivalent Model with staged data, which assumes population equilibrium and no density-dependent compensation, equates to the total loss of 912 age-3 winter flounder. This estimated loss to the local population is far less than last year's projected loss of 77,428 adults. Entrainment losses at the station for the last 13 years have ranged annually from 912 adults (1999) to the high of 77,428 adults (1998). Gibson

(1994) examined data for several winter flounder populations and found that after accounting for adult mortality, recruitment rates were lowest in three populations (located in Mt. Hope Bay, Niantic River, and off Plymouth in western Cape Cod Bay) that are subject to entrainment by nearby power plants.

Delimiting the geographic extent of the local population was important to establish the source of flounder larvae entrained at PNPS. This power plant has been shown to entrain larval winter flounder produced in PKDB and also larvae produced from sites outside the estuary in western Cape Cod Bay (Marine Research, Inc. 1988).

Juveniles

In 1999, an estimated 1,353 winter flounder were impinged at PNPS. All were juveniles (ages 0 and 1). The number impinged this year (1999) represents about 100 age-3 adults.

Juveniles tolerate water temperatures up to 27°C, but sublethal effects begin to appear at 20°C, with feeding inhibition evident at 24-27°C. This should preclude juveniles from the immediate discharge area in late summer, when temperatures can exceed these values.

Adults

Direct mortality of winter flounder has been rare in the thermal plume off PNPS. When exposed to high water temperatures, flounder probably vacate an area or try to avoid thermal stress by burying into the bottom which would be cooler than the overlying water (McCracken 1963; Olla et al. 1969). Adult flounder can tolerate water temperatures up to 26°C, but above 22.2 C they become inactive and cease feeding. Occasionally during past summers, bottom water temperatures have approached 30°C at the mouth of the PNPS discharge canal. Stone and Webster (1977) predicted that adult winter flounder would be excluded by thermal stress from the immediate vicinity of the Pilgrim discharge during late summer and early fall, although this impact area is small, at most likely less than 4,047 m^2.

Four winter flounder reportedly were caught by anglers at Pilgrim Shorefront in 1999. In the 1970's and early 1980's, this species ranked among the top five sportfish angled in the recreational fishery off the power plant.

Movements, Migration, Fidelity and Abundance

To assess the magnitude of larval winter flounder entrainment at PNPS, we have conducted a tagging experiment of sub-adult and adult winter flounder in the inshore waters of Western Cape Cod Bay/Massachusetts Bay. The ecological significance of man-induced mortalities (e.g., via power plant water withdrawal/discharge heat effects) is difficult to interpret unless the mortality can be evaluated against some measure of the size of the true biological population affected, while also considering natural mortality estimates. Our objectives have been to define movements, migration, and discreteness (i.e., fidelity to a spawning area) of the local population and to estimate its abundance (relative and absolute). This section relates our analyses of observations pertaining to the movements, migration, fidelity and abundance of winter flounder on coastal grounds north of Cape Cod.

The geographical boundaries defining the region of the sample population for our studies were defined by Eric Adams of M.I.T. employing an analytical, hydrodynamic model to predict spatial estimates of the origin of winter flounder larvae that are subject to be entrained at PNPS. This simplistic model outputted the cumulative probability density function of entrained organisms (larvae) at the power plant that originate from different locations. The question of larval transport was deemed analogous to the problem of computing the relative concentration of a contaminant released at some origin at a constant mass moving in one direction by a current of constant magnitude.

From the F/V *Alosa*, we sampled winter flounder for density estimates, and recaptured tagged fish to determine fidelity. In 1999, we successfully completed 84 standard trawl tows within the study area and caught a total of 5,947 winter flounder for a mean catch of 70.8 fish per tow (CPUE). It should be noted, however, that there were likely multiple recaptures of some smaller, untagged fish. In comparison, in 1998 we made 198 trawl tows, sampling 17,409 winter flounder; the mean CPUE was 87.9 winter flounder. The CPUE data suggest that relative abundance of winter flounder in the study area declined in 1999 from the

1998 level.

From 1993 to 1998, we had marked/tagged 22,476 winter flounder during the spring spawning season from Humarock to Manomet Point (Figure 6) in Zones 1-3 (defined study area - Figure 7) of western Cape Cod Bay (Table 2). None were tagged in 1999. All fish were released in the general vicinity of capture. Tag returns came from commercial and recreational fishermen, fish processing plants, and our research efforts.

The population of winter flounder in the environs of Plymouth is demographically open and thus subject to immigration and emigration. Our analysis is based on winter flounder tag returns obtained with accurately reported locations (Table 2). In some years, well over 50% of our tag returns came from commercial fishing catches. Through December 1999, 1038 fish (with accurate return information) had been recaptured for an overall return rate of 4.6% (Table 2). A recapture rate of 2.8% was reported by Phelan (1992) from 7,346 winter flounder (≥ 18 cm T.L.) tagged in the inner New York Bight in the late 1980's. In many fish mark and recapture programs, the percentage of returns ranges from 3 to 10%. By way of contrast, over 30 years ago, Howe and Coates (1975) of the Massachusetts Division of Marine Fisheries, having tagged 12,151 winter flounder (generally ≥ 200 mm TL) in the 1960-1965 period (late March-April) at 21 locations along the Massachusetts coast, obtained 4,440 tag returns through September 1971 for a remarkable overall finfish recovery rate of 36.5%. One of the tagging locations was Plymouth Outer Harbor, which is within our defined study area, where in 1964 they tagged 500 winter flounder, of which 36.6% eventually were recaptured. It should be noted that their returns were compiled for a longer period of time following flounder tagging.

Our overall low tag return rate is disappointing for the number of fish tagged in the study area and is a limiting factor to our drawing inferences from the subset of measurements obtained from the sample population. We believe that the low return rate is due to the under-reporting of recaptures by commercial fishermen and the spatio-temporal bans on commercial fishing in the inshore waters. The exclusion of commercial fishing from inshore waters at times during the year effectively removes a substantial source of

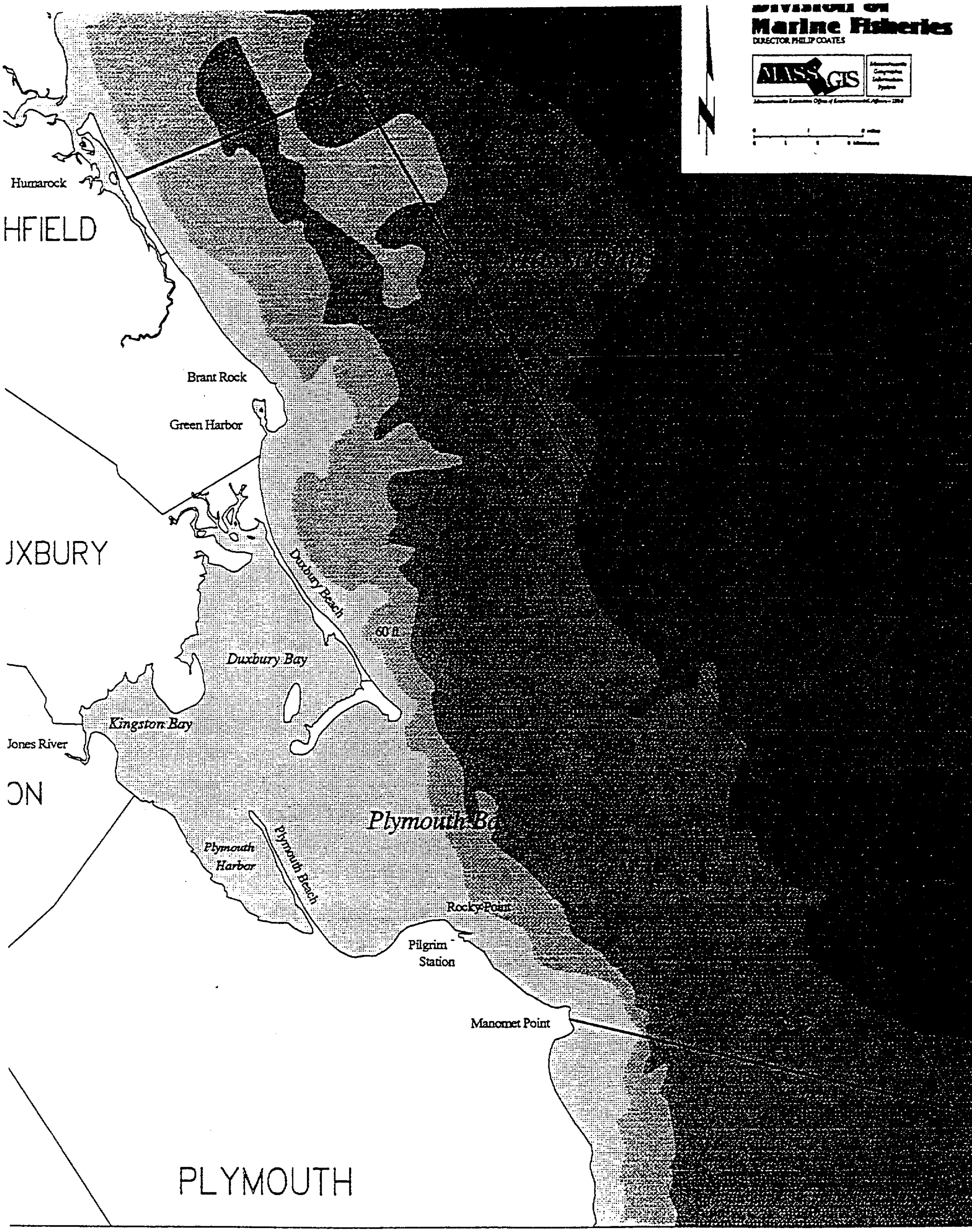

Figure 6. Division of Marine Fisheries Winter Flounder Tagging Area.

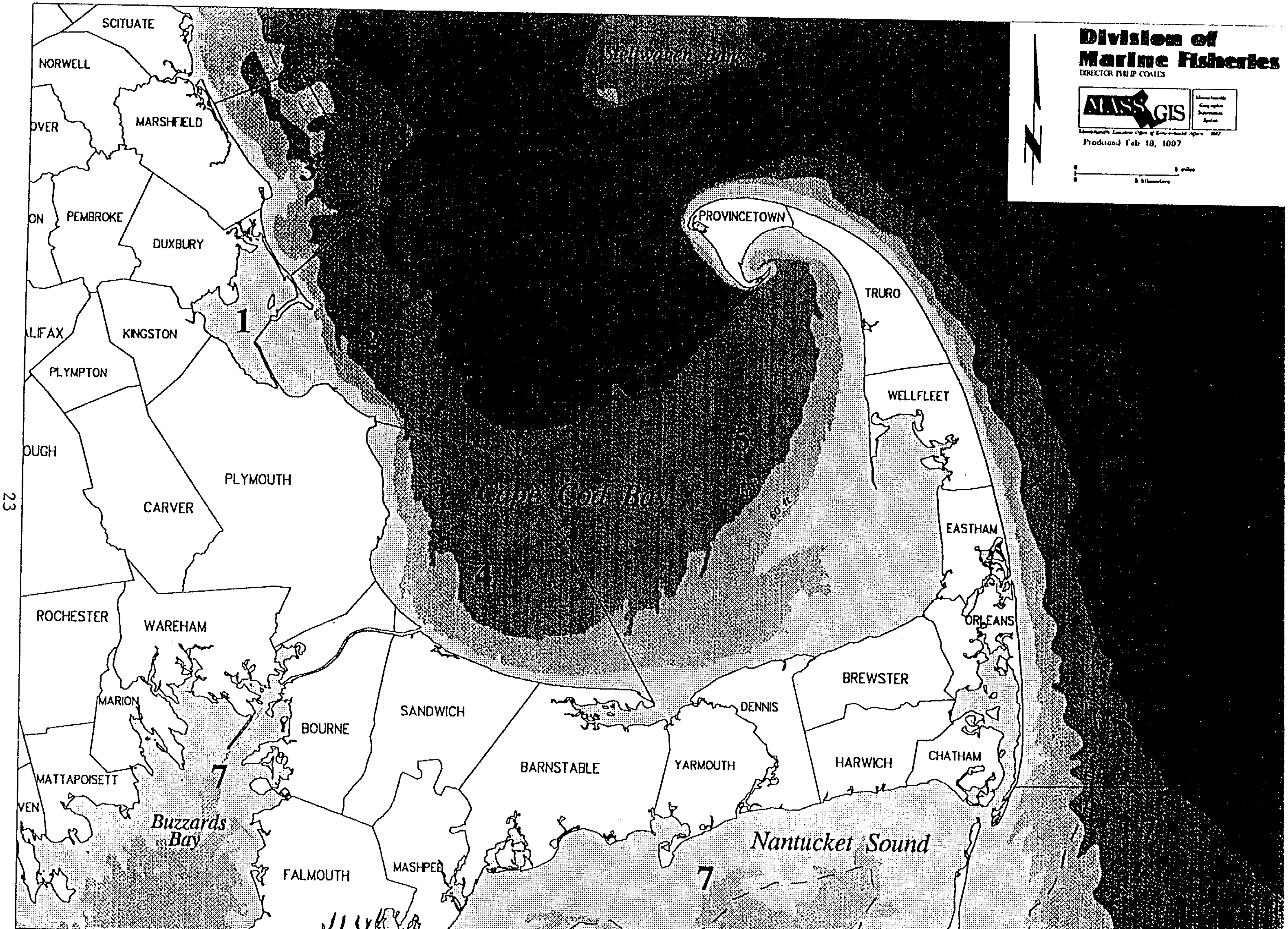

Figure 7 . Recapture zones of winter flounder (Pleuronectes americanus) tagged in areas 1 – 3 by the MA Division of Marine Fisheries in the decade of the 1990's.

recapture information. From anecdotal comments, we have been told that some commercial fishermen did not return recapture information to us because they believe the data will be used against them for management purposes. Our offering of lucrative financial rewards the last two years, via lottery, aided somewhat in obtaining tag returns, based on our conversations with certain individuals reporting tags. The number of unreported tag returns is unknown; however, we suspect it to be sizable within the commercial sector.

Tag returns (at large at least one year) by area for winter flounder recovered during the non-spawning period (June-February) from 1993-1998 and (June-December) of 1999 (Table 3) must be interpreted with some caution because of the distribution of fishing effort off the Massachusetts coast, which, in turn, is dependent on seasonal flounder distributions and fishery closures. It is clear that there was an unequal distribution of commercial fishing effort spatially. The highest numbers of recaptures, by far, came from Area 2, followed by area 3, both are within the overall tagging area. This suggests that a sizeable proportion of the flounder may not move far afield from the overall tagging area (Areas 1-3) after the spawning season (March-May). Awareness of fishermen in this area of concentrations of flounder and numbers of tagged fish (including the two commercial vessels we contracted for tagging/recapture operations) may have contributed somewhat to recaptures from here. Recapture numbers just north (Area 7) and south (Area 4) of our overall tagging area

Table 2. Summary of winter flounder mark/recapture data from western Cape Cod Bay in the 1990s.

Tagging dates	Size-total length	Number tagged (fin-clipped)	Color of tag	Recaptured through 31 Dec, 1999	% Recovery
Jan-May/Nov-Dec, 1993	≥25 cm	(206)	-	2	1.0
Mar-May/Nov-Dec, 1994	≥200 mm	226	yellow	27	11.9
April, 1995	≥200 mm	2,066	yellow	87	4.2
April, 1996	≥250 mm	4,997	red	193	3.9
Mar-May, 1997	≥250 mm	7,487	blue	408	5.4
Mar-May, 1998	≥280 mm	7,494	green	321	4.3
Totals	-	22,476	-	1038*	4.6

*** This figure does not include 103 tag returns from fish processing plants where there were incomplete reportings of recapture locations.**

Table 3. Tag returns by area for winter flounder (at large at least one year) recovered during the non-spawning period (June-February) from 1993-1998 and (June-December) of 1999. Fish were marked in Areas 1-3.

Area	Number of Recaptures	Percent of Total Recaptures
1	7	3.2
2	90	41.7
3	48	22.2
4	16	7.4
5	2	0.9
6	33	15.3
7	13	6.0
8	0	0.0
9	1	0.5
10	1	0.5
Other*	5	2.3
Totals	216	

*Other: Stellwagen Bank (4), Long Island, NY (1).

are similar, reflecting fish dispersal in both directions. A larger number of recaptures came from Area 6 off Provincetown, indicating an eastward movement of fish. A few individuals traveled considerable distances, having been reported from Georges and Stellwagen Banks; the backside of Cape Cod (Highland Light); Gay Head, Martha's Vineyard; Newport, R.I.; and Long Island, N.Y. The greatest straight-line distance from tagging area to recovery site was a remarkable 170 miles, accomplished by a 42 cm female in a span of 7 months and taken off Long Island, New York. It is evident that flounder were more broadly distributed geographically outside the spawning period.

Tag returns (at large at least one year) recovered during the spawning period (March-May) from 1993-1999 (Table 4) also are influenced by the distribution and seasonality of fishing effort off the Massachusetts coast. Many of the recaptures in Area 2 are from our contracted vessel(s) during tagging operations. There is limited commercial fishing allowed in Areas 1-5 during this March-May period based on state-mandated spawning closures, while recreational winter flounder fishing does not open until May 1. Fidelity of the local flounder population has been somewhat difficult to assess based on the inherent areal biases associated with tag return information. However, aboard contracted vessel(s) we have recaptured very high numbers of flounder in Area 2 (part of the tagging area) during the spawning season (Table 4). Fish recovered from Areas 6 and 7 (Massachusetts Bay) may have already spawned and then moved off the local spawning grounds. Seventy-seven percent of the total recaptures came from Area 2 during the spawning season.

Additional information about fidelity of winter flounder to the study tagging area came from our research recapture work conducted from late March through early May in 1998. We conducted haphazard trawl tows (totaling 110) in Areas 4 and 5 (outside our tagging area) searching for tagged fish from past years of the survey. Only 2 tagged fish (at large at least one year) were recovered. We attempted trawling for tagged flounder north of the tagging area (Area 7), but untrawlable bottom limited the number of standard tows (3) we could successfully complete in this area. No tags were recovered. The data strongly suggest, nevertheless,

Table 4. Tag returns by area for winter flounder (at large at least one year) obtained during the spring spawning season (March-May) from 1993-1999 of fish tagged in Areas 1-3.

Area	Number of Recaptures	Percent of Total Recaptures
1	0	0.0
2	249	77.3
3	11	3.4
4	7	2.2
5	4	1.2
6	32	9.9
7	19	5.9
8	0	0.0
9	0	0.0
10	0	0.0
Other	0	0.0
Totals	322	

that winter flounder return to (or never stray very far from) the locality of tagging with high frequency.

In summary, the returns from our release sites show overall relatively limited (localized) movements, basically confined to inshore waters. Thus, our data support findings from earlier studies that most observed movements of winter flounder located north of Cape Cod are restricted to relatively short distances. Finally, it appears there is fairly high fidelity and thus discreteness in the localized population within the Plymouth area, which imparts more importance to entrainment effects of PNPS. Nevertheless, geographical isolation during the spawning period is not complete in that there is some exchange with adjacent populations, with tagged fish being recaptured during this time interval in adjacent areas.

Density extrapolation (Area Swept Method), pre-stratified by depth, was used with data collected from 84 trawl tows made on the F/V *Alosa* over the period of 6 to 21 April, 1999 to estimate winter flounder population size: one estimate was for a segment of the flounder population ≥ 280 mm TL (age 3 and older considered to be adults) and the other for the entire winter flounder population (all sizes) (Table 5), with areal measurements estimated for MLW.

Our unadjusted estimates of winter flounder absolute abundance for the study area (see Methods section, this report) using area-swept are 88,135 adults and 183,953 total winter flounder. These estimates assume a trawl gear efficiency of 100%. Trawl catch efficiency is variable rather than a constant; we assumed it was more likely at least 50%. Thus, we doubled the estimates and the adjusted values were 176,271 adults and 367,908 total flounder (Table 5). Last year's area-swept estimates for adult and total flounder abundance were higher at 264,812 and 588,450, respectively. This suggests that abundance was substantially down in 1999. Precision improved with pre-stratified estimates of abundance.

Gear selectivity is a factor, in that, the F/V *Alosa* used a 4.5 mm mesh cod-end which limits the retention of small fish; thus, an expanded estimate of abundance is biased toward larger fish. There is spatial variation in abundance of this species by depth (Lawton et al. 1995), and we have not always distributed our sampling effort based on the relative areal sizes of each depth stratum. Based on the modeling by Eric Adams of M.I.T., it is predicted that winter flounder larvae entrained at PNPS can come from as far away as 17.7 km. To repeat, our study area encompassed from Humarock, Marshfield south to Manomet Point, Manomet (Figure 1).

Table 5. Estimated abundance (stratified by depth) by otter trawl density extrapolation in numbers of winter flounder (2.674 x 10^8 m^2 bottom area at MLW) with 95% confidence limits, Equivalent Adult loss from entrainment at PNPS, and Conditional mortality in the study area, Spring 1995-1999.

Year	Category	Number of flounder	Lower 95% CL	Upper 95% CL	Equivalent Adult Loss	Conditional mortality
1995	Flounder ≥280mm TL	212,989	210,637	215,341	9.9 x 10^3	4.6 %
	All Flounder	444,850	437,438	452,261		
1996	Flounder ≥280mm TL	316,986	314,365	319,607	15.4 x 10^3	4.8 %
	All Flounder	510,306	506,378	514,235		
1997	Flounder ≥280mm TL	313,959	308,896	319,021	47.1 x 10^3	15.0 %
	All Flounder	882,889	877,834	887,945		
1998	Flounder ≥280mm TL	264,812	242,799	286,825	77.4 x 10^3	29.2 %
	All Flounder	588,450	553,330	623,570		
1999	Flounder ≥280mm TL	176,271	172,306	180,236	9.1 x 10^2	0.5 %
	All Flounder	367,908	360,826	374,989		

To gain perspective on the entrainment equivalent adult estimate, we compared it with population estimates generated for the study area. These estimates came from the trawl area-swept method. First, a percent loss of adult winter flounder as a result of larval entrainment was obtained using the equivalent adult estimate (912) obtained from entrainment monitoring in 1999 and the Adult Equivalent Model as related to the area-swept estimate of the number of adults (176,271) residing in the study area in 1999.

The eventual adult loss because of entrainment corresponds to 0.5% of the adults estimated to be residing in the study area during the 1999 winter flounder spawning season. Estimated future adult stock loss due to entrainment in 1998, based on an area-swept estimate, represented 29.2% of adult abundance in 1998. However, it should be remembered that larvae of a given year will not attain adult status until age 3, so the resultant effects of entrainment in 1997 and 1998 won't be realized until winter flounder population estimates for the years 2000 and 2001 are generated.; the effect could be less or more than the current estimates. A review by Marine Research, Inc. (1986) of winter flounder early-life studies at PNPS revealed that stock reductions of 0.7 - 2.2% (relative to a larger stock size back then) were estimated to be possible because of plant operations. It is noted that back in the early 1980's, winter flounder were in greater abundance than at present. Given that coast-wide winter flounder populations have been severely depressed in recent years by overfishing , PNPS entrainment may have added markedly to total mortality affecting this fairly discrete population in recent times. However, we know from our tagging data, fidelity is not 100 %, with some mixing going on with other nearby spawning units.

3. Other Species

Data on other finfish species were obtained from a creel survey conducted at the PNPS Shorefront Recreation Area and by underwater SCUBA surveys in the thermal discharge area.

Creel Survey

There were 1,993 anglers tallied over 187 creel sampling days at the Pilgrim Shorefront from April-November, 1999. This expanded sampling represented 66 more data gathering days than last year's survey. The overall goal was to obtain basic information on sportfishing activity, including fishing effort and locations, and gamefish catch over time. There were two data collectors, who were seasonal public relations' personnel for the power plant. They conducted the creel inventory in addition to other duties. Only weekends were sampled in April and May, while there was daily coverage from June-November.

It is clear that most of the fishing effort was expended in the thermal discharge area, with anglers fishing off the two discharge canal jetties. Far less effort was expended off the outer intake breakwater, with even less effort located off the rocky beach located north of the discharge canal. Anglers primarily sought striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*), with not much directed effort for groundfish.

The overall monthly average number of angler trips per day to the Shorefront in 1999 was 10.7, while individual monthly averages ranged from a low of 6.9 in November to a high of 19.5 in May. The high monthly mean value obtained for May is probably influenced by the fact that only weekends were sampled, when angler presence is substantially higher. Effort was more uniform from June through August, ranging from a mean of 9.6 to 14.9 angler visits per day.

The recorded sportfish catch in 1999 by shore-based anglers at Pilgrim Shorefront totaled 1,446 fish, comprising five species , viz. striped bass, bluefish, winter flounder, pollock (*Pollachius virens*), and bonito (*Sarda sarda*). The overall pooled mean catch rate (i.e., catch per angler trip) was 0.73, with a monthly range of 0.08 (June) to 1.46 in November. Reported catches were somewhat down from last year, when the overall mean catch rate was 0.83 fish per angler trip. We believe that the creel data recorded over the years may under-represent the actual catch in some years, as a limited number of anglers present on a busy fishing day were interviewed during some of the surveys with no adjustment made for the catch of fishermen not interviewed.

In 1999, the percent composition of the overall recreational catch was 55.0% striped bass, 44.5% bluefish, and 0.5% for winter flounder, pollock, and bonito combined. The highest monthly catch (pooled species) occurred in August at 447 fish or 30.9% of the 8-month total, followed by July (348 fish - 24.1%), and September (336 fish - 23.2%).

Winter flounder were caught in June (2 fish), September (1 fish), and November (1 fish). Only two pollock were caught - both in August. Bonito were caught in September (2 fish). No Atlantic mackerel or tautog were reported in this year's creel survey.

Striped bass dominated the overall monthly totals for April-July, September, and November, being caught in all months of the survey. The first striped bass was landed on 3 April, which is early for their occurrence in the sportfish catch at the PNPS Shorefront. Of the 795 striped bass reportedly caught at the Shorefront in 1999, 95.8% were sublegal as to the recreational size limit in the fishery (< 71.1 cm TL). The highest monthly catches were made in September (28.7% of total bass catch), followed by November (24.8%) and July (20.0%). The overall catch rate, i.e., catch per day, averaged 4.3 bass, with monthly rates from April-November ranging from 0.7 to 9.9. These catch rates were down substantially from last year. The overall striped bass catch in 1999 was 29.1% lower than that recorded for 1998.

PNPS's warm-water discharge has attracted bass over the years when the power plant has been operating with both circulating seawater pumps in use. We observed via SCUBA diving about 50+ striped bass in the discharge canal as late as 6 December, 1999. These "overwintering" fish are susceptible to cold-shock if PNPS were to experience an outage during the winter months.

Bluefish were caught first on 11 July, 1999 and were abundant in the catches of August through

October. A total catch of 643 bluefish in a range of sizes was recorded at the Shorefront. The highest monthly catch occurred in August (58.2% of seasonal total). The overall catch rate (i.e., catch per day) averaged 3.4 bluefish per day, with the monthly totals ranging from 0.0 (April through June) to 12.5 in August.

The overall bluefish catch in 1999 at the Shorefront increased 52.0% from that in 1998. The reason for the increase may be explained by the increased number of sampling days (54.5% more) during the 1999 season. Nevertheless, it is readily evident that when PNPS is operational, the warm-water discharge attracts and concentrates bluefish as well as striped bass, to the advantage of sportfishermen. Recreational bluefish catches at the PNPS Shorefront have been notable as to the number landed over the years when the station has continually operated. Conversely, power outages at the Station have resulted in markedly reduced sportfish catches at the Shorefront area.

PNPS experienced an outage for refueling purposes from May 10th to June 11th as scheduled. During this outage, very few fish were caught off the discharge jetties and intake breakwaters with the exception of 10 sub-legal bass on May 16th and 2 flounder on June 5th. The recreational fish survey reports show fish being caught steadily at the Shorefront from mid-April until the outage on May 10th. The survey reports also show an increase in sublegal striped bass landings when the plant came back on line in mid-June. The 1999 creel data at PNPS clearly show a relationship between on-line discharge current and the numbers of fish caught.

Observational Diving

Underwater finfish diving observations provide us with visual data on occurrence and general numbers of finfish in the immediate area of the thermal effluent. In the summer and fall of 1999, SCUBA dives were made to investigate the mouth of the discharge canal and the adjacent thermal discharge area. Small aggregations of cunner (*Tautogolabrus adspersus*) were present outside the canal mouth during summer and early fall. Striped bass were the most commonly observed species, with numbers peaking in early fall. Tautog were noted up through early November, but following this they apparently had left the area as water temperatures declined. Striped bass were still seen in the discharge canal in December, not having migrated in the fall.

4. Impact Perspective

Winter flounder, rainbow smelt, cunner, alewives (*Alosa pseudoharengus*), and Atlantic silversides (*Menidia menidia*) have been negatively impacted by PNPS operations over the years (Table 6). The response of these species to perturbation may be illustrative of power plant-induced stresses on other marine finfish in the area.

Rainbow smelt

In 1993 and 1994, rainbow smelt annual impingements at PNPS were relatively high - about 9,500 and 10,600 fish, respectively. Impingements of that magnitude are likely to have been biologically important to the local smelt population. As a remedial measure to offset power station impact, we stocked over 1.8 million smelt eggs into the nearby Jones River (the major smelt spawning tributary in the area) over the years of 1994 and 1995. From 1995 through 1999, we also have employed egg collecting trays containing artificial plant substrate (sphagnum) in this stream to enhance spawning habitat for the purpose of optimizing egg survival to hatching. This latter effort will be continued in 2000.

Cunner

Entrainment of cunner eggs and larvae at PNPS has been high over the years. In 1997 alone, entrainment was equated to the equivalent loss of an estimated 498,281 adults from the local population. Entrainment of this magnitude would appear to be substantial, but the importance of this loss to the local cunner population is unknown. We have geographically bounded the local population which included all major recruitment sources. However, absolute abundance of the local population is difficult to determine because of logistics and financial constraints. Instead, for three years (1995-1997), we had conducted recruitment studies to assess power plant effects of water withdrawals.

Table 6. A summary of mechanical impacts of Pilgrim Nuclear Power Station on selected finfish species and mitigation undertaken in the offsite waters of western Cape Cod Bay.

Species	Impact of Pilgrim Nuclear Power Station	Comments/Mitigation
Rainbow smelt	High plant impingements occurred in 1978, '93, '94. In 1993 and '94, alone, an estimated 20,000 smelt were impinged which is of concern considering the low numbers of the local population in recent years.	To remunerate for impingement losses, we stocked over 1.8 million smelt eggs over the years - 1994 and '95 - into the nearby Jones River, the prime smelt spawning ground. DMF also has worked to enhance spawning habitat on the Jones River smelt run by adding artificial plant substrate for egg deposition. An annual event since 1995, this effort is intended to improve instream egg survival. We recommend that this effort be ongoing. DMF has assisted with the removal of tree snags from the river, and we recommend that this and efforts to improve overall water quality be given top priority in future restoration efforts.
Winter flounder	In 1998, an estimated 88.8 million winter flounder larvae were entrained, which equates to the theoretical loss of 77,428 age-3 flounder (model estimated) from the local population. While this seeming abundance may be the product of a robust spawning season, it also may simply be the result of localized concentration by wind and water movement. Entrainment losses, equated to adults, was roughly 29% of the possible existing adults in the study area in 1998. An estimated 1,493 flounder were impinged in 1998; all were juveniles.	Absolute abundance of adult winter flounder (≥ 280 mm TL) in the study area during the spring spawning period of 1998 was estimated by density extrapolation to be 264,812 fish. In April and May 1995, a plant outage was coincidently scheduled during the flounder spawning period. As only one circulating water pump was in operation, the volume of cooling water drawn into the plant was reduced by 50%, greatly diminishing concomitant entrainment of winter flounder larvae. It is recommended that plant outages be scheduled at this time of year as an attempt to minimize impact on this species, as well as other springtime spawners. In May 1999, both circulating pumps were off during a refueling outage.
Cunner	Cunner eggs and larvae have been entrained at PNPS in large numbers each year of station operation. Because of the behavior of cunner on rocky reefs and the number of ledges in the PNPS area, it was difficult to determine population abundance and to assess plant impact. A recruitment approach to assess plant impact was undertaken from 1995-1997.	Of the reef areas (natural and artificial) sampled in the study area in past years for cunner mark and recapture, the largest sub-unit of the local population per unit area occurred off the outer intake breakwater, where estimates of cunner adults had approached 5,000 fish. Constructed to protect the intake from wave-related damage, the breakwater provides an abundance of structurally complex habitat critical to cunner survival. As such, construction of this structure likely allowed local cunner abundance to flourish beyond what could be supported naturally. In general, the data from three years (1995-1997) of recruitment studies suggest that PNPS had a minor effect on recruitment success of the local cunner population.
Alewife	In September 1995, about 13,100 juvenile alewives were impinged and presumed to have died. The potential for this or other species to be impinged in large numbers make future impingement monitoring advisable, so mitigative measures can be undertaken as necessary.	Natural reproduction was the exclusive means relied on to replace the lost alewives, and no restocking was recommended or conducted. However, we did recommend a measure of habitat rehabilitation. To improve the passage of spawning-run alewives in local streams, we obtained a sum of money from BECo that will be used to repair a fish ladder in the Pilgrim Station area.
Atlantic silverside	An estimated 11,900 Atlantic silversides were impinged in 2 separate incidents at PNPS, occurring in late November and late December 1994. This species is typically dominant and is impinged in high numbers, estimated at several thousand individuals annually during many of the past years at PNPS.	No compensatory action has been taken to date because the Atlantic silverside is short-lived, and prolific.

In 1995, cunner recruitment success appeared to be regulated primarily during the post-settlement period by compensatory processes (density-dependent mortality), with the plant's impact of larval entrainment likely being inconsequential. In 1996, plant impact was inconclusive; a number of storm events altered recruitment patterns at the termination of sampling. In 1997, recruitment success again appeared to be mediated by post-settlement, density-dependent processes of predation and/or resource competition, with power plant impact of less importance. A difference in habitat at one of the sites (Discharge) increased survival there, resulting in higher recruit densities at the Discharge reef by the end of the recruitment season. This work was not continued in 1998.

Winter flounder

Larval winter flounder entrainment in 1997 and 1998 was inordinately high at PNPS. It is not clear whether an increase in the magnitude of entrainment of winter flounder larvae in 1997 and 1998 is representative of higher egg abundance, naturally high larval abundance (perhaps because of increased egg survival), or concentration of larval density resulting from the contribution of transport via the physical processes of on-shore winds and water currents, or by localized spawning events. Perhaps it is an amalgam of several or all of these factors. Entrainment mortalities of larvae at the levels seen in 1997 and 1998 are of great concern to MDMF. In 1999, the scheduled plant outage resulted in reduced operation of the circulating water pumps during the winter flounder spawning period and, in turn, resulted in substantially lower larval entrainment of winter flounder larvae.

We estimated adult winter flounder population size in the study area by an area swept approach (density extrapolation) using bottom trawl data. Entrainment in 1997 equated to the eventual loss of 14.7% of the estimate of possible adults in the area in 1997, while in 1998 the loss was estimated to have almost doubled at 29.2%. In 1999 (plant outage), the loss represented only 912 adults (0.5% of the possible adults in the area in 1999).

Mark-recapture data were used to address the question of population discreteness. The low number of winter flounder tag returns obtained through the present hampered our work. Despite the low number of tag returns, there is evidence of a fairly high fidelity of the local population.

Atlantic silversides

In 1994, there were two acute incidents of impingement of Atlantic silversides at PNPS: 28-29 November - 5,800 fish and 26-28 December - 6,100 fish. In 1998 it was the dominant species and in 1999 ranked second, typically leading all other species in numbers impinged. No compensatory action has been taken because the silverside is a prolific, annual species with no commercial and only limited recreational value as bait. However, the silverside provides important forage for other piscivorous fish.

Alewife

A relatively high impingement of alewives occurred at PNPS on 8-9 September 1995 when an estimated 13,100 individuals died. The alewife is important as bait for the lobster fishery and for sportfishing, while its roe and flesh are used for human consumption. Employing a special publication of the American Fisheries Society (1992), we assessed the monetary value of this kill to be ca. $5,000.00. The MDMF negotiated with BECo for this sum of money which was granted for habitat rehabilitation (i.e., to help rebuild or repair a river herring fish ladder in the PKDB estuary situated on either the Jones River or Town Brook). Large impingements of alewives have been uncommon in recent years at PNPS, although it appears that the number of river herring had declined in recent years in the nearby Jones River run. Nevertheless, impingement monitoring should be continued at PNPS, so appropriate mitigative measures can be undertaken if warranted.

V. CONCLUSIONS

Rainbow Smelt

1. To compensate for rainbow smelt impingement at PNPS, MDMF formerly stocked smelt eggs into the Jones River but continues to work at enhancing spawning habitat. Restoration has been ongoing for the last six years.
2. After two years of egg stocking (ca. 1.8 million smelt eggs) into the Jones River, this effort was terminated because there has been no good source of eggs for transplantation.
3. Specially-designed egg collecting trays have been placed on the Jones River smelt spawning ground, which has resulted in an increased number of eggs being spawned on ideal substrate for egg survival. This work will continue into 2000.
4. Spawning tributaries have been inspected and cleared of any obstructions to fish passage before anadromous smelt begin their spawning runs. The DMF has helped with the removal of several tree snags from the Jones River and would lend assistance in the future when necessary.
5. In general, we believe our smelt restoration efforts have been successful. We did move numbers of smelt eggs into the Jones River, and smelt have spawned over our collecting trays, with generally higher egg densities obtained on the artificial habitat. On a positive note, the 1998 and 1999 smelt runs were the largest in over a decade. For the first time in years, large numbers of adult smelt were observed on the spawning grounds during the daytime, and egg sets throughout the spawning ground were good.
6. A decline in smelt populations in general has taken place throughout Massachusetts Bay and in Quebec, Canada, as well. Causality for the wide-spread declines is conjectural, although there are obvious environmental concerns, such as storm-water runoff, toxicants, nutrient loading, and sedimentation problems. These alterations degrade water and habitat quality and are likely linked to

reduced smelt production. Future remediation efforts in the Jones River and other local smelt spawning streams should stress water quality issues in the respective watershed. This should be a priority in the future restoration of smelt populations, and could include, for example, watershed runoff treatment and efforts to purchase a "green belt" along a spawning river or stream to prevent development or environmentally detrimental land use.

Winter Flounder

1. The nearby location of winter flounder spawning (retention) grounds, the relatively limited movement patterns of flounder north of Cape Cod, and the geographic bounds of the local population make this species especially sensitive to entrainment and impingement at PNPS, assuming no significant input from populations further away.
2. In late summer, water temperatures in the immediate vicinity of PNPS's thermal discharge can exceed the avoidance temperature (24°C) for winter flounder which would exclude them from this relatively small (~ 4,047 m^2) area of stress.
3. The record 88.8 million winter flounder larvae entrained at PNPS in 1998 equated to an equivalent loss of 77,428 adult winter flounder from the local population. This level of entrainment is of concern to the DMF.
4. In 1999, an estimated 1,353 winter flounder were impinged at PNPS, with the majority being juveniles. Impingement of winter flounder at PNPS as a source of mortality is of lesser importance than entrainment effects.
5. Our recovery rate of tagged winter flounder has been low, being hampered by the incomplete reporting of tagged fish and the seasonal closure of the study area to commercial fishing.
6. Our population estimates of winter flounder in the PNPS study area from stratified density extrapolation improved precision of the estimates, while estimates from mark-recapture models were

hampered by the low tag recapture rates. The magnitude of entrainment impact of PNPS on winter flounder was of concern in 1997 and 1998, and mitigation should be considered at the plant site, along with restoration measures in the essential fish habitat of the surrounding waters.

VI. ACKNOWLEDGEMENTS

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III. B. BENTHIC MONITORING & IMPACT

BENTHIC ALGAL MONITORING
AT THE
PILGRIM NUCLEAR POWER STATION
(QUALITATIVE TRANSECT SURVEY)
January-December 1999

submitted to

ENTERGY Nuclear Generation Company
Environmental Protection Department
Pilgrim Nuclear Power Station
Plymouth, Massachusetts 02360

prepared by

ENSR
89 Water Street
Woods Hole, MA 02543
(508) 457-7900

1 March 2000

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APPENDIX

EXECUTIVE SUMMARY

This report presents results of the qualitative survey of benthic algae performed in 1999 in the area of thermal effluent from the Pilgrim Nuclear Power Station (PNPS) and summarizes the impact of the PNPS on algal distributions near the discharge canal. The Pilgrim Administrative-Technical Committee (PATC) Benthic Subcommittee requested that one field survey be performed in 1999. This field study was conducted in October and included a transect survey designed to map algal cover in the area of water outflow. This investigation constitutes the most recent phase of long-term monitoring of thermal effluent effects on the benthic algal community within and just offshore of the PNPS discharge canal. Starting in 1996, data from each seasonal survey was compared to the historical baseline (maximum measurements recorded prior to the 1996 survey year) for that season. Measurements greater than 15% above the historical baseline triggered a report to the (PATC) Benthic Subcommittee for review.

The qualitative transect studies of the *Chondrus crispus* (Irish moss) community indicate that from October 1995 through March 1998 (with the exception of December 1996) the sizes of the denuded and totally affected areas in the thermal plume were larger for each season surveyed than in earlier surveys when the power plant was in full or nearly full operation (1983, 1985, 1989-1995). In 1999 the denuded and totally affected areas measured in October were each slightly smaller (-6%) than the historical fall maxima.

The annual maximum dependable capacity (MDC) factor at PNPS for 1999 was 76.2%, a typical value for years with a one to two month power outage. In comparison to prior years, the *Chondrus* denuded and totally affected zones in October 1999 were considerably less than in October 1996 and 1998 when the annual MDC was over 90.0% and approximately the same as those measured in October 1995 when the annual MDC was 76.4%. An anomaly occurred in October 1997 when the annual MDC was similar (73.4%) to those found in 1995 and 1999, but the totally affected area was nearly twice as large as those measured in either 1995 or 1999. The 1999 survey reinforces the hypothesis that the dredging operation that took place during the summer of 1997 had a noticeable impact on the affected *Chondrus* zones, but that both the denuded and totally affected areas have rebounded from the anomalously large affected areas measured in 1997.

1.0 INTRODUCTION

The presence of hundreds of square meters of seafloor where the regionally abundant red alga, *Chondrus crispus*, is unnaturally absent, even in the presence of suitable substrata, provides evidence that the PNPS nearfield discharge area is affected by elevated temperature and high current velocity, causing bottom scouring, of the cooling water outflow. To study this acutely impacted area, a qualitative diver transect study was designed to map the effects of the thermal effluent on nearby algal distributions. SCUBA divers perform seasonal transect surveys to measure the extent of denudation and other reductions in size or density of the algal flora, particularly *Chondrus crispus*, in the nearfield discharge area.

This report is the latest in a series presenting results of long-term (26 yr) benthic studies at (PNPS) designed to monitor the effects of the thermal effluent. The 1999 monitoring program consisted of one qualitative underwater survey of algal cover in the nearfield thermal plume of the effluent within and beyond the discharge canal (Figure 1), performed in early October. Currently, no quantitative assessments of benthic flora or fauna are being made. Beginning in 1996, reports have been prepared after each seasonal survey to compare the collected data with an historical baseline that tabulates, for each parameter, the maximal sizes measured prior to the 1996 survey season (1983 through February 1996). This Semi-Annual Report includes one seasonal (autumn) qualitative observation, tabular and graphical comparison of this data with the historical baseline, and a summary of the potential impact on algal distributions caused by PNPS. Work was performed under Boston Edison Co. (BECo) Purchase Order LSP010919 in accordance with requirements of the PNPS NPDES Permit No. MA 0003557.

PNPS is a base-load, nuclear-powered electrical generating unit designed to produce 670 megawatts of electrical energy when operating at full capacity. The condenser is cooled by water withdrawn from Cape Cod Bay and subsequently returned to the Bay via an open discharge canal designed to dissipate heat through rapid mixing and dilution of the outflowing water. Two circulating water pumps produce a maximum water flow rate of approximately 20 $m^3\ s^{-1}$. The PNPS cooling system may affect the benthic community in three ways: 1) by warming ambient waters ($\Delta T = 18°C$), 2) through chemical discharge (mainly Cl_2), and 3) by seabed scouring from the rapid (~ 2.1 mps at low tide) flow velocity. High temperature and chemical discharges may stress the algal community so that species composition and community structure change, with the extent of change also influenced by seasonal and local oceanographic conditions. A high current velocity directly affects the benthos by actually removing benthic organisms and inhibiting settlement and recolonization. Where there is intense bottom scouring, rock surfaces may support fewer and smaller macroscopic organisms than normally would be present.

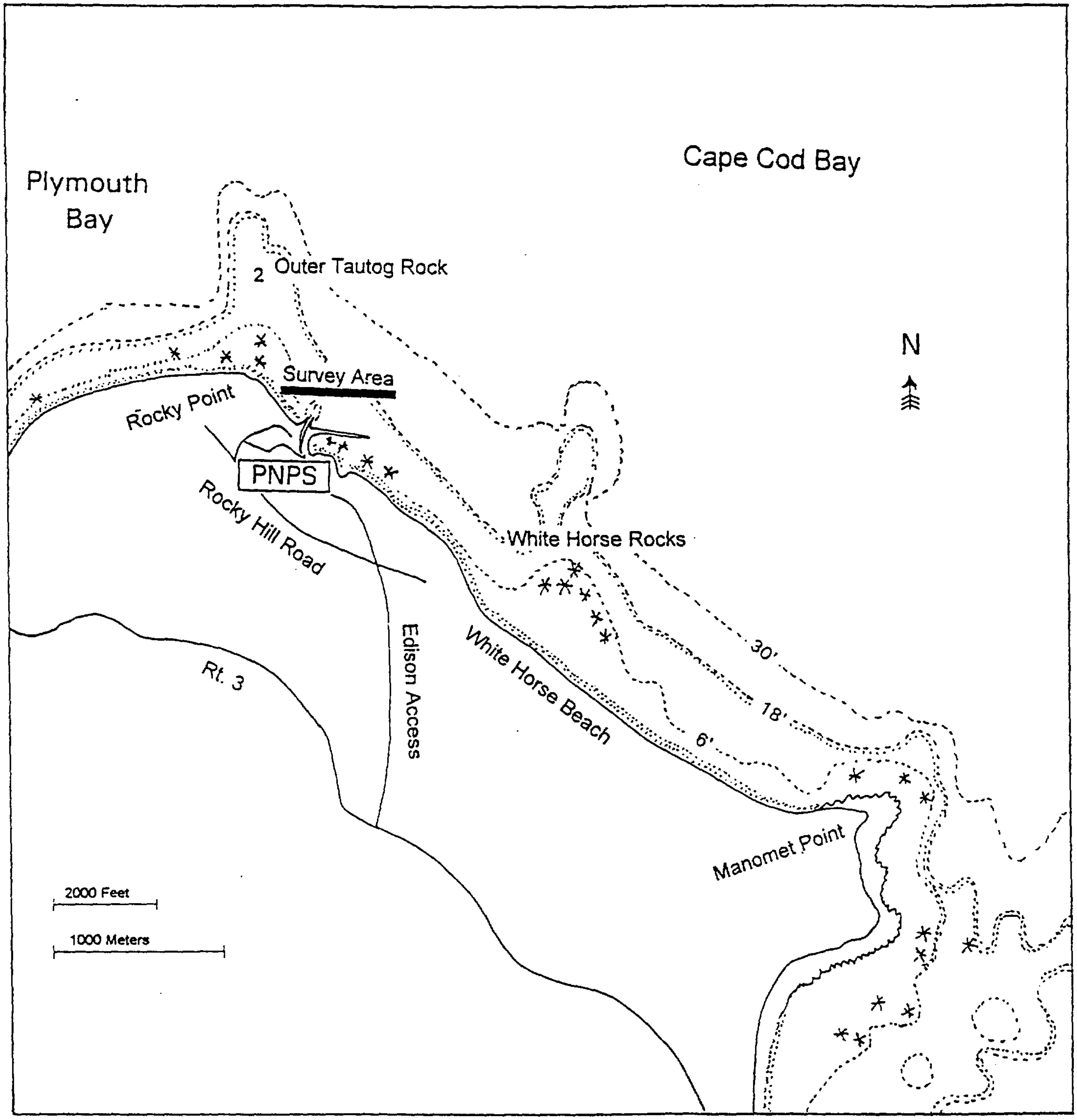

Figure 1. Location of Pilgrim Nuclear Power Station Qualitative Algal Survey Area.

2.0 FIELD STUDIES

2.1 METHODS

The qualitative algal survey is performed by SCUBA divers in the same location and with the same techniques that have been used since the present monitoring program began, approximately 18 years ago. The effluent area is surveyed by two or three SCUBA-equipped biologists operating from a small boat. For the 1999 survey, the divers were able to launch their boat from the fishermen's launching site within the PNPS facility. For the qualitative transect survey, underwater visual observations are made along the axis of the discharge canal. A line is stretched across the mouth of the discharge canal (Figure 2). A weighted central transect line (CTL), marked at 10-m intervals, is then attached to the center of this line and deployed along the central axis of the canal to a distance of 100 m offshore, where it is anchored. Using a compass, divers extend a measuring line at least 45-m long and marked at 1-m intervals, perpendicular to the CTL at each 10-m mark. A diver swims along this third line, recording changes in algal cover from the CTL through the denuded, sparse, and stunted *Chondrus* areas, until the algal cover looks normal. A large boulder, nearly exposed at mean low water, is used as a landmark by dive teams and serves as a visual fix for proper alignment of the CTL. To ensure consistency among surveys, the divers make sure that the boulder is always located at 65 m along and just to the north of the CTL.

The terminology established by Taxon (1982) and followed in subsequent years uses the general abundance and growth morphology of *Chondrus crispus* to distinguish between "denuded" and "stunted" zones. The **denuded zone** is the area in which *Chondrus* occurs sparingly and only as stunted plants restricted to the sides and crevices of rocks. In this area, *Chondrus* is found on the upper surfaces of rocks only where the microtopography of the rock surfaces creates small protected areas. In the **stunted zone,** *Chondrus* in found on the upper surfaces of rocks but is noticeably inferior in height, density, and frond development compared to plants growing in unaffected areas. In 1991 the divers began to discriminate between a stunted zone and a "sparse" zone. The **sparse zone** is an area with normal-looking *Chondrus* plants occurring only at very low densities. The **control zone** begins at the point where *Chondrus* height and density are fully developed. The dive team must keep in mind while taking measurements that the shallow depths northwest of the discharge canal hamper normal *Chondrus* growth. In addition to evaluating extent and condition of algal cover, the divers record any unusual recent events in the area such as the occurrence of unusually strong storms, and note the location of any distinctive algal or faunal associations.

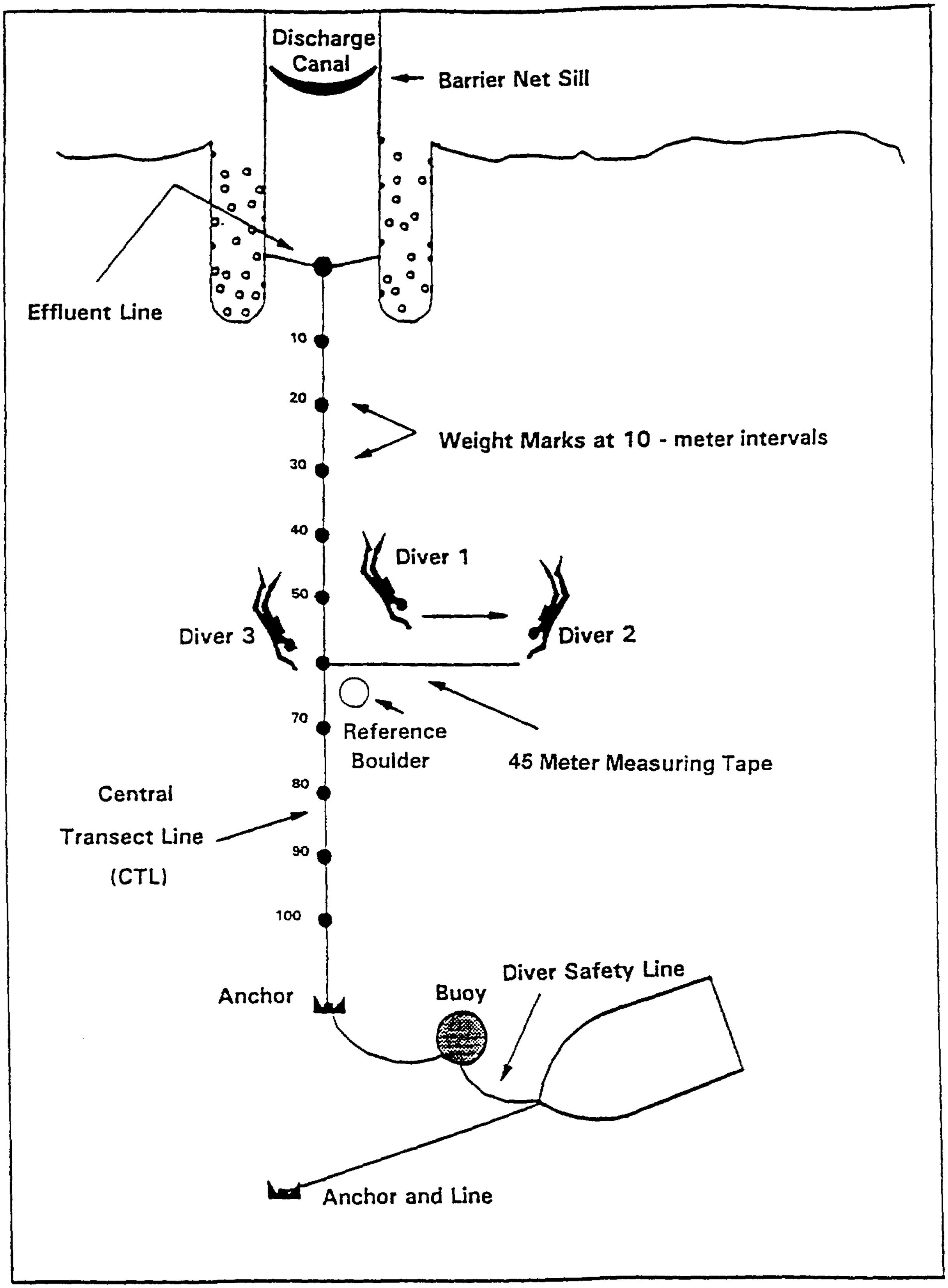

Figure 2. Design of the Qualitative Transect Survey.

Starting with the April 1996 survey, progress reports have been submitted to BECo (1996-1998) and ENTERGY (1999) following each monitoring survey. These reports tabulate areal results of each SCUBA survey and compare them to previously measured maximal sizes of *Chondrus* denuded and totally affected zones, as well as other parameters, for that season. Particular attention is paid to changes in the sizes of impacted regions that exceed earlier results (prior to 1996) by more than 15%, in which case a written report is submitted to the PATC Benthic Subcommittee. Table 1 and Figure 3 summarize these comparisons for 1999. The quality control (QC) protocol for the 1999 benthic algal monitoring program is included as Appendix A.

Table 1. Qualitative Algal Survey Data for 1999 Compared to Historical Baseline Data.

Measurement	Fall 1999	Historical Baseline	Percent Change from Baseline
Total Denuded Area	1925 m^2	2043 m^2	-6%
Total Affected Area	2204 m^2	2348 m^2	-6%
Maximal Distance of Affected Area from Discharge Canal	105 m	100 m	+5%
Maximal Width of Affected Area	37 m	42 m	-12%

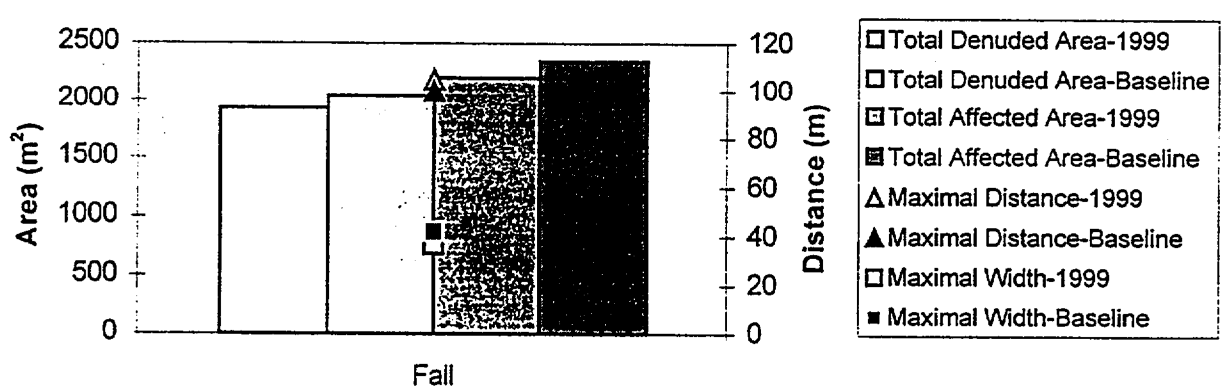

Figure 3. Qualitative Algal Survey Data for 1999 Compared to Historical Baseline Data

2.2 RESULTS

Qualitative transect surveys of acute nearfield impact zones began in January 1980 and were conducted quarterly from 1983 through 1997. This frequency was reduced to three surveys in 1998 and to one survey for 1999. The October 1999 survey brings the total number of surveys conducted to 73. Results of surveys conducted from January 1980 to June 1983 were reviewed in Semi-Annual Report 22 to BECo (BECo, 1983). A summary of surveys conducted between 1983 and 1998, including a review of the three performed in 1998, was presented in Semi-Annual Report No. 53 (BECo, 1999). The present report presents detailed results of the October 1999 survey and discusses long-term trends.

Figure 4 shows the results of the 1999 transect survey. In the figure, the denuded zone is essentially devoid of *Chondrus crispus*, while sparse zones have normal looking *Chondrus* that is sparsely distributed and stunted zones contain smaller than normal *Chondrus* plants. The landmark boulder (at 65-m) is plotted as are positions of other common algal and faunal species observed.

2.2.1 OCTOBER 1999 TRANSECT SURVEY

For most parameters, the measurements made during the October 1, 1999 survey were less than the 15% target limits (Table 1). The area of the denuded zone (1925 m^2) was much smaller (22%) than in October 1998 and 6% smaller than the October 1995 baseline. The pattern of denudation was that typically seen, with most of the affected area (more than two-thirds) north of the CTL.

The areas of the sparse and stunted *Chondrus* zones totaled 280 m^2 in October, smaller than in the fall of 1998 but approximately the same as seen in the fall 1995 (305 m^2). The total affected area in October was 2204 m^2, 29% smaller than measured in October 1998 and 6% smaller than the historical baseline (2348 m^2) established in October 1995. The totally affected area extended out along the CTL to 105 m (5% more than the baseline); the maximal width of the affected zone was 37 m at the 80-m mark on the CTL (12% smaller than the baseline). Besides *Chondrus*, other macroalgae noted were *Enteropmorpha* spp. and *Gracilaria* spp. throughout the length of the CTL, *Ulva lactuca* from the 80-m to 90 mark on the CTL, and a small amount of *Corallina*. All of the *Chondrus* identified as normal was epiphytized by various invertebrates and microalgae, suggesting that these plants were old, perhaps having grown to the observed size several months before. No *Chondrus* along the transect was actively growing, with growth expected to resume as the water temperature drops below 50°F.

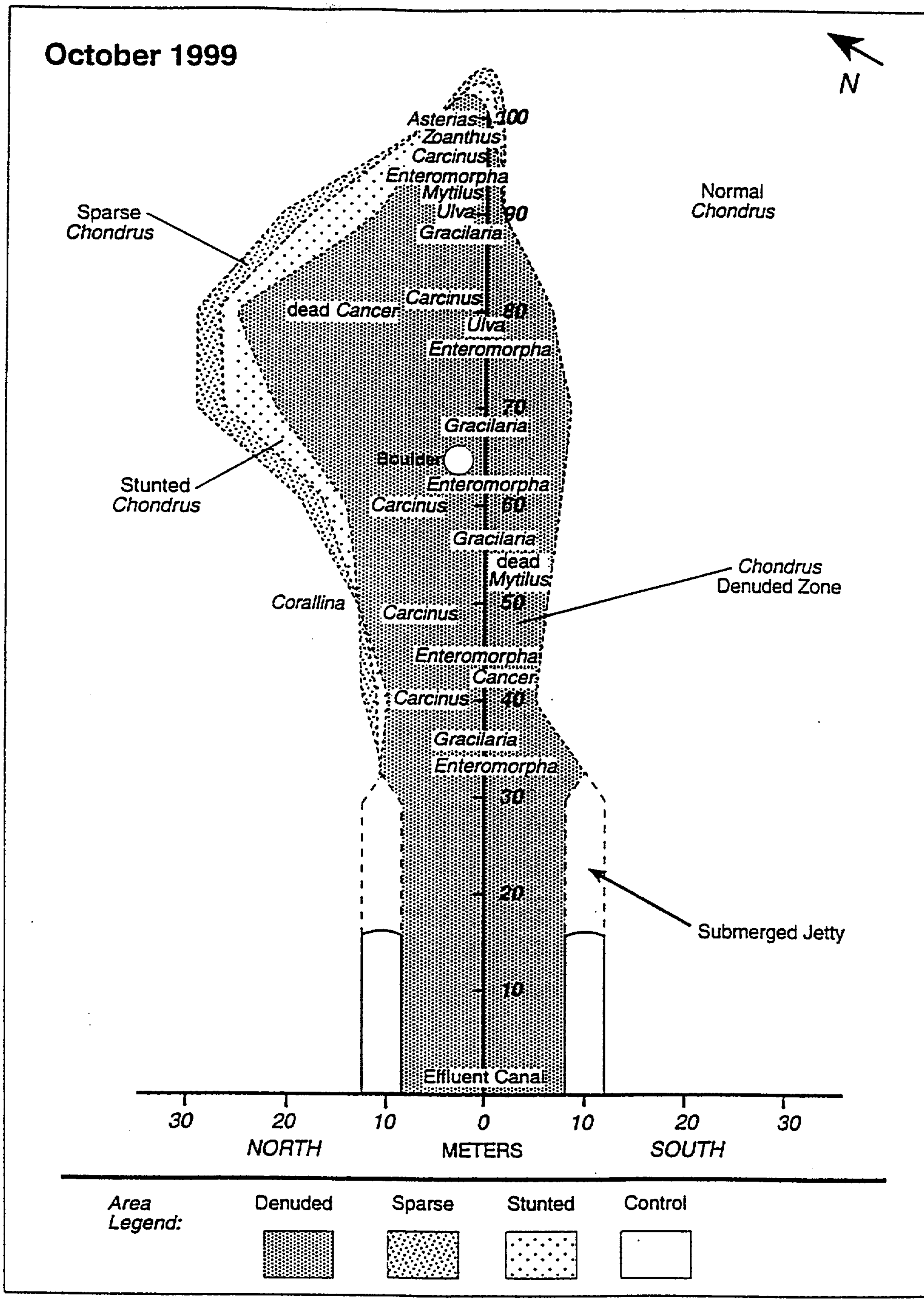

Figure 4. **Denuded, Sparse, and Stunted *Chondrus* Zones Observed in October 1999.**

The invertebrate community seen was quite different from that observed during prior autumn surveys. Historically, the rock surfaces are covered with either juvenile *Mytilus* or adult barnacles. On October 1, very few mussels or barnacles were seen. Those mussels present were located between rocks. All individuals near the mouth of the effluent canal were dead and only a small number were alive near the 100-m mark. All of the mussel shells were broken suggesting predation. The large number (30-40/m^2) of adult green crabs (*Carcinus maenus*) present, some of whom were observed preying upon mussels and barnacles, probably accounts for the low density of mussels and barnacles. Adult rock crabs (*Cancer* spp.) are usually seen in October, albeit in small numbers due to their cryptic daytime habit. During the current survey, the divers observed 100% mortality of these crabs along the south side of the CTL, and only one living individual to the north. In all, about 20 newly dead (corpses appeared fresh and intact) crabs were seen. Other invertebrates observed included: starfish and a colonial encrusting organism, *Zoanthus* spp. No fish or kelp were seen.

