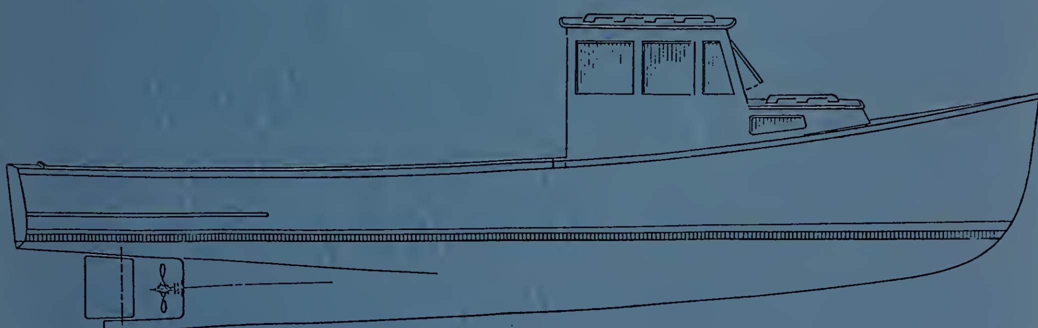
Annual Report 1983

Monitoring the Marine Environment of Long Island Sound at Millstone Nuclear Power Station

Waterford, Connecticut



Northeast Utilities Service Company

March, 1984

PAUL M. JACOBSON

MONITORING THE MARINE ENVIRONMENT OF LONG ISLAND SOUND AT MILLSTONE NUCLEAR POWER STATION WATERFORD, CONNECTICUT

ANNUAL REPORT
1983

Northeast Utilities Service Company
March 1984

DEDICATION

During 1983, the NU Environmental Laboratory suffered the tragic loss of Bonde Johnson, the laboratory manager, and Susan Hobbs, a member of the Fish Ecology group. Both Bonde and Susan were keenly aware of the importance of the work being conducted at NUEL. As laboratory manager, Bonde actively supported our efforts to obtain sound scientific data. His interest was reflected in his many suggestions, which frequently improved our programs and the quality of the data. Susan's infectious enthusiasm and genuine concern for the environment in which we all live was a constant source of inspiration for the people around her.

This report is dedicated to the memories of Bonde and Susan as a lasting tribute to the friendships made and the work accomplished at NUEL. They shall be missed by all who knew them.

EXECUTIVE SUMMARY

Table of Contents

EXECUTIVE SUMMARY

The Millstone Nuclear Power Station (MNPS) is located on the north shore of Long Island Sound in Waterford, Connecticut. The station consists of two operational units with a combined cooling water flow of 2,155 cfs, and a third unit under construction.

Extensive studies of the potential impact of MNPS on Long Island Sound were initiated in 1968. They have been modified and updated to assure that the best currently available monitoring procedures were used. This report presents 1983 results and provides comparisons with previous years as a basis for impact assessment.

ZOOPLANKTON ECOLOGY

The species composition and abundance of zooplankton collected at inshore and offshore stations during 1983 were examined. More than 80 taxa were identified during 1983 and a total of 130 since 1970. Six major groups, copepods, cirripedians, gastropods, decapods, cladocerans and amphipods accounted for more than 99% of the individuals collected in 1983, and at least 96% since 1970. Copepods contributed more than 88% of the total in 1983; this group has consistently accounted for over 79% of the total in each year since 1976. The abundances of *Acartia tonsa* and *A. husonica*, the two dominant copepods were higher in 1983 than in any of the previous eight years.

During 1983, as in all previous years, distinct winter-spring and summer-fall communities were identified at MNPS; these were similar to zooplankton communities in LIS and BIS. Inshore (Entrainment), offshore (Niantic Bay), and diel differences in zooplantkon densities during 1983 and since 1970 were attributed to natural variation since similar patterns have been observed in other areas of Long Island and Block Island Sound.

As a result, we conclude that any changes observed in the zooplankton communities over the past twelve years were natural and not due to operation of Millstone Nuclear Power Station.

ROCKY SHORE SURVEY

Rocky shores in the Millstone Point area support a diverse and abundant community throughout the year. From October 1982 through September 1983, a total of 126 species of algae were found in the qualitative collections, including 56 species of red algae, 33 browns, and 37 greens. In both numbers and relative proportions, this flora is similar to those reported since 1979.

Ascophyllum growth studies from the past growing season show the same trends seen in previous years. Plants from a tagged population 70 m from the MNPS discharge grew longer than did plants at two reference stations (2-5 km away). Differences in seasonal growth rates between experimental and reference plants indicate that the thermal addition from the power plant enhances growth in spring and autumn, but not summer.

All quantitative studies to date represent the local rocky intertidal community as being in a state of dynamic equilibrium, with processes that remove plants and animals (e.g. storms, senescence, predation) balanced by settlement and growth of new individuals. Differences in species occurrence and abundance among sites were attributed primarily to variable degree of exposure to prevailing winds and waves. Temporal variability was evidenced as seasonal changes in abundance, particularly of barnacles and ephemeral algae. The similarity of community parameters between this and past years indicates that detrimental changes due to MNPS operation did not occur in 1983.

BENTHIC INFAUNA

The sediments and benthic infauna of three intertidal and four subtidal sand stations were sampled in September and December 1982 and March and June 1983. The temporal and spatial intertidal sedimentary characteristics observed during 1983 were consistent with results obtained in previous years. Sediments ranged from medium to coarse sands and generally contained low amounts of silt/clay and organic matter. Subtidal sediments were composed of fine to coarse sediments that contained variable amounts of silt/clay and organic matter. During

1983, sediments at JC and EF were similar to previous years while those at GN and IN exhibited notable differences in grain size (GN) or silt/clay (IN). Since the GN station is located well beyond any potential power plant influence, the changes in sediment size observed during 1983 were assumed to be natural. At IN, the observed increase in silt/clay content was attributed to the erosion of soils used during construction of the Unit 3 Intake structure.

Intertidal and subtidal communities were dominated by annelids (i.e., polychaetes and oligochaetes) both in terms of species and numbers of individuals. Community parameters (density and numbers of species) at intertidal and subtidal stations were well within the range of values observed over the last several years. In addition, the seasonal values of these parameters exhibited patterns that were consistent with those observed in the past. Infaunal species composition during 1983 was also consistent with previous years. The most notable changes in dominance occurred at subtidal stations, where both *Polydora caulleryi* and *Exogone hebes* were present in much higher abundance than in previous years. The increased abundances of *P. caulleryi* at subtidal stations was considered natural, since these increases occurred at stations both within and beyond the potential influences of the Millstone Point Station. While densities of *Exogone hebes* were higher at all stations during 1983, the unusually high density observed at IN may have been due to increased silt/clay caused by construction activity and erosion of soils at the Unit 3 Intake.

During 1983, spatial differences observed among infaunal communities at our sampling sites and the temporal variations in abundance and numbers of species were typical of those observed previously. Natural, physical processes were apparently most responsible for the different spatial distribution of species and temporal variations exhibited by the communities located within and beyond the potential influence of the Millstone Station. Although some changes in community parameters were observed in 1983 relative to previous years, (some of apparent natural origin and some attributed to Unit 3 construction activities) there were no short-term or long-term changes in density or numbers of species nor any shifts in community composition that could be attributed to the operation of Millstone Units 1 and 2.

LOBSTER POPULATION DYNAMICS

The American lobster is the most valuable commercial species in Connecticut waters and record landings were reported for 1983. The lobster population in the Millstone Point area was sampled from May through October 1983 using wire traps set at three locations; lobsters were later tagged and released at the site of capture. Size frequencies, sex ratios, growth rates, molting and movement patterns, and population size were estimated to evaluate the potential impacts of the operation of the Millstone Nuclear Power Station.

The 1983 total catch and catch per unit effort (CPUE) were within the range of values reported since 1978, when wire pots were first used. Catch per 100 pots was 146 for all sizes of lobsters and 15 for legal-sized lobsters(≥81 mm carapace length). The percentage of legal-sized lobsters (10.1%) during 1983 was greater than that of all previous years when wire pots were used. The higher percentage of legal-sized lobsters in our catch, and the record lobster landings reported for Connecticut waters in 1983, was the result of a strong prerecruit size class (one molt from legal-size) observed in the 1982 catch. Several factors were found to cause variability in the catch over the sampling period. These factors include the seasonal change in water temperature, the variability among pots (within and among stations), the amount of time between pot hauls (soaktime), and the abundance of crabs and fish in the pots.

The 1983 values for size structure, sex ratios, growth per molt, and percentage of culls were within the range reported in previous years and within the ranges reported along the northeast coast of North America. A higher percentage of egg-bearing females was found in 1983 than in any year since wire pots were first used. A peak molting period occurred in early summer at water temperatures between 13-16°C and a smaller secondary peak occurred in autumn at water temperatures of about 16°C.

The total population size, (33,205), using the Jolly-Seber estimation technique, was within the range reported since 1975. The estimated number of lobsters impinged at Units 1 and 2, (1496), was within the range of previous years. Survival of impinged lobsters was greater in 1983.

FISH ECOLOGY

Of the numerous finfishes found in MNPS impingment, plankton, trawl and seine samples, nine species were discussed in detail. Young sand lance, sticklebacks and silversides were permanent residents of the Millstone Bight that prefer the shore-zone in summer and other nearby habitats in winter. Tomcod, grubby and windowpane were permanent residents that were available to capture year-round, although they were slightly more abundant in some seasons than others. Cunner and tautog were also year-round residents, but become torpid in winter making them less susceptible to capture. Anchovies were seasonal residents that were sporadically present in monitoring collections.

Regression models, which included harmonic and autoregressive terms, were used to forecast the 1983 abundances of selected species. Models were fit to historical log-transformed finfish catches. Out of 56 models examined, 41 reliably described historical patterns (R^2 greater than 0.70). The highest R^2 values were associated with models that described very seasonal data. All models, however, were used to make forecasts for 1983. The actual 1983 data were compared to the forecasts to assess 1983 fluctuations, given historical patterns. Most of the log-transformed 1983 catches did not exceed the forecast 95% confidence limits. Of those that did, only tomcod catch fell below the lower limit because its 1983 peak occurred later in the year than expected. The data for anchovies, windowpane and cunner were above the upper limit. These results were interpreted to mean that 1983 log-transformed finfish catches were within expected limits and did not reflect effects due to power plant operations. This work provides the basis for assessing impact under 3 unit operation.

WINTER FLOUNDER POPULATION STUDIES

The winter flounder (Pseudopleuronectes americanus) is an important sport and commercial finfish in Connecticut and is the most abundant demersal fish in the Millstone area. Special emphasis has therefore been placed on understanding the dynamics of the winter flounder stock spawning in the nearby Niantic River.

Results of studies conducted during 1983 were presented and, whenever possible, compared to previous years. Included were the population abundance survey in the Niantic river; age and growth, survival, reproduction, and movements of adults; early life history studies; impingement and entrainment at MNPS; and models of fluctuations in the catch of winter flounder.

An estimated 41,980 ± 15,564 winter flounder larger than 20 cm were in the Niantic River during the spawning period. The mark and recapture data were examined for potential sources of bias or error; the abundance estimate was relatively unbiased and precision was good. Estimated abundance declined 28% from 1982 and 15% from 1981, but remained larger than during the late 1970's. The number of small winter flounder ($<$ 20 cm) decreased more than a third from 1982 but this difference may have been partly related to changes in survey design.

The median was chosen as the most representative catch statistic for trawl CPUE during the surveys. Standardization of trawl distance and number of tows allocated by station reduced the variability of the 1983 data compared to previous years. The annual median CPUE and abundance estimates followed somewhat different trends. The largest difference occurred in 1982, which had an abundance estimate similar to 1981 but a significantly smaller median catch.

Spawning of winter flounder began in January or early February under the ice in the upper river; little spawning apparently took place outside of the river. Adult sex ratios have been 1.21 to 2.03 in favor of females since 1977. The median size of mature females was estimated as 25.1 cm. Annual estimates of reproduction showed that female spawners and egg production peaked in 1982 with the 1983 and 1981 estimates comparable in magnitude.

Scales were examined and measurements made to annuli to calculate growth rates. Females age 3 and older were significantly larger than males. Growth of Niantic River fish was slower during their first 2 years of life than for most other nearby populations, but they caught up to or surpassed other stocks at age 3 and older. The von Bertalanffy growth parameters, which represented theoretical population growth, were determined and were similar to those of other New England stocks.

Movements, as determined from disc-tagged winter flounder, were similar to those noted in 1982. More females tended to leave local waters than males and most movement out of the study area was to the east. About 1.5 times as many tag returns were received from the sport than the commercial fishery.

Winter flounder larvae had a successive temporal pattern of occurrence in the study area. Yolk-sac larvae were collected almost exclusively in the Niantic River. Larvae were flushed seaward into Niantic Bay primarily during the period of first feeding to the start of fin ray development. Larvae transforming into juveniles were concentrated in Niantic Bay and the lower river. The estimated developmental time in 1983 from hatching to transformation was approximately 80 days.

Larvae with developing or completely developed fins were collected at the mouth of the Niantic River in greatest abundance during a late flood tide. Many of these fish apparently used tidal currents to re-enter and remain in the river. Medusae of the lion's mane jellyfish were identified as a potentially important predator of larvae, particularly in the upper river.

Abundance and distribution of post-larval juvenile winter flounder were studied in detail for the first time in 1983. Juveniles were most abundant at the lower river station. Growth of juveniles was examined at that station and mortality was calculated. A daily total mortality rate of 2.97% was derived, which was equivalent to an average monthly survival of 40.3%.

The estimated annual impingement at MNPS during 1982-83 was the second highest recorded during the past 11 years. A large increase occurred in the impingement of specimens smaller than 15 cm, which made up 52% of the total. Most impingement occurred from December through

April. The sex ratio of impinged winter flounder (1.86:1 in favor of males) was the opposite of that seen in the Niantic River. Males may have had a lesser ability then females to escape intake currents at MNPS.

Winter flounder larvae were entrained at MNPS from late February through late June with highest densities in April and May. The 1983 entrainment estimate was the second highest since 1976, but due to overlap in confidence intervals, no significant differences were found among years. Data from an entrainment survival study indicated that a large portion of older larvae could survive entrainment; 15% of those entrained during 1983 were in these stages of development.

Fluctuations in the catch of winter flounder in several monitoring programs were analyzed using time-based harmonic regression models. The entrainment and impingement programs provided data which led to reasonably well-described models; forecasted catches for 1982-83 were similar to those actually made. In contrast, models developed from the trawl monitoring program data were inadequate. This may have been due to the large variability in the trawl catches or because the winter flounder has fluctuations in abundance greater than the 6-year period examined.

HEAVY METALS

Concentrations of heavy metals (e.g., copper, zinc, iron, chromium and lead) in seawater and in shellfish tissue samples collected in the Millstone Point area were monitored five times (February, May, July, September and December) during 1983. Seawater and shellfish tissues were examined to detect any possible increases in metal concentrations resulting from passage of water through the cooling water system of the Millstone Nuclear Power Station.

The levels of dissolved metals in seawater samples taken during 1983 were similar to 1982. Quarry and plume waters were slightly enriched with dissolved Cu and Zn, although higher levels of Zn were not consistently found. Cooling water is evidently not an enriched source of the other metals.

In general, the levels of chromium, copper and zinc from Giants Neck, Fox Island and White Point were spatially uniform for each sampling date. There was no indication of excess metal burdens in oysters that grew near the cooling water outfall. Metal concentrations in oysters from the quarry (both those held in cages and those sampled from the natural population) were 1.5 or more times higher than levels in oysters from other cages outside the quarry. Mussels collected during 1983 at the Fox Island South station did not have mean concentrations consistently greater than the other two sampling stations. As was the case for oysters, then, there was no evident relationship between metal levels in mussels and proximity to the cooling water plume.

The heavy metal study has now been conducted for 13 years and results have been consistent. There have been no detectable increases in metal concentrations in the receiving waters or in shellfish growing outside the discharge quarry. Although levels of Cu and Zn have been higher in the thermal plume, increases have not been evident in the surrounding waters. Higher concentrations of heavy metals have occurred in shellfish growing within the discharge quarry, but not in animals growing adjacent to the plume.

This study spanned the period of 1-unit and 2-unit operation and results have been the same. Given the natural fluctuations in heavy metal concentrations and the consistent results of our studies during 2-unit operation, it is unlikely that any detectable increases in the receiving waters or in the tissue of local shellfish populations will occur once Unit 3 becomes operational.

OSPREY

The American osprey (Pandion haliaetus) returned and successfully produced six fledgling from the 2 active nests located on the power plant site. The number of young produced at Millstone nesting sites during 1983 was the highest total recorded since 1969 when observations were first begun. Total number of young produced throughout the State in 1983 was also slightly higher than any year since 1969.

A total of five nesting platforms are now located on the Millstone site, two of which were erected during 1983. The new platforms are similar to those erected by the State of Connecticut; the new platforms were attached to the top of a 14 foot pole rather than the 30 foot pole used in previous years.

ACKNOWLEDGEMENTS

The following report was prepared by the Environmental Laboratory staff (NUEL) of Northeast Utilities Service Company. All contributors to this report are acknowledged below, according to their respective disciplines.

Laboratory Manager:	Paul M. Jacobson	
Secretarial Support:	Dian Audoin	
Benthic Ecology:	Jeffery Blonar	Donald Landers
	Bette Fields	Richard Larsen
	James Foertch	Douglas Morgan
	Raymond Heller	Henry Paul
	Dr. Milan Keser	Joseph Vozarik
Fish Ecology	David Balcom	David Dodge
	Linda Bireley	Christine Gauthier
	Robert Breeding	Dorothy Haggan
	John Castleman	Gary Johnson
	David Colby	JoAnne Konefal
	Donald Danila	Dale Miller
	Greg Decker	Robert Richter
Osprey:	Greg Decker	
Statistical Support:	Ernest Lorda	

NUEL Mailing address: Northeast Utilities Environmental Laboratory
P.O. Box 128,
Waterford, Connecticut 06385

Heavy Metals: Dr. Dennis Waslenchuck - Aquademia Inc.

Aquademia Mailing address:

Aquademia Inc.
50 Center Street
New London, Connecticut 06320

Special thanks are extended Dr. William Renfro, Director Environmental Programs Department (NUSCo) and the following members of the Millstone Ecological Advisory Committee for their critical review of this report:

Dr. Nelson, Marshall - University of Rhode Island,
Dr. William Pearcy - Oregon State University,
Dr. Saul Saila - University of Rhode Island,
Dr. John Tietjen - City College of New York.

Dr. Robert Wilce (University of Massachusetts) and Dr. Robert Whitlatch (University of Connecticut) are gratefully acknowledged for verifying species identifications and for providing critical reviews of early drafts of this report.

INTRODUCTION

Table of Contents

INTRODUCTION

Millstone Nuclear Power Station (MNPS) is located on the north shore of Long Island Sound (LIS) in Waterford, Connecticut. The station consists of three units located on a peninsula bounded by Jordan Cove on the east and by Niantic Bay on the west (Fig. 1). Millstone Unit 1, which commenced operation November 29, 1970, is a 652-MWe boiling water reactor (BWR). Unit 2 is an 870-MWe pressurized water reactor (PWR) that began operating October 17, 1975. Construction of Unit 3, a 1,150-MWe PWR, began in August 1974; commercial operation is planned for 1986.

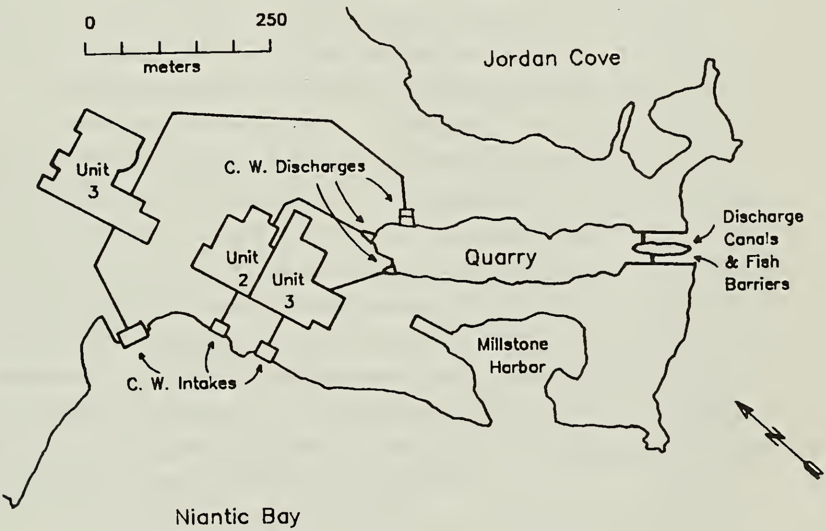


Figure 1. Site-plan of the Millstone Nuclear Power Station.

All three units use once-through condenser cooling water systems. Cooling water is generally drawn from depths greater than four feet below mean sea level by separate shoreline intakes located along Niantic Bay. The intake structures are typical of shoreline installations having coarse bar racks and traveling screens. The rated circulating flows for Units 1, 2 and 3 are 935, 1,220 and 2,000 cfs, respectively.

From discharge structures, the heated (25°F ΔT) cooling water flows through an abandoned granite quarry and into LIS through a channel equipped with a fish barrier.

The potential impact of MNPS on LIS has been the focus of study since 1968. The early biological investigations included exposure panel monitoring of woodboring and fouling communities, and surveys of the intertidal sand, rocky shore and shore-zone fish communities. The program scope increased considerably between 1970 and 1973 with the addition of heavy metal analyses of seawater and mollusc tissue, studies of pelagic (gill net) and demersal fishes (trawls), lobster and winter flounder (Niantic River) population studies, subtidal benthos and offshore ichthyoplankton (Battlle - W. F. Clapp Laboratories 1975; NUSCo 1975).

Studies of entrained plankton began in 1970 when Unit 1 became operational (Carpenter 1975); studies at Unit 2 began in 1975. To date, the routine monitoring and special investigations have covered nearly all aspects of plankton, including ichthyoplankton, phytoplankton, and zooplankton. Effects of chlorination and temperature on entrained phytoplankton were addressed as well as latent mortality of zooplankton after condenser passage (Carpenter et al. 1972; Carpenter et al. 1974). Emphasis was placed on entrained ichthyoplankton and the relative impact on fish populations in surrounding waters (NUSCo 1976, 1983).

Impingement monitoring began at Unit 1 in 1971 and at Unit 2 in 1975. The program scope has varied from counting all impinged organisms (1972-1976) to the 1982-83 program of three, 24-hour counts per week. Special studies have evaluated the effectiveness of several fish deterrent systems at the intakes, including acoustic stimuli, underwater lighting and a surface and bottom barrier (NUSCo 1976, 1979, 1980).

The potential effect of three-unit operation on selected species was also considered. Mathematical population dynamics models were developed for the Niantic River winter flounder population (Hess et al. 1975) and for the regional menhaden population (NUSCo 1976). These models incorporated the predicted entrainment and impingement losses over the life of the power station.

A number of hydrographic studies were conducted starting as early as 1966 (NUSCo 1976). Predictive models for 1, 2 and 3 unit thermal plumes were developed based on hydrographic measurements taken from field surveys. A tidal circulation model was developed, not only to predict current patterns and thermal distributions, but also to simulate dispersal and entrainment of winter flounder fish larvae (Hess et al. 1975).

As a result of these studies, the hydrographic and ecological characteristics of surrounding waters are described. Studies have been intensified and modified to provide the most representative data with respect to the changing concerns and state-of-the-art techniques. The present report provides results of 1983 studies and summarizes results of previous years as a basis for evaluating any long-term impacts. The report also satisfies certain license and permit conditions stipulated by the Connecticut State Department of Environmental Protection and the Connecticut State Power Facility Evaluation Council.

All ecological and hydrographic studies through 1976 were conducted by consulting laboratories, most notably Battelle - W. F. Clapp Laboratories, Woods Hole Oceanographic Institution (Entrainment, 1970-1975) and Normadeau Associates (Entrainment, 1975-76). In 1977, Northeast Utilities Service Company (NUSCo) began a phased, in-house takeover beginning with the entrainment and impingement programs. Some benthic and lobster program responsibilities were added in 1978. As of January 1980, all studies (excluding heavy metals) were being conducted and reported by NUSCo biologists based at the Northeast Utilities Environmental Laboratory. Critical scientific review is provided by a four-member, Ecological Advisory Committee (see acknowledgements) which has provided continuing support since 1968.

REFERENCES CITED

Battelle - William F. Clapp Laboratories. 1975. Annual Report on a monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Report No. 14592.

Carpenter, E.J. 1975. Integrated summary report to NUSCo on entrainment of marine organisms. Woods Hole Oceanographic Institution.

_____, S.J. Anderson, and B.B. Peck. 1974. Survival of copepods passing through a nuclear power station on the Northwest shore of Long Island Sound, U.S.A. Mar. Biol. 24:49-55.

_____, Peck, and S.J. Anderson. 1972. Cooling water chlorination and productivity of entrained phytoplankton. Mar. Biol. 16:37-40.

Hess, K.W., M.P. Sissenwine, and S.B. Saila. 1975. Simulating the impact of the entrainment of winter flounder larvae. In: Fisheries and Energy Production. S.B. Saila, ed. D.D. Health Co. Lexington, Mass. 298 pp.

NUSCo (Northeast Utilities Service Company). 1975. Summary report, Ecological and hydrographic studies, May 1966 through December 1974, Millstone Power Station.

_____. 1976. Environmental assessment of the condenser cooling water intake structures (316 (b) Demonstration), Vols. 1 and 2, submitted to the Connecticut State Dept. Environmental Protection.

_____. 1979. Annual report, 1978. Ecological and hydrographic studies, Millstone Nuclear Power Station. Prepared by Northeast Utilities Service Company.

_____. 1980. Annual report, 1979. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT.

_____. 1983. Annual report, 1982. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, CT.

ZOOPLANTKON ECOLOGY

Table of Contents

Section	Page

ZOOPLANKTON

INTRODUCTION

Zooplankton is composed of floating organisms that passively drift with the currents and includes a varied assemblage of animal forms ranging in size from 0.01 mm (single celled animals) to several meters (colonial hydrozoans). Representatives of nearly every invertebrate and several vertebrate phyla can be found in this assemblage at some time in their life history. Recruitment of individuals to the benthos is largely determined by survival of the organisms through their zooplanktonic stages (Hardy 1970; Cushing and Harris 1973; Bannister et al. 1974). Zooplankton, essential in marine and estuarine food webs, convert phytoplankton into animal protein, and are a principal food source for a variety of life forms including fish larvae (Garstang 1900; Lebour 1925; Schach 1939; Blaxter 1969; Kjelson et al. 1975) and planktivorous adult fish (Hardy 1970; Cushing and Harris 1973; Bannister et al. 1974). An understanding of zooplankton ecology is necessary to assess the potential impact of man's activities on marine and estuarine environments.

Six taxonomic groups dominate the larger zooplankton of eastern Long Island Sound (LIS): Copepoda, Cladocera, Cirripedia, Gastropoda, Decapoda, and Amphipoda. Copepods and cladocerans are crustaceans that are planktonic throughout their life cycles. The planktonic cirripedians are early developmental stages of barnacles, the adults of which are common to the rocky intertidal and subtidal zones of LIS. The gastropods include planktonic egg and veliger stages of local snails. The planktonic decapods consist primarily of crab zoea and megalops. The amphipods of LIS zooplankton are predominantly adult benthic amphipods that periodically enter the plankton through vertical migration or through uplifting by currents or turbulence.

The potential effect of zooplankton entrainment at the Millstone Nuclear Power Station (MNPS) is considered in this report. Entrainment is of concern due to the large volume of water used for condenser cooling. Entrained organisms are subjected to a rapid increase in temperature, mechanical stress and periodic exposure to biocides.

Initial zooplankton investigations were entrainment studies conducted at MNPS Unit 1 from November 1970 through June 1975 to determine zooplankton species composition, abundance and survival. Zooplankton has been sampled weekly at the MNPS discharges (Units 1 and 2) since July 1975. Offshore zooplankton has been sampled at several stations since 1973 (NUSCo 1974). In 1979 more frequent, year-round samples were collected at a single offshore station in mid-Niantic Bay (NUSCo 1980).

The objectives of the current monitoring program are to provide information on abundance of zooplankton around Millstone Point and in the cooling waters of MNPS, and to determine whether fluctuations in these populations are natural or power plant related. This report presents the results of the zooplankton program from October 1975 to September 1983.

METHODS AND MATERIALS

Zooplankton Laboratory Processing

Zooplankton was examined from the ichthyoplankton samples collected with 0.333 mm mesh plankton nets (see Methods and Materials of Finfish Ecology Section). The mesh size retained only the mesozooplankton, and allowed passage of smaller organisms.

Each week, one day and one night sample was processed for zooplankton from tows at the discharges (EN) and at Station 5 (NB) (Fig. 1). Whole samples or fractions were placed in a 6 liter reservoir, mixed with a slotted piston, and subsampled with a Stempel pipette. Aliquots were examined until 300 organisms were counted and identified to the lowest practical taxon.

Data Reduction and Statistical Analysis

Year designations refer to the sampling months of October of the preceding year through September of the designated year, e.g. sampling year 1983 included samples from October 1982 through September 1983.

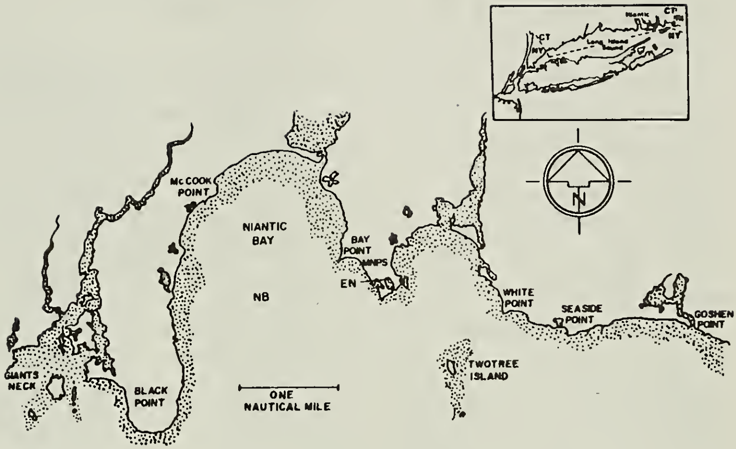


Figure 1. Location of Zooplankton sampling stations. EN - Discharge, NB - Station 5 (Niantic Bay).

Differences between weekly means of the (Ln + 1 transformed) zooplankton abundances in EN and NB samples and in day and night samples for each station, were calculated. These differences were examined using paired t-tests ($\alpha = 0.05$), to test the null hypothesis that the mean difference was zero. The data used in these paired t-tests were examined for normal distribution using the Kolmogorov-Smirnov test in the Statistical Analysis System programs (SAS Institute, Inc. 1982). Only taxa meeting the assumption of normality were used in subsequent analyses.

Harmonic regressions were used to model the log-transformed zooplankton abundance data from 1976 to 1983. The harmonic component used in these models described a seasonal abundance with a period of one year. The annual mean residual (deviation of the observed data from the model prediction) provided an indication of the yearly deviation from the model. Regressions having R^2 values approaching or greater than 0.50 were used.

RESULTS AND DISCUSSION

Taxonomic Composition of the Zooplankton Community

More than 80 taxa of zooplankton were identified at MNPS in 1983, and more than 130 taxa have been identified since the zooplankton program was initiated at MNPS in November 1970 (Appendix 1). The taxonomic composition of zooplankton collected at MNPS (Tables 1 and 2) was consistent with other studies in Long Island and Block Island Sounds (BIS) (Deevey 1952, 1956; LILCO 1983) and other North Atlantic coastal areas (Jeffries and Johnson 1973; Hulsizer 1976; Turner 1982).

Six major taxonomic groups contributed more than 99% to the zooplankton collected in 1983, copepods (88.7%), cirripedians (5.4%), gastropods (3.2%), decapods (1.2%), cladocerans (0.7%) and amphipods (0.5%). These six groups have comprised more than 96% of the zooplankton collected since 1976 (Table 3).

Two distinct zooplankton communities were identified at Millstone Point, and were identical to the winter-spring/summer-fall communities described by Deevey (1952, 1956) for LIS and BIS. The copepods *Acartia hudsonica*, *Pseudocalanus minutus*, *Temora longicornis* and planktonic larval stages of snails (Gastropoda) and barnacles (Cirripedia) dominated the winter-spring community. The summer-fall community was dominated by the copepods *Acartia tonsa* and *Pseudodiaptomus coronatus*, crab larvae and other decapods (NUSCo 1983). Because of the wide annual range of water temperature found in the MNPS area, approximately 0-21°C, few species of zooplankton occur throughout the year.

Copepoda

Copepods form the dominant zooplankton group in all the world's oceans and are the largest single group of protein producers (Thorson 1971). Copepods have constituted more than 79% of the zooplankton in the MNPS area since 1976 and more than 88% in 1983 (Table 3). The dominant calanoid copepods included *Acartia hudsonica*, *A. tonsa*, *Centropages hamatus*, *Pseudocalanus minutus* and *Temora longicornis*

Table 1. Zooplankton percent species composition (%), annual mean density (#/m³) and number of entrainment (EN) samples in which a taxon was found (N), in sampling year 1983 (October through September). Ranges of %, #/m³, and N, mean #/m³ and mean N are presented for the sampling years 1976 - 1982.

	1983			1976 - 1982				
Taxon	%	#/m³	N	Range of %	Range of #/m³	Mean #/m³	Range of N	Mean N
Acartia hudsonica	40.94	872.39	67	8.56 - 44.02	76.82 - 516.92	279.14	56 - 86	74
Acartia tonsa	27.32	582.24	63	15.57 - 34.26	182.80 - 431.16	282.35	53 - 82	73
Centropages hamatus	5.89	125.47	98	6.00 - 12.77	63.44 - 160.04	92.04	92 - 100	96
Cirripedia nauplii and cyprids	5.36	114.15	66	0.53 - 8.90	7.00 - 41.73	21.05	43 - 70	61
Pseudocalanus minutus	5.25	111.83	80	4.18 - 12.71	51.29 - 167.25	88.71	76 - 94	82
Temora longicornis	4.11	87.65	88	8.05 - 13.73	94.49 - 172.15	133.68	72 - 86	80
Gastropod eggs	1.94	41.35	70	1.74 - 6.66	22.36 - 72.30	47.24	64 - 89	77
Eurytemora herdmani	1.31	27.88	16	0.01 - 2.84	0.01 - 37.32	9.90	3 - 40	19
Gastropod veligers	1.28	27.26	81	0.52 - 2.44	6.87 - 21.93	15.59	46 - 75	63
Acartia spp. copepodites	0.81	17.28	64	0.33 - 8.04	3.82 - 83.86	25.16	25 - 100	58
Brachyuran zoea and megalopa	0.79	16.90	54	0.87 - 1.84	9.55 - 21.42	14.49	41 - 53	47
Pseudodiaptomus coronatus	0.74	15.83	49	1.10 - 4.56	12.87 - 40.98	21.05	40 - 71	55
Centropages spp. copepodites	0.71	15.08	54	0.38 - 1.88	5.02 - 22.89	14.63	46 - 87	68
Gammaridea	0.47	9.99	79	0.48 - 7.07	5.63 - 90.90	38.90	86 - 98	91
Eurytemora spp.	0.42	8.90	18	0.08 - 0.41	0.68 - 4.39	2.70	21 - 34	27
Podon spp.	0.35	7.36	29	0.09 - 0.46	1.14 - 4.73	2.91	10 - 30	16
Decapod larvae	0.30	6.39	52	0.21 - 0.78	2.75 - 9.75	5.69	40 - 63	52
Eurytemora americana	0.28	6.04	20	0.07 - 0.57	0.88 - 5.07	2.69	17 - 41	28
Harpacticoida	0.24	5.20	50	0.54 - 1.33	6.34 - 11.90	9.29	65 - 86	75
Evadne spp.	0.21	4.54	29	0.18 - 0.99	2.32 - 11.68	6.18	6 - 40	22
Labidocera aestiva	0.21	4.54	43	0.12 - 0.49	1.26 - 5.87	3.55	22 - 45	31
Centropages typicus	0.18	3.92	35	0.03 - 0.46	0.25 - 4.39	2.74	15 - 59	37
Chaetognatha	0.18	3.85	44	0.08 - 0.48	0.98 - 5.04	2.45	29 - 67	45
Tortanus discaudatus	0.13	2.81	22	0.12 - 1.47	1.38 - 19.32	5.31	7 - 66	36
Penilia avirostris	0.11	2.33	9	0.01 - 1.06	0.08 - 12.44	3.15	4 - 17	11
Mysida	0.11	2.27	37	0.21 - 0.66	2.39 - 9.01	4.94	47 - 64	57

Table 2. Zooplankton percent species composition (%), annual mean density (#/m³) and number of offshore (NB) samples in which a taxon was found (N), in sampling year 1983 (October through September). Ranges of % and #/m³, and mean #/m³ are also presented for sampling years 1976 - 1982.

	1983			1976 - 1982		
Taxon	%	#/m³	N	Range of %	Range of #/m³	Mean /m³
Acartia hudsonica	20.85	607.80	47	5.25 - 24.21	126.88 - 401.60	164.38
Acartia tonsa	35.46	1033.64	45	14.73 - 40.47	144.17 - 497.24	334.34
Centropages hamatus	9.98	290.88	73	7.13 - 12.53	77.65 - 190.43	120.13
Cirripedia nauplii and cyprids	2.57	74.96	48	0.56 - 8.92	7.32 - 87.15	40.16
Pseudocalanus minutus	7.68	224.00	64	3.52 - 17.95	38.38 - 187.83	119.98
Temora longicornis	10.71	312.20	66	12.12 - 28.30	126.88 - 567.67	272.83
Gastropod eggs	1.08	31.37	42	0.86 - 2.78	8.39 - 29.08	16.18
Eurytemora herdmani	1.31	38.11	20	0.06 - 1.46	0.54 - 15.28	4.67
Gastropod veligers	1.06	30.89	66	0.73 - 1.88	8.14 - 30.04	15.19
Acartia spp. copepodites	1.32	38.59	40	0.05 - 1.81	0.49 - 17.70	7.05
Brachyuran zoea and megalopa	1.29	37.54	48	0.52 - 1.96	5.66 - 25.58	15.52
Pseudodiaptomus coronatus	0.84	24.37	26	0.20 - 1.32	2.08 - 17.73	8.74
Centropages spp. copepodites	0.97	28.32	47	0.06 - 1.43	0.64 - 13.96	6.11
Gammaridea	0.16	4.71	24	0.02 - 1.45	0.25 - 14.20	5.21
Eurytemora spp.	0.28	8.17	13	0.02 - 0.24	0.22 - 4.73	1.40
Podon spp.	0.89	25.95	30	0.10 - 2.88	1.44 - 31.31	7.32
Decapod larvae	0.59	17.15	44	0.45 - 1.48	6.46 - 16.16	9.64
Eurytemora americana	0.08	2.36	9	0.03 - 0.11	0.41 - 1.04	0.64
Harpacticoida	0.09	2.63	19	0.02 - 0.36	0.17 - 4.88	2.18
Evadne spp.	0.57	16.48	32	0.02 - 2.07	0.35 - 22.52	9.94
Labidocera aestiva	0.46	13.51	28	0.41 - 1.12	4.04 - 14.96	8.95
Centropages typicus	0.12	3.59	19	0.11 - 1.06	1.31 - 21.29	6.84
Chaetognatha	0.35	10.24	44	0.20 - 0.83	2.44 - 8.06	5.25
Tortanus discaudatus	0.24	7.11	27	0.09 - 2.51	0.84 - 26.30	9.41
Penilia avirostris	0.29	8.36	14	0.01 - 6.16	0.04 - 67.09	17.53
Mysida	0.07	2.02	14	0.01 - 0.36	0.14 - 4.78	1.80

*The number of samples collected per year at NB has varied considerably since 1976. Therefore the categories "Range of N" and "Mean N" have been omitted.

Table 3. Zooplankton percent species composition (%) and annual mean density (#/m³) of the major taxonomic groups over the last seven years (October through September) in the entrainment (EN) and offshore (NB) samples.