2.3 DISCUSSION

The configuration of the *Chondrus crispus* denuded zone that can extend seaward even farther than 100 m beyond the discharge canal is readily apparent to SCUBA divers and easily mapped from the qualitative transect survey. Stunted and sparse zones are sometimes less obvious, but the sparse zones observed in 1999 were delineated without difficulty. In contrast to many earlier fall surveys, there was no evidence that a mussel "mat" had occurred earlier in the year.

For the October 1999 survey (annual 1999 MDC = 76.2%), the areas of the denuded and total affected zones were smaller than in the falls of 1996 and 1998, when the annual MDC was much higher (>90%). The *Chondrus* affected areas in 1999 were approximately the same as those measured in October 1995, chosen as the historical baseline, when the annual MDC (76.4%) was nearly identical. The continued decrease in the October 1999 areal measurements when compared to those delineated in the same seasons in 1997 and 1998 may reflect additional recovery from the extra stress placed on the system from the summer-time dredging operation that took place in the plant intake area in 1997.

3.0 HISTORICAL IMPACT OF EFFLUENT DISCHARGE AT PNPS ON ALGAL DISTRIBUTION

3.1 BACKGROUND

Historically, operational conditions at the PNPS have provided opportunities to assess long-term trends associated with impacts on the benthic community. Plant operations have included consecutive years of high operation as well as times when there were complete shutdowns, sometimes for prolonged periods. The longest outage in the history of the plant began in April 1986 and continued until March 1989. During that period the benthic community associated with the effluent canal and nearby areas immediately offshore experienced reduced current velocity as the use of circulating pumps was restricted to one or none (Figure 8). In addition, the discharge water remained at ambient temperature. As a consequence, the benthic community normally affected by those effluent parameters recovered, so that by 1988 there was essentially no difference between the control stations and the areas near the discharge canal.

After the power plant resumed electrical generation at full operating capacity in the summer of 1989, the impact on the benthic environment eventually returned to the conditions seen prior to the outage. Quantitative faunal and algal monitoring studies and qualitative transect surveys were conducted through 1991. In 1992, community studies of the benthic algae and fauna were discontinued. From 1992 through 1997, the monitoring program consisted of quarterly qualitative surveys of the discharge area. In 1998, three seasonal (spring, summer, and fall) qualitative surveys were performed. In 1999, one survey performed in early October was conducted.

The annual maximum dependable capacity (MDC) factor at PNPS for 1999 was 76.2%, a typical value for years (e.g. 1993, 1995, 1997) with a one to two month power outage. Figure 5 shows the monthly dependable capacity (MDC) factor and circulating water pump operation of PNPS since 1983. The percent MDC is a measure of reactor output and can be used to estimate thermal loading to the marine environment. A maximum MDC value of 100% approximates, with some seasonal variation, the greatest permitted increase (18°CΔT) in ambient temperature for effluent water discharged to Cape Cod Bay. In 1999, the monthly dependable capacity factor was greater than 93.0% for 6 months, between 71 and 87% for 4 months, and low (0-17%) for 2 months.

3.2 QUALITATIVE TRANSECT SURVEYS: 1983-1999

Results of the qualitative transect surveys from 1983 through 1999 are summarized in Figure 6. The total acute impacted area (denuded, sparse, and stunted), the area of the denuded zone only, and the monthly PNPS capacity factor (MDC) are plotted. The difference between the denuded and total acute impact zones represents the area of the sparse and stunted zones.

A lag in recovery time in the acute impact zone during and following the 1984 PNPS power outage was reported in Semi-Annual Report No. 27 (BECo, 1986). Evidence of this slow recovery included a decrease in the area of the total acute impact zone that began in mid-1984 (5 months after the cessation of power plant operations) and continued through mid-1985. Between December 1984 and December 1985, the total affected area was the smallest recorded between 1983 and 1986, indicating a delay in recovery in response to the absence of thermal discharge and reduced circulating water pump operation in 1984. This delay also held true when the situation was reversed, so that the size of the acute impact zone began to increase only 6 to 9 months (September to December 1985) after the resumption of thermal effluent discharge and normal circulating water pump operation. These results confirmed a delay of 6-9 months between the causal factors (cessation or resumption of thermal effluent discharge and normal pump operation) and associated responses (decrease or increase in size of the acute impact zone). In 1987, in response to the 1986-1989 outage, increased recolonization of the denuded and stunted zones by *Chondrus* made zone boundaries difficult to distinguish (no areal differences could be discerned from September 1987 through June 1989). As in summer 1984, the large size reduction of the denuded zone between December 1986 and June 1987 was primarily the result of the shutdown of the circulating water pumps in late February 1987 that continued into the summer (BECo, 1988). Apparently, water current scouring is a greater stress to algal colonization than elevated water temperature. Generally, it is believed that scouring denudes the substratum, whereas elevated temperature results in stunted growth (Bridges and Anderson, 1984).

In 1988, low circulating water pump activity caused few scouring effects. The 1988 transect surveys showed such an increase in recolonization of formerly denuded and stunted zones by *Chondrus*, because of the continuing outage, that divers could not detect zonal boundaries or make area measurements. In March and June 1989, divers were still unable to detect boundaries of denuded or stunted zones (BECo, 1990). In September and December 1989, presumably in response to increased PNPS operations with resultant thermal effects and scouring of the acute impact zone, boundaries began to be redefined and area measurements were made of the total impact zone.

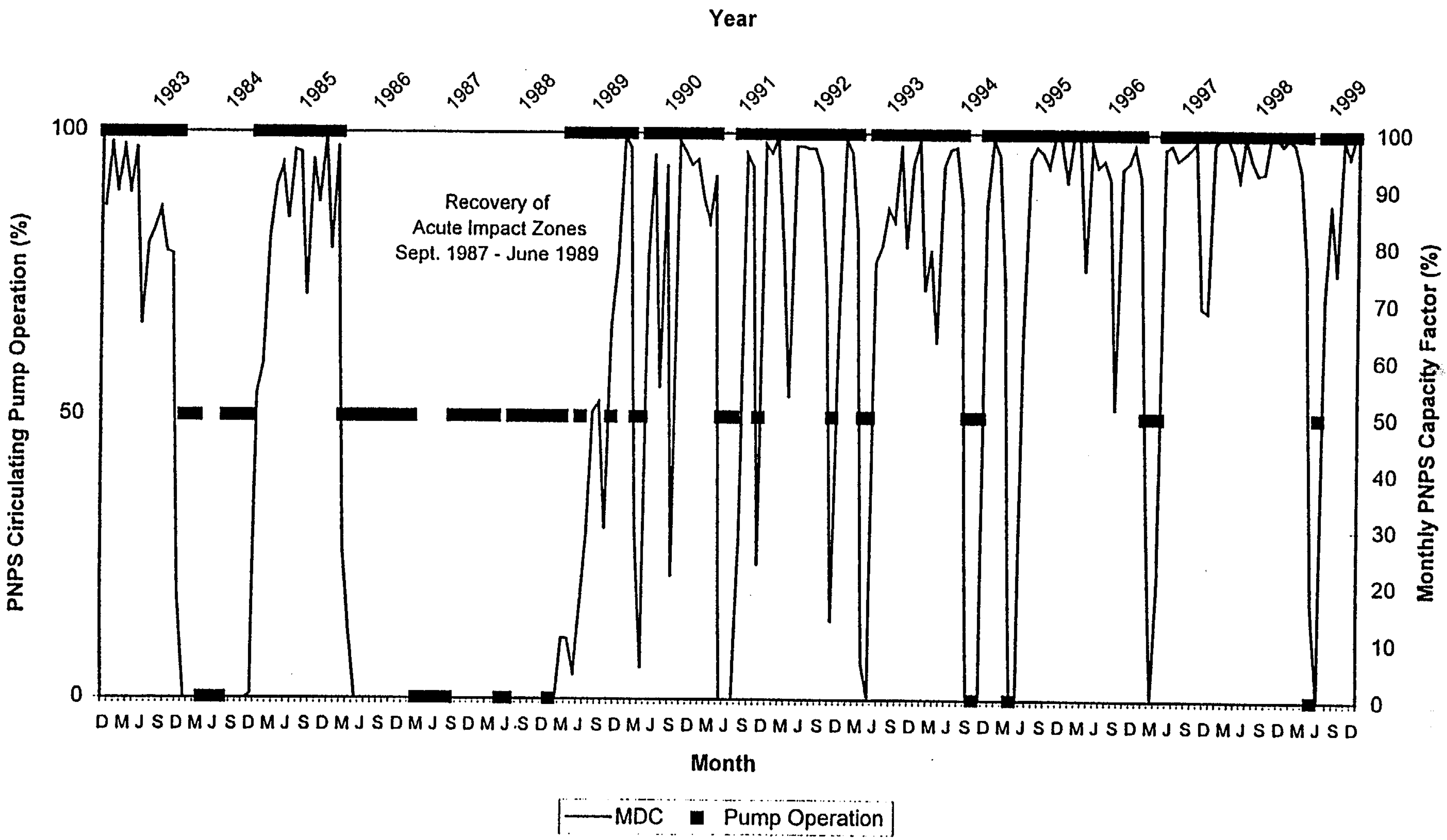

Figure 5. **Monthly PNPS Capacity Factor (solid lines) and Circulating Pump Activity (black bars at 100% = 2 pumps; at 50% = 1 pump; at 0% = 0 pumps) Plotted for the Period 1983 Through December 1999.**

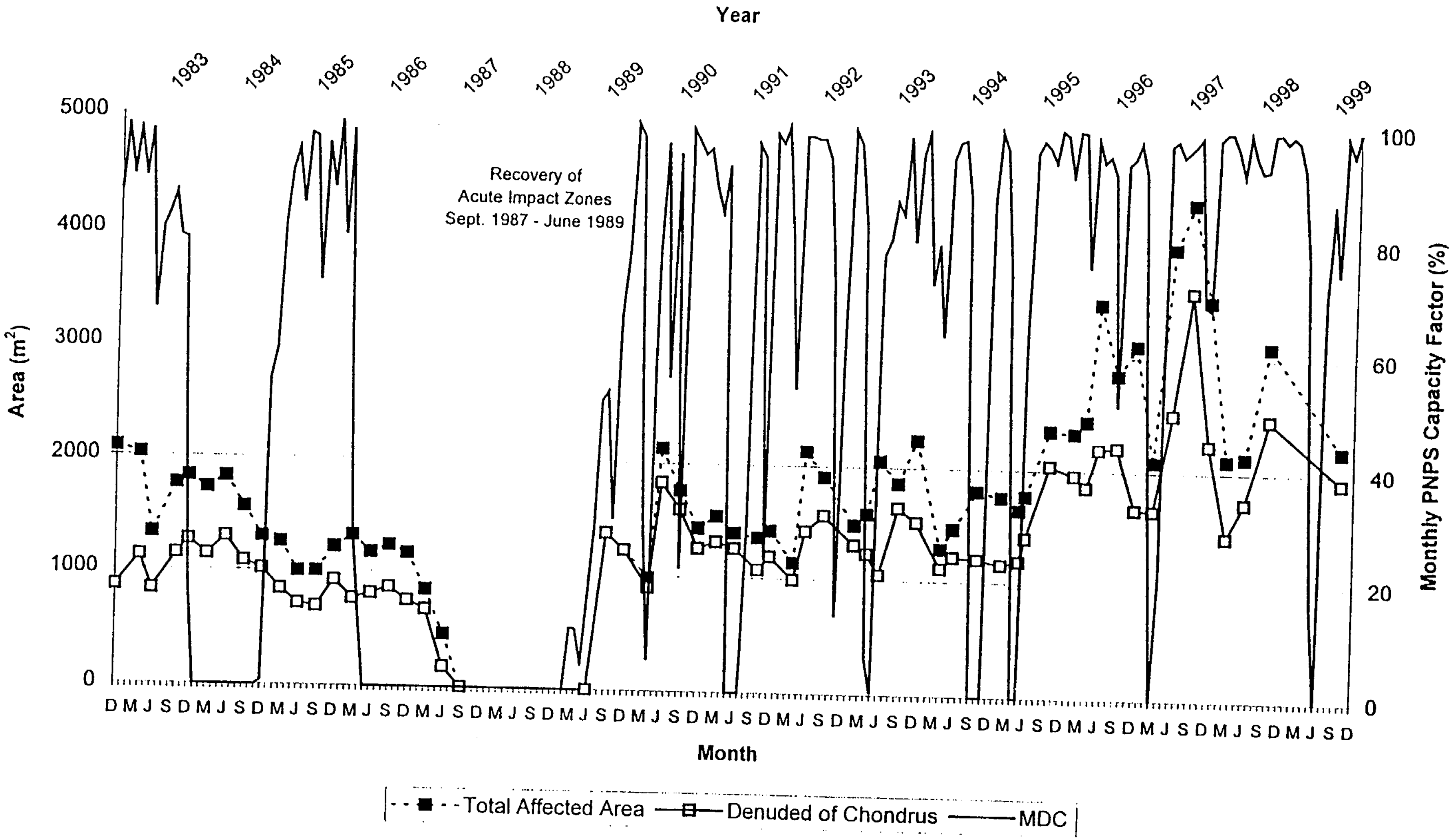

Figure 6. **Area of the Denuded and Totally Affected Zones in the Vicinity of the PNPS Effluent Canal Plotted with the Monthly PNPS Capacity Factor (MDC) for the Period 1983 Through 1999. No area measurements were made from September 1987 through June 1989 because definitive demarcations of denuded and stunted zones were absent.**

During 1990, boundaries between the stunted and denuded zones became even more clearly defined and areal measurements of both zones were made. The denuded and total impact zones in June 1990 were the largest measured since 1983 (BECo, 1991). The dramatic increase in total affected area that occurred between April and June 1990 had not been seen before. The typical pattern seen prior to 1990 was that during spring, with warmer temperatures and increased sunlight, algal growth flourishes, and the impact area declines even in years when the power plant is operating at high capacity. The pattern in 1990 appeared anomalous until, more recently, a correlation was made between the appearance of enormous numbers of juvenile mussels and the occurrence of large denuded and total affected zones. The divers noted remarkable numbers of juvenile mussels during the June 1990 dive. Thus, it would appear that the large affected zones result, at least partly, from damage suffered by the *Chondrus* plants due to the massive settlement of mussels.

In 1991, the boundaries of the acute impact zone remained well-defined, except that in June there was no true stunted zone but only an area described by the divers as "sparse", that is, where the algal plants grew normally but were thinly distributed. From March to June, the total affected area and the *Chondrus* denuded zone decreased in area, a return to the typical pattern seen before 1990 (BECo, 1992). This decrease in area continued through the October survey, perhaps aided by the power plant outage from May into August. There was a slight increase in the affected area in December.

During 1992, the divers were unable to discern a *Chondrus* stunted region. Except for June, they noted zones containing normal but sparsely distributed *Chondrus* plants. An enormous set of mussels that had reached 0.5 cm in length by June totally obliterated the boundary between the denuded and sparse areas. Parallel to results seen in 1990, the areas of the denuded and total acute impact zones in June 1992 were larger than any seen (except for 1990) since 1983, and the dramatic increase in total affected area that occurred between April and June 1990 occurred once again in 1992. Thus, the pattern seen in 1990 can no longer be considered anomalous but may be related to oceanographic conditions that lead to a large settlement of mussel larvae and consequent damage to *Chondrus* plants (BECo, 1993).

In 1993, the June mussel set that hampers *Chondrus* growth was not as dense as those that occurred in 1990 and 1992, so that the denuded zone was smaller in June than in April, the opposite of the situation in 1990 and 1992 (BECo, 1994). The area of the denuded zone in September was slightly larger than it had been in September of 1990 and 1992, but the denuded zone in December was much larger than in previous years. In addition, the total affected area in December was the largest seen since 1983, rivaling the areas measured in the summers of 1990 and 1992. This may be due both to the very early winter date (Dec. 2) of the survey and to damage from heavy infestation by the encrusting bryozoan, *Membranipora membranacea.*

In 1994, the denuded and total affected *Chondrus* areas in all four seasons were similar in size to those found during prior surveys (since 1989) at times of full or nearly full power plant operation (BECo, 1995). The dense mussel settlement seen in June obscured the boundary between the denuded and sparse/stunted regions. Damage caused by the mussels to the *Chondrus* plants contributed to the enlargement of both *Chondrus* zones between the April and June surveys. The three-month fall power plant outage (September through November) appeared to have had no effect on the size of either the denuded or total affected *Chondrus* zones.

In 1995, the sizes of the denuded and total affected *Chondrus* areas were within the ranges seen in earlier surveys only for the early May and late June surveys (BECo, 1996). The impacted areas in October 1995 and February 1996 were much larger than those measured during any earlier fall and winter surveys and most closely approximated the impacted areas seen in September and December 1993. The two-month (April/May) spring power outage appeared to have no effect on the size of the *Chondrus* affected areas seen in May or June. However, the high plant operating capacity in effect from June 1995 through February 1996, in conjunction with a high mussel set in June, may have contributed to the largest fall and winter denuded and totally affected *Chondrus* zones seen since the current monitoring program began in 1983.

In 1996, the sizes of the denuded and totally affected *Chondrus* areas continued to increase over the historical baseline measurements (1983 through February 1996) for the first three surveys. In December, the denuded zone declined in size to less than the winter historical baseline but was still the second largest ever observed in winter (BECo, 1997). The large *Chondrus* denuded and totally affected zones seen in each survey since October 1995 may be due to a combination of the high plant capacity that was in effect for the 18 months starting in July 1995 (mean = 92.6%), high summer water temperatures, and extremely dense settlement by mussel larvae in late spring that totally covered, possibly damaging, the algal plants.

In 1997, the sizes of the denuded and totally affected *Chondrus* zones were again larger than historical baseline measurements (BECo, 1998). In March 1997, the impacted areas were the second largest ever measured in spring. For the remaining three seasons, the areas of the denuded and totally affected zones were the largest ever seen for the corresponding season. The sizes of the denuded and totally affected zones in 1997 were extraordinarily large, larger than in 1996 for three surveys, and appeared not to track the reduction in the annual plant capacity factor from 90.5% in 1996 to 73.4% in 1997 that resulted from a two-month spring power outage. Turbidity from the dredging operation that took place from mid-June until the end of August, in conjunction with dense settlement by juvenile mussels that occurred sometime between March 28 and June 22, high summer water temperatures, and a moderately high 1997 power plant capacity, probably caused many *Chondrus* plants to die back to their holdfasts, yielding the very large affected *Chondrus* zones.

In 1998, some recovery apparently took place in the outfall area compared to the very large denuded and totally affected *Chondrus* zones seen in the summer, fall, and winter of 1997. The areal measurements taken in March were somewhat higher than the historical maxima, but those obtained in June were similar to those seen in previous surveys when the plant was in full or nearly full operation. The sizes of the *Chondrus* denuded and affected zones did increase dramatically between the June and October surveys, probably as a consequence of warm summer water temperatures combined with the extremely high plant capacity (97.1%) in effect in 1998, the highest seen in the history of plant operations (BECo, 1999).

In 1999, only one survey (October) was performed. Results of autumn surveys taken from 1983 through 1999 are shown in Figure 7. In comparison to earlier fall surveys, apparently additional recovery from the anomalously large affected areas seen in 1997, possibly associated with dredging of the intake area in summer 1997, took place in the outfall area. The 1999 areal measurements showed the denuded and totally affected *Chondrus* zones to be once again approximately the same size as seen in those years with similar power plant capacity (with the exception of 1997). Specifically, the affected areas are similar in size when the MDC factors are similar (1995 and 1999). As might be expected, the affected areas were larger in 1996 and 1998 when the MDC factor was above 90%. In fact, from 1989 through 1999 (except for October 1997) the totally affected areas shown on Figure 7 track the annual MDC (see star symbols on figure 7) fairly well.

Areal Measurements taken in Autumn
(September/October)

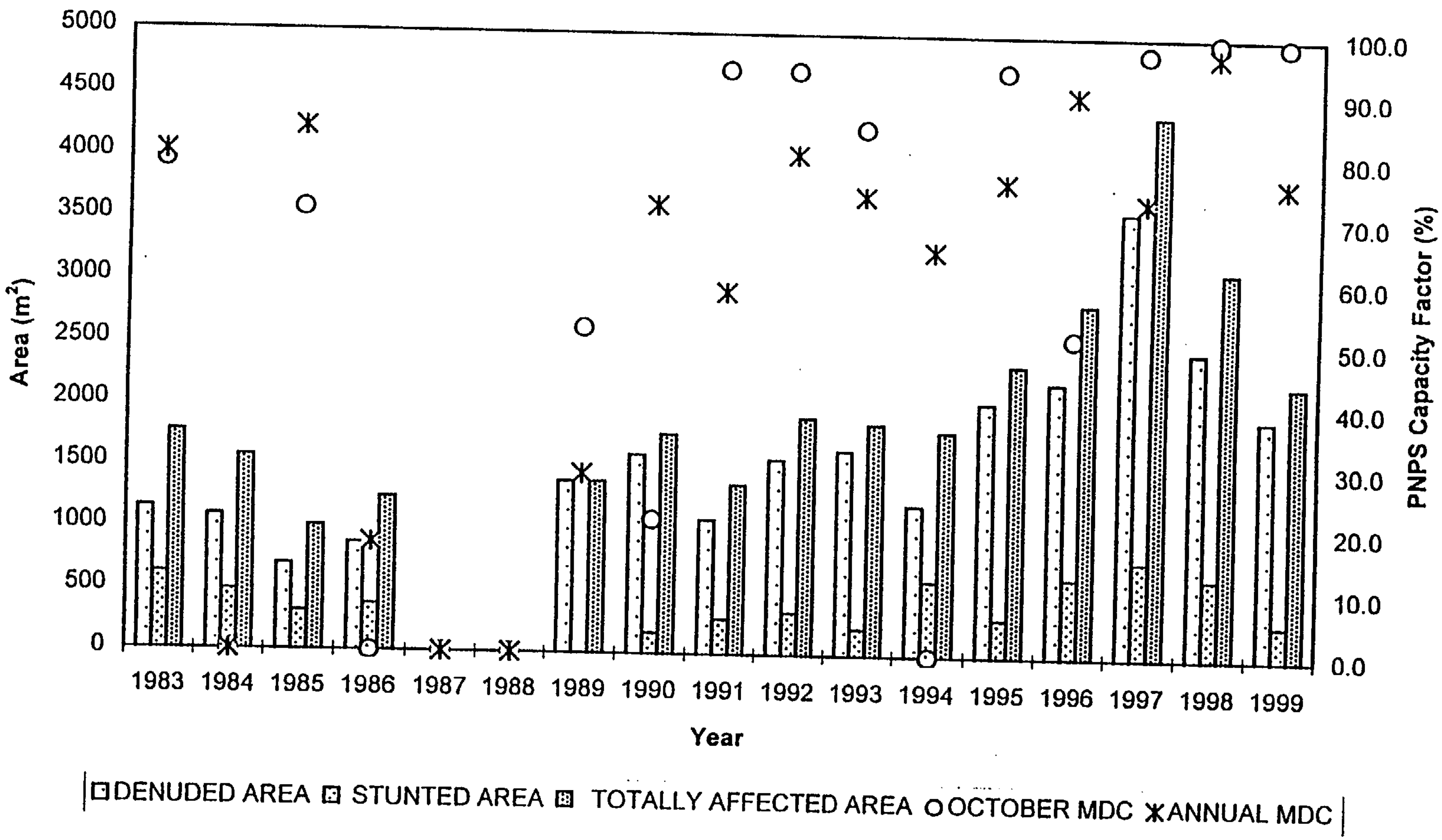

Figure 7. **Area of the Denuded and Totally Affected Zones Measured in Autumn (September or October) in the Vicinity of the PNPS Effluent Canal Plotted with the October and Annual PNPS Capacity Factor (MDC) for the Period 1983 Through 1999. No areal measurements were made from September 1987 through June 1989 because definitive demarcations of denuded and stunted zones were absent.**

4.0 CONCLUSIONS

- The *Chondrus* denuded and totally affected zones measured during the October 1999 surveys were within the range seen in prior surveys when the plant was in full or nearly full operation (with the exception of October 1997). Most parameter values were less than historical baseline values.

- The October 1999 *Chondrus* denuded and totally affected zones were less than measured in October 1996 or October 1998, years when the PNPS annual capacity factor was much higher (>90%) than in 1999.

- The denuded and totally affected *Chondrus* areas of the acutely impacted region off PNPS for the 1999 October survey were approximately the same as seen in the 1995 fall survey, when the PNPS annual capacity factor was nearly identical (76%). The 1995 October survey has been used for comparative purposes since 1996, when it was chosen as the historical autumn baseline due to having the largest *Chondrus* affected area measured prior to the 1996 survey season.

- The 1999 survey reinforces the hypothesis that the dredging operation that took place during the summer of 1997 had a noticeable impact on the affected *Chondrus* zones but that both the denuded and totally affected areas have rebounded from the anomalously large affected areas seen in 1997.

- From 1989 through 1999 (except for October 1997) the sizes of the denuded and totally affected *Chondrus* zones track the annual PNPS maximum dependable capacity (MDC) factor fairly closely.

- There was no evidence from the October survey that there had been a large settlement of mussels earlier in the year.

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APPENDIX A

Quality Control (QC) Protocol for Qualitative Transect Surveys at PNPS Outfall Area

1 Field Operation Planning

Field equipment is organized by the scientist in charge of dive operations; for 1999, the chief diver will be Mr. Erich Horgan of the Woods Hole Oceanographic Institution. Mr. Horgan has been a diver or chief diver on four quarterly surveys at the PNPS outfall site since April 1996. The survey equipment includes a boat and associated safety equipment; anchor and line; buoy and diver safety line; SCUBA gear, including a collecting bag; 100-ft kevlar line to be deployed across the mouth of the discharge canal; grapnel to aid in tying off the kevlar line to jetty boulders; the weighted 100-m central transect line (CTL), marked at 10-m intervals; two 30-m measuring tapes; compass; clipboard; data sheets on plasticized paper; two #1 pencils.

Every attempt will be made to perform the one dive between mid-September and mid-October as scheduled. Windows of opportunity, considering times of high tide (less current for the divers to contend with) and other commitments for both boats and personnel, will be blocked out in advance. Enough leeway will be planned to allow some flexibility for bad weather days.

2 Pre- and Post-dive Briefings

The chief diver and ENSR data manager, Isabelle Williams, will hold a pre- and post-dive briefing. The pre-dive briefing (may be made by telephone) will be the opportunity for determining the dive schedule, for reviewing data collection, and for informing the dive team whether or not any additional observations are requested. At this time, emphasis will be placed on the importance of the divers exploring the limits, and defining them, of the entire affected area so that a comprehensive survey map can be produced. The post-dive briefing (in person) will give the chief diver the opportunity to tell the data manager his immediate impressions about the region surveyed and whether any problems were encountered that need to be corrected.

3 Data Collection

A diver swimming perpendicularly away from the CTL, along the measuring line, records the distance away from the CTL line that changes in algal cover occur, from denuded to sparse and/or stunted *Chondrus* areas, and from sparse and/or stunted *Chondrus* to normal-looking *Chondrus*. Positions of other algal species, especially *Gracilaria*, a warm-water indicator, and kelp (*Laminaria*), a cold water indicator, are noted. Positions of animals, including mussels, starfish, crabs, and fish, and any unusual activities are also indicated.

For 1999, detailed observations will be made of *Chondrus*, including notes on robustness, color, occurrence of epiphytes, and qualitative descriptions of density and height. The divers will look for the presence of *Phyllophora*, the second dominant algal species in this community, throughout the survey area; if necessary, they will collect an algal sample from the normal *Chondrus* zone for examination in the laboratory. Particular attention will be paid to the boundaries of the high-density mussel array that may persist from the spring or summer settlement.

A sample blank data sheet is shown. A separate sheet is used for the north and south sides of the CTL. As the diver swims away from the CTL, distances and notes are recorded on the data sheet from left to right. For ease in working in an underwater environment algal cover is coded as indicated on the data sheet: 1 - denuded; 2 - stunted; 3 - sparse; 4 - normal. Codes for mussel cover are M1 - very dense; M2 - separated clumps; M3 - absent.

4 Data validation

The diver recording data during the field survey is responsible for reviewing his work at the end of the survey to ensure that the data are complete and accurate. The chief diver will submit to the data manager the original field notes and a survey report, previously reviewed for accuracy and completeness by other members of the dive team, that includes the data on the total extent of the denuded and stunted *Chondrus* zones as well as a general description of the area surveyed, including notes on flora and fauna observed. The data manager is responsible for reconciling data in the submitted field report to those recorded on the original data sheets. The data manager will discuss any questions that may arise with the chief diver. The data manager is responsible for constructing maps based on the survey data and for calculating the total areal extent of the denuded and totally affected *Chondrus* regions. All calculations performed by hand are checked for accuracy. The data manager is responsible for proof-reading the final computer-generated maps against the original maps for accuracy. All reports generated by the data manager will be reviewed by the ENSR Project Manager, Dr. James Blake.

5 Observation

The data manager will plan to accompany the divers on the 1999 field trips. She will be be on hand to accept any samples collected during those dives and to hear immediately the impressions of all divers about the conditions of the outfall area, as well as ensure that the entire affected area has been surveyed.

6 Meetings

The project and/or data manager will attend full Administrative-Technical Committee and Benthic Subcommittee meetings when appropriate. This will help ensure communication between ENSR, the field team, and the A-T Committee so that the quality of the benthic survey will be maintained as guided by the Committee.

Date:
Wind:
Visibility:

Divers Down @:
Divers Up @:

CTL (m)	NORTH/SOUTH	
30		CHONDRUS 1 DENUDED 2 STUNTED
40		3 SPARSE 4 NORMAL
50		MUSSELS M1 V. DENSE M2 CLUMPS
60		M3 ABSENT
70		
80		
90		
100		NORMAL CHONDRUS ROBUSTNESS_______ COLOR____________
>100		EPIPHYTES________ HEIGHT__________ COLOR____________

Qualitative Transect Survey Field Data Sheet.`

III.B. BENTHIC
MULTI-YEAR TREND ANALYSIS

BENTHIC ALGAL MONITORING
AT THE
PILGRIM NUCLEAR POWER STATION
(Multi-year Trend Analysis, 1980 - 1998)

submitted to

ENTERGY Nuclear Generation Company
Environmental Protection Department
Pilgrim Nuclear Power Station
Plymouth, Massachusetts 02360

prepared by

ENSR
89 Water Street
Woods Hole, MA 02543
(508) 457-7900

written by

Woollcott Smith
Isabelle P. Williams

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EXECUTIVE SUMMARY

This report presents results of a multi-year statistical analysis of areal measurements made of the *Chondrus crispus* denuded and totally affected zones during Qualitative Transect Surveys off the Pilgrim Nuclear Power Station (PNPS) effluent canal performed over the last nineteen years (1980-1998). The objectives of this analysis were to evaluate quarterly *Chondrus* cover survey data and relate the spatial area of reduced *Chondrus* cover to the operational characteristics of the PNPS. These investigations constitute the most recent phase of long-term monitoring of thermal effluent effects on the benthic algal community within and just offshore of the PNPS discharge canal. This report also summarizes the impact of the PNPS on algal distributions near the discharge canal.

A standard regression analysis was performed. Data needed for this analysis included the areal survey data, the PNPS operating parameters, and natural environmental variables. Regression analysis was the most suitable for this data set as 1) the time series was not uniform and 2) there was a large number of candidate explanatory variables. In this analysis, the response variables, *Chondrus* denuded and totally affected areas, are predicted from current summary plant operating parameters (pumping rate and power output), as well as those plant summary conditions in effect the preceding months (one season earlier). Long-term trends in *Chondrus* cover that may be unrelated to operating characteristics can be modeled by including the last observed *Chondrus* coverage (preceding season) as a lagged explanatory variable in the regression.

Four prediction models, a one-season-ahead (lagged) model and a model without lagged dependent variables each for the denuded and totally affected *Chondrus* zones, all had excellent explanatory power for the long-term behavior of *Chondrus.* Using a 2-year running mean of plant operating capacity, these four models explained from 68 to 82% of the variability in the *Chondrus* denuded and totally affected areas. In contrast, the major short-term plant-operating characteristic (monthly mean MDC) was a relatively weak predictor of short-term changes in *Chondrus* cover. Variability in natural environmental factors (biological, physical, or man-induced) accounts for most of the short-term variability. Such factors include competition, grazing, colonization, storm-generated currents and waves, and siltation from dredging. These types of detailed explanatory physical and ecological variables were not included in the database and consequently contribute to the variation attributed to random noise in the statistical models described in this report.

1.0 INTRODUCTION

The presence of hundreds of square meters of seafloor just seaward of the PNPS discharge canal where the regionally abundant red alga, *Chondrus crispus*, is unnaturally absent, even in the presence of suitable substrata, is evidence that the discharge area is affected by elevated temperature and high current velocity of the cooling water outflow. To study this acutely impacted area (Figure 1), a Qualitative Transect Study was designed (Figure 2) to map the effects of the thermal effluent on nearby algal distributions. SCUBA divers have performed transect surveys to measure the extent of denudation and other reductions in size or density of algal flora, particularly *C. crispus*, in the nearfield discharge area from 1980 through 1998. For 1999, a single transect survey, timed to coincide with the season (autumn) that typically has shown the greatest effect, will be performed.

This report presents the latest effort in long-term (30 years) pre-and post-operational benthic studies at PNPS designed to monitor the effects of the thermal effluent. Previous data, analyses, and conclusions have been reported to the Nuclear Regulatory Commission (NRC), the U.S. Environmental Protection Agency (EPA), and the Massachusetts Department of Environmental Protection (DEP) by BECo in biannual Marine Ecology Reports as well as periodic special reports.

At the request of the Pilgrim Administrative-Technical Committee (PATC), a new project consisting of a multi-year analysis of data resulting from the Qualitative Transect Surveys was undertaken for 1999. The objective of this analysis was to evaluate quarterly *Chondrus* cover survey data and attempt to relate the spatial area of reduced *Chondrus* cover to the operational characteristics of the PNPS. This Semi-Annual Report presents methods, graphical and tabular descriptions of results, and conclusions of the multi-year analysis (1980-1998) of the denuded and totally affected *Chondrus* zones. Work was performed under Boston Edison Co. (BECo) Purchase Order LSP010919 in accordance with requirements of the PNPS NPDES Permit No. MA 0003557.

PNPS is a base-load, nuclear-powered electrical generating unit designed to produce 670 megawatts of electrical energy when operating at full capacity. The condenser is cooled by water withdrawn from Cape Cod Bay and subsequently returned to the Bay via an open discharge canal that dissipates heat through rapid mixing and dilution of the outflowing water. Two circulating water pumps produce a maximum flow rate of about 20 $m^3 s^{-1}$. The PNPS cooling system may affect the benthic community in three ways: 1) by warming ambient waters ($\Delta T = 18°C$), 2) through chemical discharge (mainly Cl_2), and 3) by seabed scouring from the rapid (~ 2.1 mps at low tide) flow regime. High temperature and chemical discharge may stress the algal community so that species composition and community structure change. High current velocity affects the benthos by actually removing benthic organisms, inhibiting settlement and recolonization, and may allow rock surfaces only to support fewer and smaller macroscopic organisms than normally expected.

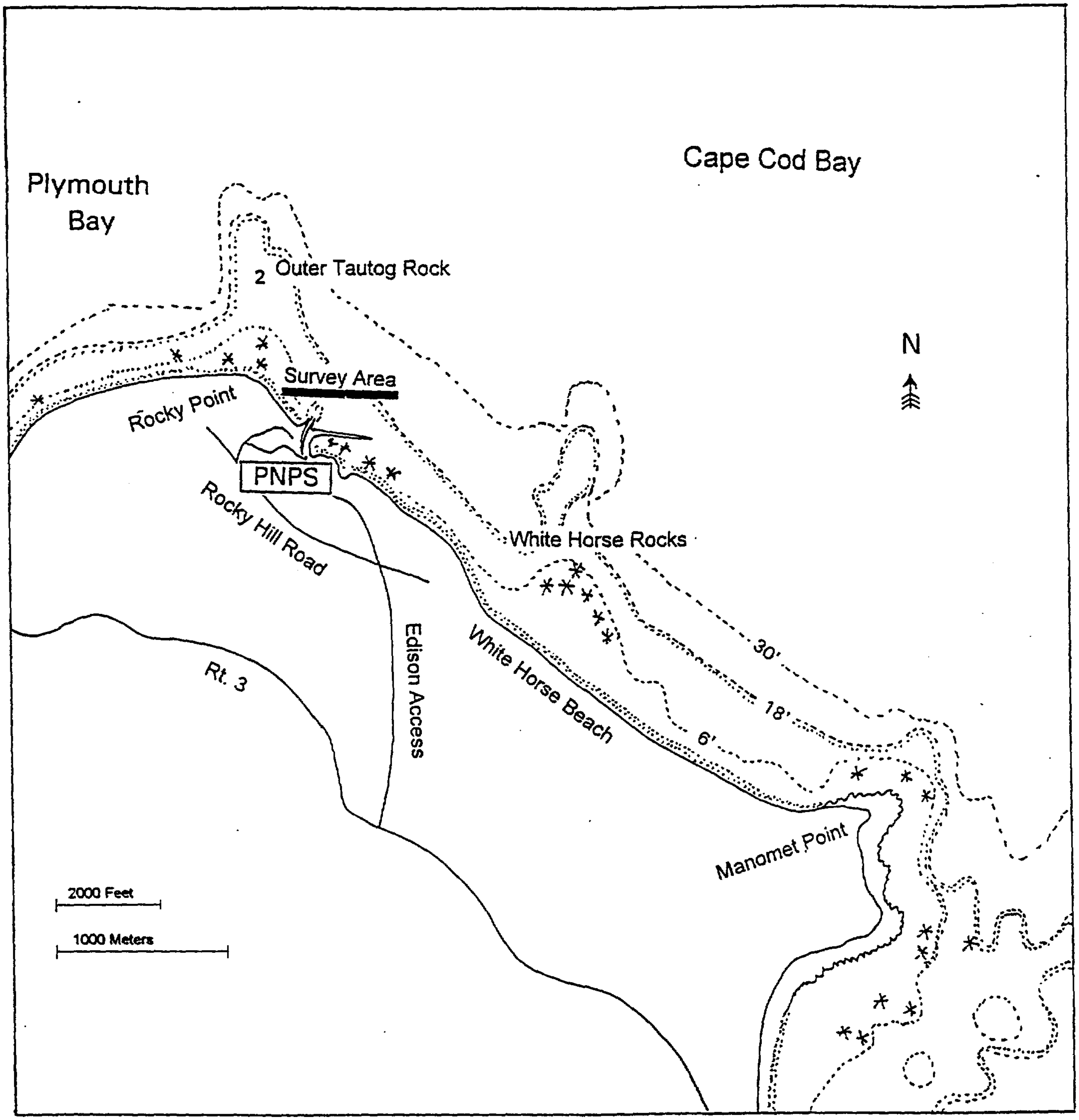

Figure 1. Location of Pilgrim Nuclear Power Station Qualitative Algal Survey Area.

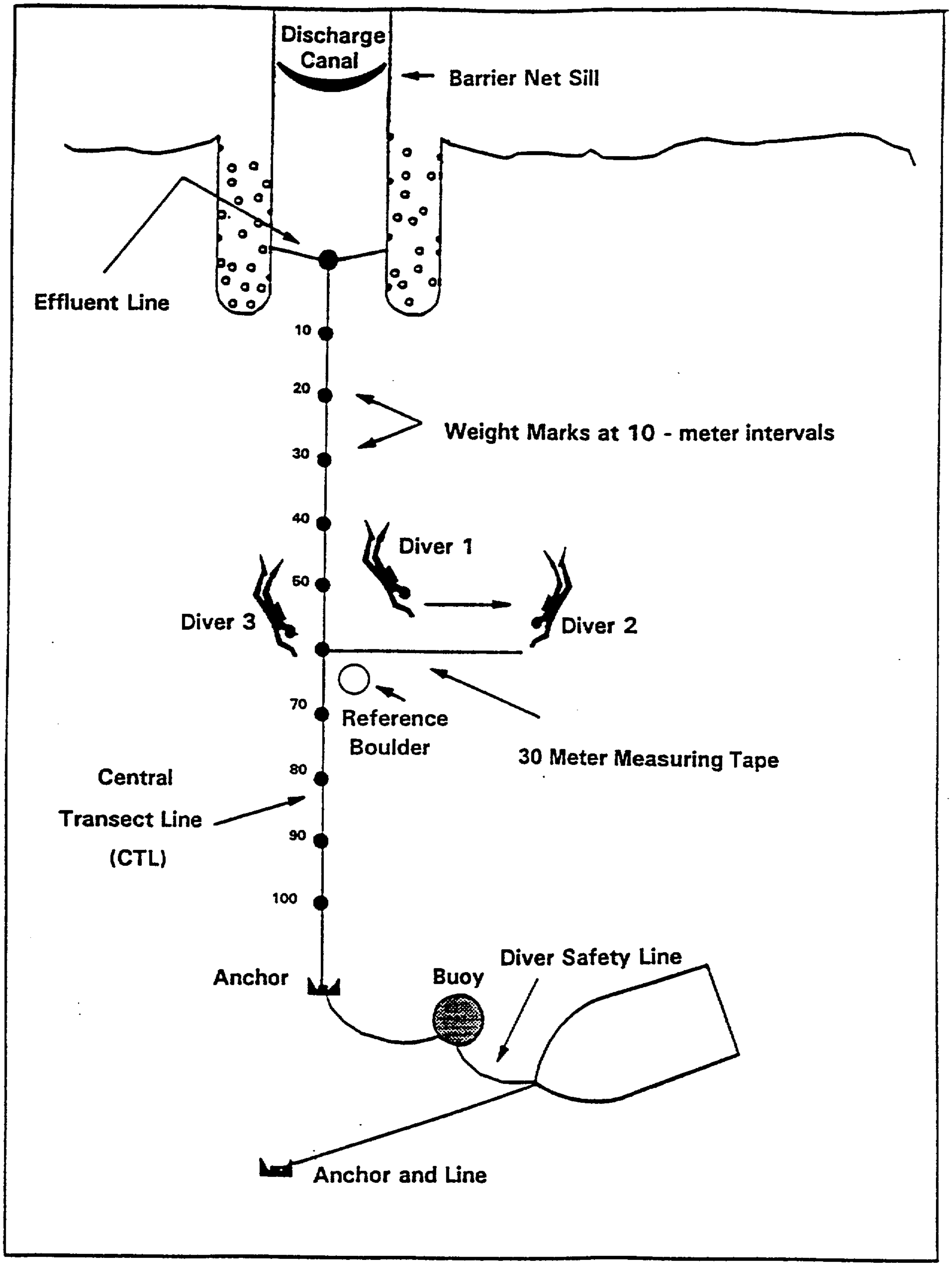

Figure 2. Design of the Qualitative Transect Survey.

2.0 METHODS

The data analysis was performed using S-plus, a very flexible statistical analysis package (S-PLUS 4 Guide) that has powerful graphics programming and the ability to do very sophisticated time-series analysis (Box and Jenkins, 1976; Chatfield, 1984) and multivariate data analysis. Data needed for this analysis included the areal survey data, the PNPS operating parameters, and natural environmental variables. The Trellus graphics package (Becker et al., 1996) was used to plot important variables by season and time periods. These data displays were useful in understanding the preliminary data and the final regression model output. For the formal statistical analysis of this data, standard regression analysis was used rather than the auto regressive integrated moving average (ARIMA) methods first proposed. The regression analysis was more suitable for this data set as 1) the time series was not uniform and 2) a large number of variables was used.

Exploratory analyses were performed to find the most parsimonious (simple) model that would best predict *Chondrus crispus* cover. Included in these initial analyses were current plant operating condition variables (power output and pumping rate), as well as lagged variables (i.e., the same observations in the preceding season or preceding year). To test the hypothesis that long-term average operating conditions of the plant had major impacts on the *Chondrus*, one-year and two-year moving averages of power output and pumping rate were included in the exploratory analysis.

In addition to the above analysis, a second set of exploratory analyses added lagged *Chondrus* variables (i.e., denuded and total affected areas measured in the preceding season or year) to equations predicting the current areal coverage. Including the last observed *Chondrus* coverage (preceding season) as a lagged variable in the regression increases prediction accuracy when long-term natural variation, unrelated to the measured plant operating characteristics, has major impacts on *Chondrus* spatial coverage. Since these lagged *Chondrus* variables will account for the long-term trends, these regression models are used to investigate whether short-term fluctuations in plant operation conditions predict short-term fluctuations in *Chondrus* cover.

The results of these exploratory analyses indicated that a lag of one-season (=one-season ahead prediction) for both plant operating condition variables (MDC and pumping rate) and the *Chondrus* cover variables (denuded and total affected areas) was a better predictor of current coverage than a one-year ahead prediction.

The specific linear prediction models described in the results section were chosen using a standard model selection procedure using the Akaike information criterion (Brown, 1998). This conservative criterion reduces the tendency to over-fit the model by including fewer variables. The result is a more stable prediction.

2.1 DATA SELECTION

The areal survey data used for this analysis included the *Chondrus* denuded and totally affected areas appraised and measured during approximately quarterly surveys. Areas of sparse and stunted *Chondrus* zones were not used as preliminary analysis gave results practically indistinguishable from results obtained using the total affected area. Terminology and field methods used for the acquisition of these data are described in BECo, 1999. Plots of these data have been shown routinely in the BECo Semi-Annual reports, from 1983 forward. However, some inconsistencies in how these data were calculated were revealed when earlier (1980-1982) survey reports were examined preparatory to their inclusion into the database. These inconsistencies required that all data from January 1980 through March 1987 be normalized so that they would be compatible with the more recent data. The details of these normalization procedures are explained and illustrated in Appendix A. Areal data used in this analysis are given in Appendix B.

For all surveys between September 1987 and June 1989, it was not possible to delineate the border between the stunted and denuded zones because of increasing recolonization of the substrate during this extended power plant outage. Although indications of denuded and patchy regions of *Chondrus* were indicated on the maps, no measurements of these affected zones were made during this time. For this data analysis, the denuded and totally affected areas were considered to be zero. This assumption was useful in finding effective predictive equations for the affected *Chondrus* areas.

The two main plant operation parameters considered are the percent of maximum circulating water pump capacity and the reactor thermal power level. The two circulating seawater pumps at PNPS operate either fully on or off, so that the percent of maximum pumping capacity can be only 0% (both pumps off), 50% (one pump running), or 100% (both pumps running). The reactor thermal power level of PNPS is given as a percentage of the maximum dependable capacity (MDC) factor and can be used to estimate thermal loading to the marine environment. An MDC factor of 100% approximates, with some seasonal variation, the greatest allowable increase (18°C ΔT) in ambient temperature for effluent water discharged to Cape Cod Bay. Most of the monthly pump operation and PNPS capacity factor (%MDC) data are available from the BECo Semi-Annual reports and are included in Appendix B.

An important explanatory natural environmental variable, related to season, is ambient (mean or maximum) water temperature (Appendix B). Intake water temperatures are recorded during fish impingement collections. Two inlet temperatures taken before and after three (3) weekly eight (8) hour collections are averaged and entered on coding forms (3 entries/week). These entries are condensed into the monthly mean and included in the BECo Semi-Annual Reports. Thus, maximum intake water temperature is not the highest occurring during the time period but is the highest entered on the coding sheets. The number of entries for a month varied from 1 to 14 but was usually around 10 to 13.

2.2 DATA PRESENTATION

A technical problem with the data is that the *Chondrus* surveys were not equally spaced in time. Figure 3 shows the timing of surveys by month and by year. Since seasonal variation in *Chondrus* cover is important, plant operating characteristics, *Chondrus* survey data, and statistical analysis are displayed by season. The quarterly *Chondrus* survey dates fit fairly well into the following seasonal pattern:

Winter:	December and February
Spring:	March, April, and May
Summer:	June
Fall:	August, September, and October

The frequency distribution of the monthly mean MDC is shown in Figure 4A. The distribution pattern of mean MDC by season is fairly uniform, that is, the shape of the bar graphs are similar for all four seasons. This means that during the 19 years covered in this analysis, the plant operated at similar levels during all seasons. In all seasons, the plant operated at a very low capacity between 20 and 40% of the time (slightly higher percentage in spring than the other three seasons) and operated at a very high capacity between 25 and 45% of the time (slightly higher percentage in winter than in the other three seasons). Consequently, there is no bias for any one season due to the operating level of the plant.

The major plant operating characteristics, pumping capacity and percent maximum power output, are highly correlated variables (Figure 4B). An interesting and important problem is how to separate the effects of increased bottom scouring due to discharge velocity when the plant is pumping water through the cooling system and increased temperature due to heating of the discharge water when the plant is generating electric power. The difficulty is that for most periods, the pumping capacity closely follows mean power output (Figure 4B). Both pumps are always running when the MDC is high, and neither pump is running when the MDC is zero. In regression analysis when two explanatory variables are linearly related (co-linearity), it is difficult or impossible to separate the two effects. According to BECo (1980, 1982a) and Bridges and Anderson (1984) the configuration and extent of the denuded zone are caused by scouring in the immediate path of the discharge plume, while the more distal stunted zone is primarily due to thermal effects. This question is addressed in more detail in the next section.

Similarly, it is difficult to distinguish between the effects of intake water temperature and season, as these variables are closely related. Figures 5A and 5B are box and whisker plots (Tukey, 1977) of the mean and maximum intake water temperatures. These plots are especially good for distinguishing differences among groups. To generate these plots: 1) the data should be in numerical order, 2) the data is then divided into two equal high and low groups, at the median, 3) the median of the low group, i.e., the first quartile (Q1), is determined, and the median of the high group, the third quartile (Q30) is determined.

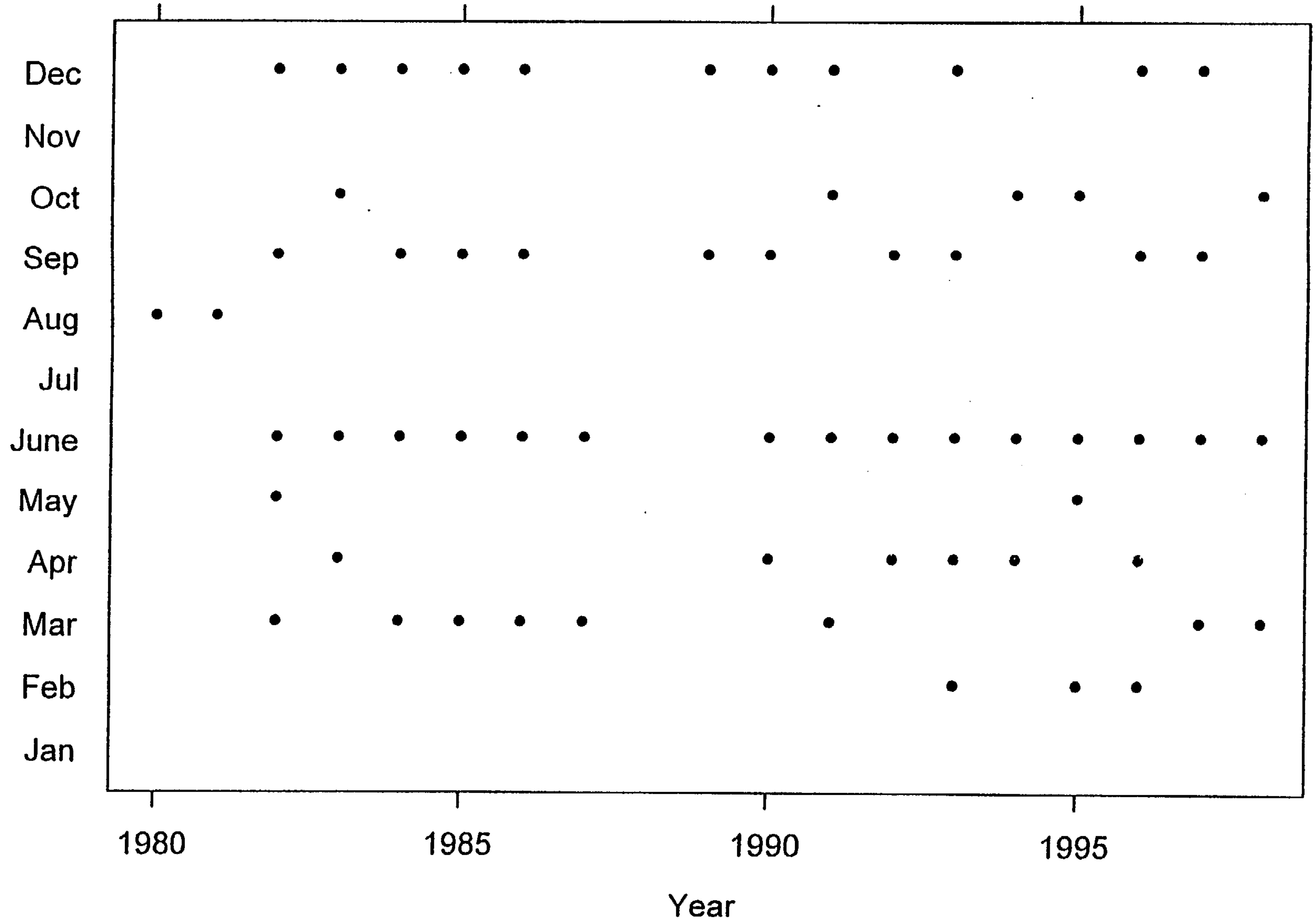

Figure 3. Areal Surveys by Month and Year.

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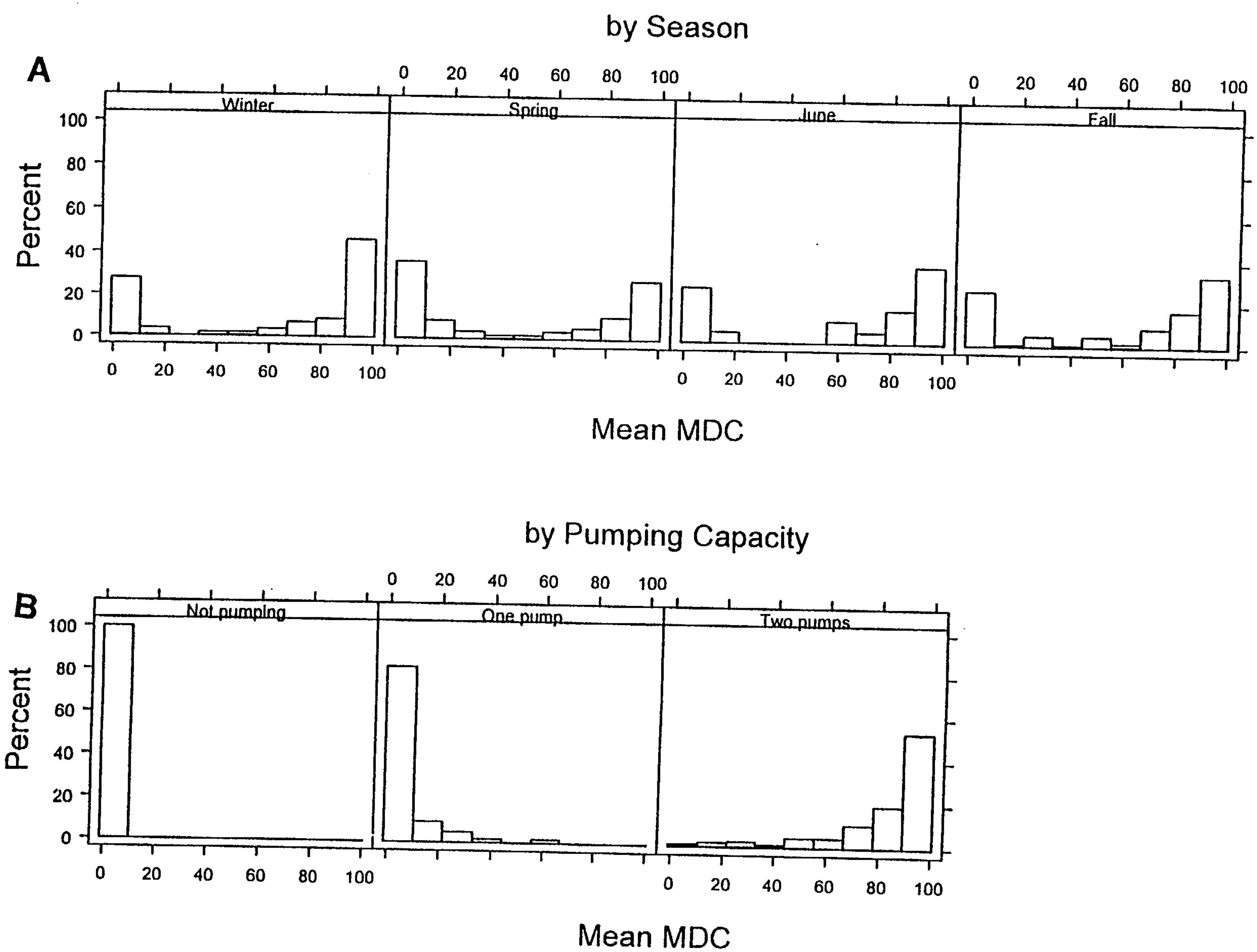


Figure 4. **Frequency Distribution of the Monthly Mean MDC by Season (A) and Pumping Capacity (B).**

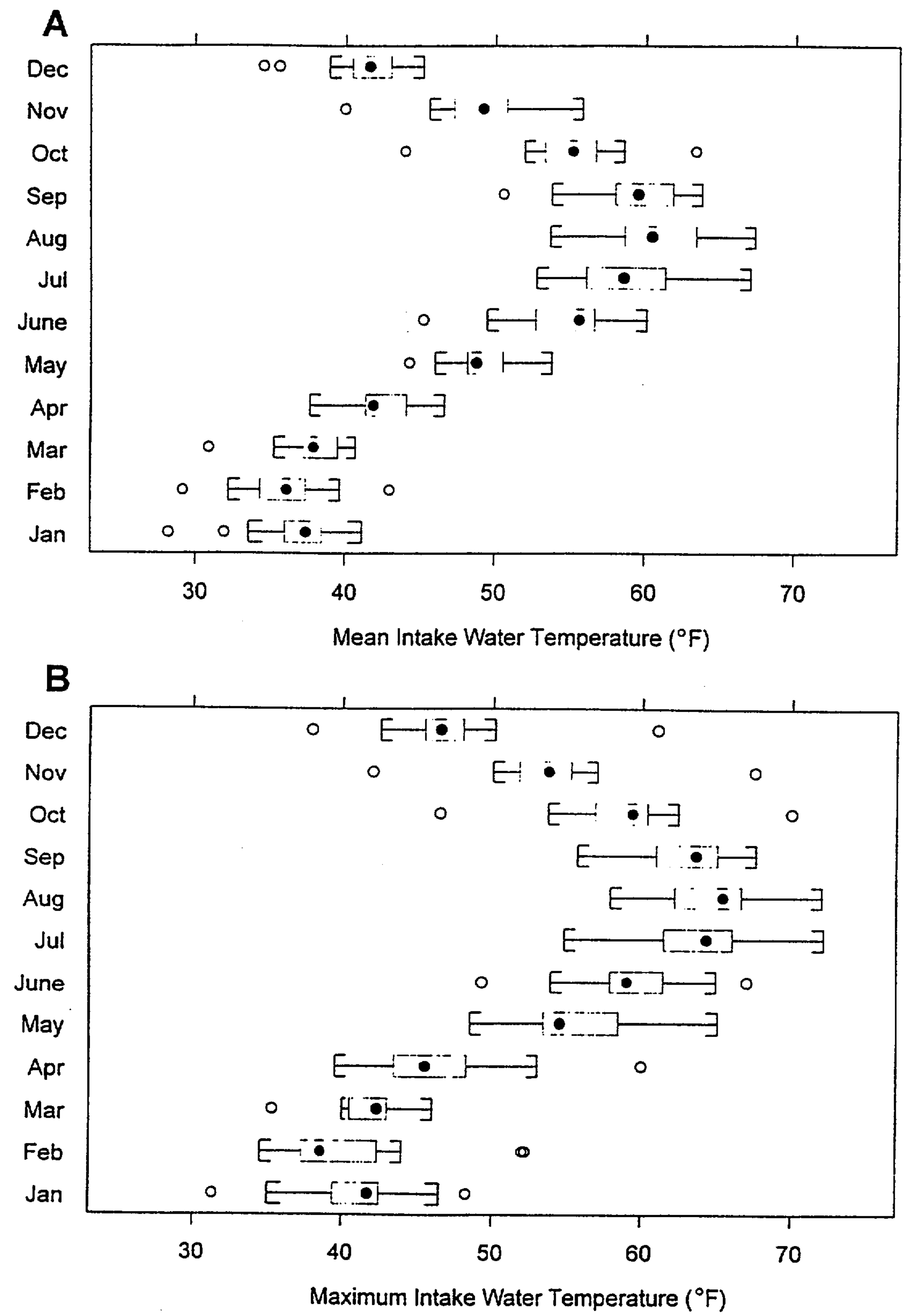


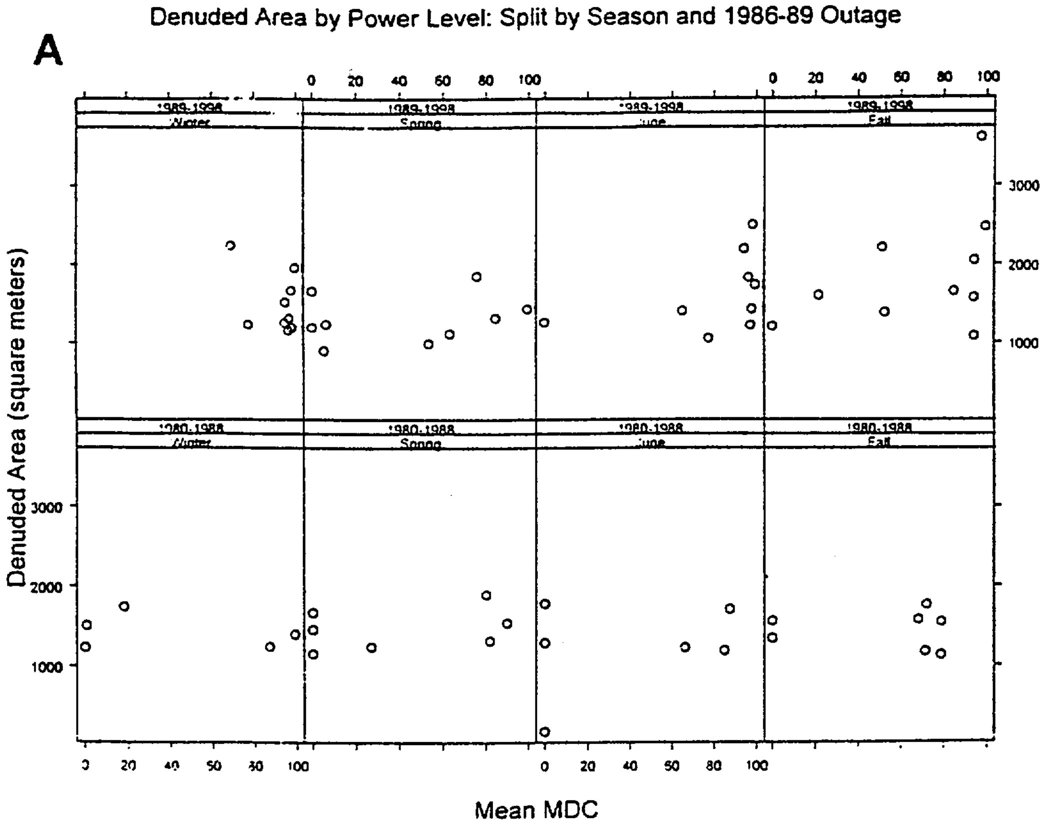
Figure 5. **Mean (A) and Maximum (B) Intake Water Temperatures (°F).**

The interquartile range (IQR) is the distance between Q3 and Q1. The ends of the box are the quartiles, Q1 and Q3, and the dot in the middle is the median. The whiskers are drawn out to include all points within 1.5 IQR of the quartiles. Open circles are outliers; that is, more than 1.5 IQR from the end of a box (Gonick and Smith, 1993). For this analysis, the maximum temperature was chosen as the more important temperature variable as some biological responses might be more sensitive to a spike in temperature than to the mean temperature.