EN	1983		1982		1981		1980		1979		1978		1977		1976	
Taxon	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³
Copepoda	88.7	1888.2	79.2	860.1	83.2	1048.6	82.4	965.9	86.9	1031.0	87.15	1161.6	84.9	1084.3	82.3	744.8
Cirripedia	5.4	114.9	5.1	55.4	2.6	32.5	5.5	64.5	1.8	21.4	0.9	12.0	1.3	16.6	2.6	23.5
Gastropoda	3.2	68.1	3.7	40.2	6.6	82.5	6.6	77.4	3.8	45.1	4.2	56.0	3.3	42.2	9.1	82.4
Decapoda	1.2	25.5	3.4	36.9	2.1	26.3	2.8	32.8	1.4	16.6	1.5	20.0	1.2	15.3	2.5	22.6
Cladocera	0.7	14.9	0.8	8.7	0.4	5.0	1.2	14.1	2.3	27.3	0.3	4.0	0.8	10.2	1.2	10.9
Amphipoda	0.5	10.6	5.2	56.5	1.9	23.7	0.5	5.8	2.7	32.0	4.7	62.6	7.1	90.7	0.7	6.3
Yearly Total	99.7	2116.2	97.4	1057.8	96.8	1210.6	99.0	1160.5	98.9	1173.4	98.7	1316.2	98.6	1259.3	98.4	890.5

NB	1983		1982		1981		1980		1979		1978		1977		1976	
Taxon	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³	%	#/m³
Copepoda	90.5	2666.4	83.0	776.9	91.6	1226.1	83.2	999.3	82.9	819.8	89.6	903.9	94.6	1898.0	82.5	890.1
Cirripedia	2.6	76.6	8.9	83.3	2.6	34.8	6.6	79.3	3.6	35.6	2.4	24.2	0.6	12.0	0.7	7.6
Gastropoda	2.1	61.9	2.2	20.6	1.9	25.4	2.8	33.6	1.8	17.8	3.6	36.3	1.5	30.1	1.9	20.5
Decapoda	1.9	56.0	3.0	28.1	2.4	32.1	2.7	32.4	2.3	22.9	1.6	16.1	1.8	36.1	2.0	21.6
Cladocera	1.7	50.1	1.0	9.4	0.6	8.0	2.3	27.6	6.7	66.3	0.6	6.1	0.2	4.0	11.1	119.8
Amphipoda	0.2	5.9	0.6	5.6	0.2	2.6	0.2	2.4	1.2	11.9	0.9	9.1	0.1	2.0	0.1	0.2
Yearly Total	100.4	2916.9	98.9	923.9	99.3	1329.0	97.8	1174.6	98.4	974.3	98.7	995.7	98.8	1982.2	98.2	1059.8

(Table 1). Harpacticoid copepods, benthic in nature, constituted less than 2% of the zooplankton collected since 1976.

Abundances of the dominant calanoid forms were examined for spatial (EN vs. NB) and temporal (day vs. night) differences for the period 1976 - 1983 (Table 4). Higher A. hudsonica abundance at EN was consistent

Table 4. Results of paired t-tests on $\log_e$ +1 transformed abundances (DI vs NB) and diurnal (Day vs Night) differences.

Taxon	DI vs NB	Day vs Night DI	Day vs Night NB
Acartia hudsonica	DI > NB	[1]NS	NS
Acartia tonsa	NS	Night> Day	Night> Day
Centropages hamatus	NS	[2]NND	NND
Pseudocalanus minutus	NB > DI	NND	NND
Temora longicornis	NB > DI	NS	Night> Day
Cirripedia nauplii	NB > DI	NS	Night> Day
Cirripedia cyprids	DI > NB	NS	Night> Day
Gastropod eggs	DI > NB	NS	NS
Gastropod veligers	NS	Night> Day	Night> Day
Brachyuran zoea	NS	NS	Night> Day
Evadne spp.	NS	NS	NS
Podon spp.	NS	NS	NS
Gammarids	DI > NB	Night> Day	Night> Day

1 - differences were not significant at = 0.05
2 - differences were not normally distributed

with previous reports (NUSCo 1982a), and reflect the inshore nature of the species (Jeffries, 1962). Pseudocalanus minutus and T. longicornis were more abundant offshore at NB while A. tonsa and C. hamatus abundances from EN and NB were not significantly different. Acartia tonsa abundances were higher at night at both stations, while higher night abundances of T. longicornis were evident only at NB.

The results of the harmonic regression analyses indicated that the annual cycles of the dominant copepods were well described by this technique. The regressions had R^2 values of 0.62 (P. minutus, NB; T. longicornis, EN) to 0.76 (A. tonsa, EN and NB). The deviations of the actual data from the model predictions were averaged annually and standard errors calculated. Plots of these mean annual residuals indicated that the observed abundance in individual years did not, deviate greatly from the average annual pattern described by the model.

The dominant winter-spring copepod at MNPS, A. hudsonica (Fig. 2), contributed between 5-24% (NB) and 8-44% (EN) to the zooplankton collected since 1976 and between 20% (NB) and 40% (EN) in 1983 (Table 1 and 2). After accounting for seasonal patterns, deviations from the harmonic model suggested A. hudsonica abundances were lowest in 1976 and 1982 and highest in 1977 and 1983 (Fig. 3). A trend of decreasing annual abundances was also evident from the residuals of the 1977 through 1982 period.

The dominant summer-fall copepod at MNPS, A. tonsa (Fig. 4), contributed between 15-34% (EN) and 14-40% (NB) to the zooplankton since 1976, and between 27% (EN) and 35% (NB) in 1983 (Tables 1 and 2). Variability of mean annual abundances was low (Fig. 5). Highest densities of A. tonsa were observed in 1983 (NB) (Table 2).

The remaining important copepods included C. hamatus, P. minutus, and T. longicornis. Centropages hamatus was collected year round at MNPS although highest densities were found in mid-winter and mid-summer (Fig. 6). This species contributed between 6% (EN) and 10% (NB) in 1983 (Tables 1 and 2). Annual mean residuals were lowest in 1976 and 1982 (Fig. 7), suggesting lower than normal abundances of C. hamatus in those years. Pseudocalanus minutus was found year round at MNPS, although highest densities were observed in late winter and early spring (Fig. 8). Pseudocalanus minutus contributed between 4-18% (NB) and 4-12% (EN)

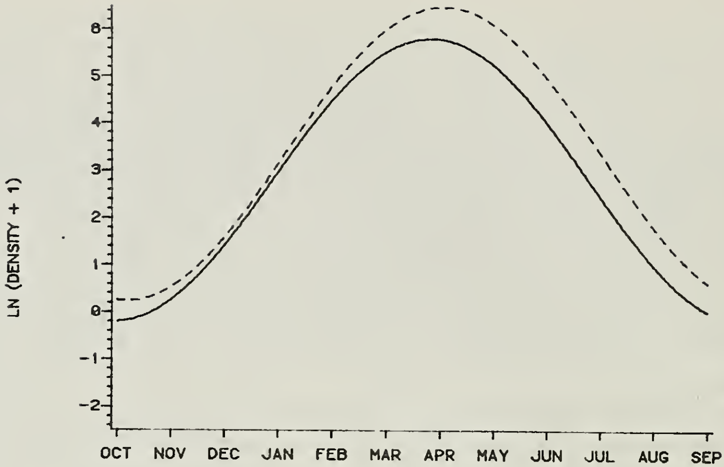


Figure 2. Annual pattern produced from the harmonic regressions developed for Acartia hudsonica at EN (-----, R^2=0.70) and NB (———, R^2=-.64).

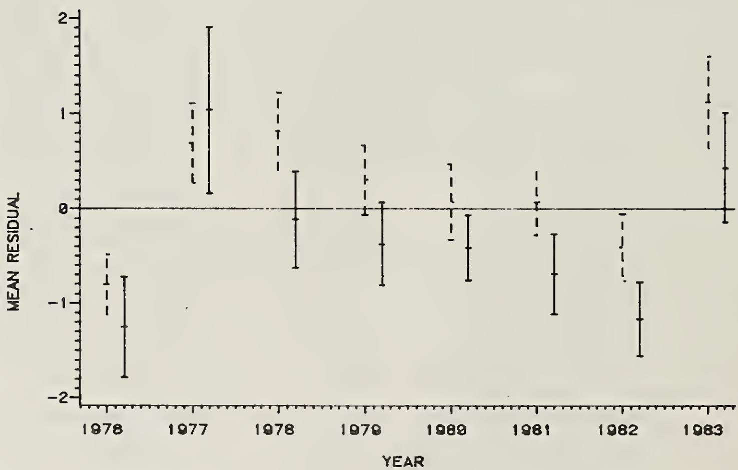


Figure 3. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for A. hudsonica at EN (-----) and NB (———).

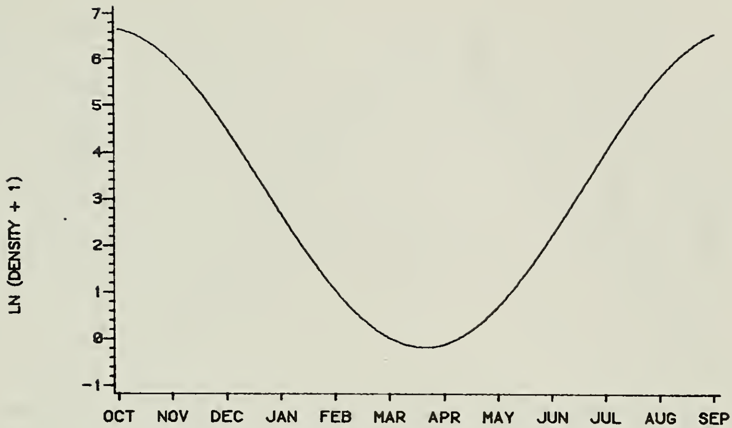


Figure 4. Annual pattern produced from the harmonic regressions developed for Acartia tonsa at EN and NB combined (R^2=0.76).

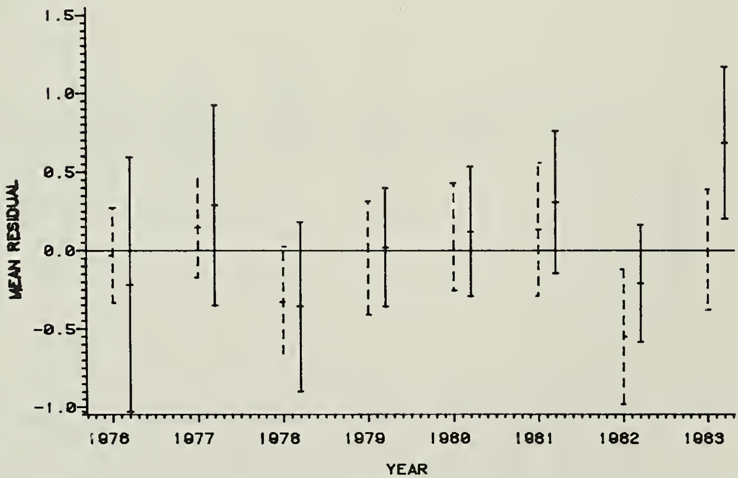


Figure 5. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Acartia tonsa at EN (------) and NB (———).

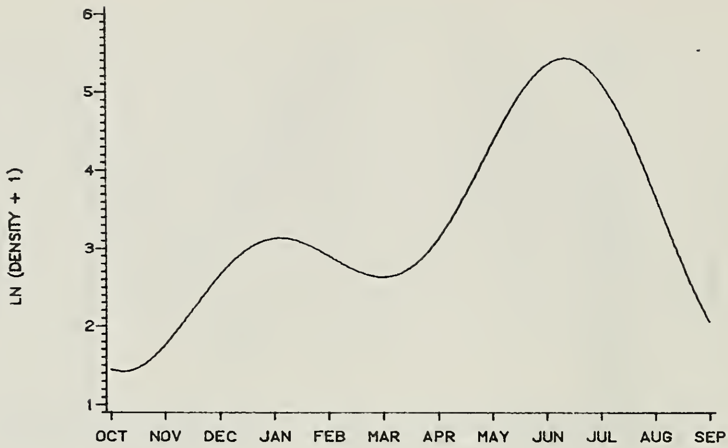


Figure 6. Annual pattern produced from the harmonic regressions developed for Centropages hamatus at EN and NB combined (R^2=0.52).

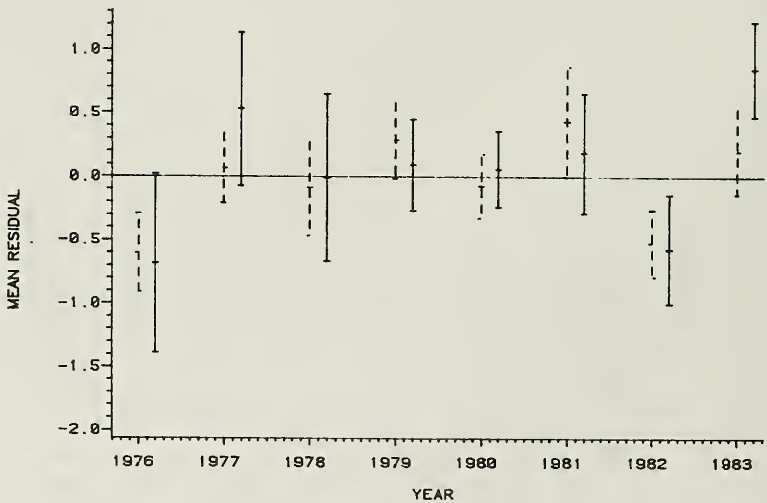


Figure 7. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Centropages hamatus at EN (-----) and NB (———).

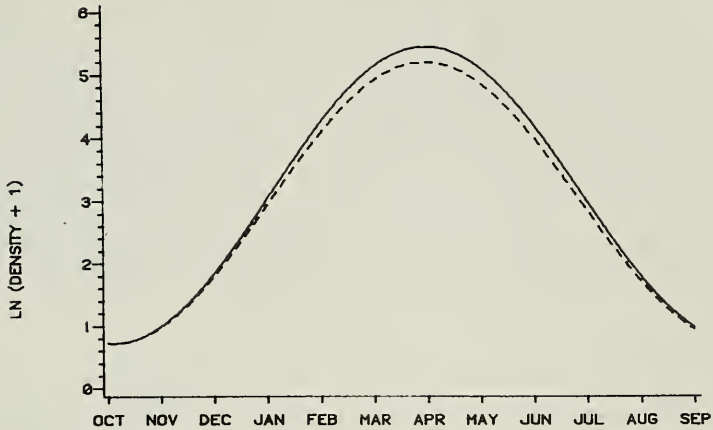


Figure 8. Annual pattern produced from the harmonic regressions developed for Pseudocalanus minutus at EN (-----, R^2=0.66) and NB (———, R^2=0.62).

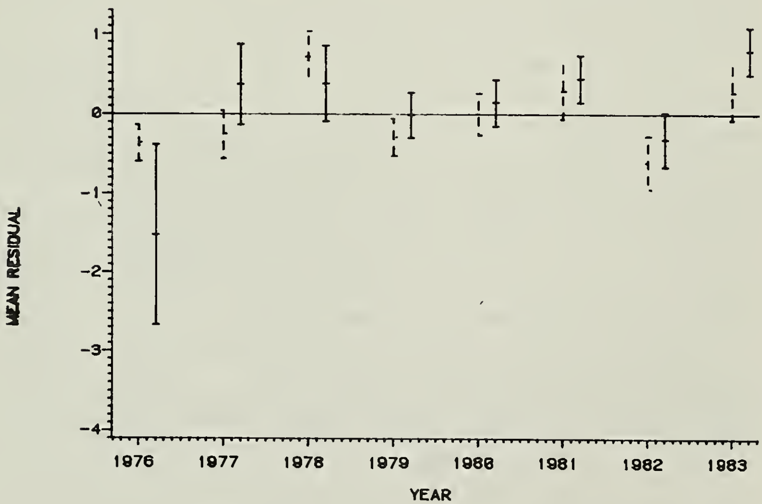


Figure 9. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Pseudocalanus minutus at EN (-----) and NB (———).

to the MNPS zooplankton since 1976, and between 5% (EN) and 8% (NB) in 1983 (Tables 1, and 2). Similar to C. hamatus, lowest P. minutus abundances were observed in 1976 and 1982 (Fig. 9). Temora longicornis was most common in winter and spring zooplankton collections at MNPS (Fig. 10) and contributed between 8-14% (EN) and 12-28% (NB) to MNPS zooplankton collections in the 1976 to 1982 period and 4% (EN) and 11% (NB) in 1983 (Tables 1 and 2). The lowest abundance was observed in 1976 (Fig. 11). The offshore predominance of P. minutus was indicated by a significant difference (see t-test results in Table 4).

Cirripedia

The cirripedia consisted of the early life stages (nauplii, cyprids) of several species of barnacles, including Balanus balanoides, B. crenatus, B. improvisus and B. eburneus. Nauplii are the earliest larval stages and provide a distribution phase while the later developing cyprids are the settling stage. Since 1976, nauplii and cyprids were found seasonally in MNPS zooplankton and accounted for 0.6 to 9% at NB and 0.9 to 5.5% at EN (Table 3).

Each year, barnacle nauplii were found in the zooplankton during two time periods (Fig. 12). In winter (January through March), the nauplii were those of the ubiquitous B. balanoides, the adults of which are an obvious constituent of New England rocky intertidal zones. In summer (July and August), nauplii consisted primarily of B. improvisus (a common subtidal form) but nauplii of B. crenatus and B. eburneus were also found. Similar winter and summer broods have been described for the southern North Sea (Newell and Newell 1973).

Barnacle cyprid abundances were lower than nauplii densities and did not exhibit the bimodal seasonal cycle. The barnacle cyprids described by our model primarily consisted of B. balanoides (Fig. 14). As indicated previously, nauplii of B. improvisus were present but in such low numbers compared to B. balanoides, that the subsequent cyprid stages were not represented by a separate peak on our model. Highest settlement densities of B. improvisus cyprids at the MNPS intake Exposure Panels have been detected during August (NUSCo 1982b). This is the same period in which B. improvisus nauplii were found in greatest

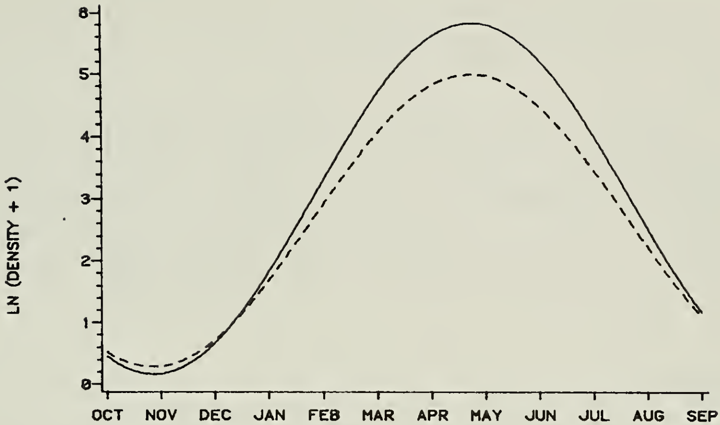


Figure 10. Annual pattern produced from the harmonic regressions developed for Temora longicornis at EN (-----, R^2=-.62) and NB (———, R^2=0.67).

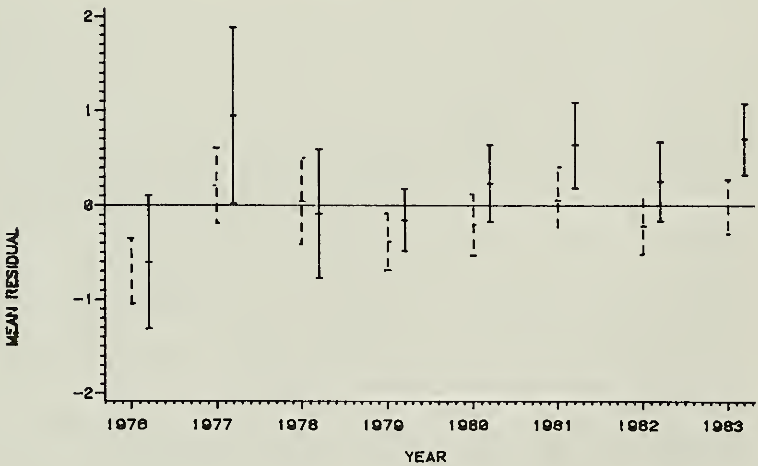


Figure 11. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Temora longicornis at EN (-----) and NB (———).

densities (Newell and Newell 1973). These observations suggest a very short cyprid stage for *B. improvisus*. Over all years, the abundance of barnacle nauplii and cyprids was lowest from 1976 - 78 (Fig. 13 and 15).

Barnacle nauplii, were found in greater abundances at NB while the cyprids were more abundant at EN where a more suitable substrate was available, particularly for the intertidal species *B. balanoides*. Both nauplii and cyprids were found in significantly greater abundances during the night at NB (Table 4). There were no significant day-night differences at EN.

Gastropoda

The gastropod taxa found in MNPS zooplankton consisted of the egg and veliger stages of local epibenthic species of snails. Gastropods have contributed between 1.5-3.6% (NB) and 3.3-9.1% (EN) to the zooplankton collected at MNPS since 1976 and in 1983 2.6% and 5.4% at NB and EN respectively (Table 3).

Regression analysis on data from this taxon produced low R^2 values (<0.3), probably due to lumping of many species into the broad taxon Gastropoda. A large proportion of eggs and veligers collected were representatives of *Littorina littorea*, the adults of which are ubiquitious on intertidal rocky shore zones around MNPS (NUSCo 1983).

Gastropod eggs were most abundant from winter through summer and lowest in the fall. Veligers were most abundant during the late spring and summer. Eggs were more abundant at EN, consistent with the areas of greatest adult abundance. Significantly higher abundances of veligers were found during the night sampling periods, suggesting nocturnal migrations into the water column (Table 4).

Decapoda

The Decapoda contain the largest crustaceans and exhibit a diversity of form and habitat (Yonge 1949). Between 1% (EN, 1977 and 1983) and 3% (EN, 1982) of the zooplankton collected at MNPS were larval decapods (Table 3).

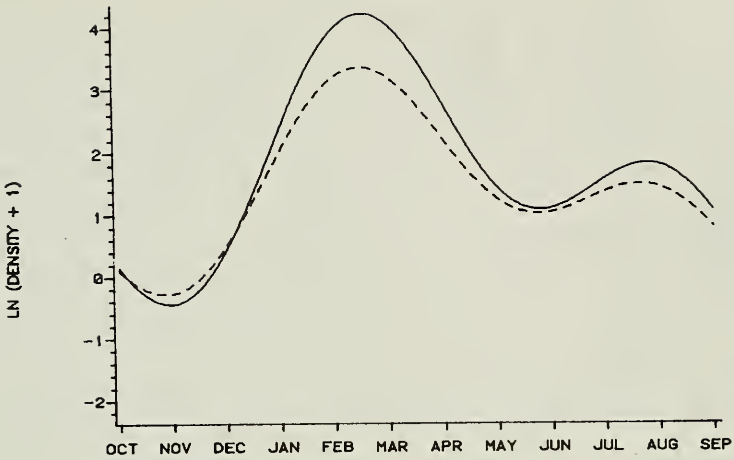


Figure 12. Annual pattern produced from the harmonic regressions developed for Cirripedia nauplii at EN (-----, R^2=0.48) and NB (———, R^2=0.51).

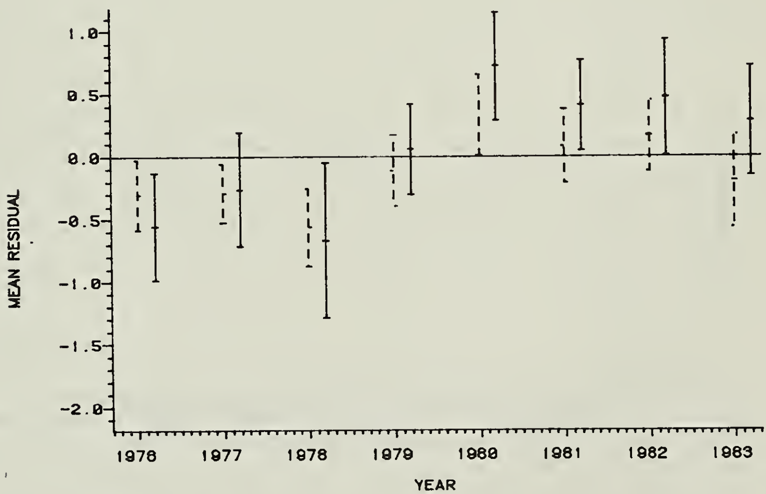


Figure 13. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Cirripedia nauplii at EN (------) and NB (———).

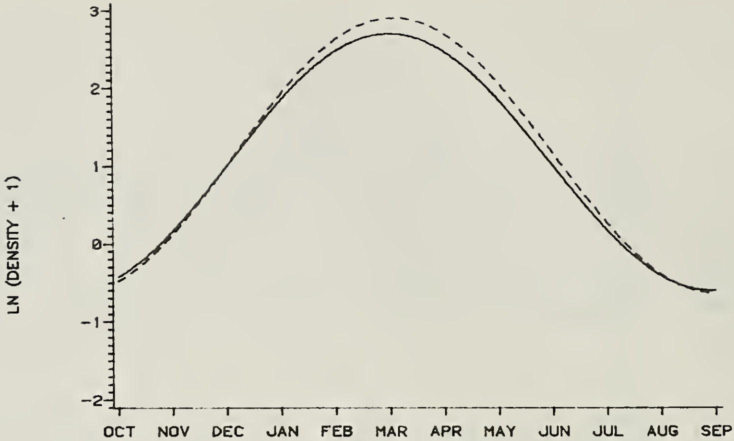


Figure 14. Annual pattern produced from the harmonic regressions developed for Cirripedia cyprids at EN (------, R^2=0.58) and NB (———, R^2=0.50).

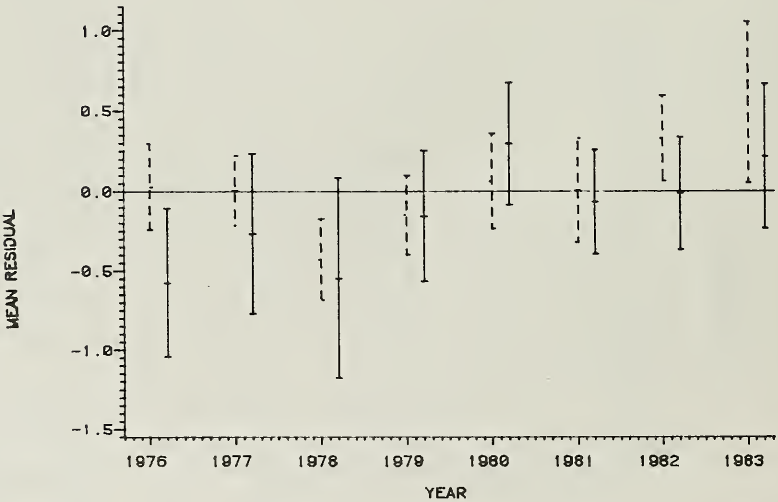


Figure 15. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Cirripedia cyprids at EN (-----) and NB (———).

The dominant zooplanktonic decapods found at MNPS were zoea and megalopa (early life stages) of the infraorder Brachyura (true crabs). Brachyuran larvae contributed between 1 and 2% to the zooplankton collected at MNPS since 1976 and more than 65% of the zooplanktonic decapods collected in 1983 (Tables 1 and 2). Brachyuran zoea were found in the zooplankton from March through November (Fig. 16), and were most abundant in late spring and summer (May through August), corresponding to the adult spawning periods (Dittel and Epifiano 1982). The harmonic regression modeled this observed seasonal pattern of brachyuran zoea abundances with R^2=0.66 (Fig. 16). Abundances of brachyuran zoea were greater during night collection periods offshore (NB). Deviations from the regression model were highest in 1983 suggesting higher than normal brachyuran zoea abundances in that year (Fig. 17).

Cladocera

Most cladocerans live in freshwater. A few marine genera are found in MNPS zooplankton including *Podon* spp., *Evadne* spp., and *Penilia* spp. Cladocerans contributed 0.2-11.1% at NB and 0.3-2.3% at EN. In 1983, they contributed 1% at EN and 2% at NB (Table 3).

There were no annual patterns evident for any cladoceran genus. No spatial (EN vs. NB) or temporal (day vs. night) preference was detected. *Evadne* spp. and *Podon* spp. were found sporadically through the years and showed no consistent seasonal preferences. However, these species commonly occur together.

Amphipoda

Most amphipods are benthic, however many appear in zooplankton collections in shallow sea areas (Newell and Newell 1973). Benthic amphipods could be present in zooplankton due to active migration into the water column at night (Newell and Newell 1973) or from being lifted by currents or turbulence.

Amphipods collected at Millstone contributed between 0.1-1.2% at NB and 0.5-7% at EN to the zooplankton since 1976 and 0.2% (NB) and 0.5% (EN) to the 1983 collection (Table 3). More than 99% of the amphipods

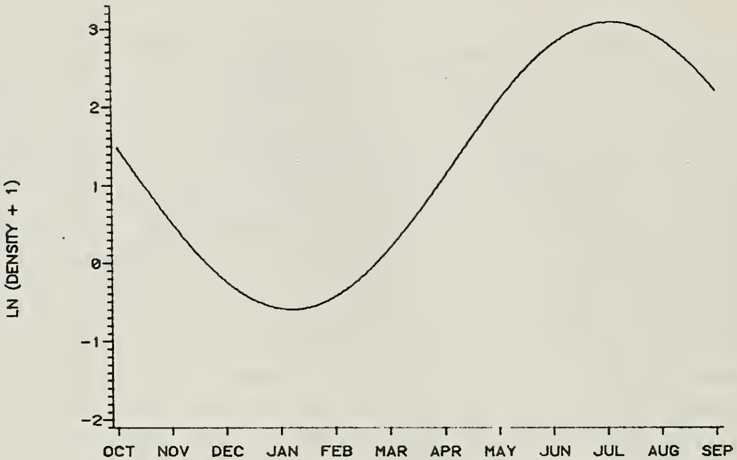


Figure 16. Annual pattern produced from the harmonic regressions developed for Brachyuran zoea at EN and NB combined (R^2=0.66).

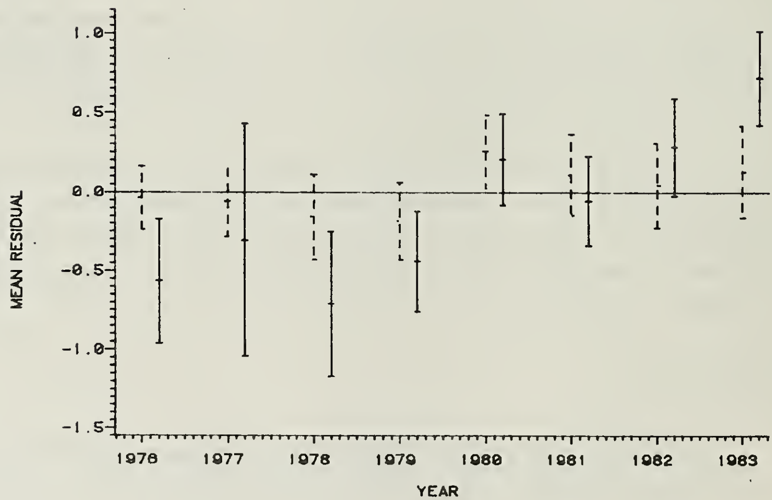


Figure 17. Annual means, (± 2 standard errors) of the residuals from the harmonic regression developed for Brachyuran zoea at EN (-----) and NB (———).

collected belonged to the family Gammaridae, and were principally *Gammarus lawrencianus*.

At Millstone, gammarids were found in greater abundances inshore (EN), and in night collections (Table 4). While gammarids were most abundant in late spring and summer, the harmonic regression R^2 values (< 0.30) reflected the high variability of gammarid abundances. Peak densities varied orders of magnitude from a low of approximately $45/m^3$ in early September 1980 to a high of over $3{,}800/m^3$ in early June of 1977. Mean annual densities ranged from $0.25/m^3$ (NB) in 1976 to $91/m^3$ (EN) in 1977 (Table 3).

CONCLUSIONS

Twelve years of marine monitoring studies at MNPS suggest that plant operation has had a negligible effect on zooplankton. The fluctuations in abundance observed in the Millstone studies have been within the expected range of natural variability and were similar to other studies in and near LIS (NAI 1976; LILCO 1983; Turner 1982). Harmonic regression models and the associated mean residuals (Figs. 2 - 17) developed for selected zooplankton species have indicated stable, recurring annual patterns in abundance.

Although entrainment by coastal power plants can result in zooplankton mortality (Carpenter et al. 1974; Lauer et al. 1974; Cannon et al. 1977), the absence of significant changes in the local zooplankton community is not unexpected, since such a small percentage of the community is directly influenced by power plant operation (Capuzzo 1980). In addition, the wide geographic range (Deevey 1948; Riley and Conover 1956; Faber 1966; LILCo 1983), high reproductive capability (Jeffries 1962; Corkett and McLaren 1969; McLaren et al. 1969; Katona 1970; Corkett and Zillioux 1975; Dagg 1978) and compensatory mechanisms (Heinle 1966, 1970) characteristic of zooplankton communities, further serve to mitigate any localized power plant impacts.

Once Unit 3 becomes operational (1986), the combined 3-unit operation will entrain about 4% of the average volume of the Niantic Bay tidal exchange (NUSCo 1976). This percentage is small considering that the tidal interchange between Long Island and Block Island Sounds totals 8.6% of the entire volume of Long Island Sound below mean low water (Bumpus et al. 1973). It is unlikely, therefore, that detectable changes in zooplankton species composition or abundance will occur during 3 unit operation.

SUMMARY

1.) The composition and abundance of MNPS zooplankton in 1983 was examined and was comparable to previous years.

2.) The Copepods were the dominant group, contributing approximately 90% to MNPS zooplankton in 1983. Dominant species in this group were *A. hudsonica*, *A. tonsa*, *C. hamatus*, *P. minutus*, and *T. longicornis*. Other dominant taxonomic groups included Cirripedia (nauplii and cyprids of *B. balanoides* and *B. improvisus*), Gastropoda (eggs and veligers of *L. littoria*), Decapoda (zoea and megalopa of Brachyura), Cladocera (*Evadne* spp. and *Podon* spp.), and Amphipoda (Gammaridea).

3.) Distinct winter-spring and summer fall zooplankton communities were identified at MNPS and were similar to zooplankton communities in LIS and BIS. Harmonic regression models and the mean annual residuals were developed for *A. hudsonica*, *A. tonsa*, *C. hamatus*, *P. minutus*, *T. longicornis*, cirripedian nauplii and cyprids, and brachyuran zoea. These models indicated recurring annual patterns in abundance for these taxa.

4.) Inshore (EN), offshore (NB) and diel differences in zooplankton densities were observed, and were attributed to natural variation.

5.) Changes observed in the Millstone zooplankton community over the past twelve years are within those observed in other areas of LIS and BIS. As a result, we conclude that any effect of the Millstone Nuclear Power Station on the zooplankton community in the vicinity of the power plant was negligible.

REFERENCE CITED

Bannister, R.C.A., D. Harding, and S.J. Lockwood. 1974. Larval mortality and subsequent year-class strength in the plaice (Pleuronectes platessa L.). Pages 21-38 in J.M.S. Blaxter, ed. The early life history of fish. Springer Verlag, New York.

Blaxter, J.H.S. 1969. Experimental rearing of pilchard larvae, Sardinia pilchardus. J. mar. bio. Ass. U.K., 49:557-575.

Bumpus, D.F., R.E. Lynde, and D.M. Shaw. 1973. Physical oceanography. Coastal and offshore environmental inventory. Univ. of Rhode Island, Mar. Publ. Ser. No. 2.

Cannon, T.C., S.M. Jinks, L.R. King, and G.L. Lauer. 1977. Ichthyoplankton and macroinvertebrates at Hudson River power plants. Pages 71-89 in L.D. Jensen, ed., Fourth national workshop on entrainment and impingement. E.A. Communications, Melville, N.Y.

Capuzzo, J.M. 1980. Impact of power-plant discharges on marine zooplankton: A review of thermal, mechanical and biocidal effects. Helgolander. Meeresunters. 33:422-433.

Carpenter, E.J., B.B. Peck, and S.J. Anderson. 1974. Survival of copepods passing through a nuclear power station on northeastern Long Island Sound, USA. Mar. Biol. 24:49-55.

Corkett, C.J. and I.A. McLaren. 1969. Egg production and oil storage by the copepod Pseudocalanus minutus in the laboratory. J. Exp. mar. Biol. Ecol. 3:90-105.

______, and E.J. Zillioux. 1975. Studies on the effect of temperature on the egg laying of three species of calanoid copepods in the laboratory. Bull. of Plankton Soc. of Japan. 21:77-85.

Cushing, D.H., and J.G.K. Harris. 1973. Stock and recruitment and the problem of density dependence. in B.D. Parrish, ed. ICES Rapp. P.V. Reun. 164:142-155.

Dagg, M. 1978. Estimated, in situ, rates of egg production for the copepod Centropages typicus (Kroyer) in the New York bight. J. Exp. mar. Biol. Ecol. 34:183-196.

Deevey, G.B. 1948. The zooplankton of Tisbury Great Pond. Bull. Bingham Oceanogr. Coll. 12:1-44.

______. 1952. Quantity and composition of the zooplankton of Block Island Sound. Bull. Bingham Oceanogr. Coll. 13:120-164.

______. 1956. Oceanography of Long Island Sound, 1952-1954. V. Zooplankton. Bull. Bingham Oceanogr. Coll. 15:133-155.

Dittel A.I., and C.E. Epifiano. 1982. Seasonal abundance and vertical distribution of crab larvae in Delaware Bay. Estuaries 5:172-202.

Faber, D.J. 1966. Seasonal occurrence and abundance of free swimming copepod nauplii in Narragansett Bay. J. Fish. Res. Board Can. 23:415-422.

Garstang, W. 1900. Preliminary experiments on the rearing of sea-fish larvae. J. mar. biol. Ass. U.K. 6:70-93.

Hardy, A. 1970. The open sea, its natural history. Riverside Press, Cambridge, G.B. 649 pages.

Heinle, D.R. 1966. Production of a calanoid copepod, Acartia tonsa in the Patuxent River estuary. Ches. Sci. 7:59-74.

_____. 1970. Population dynamics of exploited cultures of calanoid copepods. Helgolander. Meeresunters. 20:360-372.

Hulsizer, E.E. 1976. Zooplankton of lower Narragansett Bay. Ches. Sci. 17:260-270.

Jeffries, H.P. 1962. Succession of two Acartia species in estuaries. Limnol. Oceanog. 7:345-364.

_____, and W.C. Johnson. 1973. Distribution and abundance of zooplankton. in Coastal and Offshore Environmental Inventory Cape Hatteras to Nantucket Shoals. Univ. of R.I. Mar. Publ. Ser.

Katona, S.K. 1970. Growth characteristics of the copecods Eurytemora affinis and E. herdmani in laboratory cultures. Helgolander Meeresunters. 20:373-384.

Kjelson, A., D.X. Peters, G.W. Thayer and G.N. Johnson. 1975. The general feeding ecology of post larval fishes in the Newport River estuary. Fish. Bull. 73:137-144.

Lauer, G.J., W.T. Waller, D.W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko and P. C. Storm. 1974. Entrainment studies on Hudson River organisms. Pages 37-82 in L.D. Jensen, ed., Second workshop on entrainment and intake screening. Edison Electric Institute Report 15.

Lebour, M.U. 1925. Young anglers in captivity and some of their enemies. A study in a plunger jar. J. mar. biol. Ass. U.K., 13:721-734.

LILCo (Long Island Lighting Company.) 1983. Preoperational aquatic ecology study Shoreham Nuclear Power Station, Unit 1. Prepared by GeoMet for LILCo. 1983.

McLaren, I.A., C.J. Corkett and E.J. Zillioux. 1969. Temperature adaptations of copepod eggs from the arctic to the tropics, Biol. Bull. 137:486-493.

NAI. 1976. New Haven Harbor Station ecological monitoring studies. Prepared by Normandeau Associates, Inc., Bedford, New Hampshire for the United Illuminating, Co.

Newell, G.E. and R.C. Newell. 1973. Marine plankton. Third edition. Anchor Press. Essex, G.B. 234 pp.

NUSCO. (Northeast Utilities Service Company). 1974. Semiannual report, ecological and hydrographic studies, October 1973 through March 31, 1974. Millstone Nuclear Power Station, Waterford, Connecticut.

_____. 1976. Environmental assessment of the condenser cooling water intake structures (316b Demonstration), Volumes 1 and 2, submitted by Northeast Utilites Service Company to Connecticut Department of Environmental Protection.

_____. 1980. Plankton Studies. Pages 32-100 _in_ Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1979.

_____. 1982a. Plankton Ecology. Pages 1-24 _in_ Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1981.

_____. 1982b. Millstone Nuclear Power Station, Unit 3. Interim environmental report, operating license stage.

_____. 1983. Zooplankton Ecology. Pages 1-21 _in_ Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1982.

Riley, G.A. and S.A.M. Conover. 1956. Oceanography of Long Island Sound, 1952-1954. III. Chemical oceanography. Bull. Bingham Oceanogr. Coll. 15:47-61.

SAS Institute Inc. 1982. _SAS User's Guide: Statistics_ Cary, N.C. 584 pp.

Schach, H. 1939. Die Kunstliche Aufzuch von _Clupea harengus_. Helgolander. Meeresunters. 1:359-372.

Thorson, G. 1971. Life in the Sea. McGraw-Hill, New York.

Turner, T.J. 1982. The annual cycle of zooplankton in a Long Island estuary. Estuaries 5:261-274.

Yonge, C.M. 1949. The Sea Shore First, Antheneum edition. Antheneum Press, New York.

ROCKY SHORE SURVEY

Table of Contents

ROCKY SHORE SURVEY

INTRODUCTION

Rocky shores in the Millstone Point area support a community that is important both to the marine ecosystem and to the NUEL environmental monitoring program. Worldwide, intertidal and near-shore communities are extremely productive (Mann 1973), and the resulting food webs and energy flows are enormously complex (Paine 1966); the ecological balance of the system can be affected by man-induced stress (Vadas et al. 1976; Southward and Southward 1978). Nearby rocky shores are similarly productive and sensitive to perturbation; additionally, they are easily observed and frequently visited by the public.

It is therefore important that we understand the processes that determine the structure and function of local intertidal communities. Fortunately, rocky shores have attributes that facilitate our monitoring program. They are stable and easily accessible, relative to most marine habitats. Many factors that influence intertidal community development (e.g., immersion time, wave-shock, predation and grazing pressure) occur in gradients; some can be experimentally manipulated (Connell 1961; Dayton 1975). Finally, many of the individual species that comprise the community are ideal research tools for monitoring the effects of environmental perturbation. Some species are long-lived, and can integrate environmental conditions over many years; others are ephemeral, and by their presence or abundance respond very quickly to environmental changes. Some species are sessile or slow-moving, and continuously exposed to potential impacts; others are motile, and their behavior indicates the suitability of conditions at that partuclar place and time.

The Rocky Shore Survey was established to take advantage of these features of the intertidal region. Our objectives are to identify the attached plant and animal species at sites in the vicinity of Millstone Nuclear Power Station (MNPS), to establish temporal and spatial patterns of species occurrence and abundance at these sites, and to recognize the physical and biological factors that induce variability at these sites.

More specifically, we must determine if differences in the biota of these sites exist that could be attributed to the operation of the power station.

To achieve these objectives, an environmental monitoring program was designed to assess local rocky intertidal communities; the program includes qualitative algal collections, determination of percentage of substratum coverage by intertidal plants and animals, measurement of recolonization rates and patterns following small-scale perturbation, experimental exclusion of predators and grazers from selected areas, and growth studies of a dominant shore alga, *Ascophyllum nodosum*. In addition to evaluating the biological impact of operation of Millstone Units 1 and 2, this monitoring program is providing base-line data prior to three Unit operation. These data will be used to assess the additional impact of Unit 3, once it becomes operational.

MATERIAL AND METHODS

Sampling Procedures

Qualitative and quantitative sampling of the rocky intertidal stations (Fig. 1) was continued throughout the 1983 reporting year (October 1982–September 1983). This report deals primarily with results from this period, but information from previous studies is included to provide the reader with a more complete account of these experiments.

The physical character and other relevant features of the rocky shore stations have been described in previous reports (Battelle 1977; NUSCo 1983). The quantitative sampling sites were selected to represent typical rocky shores in the Millstone Point area, and degree of exposure to prevailing winds and waves is representative of the average conditions at each station. For comparison, these stations are ranked in order of decreasing relative exposure: Bay Point (BP), Fox Island-Exposed (FE), Millstone Point (MP), Seaside Exposed (SE), White Point (WP), Seaside Sheltered (SS), Giants Neck (GN), and Fox Island-Sheltered (FS).

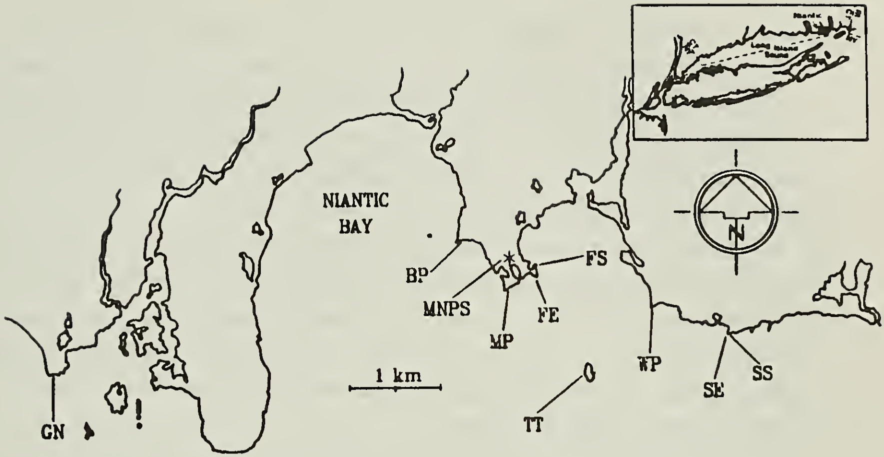


Figure 1. Location of rocky intertidal sampling sites. GN - Giants Neck, BP - Bay Point, MP - Millstone Point, TT - Twotree Island, FE - Fox Island (Exposed), FS - Fox Island (Sheltered), WP - White Point, SE - Seaside Exposed, SS - Seaside Sheltered.

Qualitative algal collections are made over a wider area than that represented by the quantitative transects, and include niches and micro-habitats (cf. Price 1980) that are not sampled quantitively. However, the relative exposure scale given above applies generally to the qualitative sites as well. Twotree Island (TT) has the widest range of exposure, as samples are taken from the lee and windward sides of the island (which consists primarily of loose rock, from cobble-sized to boulders).

Qualitative algal samples were identified fresh, or after short-term freezing. Voucher specimens were preserved in 4% formalin/seawater, as herbarium mounts, or on microscope slides, depending on the character of the material.

Quantitative studies of the intertidal communities have continued since February 1979, with the addition of Millstone Point in September 1981. At each station, five previously established half-meter wide strips, perpendicular to the waterline and extending from Mean High Water to Mean Low Water levels, were maintained as study areas. These strips (referred to as undisturbed transects) were marked with stainless steel screws. The transects were defined by paired lines marked at half-meter intervals, and the resulting 50 x 50 cm quadrats were non-destructively sampled. At low tide seven times per year (Feb., Apr., May, Jul., Sep., Oct., Dec.), the percent cover of all organisms and remaining free space were estimated and recorded. An additional percentage was given for the occurrence of 'understory' organisms, to give a more accurate measure of abundance for species that were partially or totally obscured by the canopy layer.

To represent the horizontal zonation pattern of the shore, each transect was divided into three zones that were characterized by a specific biota: Zone I - upper intertidal, dominated by blue-green algae and Balanus; Zone II - mid intertidal, largely covered with Fucus vesiculosus and Ascophyllum nodosum; and Zone III - low intertidal, dominated by Chondrus crispus.

Data from all transects at each station were pooled to generate an average percent cover for each species in each zone. Each species was then assigned to one of the following functional groups (unoccupied substrata were considered as a separate category):

Class 1 - free space; includes rock, sand, and mud.

Class 2 - barnacles; mostly Balanus balanoides.

Class 3 - mussels; mostly Mytilus edulis.

Class 4 - fucoids; Ascophyllum nodosum and Fucus spp.

Class 5 - carrageenoids; Chondrus crispus and Gigartina stellata.

Class 6 - ephemeral algae; includes host specific epiphytes, non-specific epiphytes, lithophytes, and crusts.

Class 7 - grazers; mostly Littorina spp., but includes any primary consumer.

Class 8 - predators; mostly Urosalpinx cinerea and Thais lapillus, but includes any carnivore that will prey upon barnacles, mussels, or the herbivores.

These classes were established to condense a large amount of data into a presentable form; however, all calculations of diversity and similarity indices were performed using the entire species list.

Studies to determine rates and patterns of community recolonization following perturbation were continued at four stations (GN, FE, FS, and WP). At each station, the three transects (referred to as recolonization transects; see NUSCo 1980) that had been denuded in April 1979, were again scraped and burned in September 1981, to remove all algal and faunal cover. These transects were sampled monthly, as described for the undisturbed transects.

At the four recolonization stations, a fourth series of exclusion cage studies was begun in December 1982. This experiment was identical in design to those of previous experiments run from April 1979 to May 1980 (NUSCo 1981), from May 1980 to September 1981 (NUSCo 1982), and from September 1981 to December 1982 (NUSCo 1983) except for the season in which denuding occurred.

At each recolonization station, nine exclusion cages were attached to rock, three cages in each tidal zone, i.e., upper, middle, and lower tidal level. The cages (20 x 20 x 5 cm) were constructed from 3 mm stainless steel mesh, and fastened with stainless steel screws to rock surfaces which had been burned and cleared in the same way as had the recolonization transects. Each cage had a gasket-like strip around the bottom edge to discourage entry of predators and grazers. Adjacent to each cage, a 20 x 20 cm control patch was burned and cleared.

Percent coverage by benthic plants and animals in the experimental and control areas were determined and recorded on a monthly basis. If present, 20 thalli of Fucus vesiculosus in each area were measured to the nearest millimeter. The cages were inspected, and cleaned as necessary. When growth of algae or invertebrates under a cage had reached a point where further growth was inhibited by crowding, the cage was permanently removed.

Replication of both recolonization and exclusion cage studies was undertaken to determine the effect of seasonality on recolonization. Results of the winter (1982) denuding are not yet complete; a subsequent report will summarize the entire seasonal cycle.

Ascophyllum growth studies initiated in April 1979 were continued. This report emphasizes data from plants tagged in 1982, but includes information from plants tagged in previous years. Each group of Ascophyllum plants was followed for an entire year of growth, from new bladder formation in April until the following April. Plants tagged in spring 1983 will be monitored until spring 1984, and the results presented in next year's report.

To determine growth, *Ascophyllum* tip length was measured at three stations (Giants Neck, White Point, and Fox Island). Fifty plants at each of the three sites were tagged; a numbered plastic tag was fastened to the base of the plant, and five apices were marked with small plastic cable ties and colored plastic tape. Measurements were made from the top of the most recently formed bladder to the apex, or apices if branching had occurred. In April and May 1982, the bladders had not yet developed sufficiently to be securely tagged; measurements were made of five tips on each of 50 randomly chosen plants. Monthly measurements of tagged plants began in June. Lost tags were not replaced, and the pattern of loss was used to estimate *Ascophyllum* mortality. Loss of the entire plant was assumed when the base tag and tip tags were missing; tip survival was measured both in terms of remaining tapes, and remaining tips with viable apices. The rationale for this distinction will be dealt with in the *Ascophyllum* growth section.

Data Analysis

Relative abundances of intertidal organisms were calculated on the basis of percent substratum covered by each taxon. Unoccupied substrata were classed as free space.

Similarity of the communities was determined by a percent standardized form of the Bray-Curtis coefficient (Sanders 1960), calculated as:

$$S_{jk} = \sum_{i=1}^{n} \min\left(P_{ij},\ P_{ik}\right)$$

where Pij is the percent of species i at station j, Pik is the percent for station k, and n is the number of species in common. The same clustering algorithm was applied to the resulting similarity matrix as was outlined in the Benthic Infaunal section of this report. The calculations were performed on raw percentages.

RESULTS AND DISCUSSION

Qualitative Collections

Qualitative algal collections have been made monthly at each of seven rocky shore sampling sites since March 1979. Two additional stations (TT and MP) were added in October 1981. In the 1983 reporting year, the collected flora was comprised of 126 species of algae, exclusive of diatoms and cyanophytes. On a yearly basis, this flora has remained generally constant over the past five years; changes are summarized in Table 1. Since the qualitative collection program was begun in 1979, a total of 146 species have been identified; this years collection included over 88% of that total. Most of the remainder represents small, rarely found plants.

Table 1. Changes in the Millstone rocky intertidal species lists, from 1979 to 1983.

Species listed in past reports, not found in 1983.

- Erythrotrichia carnea
- Erythrocladia subintegra
- Erythropeltis discigera
- Porphyropsis coccinea
- Gracilaria sp.
- Petrocelis middendorfii
- Gloisiphonia capillaris
- Callithamnion byssoides
- Ceramium fastigiatum
- Polysiphonia elongata
- Entonema aecidioides
- Feldmannia sp.
- Eudesme zosterae
- Phaeosaccion collinsii
- Sargassum filipendula
- Chaetomorpha melagonium
- Cladophora glaucescens

Species found for first time in 1983.

- Audouinella sp.

Changes in the overall flora from year to year have been minor, but floristic differences exist between stations and between months. Table 2 lists the species found in the 1983 reporting period and includes the number of times each species was found during each month and at each station. The final column of Table 2 represents the number of times

Table 2. Qualitative algal collections (Oct. 1982-Sep. 1983) by month and station.

Rhodophyta	O	N	D	J	F	M	A	M	J	J	A	S	GN	BP	MP	TT	FE	FS	WP	SE	SS	Times Found
Goniotrichum alsidii	7	0	0	0	0	0	0	0	0	2	0	1	1	2	1	1	1	1	1	0	2	10
Erythrotrichia ciliaris	4	4	2	6	5	4	0	2	1	2	2	3	5	4	3	3	4	5	4	0	7	35
Bangia atropurpurea	1	4	2	7	7	7	7	6	3	1	1	2	7	6	8	2	5	4	7	6	3	48
Porphyra leucosticta	5	1	0	4	4	4	2	2	0	1	0	0	1	0	4	6	2	3	2	2	3	23
Porphyra umbilicalis	3	5	6	6	8	7	8	9	9	6	5	1	9	7	6	8	8	7	10	11	7	73
Audouinella purpurea	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2
Audouinella secundata	3	2	4	5	9	7	2	1	1	0	0	0	7	4	5	2	2	5	2	5	2	34
Audouinella daviesii	0	3	0	2	0	0	0	1	0	0	0	0	1	0	0	1	0	1	1	1	1	6
Audouinella saviana	4	0	0	0	0	1	2	1	1	0	0	0	3	1	2	0	0	1	1	0	1	9
Audouinella sp.	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0	2
Gelidium crinale	0	1	1	1	1	0	1	1	2	1	1	1	0	0	0	1	0	10	0	0	0	11
Bonnemaisonia hamifera	0	2	3	3	2	5	2	5	7	4	0	0	0	6	1	5	0	1	7	6	7	33
Agardhiella subulata	1	2	5	0	0	1	0	1	2	1	1	1	1	0	1	1	1	2	7	1	1	15
Polyides rotundus	1	5	1	1	0	0	1	0	0	1	1	3	1	1	2	1	0	3	1	1	4	14
Cystoclonium purpureum	6	6	9	8	8	7	8	7	7	1	0	0	7	7	9	8	6	9	7	6	8	67
Ahnfeltia plicata	6	7	6	6	5	3	2	4	5	4	3	4	1	7	7	12	12	3	4	4	5	55
Phyllophora pseudoceranoides	5	3	1	3	2	3	1	0	0	0	1	0	1	1	3	6	1	1	4	1	1	19
Phyllophora truncata	2	3	3	3	1	2	2	1	1	0	1	0	2	1	3	1	2	5	4	0	1	19
Chondrus crispus	9	9	9	9	9	9	9	9	9	9	9	9	12	12	12	12	12	12	12	12	12	108
Gigartina stellata	6	7	4	4	4	6	5	6	8	7	3	6	1	7	9	12	3	2	8	12	12	66
Rhodophysema georgii	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Corallina officinalis	6	5	8	7	5	5	6	6	6	6	7	6	0	12	12	6	12	12	12	3	4	73
Dumontia contorta	0	0	1	4	9	7	9	8	6	2	0	1	6	5	6	6	4	5	5	4	6	47
Choreocolax polysiphoniae	0	1	1	2	3	2	1	1	0	0	1	0	4	6	0	1	0	0	0	0	1	12
Hildenbrandia rubra	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	2	0	1	0	0	1	4
Palmaria palmata	2	7	4	6	5	6	5	4	4	5	1	3	1	8	5	9	2	3	9	5	10	52
Champia parvula	8	7	4	2	1	1	0	0	0	5	7	9	4	5	2	4	4	5	8	4	8	44
Lomentaria baileyana	0	0	0	1	0	0	0	0	0	0	1	3	1	0	0	0	1	1	2	0	0	5
Lomentaria clavellosa	1	2	0	1	1	4	4	0	0	0	1	1	0	3	0	2	0	1	3	3	3	15
Lomentaria orcadensis	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
Antithamnion americanum	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Antithamnion cruciatum	7	8	5	4	2	0	1	0	0	2	5	5	4	6	4	5	3	3	6	3	5	39
Antithamnion pylaisii	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
Callithamnion corymbosum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
Callithamnion roseum	1	1	0	0	0	0	0	0	0	0	0	3	1	1	1	0	0	0	1	1	0	5
Callithamnion tetragonum	8	8	6	8	6	2	3	3	2	2	1	6	6	7	8	9	8	3	4	5	5	55
Ceramium deslongchampii	1	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
Ceramium diaphanum	3	1	1	1	0	0	0	0	0	1	5	7	3	4	1	2	0	2	3	2	2	19
Ceramium rubrum	9	8	9	8	9	8	8	8	7	7	9	8	11	12	10	10	12	10	11	12	10	98
Spermothamnion repens	7	6	6	5	3	3	3	2	1	3	4	1	6	8	2	5	1	6	7	3	6	44
Spyridia filamentosa	1	1	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	1	0	0	0	4
Grinnellia americanum	1	2	1	2	0	0	0	1	0	1	1	0	0	0	0	0	0	0	3	2	4	9
Phycodrys rubens	2	2	0	1	0	1	3	0	0	0	0	1	0	0	0	2	0	1	4	2	1	10
Dasya baillouviana	1	2	1	0	0	0	0	0	0	0	4	6	1	2	1	1	0	3	3	1	2	14
Chondria sedifolia	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	0	0	0	2
Chondria baileyana	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1	0	0	3
Chondria tenuissima	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1
Polysiphonia denudata	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Polysiphonia harveyi	1	1	4	9	3	0	1	1	3	5	9	8	5	6	5	3	5	4	7	5	5	45
Polysiphonia lanosa	7	8	7	8	9	7	5	7	7	6	7	5	12	12	12	5	12	4	7	7	12	83
Polysiphonia nigra	0	1	2	1	0	4	3	2	2	1	1	0	0	4	0	0	3	2	4	1	3	17
Polysiphonia nigrescens	2	1	1	3	0	1	2	1	2	0	2	3	1	2	1	3	0	1	6	1	3	18
Polysiphonia urceolata	1	0	0	2	2	2	6	4	4	3	0	0	3	4	1	6	1	1	4	1	3	24
Polysiphonia fibrillosa	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	3
Polysiphonia novae-angliae	9	9	7	3	6	2	4	4	2	4	1	1	5	7	6	5	7	4	8	4	6	52
Rhodomela confervoides	0	0	0	3	2	3	0	0	0	0	0	0	0	2	0	2	1	0	1	1	1	8

Values represent number of stations at which each species was found in any given month (out of 9), and number of monthsthat each species was found at any given station (out of 12). Final column indicates total number of times each species was found during the year (out of 108).

	O	N	D	J	F	M	A	M	J	J	A	S	GN	BP	MP	TT	FE	FS	WP	SE	SS	Times Found
Phaeophyta																						
Ectocarpus fasciculatus	5	1	0	0	0	0	1	1	2	2	1	4	1	1	4	1	3	0	2	3	2	17
Ectocarpus siliculosis	3	4	1	3	2	6	4	5	8	6	2	3	5	4	3	9	9	2	7	5	3	47
Ectocarpus sp.	0	0	1	0	3	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	4
Giffordia granulosa	1	3	0	0	1	1	0	0	1	0	0	1	0	1	1	2	1	0	2	1	0	8
Giffordia mitchelliae	0	0	0	0	0	0	0	0	2	0	6	3	0	1	1	1	2	2	2	1	1	11
Pilayella littoralis	2	1	3	3	1	2	3	4	4	2	2	4	11	1	1	4	2	10	1	0	1	31
Spongonema tomentosum	0	0	1	2	4	5	1	4	0	0	0	0	3	2	2	2	3	1	1	3	0	17
Acinetospora sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Ralfsia verrucosa	7	4	3	1	5	2	3	3	2	6	8	6	8	4	4	2	6	9	8	3	6	50
Elachista fucicola	5	4	2	4	7	6	5	8	6	7	8	9	8	6	9	8	9	7	7	9	8	71
Halothrix lumbricalis	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0	2
Leathesia difformis	0	0	0	0	0	0	1	3	1	1	0	0	0	0	3	0	0	0	1	0	2	6
Chordaria flagelliformis	0	0	1	0	0	0	0	1	3	1	3	2	0	0	5	2	0	0	3	0	1	11
Sphaerotrichia divaricata	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1	0	0	0	1	0	3
Asperococcus fistulosus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Desmotrichum undulatum	0	0	0	0	0	3	1	0	0	0	0	0	1	2	0	0	0	0	0	0	1	4
Punctaria latifolia	0	0	1	0	1	1	0	0	2	0	0	0	0	0	0	2	0	1	0	1	1	5
Punctaria plantaginea	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Petalonia fascia	2	4	7	7	7	6	7	8	7	8	1	0	10	8	7	5	8	7	8	6	5	64
Scytosiphon lomentaria	1	1	2	3	8	9	9	8	9	8	1	1	9	9	6	6	7	7	6	6	4	60
Desmarestia aculeata	1	3	0	1	0	2	1	1	3	0	0	0	0	0	2	2	2	1	2	1	2	12
Desmarestia viridis	0	0	0	0	1	6	3	6	1	0	0	0	1	2	2	3	0	2	4	0	3	17
Chorda filum	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	1	2
Chorda tomentosum	0	0	0	0	0	1	1	1	1	2	0	0	0	0	0	4	0	0	1	0	1	6
Laminaria digitata	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	3	0	0	0	0	0	3
Laminaria longicruris	3	0	0	0	0	2	3	2	0	1	0	0	0	0	1	4	0	0	3	1	2	11
Laminaria saccharina	7	7	4	8	3	4	4	6	7	5	7	6	11	9	8	12	5	7	3	7	6	68
Sphacelaria cirrosa	4	2	2	2	1	1	3	1	1	1	1	2	5	0	2	1	6	4	2	0	1	21
Ascophyllum nodosum	9	9	9	9	9	9	9	9	9	9	9	9	12	12	12	12	12	12	12	12	12	108
Fucus distichus s edentatus	0	0	1	1	3	1	1	2	1	0	0	0	0	1	3	5	0	0	0	0	1	10
Fucus distichus s evanescens	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	2	0	0	0	1	1	4
Fucus spiralis	1	0	0	0	0	0	1	2	3	1	0	0	0	4	0	0	0	1	3	0	0	8
Fucus vesiculosus	9	9	9	9	9	9	9	9	9	9	9	9	12	12	12	12	12	12	12	12	12	108
Chlorophyta																						
Ulothrix flacca	1	1	3	6	7	3	6	8	1	0	0	0	4	2	4	2	5	4	7	4	4	36
Urospora penicilliformis	2	0	3	5	8	4	6	5	1	0	0	0	4	3	4	3	4	3	5	5	3	34
Urospora wormskjoldii	0	0	1	3	1	0	4	0	0	0	0	0	2	3	0	0	2	1	1	0	0	9
Monostroma grevillei	0	4	2	3	8	8	6	9	1	0	0	0	7	6	5	3	4	5	4	3	4	41
Monostroma pulchrum	0	0	0	1	2	8	7	6	0	0	0	0	2	4	3	3	3	1	3	3	2	24
Spongomorpha arcta	0	0	1	2	2	1	2	2	1	0	0	0	1	2	3	3	1	0	1	0	0	11
Spongomorpha aeruginosa	0	0	0	0	0	0	0	2	0	1	0	0	1	1	1	0	0	0	0	0	0	3
Capsosiphon fulvescens	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	2
Blidingia minima	6	6	5	8	3	2	1	7	6	4	6	6	10	7	7	8	9	1	5	5	8	60
Blidingia marginata	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	1	5
Enteromorpha clathrata	3	0	0	2	0	0	0	2	1	1	2	1	1	0	1	1	1	5	3	0	0	12
Enteromorpha flexuosa	8	9	3	5	4	4	4	5	4	4	4	6	5	9	8	6	6	7	7	4	8	60
Enteromorpha groenlandica	0	0	6	0	1	0	0	0	0	0	0	0	1	2	1	1	0	0	1	0	1	7
Enteromorpha intestinalis	3	2	2	1	1	1	3	4	3	2	4	2	7	4	3	1	2	4	4	1	2	28
Enteromorpha linza	8	7	4	7	3	4	7	9	6	5	8	8	10	10	11	10	8	3	8	7	9	76
Enteromorpha prolifera	4	2	1	4	3	2	3	2	3	0	2	1	4	2	2	4	2	3	6	1	3	27
Enteromorpha torta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1
Enteromorpha ralfsii	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	0	1	2	1	0	0	5
Percursaria percursa	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	4	0	0	0	4
Ulva lactuca	9	9	8	9	8	7	8	8	8	8	8	9	12	10	12	10	12	12	12	10	9	99
Ulvaria oxysperma	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Prasiola stipitata	3	3	4	4	3	3	3	3	4	3	3	3	12	1	1	12	0	0	0	12	1	39
Chaetomorpha linum	9	8	8	9	7	4	5	7	9	9	9	9	8	9	11	11	12	10	12	10	10	93
Chaetomorpha aerea	2	4	2	1	2	3	4	3	4	4	3	3	1	4	5	0	8	7	7	1	2	35
Cladophora albida	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	1	2	0	0	4
Cladophora flexuosa	5	1	1	0	0	0	0	2	2	4	2	1	0	4	3	2	2	1	2	3	1	18
Cladophora laetevirens	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	1	1	1	3
Cladophora refracta	6	0	1	0	0	0	0	0	2	5	1	1	0	3	5	2	0	1	2	1	2	16
Cladophora sericea	2	3	0	2	1	2	6	5	6	2	3	2	3	4	4	0	7	5	7	1	3	34
Cladophora hutchinsiae	6	3	0	0	0	0	0	1	0	1	0	0	2	0	1	0	3	2	1	1	1	11
Cladophora rupestris	1	0	0	0	0	0	1	0	0	3	4	0	1	1	1	2	1	1	1	0	1	9
Rhizoclonium riparium	3	2	2	0	5	4	3	2	2	4	1	1	6	1	1	0	5	8	6	0	2	29
Rhizoclonium tortuosum	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Bryopsis plumosa	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	2	1	0	0	0	1	4
Bryopsis hypnoides	2	0	0	0	0	0	0	0	1	1	1	3	1	1	0	0	2	2	1	0	1	8
Derbesia marina	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	3
Codium fragile	7	8	7	7	8	5	5	8	6	8	7	9	7	10	7	12	12	12	9	7	9	85

each species was found in the year. Some species are ubiquitous; perennials like Fucus vesiculosus, Ascophyllum nodosum, and Chondrus crispus are found in every collection. Some algae, like Ceramium rubrum or Ulva lactuca, are aseasonal annuals; populations are found throughout the year at most stations, even though individual plants are short-lived. Some species, e.g., Gelidium crinale and Prasiola stipitata, are site specific, and found only at one or a few stations.

Table 2 also indicates the occurrence of seasonal annuals, e.g., late summer-autumn plants like Champia parvula and Antithamnion cruciatum, or winter-spring plants like Dumontia contorta or Scytosiphon lomentaria. Seasonally and spatially, the Millstone Point area supports a rich and diverse flora, owing to our location in the transition zone between boreal and subtropical floras (Taylor 1957).

Month-to-month and station-to-station patterns are more easily seen in numbers of algal species in each division (Table 3). In general, the richest collections were made in autumn (Oct.-Nov.) and in spring (Apr.-May). Of the 126 species found throughout the area in the past year, 56 were reds (Rhodophyta), 33 browns (Phaeophyta), and 37 greens (Chlorophyta). The relative percentages (45:26:29) correspond closely to those of other researchers in New England; Vadas (1972), on an open coast in Maine, found that 45% of his algal species were reds, 32% browns, and 23% greens. Mathieson et al. (1981), working in the Great Bay estuary system and adjacent open coast of New Hampshire-Maine, reported ratios of 47:28:25. Schneider (1981) sampled algae from the MNPS effluent quarry over an 18 month period, and reported total percentage ratios of 45:24:31.

The proportions of species in each division have been used as a measure of phytogeographic affinity (Druehl 1981). Generally, brown algae predominate under boreal and arctic conditions; reds and greens are more common in tropical and subtropical regions. Comparison of our data with those of Vadas (1972) and Mathieson et al. (1981) shows a latitudinal gradient; as water temperatures warm from north to south, the relative proportion of brown algae decreases. This phenomenon was seen in the MNPS quarry; Schneider (1981) included the range of water temperatures over which each species was found. He found that as temperatures increased, fewer species were collected, but that brown

Table 3. Total number of algal species from each division in each qualitative collection.

		Month												Yearly	
Sta.	Division	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Percent
GN	Reds	12	20	14	15	10	11	13	8	7	8	8	18	40	49
	Browns	9	6	6	8	8	10	11	10	8	9	5	8	15	19
	Greens	11	10	4	9	10	9	13	9	9	8	9	13	26	32
	Total	32	36	24	32	28	30	37	27	24	25	22	39	81	100
BP	Reds	16	17	9	21	15	13	14	19	15	17	12	15	35	45
	Browns	5	4	3	5	11	9	6	8	9	7	6	6	19	24
	Greens	8	7	9	11	10	7	10	11	8	10	6	5	24	31
	Total	29	28	21	37	37	29	30	38	32	36	24	26	78	100
MP	Reds	17	14	12	10	13	10	10	15	17	11	8	16	32	41
	Browns	7	6	4	3	6	6	6	16	10	10	8	8	22	28
	Greens	7	7	7	6	9	9	8	14	9	8	10	10	24	31
	Total	31	27	23	19	28	25	24	45	36	29	26	34	78	100
TT	Reds	20	12	16	18	19	18	17	14	9	10	11	9	40	46
	Browns	8	5	8	8	12	14	7	13	9	8	8	7	26	30
	Greens	12	8	7	9	9	8	6	10	8	8	7	7	21	24
	Total	40	25	31	35	40	40	30	37	26	26	26	23	87	100
FE	Reds	13	8	13	15	13	13	12	10	12	7	8	13	30	42
	Browns	8	4	5	9	8	7	8	8	8	8	7	7	15	21
	Greens	8	12	11	13	10	5	12	12	10	8	10	7	27	37
	Total	29	24	29	37	31	25	32	30	30	23	25	27	72	100
FS	Reds	14	17	15	14	16	12	14	8	8	5	14	14	42	51
	Browns	5	6	7	6	7	9	8	9	8	6	7	7	16	19
	Greens	10	6	6	10	8	5	13	12	10	8	8	9	25	30
	Total	29	29	28	30	31	26	35	29	26	19	29	29	83	100
WP	Reds	24	30	13	23	16	22	15	13	10	14	11	12	42	44
	Browns	8	8	8	4	7	8	7	10	8	9	7	8	23	24
	Greens	17	9	7	9	10	12	12	14	7	8	12	6	30	32
	Total	49	47	28	36	33	42	34	37	25	31	30	26	95	100
SE	Reds	10	21	16	12	12	14	9	8	12	8	8	8	34	48
	Browns	5	8	2	7	4	6	9	7	11	7	5	3	18	25
	Greens	8	9	5	6	6	5	6	10	7	8	4	6	19	27
	Total	23	38	23	25	22	25	24	25	30	23	17	17	71	100
SS	Reds	19	8	19	24	18	13	13	12	12	15	15	12	42	45
	Browns	5	6	5	3	4	8	9	6	13	7	6	6	24	26
	Greens	14	6	10	10	5	5	6	11	6	6	6	6	27	29
	Total	38	20	34	37	27	26	28	30	31	28	27	24	93	100
Totals	Reds	39	38	32	39	29	33	31	29	25	29	29	34	56	45
for	Browns	15	14	16	13	18	20	21	23	22	19	14	14	33	26
all	Greens	23	18	21	22	20	17	21	24	23	20	20	18	37	29
Sites	Total	77	70	69	74	67	70	73	76	70	68	63	66	126	100

algae disappeared at a faster rate. At water temperatures exceeding 25°C, the relative percentages of reds, browns, and greens were 50:12:38; at 30°C and above, the ratios were 57:5:38.

The shift in relative proportions of algae is also seen to some degree at the rocky shore sampling sites. Fox Island-Exposed is nearer to the thermal discharge than any other station, and has had the lowest ratio of browns to greens for the past three years. Twotree Island is influenced by colder, deeper water, and at this station, brown algae are more common than greens. However, the generalization does not always apply; Millstone Point is only slightly farther from the discharge than is Fox Island-Exposed, but in 1983, this station had the second highest brown/green ratio. Giants Neck is too far to be impacted by MNPS, but had the second lowest ratio of browns to greens. Explanations for the discrepancies exist, e.g., the thermal plume is directed more towards FE than MP, and the water around GN is shallow and naturally insolated. However, relative proportions must be examined closely, over several years, before valid conclusions regarding local phytogeographic affinities may be drawn. The analysis will probably be most useful for comparing the same sites over time, in response to a change in environmental conditions, e.g., beginning of three Unit operation.

In summary, the qualitative algal collections, as one facet of the rocky shore monitoring program, allow us to determine what species are present in the Millstone Point area, and the degree of seasonal and year-to-year variability in species occurrence. Change in the species composition (absolute or relative) at a station near the power plant not seen at sites more distant might be attributable to an environmental impact. These studies are qualitative; as such, they are best used to support the results of quantitative monitoring. However, the overall constancy of the flora, as evidenced by the qualitative collections, suggests that major changes have not occurred between 1979 and 1983.

Undisturbed Transects

Patterns of horizontal zonation, i.e., the spatial distribution of the intertidal community into horizontal bands (Chapman 1946; Lewis 1964; Zaneveld 1969; Stephenson and Stephenson 1972) are one of the most obvious features of rocky intertidal regions worldwide. Our sampling sites were selected as representative of the local area, and the organisms that are found in the undisturbed transects are typical of intertidal communities throughout New England (Wilce et al. 1978; Mathieson et al. 1981). These organisms are grouped into functional groups, and their abundances in 1983, measured as percent substratum

Table 4. Average percent cover of rocky intertidal stations: a) undisturbed transects b) recolonization transects.

a) UNDISTURBED TRANSECTS

ZONE	CLASS*	GN	BP	MP	FE	FS	WP	SE	SS	MEAN
1	free space	93.4	65.7	66.3	31.2	97.2	77.5	56.7	76.3	70.5
	barnacles	3.1	17.9	7.6	46.1	1.3	3.7	7.6	10.8	12.2
	mussels	0.2	1.6	0.1	0.3	0.0	0.4	0.0	t	0.4
	fucoids	1.6	0.1	0.2	3.5	0.0	8.7	2.0	2.2	2.6
	carrageenoids	0.0	t	0.0	0.0	0.0	t	0.1	0.3	0.1
	ephemerals	0.1	12.8	23.8	15.5	t	8.4	33.0	9.1	12.8
	grazers	1.7	1.8	2.1	3.4	1.4	1.3	0.7	1.3	1.7
	predators	0.0	0.2	0.1	t	0.0	t	0.0	0.1	0.1
2	free space	39.7	24.7	26.1	23.0	25.7	32.5	22.2	40.9	29.3
	barnacles	24.0	59.0	32.8	44.1	10.3	12.1	20.8	12.2	26.9
	mussels	0.6	3.5	0.9	0.6	t	0.4	0.2	4.3	1.3
	fucoids	30.8	0.2	22.1	13.6	60.8	42.6	39.2	27.3	29.6
	carrageenoids	0.6	3.4	2.9	1.4	t	3.9	6.1	8.1	3.3
	ephemerals	0.5	4.7	11.5	12.8	0.3	5.8	9.5	4.4	6.2
	grazers	3.7	3.2	3.5	4.1	2.8	2.5	1.8	2.6	3.0
	predators	0.0	1.3	0.3	0.4	0.0	0.2	0.2	0.2	0.4
3	free space	15.9	17.7	15.0	14.7	47.1	22.9	18.9	41.3	24.2
	barnacles	10.4	14.4	3.6	8.2	10.1	5.0	5.3	2.7	7.5
	mussels	1.6	1.0	t	0.1	t	0.0	14.7	29.8	6.7
	fucoids	14.3	0.1	2.1	8.9	26.3	5.2	13.0	11.8	10.2
	carrageenoids	45.2	49.6	68.6	40.6	6.8	53.7	30.8	6.9	37.8
	ephemerals	8.9	14.3	8.2	25.7	6.7	8.7	15.5	5.2	11.6
	grazers	3.7	2.2	2.3	1.6	2.6	4.2	1.7	2.1	2.6
	predators	t	0.7	0.2	0.3	0.4	0.2	0.2	0.2	0.3

b) RECOLONIZATION TRANSECTS

ZONE	CLASS*	FS	GN	WP	FE	MEAN
1	free space	86.3	76.6	65.5	56.1	71.1
	barnacles	11.0	18.4	1.5	11.0	10.5
	mussels	t	0.1	0.0	t	0.1
	fucoids	t	0.9	t	0.2	0.3
	carrageenoids	t	0.1	0.0	0.0	0.1
	ephemerals	0.3	1.5	32.0	30.9	16.2
	grazers	2.3	2.5	1.0	1.7	1.9
	predators	t	t	0.0	t	t
2	free space	47.6	57.7	57.4	32.4	48.8
	barnacles	38.0	34.5	23.2	24.0	30.0
	mussels	0.1	t	t	0.2	0.1
	fucoids	8.8	1.2	2.9	7.6	5.1
	carrageenoids	t	0.0	0.2	1.1	0.4
	ephemerals	0.7	3.0	13.1	31.5	12.1
	grazers	4.6	3.5	3.1	3.1	3.6
	predators	0.2	t	0.1	0.2	0.1
3	free space	44.0	38.2	26.1	28.1	34.1
	barnacles	26.4	32.4	17.7	18.1	23.6
	mussels	0.1	0.1	t	0.1	0.1
	fucoids	15.6	10.2	28.7	13.1	16.9
	carrageenoids	0.5	0.1	0.4	0.6	0.4
	ephemerals	8.0	14.8	23.6	36.3	20.7
	grazers	4.7	4.1	3.1	3.2	3.8
	predators	0.9	0.1	0.4	0.4	0.4

* See Materials and Methods for additional explanation of classes.

coverage, are presented in Table 4a, along with values for the percent of remaining free space. Percent coverage by individual species for each sample month is given in Appendix I. Values throughout the sampling period are similar to those of past years (NUSCo 1980, 1981, 1982, 1983). This report summarizes common features of the local rocky intertidal region, and emphasizes only those features unique to this year's study. For a more general description of intertidal community structure, as represented by the undisturbed transects, see NUSCo 1983.

On a yearly basis at most stations, over half of the available substratum in the high intertidal (Zone I) was unoccupied. Free space generally decreased with increasing exposure. For example, at Millstone Point and Seaside Exposed, a high coverage of ephemeral algae (25-35%) accounted for the low percentage of rock. The high intertidal at Bay Point had less bare rock and more barnacles and ephemeral algae than in any year since 1979, and at Fox Island-Exposed, less than 35% of the substratum was bare.