Because the data were acquired over a long time period by a variety of subcontractors using different divers, the data were divided in half to test for consistency in data acquisition. The middle of the extended power outage (1988) was chosen as a convenient division point. Figures 6A and 6B display the denuded and totally affected areas by mean MDC and split by season and the 1986-1989 power outage. The results show that the data were consistent over the time period examined (the upper and lower boxes of each group show a similar array of open circles) with the possible exception of the high fall data point in the 1989-1998 data grouping. Thus, the data by season for all 19 years can be merged.

Figures 7A and 7B show the areal measurements of the denuded and totally affected zones by season and year. The shapes displayed by the open circles in each graph are similar, a flattened U-shape, showing the effects of the power outages in 1984 and1986-1989. The affected areas decreased in size during the outages and increased in size after the plant again became operational. The box and whisker plots of the same data (Figures 8A and 8B) reveal some high outliers in June for the total affected area and high outliers in the fall and low outliers in June for both the denuded and total affected areas. Even more evident is the similarity in the sizes of the affected areas throughout the year. There is a great deal of overlap in the position of the boxes for both the denuded areas (around 1200-1800 m^2) and total affected areas (around 1600-2600 m^2) over all seasons.

The lagged relationships between adjacent seasons are shown in Figures 9 and 10. Figures 9A and 9B affirm that the data collected during the first half of the 19-year time frame and the second half are consistent. The upper and lower boxes of each group show a similar array of open circles. Consequently, the data were merged by season for all 19 years (Figures 10A and 10B). In these graphs, data for the season labeled on the graph (the later season) is plotted on the y-axis. Data plotted on the x-axis is from one season earlier, i.e., the past history. The objective of this technique is to predict the size of the affected areas in the next season from that found in the current season. This works very well. The linear slopes displayed by the data show that the area during the prior season is a good linear predictor of the area in the following season, that is, a large area in one season predicts a large area in the following season. The slopes of the regression lines are similar for winter, spring, and fall but are steeper in June.



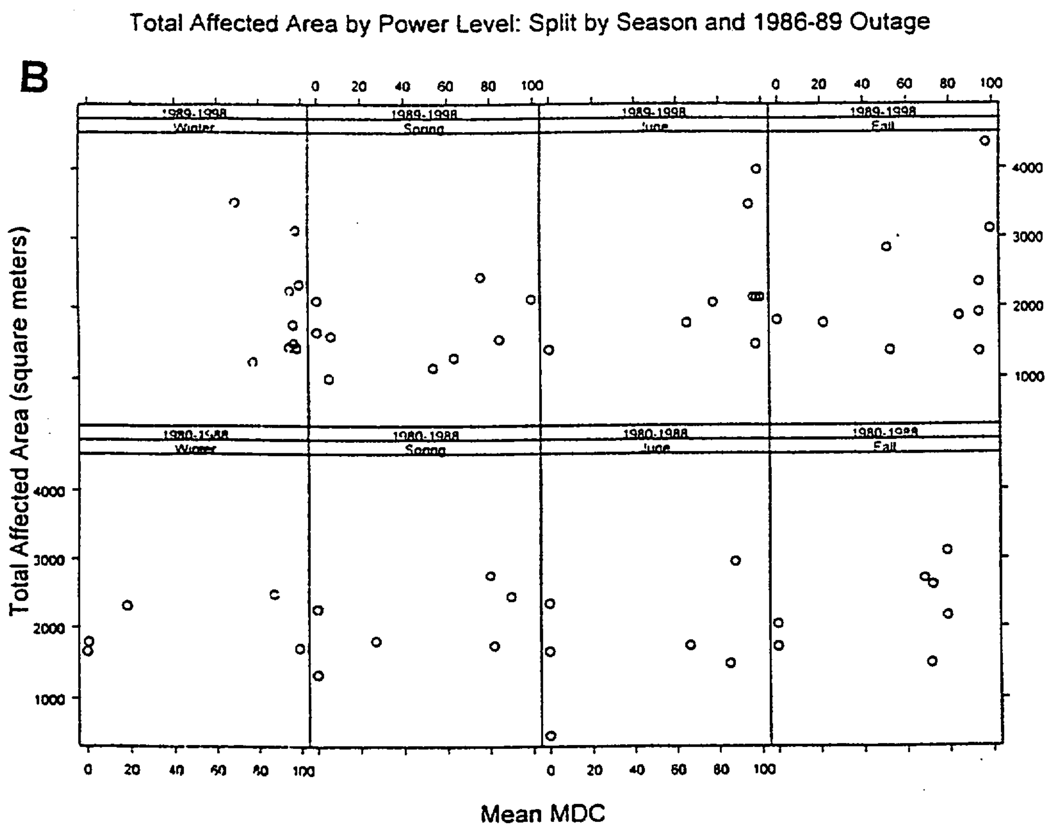


Figure 6. **Denuded Area (A) and Total Affected Area (B) by Power Level: Split by Season and 1986-89 Outage.**

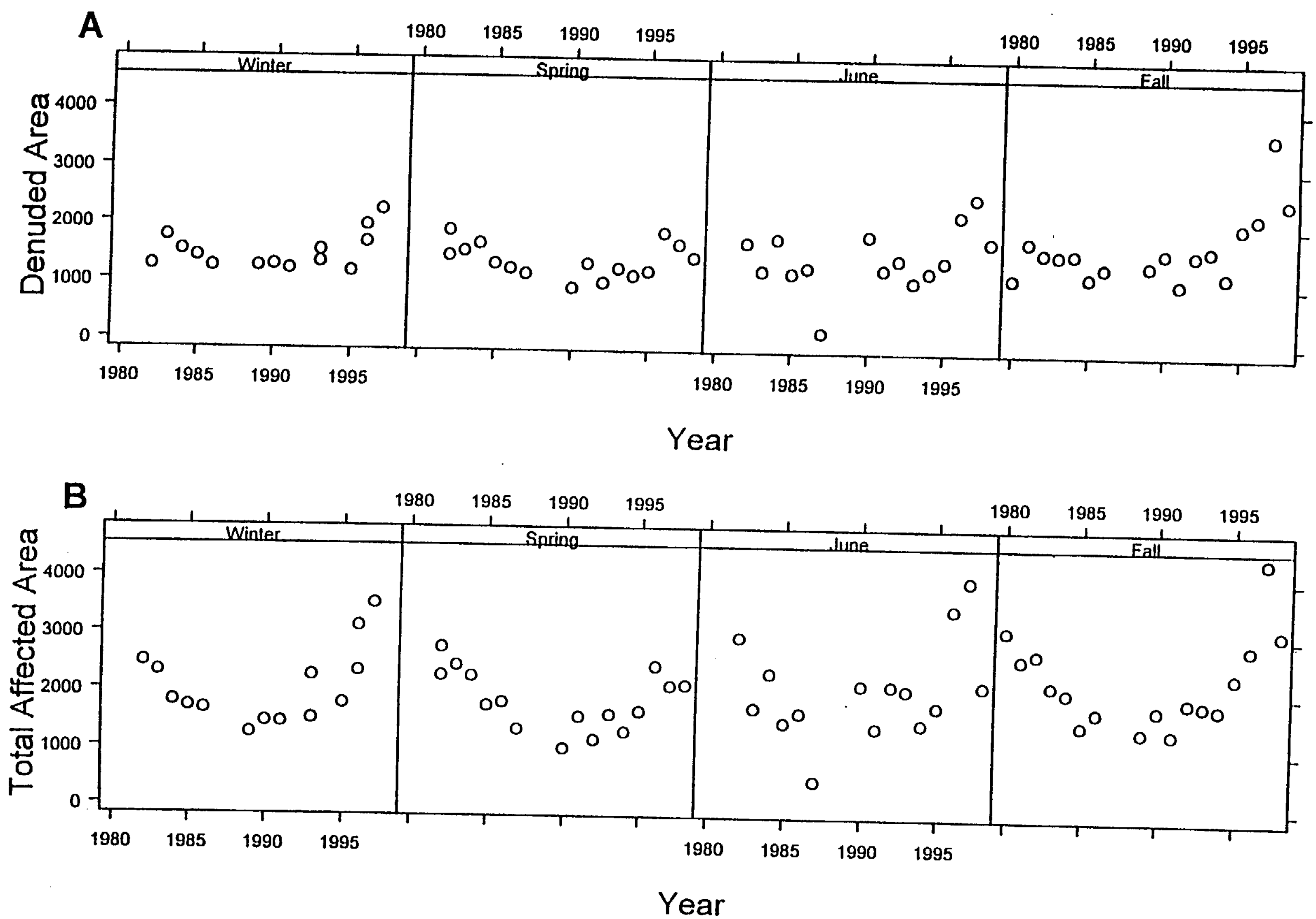


Figure 7. **Time Series of Denuded Area (A) and Total Affected Area (B) by Season.**

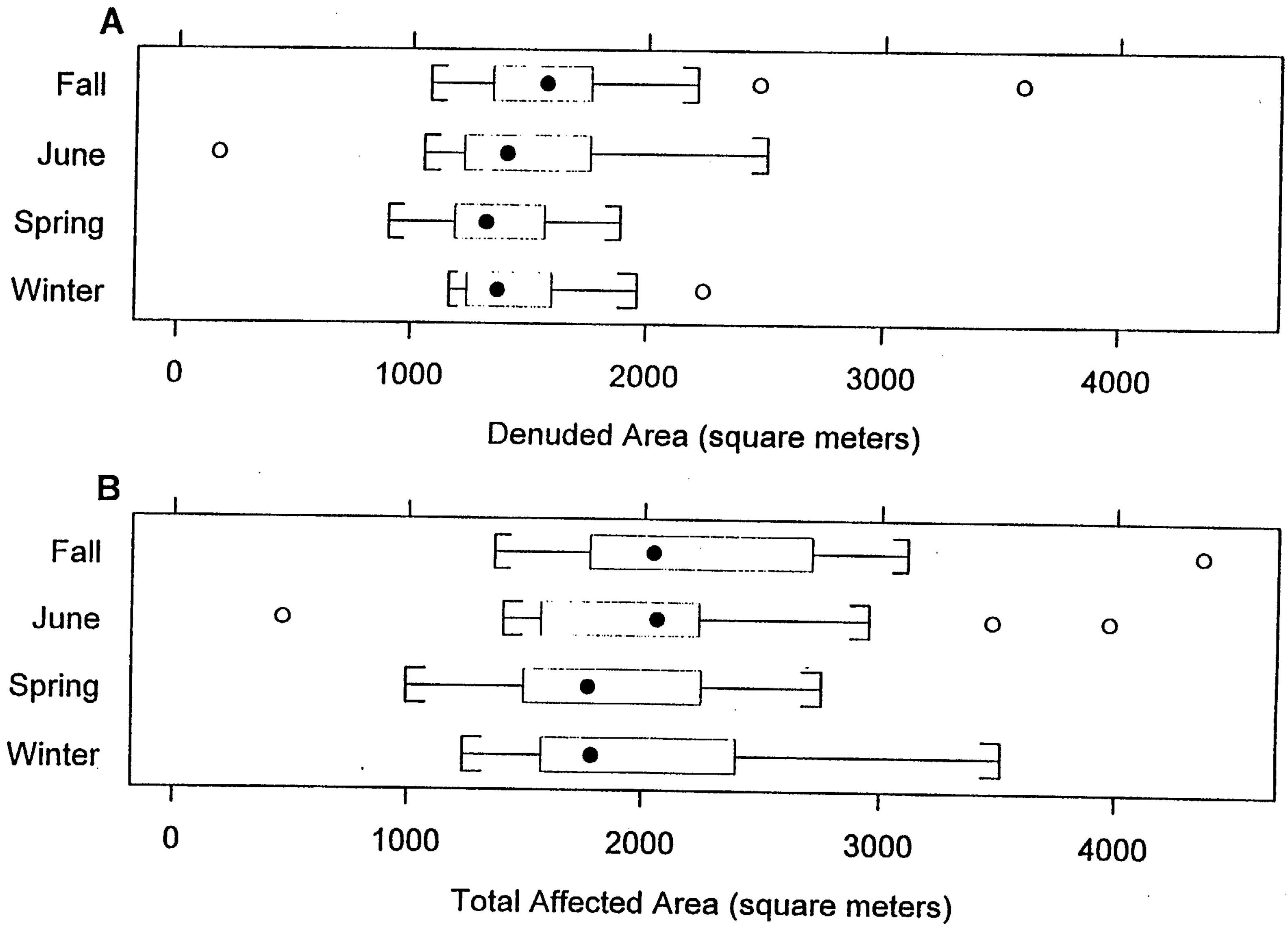


Figure 8. **Denuded Area (A) and Total Affected Area (B) by Season.**

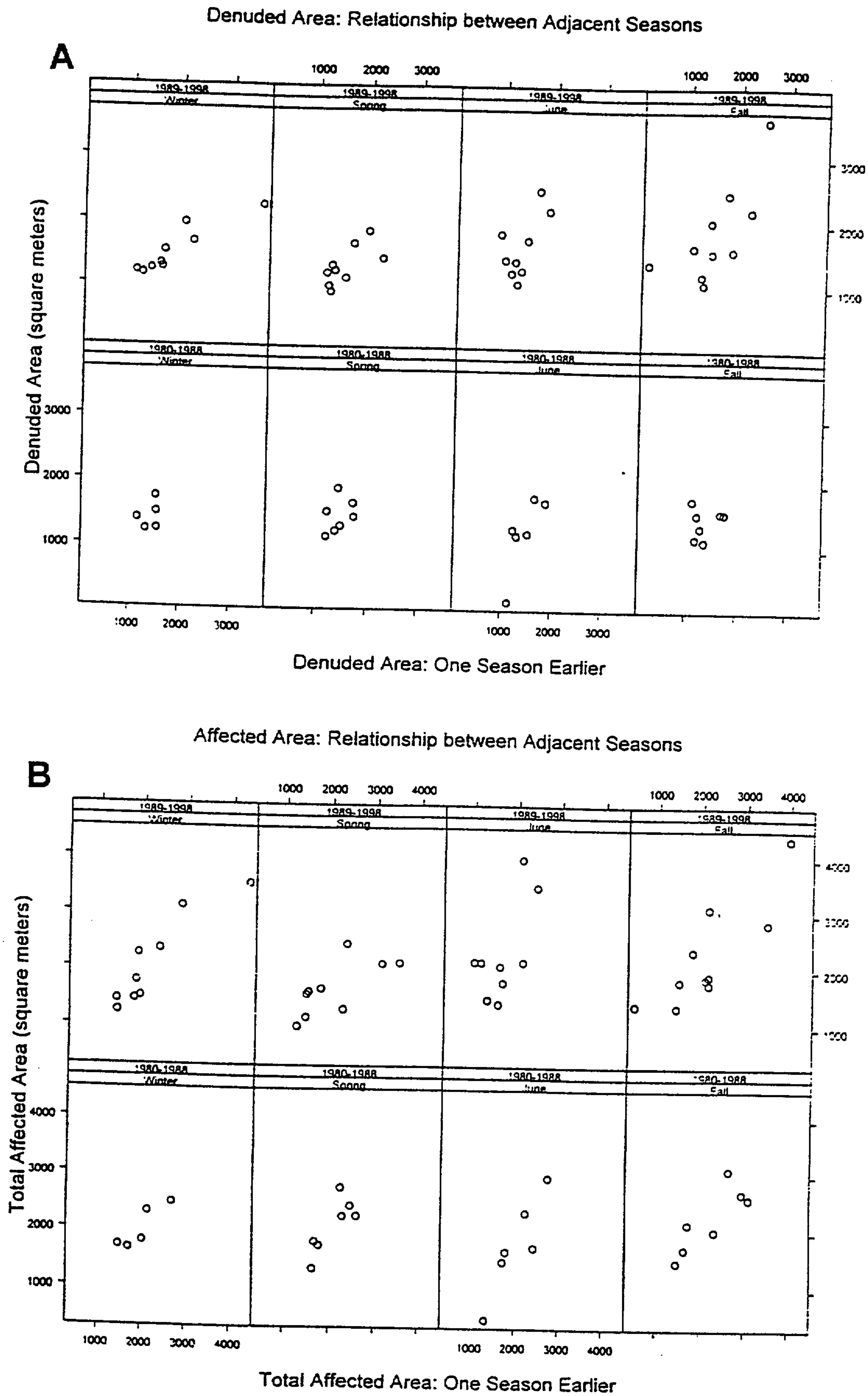


Figure 9. **Denuded Area (A) and Total Affected Area (B): Relationship between Adjacent Seasons.**

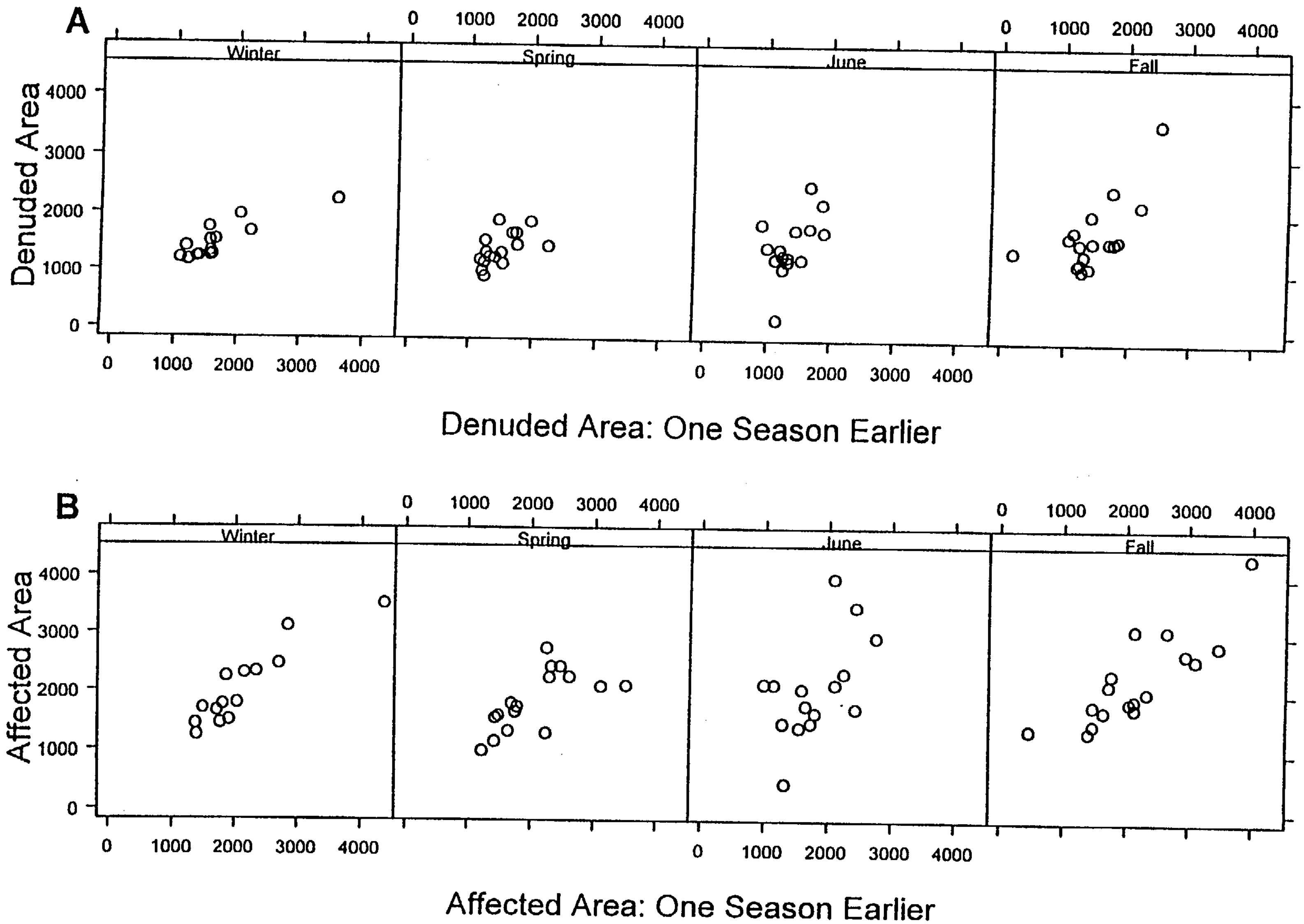


Figure 10. **Lagged Relationships between Adjacent Seasons: Denuded Area (A) One Season Earlier and Total Affected Area (B) One Season Earlier.**

2.3 DATA ANALYSIS

The question addressed is: can short-term variations in *Chondrus* cover be explained by the corresponding short-term variations in the plant operating characteristics? This question was addressed by a classical regression analysis using the following variables:

Affected *Chondrus* Area: Dependent variable

Lagged total affected area: 1 season earlier

Predictor variable accounting for long-term variation in *Chondrus* coverage

Lagged denuded area: 1 season earlier

Denuded area was used since this area might have a longer recovery time

Season:	Adjustment for known variation in seasonal growth of *Chondrus*
Maximum Intake Temperature:	Maximum monthly intake water temperature
Plant Operating Characteristics:	
Mean MDC	Monthly mean power output
12 month mean MDC	Average plant capacity in the preceding 12 months
24 month mean MDC	Average plant capacity in the preceding 24 months
Pumping capacity	Monthly mean pumping capacity (percent of maximum)
1986-89 power outage	Indicates whether observation occurred after the 1986-89 outage

Many different regression-modeling approaches to this data set were explored. In the end, a straightforward approach was used, an approach that resulted in a small set of regression models, each model using a few predictor variables. To accomplish this, we used a standard variable selection algorithm. The algorithm starts with a large number of predictor variables. Variables then are entered and removed in sequence until the model with the minimum Akaike information criterion is found. The Akaike information criterion is a standard goodness-of-fit criterion that guards against over-fitting a model with too many predictor variables.

Two qualitatively different kinds of models were estimated. One approach was to predict one-season-ahead using current observations of the affected area and plant operating characteristics. This prediction model helps answer questions about which conditions help predict short term, between-season changes in the affected area. In the second approach, only plant operating conditions and environmental variables were used in the model. Twelve-month and 24-month running means of MDC were used, rather than a shorter set of months, so that all seasons would be included. This analysis helps determine variables that are useful predictors of the long-term biological impact of plant operating conditions.

3.0 RESULTS

For both the *Chondrus* denuded and totally affected areas, the one-season-ahead prediction model did better that the model without lagged dependent variables, as it includes additional information on the impacted area from one season before. For the denuded area, the r^2 value is 0.7625 for the one-season-ahead prediction model (Table 1) and 0.6826 for the prediction model without lagged dependent variables (Table 2). For the total affected area, r^2 is 0.8257 for the one-season-ahead prediction model (Table 3) and 0.7396 for the prediction model without lagged dependent variables (Table 4).

Tables 1-4 present values in the second column that show how much each of the listed variables contributes to the affected area. For example, in Table 1, for every 1°F increase in intake water temperature, the denuded area increases by 17 m^2. This means that since the average difference between summer and winter temperatures is about 30°F, then the average increase in size of the denuded area in the summer over that in the winter is about 510 m^2 (=17 m^2 × 30). Similarly, for every 1% increase in mean MDC, the denuded area increases by 3 m^2, so that the difference between a 0% MDC and 100% MDC will account for an increase of 306 m^2 in denuded area. And, for every 1% increase in the 2-year running mean MDC, the denuded area increases by 6.5 m^2.

The same regressions were also run using only pump data. The results for the denuded data are given in Tables 5 and 6. This was an attempt to sort out the effects of pump capacity from the effects of power plant capacity. As predicted, the results were similar but not quite as good as for the regressions using the MDC data. The r^2 value was nearly the same for the one-season-ahead predictor model for the denuded area whether the MDC data or only the pump capacity data were used. The value for r^2 was slightly higher for the predictor model, without lagged dependent variables, for the denuded area when the MDC data were used ($r^2 = 0.6826$) than when the pump capacity data alone were used ($r^2 = 0.6324$).

The fitted values and the residuals of the four models using the 2-year mean MDC are plotted in Figures 11-14. The plots are primarily designed to detect departures from the regression model by season (Figures 11 and 13) and to compare visually the fit of the one-season-ahead prediction model with the prediction that did not include lagged dependent variables (Figures 12 and 14). The residuals are the differences between the predicted and observed values. If the regression model has done a good job, then there should be no pattern seen in the data display. There is no pattern seen in the data plotted in Figures 11 and 13; about as many open circles are as far above the center line as below. Figures 12 and 14 show that the predicted data (solid line) fit both models fairly well. For both the denuded and totally affected area data, the solid lines fit the lagged predictor model slightly better than the model without lagged predictors.

Table 1. **Denuded Area: One-Season-Ahead Prediction Model.**

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-820.0020	255.6765	-3.2072	0.0021
Lag.denuded	0.5586	0.0961	5.8132	0.0000
Max.temp.	17.1625	4.3917	3.9079	0.0002
Mean.MDC	3.0599	1.1280	2.7128	0.0086
Year.2.MDC	6.4660	2.6949	2.3994	0.0193
Residual standard error: 332.5 on 64 degrees of freedom				
Multiple R-Squared: **0.7625**				
F-statistic: 51.36 on 4 and 64 degrees of freedom, the p-value is 0				

Table 2. **Denuded Area: Prediction Model, without lagged dependent variables.**

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-1976.3087	632.1658	-3.1263	0.0027
Max.temp.	41.2814	11.6008	3.5585	0.0007
Season.1	24.6716	69.8744	-0.3531	0.7252
Season.2	-204.1833	70.0356	-2.9154	0.0049
Season.3	-68.3206	45.0409	-1.5169	0.1344
Mean.MDC	3.6052	1.4033	2.5690	0.0126
Year.2.MDC	17.3725	2.2455	7.7365	0.0000
Residual standard error: 390.5 on 62 degrees of freedom				
Multiple R-Squared: **0.6826**				
F-statistic: 22.22 on 6 and 62 degrees of freedom, the p-value is 0				

Table 3. Totally Affected Area: One-Season-Ahead Prediction Model.

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-1091.1057	323.7126	-3.3706	0.0013
Lag.affected	0.3855	0.1495	2.5793	0.01232
Lag.denuded	0.3946	0.2117	1.8643	0.0670
Max.temp.	20.6329	5.5524	3.7160	0.0004
Mean.MDC	4.7226	1.4037	3.3644	0.0013
Lag.mean.MDC	-2.4428	1.4815	-1.6489	0.1042
Year.2.MDC	8.5664	3.5453	2.4163	0.0186
Residual standard error: 410.7 on 62 degrees of freedom				
Multiple R-Squared: **0.8257**				
F-statistic: 48.96 on 6 and 62 degrees of freedom, the p-value is 0				

Table 4. Totally Affected Area: Prediction Model, without lagged dependent variables.

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-3395	821.5984	-4.1327	0.0001
Max.temp.	65.4242	15.1622	4.3150	0.0001
Season.1	-61.2242	90.5655	-0.6760	0.5016
Season.2	-301.6736	91.1730	-3.3088	0.0016
Season.3	-162.2912	58.5515	-2.7718	0.0074
After.1986-1989	-134.3352	68.4772	-1.9617	0.0544
Mean.MDC	5.8970	1.8648	3.1623	0.0024
Year.2.MDC	26.7861	2.9642	9.0364	0.0000
Residual standard error: 506.1 on 61 degrees of freedom				
Multiple R-Squared: **0.7396**				
F-statistic: 24.75 on 7 and 61 degrees of freedom, the p-value is 0				

Table 5. **Denuded Area: One-Season-Ahead Prediction Model, using only pump data.**

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-1314.2911	301.1694	-4.3640	0.0000
Lag.denuded	0.5578	0.0965	5.7800	0.0000
Max.temp.	16.7642	4.4409	3.7749	0.0004
Pump	3.2752	1.4436	2.2688	0.0267
Year.2.pump	9.8003	3.7516	2.6123	0.0112

Residual standard error: 335.3 on 64 degrees of freedom

Multiple R-Squared: **0.7584** [R-Squared was **0.7625** using MDC, a virtual tie]

F-statistic: 51.36 on 4 and 64 degrees of freedom, the p-value is 0

Table 6. **Denuded Area: Prediction Model, without lagged dependent variables, using only pump data.**

Coefficients:				
	Value	Std. Error	t-value	Pr(|t|≥|t-value|)
(Intercept)	-1639.4719	362.1914	-4.5265	0.0000
Max.temp.	14.3415	5.4121	2.6499	0.0101
Pump	2.8007	1.7643	1.5874	0.1173
Year.2.pump	25.4141	3.1868	7.9749	0.0000

Residual standard error: 390.5 on 62 degrees of freedom

Multiple R-Squared: **0.6324** [R-Squared was 0.6826 using MDC, a better result]

F-statistic: 22.22 on 6 and 62 degrees of freedom, the p-value is 0

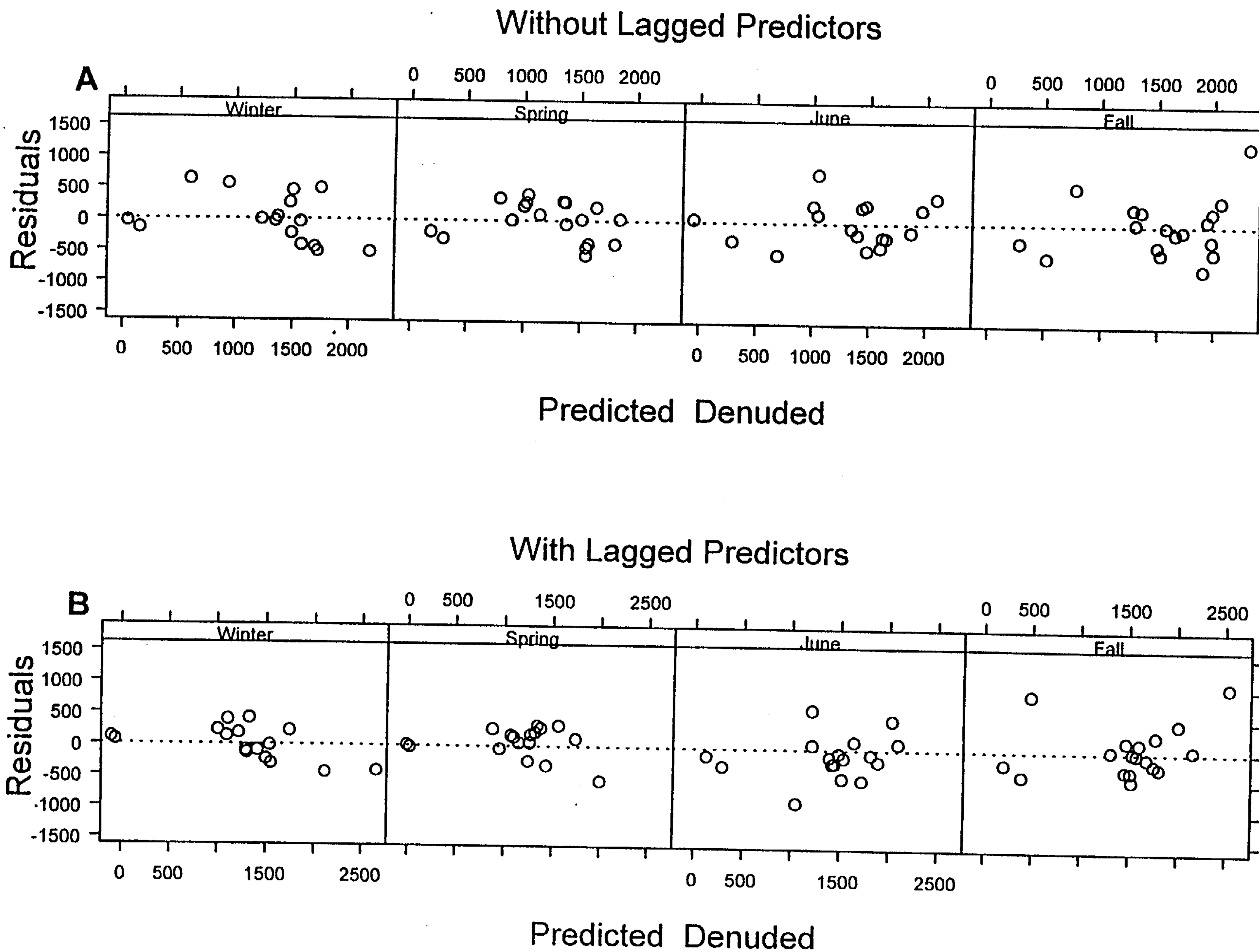


Figure 11. **Residuals for the Predicted Denuded Area without (A) and with (B) Lagged Predictors.**

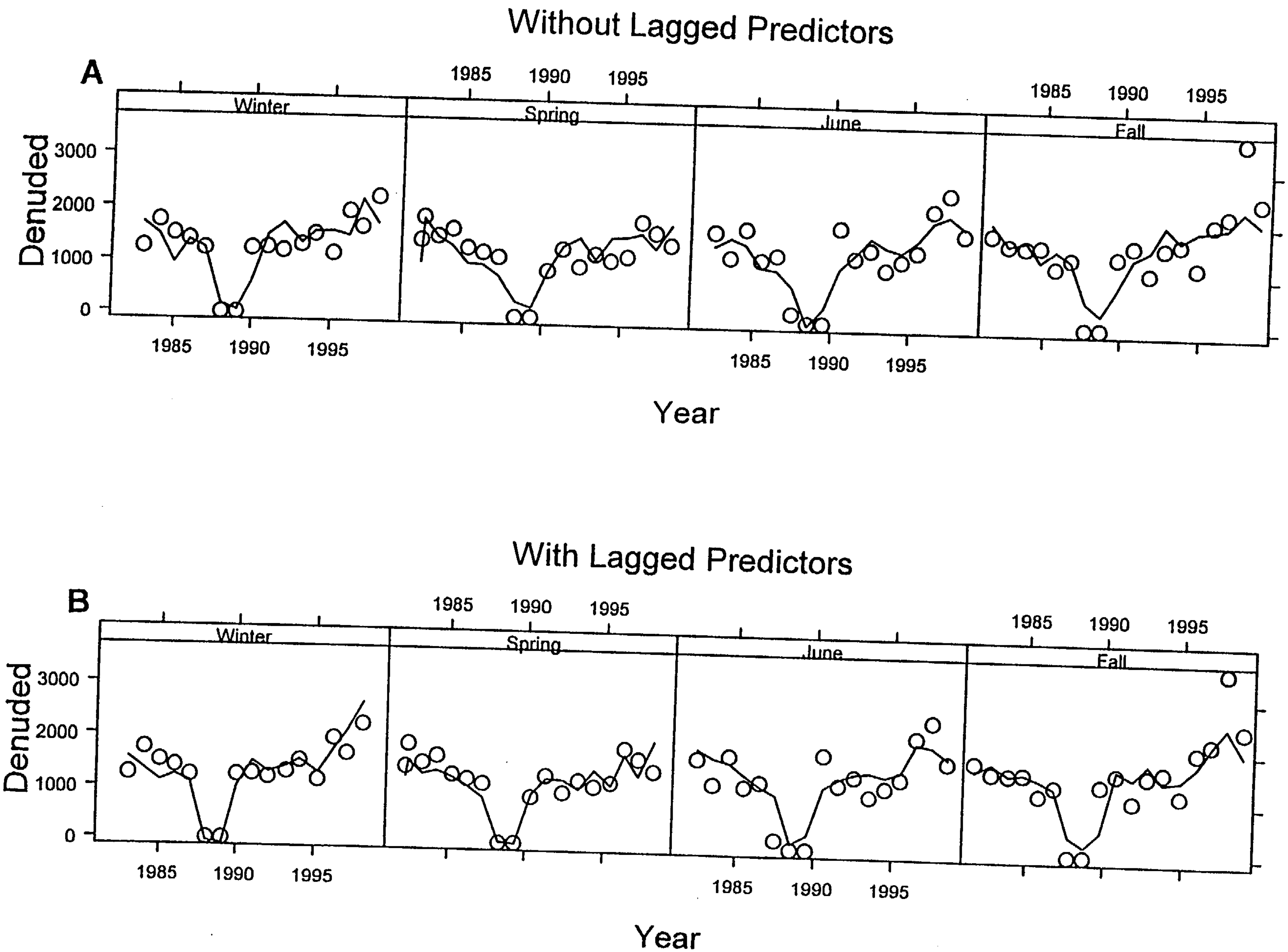


Figure 12. **Observed and Predicted Denuded Area without (A) and with (B) Lagged Predictors.**

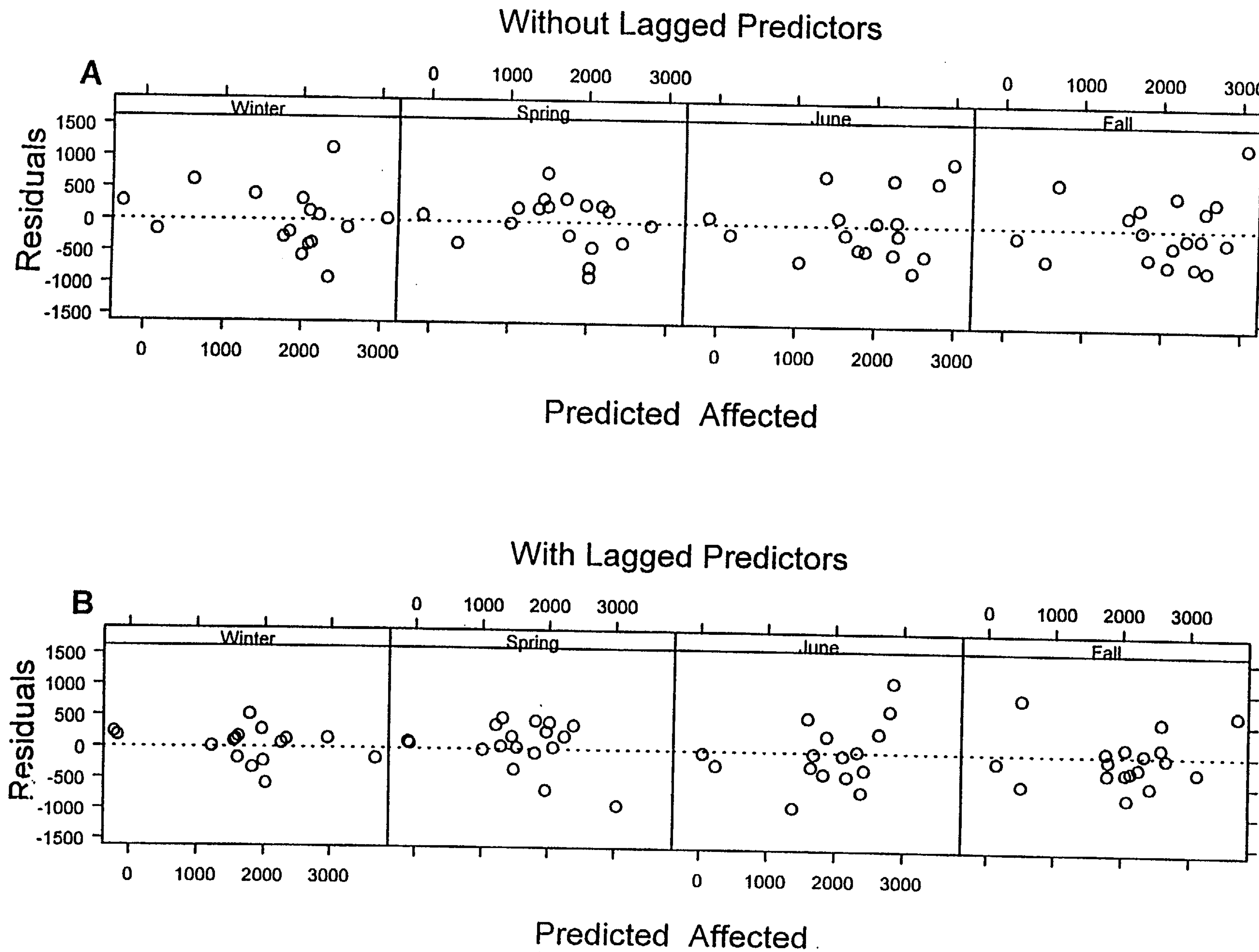


Figure 13. **Residuals for the Predicted Total Affected Area without (A) and with (B) Lagged Predictors.**

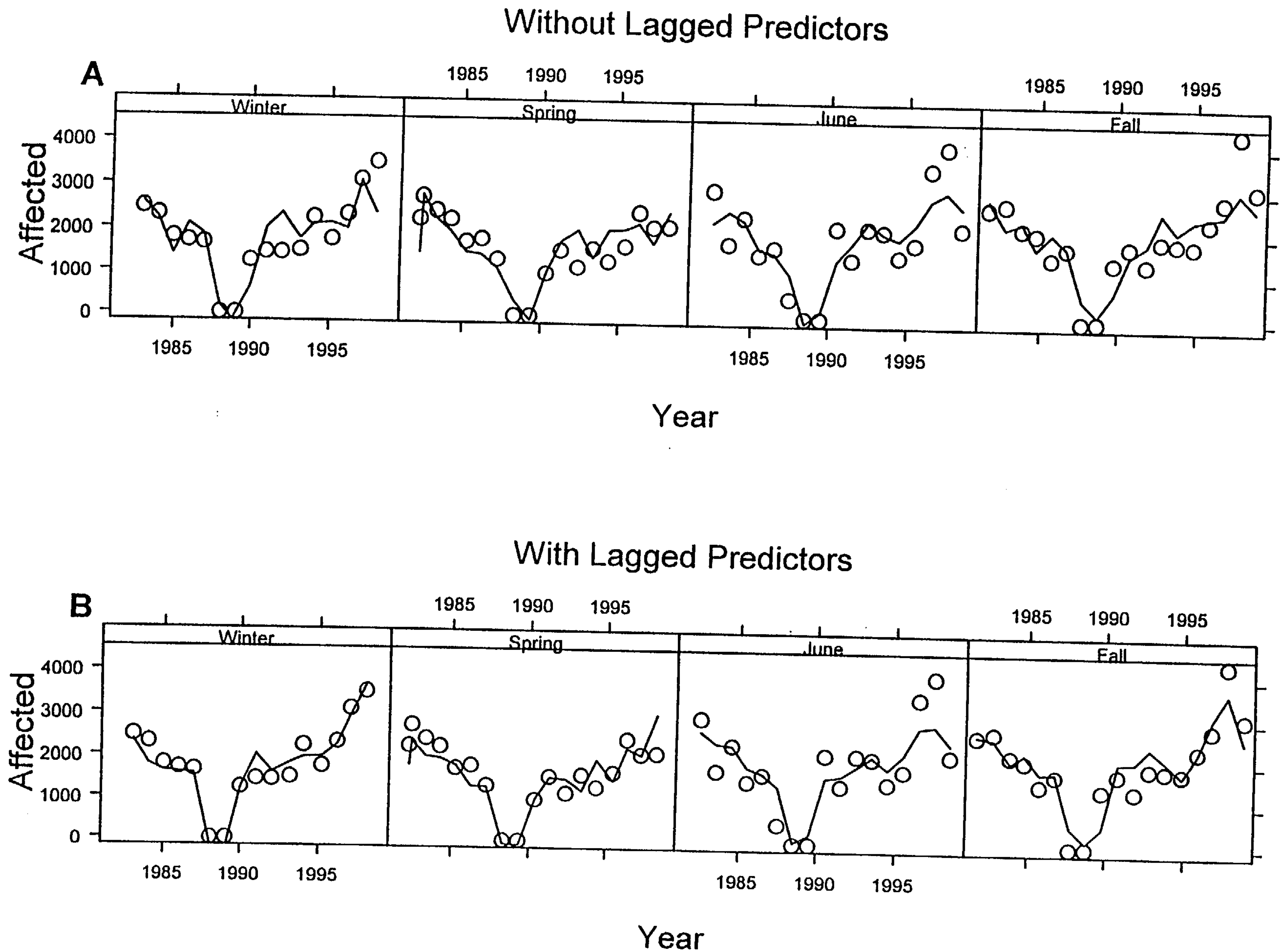


Figure 14. **Observed and Predicted Total Affected Area without (A) and with (B) Lagged Predictors.**

The 2-year running average of the mean MDC produced the best fit for the standard regression model used in this analysis. One season, the fall, was chosen, to show how the *Chondrus* affected areas related to this operating plant variable. The fall sampling dates were ordered by increasing 2-year mean MDC (Table 7) and representative maps showing the resultant effects upon the *Chondrus* denuded and totally affected zones are shown in Figure 15. Plots A and B cover a range in the running mean of the 2-year MDC of 7 to 38%. Plots C and D show *Chondrus* affected areas that are not too much larger than those displayed in A and B, but the 2-year running mean MDC ranges from 51 to 67%. A much more noticeable increase in affected area occurs by the time the 2-year running mean MDC is larger than 75% (E, F).

Table 7. Fall Sampling Dates Arranged in Increasing Order of the Two-Year Mean MDC.

Year	Year.2.MDC	Year.1.MDC	Mean.MDC	Season
1988	0.000000	0.00000	0.0	Fall
1989 *	7.254167	14.50833	52.5	Fall
1987	20.775000	0.00000	0.0	Fall
1985 *	37.766666	60.89167	71.4	Fall
1990	38.537502	62.56667	21.6	Fall
1984	49.175003	14.64167	0.0	Fall
1986 *	51.220837	41.55000	0.0	Fall
1982	58.404167	37.74166	68.3	Fall
1983	64.016678	86.96667	79.0	Fall
1991	66.308334	64.33334	94.2	Fall
1981 *	66.720833	80.56667	72.1	Fall
1994	69.104172	72.20000	0.0	Fall
1995	69.724998	67.25000	94.3	Fall
1993	74.887505	63.90833	84.8	Fall
1996 *	75.145836	90.90000	51.4	Fall
1992	75.287498	85.86667	94.1	Fall
1997	84.091675	77.28334	97.4	Fall
1998 *	84.912498	92.15000	99.4	Fall

* Sampling maps shown in Figure 15.

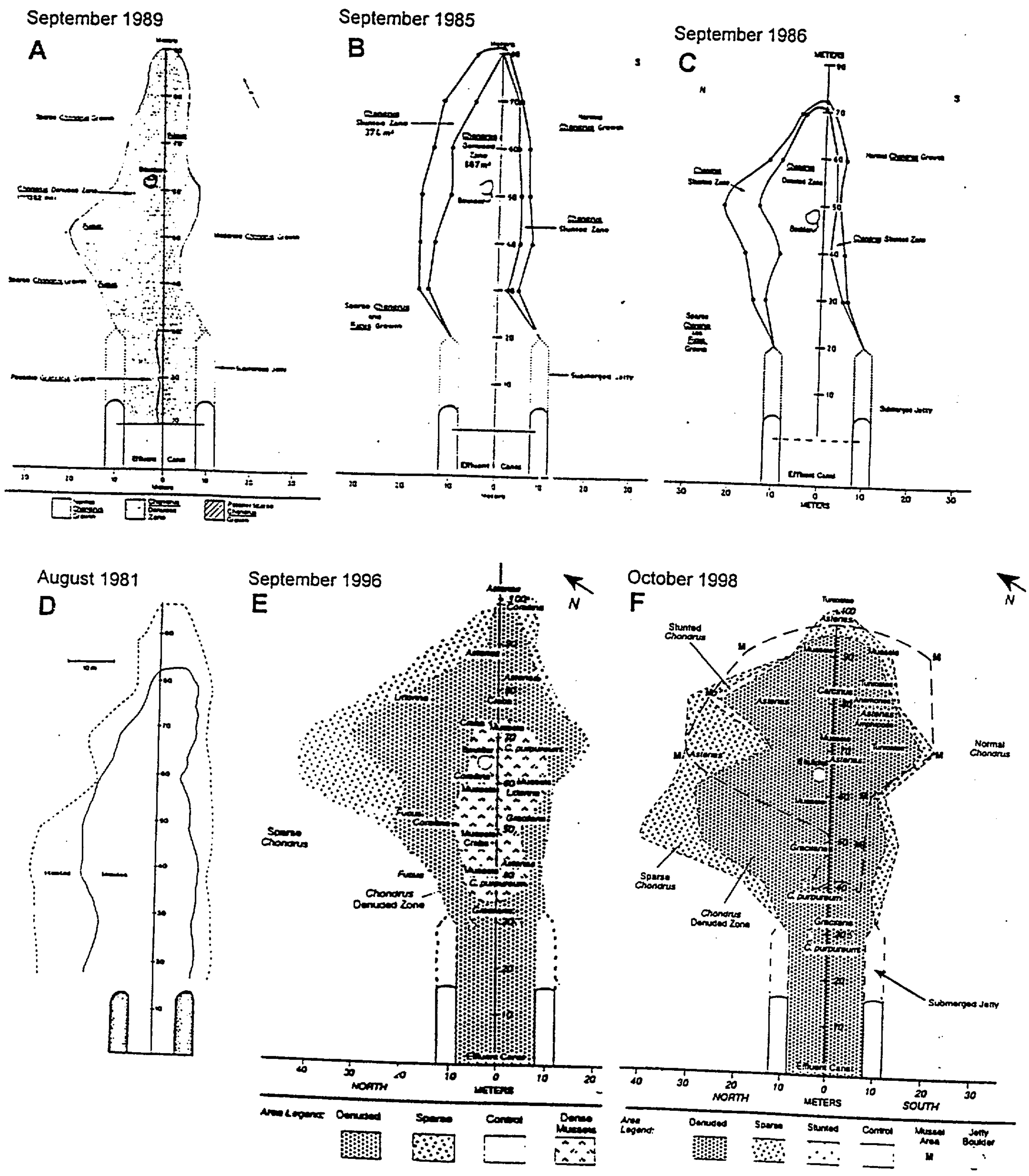


Figure 15. Representative Maps of the *Chondrus* Affected Zone Surveyed during the Fall Season from the 19-Year Survey Period: 2-Year MDC < 40% (A, B); 2-Year MDC between 50 and 70% (C, D); 2-Year MDC > 75% (E, F).

4.0 HISTORICAL IMPACT OF THE EFFLUENT DISCHARGE AT PNPS ON ALGAL DISTRIBUTION

4.1 BACKGROUND

Historically, operational conditions at the PNPS have provided opportunities to assess long-term trends associated with impacts on the benthic community. Plant operations have included consecutive years of high operation as well as times when there were complete shutdowns, sometimes for prolonged periods. The longest outage in the history of the plant began in April 1986 and continued until March 1989. During this period, the benthic community associated with the effluent canal and nearby areas immediately offshore experienced reduced current velocity as the operation of circulating pumps was restricted to one or none (Figure 16). In addition, the discharge water remained at ambient temperature. As a consequence, the benthic community normally affected by these effluent parameters recovered, so that by 1988 there was essentially no difference between the control stations and the areas near the discharge canal.

Studies conducted after the power plant resumed electrical generation at full operating capacity, with the consequent thermal discharge and consistent use of one or both circulating pumps, assessed the impact of plant operation on a benthic environment that had returned to near ambient conditions. Quantitative faunal and algal monitoring studies, and qualitative transect surveys were conducted through 1991. In 1992, community studies of the benthic algae and fauna were discontinued. From 1992 through 1997, the monitoring program consisted of quarterly qualitative surveys of the discharge area. For 1998, three seasonal (spring, summer, and fall) qualitative surveys were performed.

Figure 16 shows the monthly maximum dependable capacity (MDC) factor and circulating water pump operation of PNPS since 1980.

4.2 QUALITATIVE TRANSECT SURVEYS: 1980-1998

Results of the qualitative transect surveys from 1980 through 1998 are summarized in Figure 17. The total impacted area (denuded, sparse, and stunted), the area of the denuded zone only, and the monthly PNPS capacity factor (MDC) are plotted. The difference between the denuded and total acute impact zones represents the area of the sparse and stunted zones.

Dive surveys of the *Chondrus* zone in **1980** (annual % MDC = 51.7) occurred in January and August. The denuded area appeared to be essentially stable in extent throughout the year and was only "denuded" of algae during the colder periods of the year. In summer, this area became colonized by warm water algal species. The stunted zone varied in size, seasonally. The appearance of the stunted area did not change throughout the year except for bleaching of *Chondrus* from increased sunlight in the summer (BECo, 1980).

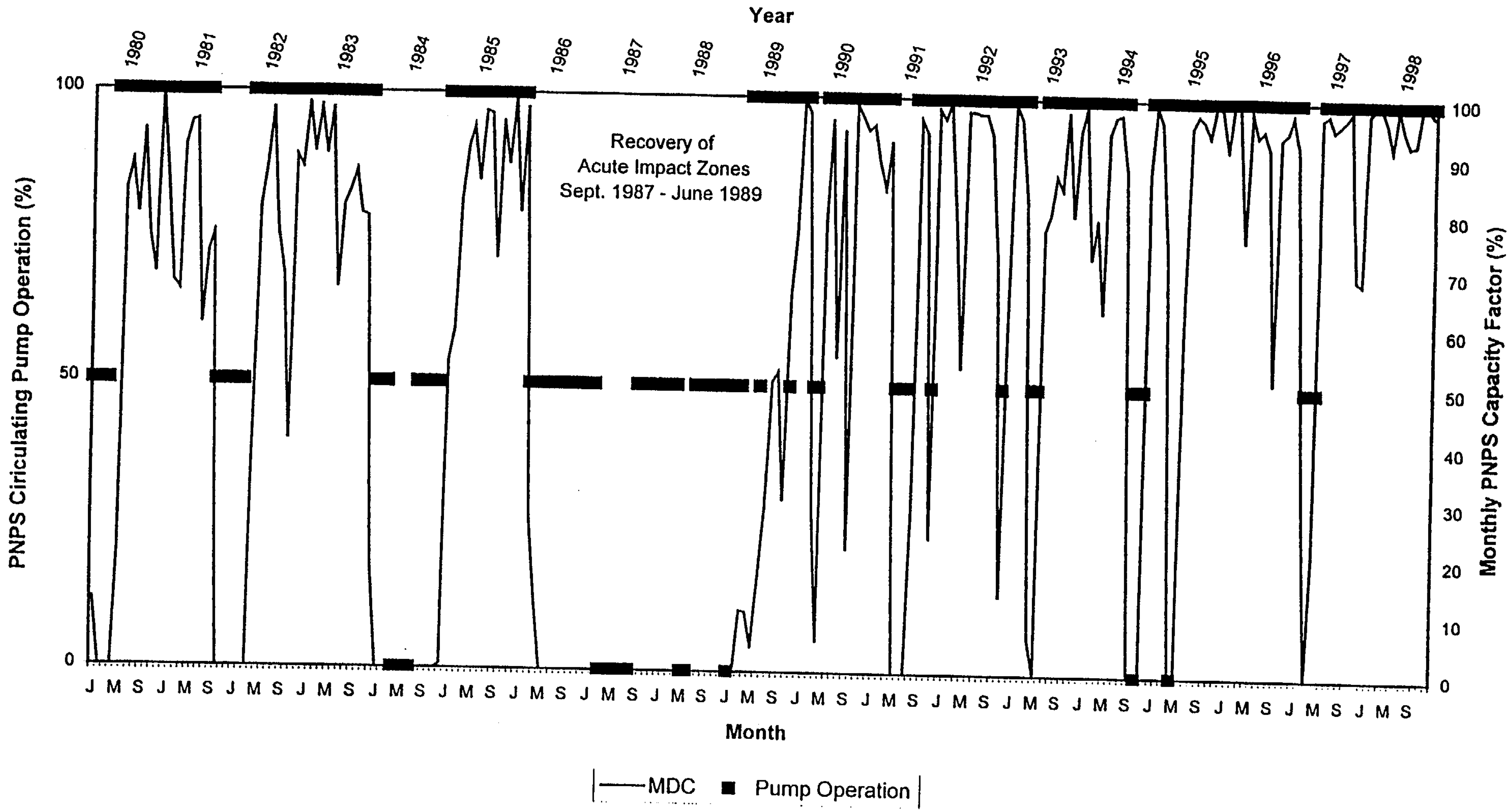


Figure 16. **Monthly PNPS Capacity Factor (solid lines) and Circulating Pump Activity (black bars at 100% = 2 pumps; at 50% = 1 pump; at 0% = 0 pumps) Plotted for the Period 1980 Through December 1998.**

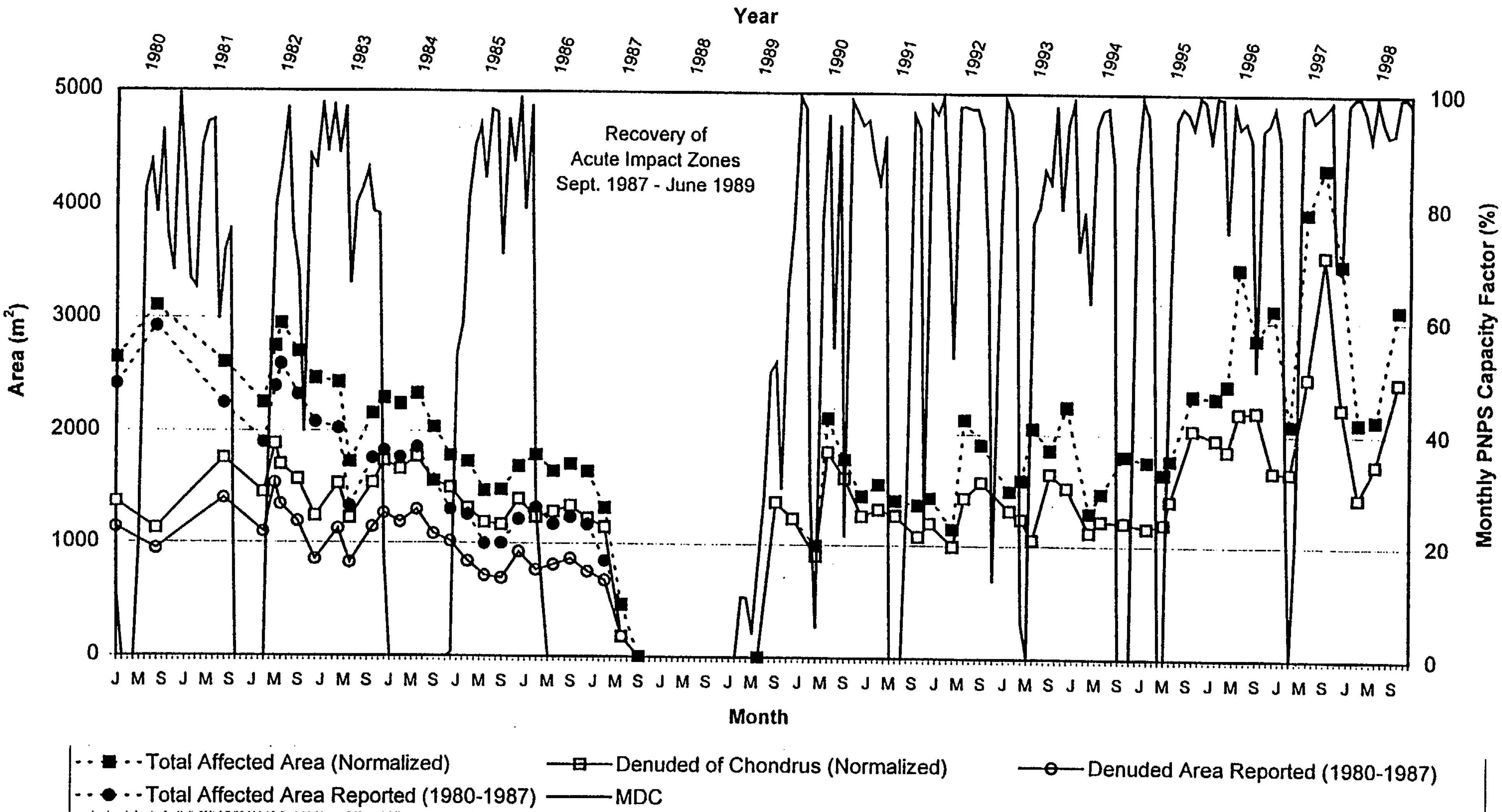


Figure 17. **Area of the Denuded and Totally Affected Zones in the Vicinity of the PNPS Effluent Canal Plotted with the Monthly PNPS Capacity Factor (MDC) for the Period 1980 through 1998. No area measurements were made from September 1987 through June 1989 because definitive demarcations of denuded and stunted zones were absent. The data shown for the 1980-1987 time period include *Chondrus* measurements as reported in the appropriate BECo reports (shown as circles) as well as the normalized data used in this analysis (shown as squares – see Appendix A).**

In **1981** (annual % MDC = 58.7), a single survey took place in August. Both the reported and normalized Chondrus denuded zones were larger in area (about 150%) than in 1980. However, the totally affected area was about 20-30-% larger in August 1980 than it was in August 1981 (BECo, 1982)

Five surveys were performed in **1982** (annual % MDC = 56.0), in March, May, June, September, and December. The data showed a tendency for the impacted area to increase in total area in spring and summer months and to decrease in size during the colder months. The plant was non-operational from October 1981 through March 1982, just prior to the April survey, and yet the *Chondrus* denuded and totally affected zones were still fairly large (BECo, 1983); the normalized values were 1454 m^2 for the denuded zone and 2254 m^2 for the totally affected zone.

The four dive surveys in **1983** (annual % MDC = 80.3) took place in April, June, October, and December. The trend seen in earlier years of the impacted areas increasing in size during the summer was not observed in 1983. In June, both the denuded and totally affected areas were smaller (even after the data were normalized) than seen in all but one earlier survey; the denuded area in August 1980 was slightly larger than in June 1983. Low air temperatures in New England in the spring of 1983 possibly were responsible for this anomaly. An attempt to correlate impact area parameters, measured in the first 10 areal surveys (1980 - June 1983), with environmental variables (wind, temperature, reactor power level, and turbidity) was reported in Semi-Annual Report No. 22 (BECo, 1984). The negative correlation discovered between mean discharge temperature and size of the denuded zone, as well as several other impact area parameters, was thought to be an artifact of the one month lag used for the preliminary analysis. It was also hypothesized that the size of the impact area might be determined by conditions well in advance of the survey.

A lag in recovery time in the acute impact zone during and following the **1984** (annual % MDC = 0.1) PNPS power outage was reported in Semi-Annual Report No. 27 (BECo, 1986). Evidence of this slow recovery included a decrease in the area of the total acute impact zone that began in mid-1984 (5 months after the cessation of power plant operations) and continued through mid-**1985** (annual % MDC = 84.4). Between December 1984 and December 1985, the total affected area was the smallest recorded between 1983 and **1986** (annual % MDC = 17.5), indicating a delay in recovery in response to the absence of thermal discharge and reduced circulating water pump operation in 1984. This delay phenomenon also held true when the situation was reversed, so that the size of the acute impact zone began to increase only 6 to 9 months (September to December 1985) after the resumption of thermal effluent discharge and normal circulating water pump operation. These results confirmed a delay of 6-9 months between the causal factors (cessation or resumption of thermal effluent discharge and normal pump operation) and associated responses (decrease or increase in size of the acute impact zone).

In **1987** (annual % MDC = 0.0), in response to the 1986-1989 outage, increased recolonization of the denuded and stunted zones by *Chondrus* made zone boundaries difficult to distinguish (no areal differences could be discerned from September 1987 through June 1989). As in summer 1984, the large size reduction of the denuded zone between December 1986 and June 1987 was primarily the result of the shutdown of the circulating water pumps in late February 1987 that continued into the summer (BECo, 1988). Water current scouring and elevated water temperatures are both stresses to algal colonization. In general, according to Bridges and Anderson (1984), scouring denudes the substratum, whereas elevated temperature results in stunted growth.

In **1988** (annual % MDC = 0.0), low circulating water pump activity caused few scouring effects. The 1988 transect surveys showed such an increase in recolonization of formerly denuded and stunted zones by *Chondrus*, because of the continuing outage, that divers could not detect zonal boundaries or make area measurements.

In March and June **1989** (annual % MDC = 28.9), divers were still unable to detect boundaries of denuded or stunted zones (BECo, 1990). In September and December 1989, presumably in response to increased PNPS operations with resultant thermal effects and scouring of the acute impact zone, boundaries began to be redefined and area measurements were made of the total impact zone.