The amount of free space is of course inversely related to the abundance of intertidal organisms that settle and grow on available surfaces. In Zone I, these organisms are mainly barnacles and ephemeral algae; their abundances vary spatially and temporally. At exposed stations, an algal turf was distinct in spring and autumn, but was reduced in summer and winter due to desiccation and grazing. Coverage by barnacles in Zone I generally increased through spring, following a new set that started in early spring (Feb. - Mar.). Barnacles grew until early summer (May - Jun.); by autumn, coverage decreased as individuals were lost to predation, starvation, or desiccation. Throughout the year, barnacles were more common at the exposed stations than at the sheltered, but all stations showed an increase in barnacle coverage compared to last year. In general, the development of the high intertidal community was dependent primarily upon availability of moisture, on a seasonal basis and according to degree of exposure, and secondarily, upon the abundance and activity of predators and grazers (Connell 1961; Grant 1977; NUSCo 1983).

The mid intertidal (Zone II) had less bare rock than did Zone I (Table 4a), although space was available for colonization in this zone at all stations throughout the year. Most of the primary substratum was occupied by barnacles, usually partially covered by a fucoid canopy. Ephemeral algae were seasonally abundant, particularly at the exposed stations.

The long term cycle of _Fucus_ abundance described previously (NUSCo 1983) continued through 1983. Typically, _Fucus_ germlings do not settle under an established Fucus canopy. However, if an area of the mid-intertidal is cleared (e.g., by ice-scour), Fucus germlings settle and grow into a new canopy (Keser and Larson 1984). As individual plants age, they become more susceptible to epiphytism (Menge 1975), storm damage and ice-scouring (Mathieson et al. 1982; Chock and Mathieson 1983); their removal makes space available for settlement and growth of new germlings to continue the cycle of abundance (Schonbeck and Norton 1980). The entire cycle generally takes 2-4 years in the Millstone Point area, but different stations may become out of phase, because of different settlement patterns, growth rates, or exposure to clearing processes.

As reported last year, from 1979 to 1981 there had been a general decline in mean annual percent cover of fucoids in Zone II. Through the past two years, however, the trend appears to be reversing. The re-establishment of a fucoid canopy was seen most clearly at Fox Island-Sheltered, where Fucus cover increased steadily from a low of 7% in April 1981, to ca. 60% by September 1982, to almost 75% by September 1983. Giants Neck, White Point and Seaside Exposed have all shown increasing fucoid cover through this report year. More temporal patterns in fucoid canopy will be presented in a later section.

Zone III was characterized by dense coverage of Chondrus crispus, sometimes obscured by a canopy of Fucus vesiculosus. Recovery of Chondrus and Fucus at most stations, beyond that reported last year (NUSCo 1983), again points to the occurrence of long-term cycles in abundance of these perennial algae. At Seaside Sheltered, the decrease in Chondrus (from over 16% in 1982 to less than 7% this year) was attributed to competition for space with mussels, whose coverage increased from ca. 16% to 30%. Mussel coverage also increased at Seaside Exposed; this may cause future loss of Chondrus.

Fox Island-Sheltered also had low coverage of Chondrus in Zone III (more than last year, but still <7%); this was not attributed to competition by Mytilus, as it has been consistent since 1979. The relatively high abundance of Fucus and free space in Zone III of Fox Island-Sheltered has also been consistent. At all stations, barnacle coverage in Zone III was lower than in Zone II, and those individuals that did settle were mostly removed before autumn as a result of predation.

Spatial relationships within and among stations may be illustrated by representing percent standardized Bray-Curtis similarity coefficients as a clustering dendrogram. Figure 2 depicts the data from the undisturbed transects in the 1983 reporting period, analyzed by station and zone; three groups (and one outlier) are apparent at the 50% level. The high degree of similarity within these groups, and the very low similarity among them illustrate the three distinct zones in the local intertidal community. The inclusion of FE1 and FS3 into a cluster otherwise made up of Zone II stations is caused by the high proportion of Fucus in the high intertidal at Fox Island-Exposed, and the low abundance of Chondrus in the low intertidal at Fox Island-Sheltered. The low degree of similarity between SS3 and any other site is attributed to an increase in mussels, to the detriment of Chondrus; as theorized previously, if the same phenomenon occurs at Seaside Exposed, this type of analysis should quickly detect it. Since 1979, this technique has consistently identified the three designated shore zones (and their variations). These analyses indicate that the criteria used originally to define the zones were biologically valid, and also that few changes to the structure of intertidal communities in the Millstone Point area have occurred from 1979 to present.

Although major changes to the intertidal community from year to year have not been detected, the same analysis technique can be used to illustrate variability within years (e.g., seasonality). When the data for each collection since April 1979 are analyzed (Fig. 3), three seasonal groupings are apparent: A) spring/early summer (April and May), characterized by high abundance of Monostroma pulchrum, Ulothrix flacca, and Bangia atropurpurea, B) late summer/autumn (July-October, and in mild years, December), when Polysiphonia harveyi, Ulva lactuca, and Chaetomorpha linum are most common, and C) winter (December-February), when epiphytism is lower and ephemeral algae are rarer. The subdivision of Cluster B is probably due to the recovery of Fucus populations at most stations over the past two years.

In summary, the intertidal community, as represented by the undisturbed transects, may be interpreted as a balance between recruitment and growth, and senescence and removal. This balance is subject to variability induced by inter- and intraspecific competition

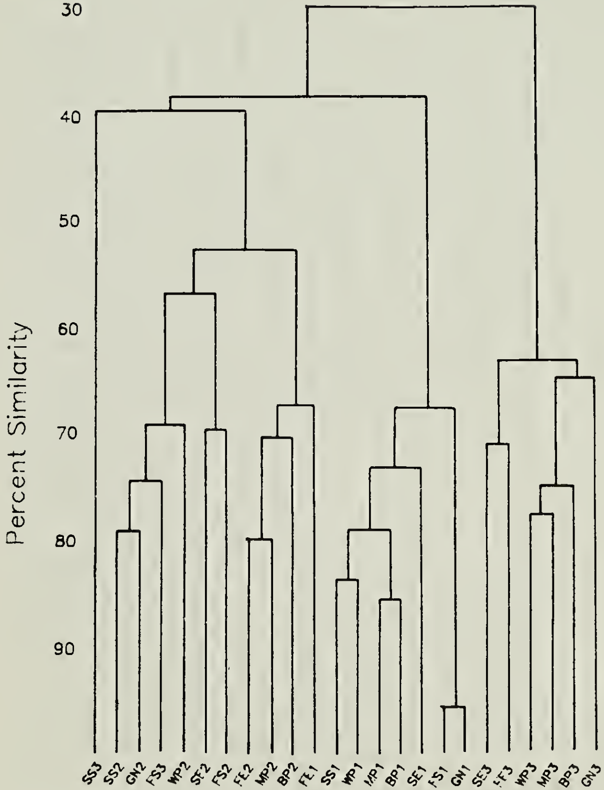


Figure 2. Clustering dendrogram of percent similarity; undisturbed transects by station and zone, Oct. 1982 - Sep. 1983.

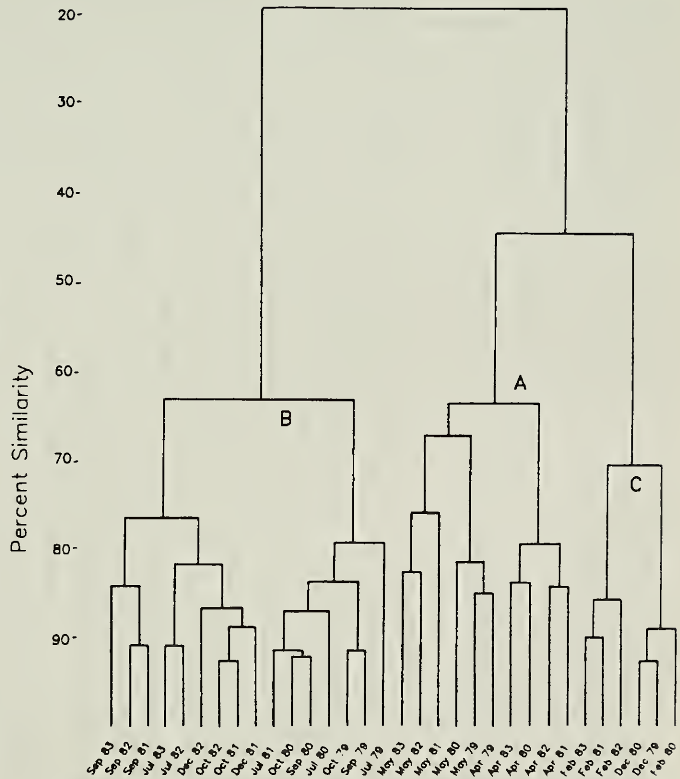


Figure 3. Clustering dendrogram of percent similarity; undisturbed transects by sample month, Apr. 1979 - Sep. 1983.

(e.g., grazing and predation), degree of exposure, intertidal height, and season. To clarify some of these relationships, the monitoring program includes manipulative experiments that try to isolate individual factors.

Recolonization Transects

Monitoring experiments to determine rates and patterns of recolonization of intertidal communities that were begun in 1979 have continued through 1983. The transects were reburned in September 1981, and represent an autumn denuding; the sampling design was the same as for the spring denuding (begun in April 1979 and described in NUSCo 1982). Average percent cover by each functional group over the latest experiment (Sep. 1981 - Sep. 1983) is given in Table 4b; monthly values for each species found in the recolonization transects are presented in Appendix II. In the following discussion "exposed stations" are represented by FE and WP; FS and GN are "sheltered stations".

Recovery towards pre-experimental conditions progressed beyond that previously reported (NUSCo 1983). Recolonization in the high intertidal (Zone I) was much faster at the exposed stations; this was attributed to wave action, which increased available moisture, and decreased the abundance and activity of grazers (Table 4b).

Recolonization in mid and low intertidal zones was seen most clearly in the rate of recovery of Balanus and Fucus populations. As reported in the past (NUSCo 1981), when substrata were denuded in spring, barnacles and Fucus colonized very quickly; particularly at the exposed stations, populations reach pre-experimental levels in as little as 8 months. When substrata were denuded in autumn, ephemeral algae settled almost immediately at the exposed stations; barnacles and Fucus did not appear at any station as more than a trace until the following spring and summer. Once settled, however, Fucus cover increased quickly at the exposed stations (faster in Zone III than in Zone II). By September 1982, Fucus cover in the low intertidal of Fox Island-Exposed was ca. 25%, and almost 50% at White Point. Fucus recovery at the sheltered stations was slower, and in September 1982, averaged only 5% at Giants Neck and Fox Island-Sheltered. As at the exposed stations, however, once Fucus became established, percent coverage increased rapidly. By September 1983, Fucus occupied 40-50% of the low intertidal at the sheltered stations. Recovery of Fucus in the mid intertidal of the recolonization stations, and comparisons of Fucus coverage in recolonization versus undisturbed transects since 1979, are shown in Figure 4.

Another way of illustrating recovery of the intertidal communities after denudation is to calculate similarity coefficients for recolonization and undisturbed transects, and apply the clustering algorithm described above. An example of this technique is shown in Figure 5, where data from the mid intertidal of the autumn denudings at Fox Island-Exposed and Fox Island-Sheltered are presented. At Fox Island-Exposed (Fig. 5a), four clusters are apparent; the first three correspond well with the seasonal groupings described for the entire area, i.e. summer/autumn, winter, and spring (cf. Fig. 3). Cluster D consists of the first three collections made subsequent to denudation; they show little similarity to each other (because of increasing amounts of ephemeral algae), and even less similarity to any other combination of collections (due to absence of barnacles and Fucus). Succeeding collections at the recolonization strips (Apr., May, Jul. 1982) reflect recovery of barnacle populations, but due to scarcity of Fucus, show more similarity to winter collections at undisturbed transects. By September 1982 (12 months after denuding), the recolonization strips closely resemble other autumn collections, and all subsequent sample months cluster 'correctly'. In July and September 1983, recolonization and undisturbed transects were highly similar, and recolonization at this site was considered complete.

At Fox Island-Sheltered, however, recovery towards pre-experimental conditions has been much slower (Fig. 5b). At this station, ephemeral algae are much less common than at the exposed stations, so the seasonality of the flora is not as evident. Rather, Fucus is the dominant algal component of the mid intertidal community, and Cluster A represents collections in 1981 and early 1982 when fucoid cover is low. As discussed above, Fucus abundance undergoes natural fluctuations, on a 2-4 year cycle, and Cluster B represents the upswing of the fucoid canopy (Jul. 1982-Sep. 1983) in the undisturbed transects. Cluster C is

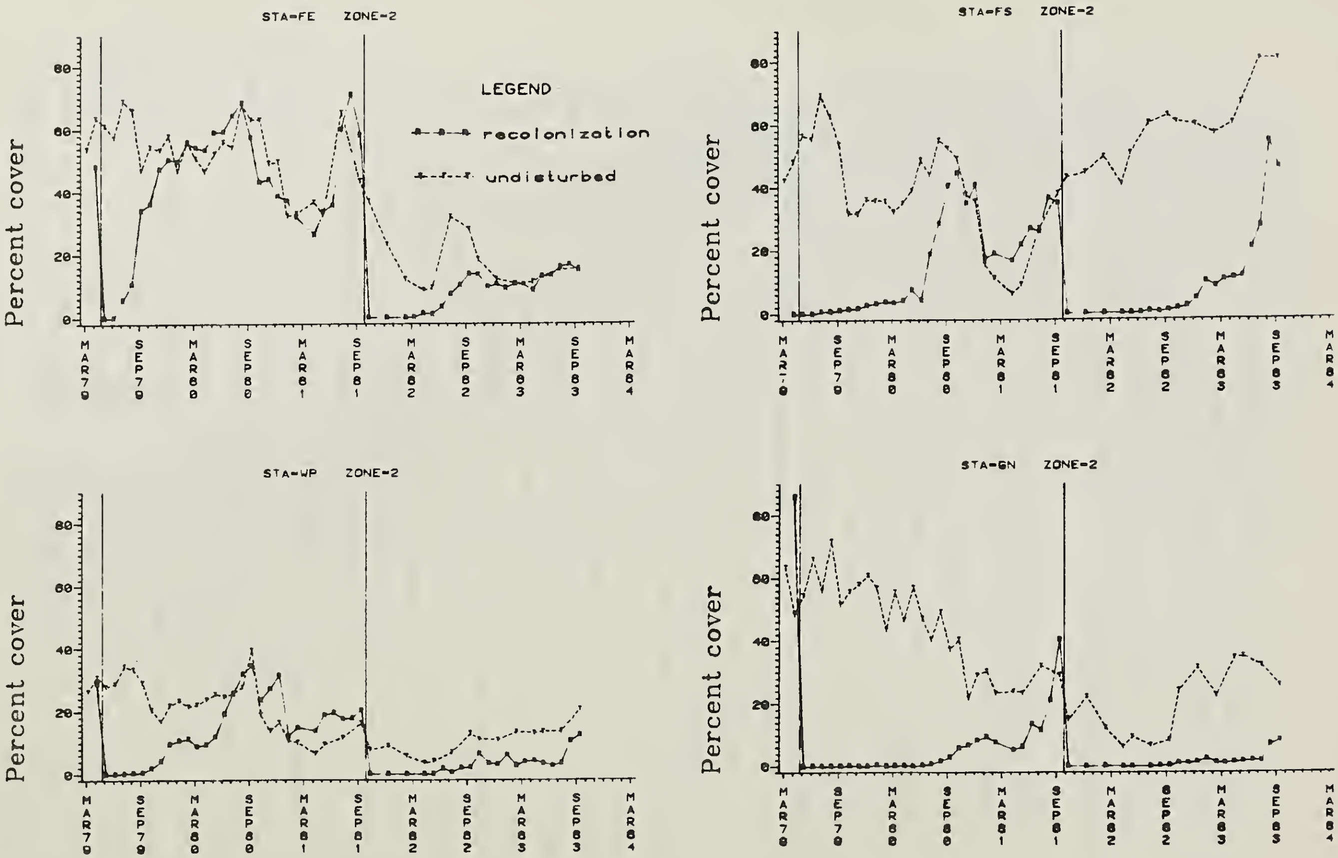


Figure 4. Percent coverage of mid-intertidal zone by <u>Fucus</u> in undisturbed and recolonization transects. Vertical lines on plots represent denudation of recolonization transects (Apr. 1979 & Sep. 1981).

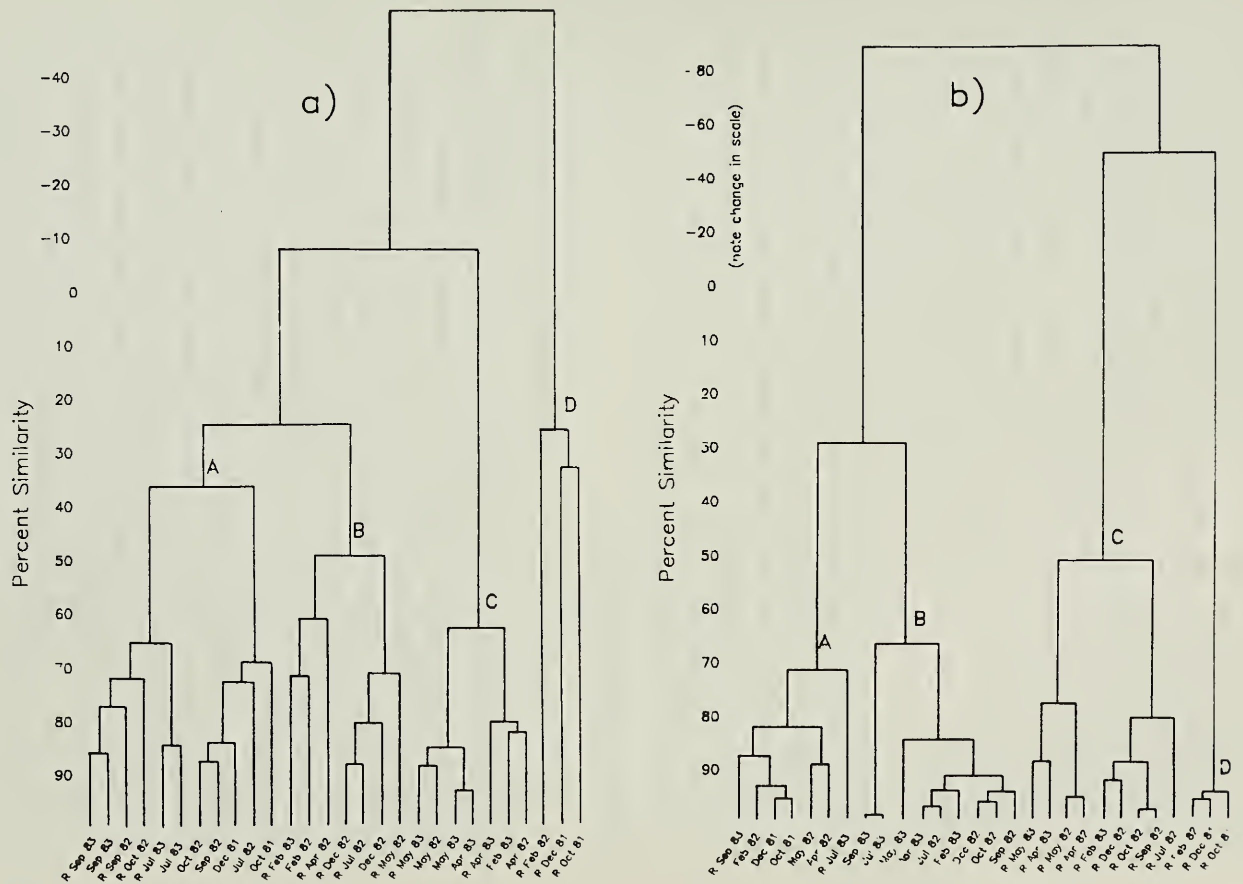


Figure 5. Clustering dendrograms of percent similarity, comparing mid-intertidal areas of recolonization transects (R) with undisturbed transect following autumn denuding (Oct. 1981 - Sep. 1983); a) Fox Island-Exposed, b) Fox Island-Sheltered.

composed entirely of recolonization collections, after the barnacle set in spring of 1982, but without much other community development. As at Fox Island-Exposed, Cluster D represents the three collections made immediately after denudation; they show low similarity to any other combination of collections but, since ephemeral algal cover is slight, considerable similarity among themselves.

Recovery to pre-experimental conditions is slower after an autumn denuding than after a spring denuding. There is a delay until the following spring for recolonization of barnacles (and Fucus at exposed stations) into strips denuded in autumn. However, the same conclusion based on data from the spring denuding holds; i.e., rate and degree of recovery of the intertidal community are directly related to degree of exposure, and inversely related to intertidal height. The experiments to determine the effect that time of year in which denuding occurs has on recolonization will be discussed in much more detail in next year's report, after the entire seasonal cycle of denudings and exclusion cage studies is completed in April 1984.

Exclusion Cages and Controls

The importance of grazing and predation to the development of the intertidal community has been discussed in previous sections, and in other reports (Hughes 1980). Snails in particular (especially Littorina littorea and Urosalpinx cinerea) exert a profound influence on the spatial and temporal distribution of algae and sessile invertebrates (NUSCo 1983). A series of exclusion cage studies has been in progress since 1979, to determine the effect that grazers and predators have on the development of recolonization communities. As in the recolonization studies described above, we wished to determine if the rates and patterns of recolonization were dependent on the time of year in which denuding occurs. Previous experiments began in April 1979, June 1980, and September 1981; each ran for 15 months. The present experiment represents a winter denuding, and was begun in December 1982. This study is not yet complete; as mentioned above, a thorough treatment of seasonality as it applies to recolonization will be included in next year's annual report.

Preliminary data from the winter denudings substantiate findings made in previous years, and in other sections of this report; namely, the local intertidal communities are in a state of dynamic equilibrium. Abundances and distributions of plants and animals reflect a balance between physical processes, short-term growth and reproductive cycles, longer cycles based on the life-span of the organisms, inter- and intraspecific competition, and of course, the variability associated with natural systems. Impact from a power plant could upset this balance by disrupting any of the processes or cycles. This impact might be seen immediately if it were to exclude a transient or motile species, or interfere with the reproductive biology of any intertidal organism; it might be apparent only after a long period, if the impact were to the growth of a long-lived perennial in an established population. It is a goal of this monitoring program to characterize the communities sufficiently well to allow us to detect such a disruption; therefore, in addition to examination of the rocky shore community as a whole, particular attention is paid _Ascophyllum nodosum_ as an indicator species.

Ascophyllum Growth Studies

Ascophyllum nodosum was selected as one of the indicator species for a variety of reasons (Keser and Foertch 1982). It is locally abundant, covering wide areas of mid and low intertidal regions; any impact that affected this plant would immediately alter the physical structure of the community. It is a long-lived intertidal alga (ca. 13-16 yrs, Baardseth 1970; Keser et al. 1981), and therefore can integrate the effects of long-term exposure to environmental conditions (cf. Borowitzka 1972; Foertch et al. 1982). Further, tip elongation has been shown to be a sensitive indicator of thermal stress (Stromgren 1977; Vadas et al. 1976, 1978; Wilce et al. 1978), and the mode of growth allows tip length to be easily measured.

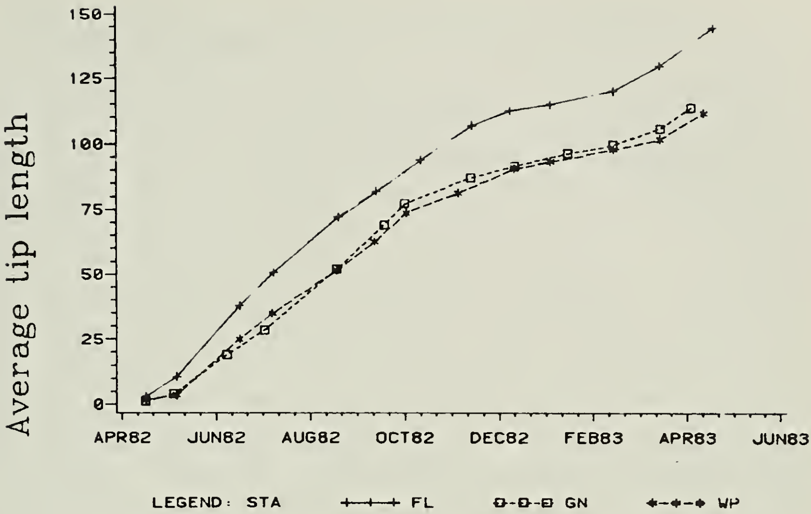
Baardseth (1970) gives a general description of vegetative and reproductive phenology for _Ascophyllum_ throughout its geographic range; development in our area is typical. In early spring (February) a small swelling appears at the tip of each viable vegetative axis. By late

March or April, the swelling has developed into a vesicle, or air bladder, and a new tip has formed beyond the bladder. Subsequent growth occurs only between the apex and bladder, so tip elongation can be determined by monthly measurements of the distance from bladder to tip.

This report presents data from April 1982 through April 1983. For the fourth consecutive year, growth (measured as total tip length) was highest at the experimental station, Fox Island (Fig. 6a). Average tip length at Fox Island was 145 mm in April 1983; at Giants Neck and White Point, tip lengths averaged 114 and 112 mm, respectively. This past growing season was the best since Ascophyllum monitoring was begun in 1979; total tip length at Fox Island was ca. 10 mm longer than in 1979-80 (previously the best season), and ca. 30-35 mm longer at the control stations. The difference in response to apparently favorable growing conditions between experimental and control plants may indicate an upper limit to growth for Ascophyllum in our area, ca. 15 cm/yr.

Support for this hypothesis is seen in Figure 6b, where 1982-83 Ascophyllum growth is represented as monthly length increments. In past years, the increased length at Fox Island has been attributed to "a higher initial growth rate in early spring and an extended growing season through November" (NUSCo 1983). This was apparent in the past growing season as well (Fig. 6), but the peak in growth rate that occurred between September and October at Giants Neck and White Point was not seen at Fox Island. Peak ambient surface water temperatures of ca. 21°C occur in early September; Baardseth (1970) reports that geographical distribution of Ascophyllum is limited by maximum summer temperatures of 22-23°C. Our studies show that (depending on power plant operating level and tidal flow) the water temperature at Fox Island is 2-3°C warmer than at the reference stations; it seems likely that in early autumn, water temperature near the power plant discharge exceeded the optimum temperature for growth. A temperature probe was placed near the Fox Island plants in early January 1984, so future reports should include accurate water temperatures.

Regardless of the actual temperature values, the slight thermal input at Fox Island has consistently, over the last four growing seasons, evidenced itself as enhanced growth of Ascophyllum tips. It would seem that year to year variability is primarily due to slight natural fluctuations in environmental growing conditions (Vadas et al. 1978).



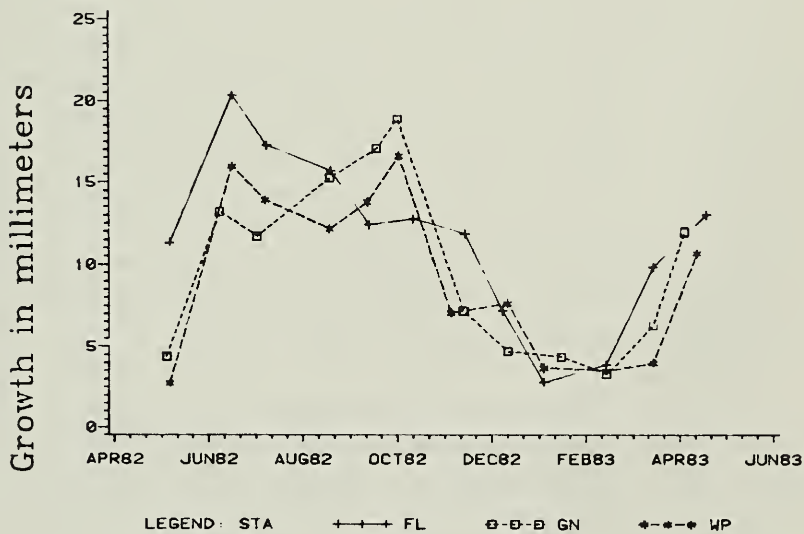
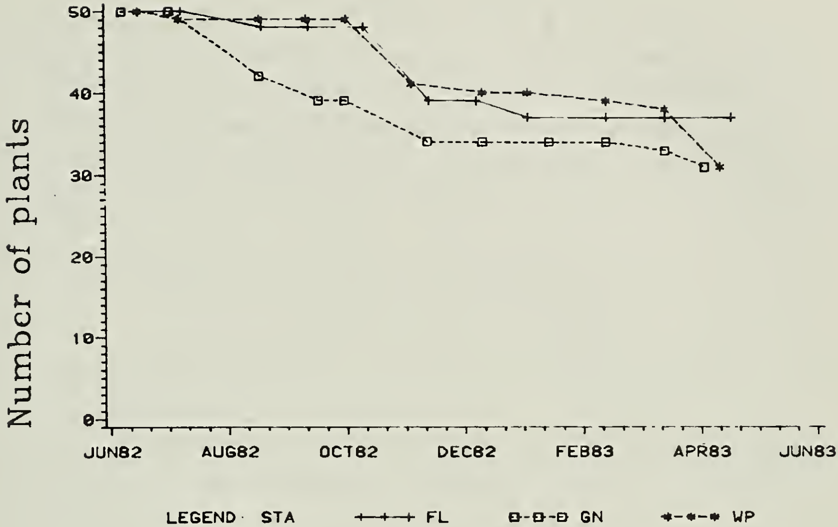


Figure 6. Ascophyllum growth, 1982-83; a) as total tip lengths, b) as incremental growth.

The populations of Ascophyllum at our study sites have remained stable over the past four years (in terms of abundance measured as percent cover), implying that plant growth is balanced by loss of plant material over the year. Other researchers (e.g., Chock and Mathieson (1983), working in New Hampshire) have reported that 50% of the autumn standing crop is lost to storms and ice-rafting. In our area as well, plant loss was related primarily to storms in autumn (Fig. 7a). The gradual loss of plants at Giants Neck through the summer may have been attributable to bathers and fishermen. In this study, the term "plant loss" is not meant to imply removal of holdfast and all attached axes, but only breakage of the axis below the base tag. Recovery of Ascophyllum populations onto denuded substrata is very slow (Knight and Parke 1950); but if the holdfast survives, other axes can continue to grow (Printz 1956; Baardseth 1970; Keser et al. 1981). Vegetative propagation and lateral proliferation can quickly replace lost material, maintaining the extensive Ascophyllum populations in our study area.

Breakage could also occur above the base tag, either between the base tag and the colored tape used as a tip tag, or between the tip tag and the growing apex. Therefore, tip mortality was examined in two ways; as surviving tapes, and as surviving tapes with at least one viable apex. This distinction was made to determine if the causes of mortality differed between stations. Loss of tip tags implies mechanical removal and immediate loss of plant material. Loss of viable apices may reflect a more subtle effect; damage to the apical cell would imply a potential loss of biomass, due to lack of growth. However, viable tip loss and tape loss decreased by about the same order of magnitude within stations from month to month (indicating mortality due to breakage of the branch below the tape), and only the loss of tagged tips is presented (Fig. 7b).

A different pattern was noted last year (NUSCo 1983); at the Fox Island station during the summer months, there was high tip mortality while most tapes remained intact. This loss of tips was attributed to heavy epiphytism, causing snagging and increased resistance to wave action. Epiphytism was not seen to be a contributing factor to apical damage in the 1982-83 growing season. Grazing by Littorina, however,



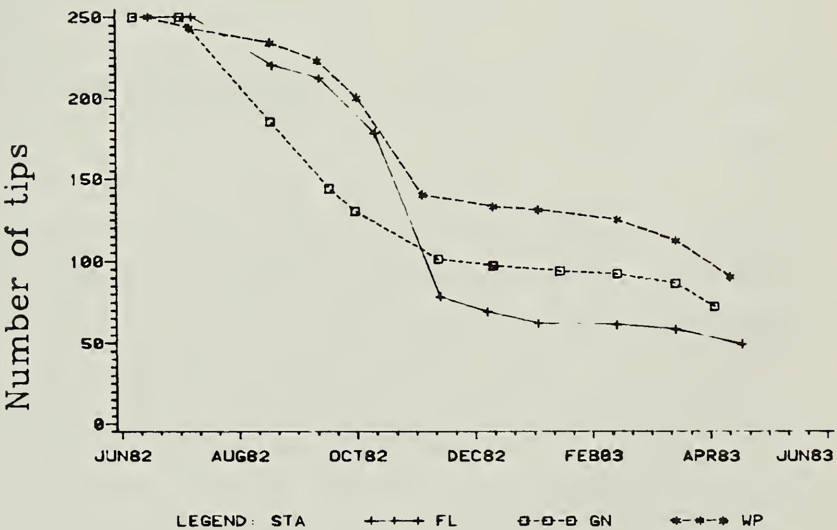


Figure 7. Ascophyllum mortality, 1982-83; a) as number of surviving plants, b) as number of surviving tips.

was a contributor to tip loss at both the control and experimental stations. Littorinid snails, particularly Littorina obtusata, are present throughout the year and have been seen to damage bladders and axes (Foertch et al. 1982; NUSCo 1982; Steneck and Watling 1982).

There has continued to be a great deal of year-to-year variability in both plant and tip mortalities between stations. The lack of pattern in mortality, concurrent with the consistency of relative growth rates, implies that neither loss of plant material nor damage to apical cells was associated with proximity to the thermal discharge. It would seem that natural variability in environmental growing conditions is the major influence on both plant and tip mortality.

Ascophyllum plants are not found in the immediate vicinity of the thermal discharge (ca. 25 m to each side), and plants nearest the effluent occur in scattered clumps; individuals are stunted and heavily epiphytized. However, the experimental area is only 70 m from the discharge; plants grow in extensive populations and show enhanced growth and similar mortality rates, relative to the control stations.

In August 1983, a new discharge canal was opened, ca. 20 m nearer the experimental area than was the old one. In light of the indications that Ascophyllum plants at the Fox Island station may be approaching their physiological limits (e.g., increased epiphytism last year, growth pattern noted this year), it will be particularly interesting to compare population parameters from the past four years to those of future growing seasons.

In summary, Ascopyllum nodosum has proven to be an ideal research tool for monitoring the effects of the thermal discharge from MNPS. The growth studies show a direct biological response to an environmental impact; the mortality studies show that, over the last four years, the impact has not stressed the Ascophyllum population beyond its ability to compensate. These studies, in conjunction with the other facets of the Rocky Shore program, demonstrate that effects of two Unit operation in the intertidal region are restricted to areas in close proximity to the discharge, and that detrimental changes to the local rocky intertidal community have not been seen.

REFERENCES CITED

Baardseth, E. 1970. Synopsis of biological data on knobbed wrack Ascophyllum nodosum (Linnaeus) LeJolis. FOA Fisheries, Synopsis #38, Rev. 1.

Battelle-William F. Clapp Laboratories. 1977. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual Report, 1976. Presented to Northeast Utilities Service Company.

Borowitzka, M.A. 1972. Intertidal algal species diversity and the effect of pollution. Aust. J. Mar. Freshwat. Res. 23:73-84.

Chapman, V.J. 1946. Marine algal ecology. Bot. Rev. 12:628-672.

Chock, J.S. and A.C. Mathieson. 1983. Variations of New England estuarine seaweed biomass. Bot. Mar. 26:87-97.

Connell, J.H. 1961. Effects of competition, predation by Thais lapillus and other factors on natural populations of the barnacle, Balanus balanoides. Ecol. Monogr. 31:61-104.

Dayton, P.K. 1975. Experimental evaluation of dominance in a rocky intertidal algal community. Ecol. Monogr. 45:137-159.

Druehl, L.D. 1981. Geographical distribution. in Lobban, C.S. and M.J. Wynne (eds). The Biology of Seaweeds. University of California Press, Berkeley and Los Angeles. pp. 306-325.

Foertch, J.F., M. Keser, and G.W. Johnson. 1982. Ascophyllum growth in southeastern Connecticut. Presented at 21st Northeast Algal Symposium, Woods Hole, Massachusetts. May 1, 1982.

Grant, W.W. 1977. High intertidal community development on a rocky headland in Maine, U.S.A. Mar. Biol. 45:15-25.

Hughes, R.N. 1980. Predation and community structure. in Price, J.H., D.E.G. Irvine, and W.F. Farnham (eds). The Shore Environment, Vol. 2: Ecosystems. Academic Press, London and New York. pp. 699-728.

Keser, M. and J. Foertch. 1982. Colonization and growth of Ascophyllum nodosum in New England. Presented at First International Phycological Congress, St. John's, Newfoundland. August 9, 1982.

Keser, M. and B.R. Larson. 1984. Colonization and growth dynamics of three species of Fucus. Mar. Ecol. Prog. Ser. 15:125-134.

Keser, M., R.L. Vadas, and B.R. Larson. 1981. Regrowth of Ascophyllum nodosum and Fucus vesiculosus under various harvesting regimes in Maine, U.S.A. Bot. Mar. 24:29-38.

Knight, M. and M.W. Parke. 1950. A biological study of Fucus vesiculosus L. and F. serratus L. J. Mar. Biol. Assoc. U.K. 29:437-514.

Lewis, J.R. 1964. The Ecology of Rocky Shores. English Univ. Press, London. 323 pp.

Mann, K.H. 1973. Seaweeds: their productivity and strategy for growth. Science 187:975-981.

Mathieson, A.C., N.B. Reynolds, and E.J. Hehre. 1981. Investigations of New England algae II: the species composition, distribution and zonation of seaweeds in the Great Bay estuary system and the adjacent open coast of New Hampshire. Bot. Mar. 24:533-545.

Mathieson, A.C., C.A. Penniman, P.K. Busse, E. Tveter-Gallagher. 1982. Effects of ice on Ascophyllum nodosum within the Great Bay estuary system of New Hampshire-Maine. J. Phycol. 18:331-336.

Menge, J. 1975. Effect of herbivores on community structure on the New England rocky intertidal region: distribution, abundance, and diversity of algae. Ph.D. thesis, Harvard Univ. 164 pp.

NUSCo (Northeast Utilities Service Company). 1980. Rocky Shore. Pages 101-142 in Monitoring the marine environment of Long island sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report, 1979.

_____. 1981. Rocky Shore. Pages 1-39 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report, 1980.

_____. 1982. Rocky Shore. Pages 1-41 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report, 1981.

_____. 1983. Rocky Shore. Pages 1-39 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report, 1982.

Paine, R.T. 1966. Food web complexity and species diversity. Amer. Natur. 100:65-75.

Price, J.H. 1980. Niche and community in the inshore benthos, with emphasis on the macroalgae. in Price, J.H., D.E.G. Irvine and W.F. Farnham (eds). The Shore Environment, Vol. 2: Ecosystems. Academic Press, London and New York. pp. 487-564.

Printz, H. 1956. Recuperation and recolonization in Ascophyllum. Second Int. Seaweed Symp. Braarud, T. and N.A. Sorenson (eds). Pergamon Press, London. pp. 194-197.

Sanders, H.L. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft bottom community. Limnol. Oceanogr. 5:138-153.

Schneider, C.W. 1981. The effect of elevated temperature and reactor shutdown on the benthic marine flora of the Millstone thermal quarry, Connecticut. J. Therm. Biol. 6:1-6.

Schonbeck, M.W. and T.A. Norton. 1980. Factors controlling the lower limits of fucoid algae on the shore. J. Exp. Mar. Biol. Ecol. 43:131-150.

Southward, A.J. and E.C. Southward. 1978. Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. J. Fish. Res. Board Can. 35:682-706.

Steneck, R.S. and L. Watling. 1982. Feeding capabilities and limitation of herbivorous molluscs: a functional group approach. Mar. Biol. 68:299-319.

Stephenson, T.A. and A. Stephenson. 1972. Life between Tide Marks on Rocky Shores. Academic Press, London. 383 pp.

Stromgren, T. 1977. Short-term effects of temperature upon the growth of intertidal fucales. J. Exp. Mar. Biol. Ecol. 29:181-195.

Taylor, W.R. 1957. Marine Algae of the Northeastern Coast of North America. Univ. of Mich. Press, Ann Arbor. 509 pp.

Vadas, R.L. 1972. Marine algae. in Third Annual Report on Environmental Studies. Maine Yankee Atomic Power Company. pp. 250-310.

Vadas, R.L., M. Keser, and P.C. Rusanowski. 1976. Influence of thermal loading on the ecology of intertidal algae. in Esch, G.W. and R.W. MacFarlane (eds). Thermal Ecology II. ERDA Symposium Series, Augusta, GA. pp. 202-251.

______. 1978. Effect of reduced temperatures on previously stressed populations of an intertidal alga. in Thorp, J.H. and J.W. Gibbons (eds). DOE Symposium Series, Springfield. VA. pp. 434-451. (CONF-771114, NTIS).

Wilce, R.T., J. Foertch, W. Grocki, J. Kilar, H. Levine, and J. Wilce. 1978. Flora: marine algal studies. in Benthic Studies in the Vicinity of Pilgrim Nuclear Power Station, 1969-1977. Summary Report, Boston Edison Co. pp. 307-656.

Zaneveld, J.S. 1969. Factors influencing the limitation of littoral benthic marine algal zonation. Amer. Zool. 13:367-390.

BENTHIC INFAUNA

Table of Contents

BENTHIC INFAUNA

INTRODUCTION

Ecological monitoring programs investigating the impacts of man-induced stress on aquatic ecosystems frequently include studies of the nearby infaunal communities (ConEd. 1977; LILCo 1983; Boston Edison Co. 1983). These communities are studied for two reasons. First, benthic organisms provide an excellent monitoring tool, since they are discretely motile and can not escape any man-induced physical or chemical change to the natural environment. The sensitivity of infaunal organisms to environmental change and the predictable manner in which they respond to stress (Boesch 1973; Reish 1973; Reish et al. 1980; Sanders et al. 1980; Gray 1982), further enhance their usefulness in impact assessment studies. Second, benthic communities are monitored due to their important role in maintaining the functioning of marine ecosystems. For example, infaunal organisms represent an important food source for demersal fish, particularly juvenile flatfishes (Kuipers 1977; De Vlas 1979; VanBlaricom 1982; Woodin 1982). Sediment reworking by these organisms also contributes to the energy recycling and nutrient regenerating processes that are necessary for maintaining ecosystem productivity (Goldhaber et al. 1977; Aller 1978; Hylleberg and Maurer 1980; Raine and Patching 1980). For example, Zeitzschel (1980) estimated that 30-100% of the nutrient requirements of shallow water phytoplankton populations were derived from sediments; the benthos played a major role in the release of inorganic nutrients to the water column. Given the varied role these organisms play in ecosystem functioning and the dependence of other communities upon them, any changes in the abundance and composition of these communities could result in system-wide changes in the ecology of the area.

Infaunal studies have been performed throughout the construction and operational phases of Millstone Unit 1 and 2 and are providing data that are needed to assess possible long-term impacts of the two operational units. In addition, such studies are providing the data base necessary for assessing impacts that may occur when Unit 3 becomes operational.

Operation of the Millstone Nuclear Power Station (MNPS) creates several changes in the natural environmental conditions that might induce changes in the composition and abundance of local benthic communities. These changes include: current generated scour near the plant intake and discharge, organism entrainment through the condenser cooling system, chemical and heavy metal additions, and increased water temperatures associated with the plant discharge.

The objectives of the Millstone infaunal monitoring program are to:

(1) establish the infaunal composition and abundance at subtidal and intertidal stations located within and beyond the area influenced by operation of the MNPS,

(2) identify seasonal and year to year patterns in species composition and abundance and establish the natural range of these measures,

(3) evaluate whether any changes in species composition and abundance (both short and long-term) are due to operation of MNPS.

The following report summarizes the 1983 results of the Millstone infaunal monitoring study and includes data collected in prior years for comparative purposes.

MATERIALS AND METHODS

Benthic infaunal communities were sampled at four subtidal and three intertidal stations in September and December 1982 and March and June 1983 (Fig. 1). The Giants Neck (GN) subtidal and intertidal stations are located 5.5 km west of the plant and serve as reference stations since they are located beyond any projected influence of the plant. The Intake subtidal station (IN) is located 0.1 km seaward of the Millstone Unit 2 intake structure, while the Effluent (EF) subtidal station is located approximately 0.1 km offshore and adjacent to the cooling water discharge into Long Island Sound. This station is positioned as close to the effluent as possible given the current produced by the discharge. The Jordan Cove (JC) subtidal and intertidal stations are located 0.5 km east of the plant and are within the area potentially influenced by the the cooling water

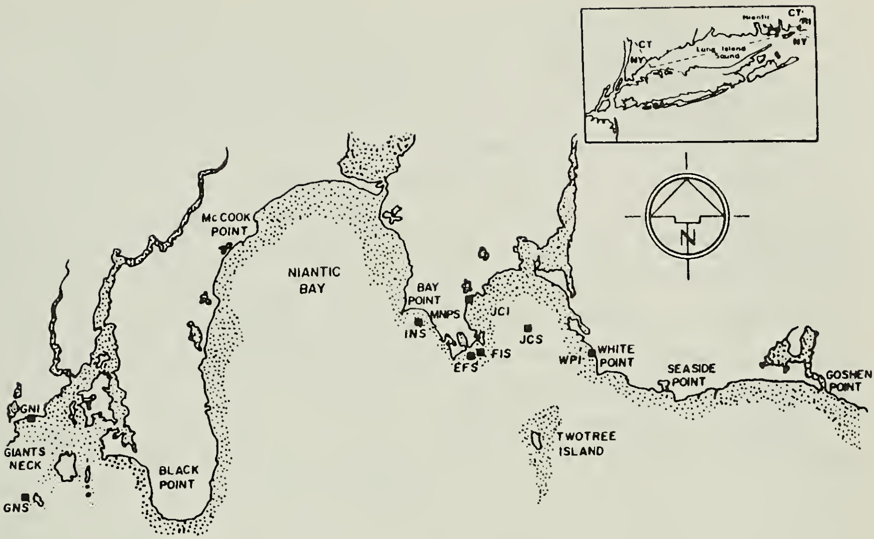


Figure 1. Map of the Millstone Point area showing the location of subtidal and intertidal sand stations. (GNS = Giants Neck subtidal, EFS = Effluent subtidal, INS = Intake subtidal, JCS = Jordan Cove subtidal, GNI = Giants Neck intertidal, JCI = Jordan Cove intertidal, WPI = White Point intertidal.

discharged during two-unit operation. The White Point intertidal station is located 1.6 km east of the plant in an area that will potentially be subjected to environmental changes when Millstone Unit 3 becomes operational.

Subtidal samples were obtained by SCUBA divers, using a corer 10 cm (i.d.) by 5 cm deep. After collection each sample was placed in a separate 0.333 mm mesh Nitex bag and brought to the surface. A total of fifteen replicates were collected at each station in September and December 1982 and 10 replicates per station in March and June 1983. This reduction was based on a two year study which concluded that 10 replicates appeared adequate to describe the local benthic communities. Intertidal samples were collected along a 5 m transect parallel to the water line at Mean Low Water.

Samples were returned to the laboratory and fixed with 10% buffered formalin containing rose bengal stain. After a minimum of 48 h, organisms were floated from the sediments onto a 0.5 mm mesh sieve and the float and residue preserved separately in 70% ethyl alcohol. Organisms were removed under dissecting microscopes, sorted into major groups (annelids, arthropods, molluscs, and others), identified to the lowest possible taxon and counted. Organisms not sampled adequately by our methods because of their small size e.g. nematodes, ostracods, copepods, and foraminifera) were not removed from the samples. Biomass of each of the major phyla was estimated using two samples of five pooled replicates. Samples were dried at 80°C for 24 h, weighed (to the nearest 0.1 mg), combusted at 500°C for 4 h, and reweighed; ash-free biomass was then expressed as the difference between dry-weight and combusted weight. Prior to drying, molluscs were decalcified in 0.1N HCL to eliminate carbonates.

Sediment analyses were performed on a 3.5 cm (i.d.) x 5 cm deep core taken at each station. The dry sieving method and the method of moments technique was used to calculate the arithmetic mean phi (Folk 1974), which was then converted to mean particle size in millimeters. Organic content of the sediments was estimated, after combusting dried sediment at 500°C for 24 h, as the difference between dry-weight and combusted weight.

DATA ANALYSIS

Since the number of replicates differed during the study, quarterly values were converted to number/core (0.0078 sq. m); annual numbers of species and individuals (by phylum) were expressed as percents.

Species Diversity

Seasonal species diversity for each station was estimated using the Shannon information index (H'), calculated as:

$$H' = \sum_{i=1}^{S} \frac{n_i}{N} \log_2 \frac{n_i}{N} \qquad \text{(Pielou 1977)}$$

where n_i = number of individuals of the i^{th} species,

N = total number of individuals for all species,

S = number of species.

The evenness component of diversity (J) was calculated as:

$$J = \frac{H'}{Hmax}, \qquad \text{(Pielou 1977)}$$

where $Hmax = \log_2 S$ and represents the theoretical maximum diversity when all species are equally abundant. Evenness ranges from zero to one; J approaches one as abundance becomes more even among species.

Diversity calculations excluded oligochaetes and rhynchocoels since they were not identified to species. Other individuals not identified to species, either because they were juveniles or in poor physical condition, were also excluded from this analysis.

Biological Index Value

At each station, the Biological Index Value (BIV) of McCloskey (1970) was calculated for the 10 most abundant taxa. Each species was ranked according to its total abundance in each sampling year and these ranks summed for all years. The sum for each taxon was then expressed as a percentage of a theoretical maximum sum, which would occur if a species ranked first in abundance in each of four years.

Numerical Classification and Cluster Analyses

The Bray-Curtis similarity coefficient was used to classify stations (normal analysis), based on transformed species counts (ln (count + 1)). The coefficient was calculated as:

$$S_{jk} = \frac{\sum_i 2 \min (X_{ij}, X_{ik})}{\sum_i (X_{ij} + X_{ik})} \qquad \text{(Clifford and Stephenson 1975)},$$

where X_{ij} = abundance of attribute i at entity j,

X_{ik} = abundance of attribute i at entity k.

Since Bray-Curtis similarities refer to only pair-wise comparisons, cluster analyses were performed to illustrate relationships among three or more stations. A flexible sorting strategy with Beta= -0.25 was used to form groups of stations at decreasing levels of similarity (Lance and Williams 1967). Cluster analysis was performed on annual collections from 1980 to 1983.

INTERTIDAL RESULTS

Sediments Characteristics

Intertidal sediments were composed of medium to coarse sand (Fig. 2) with generally low amounts of silt/clay and organic matter (Table 1). During 1983, sediment size ranged from 0.38 to 0.57 mm at GN, 0.45 to 0.74 mm at

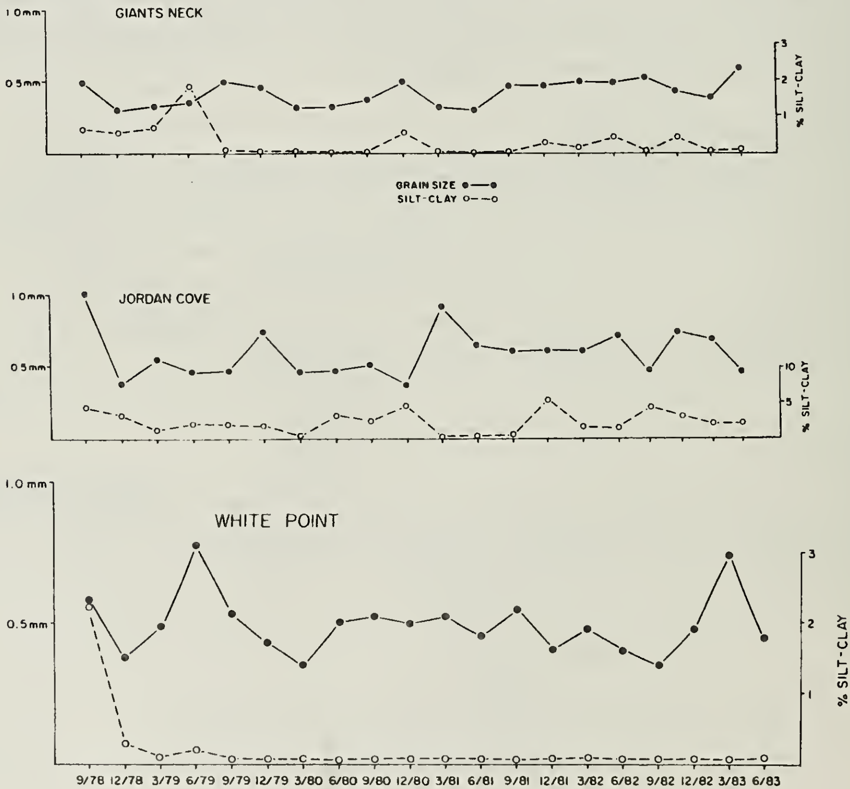


Figure 2. Sediment characteristics at the Millstone intertidal stations, September 1978 - June 1983.

JC, and 0.36 to 0.72 mm at WP. At JC and WP, coarsest sediments occurred during December or March; at GN, sediments were coarsest in September and June. June sediments at GN and March sediments at WP were coarser than any obtained since 1976. Although silt/clay (sediment > 0.06 mm) content and organic matter were generally low at all stations, higher values were generally obtained at JC. At WP and GN, silt/clay and organic matter were often undetectable.

Table 1. Percent organic matter in the sediments at Millstone intertidal stations sampled from 1981 - 1983.

	1983 Mean[a]	1982 Mean	1981 Mean
Giants Neck			
September	0.37	0.33	0.36
December	0.28	0.32	0.44
March	0.22	0.58	0.30
June	0.32	0.59	0.53
White Point			
September	0.27	0.28	0.24
December	0.29	0.28	0.34
March	0.22	0.33	0.26
June	0.26	0.83	0.34
Jordan Cove			
September	1.32	0.70	2.40
December	1.02	0.80	1.78
March	1.93	0.87	0.57
June	0.60	1.17	0.60

a - Mean of two replicates collected quarterly each year.

Sediment characteristics of the intertidal beaches during 1983 were consistent with those observed in past years. At the more exposed stations (GN and WP), only slight within and between year changes in sediment characteristics have occurred; this contrasts with the larger changes observed at the less exposed JC station.

General Community Composition

At all intertidal stations, polychaetes accounted for the majority of the species collected (75% at GN, 44% at JC, and 70% at WP) (Table 2). Arthropod species were nearly as abundant as polychaetes at JC (39%), but accounted for only 25% and 23% of the species totals at GN and WP, respectively. Mollusc species were numerous at JC (16%) and WP (6%). All species collected at intertidal stations in 1983 have been collected in previous years.

Table 2. Number of species (S), relative percent of total (%), number of individuals (N), and relative percent of total (%) for each major taxon collected at Millstone Point intertidal stations sampled from September 1982 - June 1983 with 1980 - 1982[a] ranges.

Stations	1983				1980 - 82 Range			
	S	%	N	%	S	%	N	%
Giants Neck								
Polychaetes	15	75	1036	67	13 - 24	46 - 69	1649 - 2222	61 - 82
Oligochaetes	–[b]	–	143	9	–	–	79 - 191	4 - 6
Molluscs	0	0	0	0	1 - 8	4 - 19	3 - 14	0 - 0
Arthropods	5	25	12	1	5 - 14	19 - 50	22 - 59	0 - 2
Rhynchocoels	–	–	362	23	–	–	260 - 932	10 - 31
Totals	20		1553					
Jordan Cove								
Polychaetes	19	44	2631	17	20 - 22	44 - 54	1055 - 4120	11 - 30
Oligochaetes	–	–	12430	81	–	–	4749 - 12159	63 - 85
Molluscs	7	16	26	0	6 - 9	15 - 21	10 - 711	0 - 5
Arthropods	17	40	254	2	12 - 16	28 - 36	100 - 968	1 - 14
Rhynchocoels	–		1	0	–	–	23 - 64	0 - 1
Totals	43		15342					
White Point								
Polychaetes	12	71	428	48	17 - 21	77 - 84	869 - 1548	54 - 60
Oligochsetes	–	–	107	12	–	–	59 - 669	4 - 26
Molluscs	1	6	3	0	1 - 4	5 - 16	1 - 5	0 - 0
Arthropods	4	24	5	0	0 - 3	0 - 14	0 - 6	0 - 0
Rhynchocoels	–	–	356	40	–	–	337 - 783	0 - 40
Totsls	17		895					

a - 60 replicates per station 1980, 1981, 1982 and 50 replicates in 1983.
b - Taxon not identified to the species level.

The GN and WP communities were numerically dominated by polychaetes, accounting for 66% and 47% of the individuals collected, respectively. At both stations, rhynchocoels and oligochaetes were the next most abundant groups. Oligochaetes were by far the most abundant group comprising the JC intertidal community, where they accounted for 81% of the total organisms collected. Polychaetes (17%) were the only other group that substantially contributed to the overall composition at this station.

During 1983, the major groups of infaunal organisms and their relative contributions to community composition were consistent with past years. No long-term changes in the contribution of any major group have occurred at any of the intertidal monitoring stations.

Numbers of Species and Community Density

The quarterly numbers of species comprising intertidal communities during 1983 ranged from 3-7/core at GN, 4-13/core at JC and 1-6/core at WP (Fig. 3). All stations exhibited peak species numbers in September followed by declines through March and slight increases in June. This seasonal pattern has generally occurred at all intertidal stations since 1976. Although variable within a year, the numbers of species have remained similar among years, particularly at GN and JC. The community at WP has exhibited a general increase in species numbers since September 1979, soon after the sieve mesh used to process samples was changed from 0.71 mm to 0.5 mm. The additional species obtained at this station have been small polychaetes (e.g. *Streptosyllis arenae*, *Exogone hebes*, and *Parapionosyllis longicirrata*). It is probable that these species were present at this station prior to 1979 but were not adequately sampled by our methods.

Quarterly infaunal densities in 1983 averaged from 1.6/core (WP) 769/core at JC (Fig. 4). Densities were lowest at all stations in March; however, periods of highest density occurred in different months at all stations (GN in September, JC in June, WP in December). Infaunal abundances at GN and WP in March and particularly in June during 1983 were substantially lower than those obtained since 1979, although similarly low values have been observed in previous years. At JC, in contrast, record high levels of abundance occurred in June 1983; this was due almost exclusively to the high density of oligochaetes.

Biomass

Biomass (ash-free dry weight) at the intertidal monitoring stations in 1983 ranged from 0.002 g/core at GN to 0.06 g/core at JC (Fig. 5). Seasonal fluctuations were evident at all stations and no pattern was common to all. At GN, seasonal shifts in biomass during 1983 closely followed those of

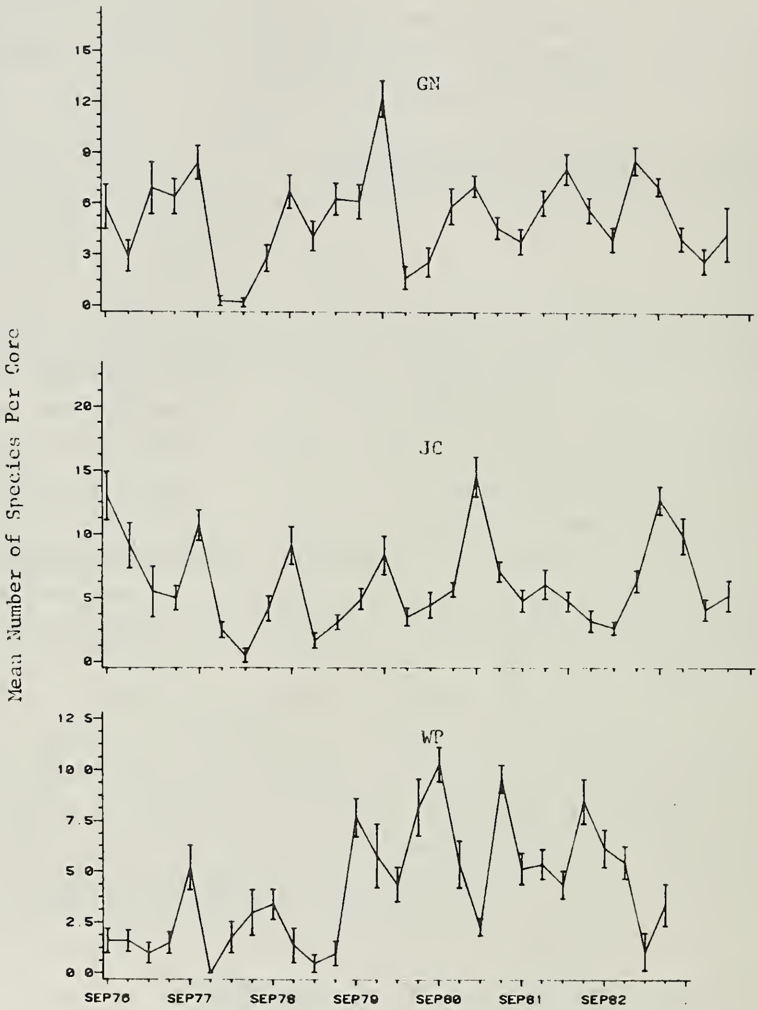


Figure 3. Mean number of species per core (± 2 standard errors) collected at Millstone intertidal stations sampled from September 1976 - June 1983.

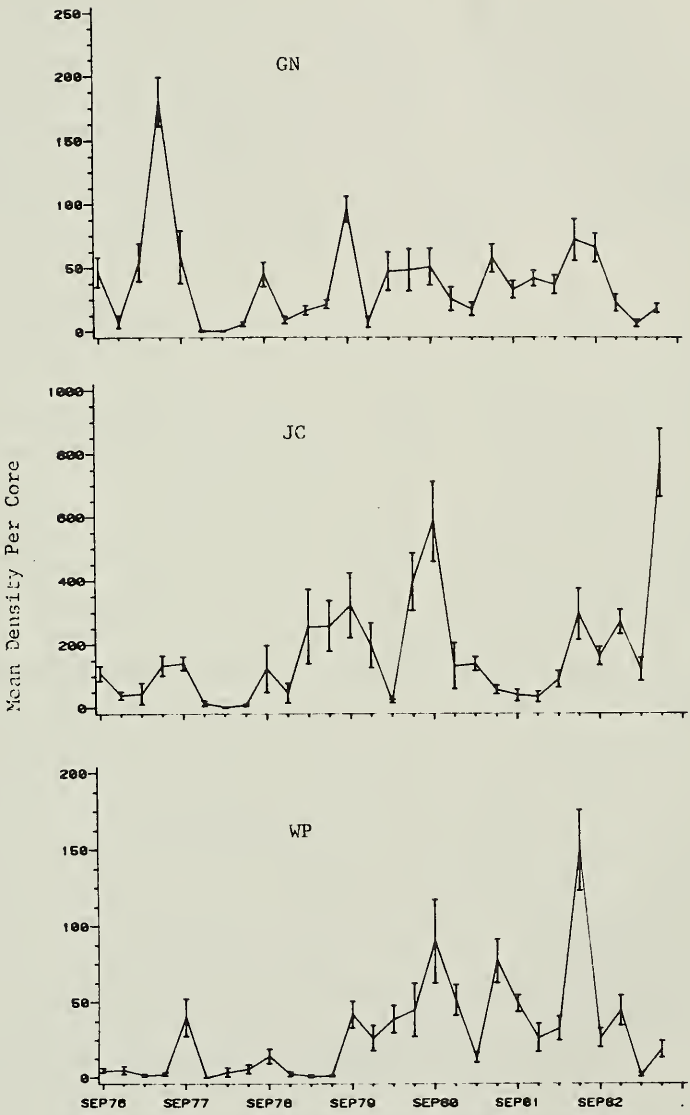


Figure 4. Mean number of individuals per core (± 2 standard errors) collected at Millstone intertidal stations sampled from September 1976 - June 1983.

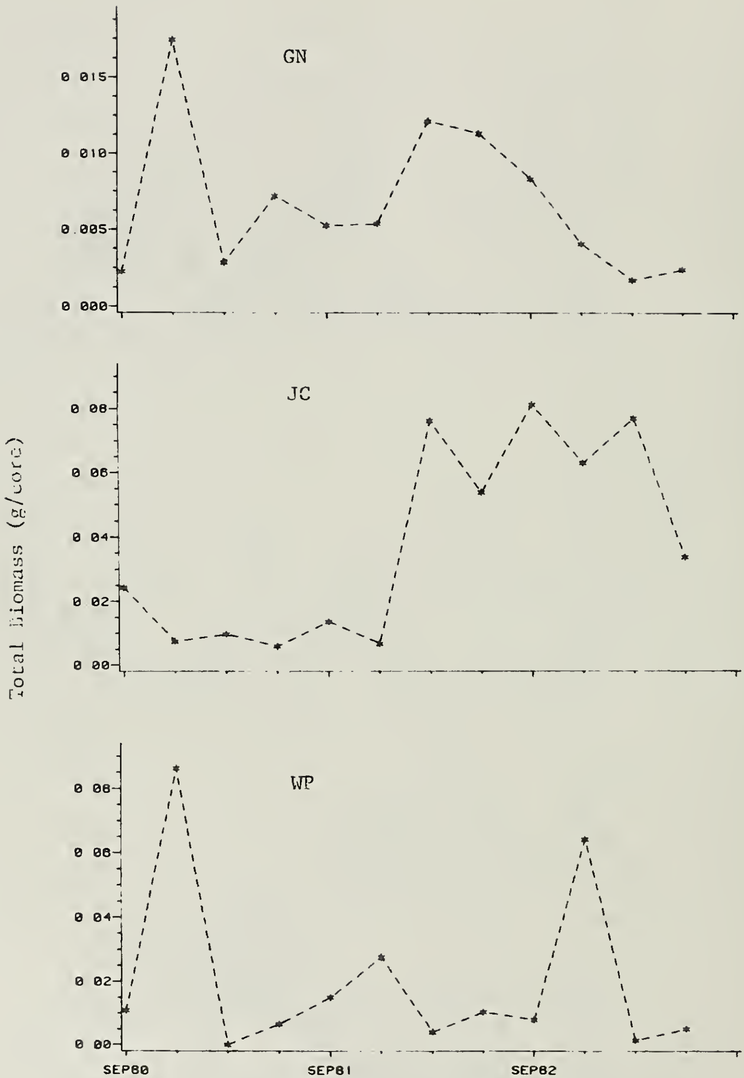


Figure 5. Biomass (ash-free dry weight), per core at Millstone intertidal stations sampled from September 1980 - June 1983.

density; values were highest in September, decreased to March and increased slightly in June. Biomass at JC was higher in September and March, and lower in December and June. The high March 1983 biomass was due in part to the presence of a few large molluscs and was not indicative of a uniform increase in community biomass. Although June densities were high, biomass was lower than other quarters since most of the organisms were small oligochaetes. Seasonal fluctuations in biomass at WP followed those of density, with highest values occurring in December.

Community Dominance

Intertidal communities during 1983 were numerically dominated by annelids and rhynchocoels; only three arthropod and one mollusc species were among the dominants at the three stations sampled (Table 3). At all stations, only a few species accounted for the majority of the individuals, with the ten most abundant taxa accounting for 99.2, 98.8 and 98.7% of the total organisms collected at GN, JC and WP, respectively. Oligochaetes were the only organisms among the top ten dominants at all stations. Both GN and WP communities included *Paraonis fulgens*, rhynchocoels, oligochaetes, and *Haploscoloplos fragilis* among their dominants.

At GN, *Paraonis fulgens* was most abundant (11/core) accounting for 37.5% of the total organisms collected (Table 3). Rhynchocoels were second in abundance at this station and accounted for 23.3% of the total. Oligochaetes, *Scolecolepides viridis*, *Haploscoloplos* spp. (juveniles), and *Capitella* spp. were collected in similar abundances and accounted for 6.3 to 9.2% of the totals. At JC, oligochaetes overwhelmingly dominated (249/core) accounting for 81% of the individuals. *Scolecolepides viridis* was the only other organism to occur in substantial numbers at this station. At WP, rhynchocoels (9/core), *Haploscoloplos fragilis* (6/core), and oligochaetes (3/core) were the most abundant taxa, accounting for 39.6, 25.6, and 11.9% of the total organisms collected.

Although the 1983 sampling program continued to identify year to year changes in the position of taxa among the dominants, there have been no long-term shifts in the composition at any of the intertidal monitoring stations.

Table 3. Feeding types, density (#/core), percent contribution, and Biological Index Value (BIV) of the ten most numerically abundant taxa at Millstone intertidal sites during 1983. Comparable data averaged over the previous three years are also included.

	Feeding[a] Type	1983 Mean Density	1980-82 Mean Density	1983 Percent	1980-82 Percent	1980-82 BIV
Giants Neck						
Paraonis fulgens	SDF	11	11	37.5	24.7	87.1
Rhynchocoela	C	7	9	23.3	21.3	94.9
Oligochaeta	SDF	3	2	9.2	5.6	64.1
Scolecolepides viridis	SDF	3	9	8.8	19.7	92.3
Haploscoloplos spp.	BDF	3	3	7.2	6.8	64.1
Capitella spp.	BDF	2	2	6.3	5.0	56.4
Haploscoloplos fragilis	BDF	1	3	3.8	6.6	69.2
Protodorvillea gaspeensis	SDF	1	1	1.4	0.1	-[b]
Chaetozone spp.	SDF	1	1	1.2	0.5	19.2
Neohaustorius biarticulatus	SF	1	1	0.5	0.1	-
Jordan Cove						
Oligochaeta	SDF	249	142	81.0	74.3	100.0
Scolecolepides viridis	SDF	30	16	9.8	8.3	88.1
Polydora ligni	SDF	9	1	2.8	0.8	45.2
Capitella spp.	BDF	7	2	2.3	1.0	71.4
Gammarus lawrencianus	SDF	3	5	1.0	2.7	47.6
Streblospio benedicti	SDF	2	1	0.6	0.1	-
Nereis succinea	SDF	2	1	0.5	0.1	20.2
Hediste diversicolor	O	1	4	0.4	2.0	78.6
Gammarus mucronatus	SDF	1	1	0.2	0.1	35.7
Eteone heteropoda	C	1	1	0.2	0.1	54.7
White Point						
Rhynchocoela	C	9	15	39.6	27.3	94.9
Haploscoloplos fragilis	BDF	6	6	25.6	12.1	87.2
Oligochaeta	SDF	3	8	11.9	15.6	73.1
Paraonis fulgens	SDF	2	11	6.7	20.1	89.7
Streptosyllis arenae	C	1	3	6.6	4.7	61.5
Haploscoloplos spp.	BDF	1	3	5.2	5.6	64.1
Parapionosyllis longicirrata	C	1	1	1.7	0.8	25.6
Polydora socialis	SDF	1	-	0.8	-	-
Exogone hebes	SDF	1	1	0.3	0.5	-
Mytilus edulis	SF	1	1	0.3	0.1	-

a - SDF=surface deposit feeder, C=carnivore, SDF-surface deposit feeder, SF=suspension feeder, O=omnivore.

b - Taxa not among top ten in last 3 years.

Trophic Structure

Feeding types of the dominant intertidal organisms were compared to identify any changes in community composition reflective of changing food resources. The majority of the dominant organisms at all intertidal stations were deposit-feeders and most were surface deposit-feeders (Table 3). At GN and WP, where the coarser sediments contain lesser amounts of fine material, large burrowing deposit-feeders (e.g. Haploscoloplos spp.) were typically found among the dominants. Small, surface deposit feeding oligochaetes dominated at JC, presumably reflecting the increased availability of fine organic material that could be used as a food source. Carnivores (primarily rhynchocoels) were primarily abundant at only GN and WP.

The taxa which dominated intertidal communities have been relatively consistent, trophic structural shifts have not occurred during our study. Although year to year changes in availability of food may have exerted an influence on the absolute abundance of certain populations, no major shifts in trophic structure have occurred in any intertidal community.

Long-term Population Densities

The abundances of the top four infaunal taxa collected at each Millstone intertidal station during 1983 were examined to identify seasonal patterns of abundance and station-specific or area-wide trends in the density that have occurred during the past six years.

Oligochaetes

Oligochaetes are small deposit-feeding worms that ranked first in abundance at JC in each of the last six years, with highest density occurring from March 1979 through December 1980 (Fig. 6 A). At GN and WP, oligochaete abundance has been consistently low throughout the monitoring program (Figs. 6 B,C). Seasonal peaks in density at these sites have occurred at GN during either June or September. At WP, oligochaete abundance from 1980-1982 at WP exhibited marked seasonal peaks, exceeding those in prior sampling years, but in 1983 collections, as those obtained prior to 1980, did not exhibit any seasonal peak.

Scolecolepides viridis

Scolecolepides viridis is a large burrowing species capable of using a wide range of food resources and occupying a variety of habitats. Scolecolepides ranked second and fourth during 1983 at JC and GN, but was not among the top ten at WP. The density of S. viridis at JC has been highly seasonal, typically peaking in June, remaining relatively high in September then declining in December and March (Fig. 6 D). In 1983, however, this species was abundant in each quarter resulting in a higher annual mean abundance and an increase in percent contribution, relative to the previous three years. At GN, major peaks in density generally occur

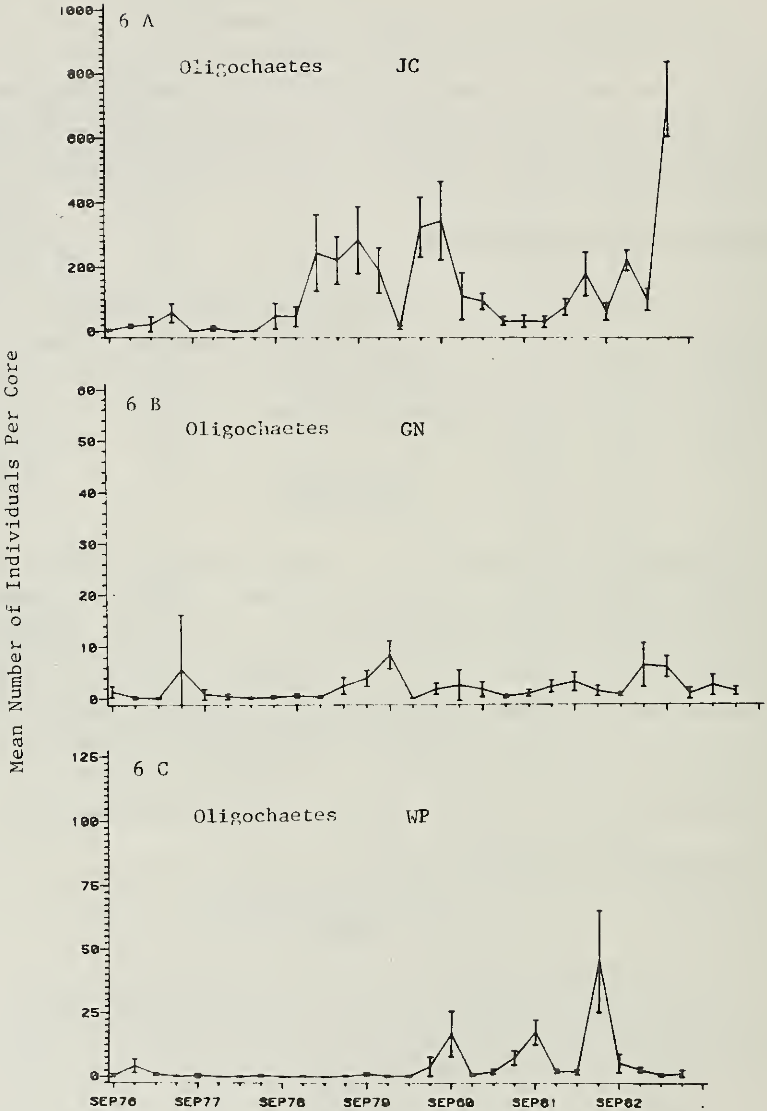
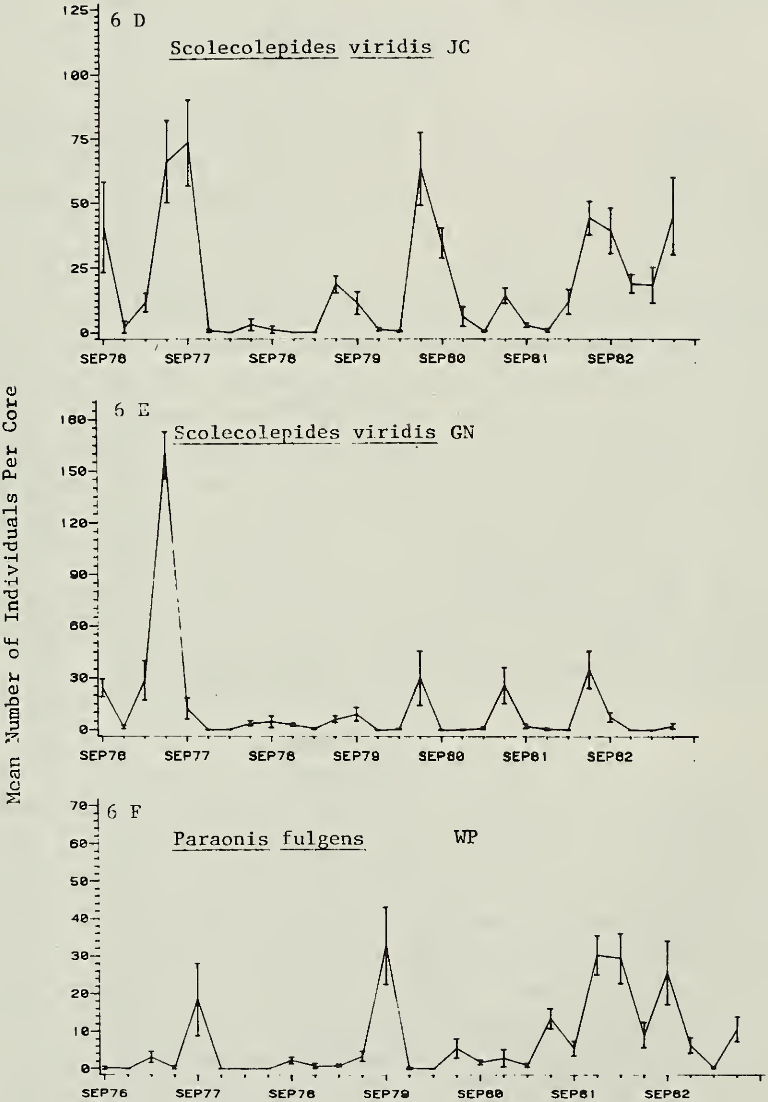


Figure 6. Seasonal mean density ($\pm$ 2 standard errors) per core (0.0078 m^2) of the four most abundant taxa collected at Millstone intertidal stations during 1983 and since September 1976.

Figure 6. (continued)



in June (Fig. 6 E). In 1983, unlike each of the last three years, the June peak did not occur; this resulted in a reduction in the annual density and percent contribution at GN.

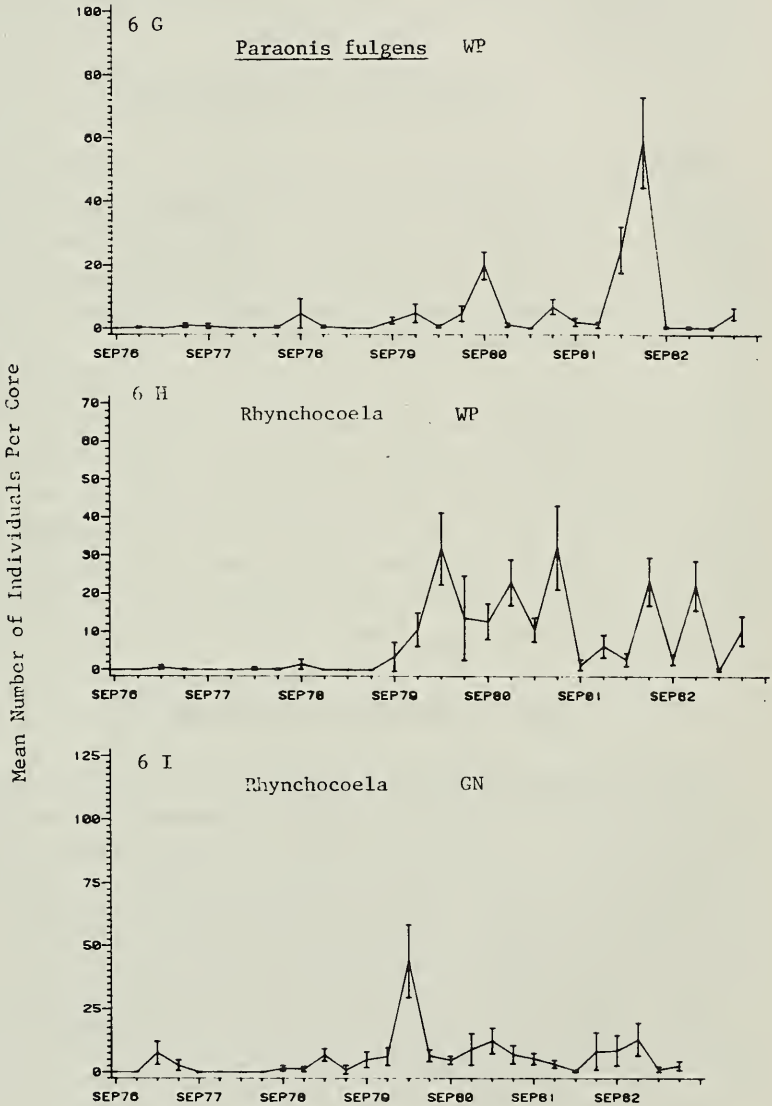
Paraonis fulgens

Paraonis fulgens is a small deposit-feeding polychaete, typically abundant in exposed, sandy intertidal and shallow subtidal habitats. Paraonis was a dominant component of the GN and WP infaunal communities, where it ranked first and fourth in overall abundance during 1983. This species has never been abundant at JC and in fact, only one individual has been collected at this station since the beginning of the monitoring program. Paraonis usually attains highest densities in June or September, but has been abundant in both December and March at GN. During last six years, sharp peaks in density occurred at GN in September 1977 and September 1979; a more constant period of high density occurred from December 1981 to September 1982 (Fig. 6 F). Although abundant at WP in 1983, Paraonis has not been a consistent dominant at this site over the last six years (Fig. 6 G). Low to moderate seasonal peaks occurred in September or June in 1978 and 1979, while a sharp peak occurred in June 1982. The 1983 values obtained at WP were well below those obtained in 1982; this year-to-year variability has been characteristic of this species at WP.