During **1990** (annual % MDC = 72.3), boundaries between the stunted and denuded zones became even more clearly defined, and areal measurements of both zones were made. The denuded and total impact zones in June 1990 were the largest measured since 1983 (BECo, 1991). The dramatic increase in total affected area that occurred between April and June 1990 had not been seen before. The typical pattern seen prior to 1990 was that during spring, with warmer temperatures and increased sunlight, algal growth flourishes, and the impact area declines even in years when the power plant is operating at high capacity. The pattern in 1990 appeared anomalous until, more recently, a relationship was perceived between the appearance of enormous numbers of juvenile mussels and the occurrence of large denuded and total affected zones. The divers noted remarkable numbers of juvenile mussels during the June 1990 dive. Thus, it would appear that the large affected zones result, at least partly, from damage suffered by the *Chondrus* plants due to the massive settlement of mussels.

In **1991** (annual % MDC = 58.4), the boundaries of the acute impact zone remained well-defined, except that in June there was no apparent stunted zone but only an area described by the divers as "sparse", that is, where the algal plants grew normally but were thinly distributed. From March to June, the total affected area and the *Chondrus* denuded zone decreased in size, a return to the typical pattern seen before 1990 (BECo, 1992). This decrease in area continued through the October survey, perhaps aided by the power plant outage from May into August. There was a slight increase in the total affected area in December.

During **1992** (annual % MDC = 80.6), the divers were unable to discern a *Chondrus* stunted region. Except for June, they noted zones containing normal but sparsely distributed *Chondrus* plants. An enormous set of mussels that had reached 0.5 cm in length by June, totally obliterated the boundary between the denuded and sparse areas. Parallel to results seen in 1990, the areas of the denuded and total acute impact zones in June 1992 were larger than any seen (except for 1990) since 1983, and the dramatic increase in the total affected area that occurred between April and June 1990 occurred once again in 1992. Thus, the pattern seen in 1990 can no longer be considered anomalous but may be related to oceanographic conditions that lead to a large settlement of mussel larvae and consequent physical damage to *Chondrus* plants (BECo, 1993).

In **1993** (annual % MDC = 74.0), the June mussel set that hampers *Chondrus* growth was not as dense as those that occurred in 1990 and 1992. Consequently, the denuded zone was smaller in June than it had been in April, the opposite of the situation seen in 1990 and 1992 (BECo, 1994). The area of the denuded zone in September was slightly larger than it had been in September of 1990 and 1992, but the denuded zone in December was much larger than in previous years. In addition, the total affected area in December was the largest observed since 1983, rivaling the areas measured in the summers of 1990 and 1992. This may be due partly to the very early winter date (Dec. 2) of the survey and partly to damage imposed by a heavy infestation of the encrusting bryozoan, *Membranipora membranacea.*

In **1994** (annual % MDC = 65.2), the denuded and total affected *Chondrus* areas in all four seasons were similar in size to those found during prior surveys (since 1989) at times of full or nearly full power plant operation (BECo, 1995). The dense mussel recruitment that occurred in June obscured the boundary between the denuded and sparse/stunted regions. Damage caused by the mussels to the *Chondrus* plants contributed to the enlargement of both *Chondrus* zones between the April and June surveys. The three-month fall power plant outage (September through November) appeared to have had no effect on the size of either the denuded or total affected *Chondrus* zones.

In **1995** (annual % MDC = 76.4), the sizes of the denuded and total affected *Chondrus* areas were within the ranges seen in earlier surveys only for the early May and late June surveys (BECo, 1996). The impacted areas in October 1995 and February 1996 were much larger than those measured during any earlier fall and winter surveys and most closely approximated the impacted areas seen in September and December 1993. The two-month (April/May) spring power outage appeared to have no effect on the size of the *Chondrus* affected areas seen in May or June. However, the high plant operating capacity in effect from June 1995 through February 1996, in conjunction with a high mussel set in June, may have contributed to the largest fall and winter denuded and totally affected *Chondrus* zones seen since the current monitoring program began in 1983.

In **1996** (annual % MDC = 90.5), the sizes of the denuded and totally affected *Chondrus* areas continued to increase over the historical baseline measurements (1983 through February 1996) for the first three surveys. In December, the denuded zone declined in size to less than the winter historical baseline but was still the second largest ever observed in winter (BECo, 1997). The large *Chondrus* denuded and totally affected zones seen in each survey since October 1995 may be due to a combination of the high plant capacity that was in effect for the 18 months starting in July 1995 (mean = 92.6%), high summer water temperatures, and extremely dense settlement by mussel larvae in late spring that totally covered, possibly damaging, the algal plants.

In **1997** (annual % MDC = 73.4), the sizes of the denuded and totally affected *Chondrus* zones were again larger than historical baseline measurements. In March 1997, the impacted areas were the second largest ever measured in spring. For the remaining three seasons, the areas of the denuded and totally affected zones were the largest ever seen for the corresponding season. The sizes of the denuded and totally affected zones in 1997 were extraordinarily large, larger than in 1996 for three surveys, and appeared not to track the reduction in the annual plant capacity factor from 90.5% in 1996 to 73.4% in 1997, that resulted from a two-month spring power outage. Turbidity from the dredging operation that took place from mid-June until the end of August, in conjunction with dense settlement by juvenile mussels that occurred sometime between March 28 and June 22, high summer water temperatures, and a moderately high 1997 power plant capacity, probably caused many *Chondrus* plants to die back to their holdfasts, yielding the very large affected *Chondrus* zones.

In **1998** (annual % MDC = 97.1), some recovery apparently took place in the outfall area compared to the very large denuded and totally affected *Chondrus* zones seen in the summer, fall, and winter of 1997. Areal measurements taken in March were somewhat higher than the historical maxima, but those made in June were well within those seen in previous surveys when the plant was in full or nearly full operation. The sizes of the *Chondrus* denuded and totalaffected zones did increase dramatically between the June and October surveys, probably as a consequence of warm water temperatures in the summer combined with the extremely high plant capacity (97.1%) in effect in 1998, the highest seen in the history of plant operations.

5.0 CONCLUSIONS

- It is well understood that the PNPS does have an impact upon the benthic algal communities in the nearfield discharge area. However, this impact is confined to a relatively small area, typically $<2,000\ m^2$ for the denuded zone and $< 3,000\ m^2$ for the total affected zone.

- The regression analyses performed for this report clearly demonstrate a nearfield impact. Even the least predictive of the four models, using power output (MDC) as a variable, had an $r^2 > 0.68$ which indicates that this model accounts for at least 68% of the variability. The r^2 values for the other three models were even higher (0.73 – 0.82).

- Surprisingly, a 2-year running mean of plant operating capacity, measured either by MDC or pumping capacity, had excellent explanatory power for the long-term distribution and density of *Chondrus* in the discharge region. In contrast, the major short-term plant-operating characteristic, i.e., monthly mean MDC, was a relatively weak predictor of short-term changes in *Chondrus* cover. This means that the response of *Chondrus* to plant operating conditions occurs over a relatively long time period (many months rather than just a few).

- Variability in natural environmental factors accounts for most of the short-term variability in size of the *Chondrus* denuded and total affected zones. Such factors can be biological and include impacts caused by competition, predation (starfish, sea urchins, etc.), grazing, or colonization by benthic organisms (e.g., coverage of algae by settlement of blue mussel larvae in the spring). Other potentially significant sources of variability, not accounted for by this data analysis, include variations in the physical environment, such as storm-generated currents and wave action. Man-induced modifications to the surrounding habitat, such as the siltation that occurs when the intake channel is dredged, are also factors that can contribute to short-term variability in the areal measurements of the algal community, which were not included in this analysis. These types of environmental factors are often observed but may occur infrequently and not be tracked as meticulously as some of the more standard variables. Changes in these unrecorded explanatory variables could occur over long time periods, affecting large segments of the 19-year benthic transect record (low frequency), or they could occur over relatively short periods of time, perhaps affecting only one *Chondrus* cover measurement (high frequency). These types of detailed explanatory physical and ecological variables are not included in the database and thus contribute to the variation attributed to random noise in the statistical models described in this report.

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APPENDIX A

NORMALIZATION OF AREAL DATA

For the semi-annual reports that have been prepared starting in 1990, the area of the *Chondrus* denuded and affected zones have been plotted routinely against time beginning in 1983. These data were all gleaned from the various BECo reports. When adding the data from eight dives made during 1980-1982 for the long-term analysis, an inconsistency was noticed immediately. Namely, that the area between the jetties was included as part of the denuded zone for the two dives performed in 1980 (BECo 1980) but was not included in the 1981 and 1982 dives (BECo, 1982a, 1982b). The area between the plotted jetties has been included as part of the denuded zone since at least Sept. 1989 (the date of the first diver's map in our possession) and the calculated area (33 m long x 16 m wide + 6 m at tip = 534 m) between the jetties has been consistent since 1989. Also, in the older plots it can be seen that in 1980-1982 the jetties were plotted much closer together (10 m) than they have been since then (16-18 m). So, the 1980-1989 plots were reviewed and where necessary the area between the plotted jetties, including an adjustment for canal width, was added to the older data so that it would be consistent with that presented since 1989.

Figure A1 shows the assorted representations of the effluent canal jetties that have been used in the various BECo reports since 1980. Figure A1-A shows the 1980 plot; the denuded area (dark color) between the jetties was indeed included in the results as confirmed by creative xeroxing of the map to scale onto graph paper and counting squares. A check of all intervening plots showed that the area between the jetties was not included in the areal results again until 1989.

Other differences in the jetty plots require additional adjustment to the areal data. Figures A1-E (March 1985) and A1-F (Sept. 1986) show a change in the map that requires adding 160 m^2, the area below the dashed line in A1-F (10 m long x 16 m wide), to all denuded zones mapped prior to Sept. 1985. An assumption was made that when the new plot shown in Figure A1-F was designed that there was an attempt to ensure that the dashed line in A1-F corresponded to the base line in A1-E (as lined up in Figure A1). To cross check this assumption, a comparison was made of the positions plotted for the large boulder in the two types of plots. Figures A2-A and A2-B show maps of the outfall area reduced to scale and with the boulder lined up horizontally. In these maps the baseline of Figure A2-A (March 1985 was the first time the boulder was plotted) lines up about 5 m above the dashed line (top of non-submerged jetty) in Figure A2-B. Holding the boulder in place (lined up with that in Figure A2-B) and adjusting the remainder of Figure A2-A so that the position of the boulder relative to the CTL is the same as in Figure A2-B (at the 53-m mark on the CTL) then the CTL and plotted outlines are pulled down about 5 m. As a result, the baseline in A2-A lines up with the dashed line in A2-B, in agreement with the alignment shown in Figures A1-E and A1-F.

Figures A2-B and A2-C show a change in the meter marks on the CTL that occurred between two adjacent reports (BECo, 1987, 1988). The dashed line at the 0-meter mark in Figure A2-B was lowered to the new baseline, so that distances measured out along the CTL were thereafter 10 meters greater than previously. The first time that a denuded zone was seen, after the extended power outage (Sept. 1987 - June 1989), the area affected was plotted as shown in Figure A2-D. Although in this figure the denuded zone was indicated by stippling only for that area beyond the 10-m mark on the CTL, the original map prepared by the divers shows the entire area as denuded zone. The data reported (BECo, 1990) matches the data from the divers' map, that is, the area of the September 1989 denuded zone reported includes the area between 30 m of jetties.

The early data were normalized by aligning the jetty template that has been used since 1989 over the earlier maps but with the current baseline placed 10 m below the early baselines. The rationale for this was based on 1) the line-up of the boulder, 2) the obvious attempt to make the diagram designed in Sept. 1985 comparable to those used in reports from Dec. 1983 through June 1985, and 3) the renumbering (adding 10 m) of the CTL that occurred in the plotted survey in March 1987. Figure A2-E depicts the template that has been used for plotting the jetties since 1990 and shows that, since then, the denuded zone has included the area between 30 meters of jetty and submerged jetty.

The adjustments made to the reported areal measurements of the *Chondrus* denuded zone in the historical data are given in Table A-1 and Figure 17. The increases in the area of the denuded zones ranged from 182 m^2 to 480 m^2 depending on differences in the plotting of canal width and where on the CTL the original measurements were made (see Table A-1). These normalized areas for the denuded zones were still well within the range seen in the decade that followed. If the historical baselines were adjusted to incorporate this new data only one value would need to be changed. Corrections of all of the reported measurements for the distance the affected area extends out along the CTL were not attempted as these dimensions were not used for the trend analysis.

Table A1. **Normalization of the denuded *Chondrus* zone in data taken from January 1980 through March 1987.**

Survey	*Chondrus* denuded zone (m^2)						
	Reported data	Area determined using maps from reports		% difference	Jetty included ?	Area to be added	Normalized area
		Area	CTL -m mark from which measurements were made				
Jan. 1980	1140	1240	0 m	+8.8	Yes (142)	229	1369
Aug. 1980	947	963	0 m	+1.7	Yes (142)	182	1129
Aug. 1981	1400	1307	14 m	-6.6	No	358	1758
March 1982	1100	1066	14 m	-3.1	No	354	1454
May 1982	1536	1625	14 m	+5.8	No	351	1887
June 1982	1346	**1550**	14 m	**+15.5**	No	356	1702
Sept. 1982	1193	1294	15 m	+8.5	No	377	1570
Dec. 1982	856	888	15 m	+3.7	No	386	1242
April 1983	1128	1059	15 m	-6.1	No	404	1532
June 1983	829	828	15 m	-0.1	No	396	1225
Oct. 1983	1145	**1390**	15 m	**+21.4**	No	396	1541
Dec. 1983	1270	1233	20 m	-2.9	No	468	1738
March 1984	1190	1220	20 m	+2.5	No	475	1665
June 1984	1300	1335	20 m	+2.7	No	474	1774
Sept. 1984	1085	1106	20 m	+1.9	No	474	1559
Dec. 1984	1020	1017	20 m	-0.3	No	480	1500
March 1985	840	854	20 m	+1.7	No	475	1315
June 1985	714	780	20 m	+9.2	No	474	1188
Sept. 1985	691	718	20 m	+3.9	No	480	1171
Dec. 1985	925	986	20 m	+6.6	No	474	1399
March 1986	765	727	20 m	-5.0	No	473	1238
June 1986	812	777	20 m	-4.3	No	475	1287
Sept. 1986	867	870	20 m	+0.3	No	474	1341
Dec. 1986	753	761	20 m	+1.1	No	474	1227
March 1987	676 - typo?	837	20 m	+23.8	No	474	1150

Bold values show areas of denuded *Chondrus* zones determined using maps from reports that are more than 15% larger than reported areas.

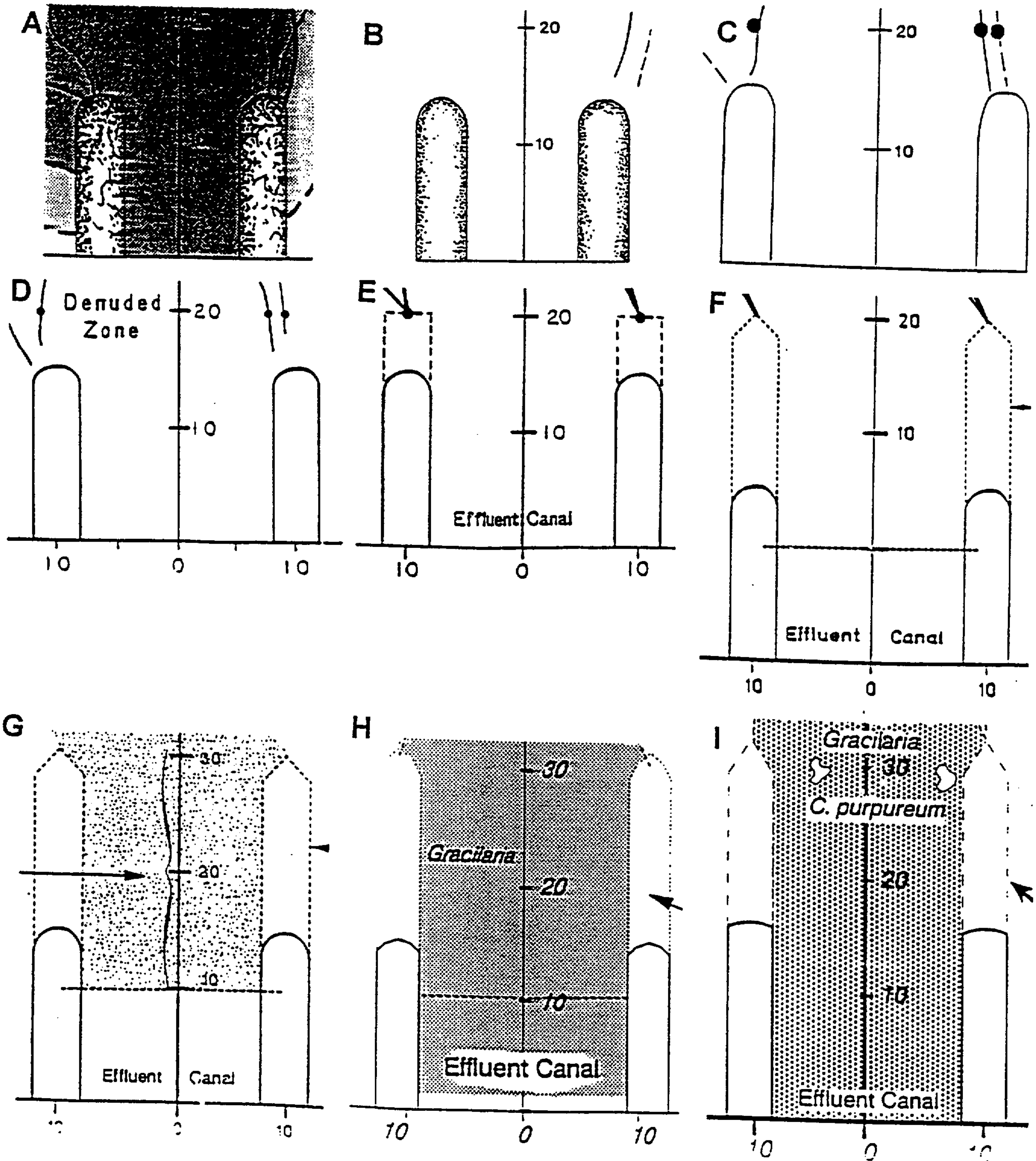

Figure A1. **Mapped Configurations of the Effluent Canal Jetties used in BECo Reports from 1980 through 1998. A, Jan./Aug. 1980; B, May 1982; C, Sept. 1982; D, June 1983; E, March 1985; F, Sept. 1986; G. Sept. 1989; H. Dec. 1990; I. April 1996.**

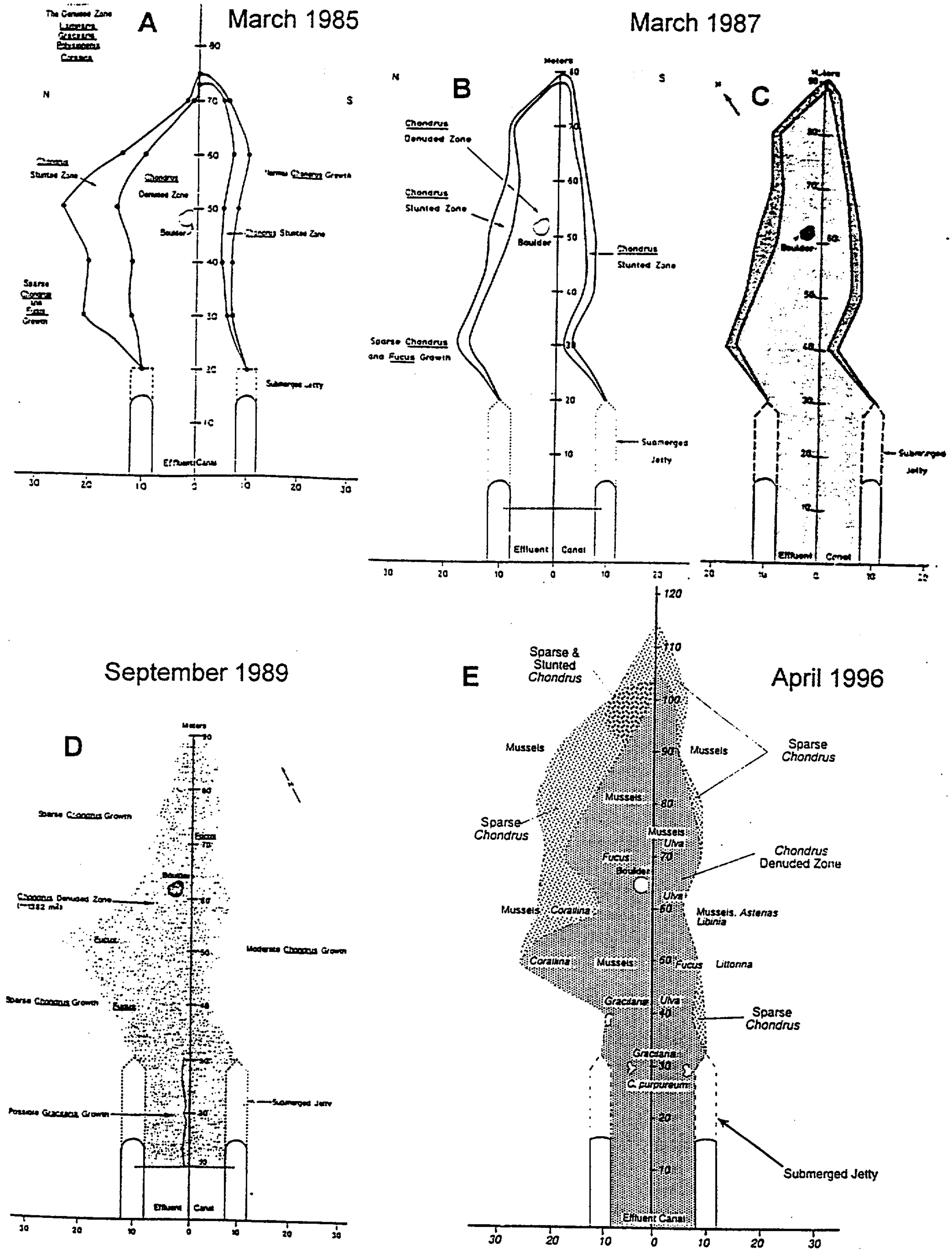

Figure A2. **Area Maps Showing Progressive Changes in Depictions of the Positions of the Baseline Relative to the Jetties and the Large Mid-Transect Line Boulder (A, B, C) and the *Chondrus* Denuded Zone (B, C, D, E). A, March 1985. B, March 1987 (BECo, 1987). C, March 1987 (BECo, 1988). D, Sept. 1989. E, April 1996.**

PNPS Operational Data; Temperature Data from Impingement Records; 1980 – 1998

YEAR	MONTH	CHONDRUS DENUDED AREA (m2)	TOTAL AFFECTED AREA (m2)	STUNTED AREA (m2)	MEAN MDC	% PUMP CAPACITY	MONTHLY MEAN INTAKE TEMP (F)	MAX. INTAKE TEMP (F)	DATE
1979	J				53.8	100	55.56	61	
1979	A				85.7	100	56.73	60.4	
1979	S				78.6	100	53.75	56.5	
1979	O				83.9	100	51.94	56.9	
1979	N				96.7	100	48.75	50.9	
1979	D				93.2	100	40.86	46.3	
1980	J	1369	2649	1280	11.8	50	*	43.7	No date given
1980	F				0	50	*	44	
1980	M				0	50	*	42	
1980	A				0	50	41.77	39.5	
1980	M				20.8	100	48.18	52.9	
1980	J				83.1	100	49.49	53.9	
1980	J				87.7	100	52.78	54.8	
1980	A	1129	3108	1979	78.7	100	58.02	62	No date given
1980	S				93.4	100	55.89	61.1	
1980	O				74.9	100	54.64	58.1	
1980	N				68.4	100	46.33	50	
1980	D				99.6	100	39.34	45.8	
1981	J				85.7	100	31.95	35	
1981	F				67	100	32.68	37.5	
1981	M				65.6	100	39.04	45	
1981	A				90.7	100	37.60	39.5	
1981	M				94.6	100	45.99	54	
1981	J				95	100	52.74	58	
1981	J				59.8	100	61.01	66.6	
1981	A	1758	2608	850	72.1	100	63.68	66.5	No date given
1981	S				75.4	100	63.70	67.5	
1981	O				0	50	*	62	
1981	N				0	50	*	56	
1981	D				0	50	*	61	
1982	J				0	50	*	38	
1982	F				0	50	*	34.5	
1982	M	1454	2254	800	0	50	*	44	No date given
1982	A				44.1	100	43.60	46	
1982	M	1887	2751	864	80.1	100	49.73	55	No date given
1982	J	1702	2951	1249	87.5	100	55.10	58.5	No date given
1982	J				97.2	100	55.98	60.5	
1982	A				75.7	100	60.23	65	
1982	S	1570	2705	1135	68.3	100	59.04	60.5	24-Sep
1982	O				39.9	100	55.60	59.5	
1982	N				88.9	100	50.36	53.7	
1982	D	1242	2468	1226	87.1	100	44.55	50	1-Dec
1983	J				98.0	100	38.88	42	
1983	F				90.0	100	37.05	41	
1983	M				97.3	100	40.25	42.5	
1983	A	1532	2433	901	89.7	100	43.14	45.5	13-Apr

YEAR	MONTH	CHONDRUS DENUDED AREA (m2)	TOTAL AFFECTED AREA (m2)	STUNTED AREA (m2)	MEAN MDC	% PUMP CAPACITY	MONTHLY MEAN INTAKE TEMP (F)	MAX. INTAKE TEMP (F)	DATE
1983	M				97.3	100	47.26	54.4	
1983	J	1225	1728	503	66.2	100	57.54	64.3	23-Jun
1983	J				80.5	100	59.44	63.4	
1983	A				83.1	100	61.46	67	
1983	S				86.5	100	61.06	64	
1983	O	1541	2158	617	79.0	100	55.38	59.2	3-Oct
1983	N				78.6	100	49.64	52	
1983	D	1738	2298	560	18.1	100	41.43	46.3	9-Dec
1984	J				0.0	50	33.55	35.7	
1984	F				0.0	50	36.08	42.7	
1984	M	1665	2245	580	0.0	50	37.62	46	28-Mar
1984	A				0.0	0	*	60	
1984	M				0.0	0	*	65	
1984	J	1774	2334	560	0.0	0	*	67	27-Jun
1984	J				0.0	0	67.00	68	
1984	A				0.0	50	64.62	68.2	
1984	S	1559	2039	480	0.0	50	60.91	63.3	11-Sep
1984	O				0.0	50	55.88	59.5	
1984	N				0.0	50	45.71	52.7	
1984	D	1500	1785	285	0.7	50	42.30	46.5	11-Dec
1985	J				54.0	100	35.61	46.5	
1985	F				59.3	100	33.40	36.2	
1985	M	1315	1735	420	81.8	100	37.84	44.2	27-Mar
1985	A				90.8	100	41.85	45.5	
1985	M				94.3	100	50.55	60.2	
1985	J	1188	1474	286	85.0	100	56.31	58.5	14-Jun
1985	J				96.9	100	58.96	65.4	
1985	A				96.5	100	63.44	66.5	
1985	S	1171	1483	312	71.4	100	63.74	67	20-Sep
1985	O				95.4	100	57.75	60.5	
1985	N				88.1	100	52.01	54.6	
1985	D	1399	1694	295	99.1	100	42.22	47.5	11-Dec
1986	J				79.5	100	35.97	39.5	
1986	F				97.7	100	34.98	38.5	
1986	M	1238	1798	560	26.9	50	37.18	42.5	13-Mar
1986	A				11.9	50	44.98	51	
1986	M				0.0	50	48.84	54	
1986	J	1287	1651	364	0.0	50	56.11	59	19-Jun
1986	J				0.0	50	61.51	66	
1986	A				0.0	50	63.29	68	
1986	S	1341	1715	374	0.0	50	58.26	63	24-Sep
1986	O				0.0	50	58.58	61.7	
1986	N				0.0	50	52.23	57	
1986	D	1227	1648	421	0.0	50	44.00	49	17-Dec
1987	J				0.0	50	38.42	41.7	
1987	F				0.0	50	38.71	52	
1987	M	1150	1326	176	0.0	0	40.70	43	25-Mar

... Data, Temperature Data from Impingement Records; 1980 – 1998

YEAR	MONTH	CHONDRUS DENUDED AREA (m2)	TOTAL AFFECTED AREA (m2)	STUNTED AREA (m2)	MEAN MDC	% PUMP CAPACITY	MONTHLY MEAN INTAKE TEMP (F)	MAX. INTAKE TEMP (F)	DATE
1987	A				0.0	0	*	52.5	
1987	M				0.0	0	*	59.7	
1987	J	179	463	284	0.0	0	56.68	59.5	9-Jun
1987	J				0.0	0	63.00	69	
1987	A				0.0	0	*	60	
1987	S				0.0	50	58.21	56.8	
1987	O				0.0	50	52.73	56.8	
1987	N				0.0	50	47.49	55	
1987	D				0.0	50	41.30	48	
1988	J				0.0	50	36.80	42	
1988	F				0.0	50	36.00	38.5	
1988	M				0.0	50	36.20	40	
1988	A				0.0	50	41.30	49	
1988	M				0.0	0	48.79	59.3	
1988	J				0.0	0	50.21	55	
1988	J				0.0	50	52.83	56.5	
1988	A				0.0	50	58.75	66	
1988	S				0.0	50	56.86	59.7	
1988	O				0.0	50	52.31	55.5	
1988	N				0.0	50	47.17	52	
1988	D				0.0	50	38.90	42.5	
1989	J				0.0	0	37.85	41.7	
1989	F				0.0	50	42.97	52.2	
1989	M				10.7	50	38.43	43	
1989	A				10.5	100	41.37	45	
1989	M				4.6	100	48.70	53	
1989	J				16.4	50	57.38	61	
1989	J				28.6	100	61.57	64.9	
1989	A				50.8	100	59.80	64.5	
1989	S	1382	1382	0	52.5	100	58.62	64.1	28-Sep
1989	O				30.1	100	53.92	56	
1989	N				66.0	50	45.60	51	
1989	D	1235	1235	0	77.1	100	35.58	42.5	15-Dec
1990	J				99.4	100	38.45	40.8	
1990	F				97.4	100	38.15	42	
1990	M				30.0	50	37.87	40	
1990	A	904	994	90	5.4	50	46.63	53	6-Apr
1990	M				77.9	100	50.86	54.5	
1990	J	1835	2135	300	96.3	100	53.63	60	19-Jun
1990	J				55.1	100	61.24	64.7	
1990	A				94.5	100	64.71	69.5	
1990	S	1600	1767	167	21.6	100	63.35	67.6	19-Sep
1990	O				98.7	100	55.13	60.2	
1990	N				96.8	100	47.88	51.5	
1990	D	1260	1440	180	94.5	100	42.86	47.3	18-Dec
1991	J				95.4	100	37.56	42	
1991	F				88.9	100	36.70	38	

YEAR	MONTH	CHONDRUS DENUDED AREA (m2)	TOTAL AFFECTED AREA (m2)	STUNTED AREA (m2)	MEAN MDC	% PUMP CAPACITY	MONTHLY MEAN INTAKE TEMP (F)	MAX. INTAKE TEMP (F)	DATE
1991	M	1321	1546	225	84.6	100	39.72	42	28-Mar
1991	A				92.7	100	44.46	47.1	
1991	M				0.0	50	53.79	58.8	
1991	J	1265	1402	137	0.0	50	60.09	61.8	27-Jun
1991	J				0.0	50	61.67	66	
1991	A				28.5	100	58.49	61.3	
1991	S				96.4	100	58.63	63.1	
1991	O	1080	1363	283	94.2	100	52.00	53.7	4-Oct
1991	N				23.7	50	47.88	52.7	
1991	D	1200	1428	228	98.1	100	41.74	46.2	26-Dec
1992	J				96.6	100	36.34	39.7	
1992	F				99.4	100	34.32	36.5	
1992	M				80.4	100	36.53	40.3	
1992	A	996	1150	154	53.5	100	43.42	45.5	9-Apr
1992	M				97.8	100	51.56	54.5	
1992	J	1429	2130	701	97.8	100	54.21	58	16-Jun
1992	J				97.4	100	55.94	61.6	
1992	A				97.4	100	60.40	65.6	
1992	S	1569	1908	339	94.1	100	57.42	61.4	29-Sep
1992	O				72.8	100	53.83	58	
1992	N				13.7	50	50.85	56	
1992	D				65.2	100	43.06	47.5	
1993	J				99.0	100	37.36	42.7	
1993	F	1315	1491	177	96.7	100	32.21	35.5	10-Feb
1993	M				83.2	100	35.24	40.5	
1993	A	1239	1590	351	6.4	50	41.16	41.1	8-Apr
1993	M				0.4	50	48.33	53	
1993	J	1055	2058	1003	77.5	100	52.70	56	28-Jun
1993	J				80.3	100	56.78	64.1	
1993	A				86.9	100	53.66	57.9	
1993	S	1648	1863	215	84.8	100	50.55	55.7	20-Sep
1993	O				98.0	100	43.96	46.5	
1993	N				80.0	100	39.97	42	
1993	D	1523	2243	720	94.8	100	34.53	37.9	2-Dec
1994	J				98.8	100	28.21	31.3	
1994	F				72.5	100	29.18	37	
1994	M				79.5	100	30.91	35.3	
1994	A	1121	1293	172	63.3	100	37.95	41.7	11-Apr
1994	M				94.5	100	44.26	48.5	
1994	J	1223	1472	249	97.2	100	45.21	49.3	27-Jun
1994	J				97.6	100	56.85	64.4	
1994	A				88.2	100	59.34	62.5	
1994	S				0.0	50	60.45	65	
1994	O	1208	1809	601	0.0	0	63.33	70	6-Oct
1994	N				0.0	50	55.78	67.5	
1994	D				87.7	100	44.88	48	
1995	J				99.1	100	41.13	48.3	

YEAR	MONTH	CHONDRUS DENUDED AREA (m2)	TOTAL AFFECTED AREA (m2)	STUNTED AREA (m2)	MEAN MDC	% PUMP CAPACITY	MONTHLY MEAN INTAKE TEMP (F)	MAX. INTAKE TEMP (F)	DATE
1995	F	1163	1758	595	96.3	100	36.61	41.3	1-Feb
1995	M				74.4	100	39.51	41	
1995	A				0.0	0	41.67	42.5	
1995	M	1198	1648	450	0.0	100	48.77	51	2-May
1995	J	1405	1772	367	65.1	100	56.43	60.9	30-Jun
1995	J				95.7	100	58.14	64	
1995	A				97.7	100	67.31	72	
1995	S				96.7	100	62.37	66	
1995	O	2043	2348	305	94.3	100	57.93	62.4	11-Oct
1995	N				99.5	100	50.61	54	
1995	D				98.8	100	40.33	45.1	
1996	J				92.1	100	37.15	39.3	
1996	F	1961	2328	367	99.4	100	35.82	38.3	21-Feb
1996	M				99.3	100	37.38	40.5	
1996	A	1860	2436	577	75.9	100	41.83	44.4	29-Apr
1996	M				98.2	100	48.56	56.5	
1996	J	2194	3473	1279	94.3	100	56.03	64.9	27-Jun
1996	J				95.3	100	56.08	60	
1996	A				92.3	100	60.78	65.1	
1996	S	2209	2845	636	51.4	100	62.92	64.9	26-Sep
1996	O				94.0	100	57.50	60.3	
1996	N				94.9	100	49.63	54	
1996	D	1671	3111	1440	97.7	100	45.18	50.1	24-Dec
1997	J				92.5	100	38.78	42.3	
1997	F				42.1	50	37.36	38	
1997	M	1662	2092	430	0.0	50	39.20	42.3	28-Mar
1997	A				21.4	50	44.08	46.3	
1997	M				97.4	100	47.82	53.8	
1997	J	2505	3972	1467	98.1	100	58.70	62.9	22-Jun
1997	J				95.5	100	60.59	72.1	
1997	A				96.4	100	62.35	62.2	
1997	S	3587	4364	777	97.4	100	61.66	65	17-Sep
1997	O				98.7	100	55.67	59.5	
1997	N				69.5	100	50.81	55.5	
1997	D	2241	3512	1271	68.8	100	41.04	42.6	17-Dec
1998	J				98.4	100	40.50	43.9	
1998	F				99.5	100	39.64	43.7	
1998	M	1437	2112	675	99.5	100	40.47	42.5	2-Mar
1998	A				97.0	100	45.23	47.5	
1998	M				92.5	100	51.45	58.1	
1998	J	1738	2136	398	99.4	100	51.81	57.8	11-Jun
1998	J				95.5	100	57.51	62.3	
1998	A				93.0	100	57.68	65.9	
1998	S				93.3	100	59.97	63.8	
1998	O	2469	3112	643	99.4	100	54.40	58.5	28-Oct
1998	N				99.6	100	49.90		
1998	D				98.2	100	45.30		

III. C. ENTRAINMENT MONITORING & IMPACT

ICHTHYOPLANKTON ENTRAINMENT MONITORING

AT PILGRIM NUCLEAR POWER STATION

JANUARY - DECEMBER 1999

Submitted to

Entergy Nuclear Generation Company

Pilgrim Nuclear Power Station

Plymouth, Massachusetts

by

Marine Research, Inc.

Falmouth, Massachusetts

April 1, 2000

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A* Densities of fish eggs and larvae per 100 m^3 of water recorded in the PNPS discharge canal by species, date, and replicate, January-December 1999.

B* Geometric mean monthly densities and 95% confidence limits per 100 m^3 of water for the dominant species of fish eggs and larvae entrained at PNPS, January-December 1981-1999.

*Available upon request.

SECTION I
SUMMARY

Sampling of entrained ichthyoplankton at PNPS 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. From March through September single samples were taken three times every week in conjunction with the impingement monitoring study. On May 10th the Station shut down both main circulating seawater pumps. During the period of time when both pumps were off, sampling was completed on seven occasions by streaming a net in the salt service water system flow. On June 11th one main seawater pump was returned to service and sampling resumed three times per week.

A total of 41 species of fish were represented in the January-December samples, three above the 25-year mean of 38 species. Winter-early spring samples were dominated by American plaice, yellowtail flounder, fourbeard rockling, Atlantic cod, and winter flounder eggs along with sand lance, sculpin, and rock gunnel larvae. Late spring-summer collections, composed of those taken in May-July, were dominated by tautog\cunner, and windowpane eggs along with cunner, sand lance, winter flounder, radiated shanny, hake, Atlantic menhaden, tautog and fourbeard rockling larvae. Late summer-autumn collections were dominated by tautog/cunner, windowpane and rockling/hake eggs and Atlantic menhaden, silver hake, Atlantic herring, rockling, hake, windowpane, tautog, black seabass, cunner, and fourspot flounder.

Comparisons of ichthyoplankton densities over the 1975-1998 time series suggested that, in many cases, numbers were consistent with those recorded from 1982 through 1998. Exceptions included mackerel eggs and larvae and hake, radiated shanny, and winter flounder larvae. These species were relatively low in 1999 compared to previous years. These differences can partly be explained because both main circulating pumps were out of service for most of the spawning season for some of these species.

Unusually high entrainment densities, as defined under PNPS's notification plan, were identified on a number of occasions in 1999. These involved Atlantic menhaden, windowpane, searobin, and tautog/cunner eggs and rock gunnel, sand lance, Atlantic herring, seasnail, hake, tautog, rockling, and Atlantic menhaden larvae. Atlantic menhaden larvae displayed the most protracted period of high numbers with unusually high densities of larvae being recorded on 25 occasions during July, August, September, October, and November. On one occasion in September, menhaden exceeded all previous densities for that month dating back to 1975. Among larval rock gunnel densities, all but one in January exceeded the notification level for that month with three of those exceeding all previous January observations.

Entrainment 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 and were assigned a market value based on current or estimated prices. Entrainment of winter flounder was examined further using population modeling software. Equivalent adult estimates for winter flounder in 1999 were 289 or 2,382 age 3 adults based on two suites of survival values. These totals were well below the time series mean as a result of low circulating water volumes during a spring refueling outage. An EA estimate for cunner lost to entrainment in 1999 was 242,511 fish about 54% of the long term mean. The 1999 value amounted to less then 1% of an estimate of the number of cunner spawning in the PNPS area. Egg and larval entrainment of Atlantic mackerel in 1999 was equivalent to 22 age 1 fish or 9 age 3 fish. Like flounder these values were well below average since the Station circulating water system was shutdown during the peak of the mackerel season. EA values for menhaden were 2,583 age 2 fish in 1999 similar to the long term average of 2,804. These totals appear very low when compared with commercial landings or an estimate of the number of menhaden which spawned in Cape Cod Bay in 1975. For Atlantic herring equivalent adult estimates for 1999 were 16,678 age 1 sardines or 11,187 age 3 adults. These values were 59 and 37% above average, respectively, consistent with high stock biomass and an underutilized management status. Lastly, cod EA values were quite small at 6 age 2 fish in 1999 compared with a time series mean of 13.

The computer software program RAMAS Stage was used to study winter flounder entrainment impacts in greater detail. Results suggested that mean stock declines ranging from 2.3 to 4.5% might be expected as a result of larval losses at the Station. Projecting into the future with alternating annual outage periods during the winter flounder larval period suggested modest population reductions of 3.7 or 3.8%.

A total of eight lobster larvae were found in the 1999 entrainment samples from June 18 through August 20. This is remarkable in that only 13 larval lobster were collected at PNPS in total dating back to 1974.

SECTION II
INTRODUCTION

This progress report briefly summarizes results of ichthyoplankton entrainment sampling conducted at the Pilgrim Nuclear Power Station (PNPS) from January through December1999 by Marine Research, Inc. (MRI) for Boston Edison Company (BECo), under Purchase Order No. LSP010844, in compliance with environmental monitoring and reporting requirements of the PNPS NPDES Permit (U.S. Environmental Protection Agency and Massachusetts Department of Environmental Protection).

In an effort to condense the volume of material presented in this report, details of interest to some readers may have been omitted. Any questions or requests for additional information may be directed to Marine Research, Inc., Falmouth, Massachusetts, through BECO.

Plate 1 shows the ichthyoplankton sampling net being deployed on station in the PNPS discharge canal approximately 30 meters from the headwall.

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 April 1994. The revised program exchanged replication for improved temporal coverage. 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 *(Pleuronectes americanus)*. 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.

In 1999 sampling was not completed on March 8, 12 or September 17 due to stormy seas nor on March 26 and June 28 due to a condenser backwash. Sampling under rough sea conditions results in such heavy detrital loads that processing the samples is all but impossible. (In the past when storm samples have been processed, ichthyoplankton has been uncommon.) On May 7 PNPS entered an outage period which included shut down of both main circulating sea water pumps. This occurred on May 9. Both pumps remained off until June 11 when one pump was returned to service. During the period of time when both pumps were off, sampling was completed as often as possible from the salt service water system flow. Due to the low volume of those pumps (~2500 gpm each), sampling could only be completed if two pumps were in operation. Sampling was also only possible at low tide; therefore the normal morning, afternoon, night routine could not be adhered to during this period. Collections were made by moving the sampling point closer to the head wall of the canal where the service water stream enters and increasing the sampling interval to 45 minutes. Nets with 0.333-mm mesh were used to improve filtration efficiency rather than the 0.202 mesh normally still in use at that time.

Beginning on or about May 24 a portion of the salt service water piping was replaced necessitating that the water be routed through temporary, smaller 12-inch diameter piping. To collect samples from that system we used a smaller 33-cm diameter net constructed of 0.333-mm mesh. Overall during the period of time that both circulating water system pumps were out of service, seven ichthyoplankton samples were obtained.

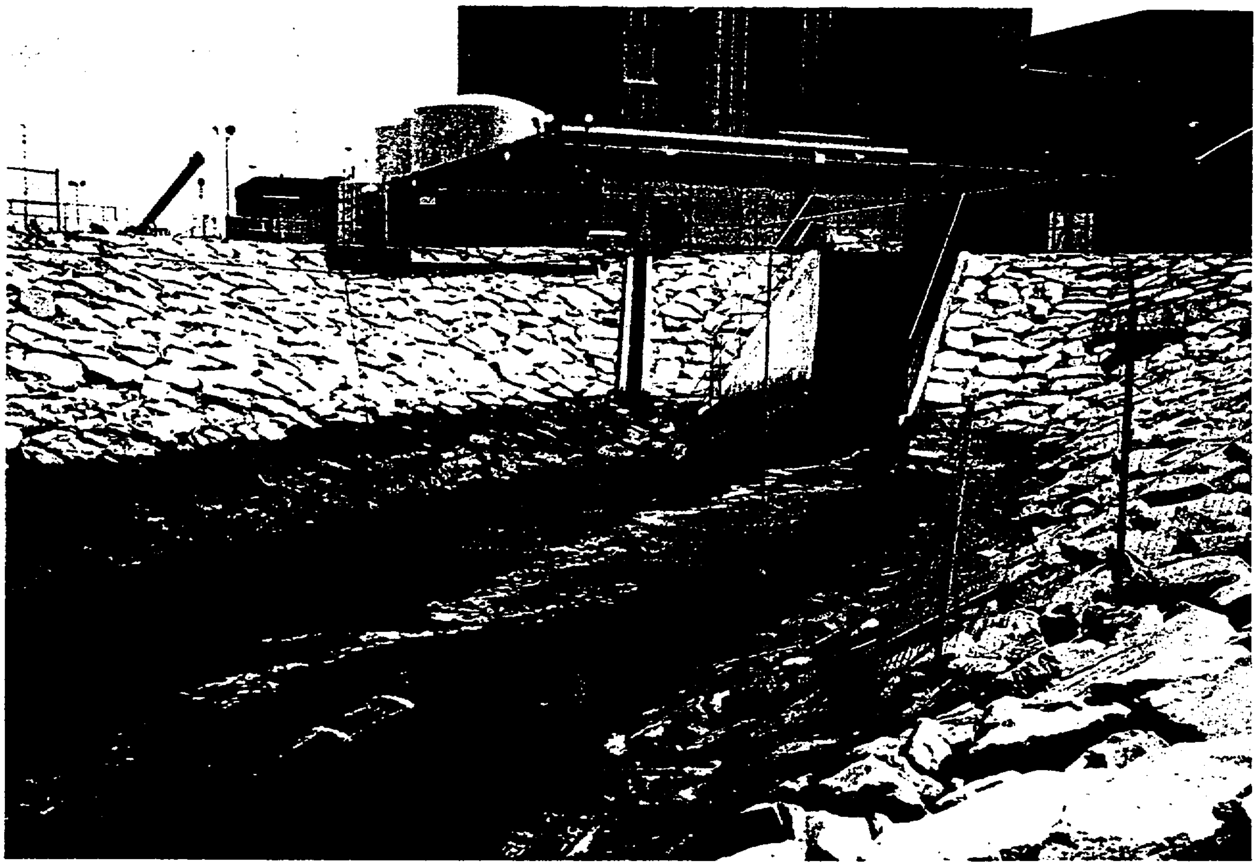

Plate 1. Plankton net streaming in the discharge canal at Pilgrim Station for the collection of fish eggs and larvae (lobster larvae are also recorded). A single, six-minute collection can contain several thousand eggs and larvae representing 20 or more species.

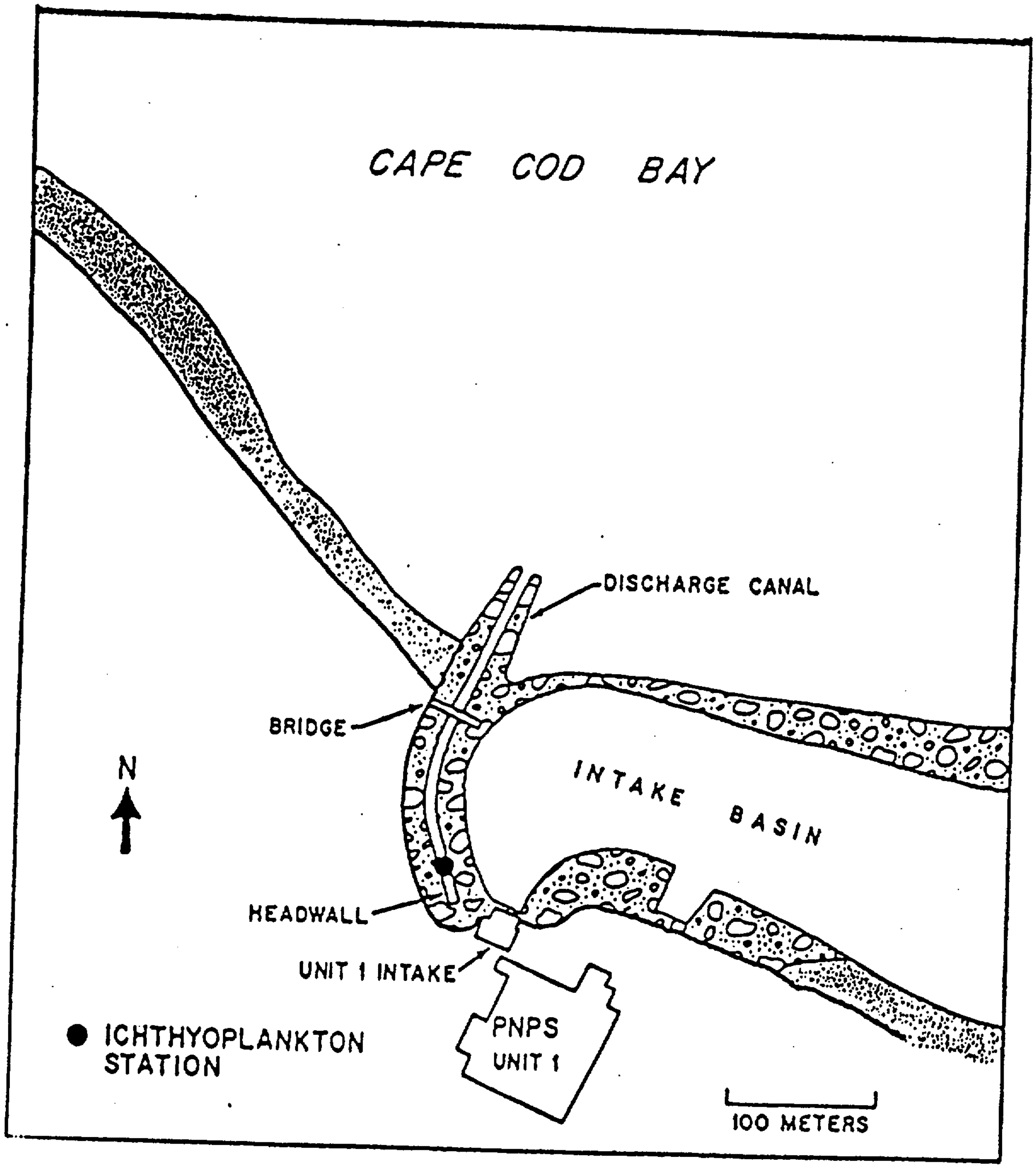

Figure 1. Entrainment sampling station in PNPS discharge canal.

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).

Notification Provisions

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 impact 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; updated each year) were examined and tested for normality following logarithmic transformation. Single sample densities obtained from 1994-1998 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 trigger notification). Species of commercial, recreational, or biological interest include Atlantic menhaden *(Brevoortia tyrannus)*, Atlantic herring *(Clupea harengus)*, Atlantic cod *(Gadus morhua)*, tautog and cunner (the labrids; *Tautoga onitis/Tautogolabrus adspersus)*, sand lance *(Ammodytes* sp.), Atlantic mackerel *(Scomber scombrus)*, windowpane

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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.

(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 1999 notification level.

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 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.

Table 1. PNPS ichthyoplankton entrainment notification levels for 1999 by species category and month. 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		1998
Sculpin	0.9		1.5	1983
Rock gunnel	0.8		1.4	1978
Sand lance[2]	5	11		1996
February				
LARVAE				
Atlantic herring[2]	0.1	0.8		1993
Sculpin	2		65	1991
Rock gunnel	4		99	1995
Sand lance[2]	16	29		1995
March				
EGGS				
American plaice[2]	2	3		1977
LARVAE				
Atlantic herring[2]	0.9	1.3		1997
Sculpin	17		608	1995
Seasnails	0.6		1	1980
Rock gunnel	10.7		723	1997
Sand lance[2]	7	164		1994
Winter flounder[2]	0.4	0.7		1997
April				
EGGS				
American plaice[2]	3	32		1978
LARVAE				
Atlantic herring[2]	1	2		1996
Sculpin	15		391	1985
Seasnails	6		10	1974
Radiated shanny	3		6	1974
Rock gunnel	4		142	1992
Sand lance[2]	21	998		1994
Winter flounder[2]	7	12		1994

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous Year High
May				
EGGS				
Labrids[2]	36	3514		1974
Atlantic mackerel[2]	18	4031		1995
Windowpane[2]	9	147		1995
American plaice[2]	2	15		1998
LARVAE				
Atlantic herring	0.7	1.1		1975
Fourbeard rockling	2		5	1997
Sculpin	3		4	1997
Radiated shanny	7		236	1998
Sand lance[2]	37	59		1996
Atlantic mackerel	2	4		1998
Winter flounder[2]	9	123		1998
Seasnails	7		208	1974
June				
EGGS				
Atlantic menhaden[2]	10	16		1998
Searobins	3		4	1987
Labrids[2]	958	21599		1995
Atlantic mackerel[2]	63	3515		1990
Windowpane[2]	27	261		1998
American plaice[2]	1	2		1980
LARVAE				
Atlantic menhaden[2]	6	10		1981
Fourbeard rockling	9		634	1992
Hake	0.3		1	1998
Cunner[2]	6	265		1998
Radiated shanny	1		15	1996
Atlantic mackerel[2]	91	155		1981
Winter flounder[2]	10	106		1998
July				
EGGS				
Atlantic menhaden[2]	2	4		1978
Labrids[2]	615	13349		1981
Atlantic mackerel[2]	9	16		1981
Windowpane[2]	12	156		1978

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous Year High
July				
LARVAE				
Atlantic menhaden[2]	2	3		1974
Fourbeard rockling	6		9	1998
Hake	0.7		1	1998
Tautog[2]	2	2		1998
Cunner[2]	7	318		1981
Atlantic mackerel[2]	2	3		1996
August				
EGGS				
Searobins	4		6	1995
Labrids[2]	23	936		1984
Windowpane[2]	15	136		1989
LARVE				
Atlantic menhaden[2]	0.4	1		1997
Fourbeard rockling	6		10	1983
Silver hake	1	2		1996
Hake	2		4	1995
Tautog[2]	1.6	2.2		1997
Cunner[2]	10	15		1997
September				
EGGS				
Labrids[2]	2	3		1993
Windowpane[2]	11	159		1993
LARVAE				
Atlantic menhaden[2]	1	2		1993
Fourbeard rockling	4		6	1993
Silver hake[2]	1	2		1976
Hake	5		9	1997
Tautog[2]	1	2		1996
Cunner[2]	1	2		1993
October				
EGGS				
Atlantic menhaden[2]	2	6		1985
Windowpane[2]	1	2		1997

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.	Previous Year High
October				
LARVAE				
Atlantic menhaden[2]	2.3	4		1997
Fourbeard rockling	1		16	1994
Hake	1		2	1985
November				
LARVAE				
Atlantic menhaden[2]	0.4	1		1997
Atlantic herring[2]	4	8		1995
December				
LARVAE				
Atlantic herring[2]	2	3		1995

[1]Geometric or Delta Mean.

[2]Species of commercial, recreational, or biological interest for which more critical notification level will be used.

SECTION IV
RESULTS

A. Ichthyoplankton Entrained - 1999

Population densities per 100 m^3 of water for each species listed by date, station, and replicate are presented for January-December 1999 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 which relies on demersal, adhesive eggs not normally entrained. As a result, more species are typically represented by larvae than by eggs. Over both life stages number of species represented in the catch increased from 6 in January to 15 in April. Considering the season as a whole, 8 species were represented by eggs, American plaice (*Hippoglossides platessoides*), yellowtail flounder (*Pleuronectes ferrugineus*), fourbeard rockling (*Enchelyopus cimbrius*), Atlantic cod (*Gadus morhua*), and winter flounder being the numerical dominants (Figure 2). Over the season as a whole these species accounted for 43, 21, 12, 12, and 9 % of the total egg catch. American plaice eggs appeared in the March and April collections with respective monthly geometric mean densities of 0.3 and 5.3 per 100 m^3 of water. Yellowtail and rockling occurred only in the April samples with monthly geometric mean densities of 2.4 and 2.3 per 100 m^3 of water, respectively. Cod eggs appeared from February through April. Assuming they accounted for the majority of eggs within the gadid-*Glyptocephalus* egg group, geometric mean densities were 0.3, 0.4, and 1.0 per 100 m^3 of water, respectively. Last among the dominants winter flounder eggs are both demersal and adhesive and unlikely to be entrained in proportion to their abundance in the surrounding waters. Nonetheless a number are entrained at PNPS each year at a time when eggs are, in general, uncommon and therefore their contribution can account for a notable proportion of the catch. In 1999 they were collected in February, March, and April with monthly geometric means of 0.1, 0.1, and 0.8 per 100 m^3 of water, respectively.

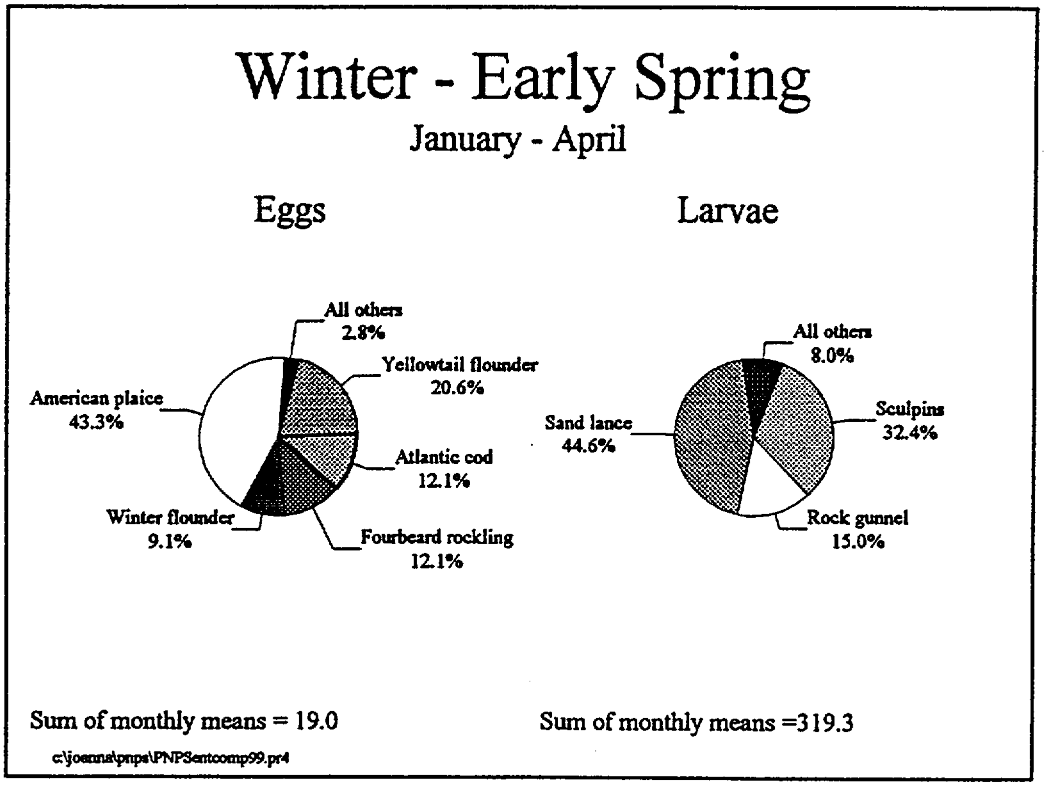


Figure 2. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the winter-early spring season, 1999. Percent of total and summed monthly means for all species are also shown.

Winter-early spring larval collections contained 16 species of fish. Numerical dominants included sand lance (*Ammodytes* sp.), sculpin (*Myoxocephalus* spp.), and rock gunnel (*Pholis gunnellus*) with respective, seasonal percent contribution values of 45, 32, and 15 (Figure 2). Larval sand lance were collected throughout the period with monthly geometric mean densities of 1, 1, 19, and 39 per 100 m^3 of water, respectively. Three species contributed to the sculpin category, the grubby (*M. aenaeus*), shorthorn sculpin (*M. scorpius*), and longhorn sculpin (*M. octodecemspinosus*). Considered as a group they occurred from February through April with monthly geometric mean densities of 2, 36, and 13 per 100 m^3 of water. Within the sculpin group grubby accounted for 71% of the seasonal total, shorthorn for 22%, and longhorn 7%. Larval rock gunnel, like larval sand lance, occurred throughout the seasonal period with monthly geometric mean densities of 5 in January, 2 in February, 10 in March, and 1 per 100 m^3 of water in April.

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 17 species were represented in the May collections, increasing to 20 in June and 21 in July. Numerical dominants among the 20 species represented by eggs included tautog (*Tautoga onitis*)/cunner and windowpane (*Scophthalmus aquosus*; Figure 3). Tautog/cunner eggs accounted for 35% of the May egg catch with a monthly geometric mean density of 32 per 100 m³ of water, increasing to 93% of the June total with a geometric mean density of 523 per 100 m³ of water, and decreasing to 88% of the July total with a geometric mean density of 406 per 100 m³. Windowpane eggs, assuming they account for most *Paralichthys-Scophthalmus* eggs, contributed an additional 8, 3, and and 6% to the May, June, and July totals with monthly geometric mean densities of 9, 22, and 43 per 100 m³ of water.

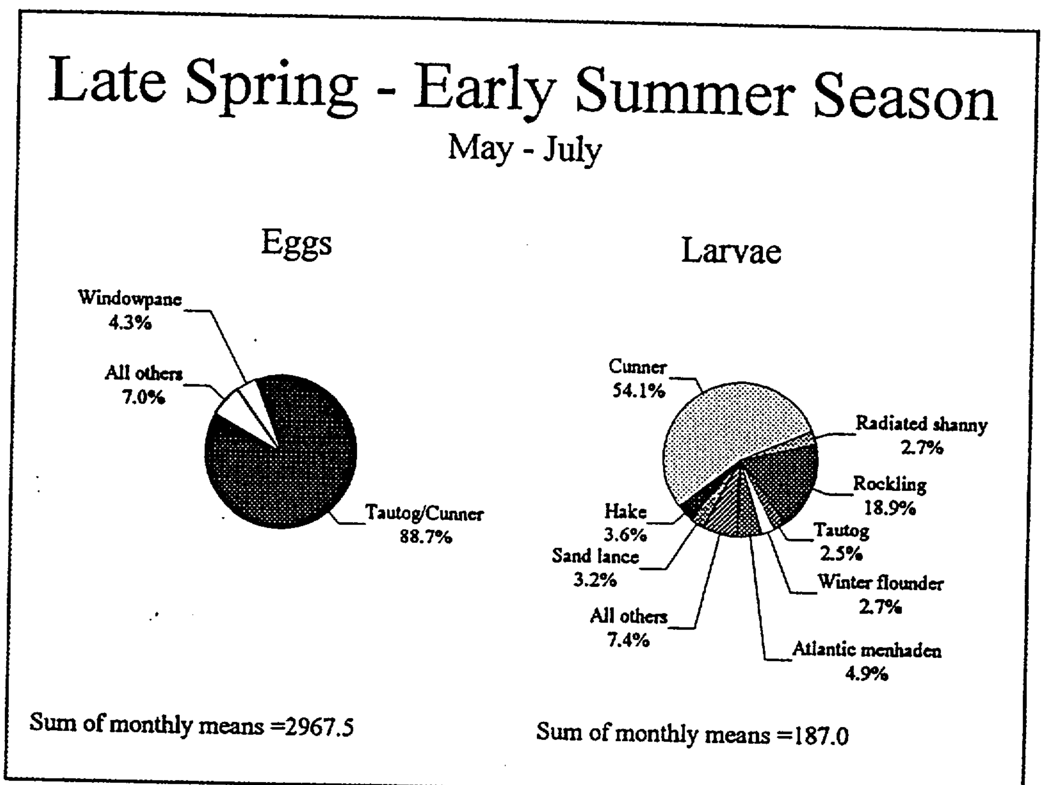


Figure 3. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late spring-early summer season 1999. Percent of total and summed monthly means for all species are also shown.