Rhynchocoels

Rhynchocoels are small, free-living carnivores that inhabit mud and sand from the low intertidal seaward. This group ranked first and second in abundance at WP and GN during 1983, and have been among the more consistently dominant organisms collected at both stations in recent years. At WP, densities have fluctuated over seasons and years (Fig. 6 H), while at GN their numbers remain relatively stable, except in March 1980 (Fig. 6 I). At both stations, rhynchocoels accounted for a greater portion of the community during 1979, when the sieve mesh was decreased to 0.5 mm. Some of the observed increase could be due to the use of a smaller mesh. However, low densities similar to those obtained prior to 1979 were

Figure 6. (continued)



obtained even after the use of the smaller mesh. The 1983 sampling continued to support previous trends of relative stability in abundance within and among years at GN, and variability within but relative stability among years at WP.

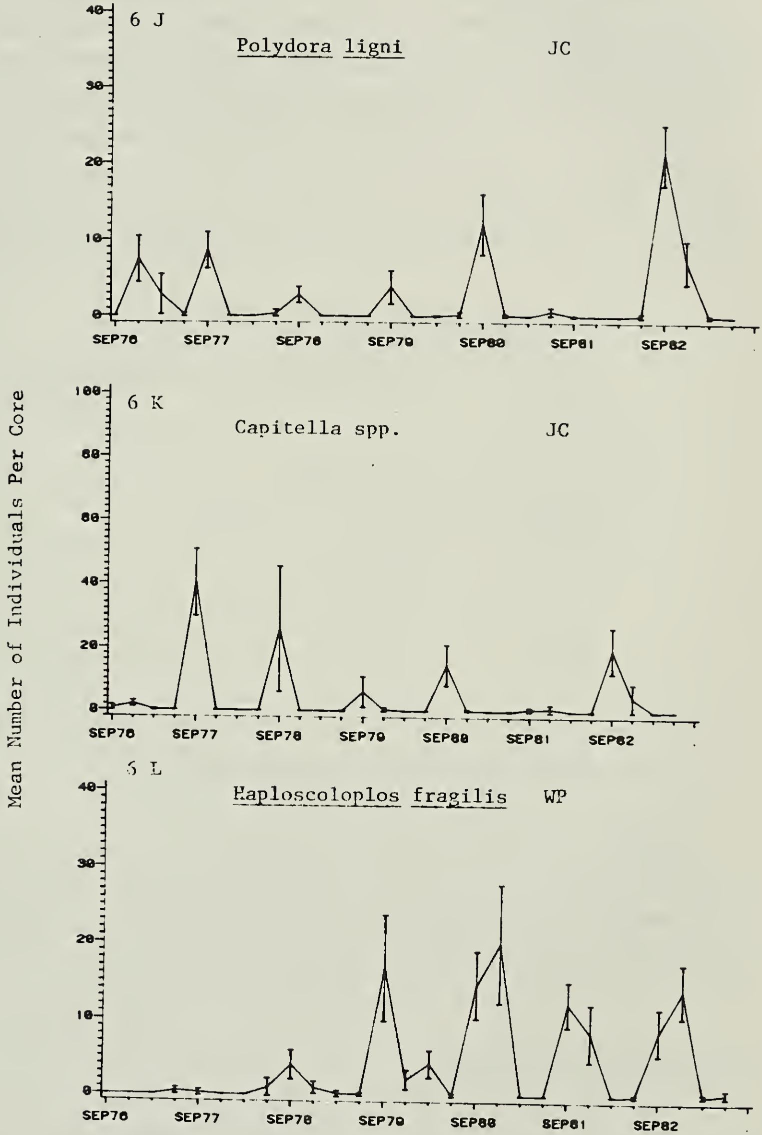
Polydora ligni and Capitella spp.

These deposit-feeding taxa have frequently been identified as pollution indicators, although they are also common components of many intertidal and subtidal sand communities. Since these taxa exhibited similar spatial and temporal patterns, they will be considered together in this report. Polydora and Capitella were among the top four dominants at only JC, where they ranked third and fourth in abundance over 1983. Both taxa are seasonal dominants being generally most abundant, and often only present in the September collections (Figs. 6 J,K). In 1983, peak abundance occurred in September as in past years; however, density remained unusually high in December and thus led to the overall increase in the annual abundance of both taxa. The peak density obtained in September for Polydora was a record high value. During 1982, the September peak for both taxa was conspicuously absent; this represented the first year since 1977 in which this peak was not evident.

Haploscoloplos fragilis

Haploscoloplos fragilis is a large deposit-feeding polychaete typically abundant on exposed to moderately exposed sandy beaches, where it can rapidly burrow into and through wave scoured sediments. Haploscoloplos was among the top four dominants at only WP in 1983, but ranked seventh at GN. At WP, this species is usually most abundant in September and December and few individuals are collected at other times of the year (Fig. 6 L). Prior to 1979, the densities of this species were low, probably due to taxonomic problems, but since then seasonal trends, levels of abundance, and its distributional patterns have been consistent.

Figure 6. (continued)



Species Diversity

Annual mean diversity (H') of intertidal communities ranged from 1.39 at GN to 1.69 at JC (Table 4). At GN, both diversity and evenness varied similarly over the four sampling periods. Both H' and S in 1983 were lower than the three year average, while evenness remained generally constant. At JC, all measures of diversity exhibited strong seasonal shifts; in 1983 both H' and J were lower than the previous three year mean while S was higher. Diversity measures at the White Point station also varied seasonally, and only S was within the previous three year averages.

Table 4. Species diversity (H'), evenness (J), and number of species (S) for each Millstone intertidal station sampled in 1983, range of means 1980 - 1982.

	1983 Annual Mean and Standard Deviation[a]	1980-82 Range of Annual Means
Giants Neck		
H'	1.39 ± 0.35	1.60 - 2.25
J	0.48 ± 0.12	0.39 - 0.65
S	8 ± 1	11 - 16
Jordan Cove		
H'	1.69 ± 1.09	1.73 - 1.80
J	0.39 ± 0.19	0.46 - 0.49
S	20 ± 12	12 - 19
White Point		
H'	1.47 ± 0.11	1.19 - 2.07
J	0.59 ± 0.24	0.37 - 0.67
S	7 ± 3	9 - 12

a - Standard Deviation calculated using quarterly collections in September, December, March and June.

Diversity measures, during the last several years have remained generally stable at all stations. Although S has varied, the species contributing to this change were generally not among the more abundant organisms and their presence or absence had little influence on the other measures of diversity.

Cumulative Species Curves

Cumulative species curves of intertidal communities sampled since 1980 were plotted to compare the total species and the seasonal shifts in the numbers of species comprising intertidal communities over the last several years. Total species numbers collected in 1983 at GN and WP were lower than values obtained in recent years (Fig. 7). At GN, quarterly species totals were consistently lower than any observed since 1980; at WP seasonal totals were generally at or below the lowest values recorded since 1980.

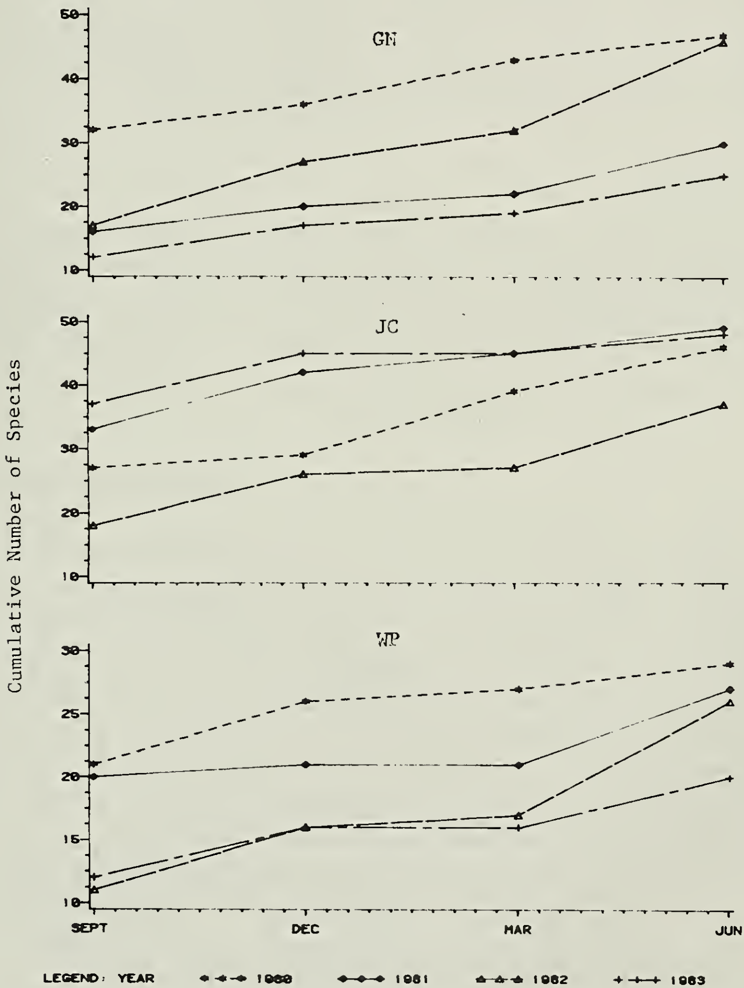


Figure 7. Annual species curves for each Millstone intertidal station from 1980 - 1983.

Annual totals at JC were similar to or above the highest species totals recorded at this station in recent years.

Seasonal increases in species numbers occurred at all stations reflecting additions to the species pool. At all stations, annual curves were gently sloped, illustrating the major contribution the September collection in determining the annual totals. The GN community exhibited the largest seasonal increase over the four sampling periods, while that of JC exhibited the smallest. In 1983, and in nearly all other years, a complement of winter (December) and early summer (June) species occurred while few if any, additional species were collected in March.

Cluster Analysis

Cluster analysis was performed on the intertidal data collected in each of the last four years to illustrate station similarity in community composition and abundance. The analysis separated the three intertidal stations into two major groups, one containing all JC years (Group I) and one containing GN and WP years (Group II) (Fig. 8). These groups linked at

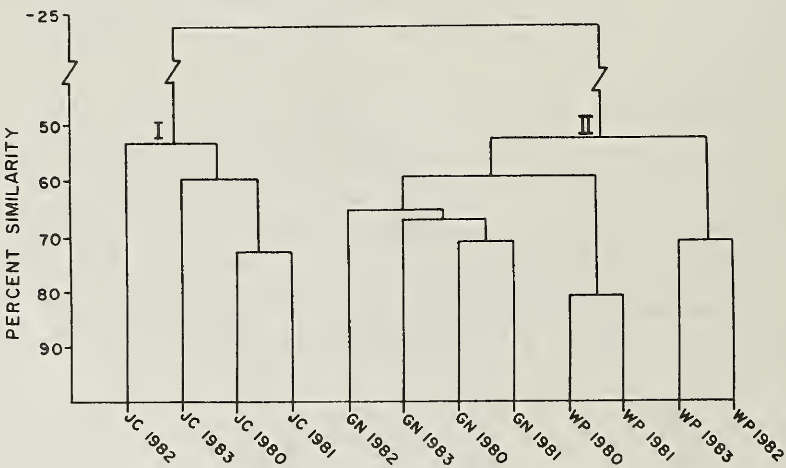


Figure 8. Dendrogram resulting from classification of annual collections at Millstone intertidal stations, September 1979 - June 1983.

low similarity because of the differential density of oligochaetes (high at JC and low at WP and GN), and more importantly, because of differences in species composition. For instance, Paraonis fulgens, Haploscoloplos spp. and rhynchocoels were primary dominants at only the WP and GN stations while Nereis spp., Hediste diversicolor, Polydora ligni, and several mollusc and arthropod species were dominants only at JC.

Linkage of annual collections within the two major groups was primarily determined by year-to-year changes in density not in species composition. For example, year-to-year changes in oligochaete abundances was the major factor forming the relationship between JC collections; the 1980 and 1981 collections contained similar numbers of oligochaetes and resulted in high similarity among these years. The GN and WP collections linked over a low range of similarity. The WP collections were separated from GN collections based on the high numbers of Haploscoloplos fragilis at WP in 1980 and 1981 and the low density that occurred in 1982 and 1983; this was also a major factor in forming linkages among WP years.

SUBTIDAL RESULTS

Sediment Characteristics

Sediment characteristics of subtidal stations are presented in Figure 9. Of all stations, IN sediments were consistently finest and those of JC coarsest (except in June). Typically, sediments at IN contained smaller amounts of silt/clay than other stations and those at GN contained higher amounts. In June, however, sediments at IN contained an unusually high amount of silt/clay (20.1%). There were no consistent seasonal trends in sediment size or silt/clay content at any subtidal station. Organic content was generally highest at GN and lowest at IN (Table 5). At all stations, sediments collected in June contained the highest amount of organic material, while at all but the JC station, lowest values were recorded in March.

Although sediment characteristics at the subtidal stations in 1983 were generally similar to previous years, notable differences were observed at GN and IN. Mean grain size at GN increased relative to previous years with a concurrent decrease in silt/clay content. At IN, an increase in

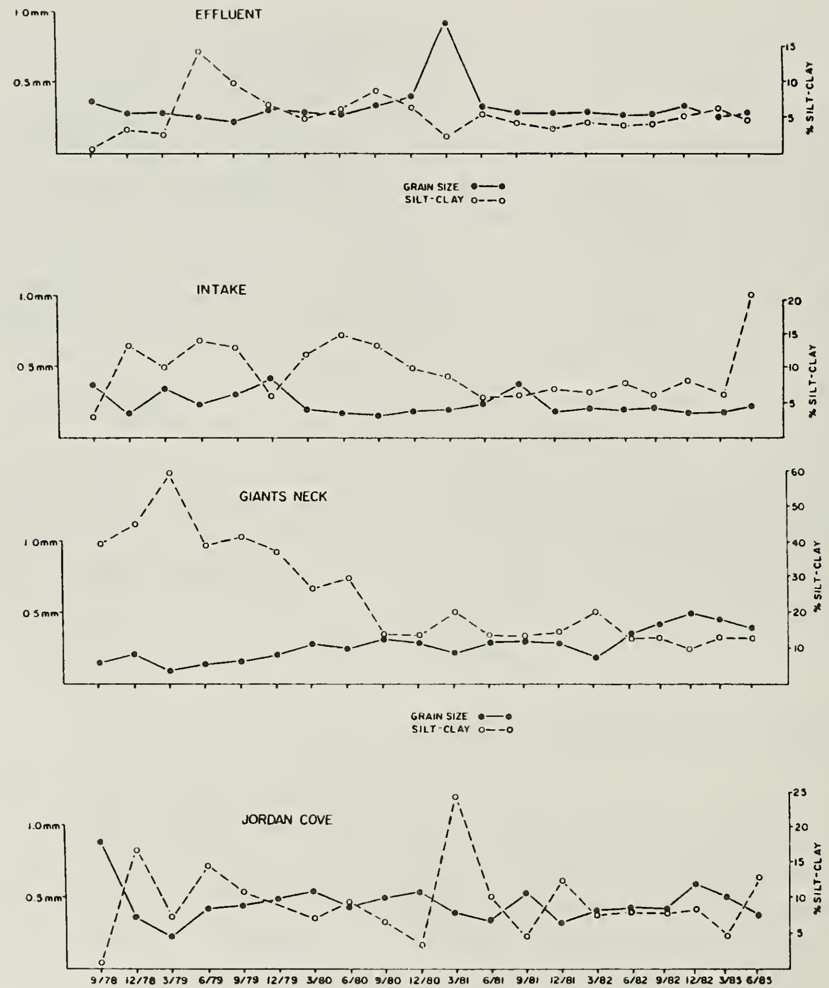


Figure 9. Sediment characteristics at the Millstone subtidal stations, September 1978 - June 1983.

both silt/clay and organic matter occurred in June 1983 in conjunction with ongoing construction at the Unit 3 Intake structure. During this period, most of the area was enveloped by highly turbid water due to erosion of material from the construction station.

Table 5. Percent organic matter in the sediments at Millstone subtidal stations sampled from September 1980 - June 1983.

	1983 $\bar{X}$	1982 $\bar{X}$	1981 $\bar{X}$
Giants Neck			
September	2.47	2.68	2.29
December	2.27	2.24	2.74
March	2.10	3.03	2.90
June	2.85	3.65	2.51
Jordan Cove			
September	1.01	0.67	0.98
December	0.85	0.75	0.75
March	0.95	1.10	1.22
June	1.27	0.97	1.52
Intake			
September	0.70	0.52	0.82
December	0.74	0.68	0.77
March	0.65	0.91	0.71
June	1.33	0.85	0.91
Effluent			
September	1.44	1.27	2.53
December	1.43	1.29	1.76
March	1.27	2.51	0.98
June	2.07	1.98	1.56

General Community Composition

During 1983, sampling of the subtidal benthic communities yielded a total of 188 species and 31,183 individuals (Table 6). In terms of species numbers, polychaetes and arthropods dominated all subtidal communities accounting for 76.7% to 81.7% of the total species collected. Mollusc species contributed 12-18% of the species. In terms of individuals, polychaetes and oligochaetes, accounted for most of the organisms, with polychaetes most abundant at GN, JC, and IN and oligochaetes at EF. Arthropods were numerically abundant at IN, where they accounted for 33% of the individuals. Molluscs contributed less than 3% of the individuals at all stations.

The general composition of subtidal communities in 1983 was similar to that observed over the last three years, although some values for percent of species and individuals were outside of the previous three year range, most differences were less than 5%. Only the percent of polychaetes individuals at EF and IN decreased by more than 5% relative to the three year mean (6.1 and 7.5%, respectively). At both stations, an increase in the percentage of oligochaetes was primarily responsible for the observed decrease in the percentage of polychaetes.

Table 6. Number of species (S), relative percent of total (%), number of individuals (N)[a], and percent of total individuals (%) for each major taxon collected at Millstone Point subtidal stations from September 1980 - June 1983.

Stations	1983				1980 - 82			
	S	%	N	%	S	%	Range N	%
Effluent								
Polychaetes	67	46	3130	38	72 - 74	46 - 52	3785 - 10387	44 - 74
Oligochaetes	-[b]	-	4197	51	-	-	2264 - 4005	16 - 47
Molluscs	27	18	162	2	26 - 33	19 - 21	201 - 671	2 - 5
Arthropods	46	31	665	8	37 - 45	27 - 29	456 - 1169	5 - 9
Others	6	4	105	1	4 - 8	3 - 5	157 - 315	1 - 2
Totals	146		8259					
Giants Neck								
Polychaetes	59	51	5495	70	66 - 80	51 - 53	6609 - 12724	59 - 71
Oligochaetes	-	-	1305	17	-	-	2963 - 3346	21 - 30
Molluscs	14	12	84	1	21 - 26	14 - 18	282 - 399	2 - 4
Arthropods	35	30	883	11	36 - 50	26 - 33	757 - 1208	5 - 7
Others	6	5	67	1	1 - 5	0 - 3	65 - 120	1 - 1
Totals	114		7834					
Intake								
Polychaetes	45	55	993	44	44 - 52	47 - 49	1790 - 2076	51 - 66
Oligochaetes	-	-	439	19	-	-	388 - 538	12 - 16
Molluscs	14	17	71	3	16 - 23	17 - 22	165 - 423	5 - 13
Arthropods	21	26	746	33	29 - 34	29 - 32	297 - 965	10 - 28
Others	1	1	13	1	0 - 3	0 - 3	15 - 27	1 - 1
Totals	81		2262					
Jordan Cove								
Polychaetes	58	54	6547	51	64 - 78	52 - 55	3704 - 10635	33 - 50
Oligochaetea	-	-	5573	43	-	-	5355 - 11898	40 - 61
Molluscs	16	15	241	2	18 - 32	16 - 22	171 - 761	2 - 6
Arthropods	29	27	376	3	27 - 34	21 - 24	325 - 476	2 - 4
Others	3	3	91	1	3 - 4	2 - 4	109 - 132	1 - 1
Totals	105		12828					

[a] - 60 replicates per station 1980, 1981, 1982 and 50 replicates in 1983.
[b] - Taxon not indentified to the species level.

During 1983, ten species were collected for the first time at Millstone subtidal stations (Table 7); two were molluscs, four were polychaetes, and four were arthropods. All newly collected taxa were found in low abundance, i.e. usually only one or two individuals collected in 1983. These taxa have probably been present in past years, but not collected because of their scarcity.

Numbers of Species and Community Density

Quarterly average number of species comprising subtidal communities in 1983 ranged from 11/core at IN to 36/core at EF (Fig. 10). The IN community included fewest species, but no station consistently contained the most. The number of species varied considerably over the four sampling

Table 7. Species reported for the first time at the Millstone subtidal (S) and intertidal (I) stations sampled from September 1982 - June 1983.

Mollusca		Arthropoda	
Pelecypoda		Xanthidae	
Mactridae		*Rhithropanopeus harrisii*	S
Spisula polynma	S	Lysianassidae	
Lasaeidae		*Orchomenella pinguis*	S
Aligena elevata	S	Bodotriidae	
Annelida		*Leptocuma minor*	S
Polychaeta		Bateidae	
Syllidae		*Batea catharinensis*	S
Brania pulsilla	S		
Terebellidae			
Amphitrite johnstoni	S		
Goniadidae			
Goniadella maculata	S		
Spirorbidae			
Spirorbis vicolaceus	S		

periods with the highest numbers collected in June at all stations, except JC.

Between-station differences in the numbers of species and the variations within years observed at all stations during 1983 has been characteristic of these communities since 1976. Overall, the numbers of species have remained fairly constant on an annual basis and no station has exhibited any consistent increase or decrease in species numbers. All but one station exhibited an increase in species numbers beginning in March 1979; this corresponded to the time when a smaller mesh sieve (0.50 mm vs 0.71 mm) was used to process samples.

Average quarterly density ranged from a high of 289/core (JC) to a low of 31/core (IN) (Fig. 11). Density was consistently highest at JC and lowest at IN, and at all stations high densities were found in September and June.

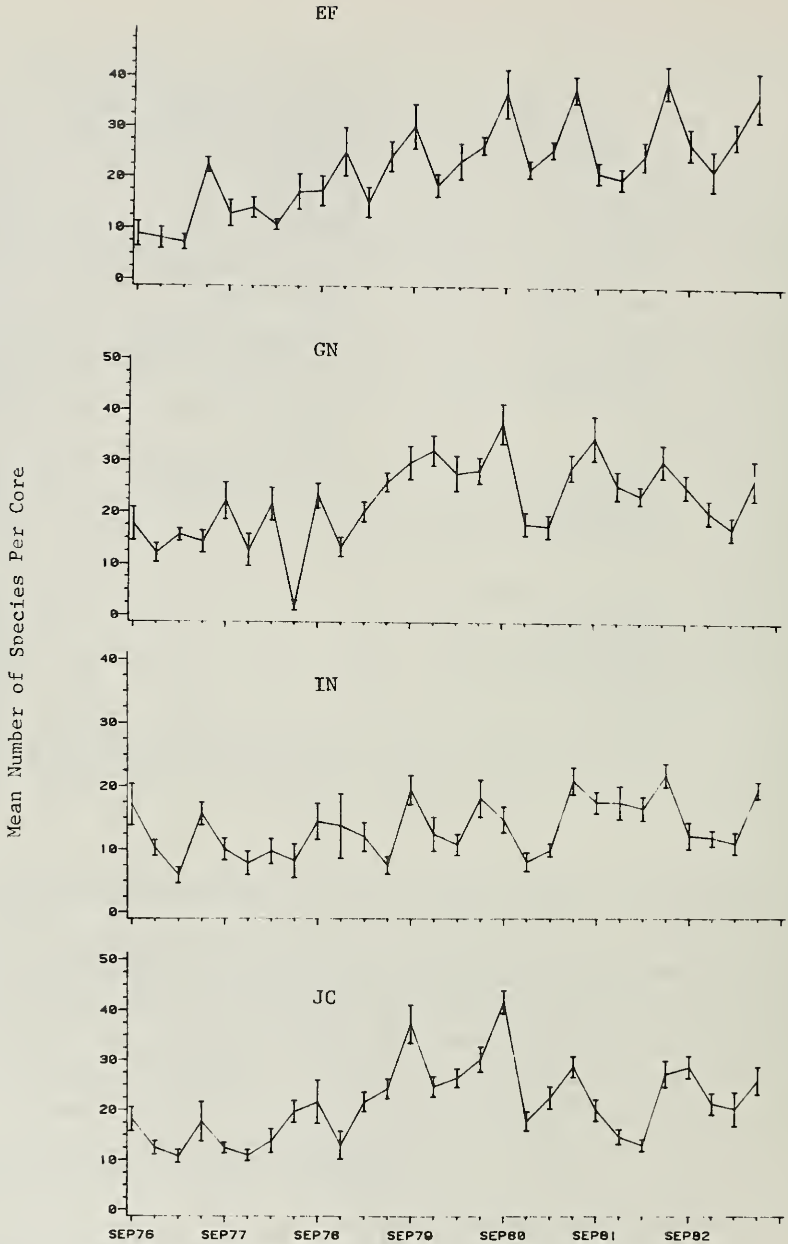


Figure 10. Mean number of species per core (± 2 standard errors) collected at Millstone subtidal stations sampled from September 1976 - June 1983.

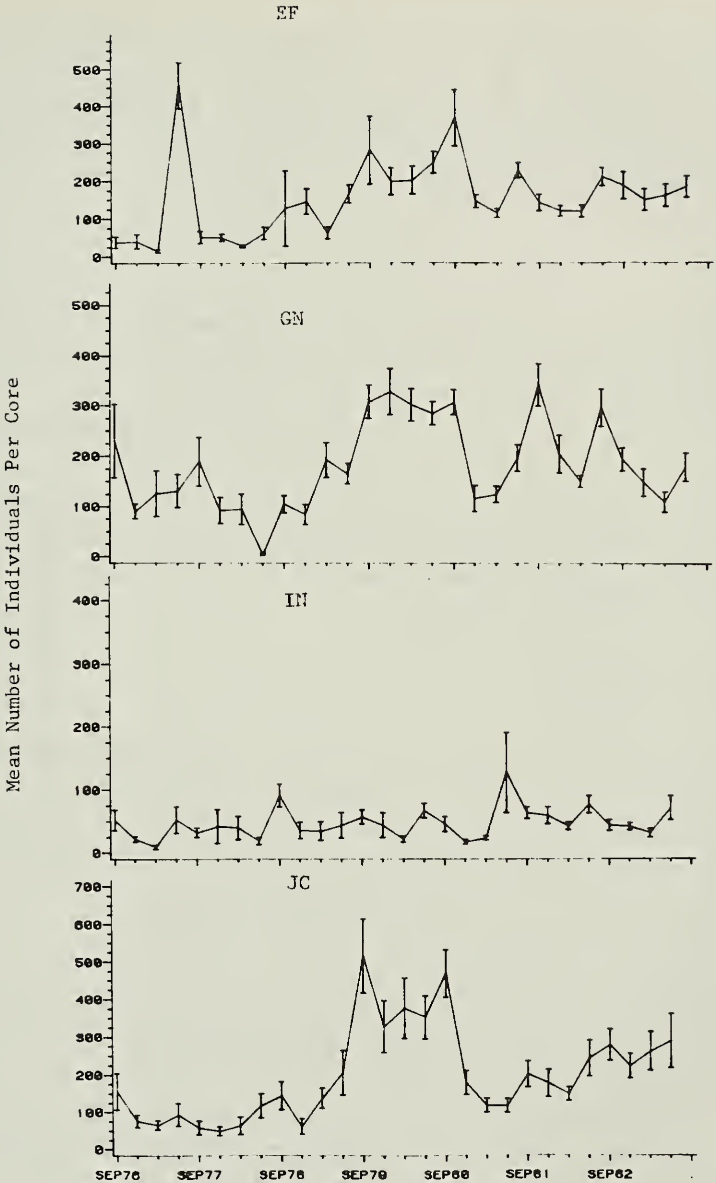


Figure 11. Mean number of individuals per core (± 2 standard errors) collected at Millstone subtidal stations, sampled from September 1976 - June 1983.

During 1983, community densities were well within the range of those obtained in past years. Densities at IN, although varying within any given year, have been generally consistent since 1976. At EF, GN and JC, peak densities occurred in 1979-80, but since then, have exhibited fairly stable levels of abundance between years.

Biomass

Average biomass (ash-weight) of subtidal communities in 1983 ranged from 0.01 g/core (IN) to 0.04 g/core (EF) (Fig.12). Over the four sampling periods, biomass fluctuated most at IN and least at JC. These within year fluctuations did not consistently follow patterns of abundance. In nearly all cases, periods of peak biomass corresponded to high densities of arthropods and molluscs, organisms that are typically large relative to annelids. During 1983, biomass exhibited less variation (except IN) than in the previous years, and all values were well within the ranges typically observed at our monitoring stations.

Community Dominance

At all stations, except IN, the ten most abundant organisms accounted for over 80% of all the organisms collected (Table 8). Oligochaetes and *Aricidea catherinae* were the only taxa among the top 10 at all stations and together comprised from 32.4% (IN) to 68.4% (JC) of the individuals identified during 1983. *Polydora caulleryi*, *Chaetozone* spp., and *Tharyx* spp. were among the dominants at all but the IN station.

Densities of individual taxa were highest at the JC station where oligochaetes (111/core) and *A. catherinae* (64/core) were most abundant. At IN, even the most abundant organism, *Ampelisca verrilli*, occurred in relatively low densities (11/core). Beyond the top two or three taxa, each of the subtidal communities included some organisms that were dominant components only at single station. *Polycirrus eximius* and *Protodorvillea gaspeensis* were important components at EF, *Tharyx* spp. at GN, *A. verrilli* and *Exogone hebes* at IN, and *P. caulleryi* and *Mediomastus ambiseta* at JC.

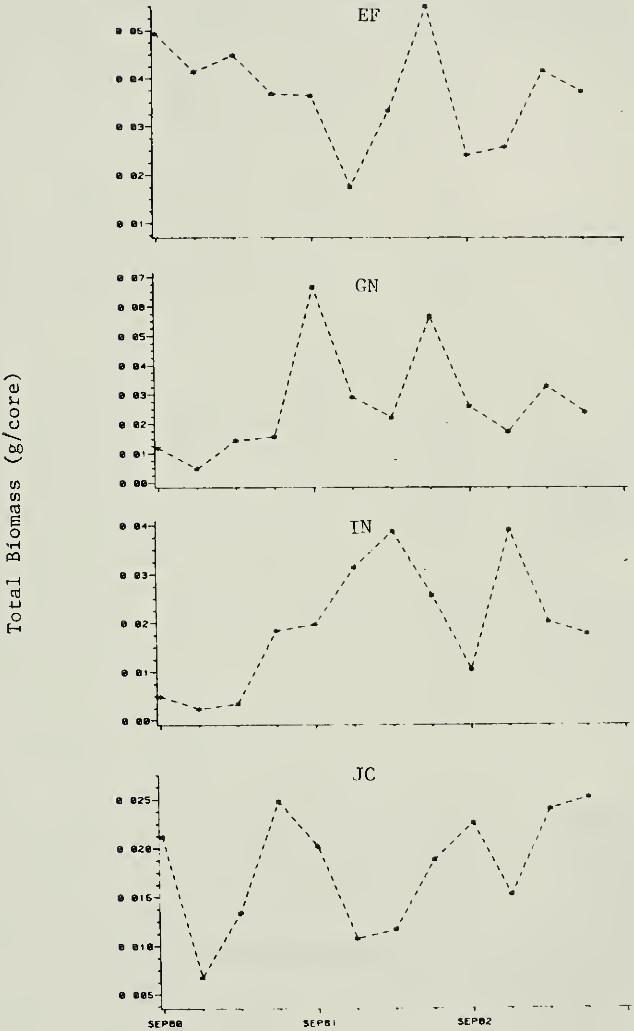


Figure 12. Biomass (ash-free dry weight) per core at Millstone subtidal stations sampled from September 1980 - June 1983.

Table 8. Feeding types, density, (#/core), percent contribution, and Biological Index Value BIV of the top ten numerically abundant taxa at Millstone subtidal sites during 1983. Comparable data averaged over the previous three years are also included.

	Feeding[a] Type	1983 Mean Density (per core)	1980-82 Mean Density (per core)	1983 Percent	1980-82 Percent	1980-82 BIV
Effluent						
Oligochaeta	SDF	84	56	50.8	29.0	95.6
Aricidea catherinae	SDF	11	12	6.6	6.2	66.7
Polycirrus eximius	SDF	10	20	5.9	10.7	88.9
Protodorvillea gaspeensis	O	8	9	4.6	4.7	75.6
Polydora caulleryi	SDF	6	1	3.6	0.05	-[b]
Chaetozone spp.	SDF	5	41	3.2	21.0	75.6
Exogone hebes	SDF	4	3	2.2	1.3	46.7
Ampelisca verrilli	SF	3	1	1.7	0.1	-
Tharyx spp.	SDF	2	3	1.4	1.8	42.2
Caulleriella spp.	SDF	2	1	1.2	0.6	27.7
Giants Neck						
Aricidea catherinae	SDF	40	55	25.7	23.3	95.2
Tharyx spp.	SDF	30	24	19.3	10.3	83.3
Oligochaeta	SDF	26	59	16.7	25.0	97.6
Chaetozone spp.	SDF	7	24	4.5	10.0	61.0
Lumbrineris tenuis	BDF	7	4	4.3	1.7	38.1
Polydora caulleryi	SDF	5	1	3.5	0.3	-
Protodorvillea gaspeensis	O	5	2	3.5	0.8	61.9
Gammarus lawrencianus	O	5	6	3.2	2.4	25.0
Leptocheirus pinguis	SDF	3	1	2.0	0.1	-
Exogone dispar	O	2	2	1.4	1.0	-
Intake						
Ampelisca verrilli	SF	11	2	24.3	4.6	55.6
Oligochaeta	SDF	9	8	19.4	16.1	100.0
Aricidea catherinae	SDF	6	5	13.0	11.5	88.9
Exogone hebes	SDF	3	2	7.0	5.0	60.0
Polydora quadrilobata	SDF	2	1	4.3	0.9	-
Capitella spp.	BDF	2	3	3.3	7.1	71.1
Leptocheirus pinguis	SDF	1	1	2.0	0.7	-
Pygospio elegans	SDF	1	1	2.1	0.4	-
Tellina agilis	SF	1	1	1.6	1.8	62.2
Unciola serrata	SF	1	3	1.6	6.5	28.9
Jordan Cove						
Oligochaeta	SDF	111	134	43.4	51.1	100.0
Aricidea catherinae	SDF	64	36	25.0	13.7	91.7
Polydora caulleryi	SDF	21	1	8.0	0.4	29.2
Lumbrineris tenuis	BDF	8	8	3.0	3.1	77.1
Polycirrus eximius	SDF	7	8	2.6	2.9	70.8
Mediomastus ambiseta	BDF	5	26	2.1	9.9	56.3
Chaetozone spp.	SDF	4	4	1.7	1.6	43.8
Capitella spp.	BDF	4	3	1.7	1.2	-
Leptocheirus pinguis	SDF	4	1	1.5	0.2	49.0
Tharyx spp.	SDF	4	4	1.5	1.6	66.7

a - SDF=surface deposit feeder, SDF=surface deposit feeder, SF=suspension feeder, O=omnivore.
b - Taxa not among top ten in last 3 years

Of all subtidal communities sampled, that of IN was most unique, with four of its top ten numerical dominants were abundant only at this station.

Generally, the dominant organisms during 1983 were the same as those observed in past years; at all stations, over 50% of the dominant taxa in 1983 were among the overall top ten from 1980-82 (7 of 10 at EF, 6 of 10 at GN and IN, and 9 of 10 at JC). In nearly all cases, species that were added or replaced as dominant in 1983 were of low abundance relative to organisms consistently found as dominants.

The major change in the taxa dominating subtidal communities was the appearance of Polydora caulleryi among the top ten at EF, GN, and JC. At EF and GN, this taxon was not among the top ten in any of the previous three years. At JC, densities of this species averaged 1/core from 1980-82, but increased to 21/core in 1983. Other compositional changes in 1983 included lower densities of Chaetozone spp. at EF and GN, lower densities of Polycirrus eximius at EF and lower densities of oligochaetes at GN. At IN, Ampelisca verrilli was unusually abundant in 1983, relative to the previous three years. A notable reduction in the abundance of Mediomastus ambiseta occurred at JC, where it averaged 5/core in 1983 compared to 26/core over the last three years. The three year BIV of 56.3% reflected the typical year-to-year fluctuations in density of this species of the the last three years.

Trophic Structure

Feeding types of the dominant subtidal organisms were examined to evaluate any observed differences in subtidal community composition between stations and years reflected changing food resources. In 1983, the top three dominant organisms at EF, GN, and JC were surface deposit-feeders while at IN, a suspension feeder was most abundant (Table 8). This type of trophic structure, and the differences among stations were consistent with observations made during the last six years. Bottom deposit-feeding species have charactertically more abundant at JC, suspension feeders at EF and particularly IN, and omnivores at GN. The relative constancy in trophic structure reflects the general stability in species composition of the Millstone subtidal communities and no major shifts have occurred at any subtidal station the last six years.

Long-Term Population Densities

The abundances of the top four infaunal taxa collected at each Millstone subtidal station during 1983 were examined to identify seasonal patterns of abundance and station-specific or area-wide trends in density that have occurred during the past six years.

Oligochaetes

Oligochaetes are small, deposit-feeding worms that feed on fine bottom deposits. During 1983, oligochaetes ranked first in abundance at JC and EF, second at IN and fourth at GN. This taxon was among the top four dominants at all subtidal stations and have been among dominant infaunal organisms collected at all monitoring stations since 1976. Oligochaetes have typically been most abundant at JC and least abundant at IN. During the last six years, no seasonal trends have been evident at any of the stations (Figs. 13 A-D). Year-to-year densities have been most stable at IN, where lowest abundances occur. During the last two years, densities at both JC and EF have also remained quite stable while those at GN have exhibited a gradual decline in abundance.

Aricidea catherinae

Aricidea catherinae is a small deposit-feeder that occupies a wide range of habitats and is subsequently a common member of many subtidal communities. Despite its widespread abundance, surprisingly little is known about its food preferences, reproductive strategy, and function within marine communities.