Larval collections during late spring-summer contained 28 species with numerical dominants being cunner, fourbeard rockling, Atlantic menhaden (*Brevoortia tyrannus*), hake (*Urophycis* spp.), sand lance, winter flounder, radiated shanny (*Ulvaria subbifurcata*), and tautog (Figure 3). Cunner accounted for 54% of the three-month total although they were collected only in June and July with a geometric mean density of 6 per 100 m^3 of water in June and 22 per 100 m^3 of water in July. Fourbeard rockling densities increased from May to July. Rockling accounted for 19% of the seasonal total with geometric mean densities of 0.3, 2, and 19 per 100 m^3 in May, June, and July. Atlantic menhaden accounted for 5% of the seasonal total of fish larvae. They occurred only in June and July with geometric mean densities of 1 and 5 per 100 m^3, respectively. Red and white hake represented 4% of the seasonal total although they were only entrained in July (geometric mean 6 per 100 m^3). Sand lance, a numerical dominant during winter-early spring, declined rapidly during late spring. Nonetheless they accounted for 36% of the May larval catch with a monthly geometric mean density of 1 per 100 m^3; none were collected following the first week of May. Winter flounder larvae occurred during May and the first half of June. They represented 18% of the May catch with a geometric mean density of 1 per 100 m^3 and 2% of the June total with a geometric mean density of 0.8 per 100 m^3 of water. Radiated shanny occurred at a geometric mean density of 1 per 100 m^3 in both May and June accounting for 3 and 17% of those respective monthly totals. They were not entrained in July. Lastly, tautog, collected only in June and July , contributed 3% of the total with a geometric mean density of 1 per 100 m^3 for each month.

Late Summer - Autumn Spawners (August - December)

This season is typically described as one where a marked decline in both overall ichthyoplankton density and number of species occurs. Considering egg and larval stages combined, 22 species were taken in August, 17 in September, 9 in October, 7 in November, and 6 in December. Numerical dominants included tautog/cunner, windowpane, and rockling/hake (*Enchelyopus-Urophycis-Peprilus* among the eggs and Atlantic menhaden, silver hake (*Merluccius bilinearis*), Atlantic herring (*Clupea harengus*), rockling, hake, windowpane, tautog, black sea bass (*Centropristis striata*), cunner, and fourspot flounder (*Paralichthys oblongus*) among the larvae (Figure 4).

Tautog/cunner eggs accounted for 45% of all eggs in August and 46% in November although the November percentage represents only two eggs collected on one day. The geometric mean densities for August and November were 10 and 0.1 per 100 m^3. They were not collected in September, October, and December. Egg measurement studies completed earlier at PNPS suggested that the majority of labrid eggs collected near PNPS are those of the cunner (Scherer 1984). In 1999 however, tautog larvae were numerically dominant suggesting that later in the season the percentage of tautog eggs was higher than the percentage of cunner eggs. Tautog larvae accounted for a higher percentage of the total than cunner larvae from August through December. Windowpane eggs accounted for 29% of all eggs in August, increasing to 47% (September) and 65% (October), with geometric mean densities of 40, 8, 0.5, respectively; none were collected in November and December. Rockling/hake eggs, only collected in August and September, accounted for 22% and 32% of all eggs during those months respectively (monthly geometric mean densities 15 per 100 m^3 in August and 3 per 100 m^3 in September). Based on collection of specifically identifiable late-stage eggs, hake

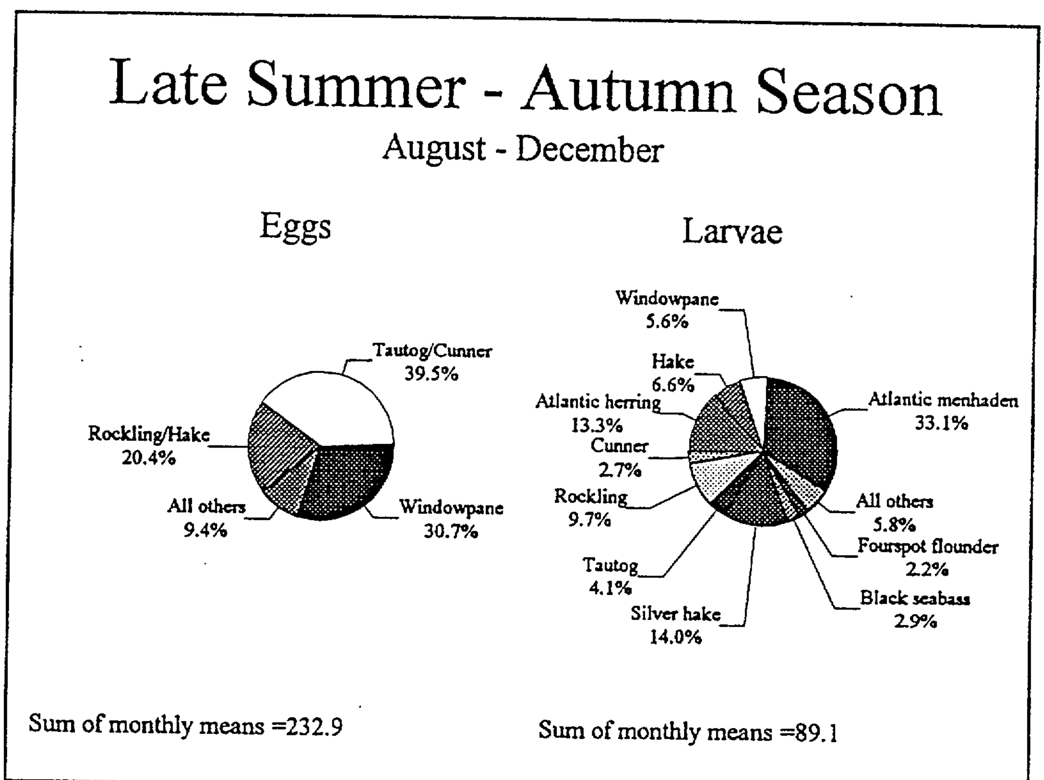


Figure 4. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late summer - autumn season 1999. Percent of total and summed monthly means for all species are also shown.

appeared to be somewhat more abundant than rockling. In August and September the geometric mean densities for rockling were 1.6 and 0.5 per 100 m^3 of water and the geometric densities for hake were 8 and 0.9 per 100 m^3 of water.

Many larval species contributed to the dominants in this late summer-autumn season. Among the larvae, Atlantic menhaden were collected in all months with the exception of December. They accounted for 7, 49, 47, and 24% of the total larvae with monthly geometric means of 0.9, 9, 5, and 1 per 100 m^3 in August, September, October, and November respectively. Silver hake were also collected in all months except December with a peak monthly geometric mean of 1.4 per 100 m^3 in September, accounting for 15% of the total larvae in that month. Atlantic herring were entrained only in November and December with monthly geometric means of 3.7 and 3.2 per 100 m^3 which accounted for 72 and 79% of the total larvae entrained during those months. Rockling made up for 18, 7, 15, and 1% of the total fish collected in August, September, October, and November. The peak monthly geometric mean was in August at1.6 per 100 m^3. Hake were entrained in all months except November. In September, the month with the greatest percentage, hake accounted for 9% of the total fish with a monthly geometric mean density of 1.2 per 100 m^3. Windowpane were collected from August through October. They accounted for 4, 5, and 15% of the total with monthly geometric means of 0.4, 0.8, and 1.4 per 100 m^3 respectively. Tautog were entrained in August, September, and October accounting for 8, 5, and 1% of the total larvae with monthly geometric means of 1, 1.4, and 0.1 per 100 m^3 respectively. Black sea bass were also collected from August through September. They accounted for 1, 3, and 8% of the total larvae. Monthly geometric means were 0.2, 0.7, and 0.4 per 100 m^3. Cunner and fourspot flounder were only collected in August and September. They both had peak monthly geometric means in August of 1 per 100 m^3 which accounted for 11 and 8% of the total larvae in August, respectively.

B. Notification Plan

Ichthyoplankton densities reaching the unusually high level during the 1999 sampling season occurred on a number of occasions. These involved Atlantic menhaden, cunner, searobin (*Prionotus* spp.), and windowpane eggs as well as the larvae of menhaden, tautog, hake, fourbeard rockling, rock gunnel, sand lance, Atlantic herring ,and seasnail (*Liparis* spp; Table 3). Among the above species, Atlantic menhaden displayed the most protracted period of high numbers with unusually high densities of larvae being recorded on 25 occasions during July, August, September, October, and November. On one occasion in September menhaden, with a density of 81 per 100 m^3, exceeded all previous densities for that month dating back to 1975. On three occasions in January and one in February, rock gunnel larvae exceeded all previous densities in those specific months since 1975 with densities ranging from 9 to 13 per 100 m^3 in January and 133 per 100 m^3 in February. On one occasion for each species, Atlantic herring larvae in April (38 per 100 m^3) and fourbeard rockling larvae in July (116 per 100 m^3) exceeded all previous densities in those months.

Additional notification level densities are mentioned in the next section.

C. Multi-year Ichthyoplankton Comparisons

A master species list for ichthyoplankton collected from the discharge canal at PNPS appears in Table 4; the years during which each species was represented are indicated for 1975 through 1999 A total of 41species were represented in the 1999 collections, three above the 25-year mean of 38 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 Mahy-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 25-year period, egg data were plotted in Figure 5 for those species whose combined total represented 99% or more of the 1999 egg catch. For this figure, cod and pollock eggs were combined with the Gadidae-*Glyptocephalus* group, rockling, hake and butterfish were combined in the *Enchelyopus-Urophycis-Peprilus* group, and labrids and yellowtail flounder were combined in the labrid-*Pleuronectes* group. For each category shown, the highest monthly geometric means obtained from 1981 through 1998 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 1999 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 (1975-1999). Appendix B and Figure 6 contain corresponding data for the 13 numerically dominant species of fish larvae, those accounting for 94% of the 1999 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 19-year geometric mean time series for Atlantic menhaden eggs, the highest annual abundance index (3023 in 1993) divided by the lowest (10 in 1992) amounted to 292. In spite of such pronounced variation, no consistent upward or downward trend is apparent over the time series for many species such as 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.

- Atlantic menhaden eggs were relatively abundant at PNPS on two occasions in July 1999 based on the notification program criteria (see above). In spite of these observations the annual index of abundance for menhaden eggs was not remarkable. The geometric mean index ranked 7th over the 1981-1999 period and the arithmetic index ranked 7th over the 1975-1999 period.
- 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

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

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, which is consistent with the downward trend reported for Atlantic cod and witch flounder stocks apparently resulting, at least in part, to overexploitation (NOAA 1998, NFSC 1998). In 1998, the annual geometric mean indices suggested that the decline had ended if not reversed, at least locally, since values for 1994 through 1997 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, however, the geometric mean indices decreased to 45. This could indicate that the trend is now reversed again or that 1998 was an unusual year.

- 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 ($p = 0.05$) in spite of a moderate catch in 1995. Any suggestion of a reversal in 1995 was erased by the 1996 value which was similar to values observed from 1992 to 1994. In spite of relatively high densities in April 1997, the 1997 indices (3819 and 1621) represented but a slight improvement over 1996 (2889 and 1299). The 1998 (5078 and 2687) and 1999 (4715 and 2366) indices suggest an upward trend is underway. Fourbeard rockling dominate within this grouping based on late-stage egg as well as larval collections. Since they are 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 considered to be underexploited. Stock abundance of red hake on southern Georges Bank and in Massachusetts waters are relatively low according to the Northeast Fisheries Center survey index (NOAA 1998).
- Searobin eggs were relatively abundant at PNPS from 1983 through 1987. Relative to that period of time numbers have been low with 1998 particularly so. The geometric curve index for 1999 (123) ranked 10th and the longer arithmetic time series (258) also ranked 10th dating

back to 1975. 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). These trends appear to be reflected in the PNPS larval 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 (83,356) arithmetic indices 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 value (50,705) nearly equaling the 1996 (51,652) index. The arithmetic index was disproportionately high due to two high densities in June. The 1999 arithmetic value (83,659) was similar to the 1997 value (83,356). The downward trend noted through 1994 is consistent with finfish observations 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 1999 (117) was comparable to impingement numbers from 1993 through 1995 (104-288; see Impingement Section).
- Eggs of the yellowtail flounder were also relatively abundant in April 1997, 1998, and 1999. While early staged 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 1997 was 4.6 per 100 m^3, increasing to 7.7 in 1998 and 2.4 in 1999, all exceeding the previous high of 1.8 per 100 m^3 noted in 1983 (Figure 5). Stock assessment information shows a slight increase since 1994, perhaps explaining the increase in egg abundance (NFSC 1998). Yellowtail flounder eggs were uncommon in May 1999 compared with the 1974-1998 time series. The monthly geometric mean density of 0.2 per 100 m^3 ranked below all previous years with 0.4 per 100 m^3 being the previous low recorded in 1986. Spawning stock biomass of yellowtail in southern New England is considered to be low relative to historic levels. The species was overexploited from 1973 to 1994 and is currently rebuilding (NFSC 1998). The low apparent egg abundance in May 1999 may also be due at least in part to shutdown of both circulating seawater pumps during the latter two-thirds of the month. Analyses completed in 1991 (MRI 1992) indicated that ichthyoplankton entrainment, particularly larval entrainment, is notably reduced when both pumps are off.

- Mackerel eggs typically display a sharp peak in their 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 at 4,754 per 100 m^3. Due to these brief sharp peaks, arithmetic and geometric indices are often quite far apart (Figure 5). Mackerel eggs have been 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, however, the numbers decreased significantly. This may be due to the fact that the main seawater pumps were off for most of the month of May, the peak season for mackerel eggs. Entrainment of high densities of mackerel eggs over the past decade in spite of 1999 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 1999. The annual geometric mean for 1997 (3144) was essentially equal to 1996 (3147) but the upward trend

continued in 1998 (4553), declining slightly in 1999 (3750). Over the entire 25-year time series the arithmetic index for 1999 ranked fifth. In general these eggs have not shown wide variations in number, at least not compared with other species regularly entrained. Consistent with the recent egg collections, current abundance indices for windowpane, based on Massachusetts Division of Marine Fisheries spring and fall surveys, suggest that stocks increased steadily from 1991 through 1996, even though they decreased again in 1997 (Steve Correia, MDMF, personal communication).

- American plaice eggs were relatively abundant during the month of April. The April 1999 geometric mean density of 5.3 per 100 m^3 of water exceeded all past April means with the exception of 1992 (7.5) and 1993 (5.7 per 100 m^3 of water). 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 1998 although remaining above the low of 1990. A strong year class was produced in 1992 which perhaps accounts for the relatively strong egg production near PNPS since then.
- While abundance of menhaden eggs was not remarkably high in 1999, larval menhaden abundance was considered so for the third straight year (Figure 6). The annual geometric mean abundance index (649) ranked fourth behind 1997 (1145), 1998 (984), and 1981 (675) dating back to 1981, and the arithmetic index (1179) also ranked fourth behind 1997 (2801), 1981 (2708), and 1998 (1893).

Menhaden are coastal migrants which travel in schools that can often be quite dense. For example, 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. On three occasions from August through November 1999 large numbers of young-of-the-year menhaden were impinged at PNPS, exceeding the regulatory notification level of 20 fish per hour. Menhaden travel in very dense schools and are often attracted to both intake and discharge currents. High impingement rates were recorded for this species at a number of power stations during the 1999 season such as Manchester Street Station in Providence and Sandwich Canal Electric Plant, suggesting that a strong year class was produced.

- 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 during the 1970's and collapsed on Georges Bank in 1976 (Anthony and Waring 1980, Smith and Morse 1993). The stock has increased more or less steadily since 1986 following reductions in fishing pressure. Presently the Atlantic coast stock is increasing in size, projected to continue doing so into the year 2000, and considered to be extremely underutilized (NFSC 1998). Larval collections at PNPS from 1994 through 1999 reflect the general increase in stock size, the geometric index for those five years ranking among the top five. In 1999 the geometric mean index (345) ranked fourth since 1981 and the arithmetic mean index (585) ranked fourth since 1975. Although numbers dropped in 1998 the geometric index (143) remained among the top eleven over the 1981-1999 time series (Figure 6). Larval Atlantic herring were relatively abundant in April 1999, with the monthly geometric mean of 3.7 per 100 m^3 of water slightly below the previous high of 4.0 recorded in 1994. On all but four dates in April 1999 the density of larval herring in the discharge canal exceeded the notification density for the month and on April 16 the density of 38.3 exceeded the previous high of 32 per 100 m^3 of water recorded in 1996.
- 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). Overall the 1999 annual geometric mean index of 760 was equal to 1997 but lower than 1998 (1620), ranking sixth in the 19-year time series. The arithmetic index (1358) was lower than 1998 (2945) and similar to 1996 (1317). 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.
- Larval hake were abundant in 1997 and 1998 but not in 1999 (Figure 6). Respective geometric mean indices in 1997 and 1998 amounted to 994 and 932 , both exceeding the

previous high of 514 recorded in 1985. Arithmetic means for those two years ranked second and third dating back to 1975. In 1999, the geometric index was lower (167), ranking 11th in the 19-year time series. Data available through 1995 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 abundance is relatively low (NFSC 1998). High larval abundance at PNPS in 1997 and 1998 may indicate production of strong year classes or simply reflect a localized spawning aggregation, especially since the trend did not continue in 1999.

- Sculpin (*Myoxocephalus* spp.) abundance has remained relatively stable in the 25-year time series (Figure 6). There was a slight increasing trend from 1977 through 1989 and a peak in 1997. The major species of this genus entrained at PNPS is the grubby. Since these fishes are small and have no commercial or recreational significance, no stock size data are available with which to compare the larval abundance patterns.
- Larval seasnail were more common in 1999 than in 1998, which is the low point in this time series (Figure 6). The geometric index (222) recorded in 1999 approximated the average number since 1981. On three dates in April seasnail densities exceeded the larval notification level and were also greater than 90% of all previous values. Since these fishes 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.
- Both tautog and cunner larvae were relatively uncommon in 1999 compared to the two previous years (Figure 6). In 1999 the geometric index (cunner = 923, tautog =156) and the arithmetic index (cunner = 3176, tautog =259) were similar to most other years since 1981. Although these numbers are low compared to 1997 and 1998, tautog larvae were abundant in July, August, and September 1999 as defined by the notification program. Current stock size data for cunner are not available but tautog are believed to be overfished and at very low levels (NFSC 1998). Perhaps two seasons of relatively high larval abundance were due to strong year classes and not the sign of an increase in stock size.
- Larval radiated shanny were relatively uncommon in 1999 (Figure 6). The geometric (73) and arithmetic (182) mean indices were lower than all years from 1989 through 1998, and ranked 17th over the 19-year time series. Radiated shanny larval abundance peaks in May (Figure 6).

The main seawater pumps were off during that month in 1999 which may account for the low mean indices. Since this is a small, rather inconspicious bottom fish, relatively little is known of its habits and data are not available concerning population trends.

- Larval rock gunnel were relatively abundant in January 1999, the monthly geometric mean density of 4.9 per 100 m^3 of water exceeding all previous January values (Figure 6). On five of the six sampling occasions in January 1999 rock gunnel densities exceeded the notification value for the month, and on three of the five the current value exceeded all previous values (Table 3). Geometric mean indices for rock gunnel were slightly higher in 1999 overall (530) than in 1998 (449), ranking 13th over the 19-year time series. Overall, however, there is no obvious trend from 1975 to 1999. 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.
- Sand lance arithmetic indices were relatively high in 1978 (14,944) and1994 (26,276) through 1996 (19,511) (Figure 6). Geometric indices peaked in 1996 (6,156). The geometric mean index in 1999 (1856), ranking 8th over the 19 year time series was greater than the geometric mean in 1998 (984). Both recent years are lower than the previous four years. Unfortunately the sand lance has little or no commercial nor recreational value, and therefore abundance data are not available with which to compare the entrainment estimates.
- 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 were relatively uncommon in 1999. This may be due to the fact that the main seawater pumps were off in May, the seasonal peak for mackerel larvae. The geometric mean indices remained relatively constant except for 1985, 1987, and 1999 when the pumps were down (Figure 6). The arithmetic mean index was high in 1981 (10,030) and again in 1995 (12,086). Except for those two peaks, the arithmetic mean indices increased from 1975 until 1995 and then decreased slightly. The arithmetic indices in 1999 (15) rank 18th, exceeding only the mean in 1987 (3).

- 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. With the main seawater pumps off for much of May 1999, larval flounder densities (monthly mean = 1.2 per 100 m^3 of water) were especially low, the lowest yet observed (Figure 6). The previous low was 1.6 per 100 m^3 of water recorded in 1987 when the main pumps were also off. Since available evidence indicates that local densities are not sampled in proportion to their true abundance when only salt service water system pumps are running, it is not possible to estimate the relative abundance of the May larval flounder stock nor estimate with any accuracy how many additional larval flounder would have been entrained had the Plant operated at full capacity. Overall the 1999 indices ranked 17th over the 19-year time series, greater only then the densities in 1987 and 1992.

  As a pooled category the monthly mean density for total larvae was particularly low during May 1999 likely as a result of both circulating seawater pumps being off following the 9th of the month. The monthly geometric mean density of 7.4 per 100 m^3 of water exceeded only the corresponding mean density for 1987 (3.3 per 100 m^3 of water) when both pumps were also off. Similarly in May 1984 when both pumps were off, a geometric mean density of 20.5 per 100 m^3 of water was recorded ranking 16th, next above 1999. Monthly geometric mean densities during years when both pumps operated ranged from 22 to 137 per 100 m^3 of water. These results are consistent with the pump analyses completed in 1991 (MRI 1992) and mentioned above.

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, 1999 (bold line). Solid lines encompassing shaded area show high and low values over the 1981-1998 period.

Brevoortia tyrannus

Gadidae-*Glyptocephalus*

Enchelyopus-Urophycis
Peprilus

Prionotus spp.

Labridae-*Pleuronectes*

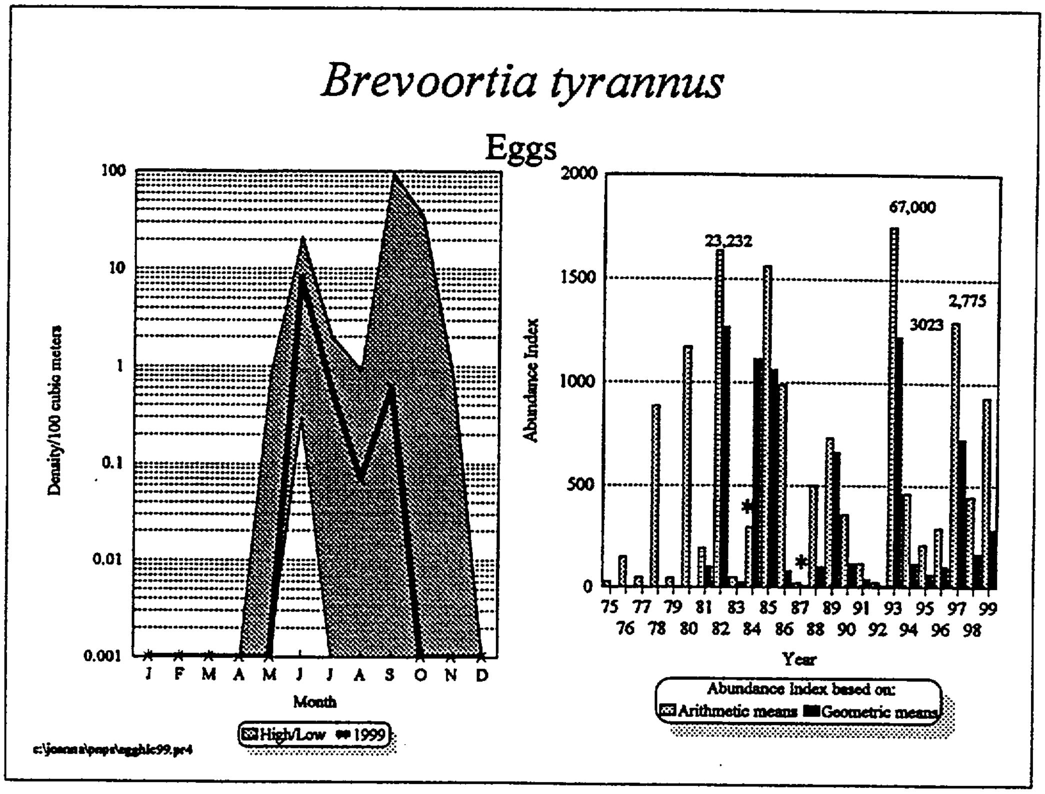
Scomber scombrus

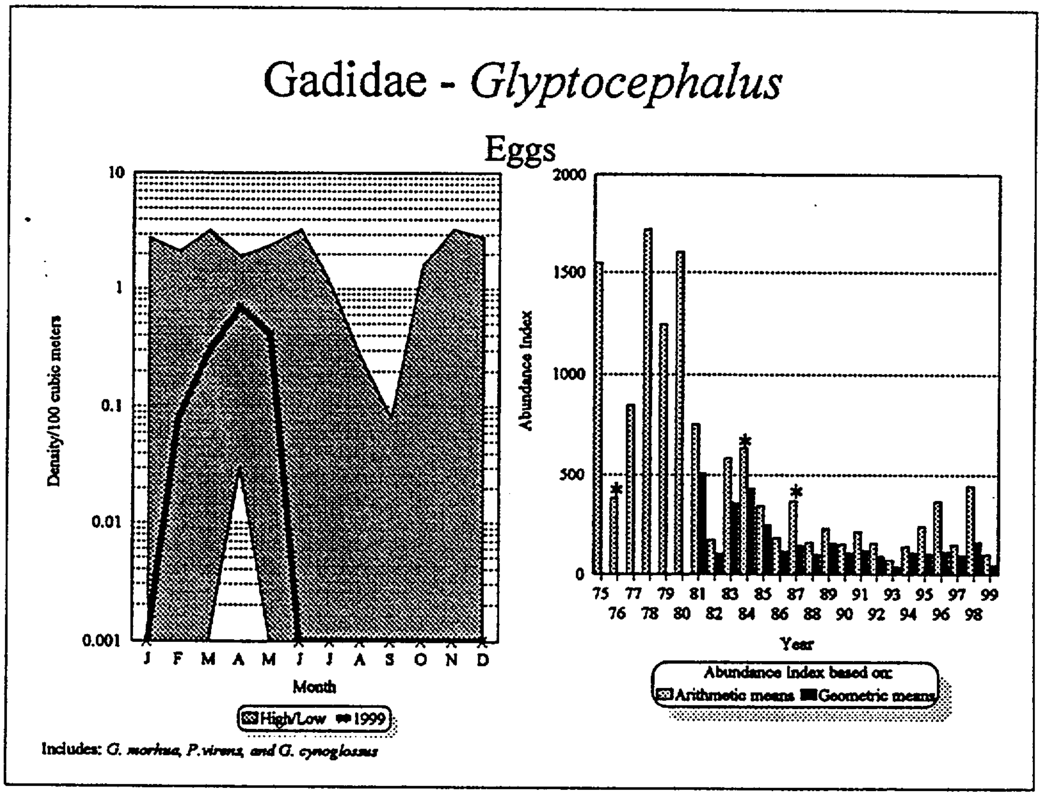
Paralichthys-Scophthalmus

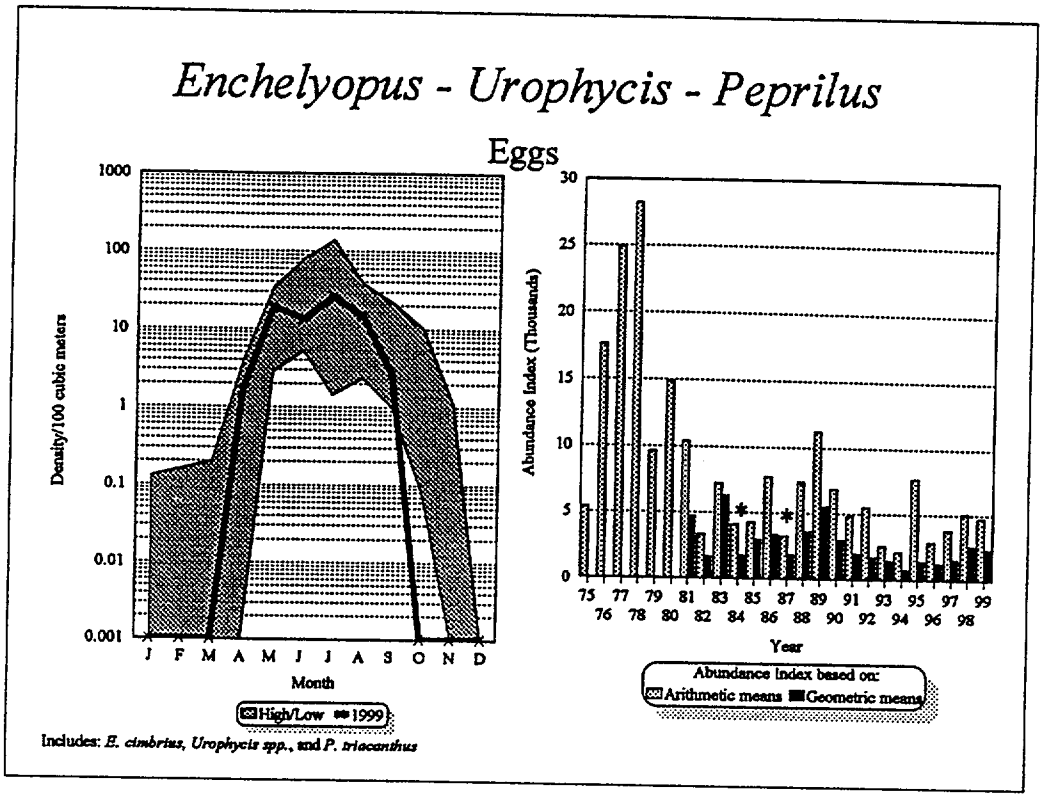
Hippoglossoides platessoides

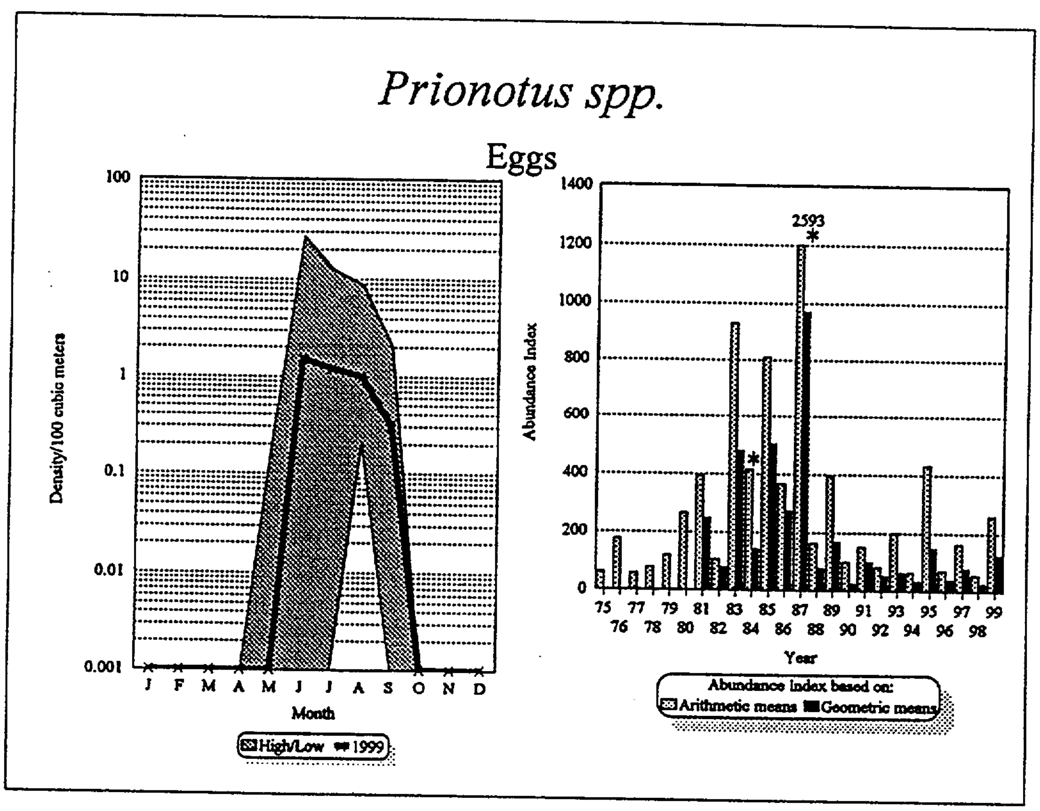
Total eggs

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-1999. An asterisk 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 asterisk 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 arithmetic means, solid bars (1981-1999) indices based on monthly geometric means.


Brevoortia tyrannus
Eggs
Density/100 cubic meters
Month
High/Low 1999
Abundance Index
23,232
67,000
3023
2,775
Year
Abundance Index based on:
Arithmetic means Geometric means

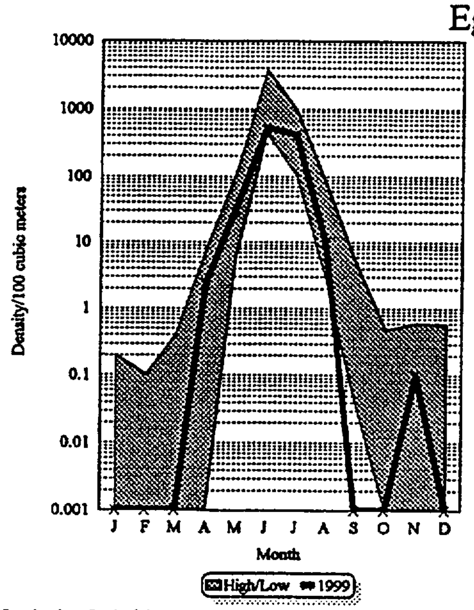

Gadidae - Glyptocephalus
Eggs
Density/100 cubic meters
Month
High/Low 1999
Abundance Index
Year
Abundance Index based on:
Arithmetic means Geometric means
Includes: G. morhua, P. virens, and G. cynoglossus

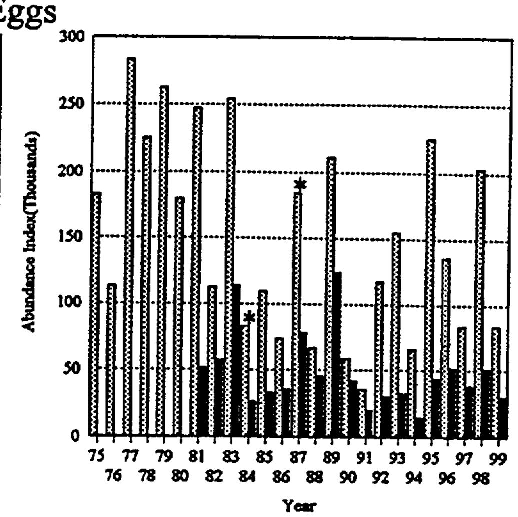

Enchelyopus - Urophycis - Peprilus
Eggs
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Includes: E. cimbrius, Urophycis spp., and P. triacanthus
Abundance Index (Thousands)
30
25
20
15
10
5
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Prionotus spp.
Eggs
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index
1400
1200
1000
800
600
400
200
0
2593
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

Labridae - *Pleuronectes*

Eggs

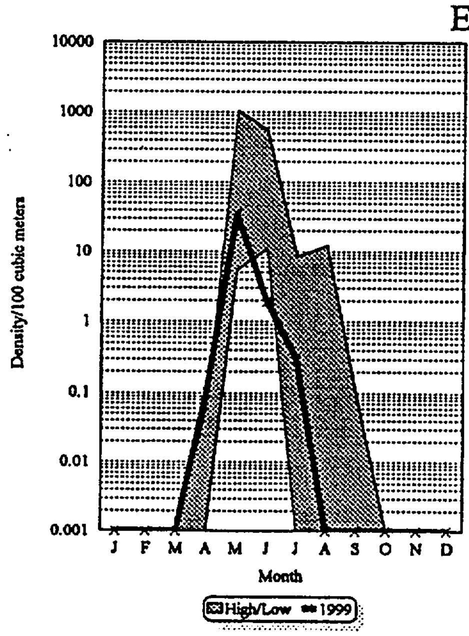


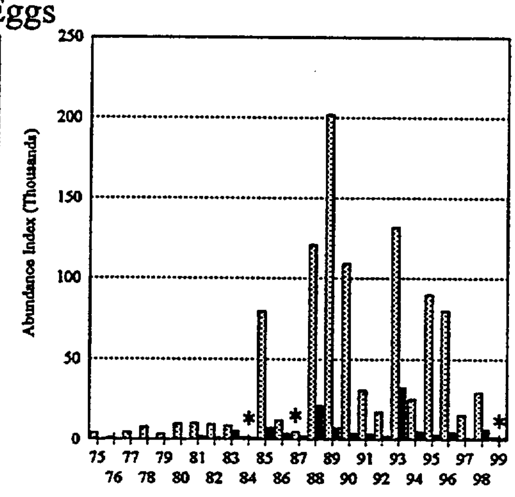


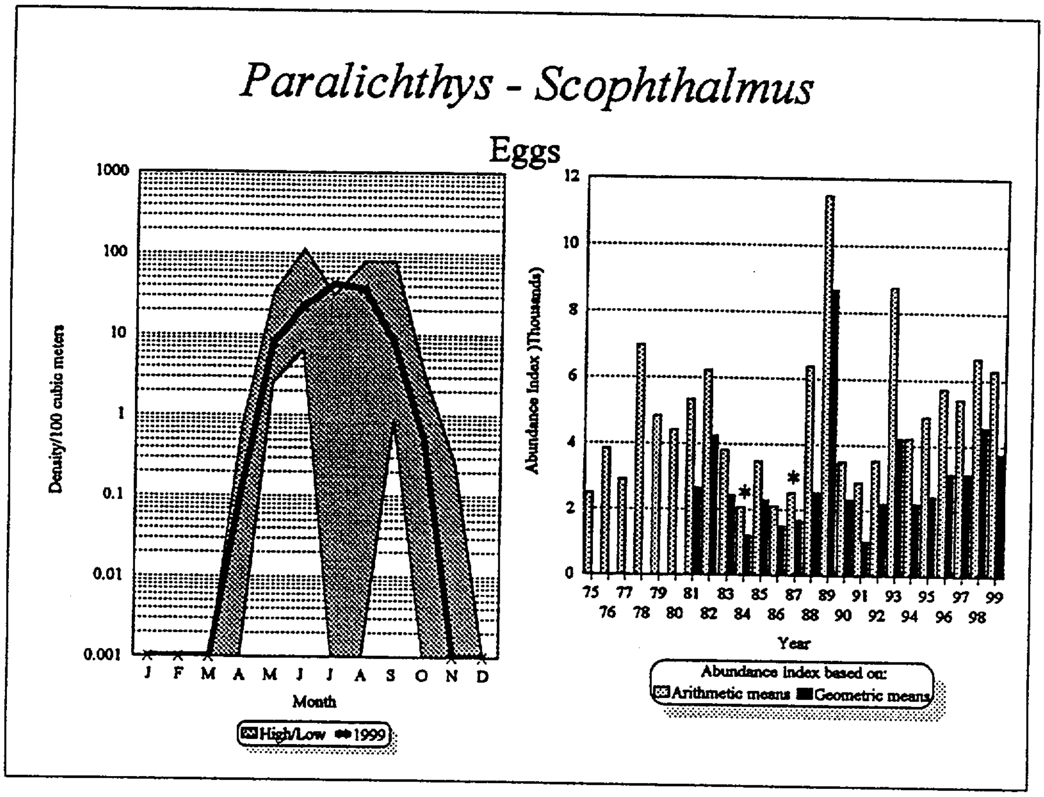
Includes Labridae and *P. ferrugineus*

Scomber scombrus

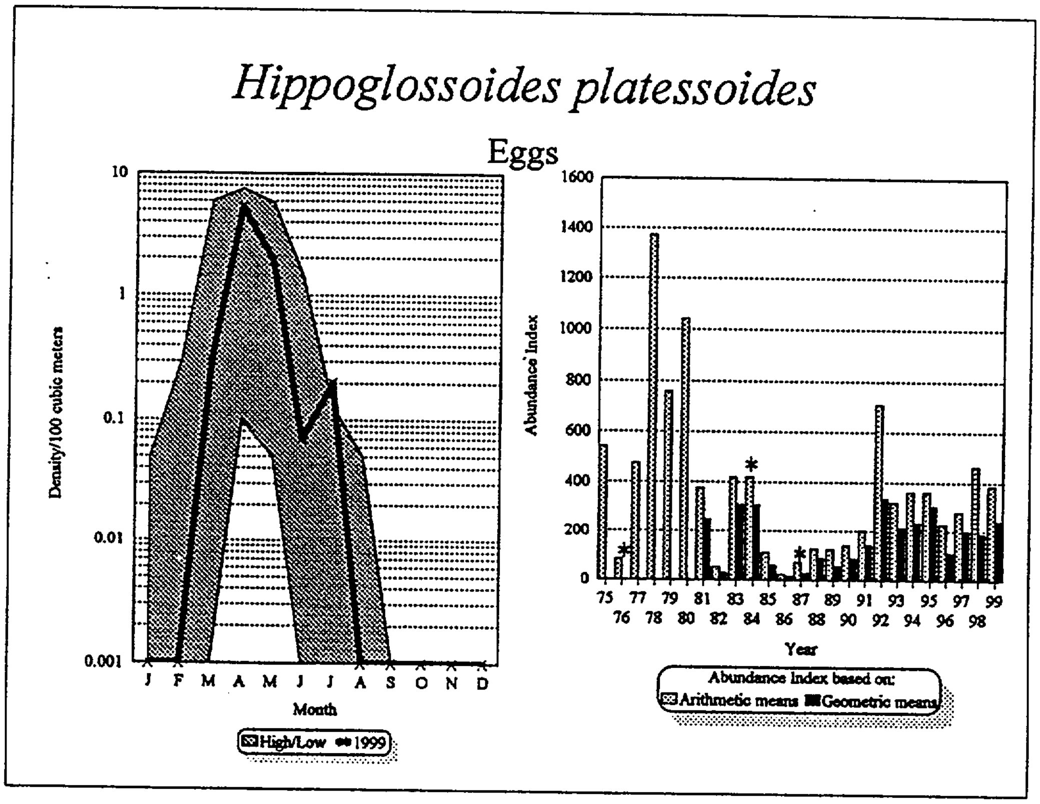
Eggs





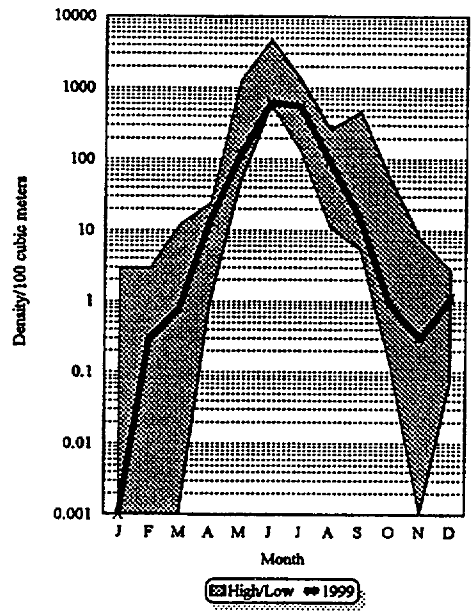


Paralichthys - Scophthalmus
Eggs
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index)Thousands)
12
10
8
6
4
2
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

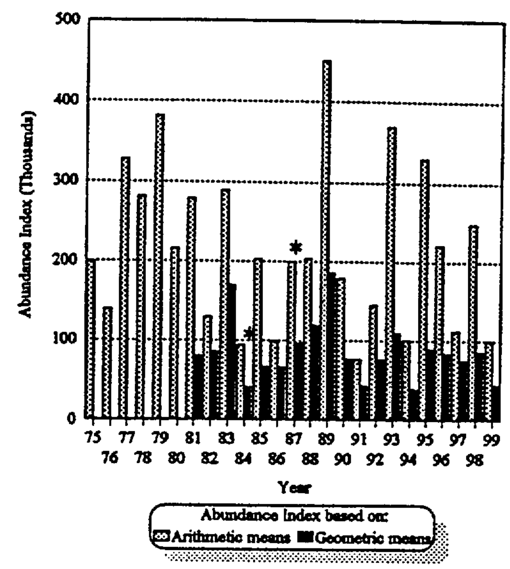


Hippoglossoides platessoides
Eggs
Density/100 cubic meters
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index
1600
1400
1200
1000
800
600
400
200
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

Total Eggs



10000
1000
100
10
1
0.1
0.01
0.001
Density/100 cubic meters
J F M A M J J A S O N D
Month
High/Low 1999



500
400
300
200
100
0
Abundance Index (Thousands)
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

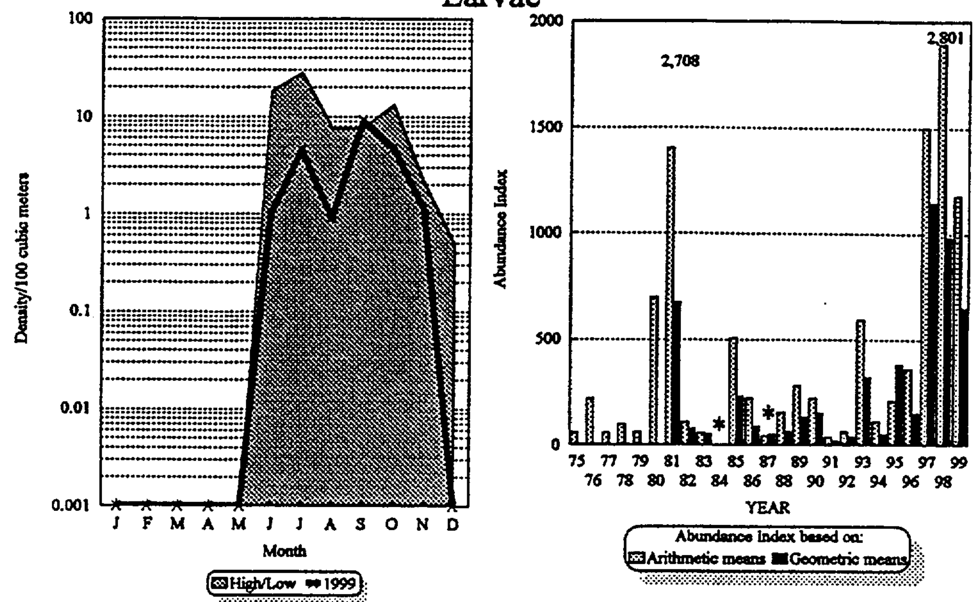
Figure 6. Geometric mean monthly densities per 100 m³ of water in the PNPS discharge canal for the thirteen numerically dominant larval species and total larvae, 1999 (bold line). Solid lines encompassing shaded area show high and low values over the 1981-1998 period.

Brevoortia tyrannus	*Tautogolabrus adspersus*
Clupea harengus	*Ulvaria subbifurcata*
Enchelyopus cimbrius	*Pholis gunnellus*
Urophycis spp.	*Ammodytes* sp.
Myoxocephalus spp.	*Scomber scombrus*
Liparis spp.	*Pleuronectes americanus*
Tautoga onitis	Total larvae

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-1999. An asterisk 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 asterisk 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 arithmetic means, solid bars (1981-1999) indices based on monthly geometric means.

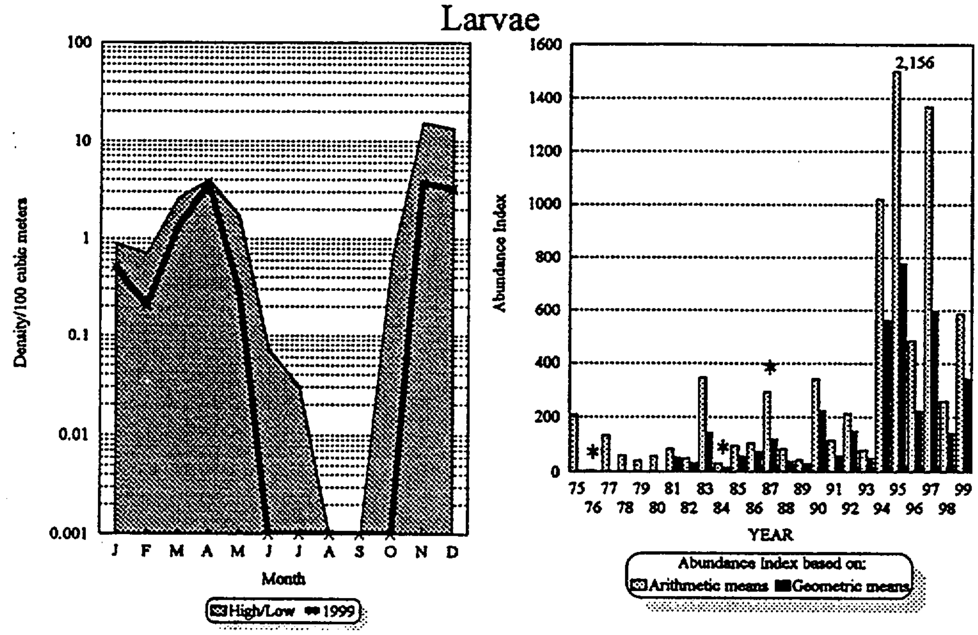
Brevoortia tyrannus

Larvae

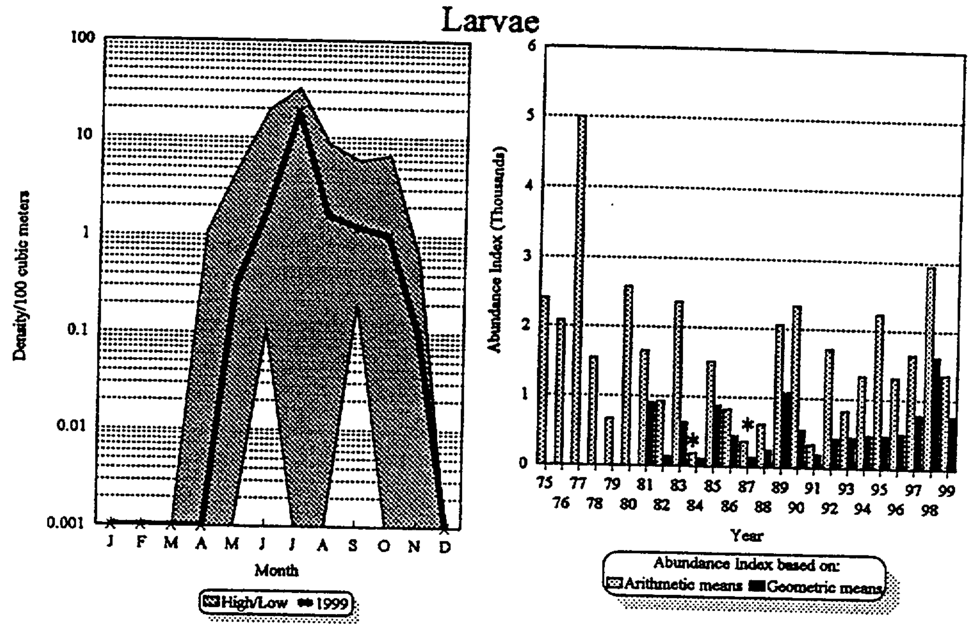


Clupea harengus

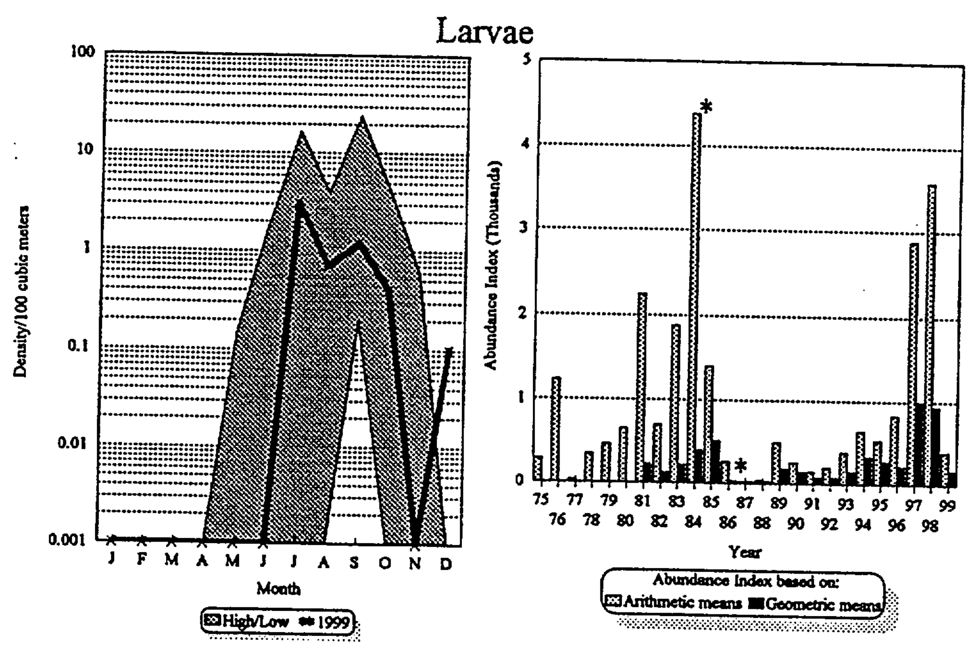
Larvae

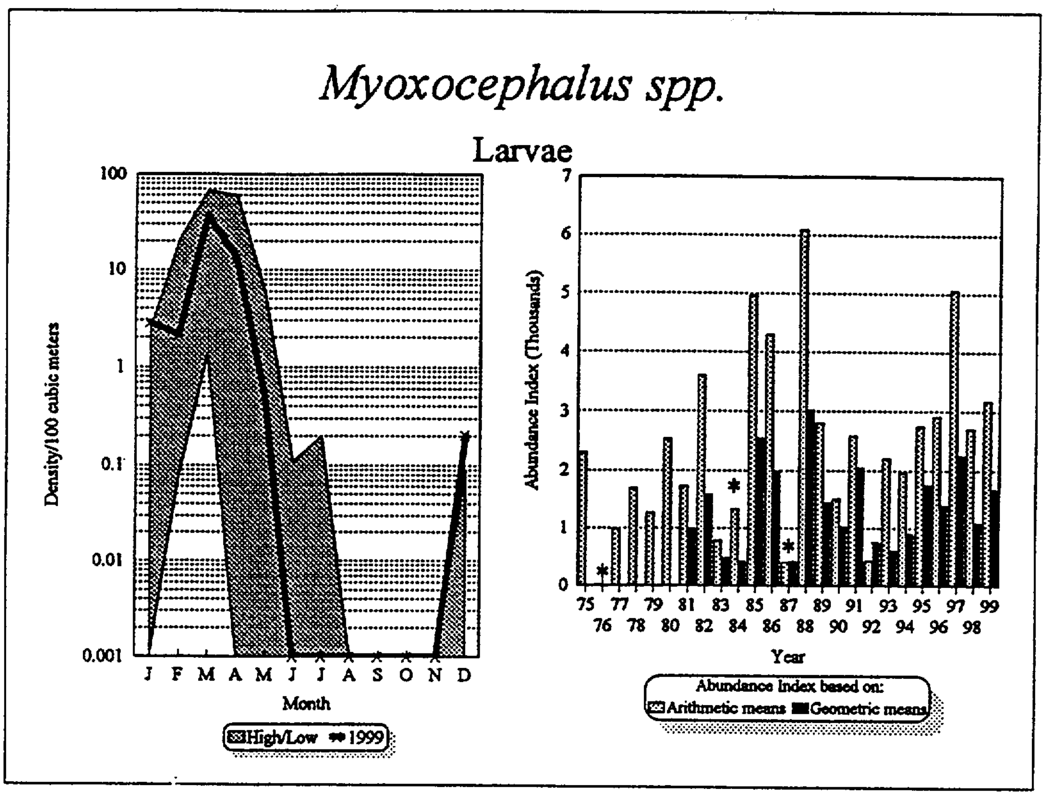


Enchelyopus cimbrius

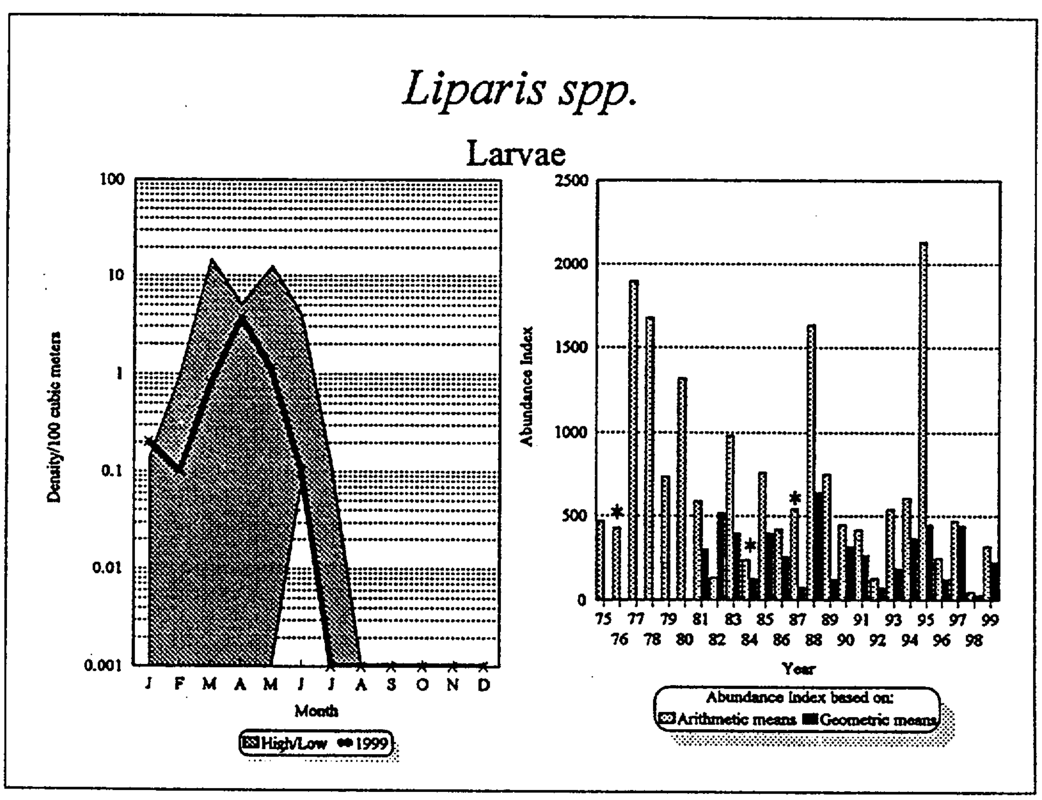


Urophycis spp.

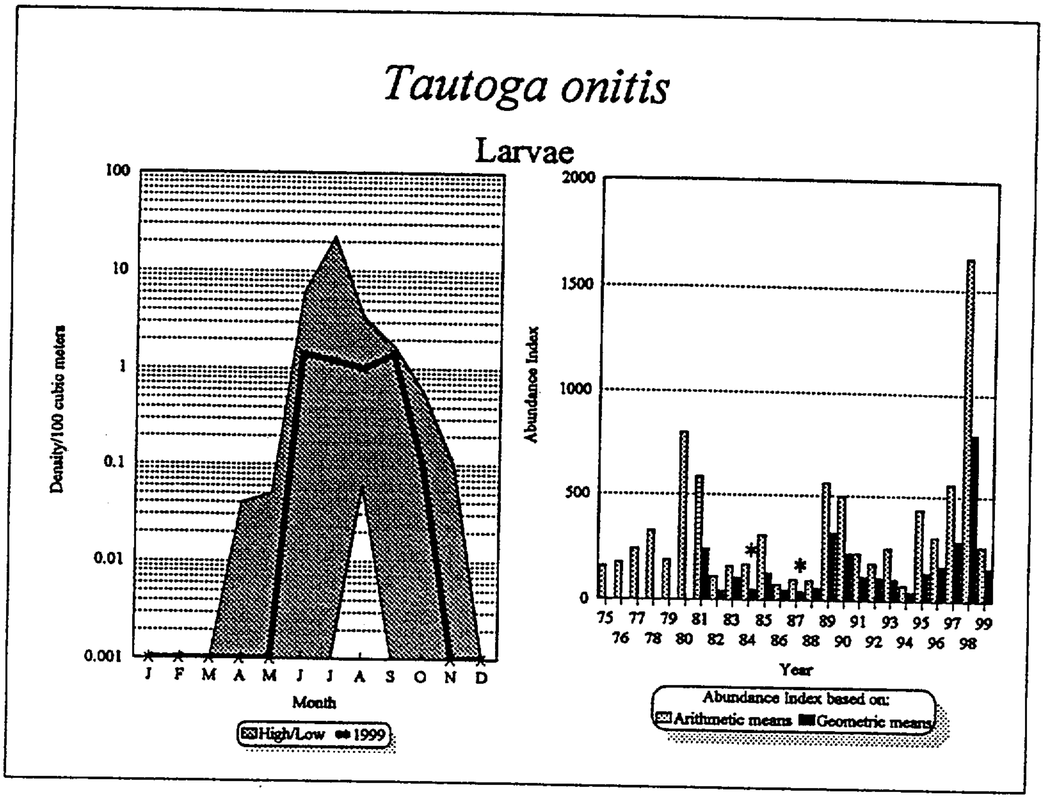


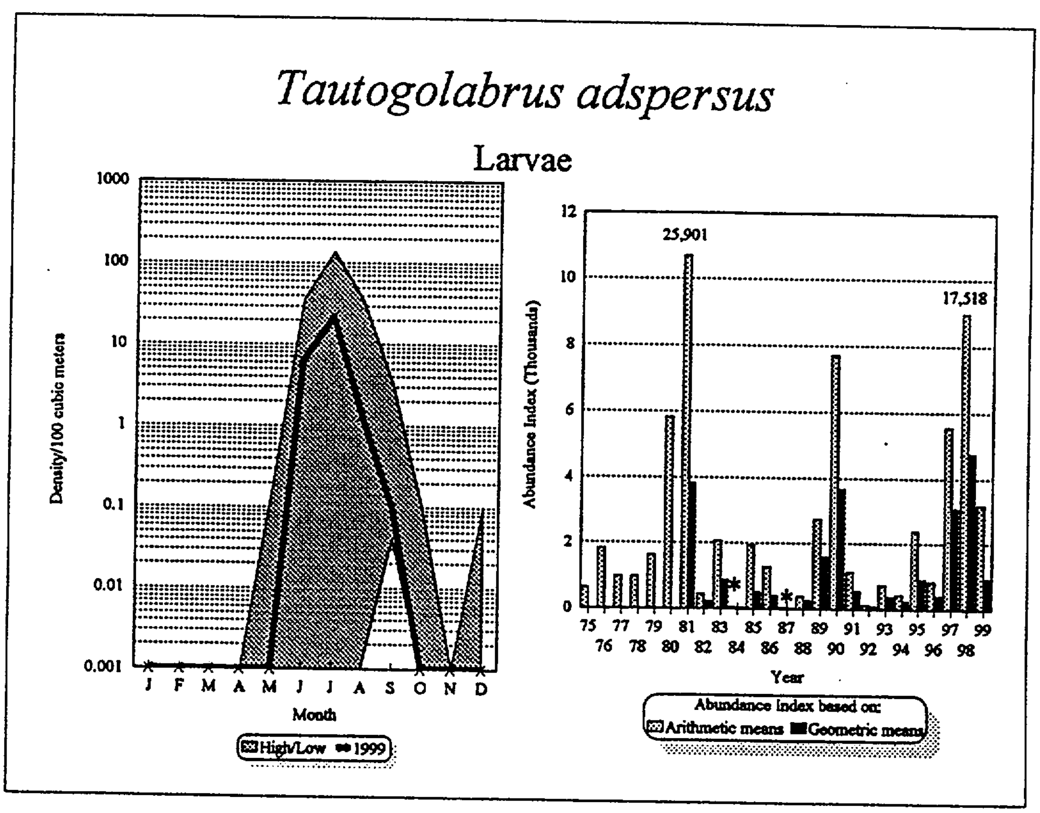


Myoxocephalus spp.
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index (Thousands)
7
6
5
4
3
2
1
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means



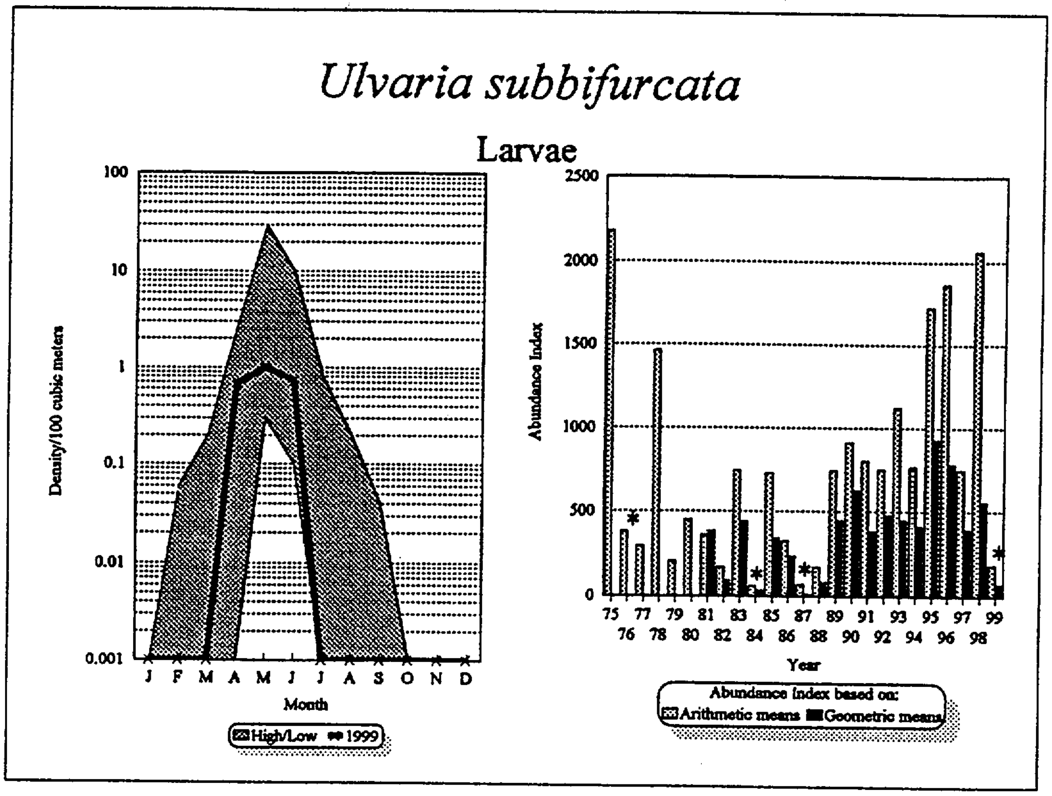
Liparis spp.
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index
2500
2000
1500
1000
500
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Tautoga onitis
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index
2000
1500
1000
500
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Tautogolabrus adspersus
Larvae
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index (Thousands)
25,901
17,518
12
10
8
6
4
2
0
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

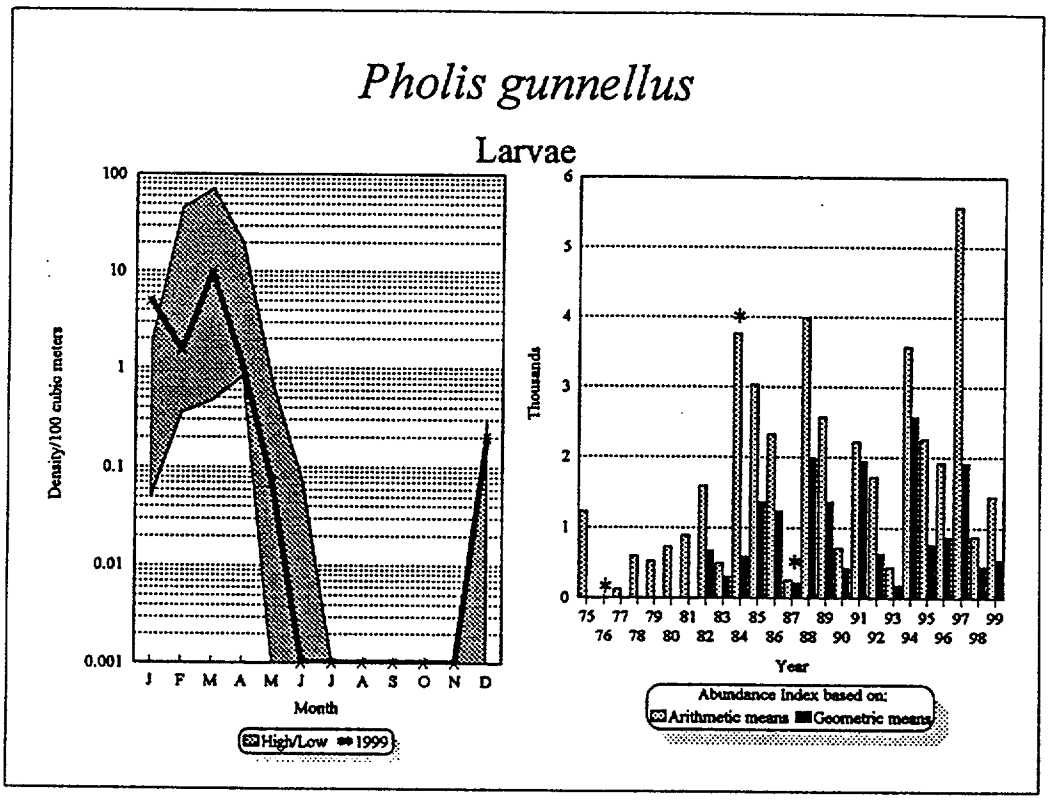
Ulvaria subbifurcata

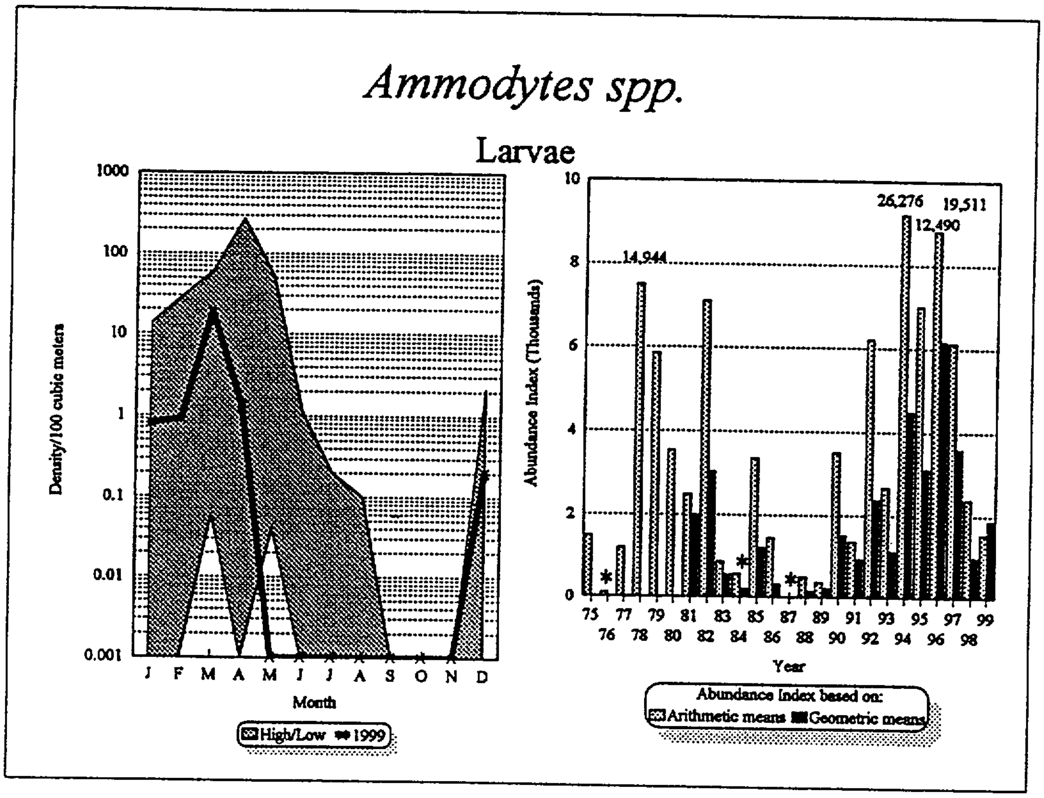
Larvae

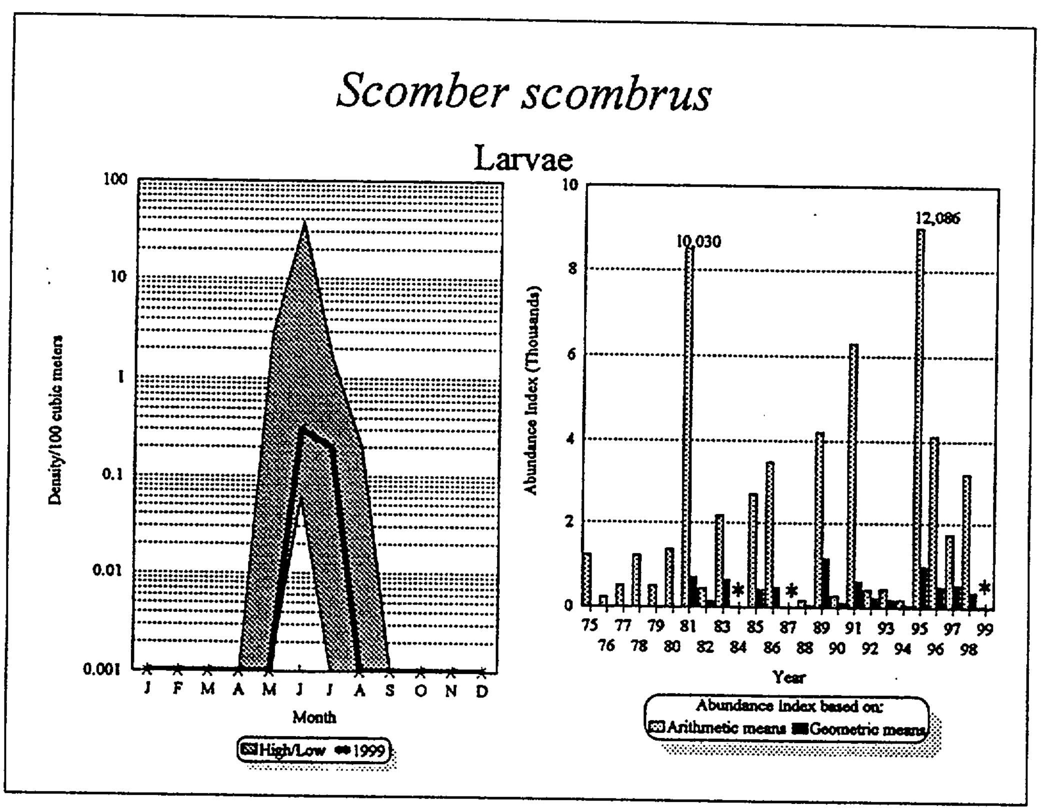


Pholis gunnellus

Larvae

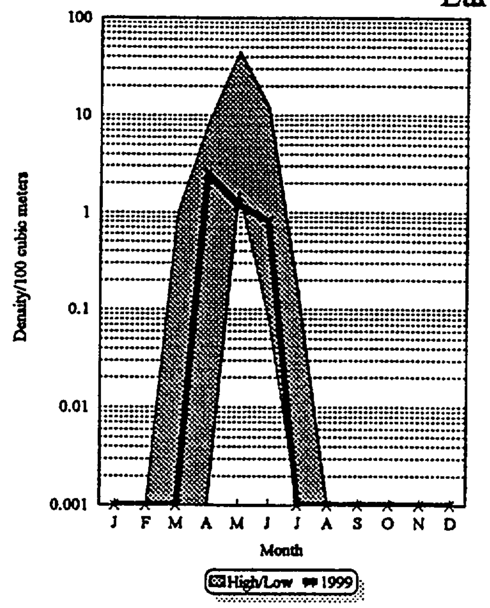


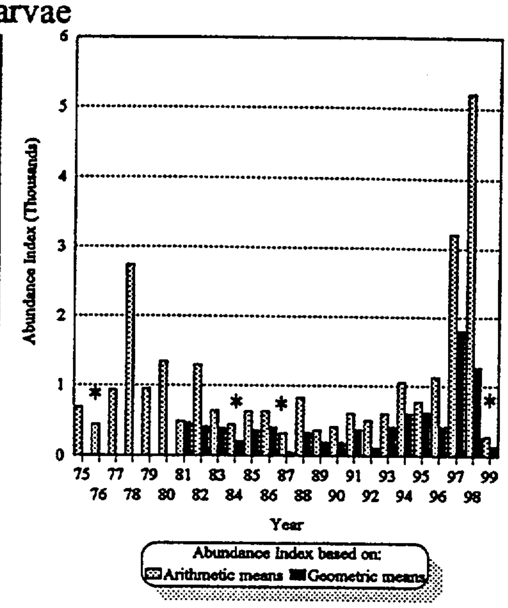

Ammodytes spp.
Larvae
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index (Thousands)
10
8
6
4
2
0
14,944
26,276
19,511
12,490
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Scomber scombrus
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1999
Abundance Index (Thousands)
10
8
6
4
2
0
10,030
12,086
75 77 79 81 83 85 87 89 91 93 95 97 99
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

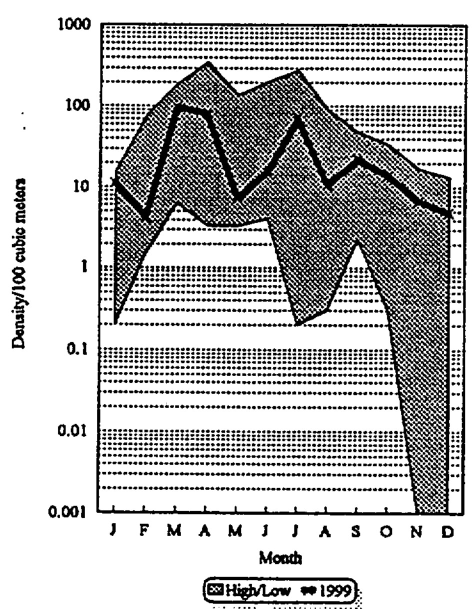
Pleuronectes americanus

Larvae





Total Larvae



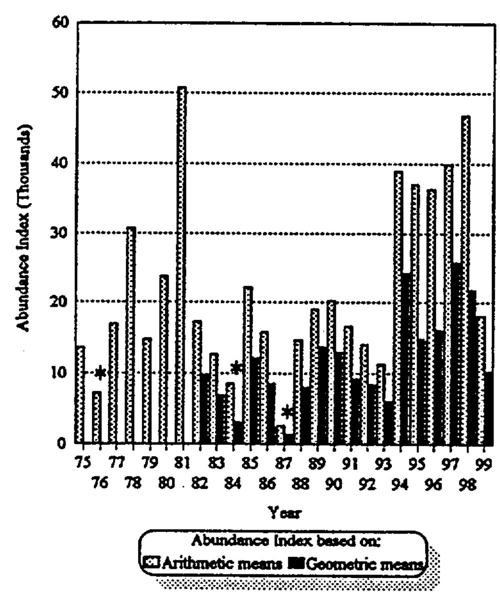


Table 2. Species of fish eggs (E) and larvae (L) obtained in ichthyoplankton collections from the Pilgrim Nuclear Power Station discharge canal, January-December 1999.

Species		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Atlantic menhaden	*Brevoortia tyrannus*						E/L	E/L	E/L	E/L	L	L	
Atlantic herring	*Clupea harengus*	L	L	L	L	L						L	L
Anchovy	*Anchoa* spp.							E/L	E	L			
Rainbow smelt	*Osmerus mordax*					E	L						
Fourbeard rockling	*Enchelyopus cimbrius*				E	E/L	E/L	E/L	E/L	E/L	L	L	
Atlantic cod	*Gadus morhua*	L	E	E/L	E/L	E		L	L			E	E/L
Haddock	*Melanogrammus aeglefinus*				E/L	E							
Silver hake	*Merluccius bilinearis*							E/L	E/L	E/L	L	L	
Atlantic tomcod	*Microgadus tomcod*			L									
Hake	*Urophycis* spp.						E	E/L	E/L	E/L	L		L
Striped cusk-eel	*Ophidion marginatum*								L	L			
Goosefish	*Lophius americanus*						E/L	L	E	L	L		
Silversides	*Menidia* spp.						L	L					
Northern pipefish	*Syngnathus fuscus*						L	L	L	L		L	
Searobins	*Prionotus* spp.						E/L	E	E/L	E/L			
Grubby	*Myoxocephalus aenaeus*		L	L	L	L							L
Longhorn sculpin	*M. octodecemspinosus*	L	L	L	L	L							
Shorthorn sculpin	*M. scorpius*		L	L									
Seasnail	*Liparis atlanticus*			L	L	L	L						
Gulf snailfish	*L. coheni*	L	L	L									
Black sea bass	*Centropristis striata*								L	L	L		
Scup	*Stenotomus chrysops*						L	E	E/L	E			

Table 2 (continued).

Species		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wrasses	Labridae					E	E	E	E			E	
Tautog	*Tautoga onitis*						L	L	L	L	L		
Cunner	*Tautogolabrus adspersus*						L	L	L	L			
Daubed shanny	*Lumpenus maculatus*			L									
Radiated shanny	*Ulvaria subbifurcata*				L	L	L						
Rock gunnel	*Pholis gunnellus*	L	L	L	L	L							L
Sand lance	*Ammodytes* sp.	L	L	L	L	L							L
Seaboard goby	*Gobiosoma ginsburgi*								L				
Atlantic mackerel	*Scomber scombrus*				E	E	E/L	E/L					
Butterfish	*Peprilus triacanthus*							L	L	L			
Smallmouth flounder	*Etropus microstomus*						E	E	E/L	E/L	L		
Fourspot flounder	*P. oblongus*							L	L	L			
Windowpane	*Scophthalmus aquosus*				E	E	E/L	E/L	E/L	E	E		
American plaice	*Hippoglossoides platessoides*			E	E/L	E/L	E/L	E/L					
Winter flounder	*Pleuronectes americanus*		E	E	E/L	E/L	L	E	E				
Yellowtail flounder	*P. ferrugineus*				E/L	E	E/L	L	E/L				
Hogchoker	*Trinectes maculatus*						E						
Number of species		6	9	13	15	17	20	21	21	17	9	7	6

Table 3. Ichthyoplankton densities (number per 100 m³ of water) for each sampling occasion during months when notably high densities were recorded, January-December 1999. Densities marked by + were unusually high based on values in Table 1. Number in parentheses indicates percent of all previous values during that month which were lower.

Rock gunnel larvae

Jan 4	1.9	+ (85)
6	7.9	+ (98)
8	0	
18	11.7	+ (100)
20	12.7	+ (100)
22	8.6	+ (100)
Previous high:	8	(1978)
Notice level:	1.4	
Feb 5	5.2	
8	1.9	
10	132.6	+ (100)
19	0.8	
24	4.1	
26	0	
Previous high:	53	(1995)
Notice level:	99	

Sand lance larvae

March 1	4.4	
3	8.8	
5	38.6	
8	STORM	
10	8.9	
12	STORM	
16	0	
17	29.5	
19	5.3	
22	STORM	
24	11.4	
26	STORM	
29	85.6	
31	308.4	+ (98)
Previous high:	511	(1998)
Notice level:	164	

Atlantic herring larvae

April 2	2.4	+ (81)
7	2.6	+ (82)
9	7.4	+ (95)
12	0.9	
14	7.9	+ (95)
16	38.3	+ (100)
19	1.3	
21	0	
23	4.4	+ (87)
26	3.2	+ (86)
28	1.5	
30	7.5	+ (95)
Previous high:	32	(1996)
Notice level:	2	

Seasnail larvae

April 2	0.8	
7	37.4	+ (97)
9	4.9	
12	3.5	
14	2.6	
16	0	
19	14.5	+ (92)
21	0	
23	11.6	+ (91)
26	6.4	
28	0.8	
30	1.5	
Previous high:	98	(1974)
Notice level	10	

Table 3 (continued).

Atlantic menhaden

	EGGS		LARVAE	
July 3	0		1.1	
5	0		1.8	
7	0		1.9	
9	0		16.5	+ (90)
12	43.0	+ (99)	2.4	
14	3.4	+ (89)	6.1	+ (82)
16	0		12.4	+ (88)
19	0		9.5	+ (86)
21	0		1.5	
24	0		22.5	+ (91)
26	0		0	
28	0		1.9	
30	0		9.4	+ (85)
Previous high:	59	(1978)	124	(1974)
Notice level:	4		3	

Atlantic menhaden larvae

Aug 2	3.9	+ (92)	Sept 1	3.0	+ (86)
4	0.9		3	0	
6	1.9	+ (89)	6	1.4	
9	0		8	15.7	+ (96)
11	0.8		10	4.5	+ (89)
13	8.3	+ (97)	13	7.5	+ (93)
16	0		15	2.4	+ (85)
18	1.9	+ (89)	17	STORM	
20	0.8		20	38.6	+ (99)
23	0		22	1.4	
25	0.7		24	81.0	+ (100)
27	0		27	24.9	+ (97)
30	0		29	7.1	+ (92)
Previous high:	47	(1997)	Previous high:	47	(1993)
Notice level:	1		Notice level:	2	
Oct 8	6.3	+ (80)	Nov 5	9.2	+ (97)
11	1.3		8	2.8	+ (94)
13	0		10	1.0	+ (86)
25	13.3	+ (93)	19	0	
27	6.9	+ (83)	22	0	
29	16.7	+ (96)	24	0	
Previous high:	70	(1997)	Previous high:	57	(1997)
Notice level:	4		Notice level:	1	

Table 3 (continued).

Hake larvae			Tautog larvae		
July 3	0		July 3	1.1	
5	0		5	0	
7	10.5	+ (90)	7	1.0	
9	18.1	+ (93)	9	6.6	+ (86)
12	15.7	+ (93)	12	14.1	+ (93)
14	0		14	1.4	
16	1.0	+ (80)	16	2.1	+ (70)
19	22.4	+ (96)	19	0.6	
21	0		21	1.5	
24	3.5	+ (88)	24	0.6	
26	0.8		26	0	
28	0		28	0	
30	3.5	+ (88)	30	0	
Previous high:	248	(1998)	Previous high:	269	(1998)
Notice level:	1		Notice level:	2	
Aug 2	0		Aug 2	0.6	
4	0		4	0	
6	1.0		6	0	
9	1.1		9	2.2	
11	7.9	+ (85)	11	3.9	+ (88)
13	3.1		13	8.3	+ (92)
16	0		16	0	
18	0		18	4.9	+ (89)
20	0.8		20	1.7	
23	0		23	0	
25	0		25	0	
27	78.0	+ (97)	27	1.9	
30	0		30	0	
Previous high:	196	(1995)	Previous high:	42	(1997)
Notice level:	4		Notice level:	2	
Sept 1	0		Sept 1	1.0	
3	0		3	0	
6	0		6	0	
8	0		8	0	
10	0.6		10	0	
13	0		13	3.7	+ (90)
15	0		15	0.8	
17	STORM		17	STORM	
20	13.5	+ (79)	20	3.9	+ (90)

Table 3 (continued).

Hake larvae (continued)			**Tautog larvae** (continued)		
Sept 22	0		Sept 22	4.3	+ (91)
24	0		24	1.6	
27	3.9		27	2.0	
29	17.2	+ (83)	29	2.4	+ (83)
Previous high:	327	(1997)	Previous high:	19	(1996)
Notice level:	9		Notice level:	2	
Oct 8	0				
11	3.3	+ (85)			
13	0				
25	1.0				
27	0				
29	0				
Previous high:	14	(1985)			
Notice level:	2				
Searobin eggs			**Labrid eggs**		
Aug 2	7.7	+ (90)	Aug 2	1181.5	+ (97)
4	0		4	46.8	
6	2.9		6	33.4	
9	1.1		9	33.4	
11	0.8		11	19.7	
13	0		13	11.4	
16	0		16	12.8	
18	6.8	+ (89)	18	25.9	
20	0		20	16.8	
23	0		23	0.8	
25	2.0		25	0	
27	9.5	+ (94)	27	1.0	
30	0		30	3.8	
Previous high:	89	(1995)	Previous high:	3500	(1984)
Notice level:	6		Notice level:	936	

Table 3 (continued).

Rockling larvae

July	3	12.9	+ (75)
	5	37.6	+ (89)
	7	15.3	+ (77)
	9	21.4	+ (84)
	12	47.0	+ (92)
	14	4.0	
	16	38.4	+ (90)
	19	11.2	+ (74)
	21	0.8	
	24	115.8	+ (100)
	26	40.9	+ (91)
	28	9.5	+ (72)
	30	9.4	+ (72)
Previous high:		114	(1990)
Notice level:		9	
Aug	2	5.2	
	4	0.9	
	6	1.9	
	9	9.7	
	11	8.7	
	13	18.6	+ (93)
	16	0	
	18	3.9	
	20	0	
	23	0	
	25	0	
	27	2.9	
	30	0	
Previous high:		205	(1983)
Notice level:		10	
Sept	1	0	
	3	0	
	6	0	
	8	0	
	10	1.3	
	13	3.7	
	15	0	
	17	STORM	
	20	13.5	+ (94)
	22	0	
	24	0	
	27	1.3	
	29	5.5	
Previous high:		69	(1993)
Notice level:		6	

Windowpane eggs

Aug	2	162.5	+ (99)
	4	40.3	
	6	51.6	
	9	126.0	
	11	35.4	
	13	138.6	+ (98)
	16	58.2	
	18	139.8	+ (99)
	20	49.4	
	23	11.6	
	25	2.7	
	27	68.5	
	30	3.8	
Previous high:		194	(1989)
Notice level:		136	
Oct	8	4.2	+ (88)
	11	1.3	
	13	0	
	25	0	
	27	0	
	29	0	
Previous high:		30	(1997)
Notice level:		2	

Table 4. Species of fish eggs (E) and larvae (L) collected in the PNPS discharge canal, 1975-1999. 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
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
Clupeas harengus	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
A. mitchilli			E	E	E		E	E/L			E	E		
Osmerus mordax	L	L	L	L	L		E/L	L	L		L	L	L	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
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
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
Microgadus tomcod			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
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
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
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
M. menidia	E/L	E/L	E						L					
Syngnathus fuscus	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Sebastes norvegicus														
Prionotus spp.	E/L	E		E	E	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L
Hemitripterus americanus														
Myoxocephalus spp.	L	L	L	L	L	L	L	L	E/L	L	E/L	L	L	L
M. aenaeus					L	L	L	L	L	L	L	L	L	L
M. octodecemspinosus						L	L	L	L	L	L	L	L	L
M. scorpius						L	L	L		L	L	L	L	L
Aspidophoroides monopterygius					L	L	L							
Cyclopterus lumpus		L	L				L	L	E		L		L	L
Liparis spp.	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. coheni							L	L	L	L	L	L	L	L
Centropristis striata	L					L			L	L	L	L	L	L
Cynoscion regalis						L					L	L		
Stenotomus chrysops	L		L											L
Menticirrhus saxatilis	L				L									

Table 4 (continued).

Species	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Period of Occ
Anguilla rostrata		J				J	J	J	J	J		Feb - Ju
Alosa spp.		J						L				May - J
Brevoortia tyrannus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (O
Clupeas harengus	L	L	L	L	L	L	L	L	L	L	L	Jan - De
Anchoa spp.	L	L	L	L	L	L	L	L	L	L	L	Jun - Se
A. mitchilli	E	E	E	E	E			L		E	E/L	Jun - Se
Osmerus mordax	E/L			L	L	L	L		L	L	E/L	Mar-Ju
Brosme brosme												Apr - Ju
Enchelyopus cimbrius	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (S
Gadus morhua	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Nov) - (D
Melanogrammus aeglefinus		E					E	E		L	E/L	Apr - Ju
Merluccius bilinearis	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	May(May) - (J
Microgadus tomcod	L	L		L	L	L	L	L	L	L	L	Jan - M
Pollachius virens	L	L	L	E/L	L	L			E			Jan-Jun,No
Urophycis spp.	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Aug) - (S
Ophidion marginatum							L		L	L	L	Aug - S
Lophius americanus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	May - O
Strongylura marina												Jul
Fundulus spp.												Jul
F. heteroclitus												Jun
F. majalis				E								Oct
Menidia spp.	L	L	L	L	L	L	L	L		L	L	May - S
M. menidia			E		E							May - S
Syngnathus fuscus	L	L	L	L	L	L	L	L	L	L	L	Apr - N
Sebastes norvegicus	L											Jun
Prionotus spp.	E	E	E	E	E/L	E	E	E	E/L	E/L	E/L	May(Jun) - (A
Hemitripterus americanus						L	L			L		Feb - M
Myoxocephalus spp.	E/L	L	E/L	L	L	L	L	L	L	L	L	Dec(Mar) - (
M. aenaeus	L	L	E/L	L	L	L	L	L	L	L	L	Jan(Mar) - (
M. octodecemspinosus	E/L	L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (A
M. scorpius	L	L	L	L	L	L	L	L	L	L	L	Feb - A
Aspidophoroides monopterygius	L											Mar - A
Cyclopterus lumpus	L	E/L		E/L	L	L	L	L				Apr - Ju
Liparis spp.	L	L	L	L	L	L	L	L	L	L	L	Jan(Apr) - (J
L. atlanticus	L	L	L	L	L	L	L	L	L	L	L	Mar(Apr) - (J
L. coheni	L	L	L	L	L	L			L	L	L	Jan(Feb) - (M
Centropristis striata	L	L			L		L		L	L	L	Jul - Oc
Cynoscion regalis												May - S
Stenotomus chrysops	E	L	L	L	L		L		L	L	E/L	Jun - Jul(
Menticirrhus saxatilis												Jul - Au

Table 4 (continued).

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Labridae	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
Tautogolabrus adspersus	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Lumpenus lumpretaeformis	L						L			L	L	L		L
Ulvaria subbifurcata	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
Cryptacanthodes maculatus				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
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
Peprilus triacanthus	E/L	E/L	E/L	E	E	E/L	E/L	L	E/L	E/L	L		E	E/L
Etropus microstomus	L								L		E	E/L	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
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
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
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
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
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
P. putnami							L	E/L						
Trinectes maculatus			E	E			E	E				E		E
Sphoeroides maculatus			L								L			
Number of Species[4]	41	36	43	35	37	35	40	38	37	34	42	37	36	41

[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	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Period of Occurrence
Labridae	E	E	E	E	E	E	E	E	E	E	E/L	Mar(May) - (Aug)Sep
Tautoga onitis	L	L	L	L	L	L	L	L	L	L	L	May(Jun) - (Aug)Oct
Tautogolabrus adspersus	L	L	L	L	L	L	L	L	L	L	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	Feb(Apr) - (Jun)Oct
Pholis gunnellus	L	L	L	L	L	L	L	L	L	L	L	Jan(Feb) - (Apr)Jun
Cryptacanthodes maculatus	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	Jan(Mar) - (May)Jun
Gobiosoma ginsburgi						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	Apr(May) - (Jul)Sep
Peprilus triacanthus	E/L	L	E/L		L	L	E/L	L	L	E/L	L	May - Oct
Etropus microstomus	E		E	E	E		E/L	E/L	E/L	E/L	E/L	Jul - Oct
Paralichthys dentatus		L			E/L	E	E/L	L		L		Sep - Nov
P. oblongus[3]	E/L	E/L	E/L	E\L	E\L	E/L	E/L	E/L	E/L	E/L	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	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		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	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	Jan(Apr) - (Jun)Aug
P. ferrugineus	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					Mar - Jun
Trinectes maculatus	E/L	E/L	E								E/L	May - Sep
Sphoeroides maculatus												Jul - Aug
Number of Species[4]	40	42	34	36	38	40	42	38	37	40	41	

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 procedure (EA, see Horst 1976, Goodyear 1978, Saila et al 1997, for example). Somewhat arbitrarily this review dates back to 1980 so that with the addition of 1999, 20 years are included. The adult equivalent methodology applies estimated survival rates to numbers of eggs and larvae lost to entrainment to obtain a number of adult fish which might have entered the local population had entrainment not occurred. It is noted that comparisons with measures of existing populations are biased in that EA values represent numbers of adults projected to be lost one to three years into the future (depending on the age used to define an adult). Any estimate of existing population size will be for the current year.

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 the potential losses the assumption is also made that no density-dependent compensation occurs among non-entrained individuals. 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). It also seems intuitively likely that nonentrained individuals might survive at a somewhat higher rate as a result of diminished competition.

Numbers of eggs and larvae entrained were determined using the full-load-flow capacity of the plant. 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. Estimated numbers entrained for species present during those months often appear low for those two years because there is some indication that ichthyoplankton entrainment is disproportionately low when only the salt service water pumps were in operation (MRI 1994).

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. For data which are skewed to the right such as plankton densities, the geometric mean is always less than the arithmetic mean (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 analytical considerations 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 area and PNPS finfish studies have been focusing on that species which appeared to be in a declining trend from 1980 to 1994 (Lawton et al. 1995). 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 1999 an estimated total of 3,500,000 larval winter flounder were entrained by PNPS (Table 5). This ranks among the lowest totals recorded over the 1980-1999 time series due in large part to shutdown of both main circulating water pumps from May 10 to June 10. The average number entrained from 1980-1998 excluding 1984 and 1987 when the main pumps were also out of service amounted to 22,500,000 (s.e. = 4,900,000), ranging from 8,700,000 in 1990 to 86,800,000 in 1998. As mentioned earlier, available evidence suggests that larvae in the waters off PNPS are not sampled in proportion to their true abundance when only salt service water system pumps are in operation. It is not possible therefore, with any confidence, to suggest how abundant larval flounder were in general in 1999 in the PNPS area from the entrainment data.

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 stage 1 and 2 larvae collected prior to 1995 were scaled upward by 1.62 to correct for mesh extrusion (MRI 1995). Two 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. The 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 by NUSCO (1993) as modified by Gibson (1993a). These are as follows:

S (stage 1) = 2.36E-01
S (stage 2) = 1.08E-01
S (stage 3) = 1.54E-01
S (stage 4) = 6.23E-01
S (age 0) = 7.30E-02
S (age 1) = 2.50E-01
S (age 2) = 4.77E-01

In using the stage-specific rates it is recognized that NUSCO employs different morphological stage criteria than those used at PNPS (NUSCO 1998). 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. Although small numbers are entrained each year, flounder eggs were ignored because they are demersal and adhesive and not generally impacted by entrainment.

Recently Rose et al. (1996) presented information on a population dynamics model for winter flounder consisting of separate young-of-the-year and adult components. The young-of-the-year model included survival rates for eggs, larvae, early and late juveniles stages. Since the model is designed to mathematically represent numbers of individuals as they develop from one stage to another, it is difficult to apply their survival rates to the mixed age pool of larvae entrained at PNPS. All individuals would need to be converted to a common starting point such as newly hatched eggs as is done with the unstaged approach. By using a value of 0.09 to step back from mixed-age larvae to hatched eggs, the rates utilized by Rose et al. produce approximately twice as many fish as the staged survival values provided above. Since the staged survival values were adjusted by Gibson (1993a) to provide an equilibrium population, the Rose et al. values likely overestimate EA values in this instance. To be consistent with the equilibrium assumption survival rates for one or more of the other life stages would have to be reduced. Without any empirical data this would be rather arbitrary.

The general, unstaged larval survival values produced an adult equivalent value of 216 age 3 fish for 1999 (Figure 7, Table 5). The stage-specific values produced an EA total about four times higher at 912 age 3 individuals. Based on a weight of 0.6 pounds per fish (Gibson 1993b), these values convert to 130 and 547 pounds, respectively. Comparable values for 1980-1998 ranged from 535 to 5,473 fish (mean = 1,397 fish, 838 pounds) for the general approach and 2,624 to 77,393 (mean = 14,530 fish, 8,718 pounds) for the staged approach. EA totals for 1984 and 1987 were omitted here because both circulating seawater pumps were off for most of the larval winter flounder seasons during protracted maintenance outages. As mentioned above, there is some indication that ichthyoplankton entrainment is disproportionately low when only the salt service water pumps are in operation. Values for 1998 using the unstaged general approach represented the second consecutive record high year exceeding the notably high value for 1997 (3,414 fish) by 60%. Values based on the staged approach also exceeded the previous high recorded in 1997 (47,087) by 64%. The relatively high EA values noted in 1998 are directly attributable to the unusually high number of larvae entrained. The large differences between the two sets of survival estimates 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 difference between unstaged and staged EA totals was relatively small in 1999 because very few stage 3 and 4 larvae were collected as the main circulating water pumps were off when they were most likely to be abundant in the surrounding waters.

A market value was estimated for the equivalent adult flounder potentially lost due to entrainment affects based on $1.15 per pound. This was the posted price on the Gloucester and New Bedford primary wholesalers market as of February 16, 2000 (available via the internet at http://www.st.nmfs.gov/market_news). The EA totals for 1999 had a market value of $149 based on the unstaged calculation and $629 based on the staged calculation both based on actual station flow. Market values of $964 and $10,026 are obtained if the current price is applied to the two average EA totals over the 1980-1998 time series (Table 5).

Over the 1982 through 1998 period an annual average of 1,465,784 pounds (s.e. = 274,182 pounds) of flounder were landed commercially from NOAA statistical area 514 which covers Cape Cod Bay and Massachusetts Bay (Table 6). Based on a weight of 0.6 pounds per fish, the average estimated loss of 838 or 8,718 pounds of equivalent adults from PNPS entrainment over a similar time frame represents 0.06 or 0.6% of those landings. Area 514 commercial landings declined sharply after 1993 from1,057,211 pounds that year to 16,788 pounds in 1995, 1,798 pounds in 1997, and only 501 pounds in 1998 (Table 6). The precipitous drop is attributable to increased fishing restrictions and stock declines. EA values for 1994 through 1998 alone appear quite high compared to the reduced commercial landings, and in fact the unstaged values for both 1997 and 1998 exceed the commercial landings for those two years, indicating that commercial landings are no longer a realistic measure of the EA values.

Winter flounder also have considerable value as a recreational species. Based on NOAA records[3] an annual average of 853,688 fish (s.e. = 289,488) weighing an average of about one pound each were landed from Massachusetts inland waters over the 1981-1998 period (Table 6). More recently (1990-1998) recreational landings have been well below earlier years because of stock declines and area closures consistent with commercial landings; an annual average of 83,828 fish (s.e. = 11,873) were reported landed in the state from inland waters during that more recent period. These fish were also apparently smaller, weighing an average of 0.72 pounds each. Unfortunately these 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

[3] Recreational landings data were obtained via the internet at http://www.st.nmfs.gov.

are not available. Arbitrarily adding 20,000 pounds of recreationally-caught flounder to the 1994-1998 Area 514 commercial landings would bring the respective totals for those five years to 348,706, 36,788, 22,961, 21,798 and 20,501 pounds. The PNPS entrainment EA values from the unstaged approach for those years then amount to 0.2, 1.4, 3.0, 9.4, and 16.0%, respectively. The 1999 unstaged estimate of 130 pounds represents 0.6% of the 1998 landings estimate. For the staged larval approach the five values range from 2.1 to 227%, respectively, with the 1999 value of 547 pounds representing 2.7% of the 1998 landings estimate. Clearly the decline in commercial landings after 1994 suggest that those values even 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 in each of three years, 1997-1999 (see Section IIIA, this report). In 1997 and 1998 they also completed estimates of stock size using several mark and recapture models. 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 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 DMF area-swept estimate for 1999 equaled 176,271 adults based on gear efficiency of 50% with confidence limits ranging from 172,300 to over 180,200 fish. This represented the third year of an apparent decline as corresponding estimates for 1997 and 1998 were 321,800 and 264,800 fish, respectively. DMF's mark-and-recapture study was limited by disappointing tag returns. Estimates ranged from 115,000 to 520,000 adults in 1997 and 76,000 to 111,000 in 1998 depending on the model employed (Lawton et al. 1999). EA estimates for 1997 using the unstaged survival values (3,400 fish) amount to 1.1% of the area swept estimate for that year and 3.0% of the low mark and recapture estimate. The 1997 EA estimate from the staged approach (47,087 fish) amounted to14.6% of the area swept estimate and 40.9% of the low-end mark-recapture estimate. Comparing the 1998 unstaged EA estimate (5,473 fish) to these values provided proportional losses of 2.1 and 7.2%, respectively. The staged estimate (77,393 fish) amounted to 29.2 and 102%, respectively. The greatly reduced EA estimates for 1999 amounted to 0.2% of the 1999 area swept estimate for the unstaged value (289 fish) and 1.4% for the staged value (2,382 fish).

As mentioned earlier, the fact that 1997 and 1998 represented two consecutive years of relatively high larval flounder entrainment at a time when local area stock size shows no sign of increasing remains unexplained. The decision to schedule the Plant's maintenance outage for the larval flounder season in 1999 and to shut down both main circulating seawater pumps during that time clearly reduced station impacts.

Additional assessment of larval winter flounder impacts attributable to PNPS were completed using a model which indicates an overall population impact of <5% for various scenarios. This information appears in a separate section below.

Cunner

As described, above cunner eggs are among the most abundant fish eggs in PNPS entrainment samples. Total numbers entrained ranged from 675,000,000 in 1991 to 6,600,000,000 in 1981 with a time series mean of 2,918,922,000 (s.e. = 378,505,500). For cunner larvae annual totals ranged from 2,800,000 in 1992 (1984 excluded) to 586,500,000 in 1981 with a time series average of 107,900,000 (s.e. = 39,612,000). Totals for 1999 amounted to 1,098,618,000 eggs and 46,551,000 larvae, less then half the average.

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 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 1996, and 1.10 for eggs taken in 1997. The 1997 value was used for 1998 and 1999. Larval cunner mesh values applied were 1.16 for stage 1 and 1.28 for stage 2, irrespective of year. From 1980 to 1998 the larva/egg ratio ranged from 0.001284 to 0.128812 and averaged 0.030480; 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). 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 4 = 0.342
Age 5 = 0.645
Age 6 = 1.260
Age 7 = 0.653
Age 8 = 1.463
Age 9 = 0.728

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), 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 and average lifetime fecundity, a survival estimate for larvae to adult of 3.03E-3 was obtained. Converting numbers of eggs to larvae utilizing the larvae/egg ratio and then converting numbers of larvae to adults produced an estimate of 242,511 cunner potentially lost to entrainment effects in 1999 based on recorded station flow. Comparable values for 1980-1998 ranged from 113,048 in 1991 to 2,353,607 adults in 1981 averaging 529,461 (s.e. = 125,402) over the 19-year period (Figure 8, Table 7). The high value of 2,571,973 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 lesser extent those made in1987 were relatively low apparently due to reduced flow during outage periods (Table 7 presents estimates for 1984, 1987, and 1999 based on both full-load flow rates and those actually recorded). Without those three values a mean of 445,266 (s.e. = 86,425) was obtained.

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 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 242,511 adults in 1999 due to PNPS operation represents 0.11% of the estimated spawning stock. The annual mean loss of 529,461 fish, including all years, represents 0.26% of the stock estimate.

MDMF personnel have chosen 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). 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 (see also section III.A) 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. The number of eggs entrained indicate that cunner must be abundant in these waters.

The numbers of equivalent adult fish potentially lost through the effects of entrainment were given a market value in U.S. dollars. Numbers of fish were first expressed on a weight basis using 0.12 pound per fish (55 grams for a 150 mm fish, MRI unpublished). Numbers of pounds were then valued based on $0.15 per pound. Since cunner have no specific market price, the value of Atlantic herring (see below) was used. With this approach, losses in 1999 were valued at $4,400. The average over the 1980-1998 times series amounted to $9,500 based on current prices.

Atlantic Mackerel

Numbers of mackerel eggs entrained at PNPS ranged from 81,600,000 in 1981 (excluding 1984 and 1987) to 4,700,000,000 in 1989 with an average of 1,150,713,110 (s.e. = 303,529,902). Totals for larval mackerel ranged from 3,400,000 in 1988 (again 1984 and 1987 omitted) to 320,135,596 in 1981 with an average of 59,274,414. Corresponding values for 1999 were 6,182,166 for eggs and 311,394 for larvae based on actual station flow, less than 1% of the time series average values.

Procedures outlined by Vaughan and Saila (1976) were used to derive a survival rate for 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 mortality was obtained from Overholtz et al. (1988) and NOAA (1995). 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). The observed average ratio of eggs to larvae for PNPS of 0.09143 (1980-1998) provided a larva-to-age 1 survival rate of 2.5053E-5. 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 most of the mackerel egg and larval seasons during maintenance outages. A mesh adjustment factor of 1.12 was applied to the egg data based on mesh comparison collections completed from 1994 through 1997 (MRI 1998). No mesh adjustment was justified for larvae. According to NOAA (1995, 1996) stock biomass consists of fish age 1 and older while fish completely recruit to the spawning stock by age 3. Therefore, adult equivalent values are shown for both age groups (Figure 9, 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 provide annual survival rates of S = 0.595 and 0.691, respectively. Numbers of age 1 and 3 mackerel were expressed on a weight basis based on 0.2 and 0.7 pounds per fish, respectively (Clayton et al. 1978).

PNPS equivalent adults attributable to entrainment for 1999 amounted to 22 age 1 fish weighing 4 pounds or 9 age 3 fish weighing 6 pounds. Corresponding age 1 values over the 1980 through 1998 time series ranged from 483 (1982) to 12,349 (1989) fish with an average of 4,121 (s.e. = 825). Age 3 values ranged from 199 to 5,077 with an annual average of 1,694 (s.e. = 339) individuals. Data from 1984 and 1987 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 1998 of 824 pounds (s.e. = 165 pounds) or 1186 pounds (s.e. = 237), respectively (1984 and 1987 excluded). The number of eggs and larvae entrained in 1999 and therefore the number of equivalent adults was quite low regardless of whether the number was calculated assuming full plant flow or actual flow (Table 8). Numbers were comparable to 1984 and 1987 when the Station circulating flow was also minimized. The Station circulating water pumps were shut down when mackerel eggs were most abundant and, whether because of that or low abundance in Cape Cod Bay, very few larvae were collected in the 1999 entrainment samples.

According to NOAA statistical records, an annual average of 339,040 pounds (s.e. = 88,862) of mackerel were taken commercially from statistical area 514 over the years 1982-1998. For PNPS the loss of an average of 824 pounds of age 1 fish (1980-1998, 1984 and 1987 omitted) amounts to 0.2% of those landings and the loss of an average of 1,186 pounds of age 3 fish, 0.3%. In addition to commercial landings, mackerel have considerable recreational value. For example, over the years 1981-1998 an average of 1,037,279 fish (s.e. = 200,882) 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 one-pound fish to the commercial landings brings the harvest total to 539,040 pounds and the mean PNPS EA total to 0.1 and 0.2%, respectively.

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 (1980-1998; 1984, 1987 omitted) of 1,694 age 3 fish due to PNPS entrainment represents 0.08% of that value.

Equivalent adult mackerel losses were assigned a market value based on $0.31 per pound. This price was obtained from the value of mackerel landings in Massachusetts in 1998 posted on the internet by the National Marine Fisheries Service (http://www.st.nmfs.gov). Based on this, the 1999 loss of 6 pounds was valued at $1.95 and the long term mean loss of 1,186 pounds was valued at $367.65.

Atlantic Menhaden

Total numbers of Atlantic menhaden eggs entrained at PNPS ranged from 393,000 in 1992 (1984 and 1987 omitted) to 947,800,000 in 1993 with an overall average of 90,684,438 (s.e. = 57,493,301). Corresponding totals for menhaden larvae ranged from 512,000 in 1991 (1984 and 1987 omitted) to 48,300,000 in 1997 averaging 11,583,277 (s.e. = 3,549,111) over the 1980-1998 time series. Totals for 1999 amounted to 10,385,304 eggs and 18,939,526 larvae based on actual station flow during the spring outage period (Table 9).

Numbers of eggs and larvae entrained each year at PNPS were converted to numbers of equivalent adults using both the Goodyear (1978) and the Vaughan and Saila (1976) approaches. Both procedures require 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 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 0.987 were obtained in 1980, 1982, 1985, 1986,1988-1991,1993, 1994, 1997, and 1998. A geometric mean of 0.183 was obtained over those 12 estimates. In the Mount Hope Bay section of Narragansett Bay from 1973-1991 a geometric mean ratio of 0.066 was obtained. An average of the two estimates, 0.125, was used to approximate Se. An average lifetime fecundity for an age 3 female of 456,481 was calculated by the Goodyear procedure using an instantaneous natural mortality rate (M) of 0.45 and maximum age of 9 from Ahrenholz et al. (1987). 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 is uncommon in upper Narragansett Bay (MRI and NEP 1980), 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. An estimate of fishing mortality F = 0.8 was taken from Ruppert et al. (1985) who found that value to be optimal for maximizing catch. The larva/egg ratio of 0.125 and average lifetime fecundity of 456,481 provided an estimated larva to age 3 adult survival rate of 3.5051E-05.

The procedure of Vaughan and Saila (1976) using the Leslie matrix algorithm provided an estimate of survival from spawned egg to age 1. Fecundity and survival rates were set as for the average lifetime fecundity procedure providing an estimated survival rate of 2.398E-05 from egg to age 1.

The Goodyear approach with average lifetime fecundity provided an estimate of 740 age 3 fish for 1999. The Vaughan and Saila method provided an estimate of 4,052 age 1 individuals. Since menhaden enter the fishery at age 2 (Durbin et al. 1983), the annual natural mortality rate of M = 0.45 (S = 0.638) was applied to arrive at an estimate of 2,583 age 2 fish potentially lost to the fishery (Figure 10). Based on a wet weight of 0.5 pound for age 2 individuals (Durbin et al. 1983), these estimates equal 1,292 pounds. Corresponding values for 1980 through 1998 ranged from 41 in 1992 to 4,568 in 1993 and averaged 803 age 3 adults (s.e. = 279) or 2,804 age 2 fish (s.e. = 973) weighing 1,402 pounds which might have entered the fishery.

Over the period 1981 to 1993 an average of 15,306,000 pounds of menhaden were landed from statistical area 514 with a range from 1.3 to 52.1 million pounds. The average entrainment loss of 1,402 pounds of menhaden amounts to 0.01% of the average landings or 0.1% of the minimum landings.

Numbers of menhaden eggs were re-examined from 1975 when ichthyoplankton sampling was completed throughout 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 4.6 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 803 age 3 menhaden would amount to 0.04% of the estimated spawning stock in Cape Cod Bay.

The numbers of equivalent age 2 menhaden potentially lost through the effects of entrainment were given a market value in U.S. dollars based on $0.57 per pound. This value was obtained from

American Fisheries Society (1992) inflated by 5% per year from 1990 to 2000. Equivalent adult menhaden losses in 1999 were valued at $736.00. while the average over the 1980-1998 times series amounted to $799.00 based on current prices. (Table 9).

Atlantic Herring

Since Atlantic herring spawn demersal, adhesive eggs primarily on offshore banks they are not subject to entrainment at PNPS. Larval entrainment based on full-load circulating water flow at the station ranged from 469,000 in 1984 to 43,000,000 in 1995 and averaged 7,168,322 (s.e. = 2,738,185). For the 1999 season the number entrained was estimated to be 11,379,446 larvae. Since they are relatively large, no mesh adjustment factor was applied to them. Larval herring have typically been impinged from autumn to early spring, so total numbers entrained in 1984 when no sampling was conducted in April and in 1987 when the circulating water system was shut down in April may have been underestimated 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 McGurk (1993). 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 16,678 age 1 herring potentially lost to entrainment effects in 1999, which might have entered the sardine fishery. Based on a natural mortality rate of 18.1% per year (M = 0.20, NOAA 1995, NFSC 1998), 16,678 age 1 fish would produce 11,187 age 3 adults, the age at which 50% of fish recruit to the spawning stock (NOAA 1995; Figure 11). Assuming age 1 (sardines) weigh 0.03 pounds and age 3 adults, 0.4 pounds, 500 pounds of sardines or 4,475 pounds of adults would have been lost due to entrainment in 1999. These values are approximately 59 and 37% above the long-term average for age 1 (315 pounds) and age 3 (3,524 pounds) equivalent fish based on the 1980-1998 time series. This is consistent with the general increase in Atlantic herring stocks discussed above.

Consistent with high stock biomass and the underutilized status of herring stocks (NOAA 1998) landings of herring from Area 514 were well below average over the 1995-1997 period. From 1981-1997 landings averaged 20,540,000 pounds but only 413,720 pounds from 1995-1997. The loss of an average of 3,524 pounds over the 1981-1998 period amounts to 0.9% of the recent landings and the loss of 4,475 pounds in 1999 1.1% of those landings.

A U.S. dollar value was applied to the numbers of equivalent juvenile and adult fish using a price of $0.12 per pound. This price was obtained from NMFS Fishery Market News which listed European prices for 1998 at $ 234 per ton recognizing that herring landings in Massachusetts for 1998 were priced at a only $0.05 per pound. Based on that price, numbers of equivalent age 3 fish potentially lost to entrainment in 1999 had a value of $537. The long-term average of 3,524 pounds of age 3 fish had a value of $423.

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 5,602,223 (s.e. = 1,103,166) over the 19-year time series. For cod larvae estimates ranged from 119,436 in 1989 to 2,173,076 in 1981 averaging 893,906 (s.e. = 167,462) over the time series. Corresponding estimates for 1999 amounted to 1,932,894 eggs and 464,125 larvae 35 and 52% 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 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 was estimated by averaging three values, the average larvae/egg ratio obtained at PNPS from 1980-1999 (Se = 0.1399), the value of Se given for the closely related pollock by Saila et al (1997; 0.39772), and a third value (Se = 0.0077) 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 = 0.182, 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 6 age 2 fish in 1999 (Figure 12). This compared with the time series mean of 13 (s.e. = 2). Numbers of fish were converted to weight in pounds using an estimate of 2.0 pounds per fish (Bigelow and Schroeder 1953). For 1999 a weight of 11 pounds was obtained which compares with the overall mean of 27 pounds (s.e. = 4 pounds). These totals were considered low relative to any landings information for the Cape Cod Bay area.

Cod were assigned a market value of $2.50 per pound based on NewYork's Fulton Fish Market listings for February 22. Therefore the 1999 loss was valued at $28.46 and the mean estimated loss at $66.74.

E. Lobster Larvae Entrained

A total of eight lobster larvae were found in the 1999 entrainment samples from June 18 through August 20. This is remarkable in that only 13 larval lobster were collected at PNPS in total dating back to 1974 including more intensive sampling directed specifically at lobster larvae in 1976. Seven of the lobster found were stage 1. Since stage 1 larvae are released from among the pleopods of females at about the same time each day, near sunset, (Charmantier et al. 1991), they no doubt occur in patches as they drift about. While entrainment of larval lobster at PNPS is clearly an uncommon event, it is perhaps not surprising that more then one would be found when they do encounter the Station. The total number of lobster larvae, dating back to 1974, is 21. Following is a tabulation of previous collections:

1998: none found.

1997: none found

1996: none found.

1995: 1 larvae - 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, June 14.

1981: 1 larva - stage 4, June 29.

1980: none found.

1979: 1 larva - stage 1, July 14.

1978: none found.

1977: 3 larvae - 1 stage 1, June 10, 2 stage 1, June 17.

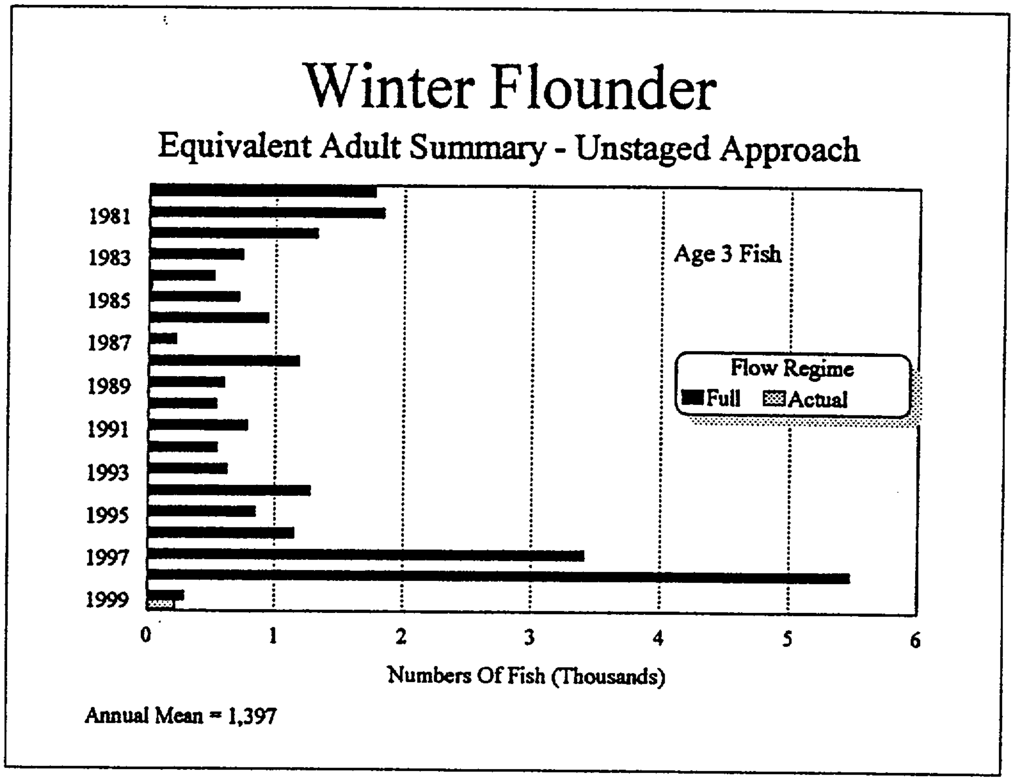
1976: 2 larvae - 1 stage 1, July 22; 1 stage 4-5, August 5.

1975: 1 larva - stage 1, date unknown.

1974: none found.

The lobster larvae collected in 1976 were obtained during a more intensive lobster larvae program which employed a 1-meter net, collecting relatively large sample volumes, in addition to the standard 60-c plankton net (MRI 1977). Both larvae taken in 1976 were collected in the meter net; none were found in the routine ichthyoplankton samples.

During the three-season Cape Cod Bay neuston study for larval lobster begun in 1974, larvae were found from May through September at monthly mean densities ranging from 0.2 (September) to 3.8 per 1000 m^3 (July; Matthiessen and Scherer 1983). Considering that a minimum of roughly 10,500 m^3 of water were sampled during these months each year, larval lobster must indeed be rare in the PNPS circulating water system.



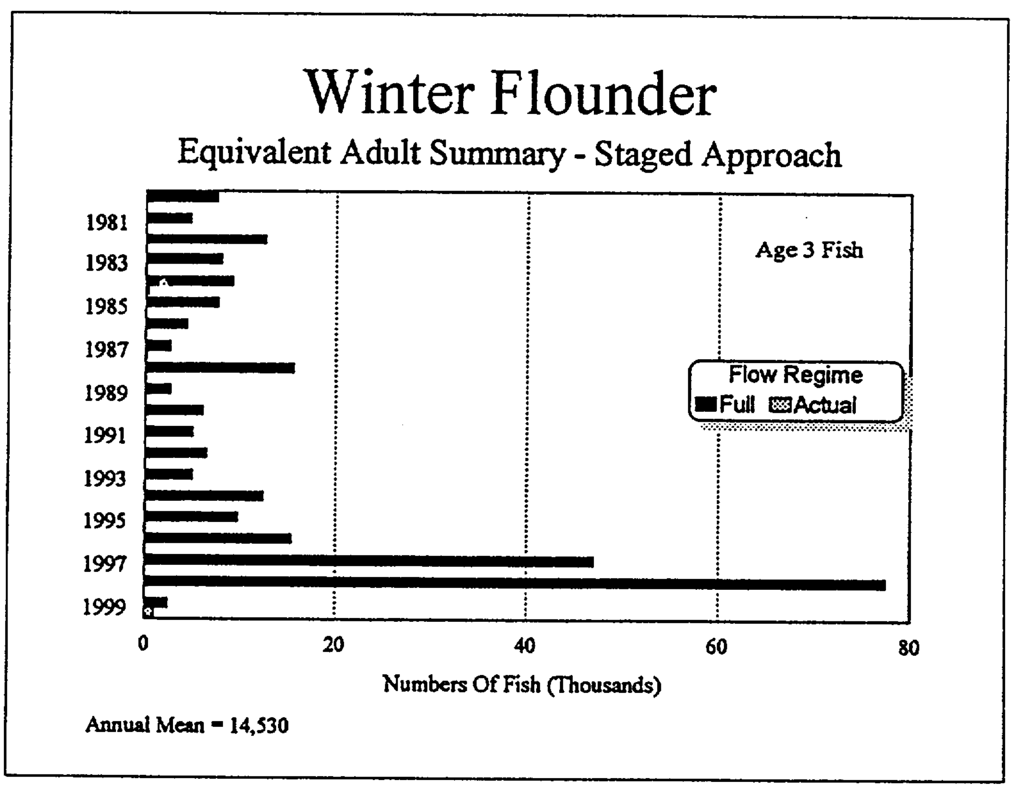


Figure 7. Numbers of equivalent adult winter flounder estimated to have been lost to entrainment at PNPS, 1980-1999.

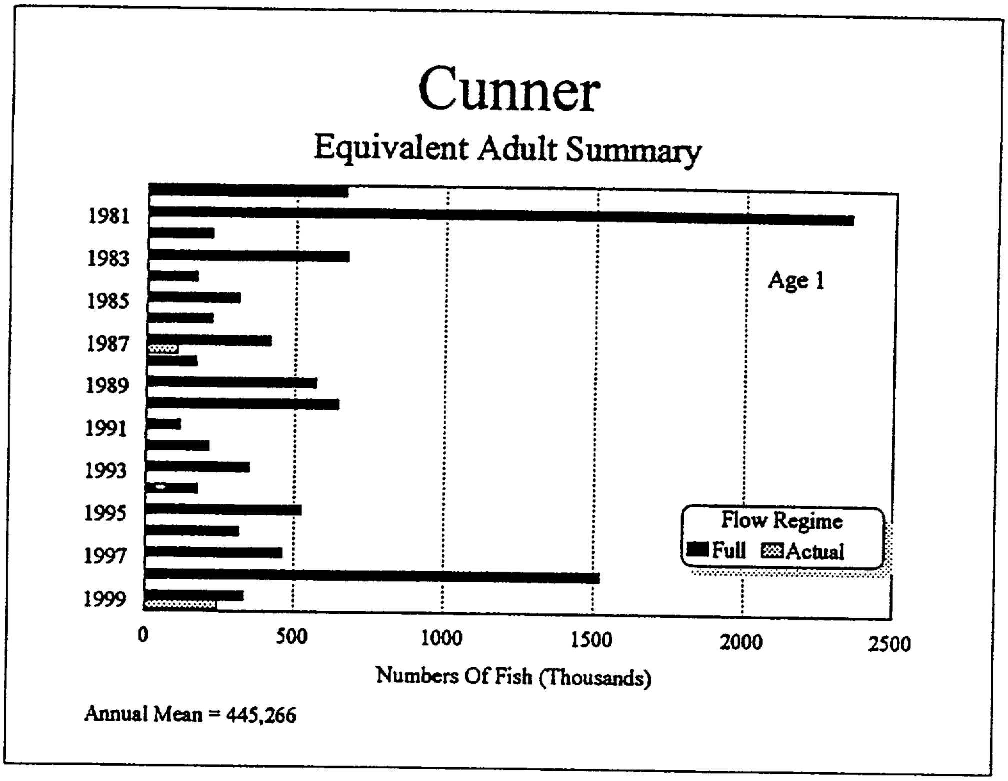


Figure 8. Numbers of equivalent adult cunner estimated to have been lost to entrainment at PNPS, 1980-1999.