During 1983, *Aricidea* ranked first in abundance at GN, second at EF and JC, and third at IN; this species was the only taxon other than oligochaetes that was among the top four at all subtidal stations. *Aricidea* has consistently been among the top ten taxa at all stations since 1976, despite the strong within and between-year fluctuations in density that have occurred at all stations (Figs. 13 E-H). On a seasonal basis, peak densities often occurr in September or June, although peaks have occured in all seasons. The abundance of *Aricidea* has been most

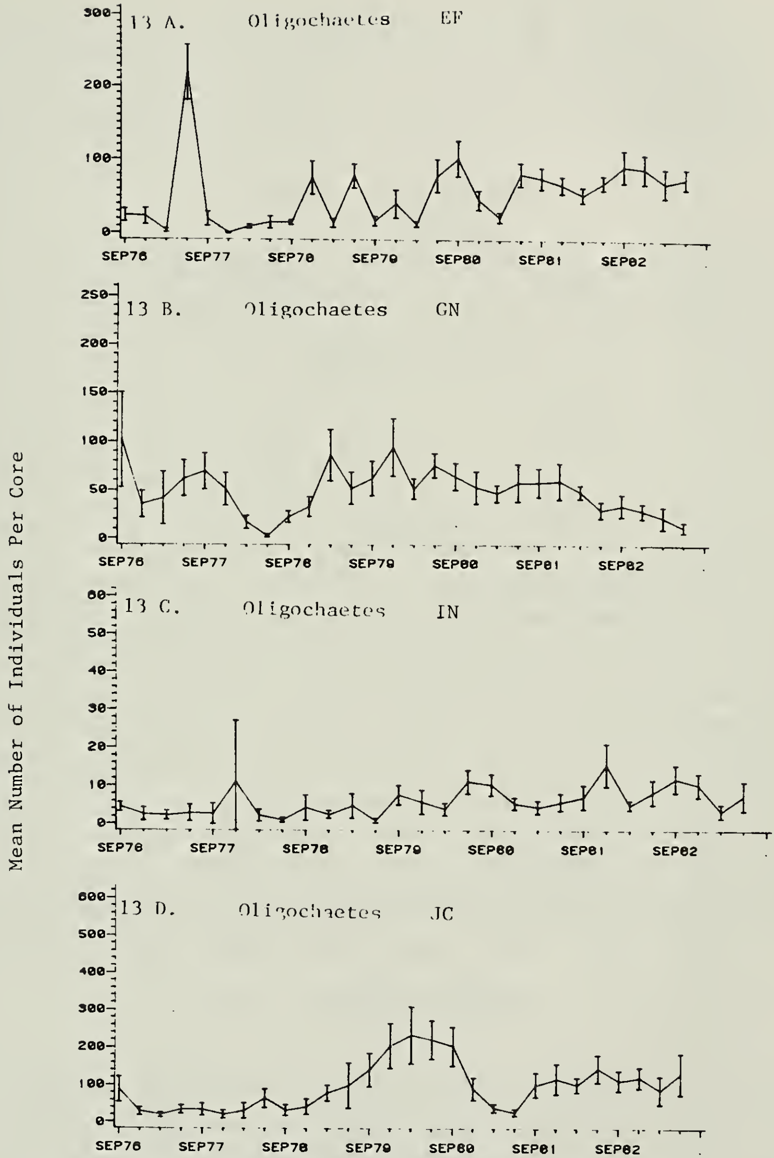
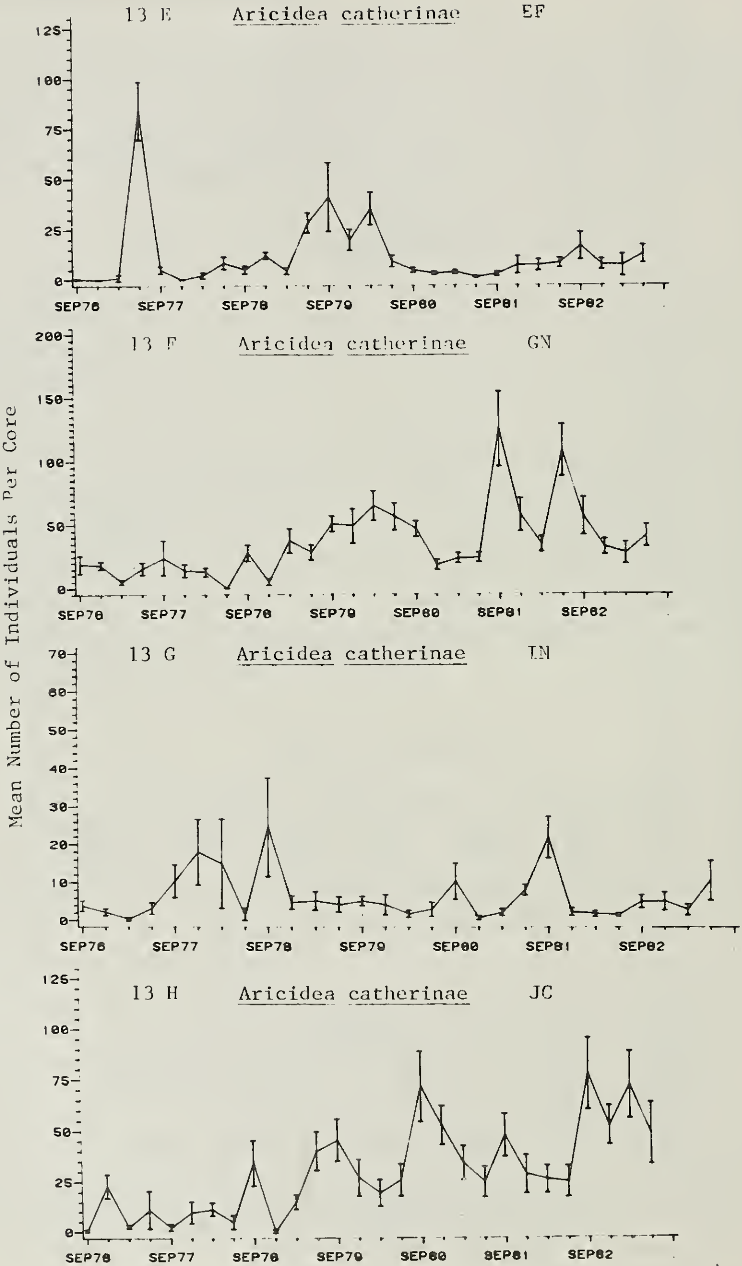


Figure 13. Seasonal mean density ($\pm$ 2 standard errors) per core (0.0078 m^2) of the four most abundant taxa collected at each subtidal station during 1983 and since September 1976.

Figure 13. (continued)



consistent at IN and EF, where lower numbers have generally been collected. The 1983 abundances of Aricidea at EF, IN and GN were consistent with previous years values. Those at JC were generally higher than those obtained in the past, continuing an apparent trend of increased abundance.

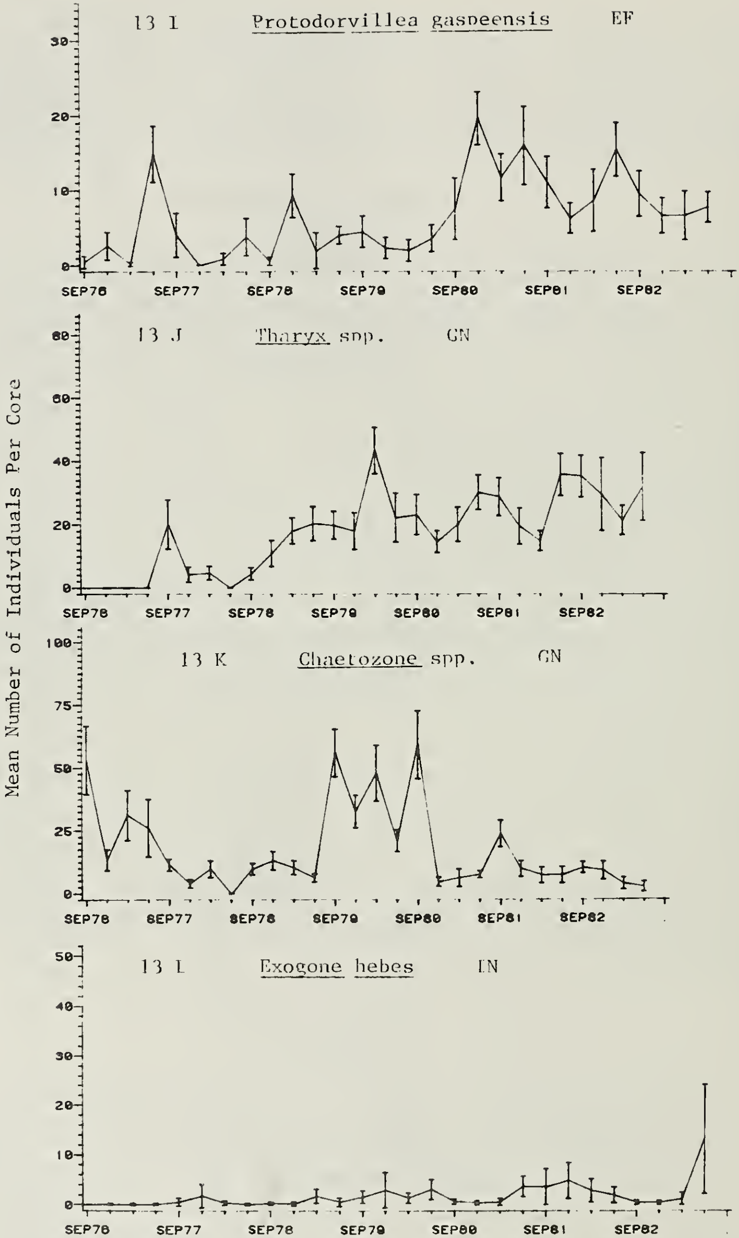
Protodorvillea gaspeensis

Protodorvillea gaspeensis is a small dorvilleid polychaete that commonly inhabits shallow subtidal areas where sediments are composed of sand or sandy mud. During 1983, Protodorvillea was among the top four at dominants at only EF and was among the top ten at only one other station (GN). This species has consistently been most abundant at stations where sediments generally contain large amounts of shell (i.e. EF). Since 1976, the abundance of this taxon has exhibited considerable within year variations, although periods of peak abundance have not consistently occurred in any one season. From 1980-83, densities of this species at EF were higher than those observed in the previous three years (Fig. 13 I). In addition, both within year and between replicate variability has increased. Year-to-year variability has also increased at the GN station since 1981. The increased density observed at JC began soon after the smaller mesh sieve was used to process infaunal samples (March 1979); however increased density at EF began in 1980, six sampling quarters after the smaller mesh was used. Thus, it is unlikely that the observed increase at EF was a sampling artifact. Densities of Protodorvillea observed in 1983 were within the range observed in past years. More importantly, this species remained dominant at those subtidal stations where it had been abundant in past years.

Tharyx spp.

Tharyx spp. are surface deposit-feeders that ranked among the top 4 at only GN during 1983, but was among the top ten at EF and JC. Although in early years (particularly prior to September 1977), taxonomic problems with this group make density comparisons inappropriate, it has been an important component of the both GN and JC communities. In June 1981, this species became a dominant also at EF. Tharyx spp. have been most abundant at GN

Figure 13. (continued)



usually in September or June, and during the last several years, these peaks have been very consistent (Fig. 13 J). At JC, densities of Tharyx spp. in 1983 were consistent with previous years values; those at GN were slightly higher, continuing a trend of increased density which began in September 1978 period.

Chaetozone spp.

Chaetozone spp. are surface deposit-feeders that commonly inhabit the muddy interstices within mussel beds and among kelp holdfasts. Chaetozone spp. were among the top four at only GN in 1983, but were also among the top ten at EF and JC in 1983. This taxon has been a consistently dominant organism at GN (Fig. 13 K), while at the other stations, it has exhibited large year-to-year changes in abundance. For example, it was very abundant at EF from September 1979 to September 1980, although prior to and after this time, densities were relatively low. Chaetozone spp. are frequently found in highest densities in September, although like many other subtidal taxa, it has been collected in high densities at other times of the year. Overall, the 1983 abundance of Chaetozone spp. at all stations was similar to those of 1982, but remained well below values obtained from September 1979-80.

Exogone hebes

Exogone hebes is a small deposit-feeder common in the silt layers of sandy deposits from coastal to deep-sea areas of New England. During 1983, this species was among the top four at only IN, and among the top ten at EF. Although Exogone has not consistently been among the most abundant forms at IN, the high density in June 1983, resulted in high annual densities (Fig. 13 L). In 1983, densities of Exogone were highest in June at all stations; this seasonal peak has characteristically occurred over the last six years. Relative to previous years, the 1983 densities of Exogone were higher (IN) or among the higher (EF) values obtained since 1976; those at JC and GN in 1983 were within the ranges of previous years.

Polycirrus eximius

Polycirrus eximius is a surface deposit-feeder that typically inhabits empty gastropod shells, crevices in other calcareous material, or the empty tubes of other polychaetes and hence its abundance may be directly related to the availability of this material within subtidal sediments. Polycirrus ranked among the top four at only EF during 1983 and was among the top ten at only one other station (JC). This species has been a consistent component at all subtidal stations except IN, although densities in 1983 at GN were generally lower than those previously obtained. At EF and other stations as well, this species is frequently most abundant in September (Fig. 13 M). During the last six years, densities were highest from September 1979 to September 1980. The 1983 densities, at all stations, were comparable to those found in the past, and there have been no consistent increasing or decreasing trends in density at any of the stations.

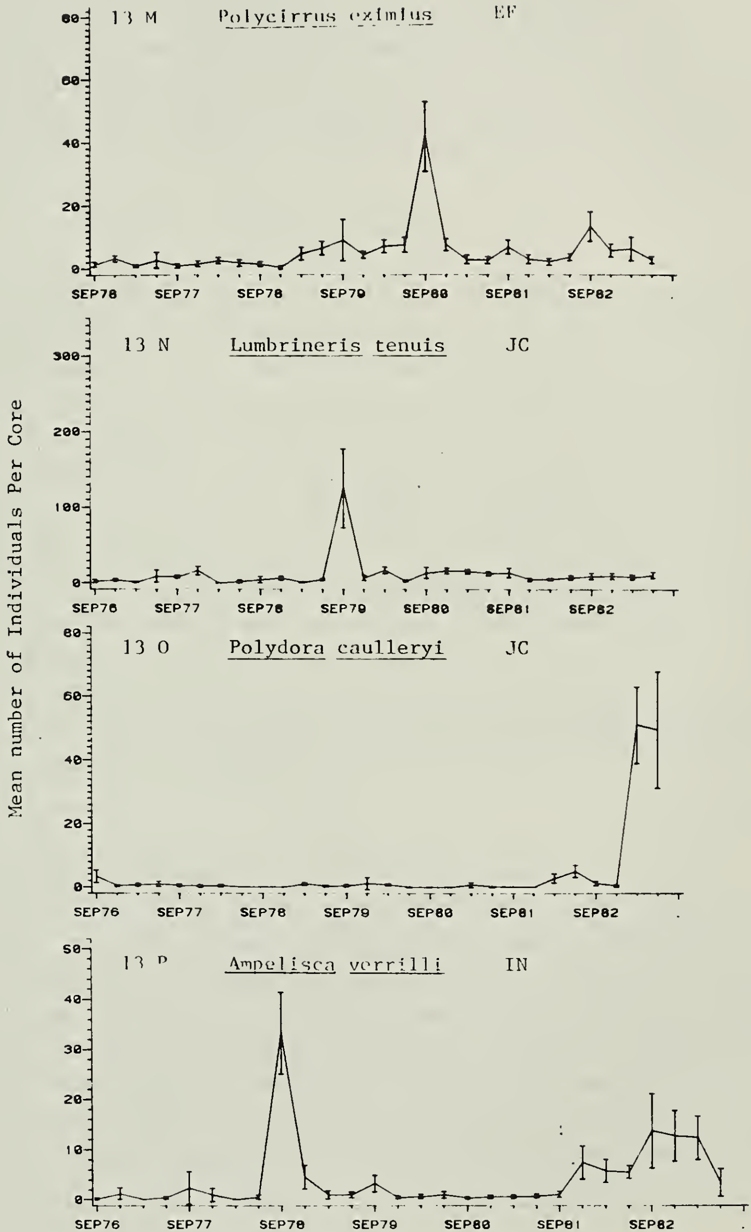
Lumbrineris tenuis

Lumbrineris tenuis is a motile deposit-feeder that ranked fourth in abundance at JC during 1983 and was among the top ten at only one other station (GN). Densities at JC and GN were comparable to each other despite their differing ranks. This species has been a relatively consistent member of all subtidal communities except IN, with densities usually highest at JC (Fig. 13 N). Since 1976, the abundances of this species has varied between years at GN, but remained relatively stable at JC. The 1983 values at JC were consistent with those obtained during the last six years, while those at GN were among the highest recorded at this station since 1976.

Polydora caulleryi

Polydora caulleryi is a tube dwelling polychaete which can obtain food through either surface deposit or suspension feeding. Polydora ranked third in abundance at JC and was among the top ten at both GN and EF during 1983. At these stations, annual densities in 1983 were well above those obtained in recent years; this increase was primarily due to the unusually

Figure 13. (continued)



high values obtained in the March and June 1983 (Fig. 13 O). Seasonal peaks also occurred in 1981 and 1982 at these stations; moderately large numbers were collected at GN in 1977. This species apparently peaks in June, although its recent appearance makes interpretation of any long-term seasonal trends difficult. Of all population changes that occurred at subtidal stations, the increased abundance of Polydora caulleryi throughout the Millstone area during 1983 was most notable.

Ampelisca verrilli

Ampelisca verrilli is a suspension feeding arthropod that is frequently found in dense aggregations where their fine sand tubes can form sediment stabilizing carpets over the bottom. Large fluctuations in their abundance however can occur as the food resources in the area are depleted. Reductions in density have also been attributed to pollution, wave induced bottom scouring, and siltation. Ampelisca was the most abundant species collected at the IN station during 1983, and was among the top ten only at IN and EF. Since 1980 this species has been consistently among the top ten dominant taxa at IN and rare or absent at the other stations. Distinct seasonal peaks have generally occurred in September at all stations (Fig. 13 P). At EF, the high annual densities of this species during 1983 were due to very high values obtained in September 1982; all other quarterly density estimates were comparable to previous years.

Species Diversity

Annual mean species diversity (H') of the subtidal communities ranged from 4.59 at EF to 3.01 at JC (Table 9). High EF diversity was due to high evenness (J) and number of species (S) relative to the other stations. All subtidal communities exhibited seasonal variation in diversity with the number of species varying most over the sampling stations and evenness varying least. Relative to measures of diversity in previous years, those at EF were higher or equal to the three year average; at IN and GN all measures were below the three year average; at JC, H' and J were lower than the three year ranges. Although diversity measures at some subtidal

Table 9. Species diversity (H'), evennesa (J), and number of species (S) for each Millstone subtidal station sampled from September 1980 - June 1983.

	1983 Annual Mean and Standard Deviation[a]	1980-82 Range of Annual Means
Effluent		
H'	4.59 ± 0.23	2.90 - 4.46
J	0.73 ± 0.01	0.47 - 0.72
S	80 ± 14	76 - 80
Giants Neck		
H'	3.37 ± 0.18	3.42 - 3.86
J	0.58 ± 0.02	0.54 - 0.61
S	59 ± 13	66 - 90
Intake		
H'	3.53 ± 0.31	3.79 - 4.06
J	0.66 ± 0.05	0.71 - 0.72
S	41 ± 9	43 - 54
Jordan Cove		
H'	3.01 ± 0.32	3.11 - 3.63
J	0.51 ± 0.03	0.54 - 0.58
S	61 ± 14	55 - 89

[a] - Standard Deviation calculated using quarterly collections in September, December, March and June.

stations in 1983 were outside the range of values obtained in the past, the changes were not of the magnitude believed indicative of major shifts in the composition of subtidal communities.

Cumulative Species Curves

Cumulative species curves for subtidal stations sampled in each of the last four years are presented in Figure 14. The total number of species comprising all subtidal communities in 1983 was the lowest total observed in the last four years. Cumulative totals at GN and IN were consistently lower in 1983 sampling quarters than those obtained since 1980; at EF and JC, three of the four 1983 values were lower. Curves for all stations were sloped indicating the addition of species throughout the sampling year. The steepest slope, and thus the greatest seasonal species addition, occurred at EF where the annual number of species was nearly double that of

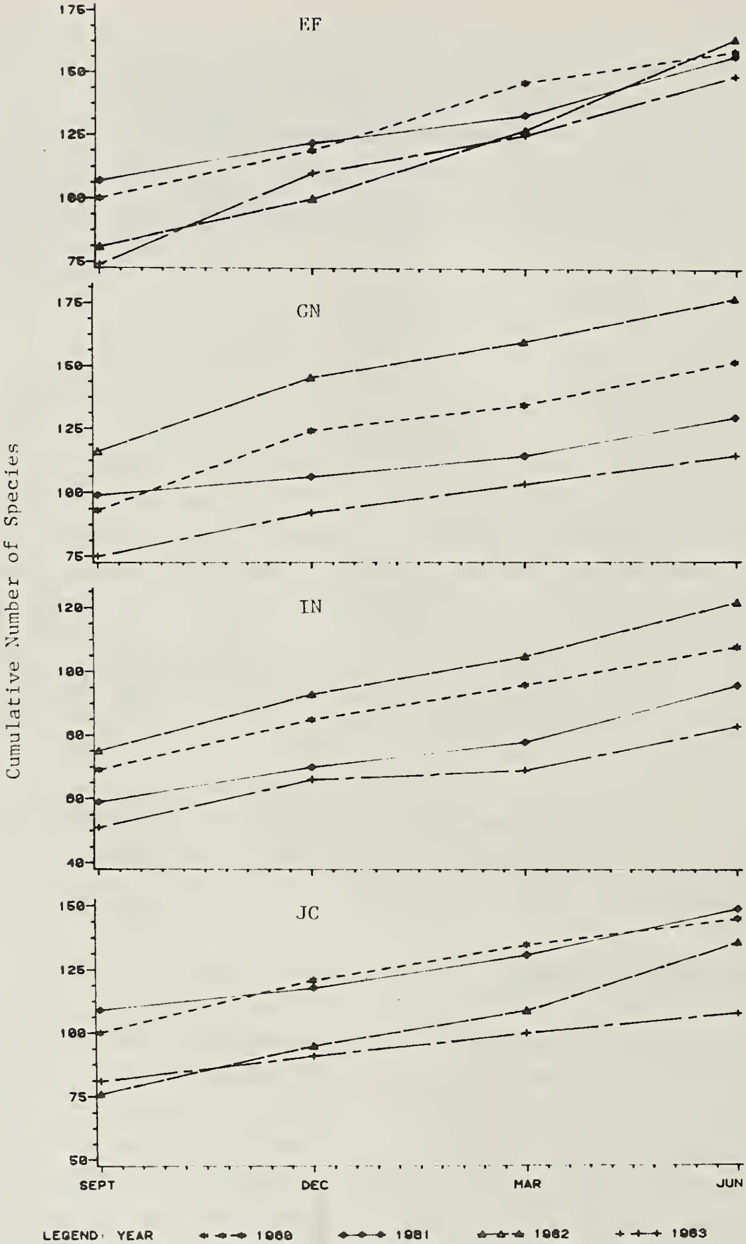


Figure 14. Annual species curves for each Millstone subtidal station sampled from 1980 - 1983.

September. Seasonal increases were smallest at JC as reflected by the very gradual slope of the species curve.

The cumulative curves over the last several years at both GN and IN were generally parallel and the relationship among annual totals over the last four years was identical to the relationship among the September collections. In contrast, curves generated for EF and JC bisected one another and despite the often large disparity in the numbers of species collected in September, the annual totals were generally quite similar. The JC curve for 1983 was an exception to this pattern and the absence of a large June species complement (as observed in the previous year) resulted in a relatively low 1983 total.

Cluster Analysis

The cluster analysis of subtidal community data from 1980-1983 produced four groups (I-IV), each containing all years from a particular station (Fig. 15). Group I contained IN sampling years, and because of low

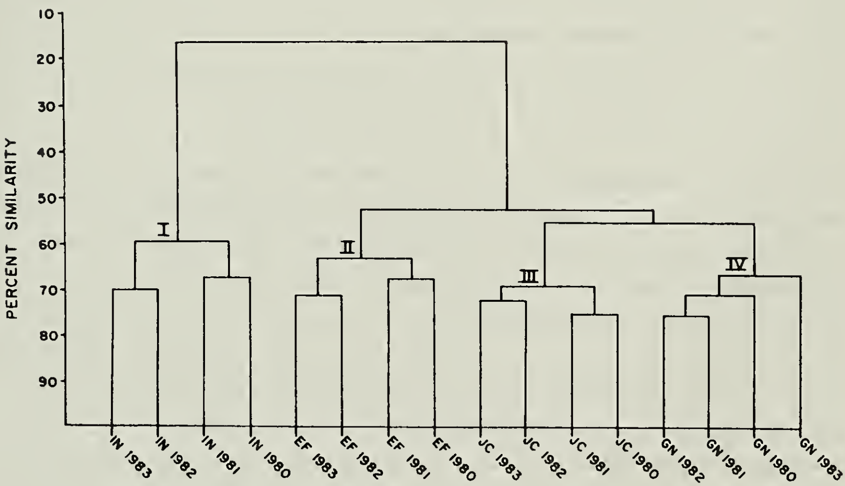


Figure 15. Dendrogram resulting from classification of annual collections at Millstone subtidal stations, September 1979 - June 1983.

population densities and differences in species composition, it exhibited low similarity to other stations. The linkage of 1983 and 1982 resulted from similarly low densities of Tellina agilis and Exogone hebes, and high densities of Gammarus lawrencianus relative to collections made in 1980 and 1981. Within Group II (EF), low abundances of Chaetozone spp. and Polycirrus eximius, and higher densities of oligochaetes and Caulleriella spp. resulted in the linkage of 1982 and 1983 collections. Lower densities of Lumbrineris impatiens and high densities of Chaetozone spp. were primarily responsible for the linkage of 1982 to 1983 JC collections (Group III). The association among GN sample years was unlike that of all other subtidal stations. Similar population densities in 1981 and 1982 resulted in the coupling of these years, but the high densities observed in 1980 and the low densities of many species in 1983, caused these sampling years to chain rather than cluster into the group.

The cluster analysis illustrated high within-station similarity among subtidal communities and the relatively high between- station similarity (except IN). Since 1980, the dominant species comprising the IN community have consistently been different from those found as dominants at other subtidal stations. The remaining stations have consistently exhibited relatively high similarity over the last several years; their separation in 1983 was primarily due to variations in the abundance of the few species not to changes in species composition.

DISCUSSION

Infaunal communities in the Millstone area are monitored to identify power plant-induced changes in the structure and composition of intertidal and subtidal communities and to evaluate whether any observed changes would significantly alter the local the marine communities. This can only be accomplished if plant-induced changes can be distinguished from those natural temporal and spatial environmental variation which occurs in the Millstone Point area. These factors can strongly influence the structure and composition of shallow water subtidal and intertidal communities (Levings 1975; Maurer et al. 1979; Warwick and Uncles 1980). Given the degree to which natural changes occur, long-term sampling is a necessary part of any monitoring program, and with time, will result in sufficient data to distinguish natural from man-induced changes in the community. This discussion will examine the spatial relationships among stations and the temporal variations at all stations observed in 1983 that could be related to power plant operation.

INTERTIDAL

Spatial differences among potentially impacted and non-impacted stations

The 1983 sampling program clearly identified the presence of two different intertidal communities inhabiting beaches in the Millstone Point area. The community at JC included higher numbers of species and individuals than either WP or GN and was primarily dominated by oligochaetes. Other analyses, based on species composition and abundance, i.e. species diversity, cumulative species curves, cluster analysis, supported the distinction between these communities.

Although the JC station is located in an area potentially influenced by power plant operation, differences between this and other communities is most likely reflective of the station-specific differences in the degree to which the JC community is subjected to natural, wave-induced beach scour. The influence of scour in dictating sedimentary characteristics and in structuring intertidal communities has been well documented (Maurer and Aprill 1979; Oliver et al. 1980; Knott et al. 1983). Sheltered intertidal communities, like that of JC, would be expected to include higher numbers of species and individuals, and would include smaller, less mobile forms. In contrast, communities inhabiting exposed beaches would include few species in lower numbers with the organisms well suited to burrowing within and through a constantly shifting habitat (Croker 1977; Withers and Thorpe 1978; Dexter 1979).

Since the JC station is a southeasterly facing beach, wave scour generally occurs only in winter; during the remainder of the year, finer sand and large amounts of eelgrass and algae accumulate on the beach. This habitat provides ideal conditions for small deposit-feeding organisms such as oligochaetes (Caspers 1980; Soulsby et al. 1982). In contrast, the GN and WP beaches are subject to more constant wave scour from the dominant southwesterly and northwesterly winds. Sediments at these stations are uniformily composed of medium sand with low organic content and both infaunal communities are dominanted by species that are less dependent on fine organic material as food and more adapted to a constantly shifting sand environment.

The differences observed in 1983 between the potentially impacted JC community and other monitoring communities are consistent with observations made in previous years at Millstone (NUSCo 1982, 1983). These differences (between JC and GN/WP), and the similarity between GN and WP communities are most likely related to the natural environmental conditions that exist in the Millstone area and not to any physical or chemical changes resulting from power plant operation.

Temporal Differences at potentially impacted vs non-impacted stations.

In 1983, all monitoring stations exhibited seasonal changes in animal populations typical of temperate intertidal assemblages (Sanders 1968; Green 1969; Holland and Polgar 1976; Whitlatch 1977). At all stations, the numbers of species and animal abundances were generally higher in summer and fall and lower in winter and early spring. Intertidal communities were primarily dominated by few species, and as with other infaunal communities of low diversity, seasonal patterns of these organisms strongly influenced the pattern of the community (Holland and Polgar 1976; Zajac and Whitlatch 1982). Many species exhibited periods of peak abundance in September, following the favorable environmental conditions of summer.

Seasonal changes in abundances, species composition and the sedimentary environment in 1983 were considerably more pronounced at the potentially impacted station (JC) than at either the other potentially impacted station (WP) or the reference station (GN). This larger seasonal variability at JC has been characteristic of this station throughout the monitoring program and appears to be related to natural seasonal changes in intensity of the wave-induced scour and not to plant- induced physical changes. Temporal patterns observed in the communities inhabiting the other potentially impacted station (WP) were similar to those at the reference station (GN); this is consistent with past observations.

In addition to seasonal changes, annual differences in infaunal densities and species numbers have occurred at all intertidal monitoring stations. Again, these changes were more evident at JC. Since 1976, unusual periods of low population densities (in the case of JC, low community densities) occurred between September 1977-September 1978 and September 1980-September 1981. In many cases, reduced abundance has been evidenced by the lack of a September peak, the period when many of the dominant intertidal species were most abundant. This has been particularly true at JC. Since intertidal communities are so strongly influenced by seasonal environmental conditions, an increase (or decrease) in the intensity of the naturally rigorous winter conditions, could lead to regional changes in these assemblages which should be evident at all stations. However, due to the difference in station orientation, this influence was more apparent at the JC station.

During 1983, the abundances, number of species, and species composition were consistent with the long-term patterns established by previous years studies. No long-term changes in any community parameter have occurred solely at impacted stations.

SUBTIDAL

Spatial differences among potentially impacted vs non-impacted stations

During 1983, the potentially impacted IN community was spatially most distinct from all other subtidal communities. This assemblage contained fewer species, and individuals and included more suspension feeders than any other community. Although this station is located near the power plant intake structures, previous hydrographic studies (NUSCo 1978) and observations by divers indicate that natural tidal currents in this area exceed those created during power plant operation. During 1983, however, there were physical differences in the IN sediments collected in June most likely as the result of wave induced erosion of soils being used during construction of the Unit 3 intake. Sedimentation of this fine material in the vicinity of the IN station lead to a considerable increase in the silt/clay fraction of the sediments. However, the June infaunal sampling was performed just after construction began and most likely, before the local infaunal community had fully responded to the changing conditions. Communities at all other subtidal stations, including those potentially impacted by power plant operation (EF and JC), exhibited similarities in density, species composition and trophic structure during 1983. Although differences occurred in the actual ranking of the dominant species, several were common to all stations.

Temporal differences at potentially impacted vs non-impacted stations.

In 1983, seasonal variation in the abundance, composition and numbers of species was evident at all subtidal stations. Changes in these community parameters occurred throughout the year at potentially impacted stations (IN, JC, EF) and the reference station (GN). Yet, the general trend of June and September peaks in density and species numbers remained similar to previous observations. Further, there were no changes in these parameters that were more evident at the potentially impacted stations than at the reference station. Changes in species composition (e.g. increased number of *Polydora caulleryi*) occurred equally among all stations, (except IN) and the significance of this change can only be evaluated by continued monitoring.

Temporal variations in species composition and abundance have been characteristic of Millstone subtidal communities. Infaunal population fluctuations were generally similar for taxa common to all stations, and changes in the relative abundance of ubiquitous taxa have occurred throughout the year. Although reduced population densities were noted for taxa considered characteristic of a particular station, these reductions were not confined to stations within the influence of plant operation, nor were these taxa totally removed from their respective communities. Seasonal changes, like those observed in the Millstone area, are characteristic of shallow-water benthic assemblages throughout the temperate range (Levings 1975; Maurer et al. 1979; Warwick and Uncles 1980).

Notable year to year changes in subtidal benthos occurred at both the non-impacted station (GN) and the potentially-impacted stations (EF, IN, JC). These changes were evident in the sedimentary characteristics at the IN and GN stations and additions to the dominant taxa at all subtidal stations.

The mean particle size of GN sediments increased throughout the year and the silt-clay content decreased. Since the GN station is not effected by plant operation these changes are considered natural and the continuation of a trend that began during 1980. The mean particle size of IN sediments remained consistent over the year, but the silt-clay content increased substantially in June. This increase in silt-clay was caused by erosion of soils used in construction of the Unit 3 intake, and not by the operation of Units 1 and 2.

Changes in the subtidal communities involved the addition of *Polydora caulleryi* among the dominant species at three of the four stations, (GN, JC, EF), and the increased density of *Exogone hebes* at all stations, particularly IN. The increased abundances of *P. caulleryi* at Millstone subtidal stations was considered a natural and sediment associated change since the non-impacted (GN) and potentially-impacted stations (JC, EF) showed elevated densities during the same sampling period. Further, Kinner and Maurer (1978) noted high densities of *P. caulleryi* in medium to coarse sediments within Delaware Bay. Sediments of this type are common at JC, EF and GN, while the IN station is generally comprised of fine sediments. Additionally, heavy siltation in June at IN may have buried newly settled *P. caulleryi*.

While the density of *Exogone hebes* increased at all stations in 1983, the high abundance at IN may have also resulted from changes in the sedimentary environment. Gibbs (1969) reported high densities of *E. hebes* in the silty layers of fine to very fine sediments in Plymouth Sound, England. The addition of silt to the already fine IN sediments could have enhanced niche availability, while the active burrowing nature of *E. hebes* would prevent burial caused by siltation.

CONCLUSIONS

During 1983, the spatial differences observed among infaunal sampling stations and the temporal variations in abundance and species numbers were typical of those observed in previous years. Natural, physical processes appeared most responsible for the different spatial distribution of species and temporal variations exhibited by the communities located within and beyond the influence of the power plant. Changes in community structure and composition observed in 1983, relative to previous years, occurred at both potentially impacted and non impacted stations, suggesting that the factors responsible for the changes were not limited to those stations within the influence of plant operation. At IN, Unit 3 construction activities apparently influenced local sedimentary characteristics, although no concomitant change occurred in the infaunal communities. It is probable that biological changes were not observed because sampling was performed soon after construction began and before the local infaunal community had responded to the changing physical conditions. There were, however, no short or long-term changes in the sediments nor any shifts in the abundance and composition of infaunal communities that could be attributed to operation of Millstone Units 1 and 2.

REFERENCES CITED

Aller, R.C. 1978. Experimental studies of changes produced by deposit feeders on pore water, sediment, and overlying water chemistry. Am. J. Sci. 278:1185-1234.

Boesch, D.F. 1973. Classification and community structure of the Hampton Roads area, Virginia. Mar. Biol. 21:226-244.

Boston Edison Co. 1983. Marine ecology studies related to operation of Pilgrim Station. Semi-Annual Report No. 22.

Caspers, H. 1980. The relationship of saprobial conditions to massive populations of tubificids. Pages 503-505 in R.O. Brinkhurst and D.G. Cook, eds. Aquatic oligochaete biology. Plenum Publishing Corp., New York.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

ConEd (Consolidated Edison Company of New York). 1977. Near-field effects of once through cooling system operation on Hudson River biota. Indian Point Units 2 and 3.

Croker, R.A. 1977. Macrofauna of northern New England marine sand: long term intertidal structure. Pages 439-450 in B.C. Coull, ed. Ecology of marine benthos. University of South Carolina Press, Columbia, South Carolina.

De Vlas, J. 1979. Annual food intake by plaice and flounder in a tidal flat area in the Dutch Wadden Sea, with special reference to consumption of regenerating parts of macrobenthic prey. Neth. J. Sea Res. 13:117-153.

Dexter, D.M. 1969. Structure of an intertidal sandy-beach community in North Carolina. Estuarine Coast. Mar. Sci. 9:543-558.

Folk, D. 1974. Petrology of sedimentary rocks. Hempshill Publishing Company, Austin, Texas. 192 pp.

Gibbs, P.E. 1969. A quantitative study of the polychaete fauna of certain fine deposits in Plymouth Sound. J. Mar. Biol. Assoc. U.K. 49:311-326.

Goldhaber, M.B., R.C. Aller, J.K. Cochran, J.K. Rosenfield, C.S. Martens, and R.A. Berner. 1977. Sulfate reduction, diffusion, bioturbation in Long Island Sound sediments: Report of the FOAM Group. Am. J. Sci. 277:193-237.

Gray, J.S. 1982. Effects of pollutants on marine ecosystems. Neth. J. Sea Res. 16:424-443.

Green, R.H. 1969. Population dynamics and environmental variability. Am. Zool. 9:393-398.

Holland, A.F., and T.T. Polgar. 1976. Seasonal changes in the structure of an intertidal community. Mar. Biol. 37:341-348.

Hylleberg, J., and D. Maurer. 1980. The central role of bioturbation in sediment mineralization and element recycling. Ophelia (Suppl. 1):1-16.

Kinner, P. and D. Maurer. 1978. Polychaetous annelids of the Delaware Bay Region. Fish. Bull., U.S. 76:209-224.

Knott, D.M., D.R. Calder, and R.F. Van Dolah. 1983. Macrobenthos of sandy beach and nearshore environments at Murrells Inlet, South Carolina, USA. Estuarine, Coast. Shelf Sci. 16:573-590.

Kuipers, B.R. 1977. On the ecology of juvenile plaice on a tidal flat in the Wadden Sea. Neth J. Sea Res. 11:56-91.

Lance, G.N., and W.R. Williams. 1967. A general theory of classificatory sorting strategies, I. Hierarchical systems. Comput. J. 9:373-380.

Levings, C.D. 1975. Analysis of temporal variation in the structure of a shallow-water benthic community in Nova Scotia. Int. Rev. ges. Hydrobiol. 55:449-470.

LILCo (Long Island Lighting Company). 1983. Preoperational aquatic ecology study, Shoreham Nuclear Power Station, Unit 1. Prepared by GeoMet for

Maurer, D., and G. Aprill. 1979. Intertidal benthic invertebrates and sediment stability at the mouth of Delaware Bay. Int. Rev. ges. Hydrobiol. 64:379-403.

Maurer, D., W. Leathem, P. Kinner, and J. Tinsman. 1979. Seasonal fluctuations in coastal benthic invertebrate assemblages. Estuar. Coastal Mar. Sci. 8:181-193.

McCloskey, L.R. 1970. The dynamics of the community associated with a marine scleractinian coral. Int. Rev. ges Hydrobiol. 55:13-81.

NUSCo (Northeast Utilities Service Company). 1978. Millstone Unit No. 1 Intake structure velocity profiles. Report to B. R. Johnson from R. J. Factora, GCE-78-104.

______. 1982. Benthic infauna. Pages 1-39 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1981.

______. 1983. Benthic infauna. Pages 1-47 in Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1982.

Oliver, J.S., P.N. Slattery, L.W. Hulberg, and J.W. Nybakken. 1980. Relationship between wave disturbance and zonation of benthic invertebrate communities along a subtidal high-energy beach in Monterey Bay, California. Fish. Bull., U.S. 78:437-454.

Pielou, E.C. 1977. Mathematical ecology. Wiley-Interscience, New York. 385 pp.

Raine, R.C.T., and J.W. Patching. 1980. Aspects of carbon and nitrogen cycling in a shallow marine environment. J. Exp. Mar. Biol. Ecol. 47:127-139.

Reish, D.J. 1973. The use of benthic animals in monitoring the marine environment. J. Envir. Plan. Poll. Control. 1:32-38.