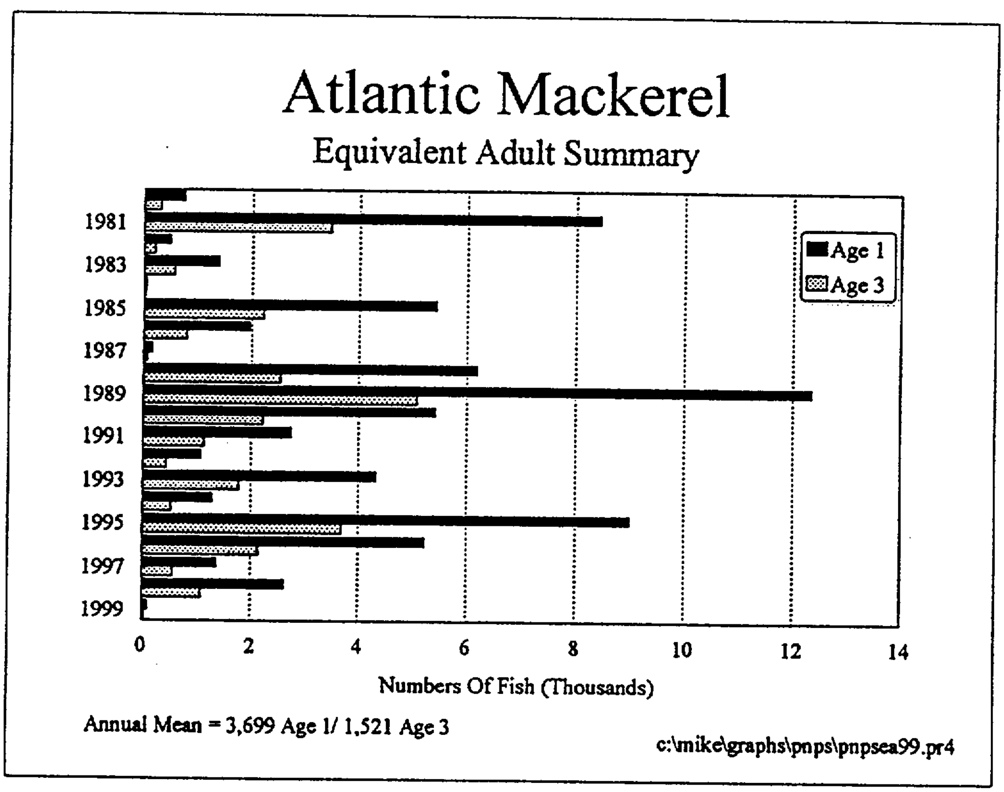


Figure 9. Numbers of equivalent adult Atlantic mackerel estimated to have been lost to entrainment at PNPS, 1980-1999.

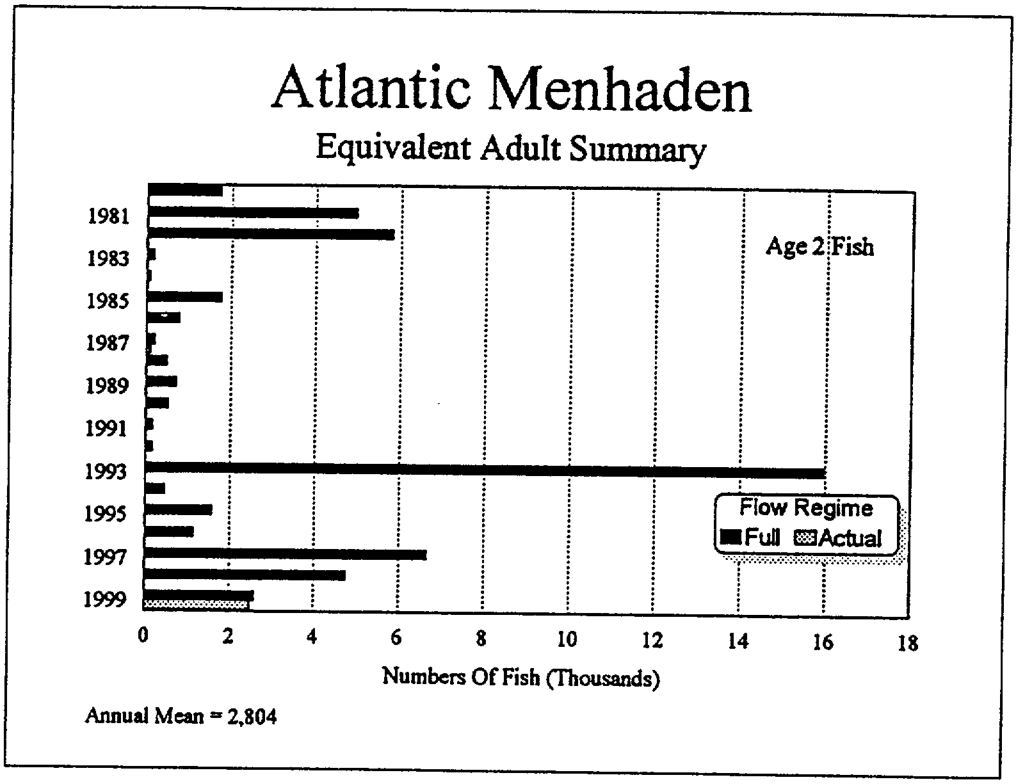


Figure 10. Numbers of equivalent adult menhaden estimated to have been lost to entrainment at PNPS, 1980-1999.

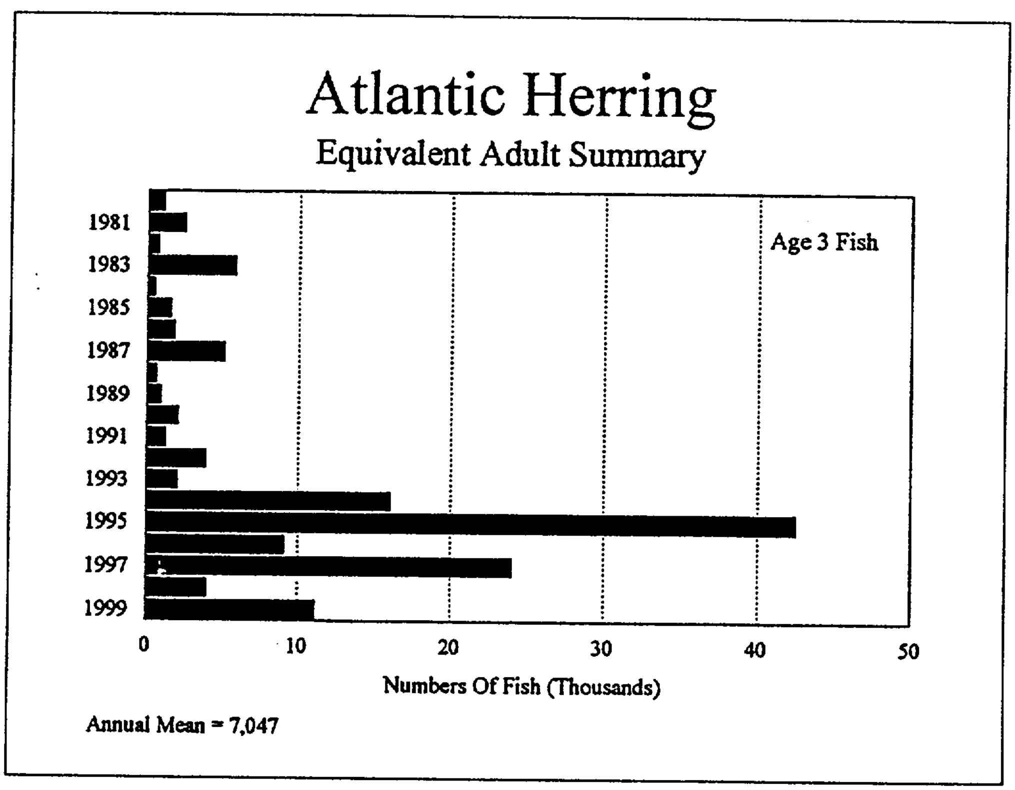


Figure 11. Numbers of equivalent adult Atlantic herring estimated to have been lost to entrainment at PNPS, 1980-1999.

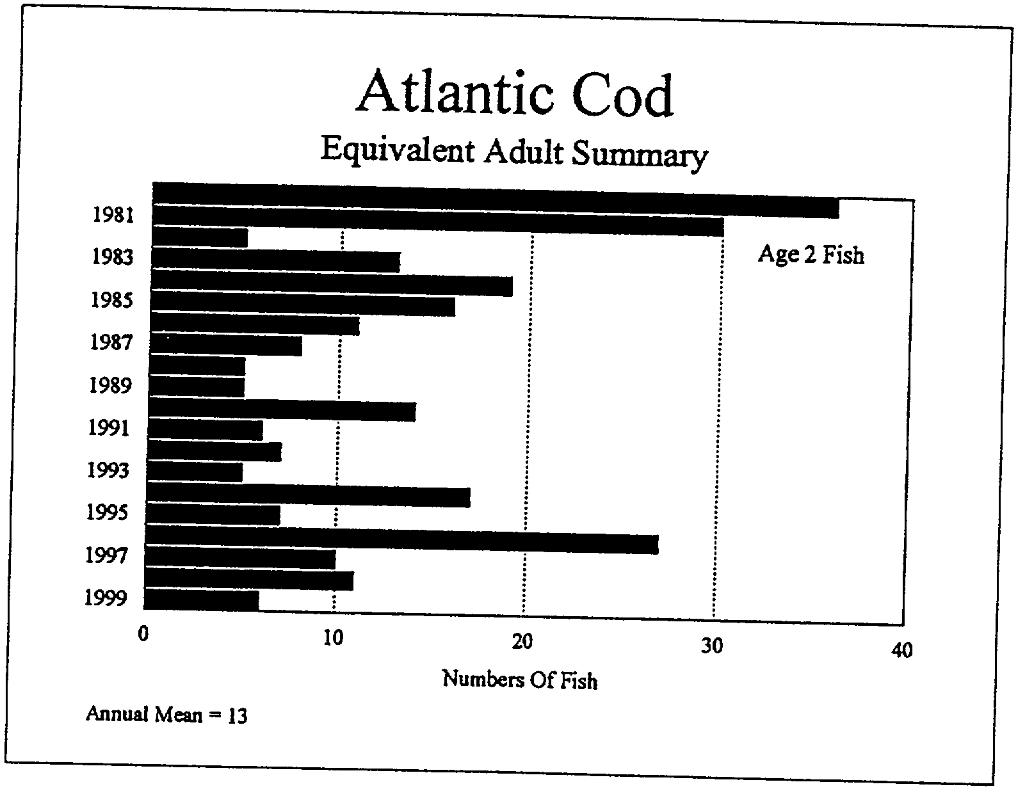


Figure 12. Numbers of equivalent adult Atlantic cod estimated to have been lost to entrainment at PNPS, 1980-1999.

Table 5. Numbers of larval winter flounder entrained at PNPS annually by stage, 1980 - 1999. Number and weight of equivalent age 3 adults calculated by two methods is also shown. Estimates based on full-load flow except where indicated.

Year	Number Of Larvae Entrained Stage 1	2	3	4	Total	Equivalent Age 3 Adults General Number	General Pounds	Staged Number	Staged Pounds
1980	8,694,456	12,714,822	7,317,129	0	28,726,407	1,771	1,063	7,443	4,466
1981	7,606,942	19,133,121	3,073,126	43,304	29,856,494	1,841	1,105	4,689	2,813
1982	2,706,834	6,724,795	11,583,134	425,011	21,439,774	1,322	793	12,643	7,586
1983	1,933,453	2,246,172	7,558,534	260,350	11,998,508	740	444	7,969	4,781
1984	248,082	0	7,570,145	516,247	8,334,475	514	308	9,128	5,477
1985	1,039,001	2,312,789	8,025,452	130,786	11,508,028	710	426	7,643	4,586
1986	5,397,403	5,783,669	3,963,747	77,005	15,221,823	939	563	4,365	2,619
1987	0	437,608	3,088,405	0	3,526,013	217	130	2,619	1,571
1988	1,995,968	1,656,376	15,079,960	511,009	19,243,314	1,187	712	15,558	9,335
1989	1,668,823	5,755,240	2,224,675	39,114	9,687,851	597	358	2,624	1,574
1990	643,683	1,155,404	6,846,718	33,002	8,678,807	535	321	6,016	3,610
1991	3,471,022	3,908,488	5,188,056	37,717	12,605,283	777	466	4,966	2,980
1992	873,660	876,914	7,034,690	26,192	8,811,456	543	326	6,114	3,668
1993	1,595,700	3,540,750	4,934,952	88,617	10,160,019	626	376	4,958	2,975
1994	1,034,617	6,433,716	13,060,373	172,606	34,356,596	1,276	766	12,446	7,468
1995	1,632,907	2,820,023	8,826,496	375,857	13,655,283	842	505	9,699	5,819
1996	504,810	5,818,499	11,329,855	995,127	74,022,009	1,150	690	15,395	9,237
1997	2,225,634	9,537,788	41,484,016	2,126,280	55,373,718	3,414	2,048	47,087	28,252
1998	3,111,891	20,282,772	58,546,916	4,904,482	86,846,061	5,473	3,284	77,393	46,436
Mean	2,441,310	5,849,418	11,933,494	566,458	24,423,785	1,288	773	13,619	8,171
s.e.	548,062	1,344,523	3,244,875	267,396	5,343,796	284	170	4,192	2,515
Market Value Of Mean							$889		$9,397
1984, 1987 Omitted									
Mean	2,713,930	6,511,843	12,710,461	602,733	26,599,496	1,397	838	14,530	8,718
s.e.	577,436	1,418,477	3,583,795	297,709	5,749,088	307	184	4,639	2,783
Market Value Of Mean							$964		$10,026
1999	2,031,988	588,974	1,936,648	123,103	4,680,713	289	173	2,382	1,429
Market Value							$199		$1,644
Plant outage years recalculated with actual circulating water flow.									
1984	166,925	0	164,036	15,729	346,690	21	13	226	136
1987	0	5,613	23,555	0	3,534,685	218	131	20	12
1999	2,030,743	496,056	977,373	1,345	3,505,517	216	130	912	547
Market Value For 1999							$149		$629

Notes:
Mesh factor = 1.62 applied to Stages 1 and 2 prior to 1995.
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.
Market value based on $1.15 per pound.
See text for details.

Table 6. Area 514 commercial landings and Massachusetts recreational landings from inland waters for winter flounder (pounds), 1982 - 1998.

	Commercial (pounds)	Recreational (pounds)	Total (pounds)
1982	3,830,162	4,146,553	7,976,715
1983	2,936,176	874,245	3,810,421
1984	2,558,483	839,561	10,083,623
1985	2,450,319	1,858,645	6,685,579
1986	1,667,938	708,677	2,376,615
1987	1,739,664	568,822	2,308,486
1988	1,846,171	729,200	2,575,371
1989	1,896,609	1,163,315	3,059,924
1990	1,737,733	139,641	1,877,374
1991	1,520,470	67,659	1,588,129
1992	1,326,646	85,256	1,411,902
1993	1,057,211	147,287	1,204,498
1994	328,706	71,403	400,109
1995	16,788	43,362	132,982
1996	2,961	69,871	72,832
1997	1,798	69,893	132,270
1998	501	60,078	60,579

Table 7. Numbers of cunner eggs and larvae entrained at PNPS annually, 1980 - 1999. 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	Number	Pounds
1980	3,257,891,776	76,282,260	40,480,032	4,229,248	697,314,106	667,485	80,098
1981	6,576,294,915	316,245,739	256,567,950	3,508,876	586,459,128	2,353,607	282,433
1982	2,010,779,150	6,351,445	3,187,760	597,356	10,136,561	216,418	25,970
1983	5,895,329,347	10,961,646	27,571,530	3,955,802	42,488,978	673,201	80,784
1984	1,766,764,864	0	176,682	1,029,352	1,206,034	166,823	20,019
1985	2,021,886,071	17,182,039	20,392,615	2,307,617	39,882,271	307,573	36,909
1986	1,493,653,289	4,419,092	22,197,318	297,368	26,913,778	219,494	26,339
1987	4,465,564,080	40,247,222	314,474	248,738	40,810,434	415,062	49,807
1988	1,539,089,318	2,290,972	2,624,077	2,461,452	7,376,502	164,492	19,739
1989	4,469,416,004	34,100,052	15,224,141	2,863,938	52,188,130	570,900	68,508
1990	1,336,048,112	65,705,970	62,378,298	44,014,528	172,098,797	644,849	77,382
1991	675,000,390	5,790,172	3,701,490	7,243,966	16,735,627	113,048	13,566
1992	2,174,661,078	0	1,186,819	1,605,055	2,791,875	209,299	25,116
1993	3,235,317,207	148,674	7,178,133	7,923,303	15,250,109	345,004	41,400
1994	1,558,253,667	0	5,545,977	4,440,095	9,986,072	174,169	20,900
1995	4,116,491,874	7,961,638	29,910,748	9,257,792	47,130,178	522,981	62,758
1996	2,807,124,109	3,765,455	8,094,509	5,558,849	17,418,813	312,029	37,444
1997	1,718,289,720	6,444,923	51,895,511	41,294,559	469,852,445	460,586	55,270
1998	4,341,664,826	104,908,332	211,248,501	54,060,618	370,217,451	1,522,731	182,728
Mean	2,918,922,095	36,989,770	40,519,819	10,363,080	138,224,068	529,461	63,535
s.e.	378,505,499	16,977,158	16,263,177	3,764,153	50,332,880	125,402	15,048
Market Value Of Mean							$9,530
1981, 1984, 1987 Omitted.							
Mean	2,665,680,996	21,644,542	32,051,091	12,006,972	124,861,356	445,266	53,432
s.e.	358,672,742	8,021,378	12,810,731	4,361,818	51,412,846	86,425	10,371
Market Value Of Mean							$8,015
1999	1,717,578,656	36,934,878	11,960,388	7,510,427	56,405,693	329,535	39,544
Market Value							$5,932
Outage years recalculated with actual circulating water flow.							
1984	56,209,029	0	33,596	10,105	43,701	5,324	639
1987	1,122,803,794	118,232	119,740	1,868	239,840	104,423	12,531
1999	1,098,618,436	30,161,622	8,878,633	7,510,427	46,550,682	242,511	29,101
Market Value For 1999							$4,365

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.
Market value based on $0.15 per pound.
See text for details.

Table 8 . Numbers of Atlantic mackerel eggs and larvae entrained at PNPS annually, 1980 - 1999. 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 Adults: Age 1 Number	Age 1 Pounds	Age 3 Number	Age 3 Pounds
1980	81,599,432	22,293,108	745	149	306	215
1981	183,959,791	320,135,596	8,442	1,688	3,471	2,430
1982	108,234,931	9,388,143	483	97	199	139
1983	148,616,621	41,333,673	1,376	275	566	396
1984	22,486,619	78,315	53	11	22	15
1985	1,867,648,438	45,711,343	5,423	1,085	2,230	1,561
1986	219,488,066	58,333,520	1,964	393	808	565
1987	71,222,294	215,561	169	34	69	49
1988	2,663,608,568	3,401,489	6,186	1,237	2,544	1,780
1989	4,673,915,938	65,562,469	12,349	2,470	5,077	3,554
1990	2,313,416,455	4,627,282	5,415	1,083	2,226	1,558
1991	479,761,865	66,009,482	2,753	551	1,132	792
1992	377,610,764	8,086,393	1,068	214	439	307
1993	1,801,378,418	8,325,789	4,335	867	1,782	1,248
1994	520,917,221	3,419,299	1,279	256	526	368
1995	1,767,609,278	197,689,693	9,002	1,800	3,701	2,591
1996	1,507,370,682	70,947,053	5,230	1,046	2,150	1,505
1997	316,969,390	25,778,062	1,372	274	564	395
1998	530,017,006	56,622,648	2,633	527	1,082	758
Mean	1,034,517,462	53,050,469	3,699	740	1,521	1,065
s.e.	289,961,350	18,726,465	812	162	334	234
Market Value Of Mean						$330.00
1984, 1987 Omitted						
Mean	1,150,713,110	59,274,414	4,121	824	1,694	1,186
s.e.	303,529,902	19,867,610	825	165	339	237
Market Value Of Mean						$367.65
1999	35,022,927	483,595	92	18	38	27
Market Value						$8.25
Outage years recalculated with actual circulating water flow.						
1984	570,854	2,480	1	0	1	1
1987	2,397,224	107,727	8	2	3	2
1999	6,182,166	311,394	22	4	9	6
Market Value For 1999						$1.95

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.
Market value based on $0.31 per pound.
See text for details.

Table 9. Numbers of Atlantic menhaden eggs and larvae entrained at PNPS annually, 1980-1999. Numbers of equivalent age 2 and 3 fish are also shown. Estimates based on full-load flow.

Year	Total Number Entrained		Equivalent Adults		
			Number Of Fish		Age 2
	Eggs	Larvae	Age 2	Age 3	Weight (lbs)
1980	16,468,408	12,060,791	1,727	495	864
1981	3,473,080	40,076,799	4,956	1,420	2,478
1982	365,091,471	1,845,849	5,809	1,664	2,905
1983	869,580	1,227,190	163	47	82
1984	4,751,607	0	73	21	36
1985	41,131,470	9,190,654	1,753	502	877
1986	21,112,802	3,654,854	770	221	385
1987	311,687	1,560,529	196	56	98
1988	9,273,771	2,713,857	474	136	237
1989	11,212,165	4,411,807	711	204	356
1990	7,057,041	3,263,718	507	145	254
1991	5,744,115	512,319	151	43	75
1992	392,533	1,117,881	143	41	71
1993	947,815,345	11,833,443	15,942	4,568	7,971
1994	10,221,752	2,361,834	445	128	223
1995	3,280,481	12,419,886	1,570	450	785
1996	4,861,265	8,660,874	1,134	325	567
1997	48,899,715	48,283,152	6,655	1,907	3,327
1998	44,730,447	33,280,806	4,756	1,363	2,378
Mean	81,405,197	10,446,118	2,523	723	1,261
s.e.	51,668,256	3,260,710	889	255	444
Market Value Of Mean					$719.03
1984, 1987 Omitted.					
Mean	90,684,438	11,583,277	2,804	803	1,402
s.e.	57,493,301	3,549,111	973	279	486
Market Value Of Mean					$799.12
1999	14,395,648	19,324,314	2,583	740	1,291
Market Value					$736.13

Planr outage years recalculated with actual circulating water flow.

1984	300,943	0	3	1	2
1987	135,755	731,741	91	26	45
1999	10,385,304	18,939,526	2,475	709	1,237
Market Value For 1999					$705.29

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.
Market value based on $0.57 per pound.
See text for details.

Table 10 . Numbers of Atlantic herring larvae entrained at PNPS annually 1980-1999. Numbers of equivalent age 1 and 3 fish are also shown.

Year	Total Number Larvae Entrained	Equivalent Juveniles\Adults Number Of Fish Age 1	Age 3	Weight(lbs) Age 1	Age 3
1980	1,068,466	1,566	1,050	47	420
1981	2,471,492	3,622	2,430	109	972
1982	732,857	1,074	720	32	288
1983	5,880,315	8,618	5,781	259	2,312
1984	468,840	687	461	21	184
1985	1,580,435	2,316	1,554	69	621
1986	1,811,101	2,654	1,780	80	712
1987	5,142,045	7,536	5,055	226	2,022
1988	639,089	937	628	28	251
1989	911,487	1,336	896	40	358
1990	2,079,483	3,048	2,044	91	818
1991	1,280,273	1,876	1,259	56	503
1992	3,970,208	5,819	3,903	175	1,561
1993	2,098,952	3,076	2,063	92	825
1994	16,351,765	23,966	16,075	719	6,430
1995	43,247,883	63,385	42,517	1,902	17,007
1996	9,265,826	13,580	9,109	407	3,644
1997	24,445,056	35,827	24,032	1,075	9,613
1998	4,026,783	5,902	3,959	177	1,583
Mean	6,709,071	9,833	6,596	295	2,638
s.e.					
Market Value Of Mean					$316.59
1984, 1987 Omitted					
Mean	7,142,808	10,469	7,022	314	3,511
s.e.	2,656,559	3,894	2,612	117	1,306
Market Value Of Mean					$421.32
1999	11,379,446	16,678	11,187	500	4,475
Market Value					$536.98

Notes:
Outage periods in 1984 and 1987 did not occur during the herring season.
Weight conversion based on 0.03 for age 1, 0.4 pound per age 3 fish.
Dollar value based on $0.12 per pound.
See text for details.

Table 11. Numbers of Atlantic cod eggs and larvae entrained at PNPS annually, 1980-1999
Numbers of equivalent age 2 fish are also shown.

Year	Total Number Entrained		Equivalent Adults	
	Eggs	Larvae	Number Of Fish Age 2	Weight (lbs) Age 2
1980	20,388,850	1,450,522	36	72
1981	11,620,588	2,173,076	30	60
1982	2,582,984	222,721	5	10
1983	9,349,728	142,136	13	26
1984	11,726,579	587,054	19	38
1985	5,071,151	1,441,442	16	33
1986	2,788,767	1,035,987	11	22
1987	5,623,282	122,579	8	16
1988	2,747,034	254,239	5	11
1989	3,395,726	119,436	5	10
1990	2,406,536	1,566,291	14	28
1991	3,668,649	239,746	6	13
1992	2,819,673	469,713	7	14
1993	1,268,748	446,489	5	9
1994	3,119,312	1,904,519	17	34
1995	2,549,370	602,594	7	15
1996	8,542,922	2,369,255	27	55
1997	1,800,711	1,101,118	10	20
1998	4,971,621	735,301	11	23
Mean	5,213,252	838,848	12	27
s.e.	1,103,166	167,462	2	4
Market Value Of Mean				$67.02
1999	1,932,894	464,125	6	11
Market Value				$28.46

Notes:
Weight conversion based on 2.0 pounds per fish.
Market value based on $2.50 per pound.
See text for details.

SECTION V
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WINTER FLOUNDER ENTRAINMENT IMPACT ASSESSMENT

RAMAS MODEL APPROACH

April 1, 2000

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Introduction

Impact assessment of winter flounder entrainment at PNPS has included the equivalent adult (EA) methodology (MRI 1999). While this is a useful, widely used tool to assess the likely magnitude of egg and larval entrainment, the methodology does not readily allow the cumulative effects of entrainment mortality to be assessed over time. Random variability in survival rates and environmental parameters are also difficult to consider with the EA approach. The computer software program RAMAS Stage (Risk Analysis Management Alternatives System, Ferson 1993) was used to further explore possible impacts of PNPS on the winter flounder population in Cape Cod Bay. RAMAS allows population models to be developed which include information on age and stage-based survival rates, population structure, longevity, and fecundity. With these models "what if?" studies can be readily completed which include the simulated removal of individuals by power plants or other anthropogenic forces. Results of that exercise are summarized here.

Approach

In brief, a stage-structured model was developed using an empirically derived Ricker stock-recruitment (s-r) function for winter flounder. The Ricker function was used to estimate the number of age 1 fish produced in Cape Cod Bay from the number of eggs spawned the previous year. Annual entrainment effects were simulated by removing age 1 fish. The number of age 1 fish removed each year was estimated by using stage-specific larval survival rates applied to the observed number of larvae entrained at PNPS. Model runs included 50 time steps, each representing one year, with 500 to 750 replications to provide measures of variability. Runs of 50 years allowed initialization values to be replaced (time steps 1 - 25 were allocated for this) and at the same time allowed examination of a length of time realistic to the life of a power plant (25 years over time steps 26 - 50). Details of the model procedures appear in the appendix.

The extensive database used to develop the relationship between adult spawner production and age 1 fish came from the northeast sector of Narragansett Bay. It is recognized that developing a winter flounder population model based, to a large extent, on data from south of Cape Cod has less intuitive appeal then using data from waters around PNPS and Cape Cod Bay. The presence of Brayton Point Power Station in upper Narragansett Bay along with other anthropogenic factors such as sewage treatment facilities likely has some influence over the shape of the s-r curve along with various environmental factors. It is likely that similar factors have an influence in Cape Cod Bay. For the exercise described here the Narragansett Bay data were used because of the length of the time series, many years being required to define a relationship between stock and recruitment. The Narragansett Bay data set also spanned a wide range of spawner abundance, an important ingredient in establishing such a stock-recruitment relationship (Myers et al. 1995). Chambers et al. (1995) hypothesized that latitudinal differences in the relationship between stock and recruitment exist among winter flounder populations over a broad geographical range of 20^0 latitude. While the center of the northeast sector of Narragansett Bay and PNPS are separated by only 15 minutes latitude or 15 nautical miles, Cape Cod is a well recognized faunal barrier (see for example Davis and Merriman 1984) and it would therefore be preferable to develop a spawner stock recruitment relationship for that area given sufficient data. In reality the relationship between adult egg production and age 1 fish is largely based on the intrinsic biology of the species and can be expected to be comparable over at least narrow geographical areas (Myers 1991, Myers et al. 1995).

Results

Base Model

The initial step in using the RAMAS program was to develop a base model which simulated a stable winter flounder population not subject to the effects of entrainment losses. Area-swept population estimates conducted in western Cape Cod Bay, the area most likely to contribute larval flounder to PNPS (Lawton et al. 1999) during the spring of 1997 and 1998, suggested a mean adult population of about 293,300 assuming gear efficiency of 50%. Accordingly the beta parameter of the Ricker function was adjusted iteratively until a stable adult population of about 300,000 was obtained. This was done by using numbers of fish in each age class at the end of one model run to initialize subsequent runs. The intrinsic rate of increase represented by the slope of the s-r curve at the origin was not changed.

A third area-swept estimate was completed in the spring of 1999. With the addition of that estimate (Robert Lawton, personal communication), a three-year mean of 254,300 age 3+ fish was obtained, about 13% lower than the two-year mean. Since the gear-efficiency factor of 50% is a "best-guess" value and other sources of error exist with any area-swept estimates, model runs were completed with both the two-year and three-year base population values. Changing the beta parameter from 2.500E-11 for the 300,000 base to 2.955E-11 produced a base model with an average of 253,800 age 3+ fish.

Running the 300K base model through 50 time steps (50 years) with 500 replicates produced a mean population over the final 25 years of 299,900 age 3 and older fish. The RAMAS software generates 95% confidence limits about each annual mean estimate based on the replications; these averaged 148,200 to 451,500. Considering all replicates over each of the final 25 years, numbers of adults ranged from 73,777 to 1,312,840. A population with approximately 300,000 adult fish produced an average of about 852,300 age 1 fish each year.

Running the 254K base model through 50 time steps (50 years) with 500 replicates produced a mean population over the final 25 years of 253,800 age 3 and older fish with average 95% confidence limits ranging from 122,400 to 385,300. A population of 254,000 adults contains about 722,000 age 1 fish annually.

Entrainment Level: 1980-1996

For this model larval winter flounder entrainment was introduced using the observed mean value and observed variance for each stage over the 1980-1999 period after removing the extreme years (Table 1). The low-entrainment years, 1984, 1987, and 1999, when the main circulating seawater pumps were shut down for extended periods, were excluded. The two uncommonly high-entrainment years of 1997 and 1998 were also excluded. In each case numbers entrained were estimated using observed station flow.[1] The mean number of larvae entrained over the 15-year period was 13,500,000. Removing larvae at that rate resulted in the loss of an average of 57,800 age 1 fish with mean 95% confidence limits of 29,300 to 86,300 and mean range of 13,291 to 219,855 (Figure 1, Appendix Table A1).

300K Base: The average number of adults in the population during the second 25 years was 292,900 with mean 95% confidence limits of 135,200 to 450,500. Considering all replicates a mean range of 62,300 to 1,347,300 was obtained (Appendix Table A2). Overall the mean adult population size of 292,900 represented a decline in population size relative to the mean population with no entrainment (299,900) of 2.3% (Figure 2).

254K Base: The average number of adults in this smaller base population during the second 25 years was 245,800 age 3+ flounder with 95% confidence limits of 109,800 to 381,800. Considering all replicates, a mean range of 25,600 to 1,201,100 was obtained (Appendix Table A3). Overall the mean adult population with entrainment represented a decline in population size relative to the mean population with no entrainment of 3.2% (Figure 3).

<u>Entrainment Level: 1997 and 1998</u>

Two pairs of model runs were completed to focus on the high levels of entrainment recorded in 1997 and 1998. In the first run larval flounder were removed as age 1 fish at a rate equivalent to the level of entrainment recorded in 1997 (total = 55,400,000 larvae; Table 2). The rate of entrainment was fixed at the 1997 level without variance. A subsequent model run repeated the exercise with entrainment at the higher 1998 level (total = 86,846,000 larvae; Table 2). While these model runs were clearly unrealistic based on empirical data from the entrainment collection program, the goal was to determine if consistent high entrainment would cause the population to collapse.

300K Base: Removing larvae from the population every year at the 1997 level produced a mean population size over a 25-year period of 248,200 age 3+ fish. Confidence limits and range averaged 66,100 to 430,200 and 2,900 to 1,689,000 respectively. Removing larvae at the 1998 level produced a mean adult population of 209,200 fish with confidence limits and range of 41,300 to 377,200 and 0 to 1,396,000, respectively. The population subjected to 1997 entrainment showed a decline of 17.2% and the population subject to 1998 entrainment showed a decline of 30.2% relative to the 300K base model without entrainment (Figure 2). In both cases populations continued to average 200,000 adult fish or more over the second 25-year period. However, the range in adult population size included zero during the final 12 years of the 1997 run and every year during the final

[1]Estimates of numbers entrained which appear in previous annual reports for PNPS were conservatively based on maximum station flow regardless of actual conditions at the time samples were collected. Entrainment values presented here therefore differ from those estimates but are believed to more closely reflect actual conditions.

25 years of the 1998 run. These data indicated that over 500 replications the probability of collapse does exist although it is small (about 4% for the 1998 entrainment level). It is unlikely, of course, that larval entrainment densities could remain at such a high level as the population approached very low levels.

254K Base: Removing larvae from this population every year at the 1997 level produced a mean population size over a 25-year period of 202,300 age 3+ fish. Confidence limits and range averaged 53,400 to 351,200 and 374 to 1,182,100, respectively. Removing larvae at the 1998 level produced a mean adult population of 160,100 fish with confidence limits and range of 12,878 to 307,300 and 0 to 1,290,300, respectively. The population subjected to 1997 entrainment showed a decline of 20.3% and the population subject to 1998 entrainment showed a decline of 36.9% relative to the 300K base model without entrainment (Figure 3). The probability of collapse rose to 7.5% for the 1998 entrainment level with the smaller base population.

Entrainment Level: 1980 -1999

Perhaps the most realistic view of the long-term entrainment of larval winter flounder at PNPS is the overall mean number entrained by larval stage over the 1980-1999 period including years when the station was off line for maintenance. The actual variance in number of each stage entrained was entered in the model to account for the observed variability over those 20 years. Table 2 presents the annual values along with the mean and variance over the period. As indicated above, actual station circulating flow was used to calculate numbers entrained. Summed over stage an average of 17,800,000 larvae were entrained each year.

300K Base: Removing larvae at the observed time series mean level resulted in a mean flounder population of 287,100 fish with mean confidence limits of 127,900 to 446,400 and a mean range from 44,000 to 1,461,000. The mean value represented a reduction of 4.3% relative to the base population of 299,900 fish (Figure 2). Numbers of age 1 fish lost due to entrainment averaged 96,300 with 95% confidence limits of 0 to 206,700. Figures 4 and 5 and Appendix Tables A4 and A5 present the mean, 95% confidence limits, and the range for each of the final 25 years for equivalent age 1 losses and age 3+ fish in the simulated population.

254K Base: Removing larvae at the observed 1980-1999 time series mean level from the smaller base population resulted in a mean adult population of 242,300 with mean confidence limits of 105,500 to 379,100 (Figure 6, Appendix Table A6). The mean value represented a decline of 4.5% relative to the base population with no entrainment losses (Figure 3).

Entrainment Level: Projected

PNPS typically enters a scheduled refueling outage every two years. Efforts are being made to schedule those outage periods for at least a portion of the winter flounder larval season to minimize entrainment. To explore this option two model runs were completed assuming a relatively low level of entrainment every other year with a "normal" entrainment level during the years between. Estimated entrainment values for the low level years were based on the mean number entrained in

1984, 1987, and 1999 (1,271,800), the three years during which both circulating seawater pumps were shut down for a month or more during the season of larval flounder occurrence. The mean number entrained during all other years (20,567,200) was used to represent the typical operational year. Alternating these estimates for an arbitrary 16-year period produced a mean number entrained of 10,919,500 larvae (summed over stage), 38% below the mean for the 1980-1999 period. Variance estimates were based on the observed values (Table 3).

300K Base: Removing larvae from the larger base population at the mean level of 14,300,000 resulted in a 25-year average loss of 59,100 age 1 fish and an adult stock of 293,200, a decline of 2.2% relative to the base stock (Figure 2). Mean confidence limits ranged from 134,500 to 452,000.

254K Base: Removing the same average number of larvae annually from the lower 254K base population produced an average population of 245,100 adults, a decline of 3.4% (Figure 3). Mean confidence limits ranged from 111,500 to 378,600 fish.

Conclusions

In the mid 1970's, MIT and Stone and Webster Engineering conducted modeling studies on winter flounder for PNPS largely based on hydrodynamics (Leimkuhler 1974, Wang and Connor 1975, Stone and Webster Engineering 1975, Pagenkopf et al. 1976; also summarized in MRI 1986). Those studies suggested that over a 40-year period entrainment of winter flounder larvae would result in an adult population reduction of 0.2%. MRI (1978) also developed a model based on field data obtained in 1976 and 1977. Those exercises suggested that 0.7 to 2.2% of the larvae produced in Plymouth Harbor-Kingston, Duxbury Bay were entrained depending on various natural mortality rates.

Results obtained with the RAMAS\Stage model, suggesting stock reductions from 2.3 to 4.5%, appear consistent with the earlier modeling work considering the many assumptions which are required to complete them and the high variance associated with each variable. The model based on mean numbers entrained over the 1980-1999 period suggested population reductions of 4.3 or 4.5% depending upon the size of the existing adult population. Projecting into the future with alternating outage periods during the winter flounder larval period suggested modest population reductions of 2.2 or 3.4% might be expected.

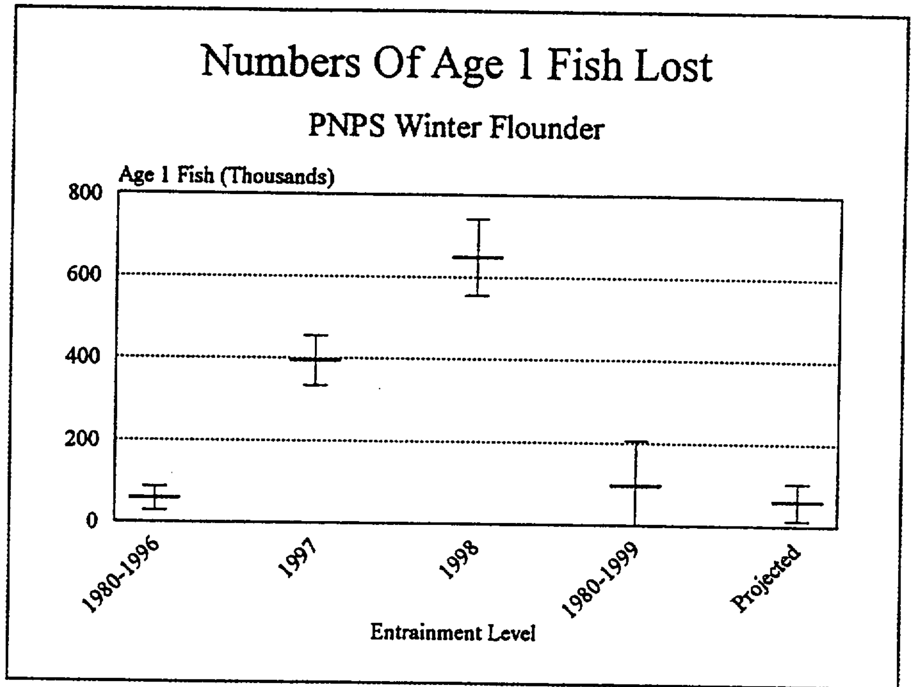

Figure 1. Equivalent number of age 1 fish, mean, and 95% confidence limits, estimated to be lost as a result of larval entrainment at four levels, PNPS.

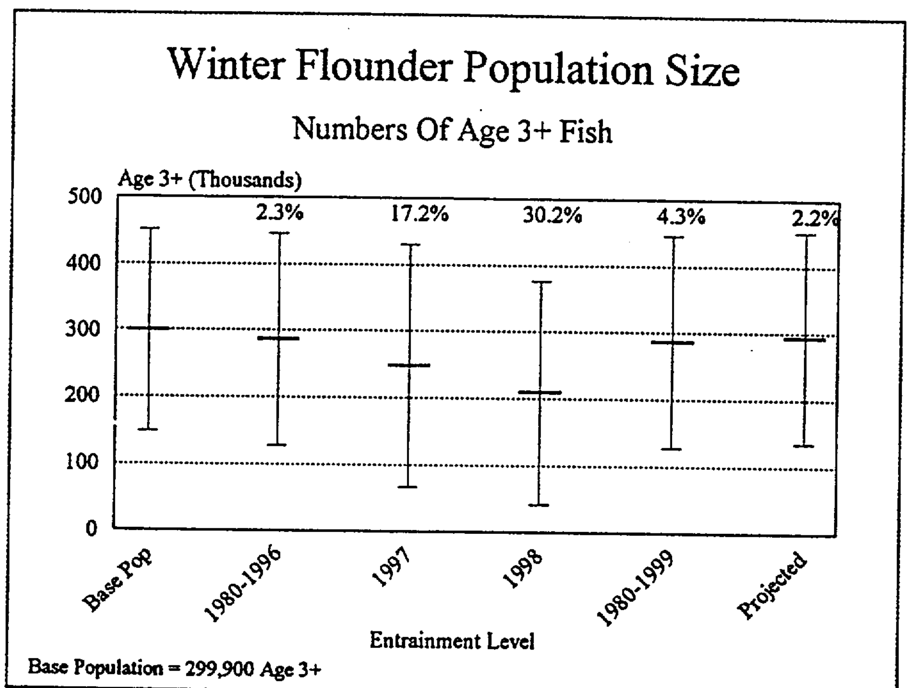

Figure 2. Mean number of age 3+ winter flounder with 95% confidence limits in western Cape Cod Bay under five entrainment levels. Percent population reduction relative to a 300K base population is shown along the top.

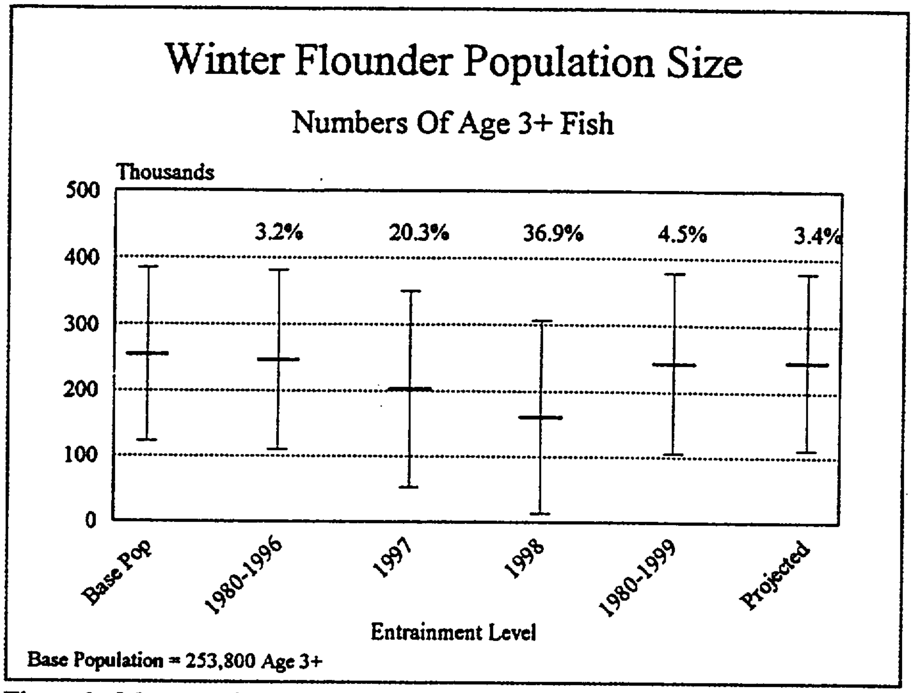

Figure 3. Mean number of age 3+ winter flounder with 95% confidence limits in western Cape Cod Bay under five entrainment levels. Percent population reduction relative to a 254K base population is shown along the top.

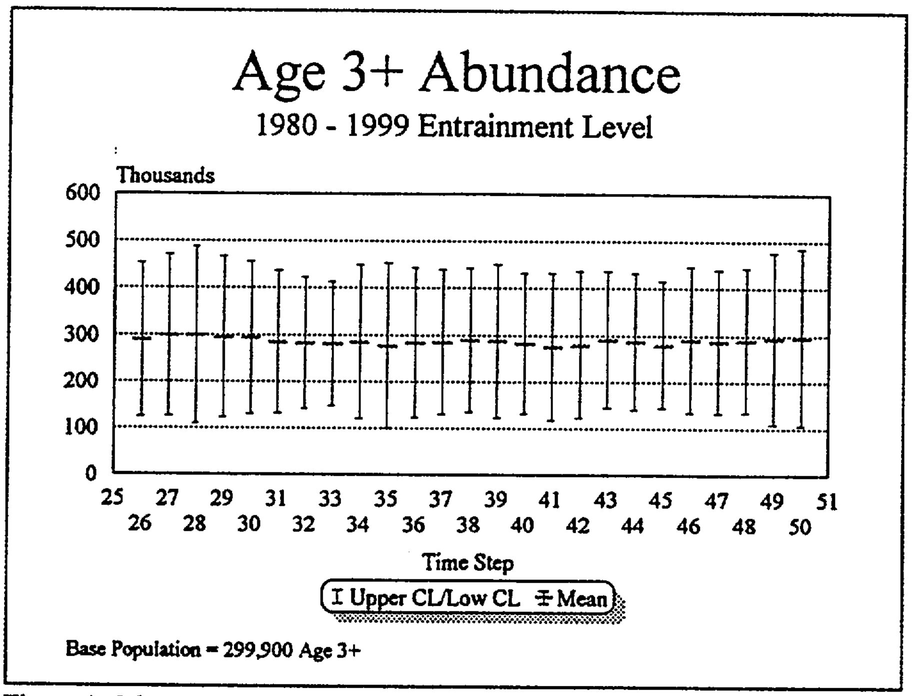

Figure 4. Mean number of age 3 winter flounder with 95% confidence limits for each 25 yearly time steps, PNPS simulation model based on empirical entrainment data from 1980-1999. Base population = 300K.

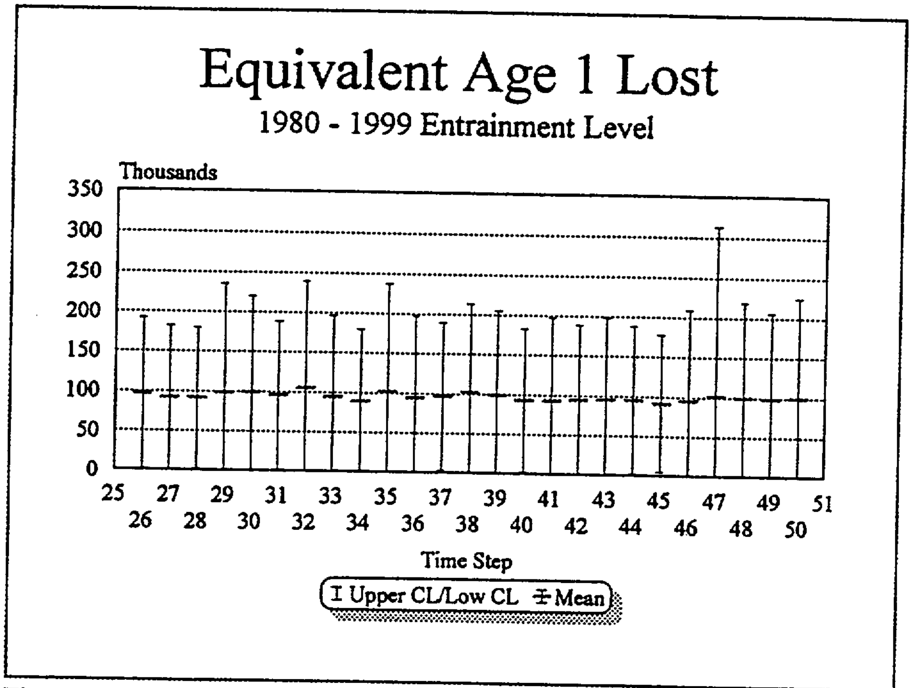

Figure 5. Mean number of age 1 winter flounder lost with 95% confidence limits for each of 25 yearly time steps. PNPS simulation model based on empirical entrainment data from 1980-1999.

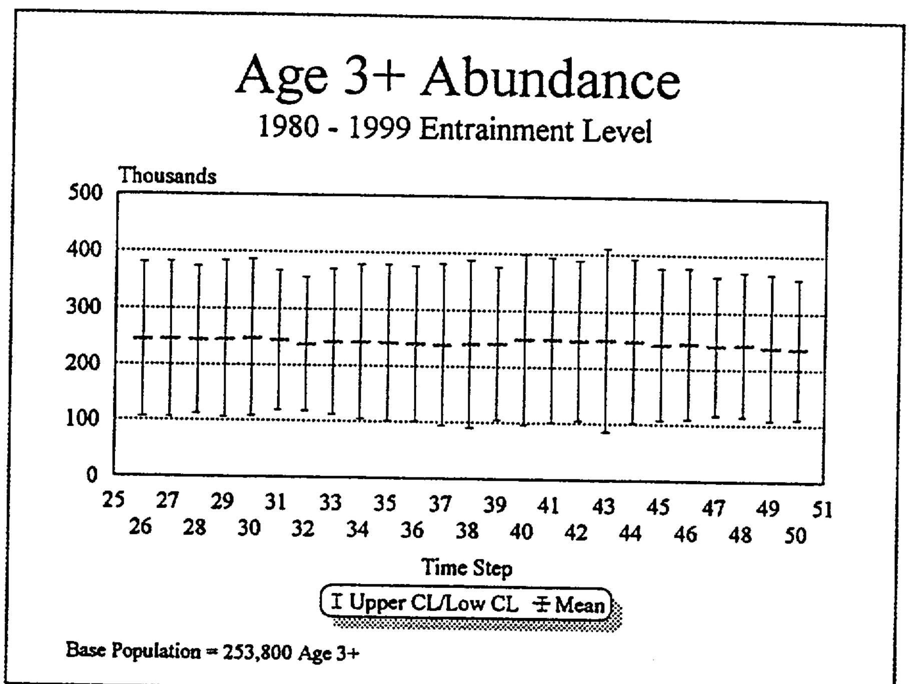

Figure 6. Mean number of age 3+ winter flounder with 95% confidence limits for each 25 yearly time steps, PNPS simulation model based on empirical entrainment data from 1980-1999. Base population = 254K.

APPENDIX A

MODEL METHODS

Appendix
Model Methods

The computer software program RAMAS Stage (Risk Analysis Management Alternatives System, Ferson 1993) was used to further explore possible impacts of PNPS on the winter flounder population in Cape Cod Bay. RAMAS\Stage uses matrix formulations to track the abundance of plant or animal stages through time (see for example Caswell 1989). For the exercise described here a stage-structured model was developed using data collected from Mount Hope Bay which forms the northeast section of Narragansett Bay. Data have been collected there since 1972 in conjunction with studies for Brayton Point Power Station formerly owned by New England Power Company and now owned by U.S. Generating Company (see for example MRI 1999). Since the database for that area is extensive, sufficient information was available to develop a Ricker stock-recruitment relationship which included a water temperature term (Ricker 1975, Hilborn and Walters 1992). The Ricker temperature function used here relates numbers of eggs produced by an adult winter flounder population in year 't' to the mean number of age 1 fish in year 't+1'.

$$R = \propto * F * \exp(-B_0 * F - B_1 * T)$$

where:
- R = age 1 flounder per trawl tow, February-April, in year 't+1'.
- $\propto$ = recruitment rate at low population levels
- F = total number of eggs produced by the adult population in year 't'.
- B_0 = density dependent coefficient.
- B_1 = temperature effect coefficient.
- T = average temperature during February-April expressed as the deviation from the long-term mean temperature.

Number of eggs produced each spawning season by the Mount Hope Bay population was determined by converting each one-centimeter-length class in the February-April bottom trawl catch to weight since weight is a better predictor of fecundity then length (Hoursten 1981). Fecundity was then determined from weight. All fish greater than or equal to 270 mm were considered adults (Gibson 1993). Length to weight utilized an equation from Gibson (1993)[2] and weight to fecundity an equation from Saila (1962)[3]. The non-linear regression routine available as part of the Number Cruncher Statistical Software package (NCSS 1991) was used to fit the Ricker temperature function to the Mount Hope Bay data.

Abundance of age 1 flounder was defined as the number of individuals equal to or less than 150 mm in the February-April trawl catch (Gibson 1993). From 1972 through 1993 age 1 abundance was determined using the Mount Hope Bay standard trawl constructed with a cod end of 1.5 inch bar mesh. Since this mesh under-samples age 1 flounder, counts were scaled upward by a factor of 30.7

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[2] Weight (gms) = (6.76E-6) * Length (mm) ^ 3.124

[3] Log Fecundity = 2.6712 + 1.1383 Log Weight (gms)

(see NEP and MRI 1996). From 1994 onward age 1 abundance was determined by a fine mesh Wilcox trawl which is believed to retain all age 1 fish.

The initial step in using the RAMAS program was to develop a base model which simulated a stable winter flounder population not subject to the effects of entrainment losses. Area-swept population estimates conducted in western Cape Cod Bay, an area likely to contribute larval flounder to PNPS, by the Division Of Marine Fisheries (Lawton et al. 1999) during the spring of 1997 and 1998, suggest a mean adult population of about 293,000 assuming gear efficiency of 50%. Accordingly the beta parameter of the Ricker function was adjusted iteratively until a stable adult population of about 300,000 was obtained. This was done by using numbers of fish in each age class at the end of one model run to initialize subsequent runs.

Once the base model was established, subsequent models incorporated an additional parameter which accounted for entrainment. The entrainment parameter moved numbers of larvae lost to entrainment through four larval stages and a young-of-the-year stage to age 1 fish which were then subtracted from the population. Each model run included 50 time steps and 500 replications. Since maximum age for winter flounder was assumed to be 12 years, 50 years allowed initialization values to be replaced and at the same time allowed examination of a length of time realistic to the life of a power plant. Table A8 presents survival values for each life stage, fecundity by age, and variance for each parameter used in each model run. Where no direct measurements of variance were available, an estimated variance was derived by assuming a coefficient of variation of 0.20.

The temperature Ricker function used to simulate a population of about 300,000 adult fish took the form:

No. Age 1 in year 't+1' = 7.1069E-5 * F * exp(-2.500E-11 * F - 7.85591304E-1 * T)

where, as defined above, F designates the total number of eggs produced by the population in year 't' and T is the deviation in February-April water temperature in year 't'. Figure A1 shows a plot of the Ricker function with the temperature term set to a mean value of -0.08 C. Decreasing the absolute value of B_0, the density dependent coefficient, decreases the rate at which egg production declines at higher population sizes and increases population size. For example, decreasing B_0 from 2.500E-11 to 1.955E-11 results in an average adult population of about 385,000 fish with correspondingly higher age 1 production (Figure A2). The temperature term accounts for the increase in production which is attributable to colder winter, early spring periods (NUSCO 1989, Jeffries and Johnson 1974, Jeffries and Terceiro 1985, Buckley et al. 1990). The effect of increasing the seasonal temperature term from -0.08 C to + 0.05 C and +1.0 C while holding the remaining terms constant is shown in Figure A3. Egg production was estimated by multiplying the number of fish in each age class by the mean fecundity for that age class and totaling over all age classes. Although northern stocks of winter flounder can reach an age of 15 years (Witherell and Burnett 1993), these fish are uncommon, particularly under high exploitation rates; a maximum age of 12 was assumed (Saila et al. 1965).

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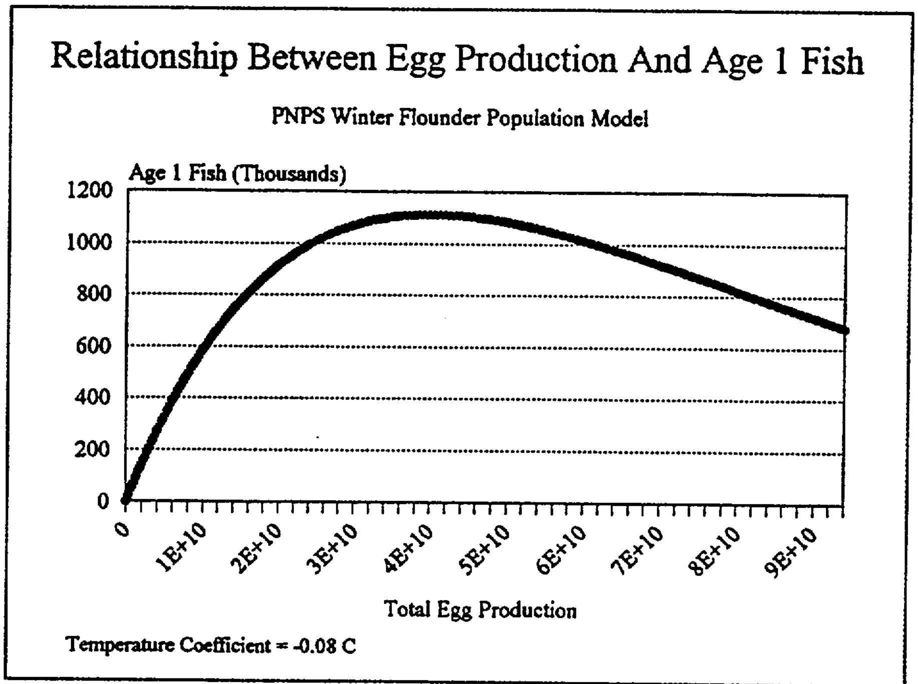


Figure A1. Ricker stock-recruitment relationship with temperature term used to estimate numbers of age 1 fish from total egg production.

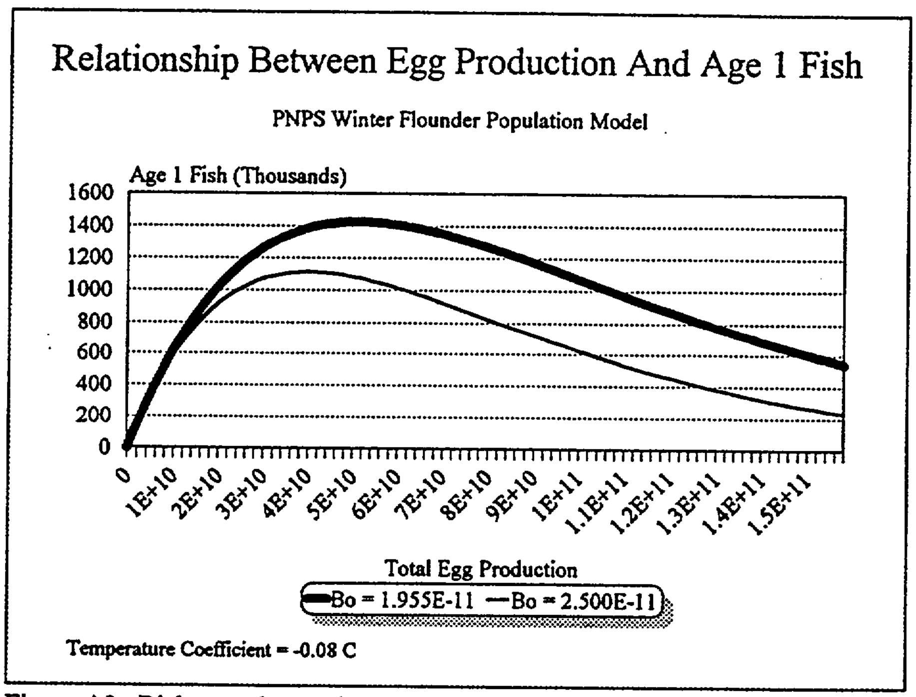


Figure A2. Ricker stock-recruitment relationship comparing two density dependent coefficients.

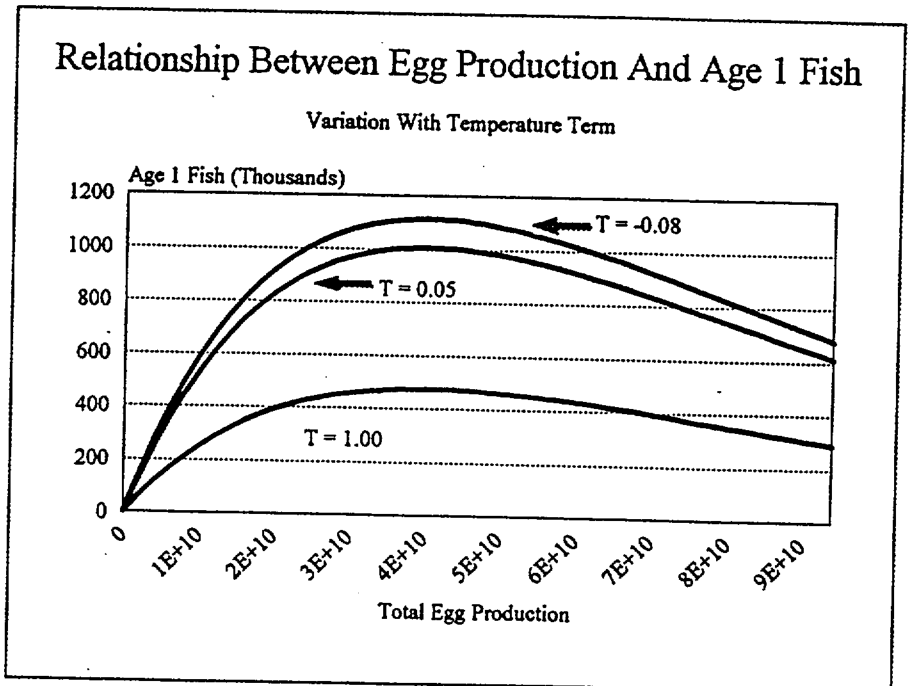


Figure A3. Ricker stock-recruitment relationship comparing changes in the temperature term.

Table A1. Mean, 95% confidence limits, minimum, and maximum numbers of equivalent age 1 winter flounder lost to entrainment for simulation years 26 through 50. Entrainment level based on 1980-1996 empirical data.

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	11,871	27,928	57,149	86,370	287,475
27	14,950	29,508	59,465	89,422	183,042
28	11,238	29,437	55,843	82,249	191,327
29	14,929	30,283	56,411	82,539	227,379
30	15,933	30,660	59,023	87,387	181,231
31	11,225	27,480	60,308	93,136	376,039
32	9,490	30,663	57,932	85,201	193,531
33	13,322	28,966	58,290	87,614	193,229
34	15,669	29,898	56,167	82,436	195,937
35	12,018	28,132	57,626	87,120	238,223
36	13,636	29,961	56,717	83,473	181,759
37	13,126	29,461	59,852	90,242	231,660
38	11,883	28,302	58,501	88,700	266,130
39	9,710	29,622	57,070	84,518	215,334
40	12,507	29,693	58,553	87,414	214,560
41	16,150	30,287	59,714	89,141	203,413
42	15,038	28,946	57,907	86,868	247,567
43	14,240	29,662	57,158	84,654	220,142
44	14,010	29,694	57,481	85,268	196,542
45	15,915	28,055	55,066	82,077	243,137
46	11,069	30,935	57,798	84,660	225,439
47	13,528	27,800	56,974	86,147	241,417
48	12,978	29,078	57,105	85,133	175,159
49	12,961	29,194	59,093	88,991	193,387
50	14,876	29,423	58,365	87,306	173,305
Mean	13,291	29,323	57,823	86,323	219,855

Numbers based on 500 replications.

Table A2. Mean, 95% confidence limits, minimum, and maximum numbers of age 3+ winter flounder for simulation years 26 through 50. Entrainment level based on 1980-1996 with 1984 and 1987 omitted. Base population = 299,900.

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	43,793	103,716	297,557	491,397	2,137,293
27	32,293	134,020	293,152	452,283	1,319,939
28	44,972	136,082	301,189	466,296	1,360,066
29	69,056	133,336	299,440	465,544	1,300,184
30	62,962	127,789	294,310	460,831	1,485,717
31	80,295	139,287	295,576	451,865	993,713
32	75,143	144,391	288,369	432,346	947,354
33	72,152	153,918	282,652	411,386	800,208
34	54,096	145,946	283,387	420,828	1,116,667
35	36,851	145,700	286,641	427,583	997,232
36	25,048	134,294	285,595	436,896	1,550,763
37	59,065	142,414	289,817	437,220	1,290,661
38	51,055	134,963	289,548	444,133	1,591,551
39	52,669	121,756	294,404	467,052	1,959,131
40	55,604	126,862	298,536	470,211	1,656,715
41	78,956	143,443	299,250	455,056	1,156,252
42	86,307	144,534	301,628	458,723	1,056,525
43	99,396	144,094	293,170	442,246	1,063,320
44	72,950	145,827	299,941	454,055	948,224
45	82,509	133,114	293,801	454,488	1,768,205
46	72,075	136,117	290,352	444,588	1,540,419
47	76,139	127,541	292,420	457,299	1,683,264
48	50,238	132,575	284,612	436,650	1,106,181
49	61,817	122,109	291,073	460,036	1,545,920
50	61,596	126,854	295,626	464,398	1,306,241
Mean	62,281	135,227	292,882	450,536	1,347,270

Numbers based on 500 replications.

Table A3. Mean, 95% confidence limits, minimum, and maximum numbers of age 3+ winter flounder for simulation years 26 through 50. Entrainment level based on 1980-1996 with 1984 and 1987 omitted. Base population = 254,300

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	1,759	94,993	236,966	378,938	1,833,775
27	1,010	105,943	237,854	369,765	1,274,557
28	8,957	107,034	248,246	389,457	1,171,036
29	11,055	120,549	249,950	379,351	905,581
30	7,421	119,431	255,002	390,573	1,083,346
31	5,012	111,178	253,899	396,620	1,387,219
32	3,572	107,731	255,049	402,367	1,096,579
33	2,620	117,405	254,527	391,650	998,240
34	1,964	126,009	244,035	362,062	761,791
35	11,707	116,050	243,615	371,180	914,626
36	17,887	114,674	239,646	364,619	943,682
37	21,173	113,317	236,190	359,063	1,367,893
38	26,275	104,624	236,894	369,164	1,248,816
39	56,736	95,999	242,485	388,971	1,630,524
40	38,702	102,980	241,485	379,990	1,028,298
41	37,631	99,928	247,434	394,940	1,484,963
42	42,054	111,747	250,976	390,205	1,373,571
43	50,927	116,659	251,161	385,663	931,580
44	46,941	101,996	254,262	406,527	1,613,649
45	39,569	108,931	249,693	390,455	1,290,057
46	54,173	102,569	252,816	403,062	1,316,159
47	63,253	111,805	242,123	372,440	891,344
48	45,499	110,208	240,885	371,562	1,381,773
49	17,951	109,422	235,338	361,253	977,150
50	26,711	113,111	244,033	374,954	1,120,168
Mean	25,622	109,772	245,783	381,793	1,201,055

Numbers based on 500 replications.

Table A4. Mean, 95% confidence limits, minimum, and maximum numbers of age 3+ winter flounder for simulation years 26 through 50. Entrainment level based on 1980-1999. Base population = 299,900.

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	59,390	125,767	289,191	452,615	1,549,076
27	77,762	127,244	299,311	471,379	1,185,512
28	54,447	109,404	298,620	487,837	2,410,915
29	67,928	123,706	294,979	466,253	1,546,210
30	13,895	130,743	292,911	455,079	1,374,809
31	31,495	132,146	284,652	437,157	1,074,303
32	32,123	141,203	281,968	422,733	944,465
33	66,818	148,546	280,546	412,546	954,519
34	24,121	120,763	284,521	448,279	1,501,243
35	26,209	99,908	276,382	452,857	2,712,906
36	56,295	123,883	283,518	443,152	1,691,032
37	42,934	130,678	285,227	439,777	1,165,265
38	32,478	135,460	289,068	442,675	1,144,747
39	56,424	124,159	287,166	450,174	1,803,511
40	47,005	131,445	282,055	432,664	1,243,437
41	55,298	118,071	275,295	432,518	1,453,257
42	62,035	124,391	280,157	435,922	1,202,610
43	76,599	144,133	290,490	436,848	987,817
44	31,104	140,380	286,587	432,794	1,513,872
45	6,454	144,695	279,977	415,259	1,016,164
46	3,256	134,202	290,189	446,177	1,155,077
47	47,933	134,071	286,972	439,873	1,722,766
48	37,541	134,407	289,213	444,019	1,435,853
49	33,675	110,154	293,483	476,812	1,928,413
50	56,342	107,214	295,796	484,378	1,815,540
Mean	43,982	127,871	287,131	446,391	1,461,333

Numbers based on 500 replications.

Table A5. Mean, 95% confidence limits, minimum, and maximum numbers of equivalent age 1 winter flounder lost to entrainment for simulation years 26 through 50. Entrainment level based on 1980-1999 empirical data. Base population = 29

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	8,307	1,292	96,444	191,597	760,429
27	8,421	463	91,382	182,301	777,599
28	7,281	2,540	91,294	180,048	957,568
29	6,334	0	97,742	235,793	1,876,017
30	7,055	0	98,701	220,478	1,510,212
31	7,512	1,296	95,193	189,089	642,915
32	6,329	0	104,957	239,634	1,467,598
33	4,107	0	94,044	196,498	1,125,214
34	7,507	0	89,278	179,720	869,938
35	8,899	0	102,072	237,649	1,957,683
36	8,305	0	94,136	197,499	1,290,388
37	6,217	3,012	96,175	189,339	838,714
38	7,340	0	101,712	214,052	927,606
39	7,128	0	98,975	205,479	865,729
40	5,336	2,701	92,885	183,070	672,831
41	6,751	0	92,963	197,296	1,130,231
42	8,939	0	94,318	188,979	853,295
43	6,298	0	95,081	198,633	1,086,845
44	4,672	1,974	95,140	188,307	642,555
45	7,918	4,517	90,929	177,340	623,689
46	6,140	0	94,722	209,923	1,643,363
47	3,820	0	101,171	313,272	3,664,949
48	6,717	0	99,583	219,552	1,153,049
49	3,996	0	98,277	206,579	1,279,758
50	7,869	0	99,814	225,317	1,911,955
Mean	6,768	712	96,280	206,698	1,221,205

Numbers based on 500 replications.

Table A6. Mean, 95% confidence limits, minimum, and maximum numbers of age 3+ winter flounder for simulation years 26 through 50. Entrainment level based on 1980-1999. Base population = 254,300.

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	54,015	105,350	243,046	380,742	1,149,754
27	54,122	106,359	244,089	381,818	1,126,912
28	56,426	112,131	242,897	373,663	869,048
29	18,589	106,030	245,178	384,326	1,552,253
30	68,401	108,063	247,371	386,679	1,228,412
31	54,498	118,707	242,954	367,201	800,980
32	25,195	117,287	236,716	356,144	982,738
33	31,606	111,233	240,840	370,447	922,480
34	29,752	104,851	241,598	378,345	1,019,161
35	35,905	101,824	240,460	379,097	985,594
36	43,807	101,086	238,854	376,623	1,265,776
37	37,255	94,085	237,728	381,371	1,619,778
38	44,494	90,518	238,914	387,310	1,566,358
39	39,409	104,247	240,072	375,897	1,311,231
40	18,507	96,274	247,700	399,125	1,280,029
41	53,263	100,895	247,450	394,006	1,235,152
42	54,718	104,311	246,415	388,520	1,180,629
43	40,228	85,857	248,160	410,463	2,739,715
44	41,562	101,940	246,912	391,884	1,859,716
45	47,829	106,512	241,436	376,360	1,283,643
46	33,268	109,698	243,511	377,324	1,441,553
47	43,309	116,714	239,634	362,555	934,114
48	16,640	114,105	242,421	370,737	1,051,545
49	7,688	108,574	238,133	367,692	1,052,121
50	1,875	110,785	234,918	359,052	1,111,123
Mean	38,094	105,497	242,296	379,095	1,262,793

Numbers based on 750 replications.

Table A7. Mean, 95% confidence limits, minimum, and maximum numbers of age 3+ winter flounder for simulation years 26 through 50. Entrainment level projected. Base population = 254,300.

Year	Minimum	Lower C.L.	Mean	Upper C.L.	Maximum
26	28,156	109,073	245,932	382,791	1,112,977
27	35,011	92,647	241,998	391,348	2,581,040
28	39,825	104,939	245,919	386,899	1,565,899
29	31,765	110,669	250,695	390,720	1,131,010
30	49,598	121,714	249,647	377,580	936,230
31	10,908	112,718	251,994	391,269	1,834,532
32	17,240	103,986	255,072	406,158	1,845,962
33	28,063	110,788	249,374	387,959	1,154,221
34	42,219	111,066	243,142	375,219	1,047,715
35	38,974	108,913	242,626	376,340	1,118,178
36	27,957	108,378	243,765	379,151	1,216,260
37	6,334	118,603	233,490	348,377	797,001
38	9,005	124,863	237,841	350,818	813,432
39	43,896	113,270	241,940	370,609	1,298,529
40	44,188	107,352	242,892	378,433	1,279,047
41	44,845	105,771	238,011	370,251	1,159,248
42	19,717	106,296	243,176	380,056	1,669,754
43	49,493	111,564	241,807	372,051	1,136,153
44	47,747	113,570	242,906	372,242	1,111,492
45	14,088	108,312	249,351	390,390	1,494,320
46	25,138	117,979	246,103	374,227	1,097,337
47	27,473	116,315	243,162	370,010	1,148,589
48	30,739	119,774	251,337	382,900	998,630
49	25,621	112,572	247,641	382,711	1,304,917
50	37,827	117,085	247,369	377,653	1,096,755
Mean	31,033	111,529	245,088	378,646	1,277,969

Numbers based on 750 replications.

Table A8. Model input parameters, PNPS entrainment analysis.

Age	Fecundity Mean	Fecundity Variance	Inital Stage Values 300 K Base	Inital Stage Values 254K Base	Survival Rate
1			910,000	900,000	0.25
2			215,000	210,000	0.48
3	82,127	269,793,765	93,000	90,000	0.60
4	251,913	2,538,406,383	67,000	65,000	0.66
5	409,572	6,709,968,927	40,000	38,000	0.70
6	542,695	11,780,714,521	20,000	18,000	0.73
7	647,080	16,748,501,056	14,000	13,000	0.74
8	729,897	21,309,985,224	10,000	9,000	0.76
9	793,893	25,210,643,818	7,600	7,500	0.76
10	847,169	28,707,812,582	5,800	5,500	0.76
11	882,915	31,181,555,889	4,500	4,400	0.77
12	911,476	33,231,539,943	3,400	3,300	

Larvae	Survival Rate	Variance
Stage 1	1.79E-04	1.28E-09
Stage 2	7.56E-04	2.29E-08
Stage 3	7.00E-03	1.96E-06
Stage 4	4.55E-02	8.30E-05
YOY	7.30E-02	2.13E-04

Temperature Deviation Mean	Temperature Deviation Variance
-0.08	1.1

Notes: Fecundity is entered on a 'per fish' basis assuming an equal sex ratio.
YOY = young-of-the-year.

III. D. IMPINGEMENT MONITORING & IMPACT

IMPINGEMENT OF ORGANISMS AT

PILGRIM NUCLEAR POWER STATION

(January - December 1999)

Prepared by: [signature]

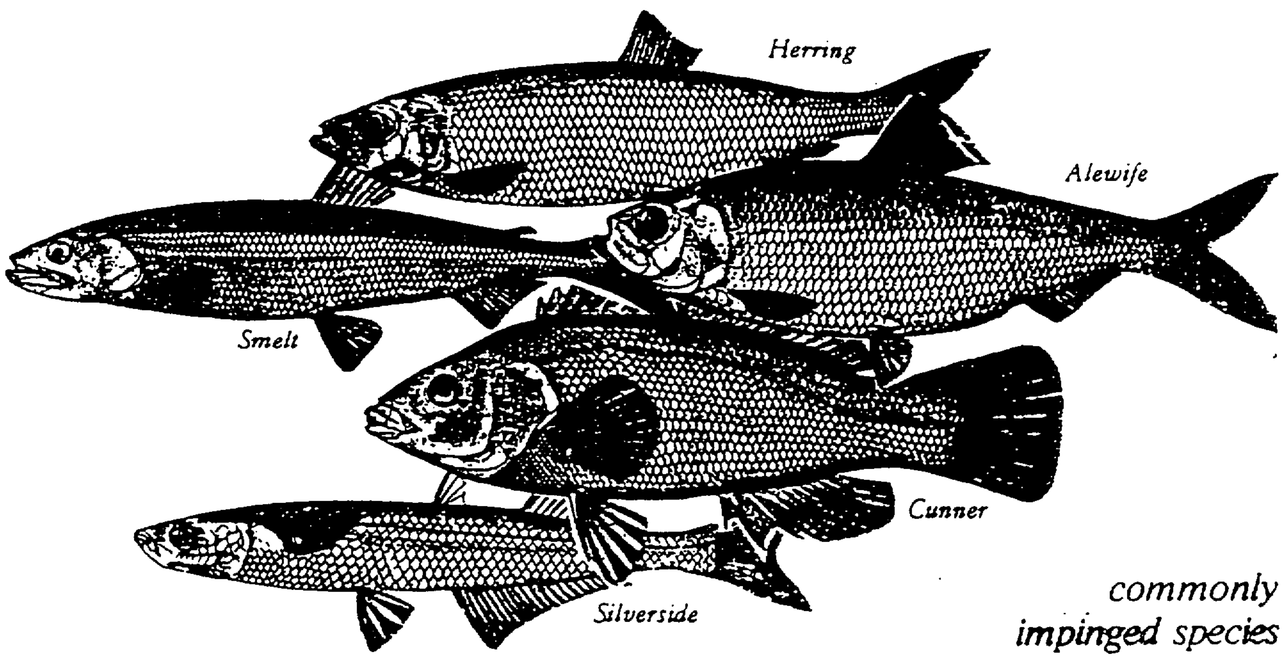
Robert D. Anderson

Senior Engineer

Environmental Protection Department

Entergy Nuclear Generation Company

April 2000



commonly impinged species

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SECTION I

SUMMARY

Fish impingement rate averaged 7.21 fish/hour during the period January-December 1999, which is considerably higher than recent years primarily because of a large Atlantic menhaden (Brevoortia tyrannus) impingement incident in September. Atlantic menhaden accounted for 63.9% of the fishes collected followed by Atlantic silverside (Menidia menidia) at 21.9%. Rainbow smelt (Osmerus mordax) and winter flounder (Pseudopleuronectes americanus) represented 2.3 and 2.1%, respectively, of the fishes impinged. The peak period was September 17/18 when fish impingement was dominated by a large incident involving an estimated 4,900 menhaden. This was the first large impingement incident identifying menhaden specifically. Initial impingement survival for all fishes from static screen wash collections was approximately 37% and from continuous screen washes 84%.

At 100% yearly (January-December) operation of Pilgrim Nuclear Power Station (PNPS) the estimated annual impingement was 63,160 fishes. The PNPS capacity factor was 76.2% during 1999.

The collection rate (no./hr.) for all invertebrates captured from January-December 1999 was 1.82+. Ctenophores and sevenspine bay shrimp (Crangon septemspinosa) were most numerous. Common starfish (Asterias forbesi) and green crab (Carcinus maenus) accounted for 8.0 and 6.1%, respectively, of the invertebrates impinged and enumerated. Mixed species of algae collected on intake screens amounted to 1,378 pounds.

SECTION 2

INTRODUCTION

Pilgrim Nuclear Power Station (lat. 41°56' N, long. 70°34' W) is located on the northwestern shore of Cape Cod Bay (Figure 1) with a licensed capacity of 670 MWe. The unit has two circulating water pumps with a capacity of approximately 345 cfs each and five service water pumps with a combined capacity of 23 cfs. Water is drawn under a skimmer wall, through vertical bar racks spaced approximately 3 inches on center, and finally through vertical traveling water screens of 3/8 inch mesh (Figure 2). There are two traveling water screens for each circulating water pump.

This document is a report pursuant to operational environmental monitoring and reporting requirements of NPDES Permit No. 0003557 (USEPA) and No. 359 (Mass. DEP) for Pilgrim Nuclear Power Station, Unit I. The report describes impingement of organisms and survival of fishes carried onto the vertical traveling water screens at Unit I. It presents analysis of the relationships among impingement, environmental factors, and plant operational variables.

This report is based on data collected from screen wash samples during January-December 1999.

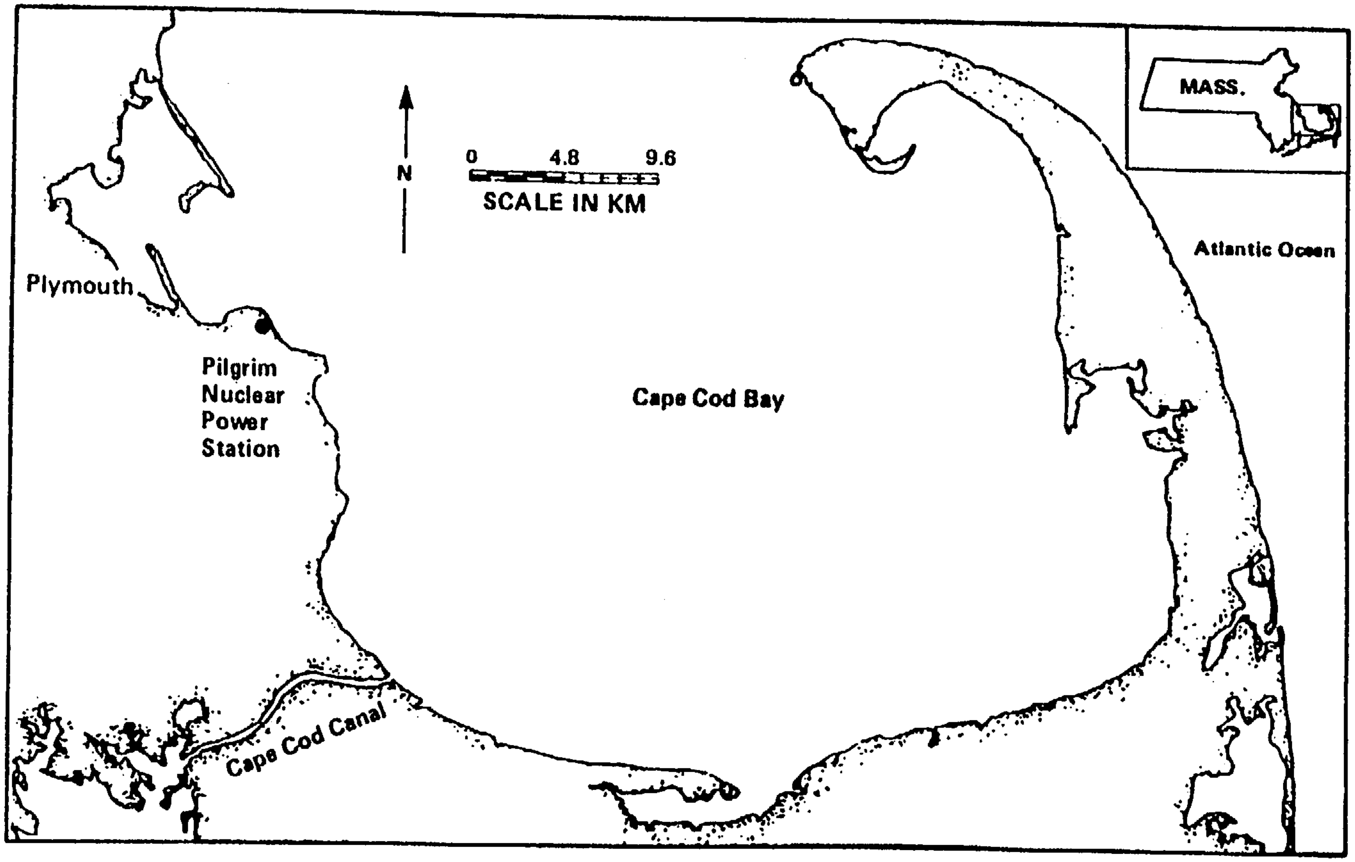

Figure 1. Location of Pilgrim Nuclear Power Station.

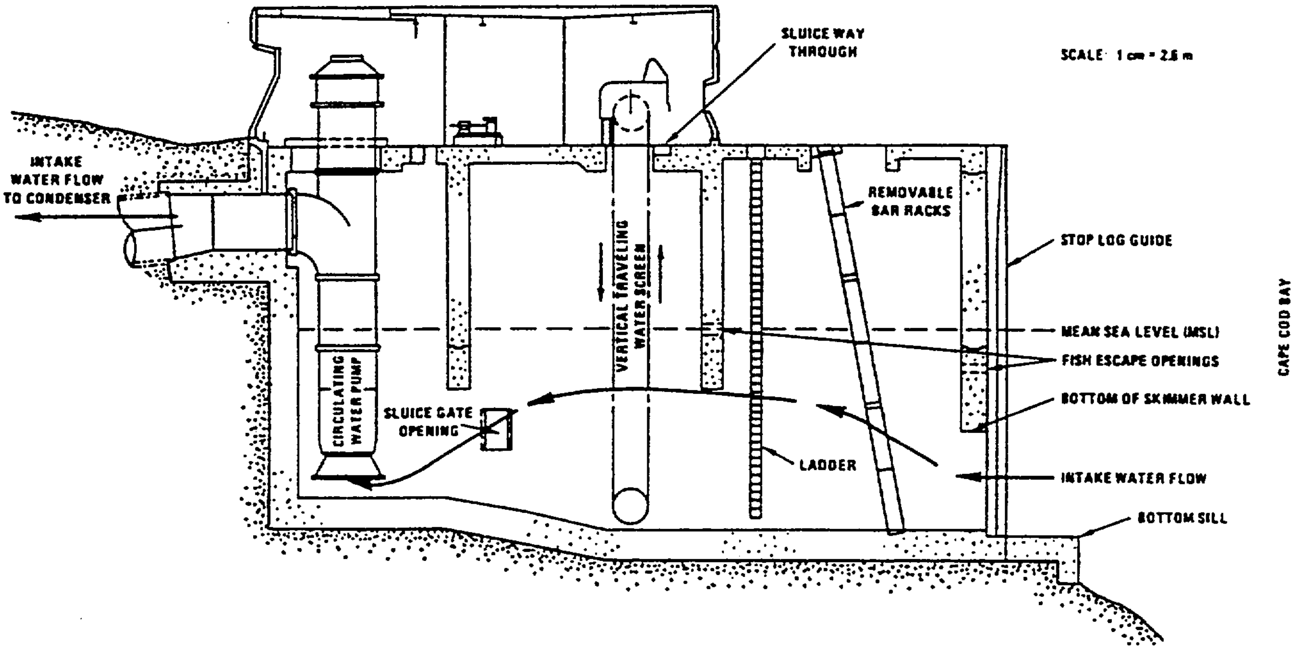

Figure 2: Cross-section of intake structure of Pilgrim Nuclear Power Station.

SECTION 3

METHODS AND MATERIALS

Three screen washings each week were performed from January-December 1999 to provide data for evaluating the magnitude of marine biota impingement. The total weekly collection time was 24 hours (three separate 8-hour periods: morning, afternoon and night). Two collections represented dark period sampling and one represented light period sampling. At the beginning of each collection period, all four traveling screens were washed. Eight hours later, the screens were again washed (approximately 30 minutes each) and all organisms collected. When screens were being washed continuously, one hour collections were made at the end of the regular sampling periods, and they represented two light periods and one dark period on a weekly basis.

Water nozzles directed at the screens washed impinged organisms and debris into a sluiceway that flowed into a trap. The trap was made of galvanized screen (3/8-inch mesh) attached to a removable steel frame and it collected impinged biota, in the screenhouse, shortly after being washed off the screens. Initial fish survival was determined for static (8-hour) and continuous screenwash cycles.

Variables recorded for organisms were total numbers, and individual total lengths (mm) and weights (gms) for up to 20 specimens of each species. A random sample of 20 fish or invertebrates was taken whenever the total number for a species exceeded 20; if the total collection for a species was less than 20, all were measured and weighed. Field work was conducted by Marine Research, Inc. Intake seawater temperature, power level output, tidal stage, number of circulating water pumps in operation, time of day and date were recorded at the time of collections. The collection rate (#/hour) was calculated as number of organisms impinged per collecting period divided by the total number of hours in that collecting period.

Beginning in 1990, if all four intake screens are not washed for a collecting period then the number of fishes collected is increased by a proportional factor to account for the unwashed screens. Common and scientific names in this report follow the American Fisheries Society (1988, 1989, 1991a and 1991b) or other accepted authority when appropriate.

SECTION 4

RESULTS AND DISCUSSION

4.1 Fishes

In 375.5 collection hours, 2,707 fishes of 33 species (Table 1) were collected from Pilgrim Nuclear Power Station intake screens during January - December 1999. The collection rate was 7.21 fish/hour. This annual impingement rate was relatively high compared to recent years primarily because of the high impingement of Atlantic menhaden (Brevoortia tyrannus) on September 17/18 when an estimated 4,900 were caught on intake screens. Atlantic menhaden was the most abundant species in 1999 accounting for 63.9% of all fishes collected, followed by Atlantic silverside (Menidia menidia) at 21.9% (Table 2). Rainbow smelt (Osmerus mordax) and winter flounder (Psuedopleuronectes americanus) accounted for 2.3 and 2.1% of the total number of fishes collected and identified to lowest taxon.

Atlantic menhaden occurred most predominately in monthly samples from September and November. Hourly collection rates per month for them ranged from 0 to 35.78. Menhaden impinged in September and November accounted for 76% of all this species captured in impingement collections from January-December 1999. They averaged 78 mm total length and 5 grams in weight. Their impingement indicated no relationship to tidal stage or diurnal factors. They haven't previously been the dominant fish identified in the annual impingement catch, although herrings (clupeids) as a general category dominated impingement in 1973 and 1974. Menhaden ranked second in 1989/1990 and third in 1986/1991/1997. Impingement histories of abundant species impinged at Pilgrim Station in 1999, over the past 10 years, are documented in Table 3.

Atlantic silverside were relatively prevalent in December-April samples and have been most abundant in the early Winter and/or early Spring periods. Generally, it has been the most impinged fish over the years at Pilgrim Station, being the dominant species in six of the last ten years.

Table 1 - Monthly Impingement for All Fishes Collected from Pilgrim Station
Intake Screens, January - December 1999

Species	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Atlantic menhaden	1						1	176	805	43	517	188	1,731
Atlantic silverside	50	37	78	30						1	61	335	592
Rainbow smelt	1	1	2		1			3	2		2	50	62
Winter flounder	4	14	7	6			1				5	21	58
Grubby		3	1	6			2	2			5	21	40
Blueback herring				2			1			3	6	27	39
Alewife							2	6			16	10	34
Windowpane	2	5	1	12								5	25
Red hake				1	4		1	4	2		8	2	22
Atlantic tomcod					1					1	5	11	18
Lumpfish				3						1		5	9
Tautog		1									2	6	9
Atlantic moonfish									3	5			8
Northern pipefish			2					2		2		1	7
White perch	2	1	1								1	2	7
Butterfish								4	2				6
Cunner					1		1				2	1	5
Striped killifish												5	5
Silver hake							1				3		4
Striped searobin											4		4
Atlantic herring					2				1				3
Mummichog											1	2	3
Atlantic cod									1			1	2
Fourspot flounder									1		1		2
Northern searobin											2		2
Pollock					1			1					2
Yellowtail flounder				2									2
Black sea bass											1		1
Longhorn sculpin											1		1
Radiated shanny		1											1
Rock gunnel				1									1
Smallmouth flounder												1	1
Threespine stickleback	1												1
Totals	61	63	92	63	10	0	10	198	817	56	643	694	2707
Collection Time (hrs.)	39	26	34	45	10	16	20	24	22.5	21	47	71	375.5
Collection Rate (#hr.)	1.56	2.42	2.71	1.40	1.00	0.00	0.50	8.25	36.31	2.67	13.68	9.77	7.21

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Table 2 - Species, Number, Total Length (mm), Weight (gms), and Percentage For All Fishes Collected From Pilgrim Station Impingement Sampling, January - December 1999

Species	Number	Length Range	Mean Length	Weight Range	Mean Weight	Percent Of Total Fish
Atlantic menhaden	1,731	36-137	78	1-19	5	63.9
Atlantic silverside	592	69-155	97	1-15	4	21.9
Rainbow smelt	62	59-186	88	1-28	4	2.3
Winter flounder	58	42-158	80	-	-	2.1
Grubby	40	45-140	74	-	-	1.5
Blueback herring	39	51-112	80	2-9	4	1.4
Alewife	34	46-157	83	1-22	5	1.3
Windowpane	25	45-266	70	-	-	0.9
Red hake	22	60-170	88	1-28	5	0.8
Atlantic tomcod	18	57-240	155	-	-	0.7
Lumpfish	9	34-80	58	-	-	0.3
Tautog	9	60-92	74	-	-	0.3
Atlantic moonfish	8	40-54	47	1-3	2	0.3
Northern pipefish	7	76-157	120	0.2-11	2	0.3
White perch	7	94-148	124	-	-	0.3
Butterfish	6	37-63	47	1-3	2	0.2
Cunner	5	46-148	90	1-54	20	0.2
Striped killifish	5	71-82	77	4-5	5	0.2
Silver hake	4	68-105	92	2-6	5	0.1
Striped searobin	4	41-110	73	1-18	7	0.1
Atlantic herring	3	30-94	53	0.1-6	2	0.1
Mummichog	3	63-80	73	3-6	5	0.1
Atlantic cod	2	78-144	111	3-26	15	0.1
Fourspot flounder	2	75-101	88	3-9	6	0.1
Northern searobin	2	45-113	79	1-21	11	0.1
Pollock	2	60-163	112	2-38	20	0.1
Yellowtail flounder	2	85-105	95	6-9	7	0.1
Black sea bass	1	60	60	2	2	0.04
Longhorn sculpin	1	275	275	-	-	0.04
Radiated shanny	1	125	125	16	16	0.04
Rock gunnel	1	152	152	10	10	0.04
Smallmouth flounder	1	59	59	2	2	0.04
Threespine stickleback	1	58	58	2	2	0.04

Table 3. Annual Impingement collections (1990 - 1999) for the 10 Most Abundant Fishes From Pilgrim Station Intake Screens During January - December 1999

Number of Impinged fishes Collected From January - December

Species	1990	1991	1992	1993	1994*	1995**	1996	1997	1998	1999***	Totals
Atlantic menhaden	345	113	2	4	14	73	75	56	65	1,731	2,478
Atlantic silverside	457	275	232	720	3,112	1,100	765	302	387	592	7,942
Rainbow smelt	38	41	25	735	896	162	174	82	51	62	2,266
Winter flounder	31	67	72	90	90	92	41	40	98	58	679
Grubby	59	46	43	51	98	45	57	23	17	40	479
Blueback herring	103	31	11	25	24	87	58	18	8	39	404
Alewife	131	24	22	52	11	1,871	11	15	13	34	2184
Windowpane	15	11	3	10	14	10	13	4	25	25	130
Red hake	0	6	1	6	1	6	5	4	4	22	55
Atlantic tomcod	26	16	11	26	14	15	14	3	2	18	145
Totals	1,205	630	422	1,719	4,274	3,461	1,213	547	670	2,621	16,762
Collection Time (hrs.)	919.50	930.25+	774	673.50	737.39	607.67	416	455	575	375.5	6,464.41+
Collection Rate (#/hr.)	1.31	0.68	0.55	2.55	5.80	5.70	2.92	1.20	1.17	6.98	2.59

* No CWS pumps were in operation 9 October - 16 November 1994.

** No CWS pumps were in operation 30 March - 15 May 1995.

*** No CWS pumps were in operation 10 May – 10 June 1999.

Rainbow smelt were abundant in December impingement collections and have been most prevalent in the late Fall/ Winter period in the past, ranking first in 1978, 1987 and 1993 in total numbers impinged. In 1978, 1993 and 1994, large impingement incidents involving smelt occurred during December.

Winter flounder were relatively prevalent in February and December samples, indicative of this species' juvenile stage movements. It has been one of the more commonly impinged fish over the years. Monthly intake water temperatures and impingement rates for the five dominant species in 1999 are illustrated in Figure 3.

There were seven small fish impingement incidents (20 fish or greater/hr.) at Pilgrim Station in 1999 (August 21; September 4; November 22, 29; December 6, 8, 22) when mostly Atlantic menhaden and/or Atlantic silversides were recorded, but their impingement rates rapidly decreased upon subsequent sampling, indicating minimal impact. There was one large fish impingement incident (1,000 fish or greater) in 1999 during September 17 and 18 when an estimated 4,910 Atlantic menhaden (289/hour) were impinged on intake screens. The menhaden were mostly juveniles averaging ~84 mm in total length. Most large fish impingement mortalities have occurred while both circulating water pumps were operating, as in this case.

Sixteen large fish incidents have been documented since Pilgrim operation in 1973, and most (12) have involved impingement as the causative agent (Table 4). However, at least in two of these, the possibility of pathological influence was implicated as indirectly contributing to the mortalities. They were the Atlantic herring (tubular necrosis) and rainbow smelt (piscine erythrocytic necrosis) impingement incidents in 1976 and 1978, respectively.

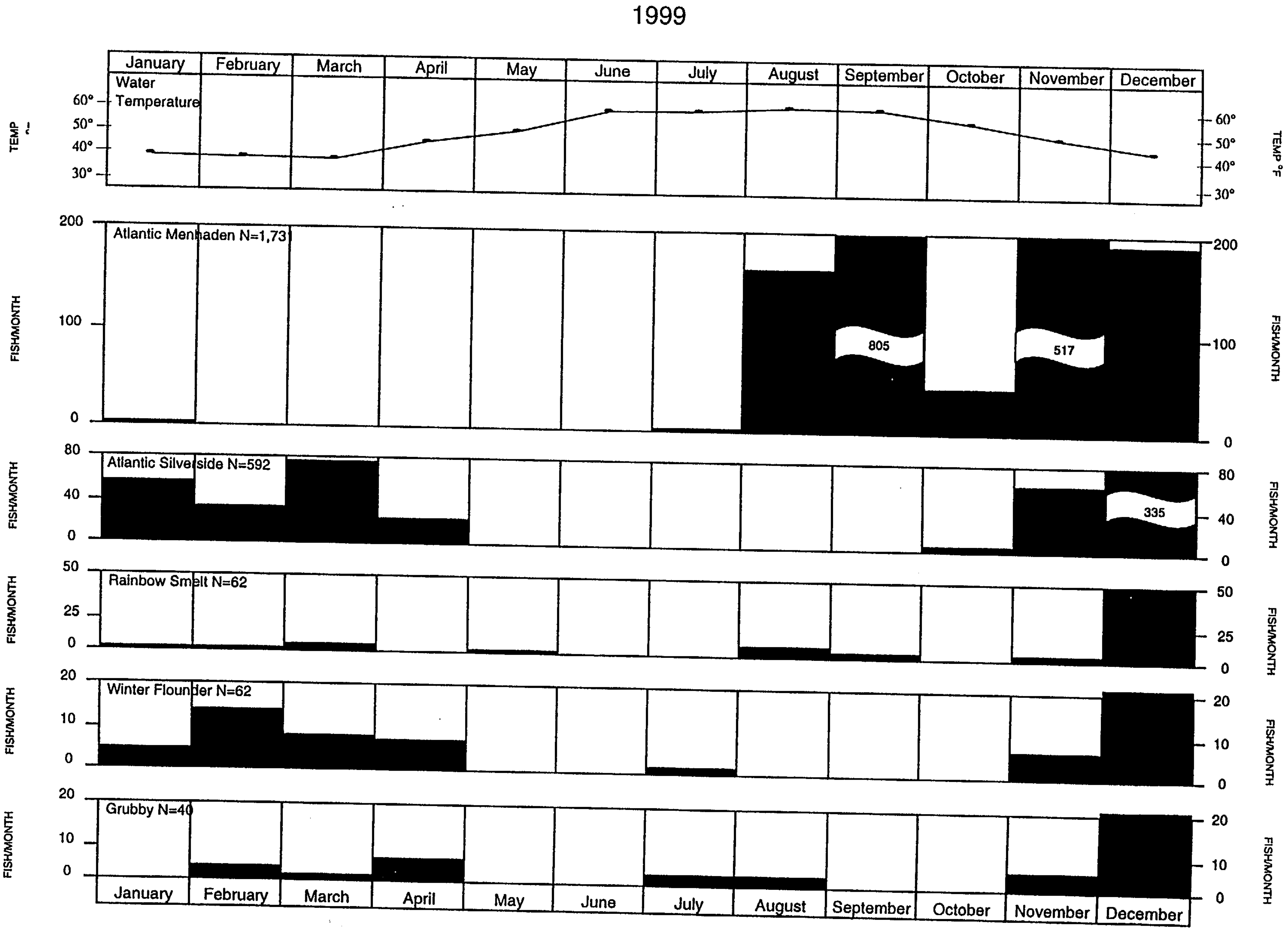

Figure 3: Trends of Intake Water Temperature and Number of Fish Captured by Month from Pilgrim Station Intake Screens for the Five Most Abundant Species Collected, January - December 1999

license/radmisc.fishchart

Table 4. Approximate Number and Cause for Dominant Species of Most Notable Fish Mortalities at Pilgrim Nuclear Power Station, 1973-1999

Date	Species	Number	Cause
April 9-19, 1973	Atlantic menhaden	43,000	Gas Bubble Disease
August/September, 1973	Clupeids	1,600	Impingement
April 2-15, 1975	Atlantic menhaden	5,000	Gas Bubble Disease
August 2, 1975	Atlantic menhaden	3,000	Thermal Stress
August 5, 1976	Alewife	1,900	Impingement
November 23-28, 1976	Atlantic herring	10,200	Impingement
August 21-25, 1978	Clupeids	2,300	Thermal Stress
December 11-29, 1978	Rainbow smelt	6,200	Impingement
March/April, 1979	Atlantic silverside	1,100	Impingement
September 23-24, 1981	Atlantic silverside	6,000	Impingement
July 22-25, 1991	Atlantic herring	4,200	Impingement
December 15-28, 1993	Rainbow smelt	5,100	Impingement
November 28-29, 1994	Atlantic silverside	5,800	Impingement
December 26-28, 1994	Atlantic silverside	6,100	Impingement
	Rainbow smelt	5,300	Impingement
September 8-9, 1995	Alewife	13,100	Impingement
September 17-18, 1999	Atlantic menhaden	4,910	Impingement

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The fish impingement rate at Pilgrim Station has been shown to be related to the number of circulating water pumps operating, in general (Lawton, Anderson et al,1984b). Reduced pump operation has lowered total impingement, particularly during the April to mid-August 1984 and portions of the mid-February to August 1987 periods when no circulating water pumps were operating for extended time frames. The significance of this relationship is supported by the fact that total fish impingement and rate of fish impingement were several times lower in 1984 and 1988 (low-pump operation years) than in 1989 - 1999, despite a greater number of collecting hours in 1984 and an average number of hours in 1988. In 1987, far fewer collecting hours were possible when both circulating pumps were off than in these other years which limits comparisons to them. However, total fish impingement rates in 1984, 1987 and 1988 were several times lower than in 1989-1999 when at least one circulating pump was more consistently in operation. Although there were brief periods in 1994, 1995 and 1999 when no circulating water pumps were operational, mixed results were noted regarding the effect on impingement of pump operation, possibly influenced by conditions causing large impingement incidents in these years.

Projected fish impingement rates were calculated assuming 100% operation of Pilgrim Nuclear Power Station, under conditions at the times of impingement, during the period January-December 1999. Table 5 presents hourly, daily, and yearly impingement rates for each species captured (rates are rounded to significant figures). For all fishes combined, the respective rates were 7.21,173.40 and 63,160. The yearly rate of 63,160 is above normal at 292% of the last 20-years' (1980-1999) mean annual projection of 21,637 fishes (Table 6). This was considerably higher than most recent years' rates and comparable to 1994 (52,259) and 1995 (51,464) when large impingement incidents also inflated yearly projections. Relatively high impingement rate years offset low impingement years, and they may be attributed to population variances of the dominant species and/or extreme meteorological or operational conditions influencing species' behavior and vulnerability.

Table 5. Impingement Rates Per Hour, Day and Year For All Fishes Collected From Pilgrim Station Intake Screens During January – December 1999. Assuming 100% Operation of Pilgrim Unit 1*

Species	Rate/Hr.	Rate/Day	Rate/January-December 1999	Dominant Months Of Occurrence
Atlantic menhaden	4.61	110.64	40,382	September
Atlantic silverside	1.58	37.84	13,811	December
Rainbow smelt	0.17	3.96	1,446	December
Winter flounder	0.15	3.71	1,353	December
Grubby	0.11	2.56	933	December
Blueback herring	0.10	2.49	910	December
Alewife	0.09	2.17	793	November
Windowpane	0.07	1.60	583	April
Red hake	0.06	1.41	513	November
Atlantic tomcod	0.05	1.15	420	December
Lumpfish	0.02	0.58	210	December
Tautog	0.02	0.58	210	December
Atlantic moonfish	0.02	0.51	187	October
Northern pipefish	0.02	0.45	163	August/October
White perch	0.02	0.45	163	January/December
Butterfish	0.02	0.38	140	August
Cunner	0.01	0.32	117	November
Striped killifish	0.01	0.32	117	December
Silver hake	0.01	0.26	93	November
Striped searobin	0.01	0.26	93	August/October
Atlantic herring	0.008	0.19	70	May
Mummichog	0.008	0.19	70	December
Atlantic cod	0.005	0.13	47	September/November
Fourspot flounder	0.005	0.13	47	September/November
Northern searobin	0.005	0.13	47	November
Pollock	0.005	0.13	47	May/August
Yellowtail flounder	0.005	0.13	47	April
Black sea bass	0.003	0.06	23	November
Longhorn sculpin	0.003	0.06	23	November
Radiated shanny	0.003	0.06	23	February
Rock gunnel	0.003	0.06	23	April
Smallmouth flounder	0.003	0.06	23	December
Threespine stickleback	0.003	0.06	23	January
Totals	7.31	173.04	63,160	

*Rates have been rounded to significant figures.

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Table 6. Impingement Rates Per Hour, Day and Year For All Fishes Collected From Pilgrim Station Intake Screens During 1980-1999, Assuming 100% Operation of Pilgrim Unit 1*

Year	Rate/Hr.	Rate/Day	Rate/Year	Dominant Species (Rate/Year)
1980	0.66	15.78	5,769	Cunner (1,683)
1981	10.02	240.42	87,752	Atlantic silverside (83,346)
1982	0.93	22.39	8,173	Atlantic silverside (1,696)
1983	0.57	13.65	4,983	Atlantic silverside (1,114)
1984+	0.13	3.13	1,143	Atlantic silverside (185)
1985	1.14	27.46	10,022	Atlantic silverside (3,278)
1986	1.26	30.34	11,075	Atlantic herring (3,760)
1987+	0.28	6.74	2,460	Rainbow smelt (682)
1988+	0.27	6.48	2,372	Atlantic silverside (586)
1989	0.80	19.30	7,045	Atlantic silverside (1,701)
1990	1.70	40.74	14,872	Atlantic silverside (4,354)
1991	3.38	81.14	29,616	Atlantic herring (22,318)
1992	0.63	15.22	5,572	Atlantic silverside (2,633)
1993	2.78	66.78	24,375	Rainbow smelt (9,560)
1994+	5.97	143.18	52,259	Atlantic silverside (36,970)
1995+	5.87	141.00	51,464	Alewife (26,972)
1996	3.11	74.64	27,318	Atlantic silverside (16,153)
1997	1.43	34.29	12,514	Atlantic silverside (5,814)
1998	1.30	31.30	11,426	Atlantic silverside (5,896)
1999	7.21	173.04	63,160	Atlantic menhaden (40,382)
Means	2.47	59.28	21,637	

*Rates have been rounded to significant figures.
+No CWS pumps were in operation 29 March - 13 August 1984, 18 February - 8 September 1987, 14 April - 5 June 1988, 9 October - 16 November 1994, 30 March - 15 May 1995 and 10 May – 10 June 1999.

Over the past 20-year period (1980-1999), Pilgrim Station has had a mean impingement rate of 2.47 fishes/hr., ranging from 0.13 (1984) to 10.02 (1981) (Table 6). Anderson et al. (1975) documented higher annual impingements at seven other northeast power plants in the early 1970's. Stupka and Sharma (1977) showed annual impingement rates at numerous power plant locations for dominant species, and compared to these, rates at Pilgrim Station were lower than at most other sites. Recently, Normandeau Associates (1996) compared fish impingement at several marine power plant intakes which demonstrated Pilgrim rates to be among the lowest with the exception of incidents that involve one or two species occasionally. However, in terms of the number of fish species impinged, Pilgrim Station displays a greater variety than most other power plants in the Gulf of Maine area (Bridges and Anderson, 1984a), perhaps because of its proximity to the boreal-temperate zoogeographical boundary presented to marine biota by Cape Cod.

Monthly intake water temperatures recorded during impingement collections at Pilgrim Station were above normal during 1999 compared to the mean monthly temperatures for the 10-year interval 1990-1999 (Table 7). Overall 1990/1995/1997/1998/1999 displayed relatively warm water temperatures, 1987/1989/1991/1994/1996 were average years, and 1988/1992/1993 were cold water years. Pilgrim Station intake temperatures approximate ambient water temperatures. A dominance of colder water species (i.e., Atlantic silverside, winter flounder, and rainbow smelt) appeared in impingement collections during 1999, with the warmer water species Atlantic menhaden being caught in exceptionally high numbers late into the fall season, including December.

Table 7. Monthly Means of Intake Temperature (°F) Recorded During Impingement Collections at Pilgrim Nuclear Power Station, 1990 - 1999

Month	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	(X̄) 1990-1999
January	39.1	40.5	38. 8	37.1	41.1	28.2	37.3	36.3	37.6	38.4	37.4
February	39.0	39.6	37.4	35.8	36.6	29.2	32.2	34.3	36.7	38.1	35.7
March	38.5	40.1	39.2	37.4	39.5	30.9	35.2	36.5	39.7	37.9	37.6
April	45.7	45.2	44.1	41.8	41.7	37.9	41.2	43.4	44.5	46.6	43.7
May	50.8	51.4	47.8	48.6	48.8	44.3	48.3	51.6	53.8	50.9	49.7
June	59.2	52.6	58.7	56.0	56.4	45.2	52.7	54.2	60.1	53.6	55.1
July	59.4	57.5	60.6	56.1	58.1	56.8	56.8	55.9	61.7	61.2	58.4
August	61.9	57.7	62.3	60.8	67.3	59.3	53.7	60.4	58.5	64.7	60.8
September	61.5	60.0	61.7	62.9	62.4	60.4	50.5	57.4	58.6	63.3	60.4
October	55.7	54.4	55.7	57.5	57.9	63.3	43.9	53.8	52.0	55.1	55.3
November	49.6	49.9	50.8	49.6	50.6	55.8	39.9	50.8	47.9	47.9	49.6
December	44.3	45.3	41.0	45.2	40.3	44.9	34.5	43.1	41.7	42.9	42.5
Mean											48.8

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4.2. Invertebrates

In 375.5 collection hours, 685+ invertebrates of 18 species (Table 8) were recorded from Pilgrim Station intake screens between January-December 1999. The annual collection rate was 1.82+ invertebrates/hour. Ctenophores dominated, being caught only in March. Sevenspine bay shrimp (Cragon septemspinosa) were captured in greatest numbers in November/December and were 71% of the enumerated catch. Common starfish (Asterias forbesi) and green crab (Carcinus maenus) represented 8.0 and 6.1%, respectively, of the total invertebrates impinged. Unlike the fishes, the 1987 and 1988 invertebrate impingement rates were comparable to 1989-1999 despite relatively low circulating water pump capacity available in 1987 and 1988.

A noteworthy occurrence was the collection of so many blue mussels during 1986-1989. This could be an effect of the Pilgrim Station outage during the late 1980s (reduced power level in 1989) which precluded the use of regular thermal backwashes for macrofouling control and the migratory/adhesive abilities of mussels. In 1990 - 1999 several thermal backwashes were performed and blue mussel impingement was relatively minor for those years. During 1999 aggressive biofouling control activities included three effective thermal backwashes during the months of, July, September and November.

Common starfish were the third most abundant invertebrate impinged, peaking in July. Green crabs were fourth, being most represented in December. Eighteen specimens of the commercially important American lobster were captured in 1999 ranking them seventh. This equals 420 lobsters impinged on an annual basis at 100% operation of Pilgrim Station, under conditions at the times of impingement. This is considerably less than in 1991-1994 and is more comparable to the number of lobsters impinged in most previous years. The lobsters ranged in size from 28-63 mm carapace length and were impinged mostly in September.

Table 8 - Monthly Impingement for All Invertebrates Collected from Pilgrim Station Intake Screens, January - December 1999

Species	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Ctenophores			*										*
Sevenspine bay shrimp	26	39	67	95	2						105	154	488
Common starfish			1		1		40	8				5	55
Green crab		1		1			8	8	1	3	3	17	42
Longfin squid							2	21	9				32
Rock crab	1	1	1	1			3				4	10	21
American lobster			1	1	2		5	3	2	1	2	1	18
Nereis sp.	10	6			1								17
Nemertean		3											3
Axius serratis		1											1
Glycera sp.								1					1
Green sea urchin							1						1
Horseshoe crab										1			1
Lady crab				1									1
Nephthyidae		1											1
Nudibranch											1		1
Stomatopoda												1	1
Tunicate													
Totals	37	52	70+	99	6	0	59	41	12	5	115	189	685+
Collection Time (hrs.)	39	26	34	45	10	16	20	24	22.5	21	47	71	375.5
Collection Rate (#hr.)	0.95	2.00	2.06+	2.20	0.60	0.00	2.95	8.25	0.53	0.24	2.45	2.66	1.82+

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Approximately 1,378 pounds of mixed algae species were recorded during impingement sampling, for a rate of 3.67 pounds/hr. This equates to 16 tons of algae annually on Pilgrim intake screens. This rate is considerably higher than the low flow 1984, and 1988 outage years, comparable to 1989-1992 and 1994-1998, and much lower than 1993 which experienced very adverse meterological conditions of high winds and coastal storms (particularly in December).

4.3 <u>Fish Survival</u>

Fish survival data collected in 1999 while impingement monitoring are shown in Table 9. Continuous screenwash collections provided the greatest numbers of fishes and revealed an overall survival rate of approximately 84%. Fishes collected during static screen washes fared worse showing a survival rate of 37%. The lower initial survival rate for static screen washes was influenced by the low initial survival of Atlantic menhaden and Atlantic silverside which were both impinged in abundant numbers. As illustrated in 1993-1999, fishes have a noticeably higher survival rate during continuous screen washes because of reduced exposure time to the effects of impingement. However, reduced intake currents in 1984, associated with limited circulating water pump operation, may have been a factor in higher static wash survival then because of less stress on impinged individuals; although this wasn't apparent from 1987 and 1988 limited pump operation results.

Among the ten numerically dominant species impinged in 1999, six demonstrated overall initial survival rates of 50% or greater. Grubby showed 90% survival, winter flounder 95%, alewife 21%, Atlantic silverside 56%, windowpane 72%, rainbow smelt 21%, Atlantic tomcod 56%, Atlantic menhaden 69%, red hake 32%, and blueback herring 23%. Some of these high survival percentages may be explained by the robustness and durability of some of the species that were sampled during screenwashes.

Table 9 – Summary for the Fishes Collected During Pilgrim Station Impingement Sampling, January – December 1999. Initial Survival Numbers are Shown Under Static (8-hour) and Continuous Wash Cycles

	Number Collected		Number Surviving		Total Length (mm)	
Speicies	Static Washes	Cont. Washes	Static	Cont.	Mean	Range
Atlantic menhaden	693	1,038	263	923	78	36-137
Atlantic silverside	300	292	78	254	97	69-155
Rainbow smelt	6	56	2	11	88	59-186
Winter flounder	23	35	21	34	80	42-158
Grubby	25	15	21	15	74	45-140
Blueback herring	24	15	0	9	80	51-112
Alewife	19	15	0	7	83	46-157
Windowpane	14	11	9	9	70	45-266
Red hake	14	8	5	2	88	69-170
Atlantic tomcod	3	15	1	9	155	57-240
Lumpfish	7	2	6	2	58	34-80
Tautog	5	4	5	4	74	60-92
Atlantic moonfish	0	8	-	1	47	40-54
Northern pipefish	2	5	1	5	120	76-157
White perch	4	3	1	3	124	94-148
Butterfish	1	5	1	3	47	37-63
Cunner	4	1	2	0	90	46-148
Striped killifish	2	3	2	3	77	71-82
Silver hake	3	1	0	0	92	68-105
Striped searobin	3	1	2	1	73	41-110
Atlantic herring	2	1	0	0	53	30-94
Mummichog	2	1	2	1	73	63-80
Atlantic cod	0	2	-	1	111	78-144
Fourspot flounder	2	0	1	-	88	75-101
Northern searobin	2	0	0	-	79	45-113
Pollock	1	1	0	0	112	60-163
Yellowtail flounder	2	0	1	-	95	85-105
Black sea bass	1	0	0	-	60	60
Longhorn sculpin	1	0	1	-	275	275
Radiated shanny	1	0	1	-	125	125
Rock gunnel	1	0	1	-	152	152
Smallmouth flounder	0	1	-	1	59	59
Threespine stickleback	0	1	-	1	58	58
All Species	1,167	1,540	427	1,299		
Number (% Surviving)			(36.6)	(84.4)		

SECTION 5

CONCLUSIONS

1. The average Pilgrim impingement rate for the period January-December 1999 was 7.21 fish/hour.

2. Thirty-three species of fish were recorded in 375.5 impingement collection hours during 1999. In 1989-1999 several times the number of fishes were sampled as compared to 1984 and 1988, despite more collection hours in 1984 and an average number of hours in 1988. This illustrates the importance that the number of circulating pumps operating has on the quantity of impinged organisms. Substantially less collecting hours for portions of 1987 precluded its comparison with other years.

3. At an assumed 100% yearly operation the estimated maximum January-December 1999 impingement rate was 63,160 fishes. This projected annual fish impingement rate was much higher than most recent years' rates and comparable to 1994 and 1995, because of large impingement incidents during these years.

4. The major species collected and their relative percentages of the total collections were Atlantic menhaden, 63.9%; Atlantic silverside, 21.9%; rainbow smelt, 2.3%; and winter flounder, 2.1%.

5. The peak Atlantic menhaden impingement collections occurred during September/ November when 76% of the annual catch for this species occurred.

6. Monthly intake water temperatures, which generally reflect ambient water temperatures, were higher for 1999 than the ten-year monthly averages for the period 1990-1999, with the exception of November, which was normal.

7. The hourly collection rate for invertebrates was 1.82+. Ctenophores dominated in March. Sevenspine bay shrimp were second because of relatively large late fall collections. Common starfish and green crab were 8.0 and 6.1% of the enumerated catch. Eighteen American lobsters were collected which equates to a potential 1999 impingement of 420 lobsters.

8. Impinged fish initial survival was approximately 37% during static screen washes and 84% during continuous washes for pooled species. Of the ten fishes impinged in greatest numbers during 1999, six showed initial survival rates of 50% or greater.

SECTION 6

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IV. P.A.T.C. MINUTES

The Commonwealth of Massachusetts

Division of Marine Fisheries
50A Portside Drive
Pocasset, MA 02559

PHILIP G. COATES
DIRECTOR

617-727-0394
508-563-1779
Fax: 508-563-5482

MEMORANDUM

TO: Members of the Administrative-Technical Committee, Pilgrim Power Plant Investigations
FROM: Brian Kelly, Recording Secretary
SUBJECT: Minutes from the 92nd Meeting of the A-T Committee
DATE: December 20, 1999

The 92nd meeting of the Pilgrim A-T Committee was called to order by Chairman Szal at 9:45 AM on September 29, 1999, at Entergy's Pilgrim Nuclear Power Station in Plymouth.

Minutes of the 91st Meeting

The minutes of the previous full A-T meeting (June 23, 1999) were accepted unanimously.

Pilgrim Station Status Update

Bob Anderson noted there have been a couple of small outages this year since the scheduled refueling outage in June (one in early August and one in late September). Entergy believes that the Maximum Dependable Capacity (MDC, an index of plant operational status that approximates thermal loading into the receiving waters of the marine environment) for 1999 will be close to 75% by the end of the year, even with the planned and unplanned outages. The Nuclear Regulatory Commission (NRC) license for Pilgrim Station expires in 2012, which Entergy will try to extend. Gerry Szal suggested that Entergy look at installing variable speed pumps when the present circulating water pumps need replacement, as it would help in flow reduction and concomitant entrainment mitigation. Jack Alexander said his company will look into this during their 316b demonstration. Bob Lawton noted that winter flounder entrainment in 1999 may be substantially lower than past years of station operation because both circulating water pumps were off during the refueling outage (May 11 - June 11). It remains to be seen what will happen regarding winter flounder entrainment and Entergy's response in the spring of 2000.

Bob Anderson noted there was a major Atlantic menhaden impingement event on September 18 of 5,000+ 75-98 mm juvenile fish, which prompted the plant's contingency notification plan. There were also smaller menhaden impingements in mid-August and early September. This seems to be the result of a dominant year class of menhaden, as other power plants along the coast have also experienced high late-summer impingements. Entrainment of menhaden larvae also was relatively high at Pilgrim Station in late September.

Jack Alexander noted Entergy may bid to buy other nuclear plants in New England, and may be petitioning for licensing to build new combined cycle units at Pilgrim Station in the future. Entergy may consolidate certain functions (such as their environmental group) as they purchase other nuclear and/or fossil fuel plants in the area.

Year 2000 Benthic Monitoring

Jack Paar stated that Committee members had a limited opportunity to comment on ENSR's draft of their final benthic report on 18 years of algal monitoring data at Pilgrim Station. The Committee asked Bob Anderson to give its members more time to edit the report and for ENSR to incorporate Committee members' comments into the final draft. This was agreed upon. This report will be published as part of the multi-series reports. Jack noted that the findings of this report are important, for it documents that Pilgrim's benthic impact is minimal.

A lengthy discussion ensued regarding what benthic studies, if any, to pursue at Pilgrim Station in the coming years. There were concerns expressed that any future operational/site changes by Entergy at the station were likely to change the benthic impact. Jack Alexander suggested that the company once each permit cycle (every five years) conduct a seasonal (spring/summer/fall) qualitative benthic algal survey and benchmark it against ENSR's last report. Also, if there is a proposed change in flow, Entergy would do this study as part of its 316 process. Jack Alexander proposed doing this study two years from now (year 2002) - an idea which the Committee endorsed. He mentioned that this contract would go out to bid and not be sole source. Bob Lawton had concerns regarding the future continuity and uniformity of this study and suggested that ENSR provide initial assistance to whomever does the study again to assure a smooth and consistent transition in data collection.

Jack Alexander would like to see more diversity in the Pilgrim A-T Committee composition (e.g., flounder experts, other company environmental personnel, and perhaps members of academia). There was a lengthy discussion regarding the FACA (Federal Advisory Committee Act) and the role of the Pilgrim A-T Committee. Chairman Szal will look for comments from Committee members regarding the issues brought up at the A-T meetings. Recommendations are appropriate and a consensus would be sought. However, there will no longer be voting at the A-T meetings, pending review from the EPA law staff regarding this issue.

Year 2000 Marine Fisheries Monitoring

Bob Anderson reported that winter flounder stock enhancement to offset plant impact is a present goal of Entergy. However, building a flounder hatchery at this time is premature. Jack Alexander noted that the company is very interested in the hatchery concept, and that they have expert advice. Further, the technology to raise flounder has been developed. The first big hurdle is to determine the survival rate of hatchery-reared flounder when placed out in the local environment. Will they be as þfitþ as wild fish? To this end, a pilot study is being contemplated, which must also consider: (1) finding the proper release sites to stock them and (2) will the fish imprint, i.e., show an affinity to the area they are stocked in? He mentioned that Entergy wishes to tag the hatchery fish, release them, and follow up with a couple of years of field monitoring. The company wants to target winter flounder to mitigate for power plant entrainment.

Bob Lawton began the discussion regarding winter flounder studies at Pilgrim for year 2000. Mike Scherer of MRI was desirous of a third year of an area-swept abundance estimate for the RAMAS model. That third data point will be available when the recent 1999 flounder data are analyzed. There was much discussion on the population assessment models being considered, including the Empirical Transport model, with its larvae to larvae approach and the biological significance of reducing a certain percentage of the source larval pool. There were additional concerns regarding the complexity of the RAMAS model, and the assumptions behind the Adult Equivalent model. Jack Alexander noted that Entergy's perception is the area-swept approach has been used and its utility is questionable; an optional consideration would be the larvae to larvae approach. The Committee realized a special meeting of the fisheries subcommittee was required to discuss these issues and to make recommendations for both flounder field studies and what population model or models should be used to assess plant impact for year 2000. At this meeting, Carolyn will request the presence of either John Boreman or Steve Cadrin of NMFS for their population dynamics expertise. Bob Maietta will assist in setting up the subcommittee meeting for mid-October at Pilgrim Station. Entergy will be represented at this meeting.

Jack Alexander asked what could the company do as the regulated party regarding winter flounder impacts, besides contolling the timing of refueling outages. In the discussion that followed, it was mentioned that the upcoming 316B Demonstration for Pilgrim Station should identify other Best Technology Available (BTA) for mitigative actions which the company could take. Dave Webster noted that all power plants should employ BTA. He will listen to A-T Committee recommendations, especially regarding entrainment and impingement mitigation using BTA. Jack Paar noted that EPA does not want power plants to pursue expensive studies that won't answer the questions addressed; he would rather see money effectively channeled into BTA, including restoration projects.

The Committee recommended that impingement and entrainment monitoring at Pilgrim Station for year 2000 remain the same as this year.

Restoration Projects

The fisheries subcommittee had recommended that smelt restoration in the Jones River continue. Jay Scheffer noted that Entergy will fund $1,000 for this work in year 2000.

Regarding Entergy's flounder propagation proposal, Bob Anderson stated that the initial objective of their pilot study is to see if the hatchery concept is feasable, with the ultimate goal being to replace the Equivalent Adult flounder lost to entrainment at the plant. Entergy initially plans on raising approximately 15,000 juvenile fish to six months of age before their release to improve survival. Committee members requested that Bob Anderson investigate the question of when winter flounder imprint to their natal waters and what permits would be needed at the state and federal levels to conduct this proposed pilot study.

Bob Lawton noted that the company granted $45,000 in compensation for the 1997 loss of ~45,000 winter flounder which will be used for anadromous fisheries restoration and stormwater runoff treatment projects. He then asked what would be Entergy's compensation for the 1998 mortality of ~77,000 winter flounder. Bob Anderson replied that in the company's opinion the flounder hatchery demonstration and any identified BATs in their 316B Demonstration document as requested will be the company's response to the 1998 mortality. Gerry Szal mentioned that the A-T Committee does not yet know if they are þbuyingþ into the hatchery idea to offset plant impact, but it seems to be a positive idea. Bob Anderson noted that Entergy will let EPA know the status of the 316 demonstration in January 2000, which will include BAT potential technologies.

The meeting adjourned at 1:45 P.M., wherein members went to observe MRI's entrainment sampling at the Pilgrim discharge canal.

PNPS 92nd A-T Committee Meeting Attendance
September 29, 1999

Gerald Szal, Chairman	Mass. DEP, Worcester
Robert Anderson	Entergy
Carolyn Griswold	NMFS, Narragansett
David Webster	US EPA, Boston
Nick Prodany	US EPA, Boston
Robert Lawton	Mass. DMF, Pocasset
Jack Alexander	Entergy
Robert Maietta	Mass. DEP, Worcester
Jack Parr	US EPA, Lexington
Jay Scheffer	Entergy
Matt Camisa	Mass. DMF, Pocasset
Brian Kelly	Mass. DMF, Pocasset Recording Secretary