_____, D.F. Soule, and J.D. Soule. 1980. The benthic biological conditions of Los Angeles-Long Beach harbors: Results of 28 years of investigations and monitoring. Helgolander. Meeresunters. 34:193-205.

Sanders, H.L. 1968. Marine benthic diversity: a comparative study. Am. Nat. 102:243-282.

_____, J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. Mar. Res. 38:265-380.

Soulsby, P.G., D. Lowthion, and M. Houston. 1982. Effects of macroalgal mats on the ecology of intertidal mudflats. Mar. Poll. Bull. 13:162-166.

VanBlaricom, G.R. 1982. Experimental analyses of structural regulation in a marine sand community exposed to oceanic swell. Ecol. Monogr. 53:283-305.

Warwick, R.M., and R.J. Uncles. 1980. Distribution of benthic macrofauna associations in the Bristol Channel in relation to tidal stress. Mar. Ecol. Prog. Ser. 3:97-103.

Whitlatch, R.B. 1977. Seasonal changes in the community structure of the macrobenthos inhabiting the intertidal sand and mud flats of Barnstable Harbor, Massachusetts. Biol. Bull. 152:274-294.

Withers, R.G., and C.H. Thorpe. 1978. The macrobenthos inhabiting sandbanks in Langstone Harbour, Hampshire. J. Nat. Hist. 12:445-455.

Woodin, S.A. 1982. Browsing: important in marine sedimentary environments? Spionid polychaete examples. J. Exp. Mar. Biol. Ecol. 60:35-45.

Zajac, R.N., and R.B. Whitlatch. 1982. Responses of estuarine infauna to disturbance. II. Spatial and temporal variation of succession. Mar. Ecol. Prog. Ser. 10:15-27.

Zeitzschel, B. 1980. Sediment-water interactions in nutrient dynamics. Pages 195-218 in K.R. Tenore and B.C. Coull, eds. Benthic dynamics. University of South Carolina Press, Columbia, South Carolina.

LOBSTER POPULATION DYNAMICS

Table of Contents

LOBSTER POPULATION DYNAMICS

INTRODUCTION

The American lobster (Homarus americanus) is the most valuable commercial species within Long Island Sound (LIS). Record annual landings in 1983 of 2.04 million pounds were greater than the state's previous best year in 1982 of 1.02 million pounds. The estimated retail value of the 1983 catch is in excess of 3 million dollars. The Connecticut Department of Environmental Protection marine fishery statistics indicate that 31% of the total catch was caught in New London County waters. Because of the commercial importance of the local lobster fishery in the Millstone Point area, this population has been monitored since 1969 (Keser et al. 1983; NUSCo 1983b). The primary objective of this monitoring program is to identify changes in the local lobster population that may be attributable to the operation of the Millstone Nuclear Power Station (MNPS). Potential stresses associated with power plant operation include: impingement of lobsters on the intake traveling screens, entrainment of larvae through the cooling water systems, and exposure to the effluent. The above stresses may affect survival of lobster larvae and juveniles or alter the behavior of adults resulting in a decline in the local inshore fishery.

To assess structural changes in the local lobster population, the monitoring program was designed to: quantify catch per unit effort, measure population characteristics (size frequency distribution, sex ratios, female size at sexual maturity, incidence of berried females, growth rates, and incidence of culled lobsters), estimate the size of the lobster population, and establish patterns of lobster movement. To evaluate any changes due to MNPS operation, the results of the study are compared among years, seasonally, between stations, and to studies conducted along the northeastern coast of North America.

MATERIALS AND METHODS

Suitable lobster habitats in the vicinity of MNPS (6.5 km^2) are characterized by rocky outcrops interspersed with patches of sand. From May through October 1983, 20 commercial vinyl coated wire pots (76 x 51 x

30 cm; 2.5 cm^2 mesh) were set at each of three stations (Fig. 1): Jordan Cove (JC) (east of Millstone Point; 500 m from discharge), Intake (IN) (along the western shore of Millstone Point near the power plant intake structures; 600 m from discharge) and Twotree (TT) (1,600 m offshore, near Twotree Island). Four trawls, each consisting of five numbered pots equally spaced along a 50-75 m line bouyed at both ends, were fished at each station. Pots were numbered to examine the variability in catch between pots and to provide more accurate values for catch based on a larger number of observations (i.e. number of lobsters caught in each pot vs. number caught in 20 pots).

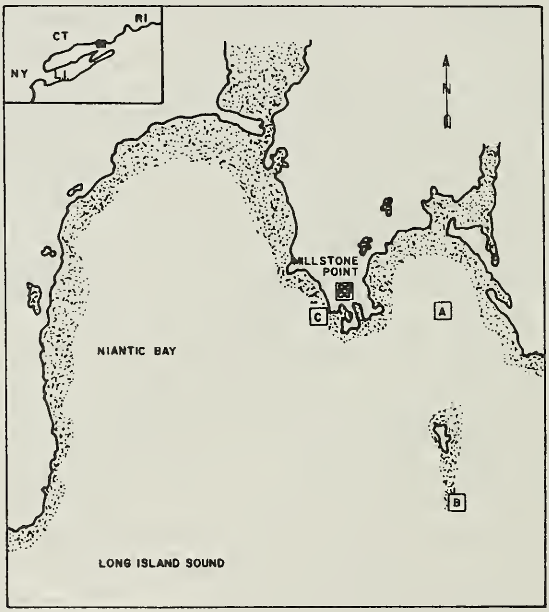


Figure 1. Location of the Millstone Nuclear Power Station and the three lobster sampling stations. A=Jordan Cove, B=Twotree, C=Intake.

Throughout the study, pots were hauled on Monday, Wednesday, and Friday, weather permitting. At each station, lobsters were removed from traps, claws restrained with rubber bands, and pots rebaited with flounder carcasses obtained from a local fish market. Carapace length (CL), sex, presence of eggs (berried), missing claws, and molt stage were reported for each lobster captured. Molt stage was determined using criteria established by Aiken (1973). Recaptured tagged lobsters, severely injured individuals, and those <55 mm CL were returned to the water untagged. All others were returned to the laboratory and held in continuous-flow salt water tanks. Each Friday, all lobsters were tagged with a numbered international orange sphyrion tag (Scarratt and Elson 1965; Cooper 1970; Scarratt 1970), and returned to the site of capture. Surface and bottom water temperatures and salinities were recorded at each station during each sampling trip with a Beckman salinometer.

The size of the local lobster population was estimated using the method of Jolly (1965) as modified by Seber (1965). This multiple census method uses tag and recapture data collected from an open population assuming the processes of birth, death and migration occur. The Jolly-Seber model allows for parameter estimation of population size, survival rates, recruitment, and capture probability. In addition, this model was chosen because it is useful for long-term studies on open populations. In our study individuals were considered recruits to the population when they grew to a size vulnerable to capture by our traps.

Methods for the collection of lobsters impinged on the intake traveling screens are described in the Fish Ecology-Impingement Sampling section of this report. A probability level of significance $\alpha=0.05$ was used in all statistical tests.

RESULTS AND DISCUSSION

Abundance and Catch Per Unit Effort

A total of 6376 lobsters were collected in the study area from May through October 1983. Over all stations and months, catch per 100 pots (CPUE) was 146 for all sizes of lobsters and 15 for legal-sized lobsters ($\geq$ 81mm CL). Since 1979, TT has had the highest total and legal CPUE of the three stations; however, during 1983 JC had the highest total CPUE (Table 1). The highest CPUE for total catch and legal catch occurred in July at all stations (Table 2). In the Millstone Point area, as temperature increased, catch increased, and as temperature decreased, catch decreased (Fig. 2). This relationship between CPUE and water temperature has been reported by other researchers (McLeese and Wilder 1958; Dow 1966, 1969, 1976; Flowers and Saila 1972).

Table 1. Total and legal ($\geq$81mm carapace length) catch per unit effort (CPUE per 100 pot hauls) from 1979 to 1983 at each station for wire pots.

	Total Catch	Legal Catch
	Jordan Cove	
1978	199	14
1979	188	14
1980	134	9
1981	88	7
1982	192	10
1983	163	15
	Intake	
1978	197	22
1979	166	13
1980	124	8
1981	103	5
1982	189	11
1983	114	9
	Twotree	
1978	140	20
1979	116	11
1980	150	17
1981	115	17
1982	250	28
1983	160	21

During 1983, the number of crabs and fish caught in each trap were recorded to examine the influence of competing species on lobster catch. Crab abundance was greatest at IN with more crabs than lobsters being trapped in 18 out of 20 pots (Fig. 3). To identify the effects of crabs and fish on lobster catch an analysis of covariance was performed on the catch of lobsters in each pot using the numbers of crabs and fish caught and soak time (number of days between pot hauls) as covariates. The analysis indicated that the main effects of month, station, and pots within station were significant (Table 3). Also, the abundance of crabs and fish in the pots and the amount of time between pot hauls were significantly correlated with the catch of lobsters. Since this significant correlation implies that mean CPUE estimates per pot will be biased (the numbers of crabs and fish caught are different for each pot), the means adjusted for the covariance provided by the SAS GLM procedure were used as mean CPUE estimates per pot (Table 4). Richards et al. (1983) reported that traps

Table 2. Monthly catch per unit effort (per 100 pot hauls) for total and legal catch (carapace $\geq$ 81mm) at each station in 1983.

	Total Catch	Legal Catch
Jordan Cove		
May	148	5
June	214	28
July	238	29
August	172	16
September	117	8
October	86	3
Intake		
May	103	5
June	122	14
July	171	16
August	129	7
September	89	6
October	71	4
Twntree		
May	107	12
June	179	28
July	231	31
August	194	24
September	128	15
October	121	17

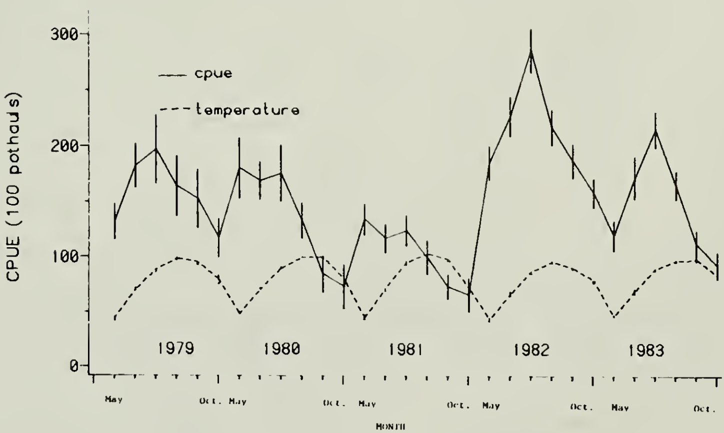


Figure 2. Mean monthly catch per unit effort (CPUE ± 2 S.D.) and bottom water temperature (x5) 1979–83.

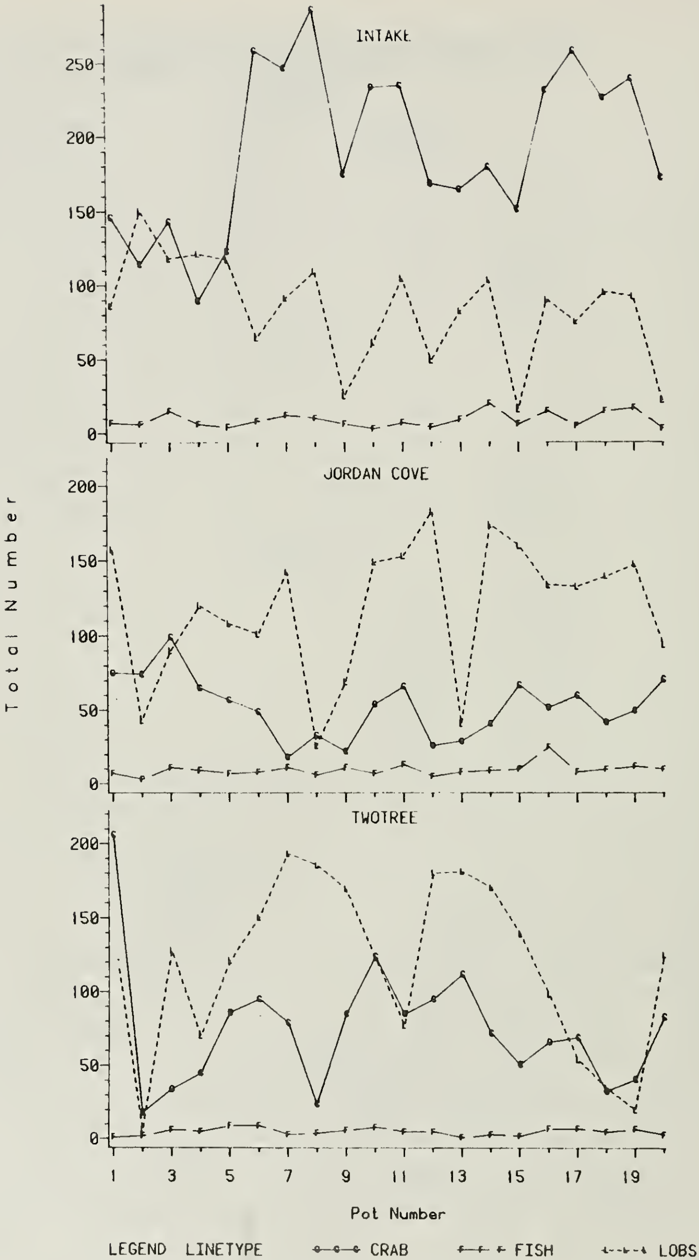


Figure 3. Total number of lobsters, crabs, and fish caught in each pot at each station in 1983.

Table 3. Summary of covariance analysis of lobster catch per pot in 1983 using the numbers of crabs and fish caught and the soaktime as covariates.

Source of variation	df	SS	MS	F
Model	77	2873.75	37.32	25.08*
Month	5	706.50	147.53	99.13*
Station	2	226.96	64.21	43.14*
Pots (Station)	57	1673.26	29.90	20.09*
Month X Station	10	88.35	5.36	3.60
Crab catch	1	127.67	132.37	88.93*
Fish catch	1	28.51	27.92	18.76*
Soaktime	1	22.49	22.49	15.11*
Error	4302	6402.86	1.49	
Corrected Total	4379	9276.60		

* Significant $\alpha < 0.05$.

Table 4. Unadjusted and adjusted mean pot CPUE for each month and station during 1983. Means adjusted for the effects of catching crabs and fish and the amount of soaktime.

	UNADJUSTED MEAN	ADJUSTED MEAN
Jordan Cove		
May	1.55	1.51
June	2.11	2.09
July	2.33	2.31
August	1.70	1.66
September	1.10	1.05
October	0.85	0.80
Intake		
May	1.06	1.20
June	1.22	1.43
July	1.56	1.63
August	1.30	1.29
September	0.87	0.86
October	0.67	0.67
Twotree		
May	1.10	1.28
June	1.79	1.80
July	2.25	2.16
August	1.93	1.86
September	1.28	1.18
October	1.10	1.00

stocked with 3 or 8 crabs (Cancer irroratus, Cancer borealis) had no affect on the catch of lobsters. However, their study did not investigate the effects of spider crabs (Libinia spp.) on lobster catch. Spider crabs were the dominant crab species caught at IN and in some cases as many as 25 were found in a trap, completely clogging both entry funnels. We will continue to monitor the relative abundance of possible competing species in the future to provide the least biased values for lobster catch.

Population Characteristics

Size Frequencies

The yearly size distribution of male and female lobsters caught from 1979 to 1983 is presented in Figure 4. Percent legal catch, mean carapace lengths, sex ratios, percent of berried females, and size frequency distributions for the 1983 catch are presented for each station in Figure 5. The percentage of legal-sized lobsters in 1983 (10.1%) was greater than the percent legal caught in any previous year for wire pots (range 7.2-9.6%), reflecting a strong prerecruit size class in 1982. The Twotree catch continued to have the highest percent of legal-sized lobsters (13.0%), compared to JC (9.0%) or IN (7.5%). The percentage of legal-sized individuals in our catch was lower than that reported by other studies in LIS (Smith 1977; Briggs and Mushacke 1979) and in Block Island Sound (Marcello et al. 1979). The mean CL of lobsters caught in 1983 was 71.7 mm and was very similar to previous values for mean CL since wire pots were first used (range 70.8-71.5 mm).

Sex Ratios

During 1983, the sex ratio of males to females was 1.0:0.87 (53.5% males; 46.5% females) (Fig. 4). Females were less abundant at the shallow inshore stations (IN 1.0:0.67, JC 1.0:0.72), than at the deeper offshore station TT (1.0:1.25) (Fig. 5), a trend consistent since 1975 (Keser et al. 1983). Variability in the sex ratios of lobsters is often associated with the size composition of the catch, which is affected by sampling methods and depth of water (Ennis 1980). In northern and offshore waters, ratios

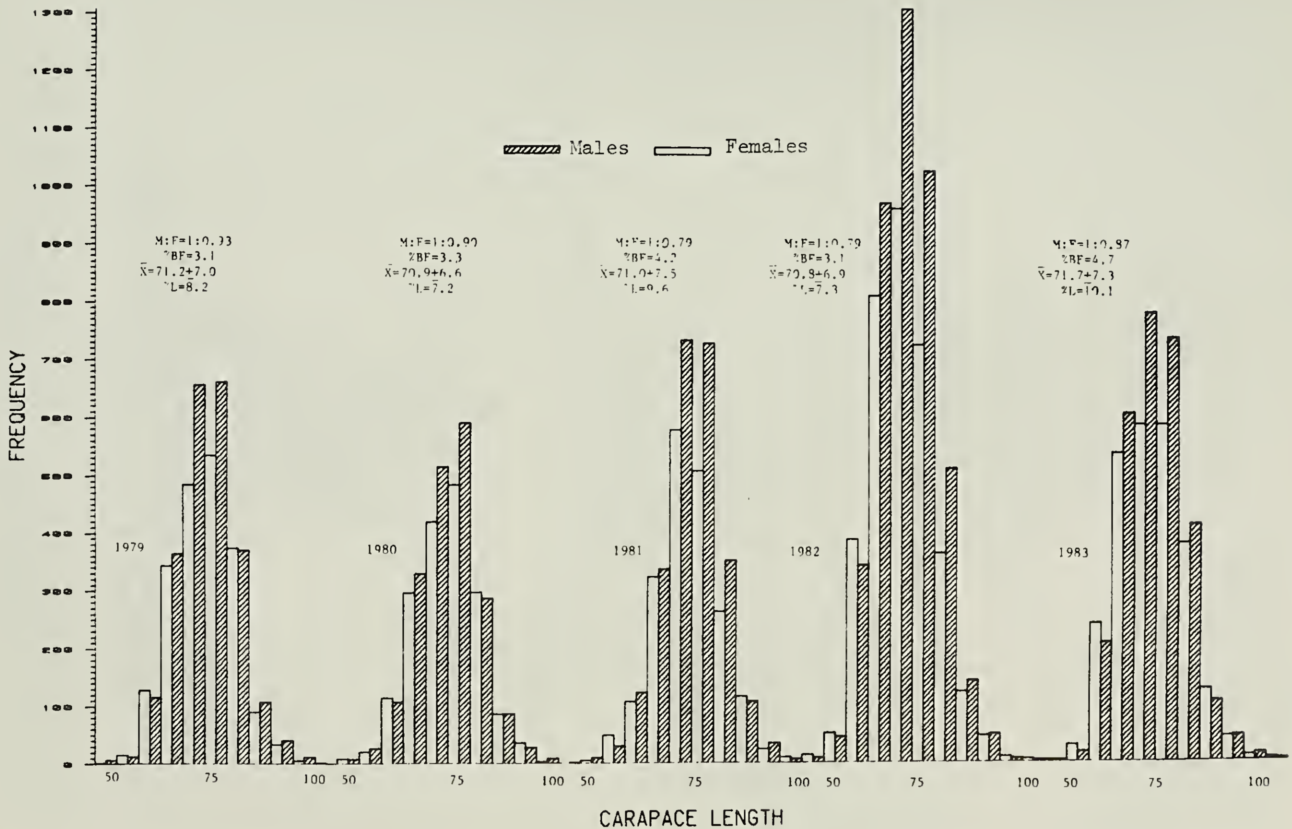


Figure 4. Size frequency distributions for male and female lobsters 1979-83. Thirty wood and 30 wire pots used from 1979-81, 60 wire pots used in 1982-83. Population statistics presented for wire pots only; M:F=Male to female sex ratios, %BF= Percent of berried females, $\bar{X}$=Mean carapace length ± 1 S.D., %L=Percent of legal-sized lobsters.

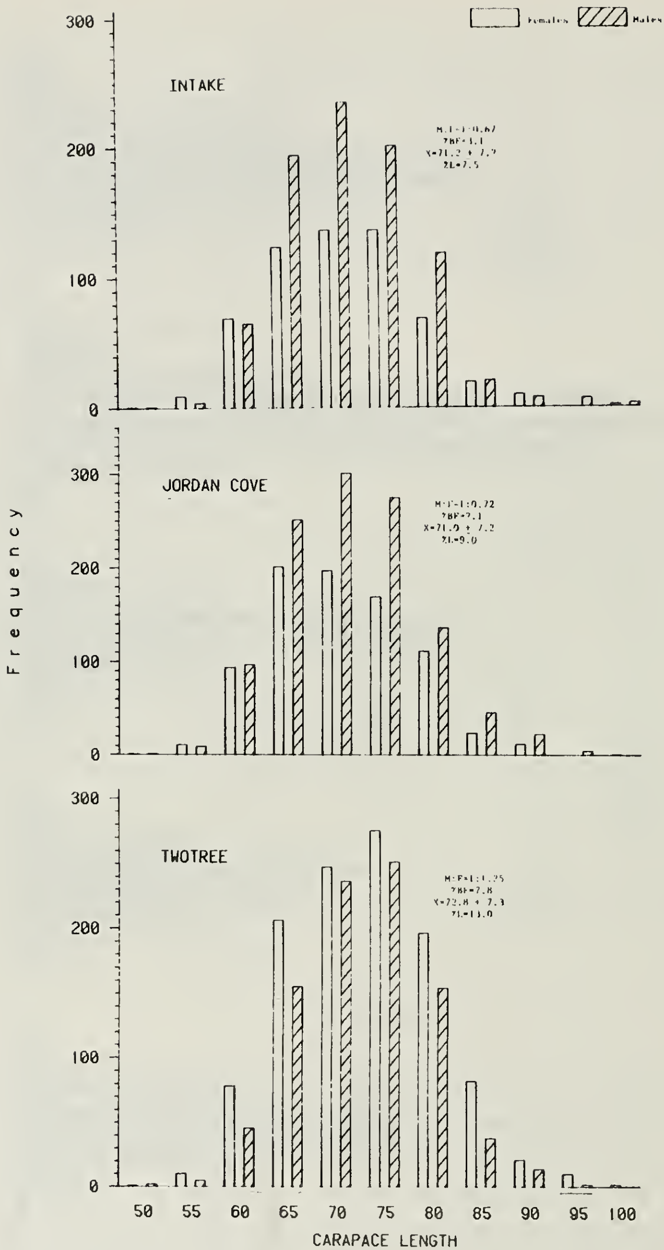


Figure 5. Size frequency distribution for male and female lobsters caught at each station in 1983.

close to 1:1 occur up to the size at which females are sexually mature, after which females tend to predominate in the catch due to the legal restrictions of landing egg-bearing females and the fact that mature females molt less frequently than males (Skud and Perkins 1969; Cooper et al. 1975; Ennis 1980). Sex ratios in 1983 were within the range reported in previous years (1.0:0.79 - 1.0:0.93).

Female Size at Sexual Maturity

The size at which females reach maturity was determined by measuring the width of the second abdominal segment, calculating the ratio of the abdominal width vs. carapace length and plotting that ratio against the carapace length (Skud and Perkins 1969; Krouse 1973). The best fit to these data is a cubic polynomial regression that should be flat where all females are immature, inflect upward at the onset of maturity, and become flat again where all or nearly all are mature (Briggs and Mushacke 1979; Ennis 1980). The morphometric relationship between carapace length and abdominal width for our data is illustrated in Figure 6. This curve shows

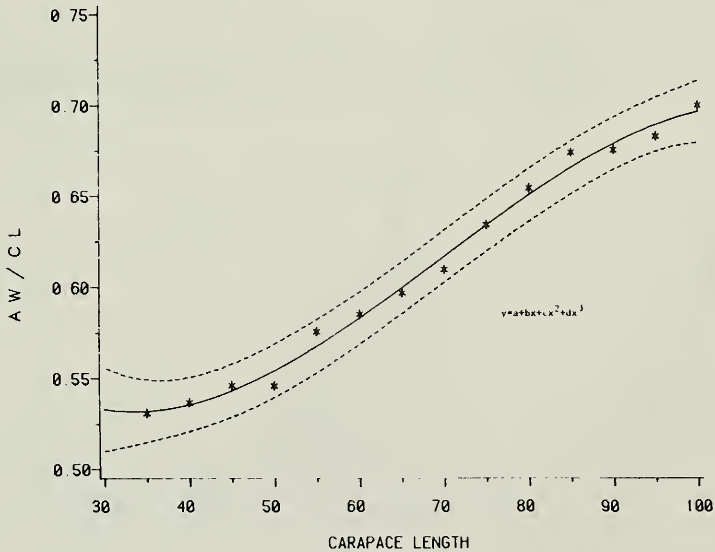


Figure 6. Ratio of the width of the second abdominal segment to the carapace length compared with the carapace length for female lobsters caught in traps and on the traveling screens in 1983 (---=±95% C.I.).

that maturity in our area begins between 40-50 mm CL and that all females are mature at lengths > 90 mm CL. This size at first maturity is substantially smaller than that reported for the South Shore of Long Island (81 mm CL; Briggs and Mushacke 1979) and for northern waters (60-70 mm CL; Ennis 1980). In addition, the presence of extruded eggs on female lobsters is obvious evidence of maturity. The range of CL's for berried females in our study (66-103 mm) and the modal size (77 mm CL) confirm the smaller size of mature females in our area.

Egg-bearing Females

The percentage of berried females in 1983 (4.7%) was higher than that reported in any year for wire pots 1978-82 (range 3.1-4.2%). The Twotree catch had the highest proportion of berried females (7.8%) when compared to IN (3.1%) or JC (2.1%). The percentage of berried females was variable over months corresponding to the reproductive cycle; in May 3.6% of the females were berried and in July the percentage decreased to 0.6%, indicating the completion of the biennial spawning cycle. Post-spawning females molted, mated, and as summer progressed, females that mated the previous year began to extrude eggs and the percentage of berried females increased to 5.7% in August. By October 19.4% of the females were berried. The size distribution of berried females is presented in Figure 7. The mean

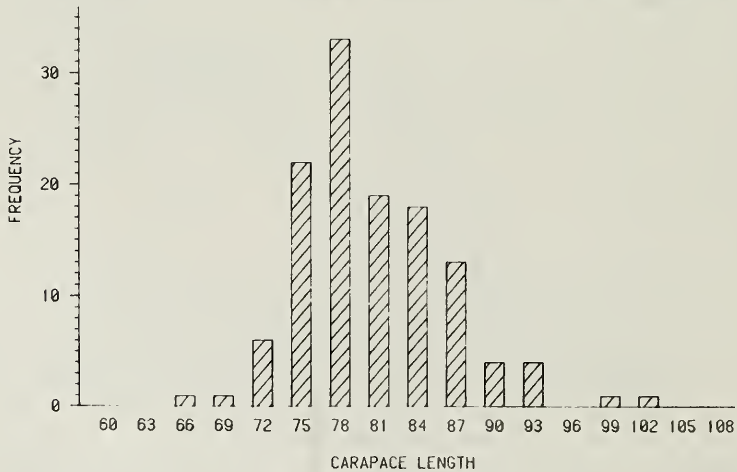


Figure 7. Size distribution for berried female lobsters in 1983.

CL of berried females 80.5 ± 5.9 mm was within the range of previous years (79.1-82.9 mm) (Keser et al. 1983). Over half (52%) of the berried females were of sublegal size, providing further evidence for the small size at which females become mature in our area, relative to more northern and offshore waters where females begin to mature at sizes > 80 mm CL (Krouse 1973; Thomas 1973; Skud and Perkins 1969).

Molting and Growth

During 1983, we observed molting lobsters throughout our study, with a major peak occurring in June at water temperatures between 13-16°C and a smaller secondary peak in autumn at water temperatures of about 16°C (Fig. 8). This is the second consecutive year that we observed two peaks of molting (NUSCo 1983a). The autumn peak was not evident from 1975 to 1981. Two peaks of molting were also observed by Lund et al. (1973) in LIS and by Russell et al. (1978) in Narragansett Bay.

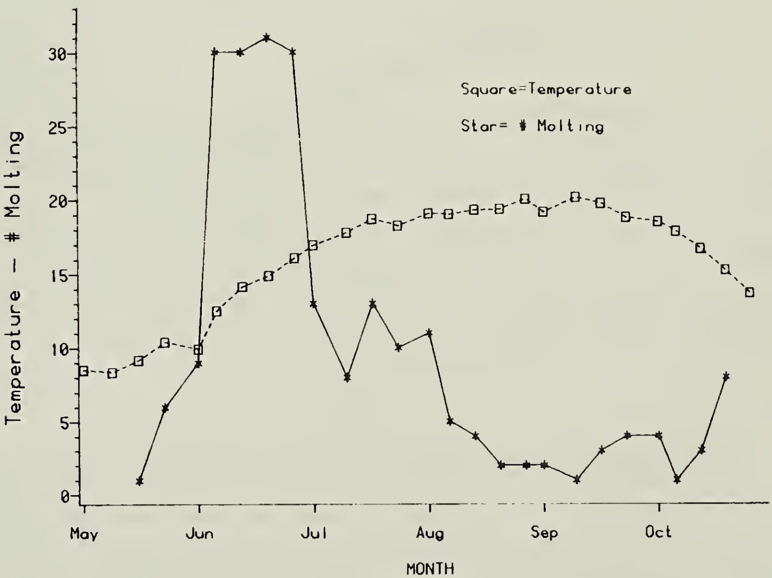


Figure 8. The number of molting lobsters plotted with bottom water temperatures in 1983.

The average growth per molt (in percent) for males (13.92%) and females (13.89%) is similar to the percentages reported by other researchers working in inshore waters, which ranged from 12.0-17.5% (Wilder 1953; Cooper 1970; Ennis 1972; Fair 1977). In deeper offshore waters growth increments are greater: males (18.7%) and females (16.7%) (Cooper and Uzmann 1971). The smaller growth of inshore lobsters is attributed to their relative inactivity (feeding) during the colder months of the year (Cooper and Uzmann 1980).

Data from our mark and recapture program (1978-83) were used to calculate growth for 250 individuals that molted once between the time of tagging and the time of recapture. A functional regression was fitted to these pre- and post-molt lobster sizes for each sex (Fig. 9). This regression was used because the relationship between the pre- and post-molt sizes are subject to measurement errors or fluctuations in both variables (Jolicoeur 1975). The equations for the growth of males and females are respectively;

$$Y=2.821 + (1.097)X, \quad r=.94, \quad n=79$$
$$Y=3.881 + (1.083)X, \quad r=.93, \quad n=171$$

In addition to the tag recovery growth calculations it was also possible to measure the cast shells of lobsters that molted in our holding tanks. These pre- and post-molt lobster sizes are also included in Figure 9. The growth of these untagged lobsters is similar to that of tagged lobsters and confirms that accumulating data on long term growth of internally tagged lobsters is representative of the growth of untagged lobsters (Cooper 1970; Ennis 1972).

Culls

The percentage of culls, missing either one (11.6%) or both claws (0.8%) in 1983 was 12.4% of the total catch and was within the range reported for wire pots since 1978 (12.1-15.5%; Keser et al. 1983). Intake had the highest percent of culls (15.3%), compared to JC (14.5%) or TT (8.2%). Legal-sized and sublegal-sized lobsters exhibited similar claw loss (12.3% and 12.4% respectively) as did males (12.5%) and females

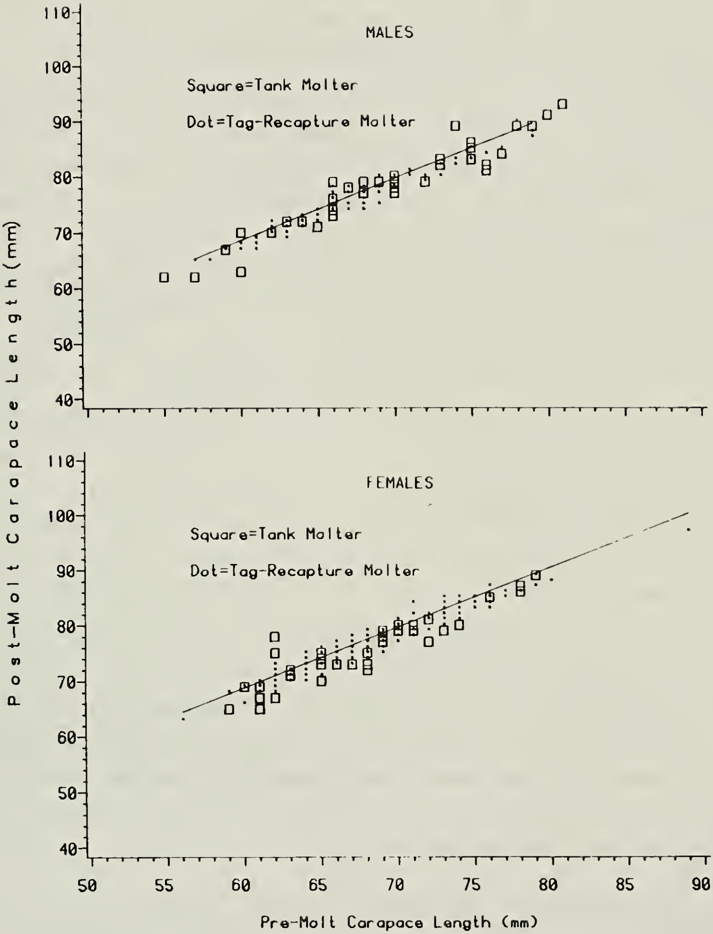


Figure 9. Functional regression for pre-molt vs. post-molt lobster size for male and female lobsters.

(12.2%). However legal-sized males suffered greater claw loss (16.0%) compared to legal-sized females (9.0%). Other LIS researchers reported culls varying between 7.4% and 26.4% (Briggs and Mushacke 1979; Smith 1977).

Tagging Program

During 1983, 6376 lobsters were caught from May through October of which 5160 were tagged and 936 subsequently recaptured (18.1%). Ninety-seven percent of our recaptures were caught at the station where they were released. Lobsters were at large an average of 30 days (range 2-169) before being recaptured. Most lobsters were recaptured once (89%), 9% were recaptured twice, 2% were recaptured 3 times and 5 individuals (0.6%) were recaptured 4 times.

Tag losses were detected by the presence of tag scars during tagging procedures. Percent tag loss was 14.4% in 1983 and was within the range reported in previous years (11.4 - 15.0%). Recapture data from our program and from commercial fishermen are summarized in Table 5. The commercial returns were compiled by totaling the number of lobsters returned to us near each of our stations (JC, IN, TT, MP-Millstone Point) and in each of the Connecticut DEP statistical areas (Fig. 10). The majority of commercial returns were caught near our stations (91%) and almost all were caught in Area 1 (New London County) (94%). Lobsters that moved out of our study area (westerly, 0.4%; and offshore, 0.3%); accounted for a very small percentage, indicating a resident population with little migration (Wilder and Murray 1958; Wilder 1963; Cooper 1970; Cooper and Uzmann 1980). Two lobsters that moved outside LIS were caught in Buzzards Bay, and one was caught off Nantucket Island, Massachusetts. Several lobsters traveled greater distances, in some cases several hundred kilometers, where they were caught off the continental shelf (Block and Hudson canyons), by commercial offshore fishing vessels.

Table 5. Summary of lobster mark recapture program and commercial fishery tag returns 1978-83.

Year	NUSCo Number Tagged				NUSCo Number Recaptured[1]				Commercial Fishermen												
														Area							
	JC	IN	TT	TOTAL	JC	IN	TT	TOTAL	JC	IN	TT	MP	Other	1	2	3	5	6	7	LIS	Unknown
1978	1004	1145	1046	3195	234	112	198	544	88	68	321	204	203	741	8	0	0	46	0	2	87
1979	1412	1440	880	3732	342	150	230	722	256	88	560	724	148	1678	4	0	0	45	2	1	46
1980	1134	1317	1183	3634	214	104	204	522	248	189	236	539	151	1260	4	1	0	31	0	6	61
1981	1230	1383	1633	4246	282	165	260	707	124	159	697	444	56	1451	4	1	0	14	2	2	6
1982	2222	2322	3031	7575	486	336	456	1278	518	217	1147	401	235	2353	4	1	0	140	7	2	11
1983	1873	1341	1946	5160	407	210	319	936	619	40	980	208	131	1950	8	1	1	8	7	3	0
Total	8875	8948	9719	27542	1965	1077	1667	4709	1853	761	3941	2520	924	9433	32	4	1	284	18	16	211

1 - Number recaptured includes multiple recaptures and lobsters tagged in previous years.
MP - Millstone Point
LIS - Outside Long Island Sound

Figure 10. State of Connecticut commercial fishery statistical areas.

Population Estimates

The monthly estimates for population size are presented in Table 6. The total population size (33,205) was within the range reported since 1975 (16,506-44,761). The maximum population estimate and recruitment occurred in June, reflecting the spring molt. As fishing pressure increased through the summer the population estimates decreased. The probability of survival averaged 53% and ranged from 69% in June, when fishing pressure was low, to 38% in July, when fishing pressure was greatest. The relationship between the estimated population size and yearly CPUE was examined by plotting the two measures of abundance over time (Fig. 11). The plot shows a strong relationship between the population size and yearly CPUE in 1982-83, when wire pots were used exclusively.

Table 6. Estimated monthly lobster population size, number of recruits, and probability of survival in the the Millstone Point area 1983.

Month	Estimated Population Size N_i	Standard Deviation of N_i	Estimated # of Recruits B_i	Standard Deviation of B_i	Estimated Probability of Survival ϕ_i	Standard Deviation of Survival ϕ_i
June	16120	3762	7458	2225	0.68	0.12
July	13506	2512	4690	1432	0.38	0.06
August	10536	1672	1808	914	0.44	0.06
September	7110	1299	3129	1235	0.50	0.09
October	7823	2282	-	-	0.66	0.19

Total Population = June $_{Ni}$ + Recruits $_{Bi}$ (June - Sept.).

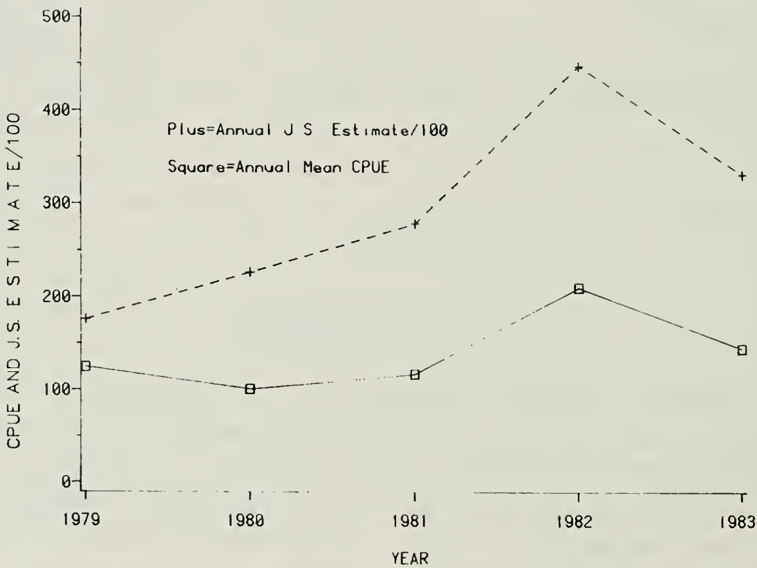


Figure 11. Yearly mean catch per unit effort (CPUE) and Jolly-Seber estimated population size 1979-83.

Impingement

The 1983 monthly impingement estimates for lobsters caught on Units 1 and 2 traveling screens are presented in Table 7. Since 1976, Unit 2 has impinged more lobsters than Unit 1 (NUSCo 1983b); however, in 1983 Unit 1 impinged more lobsters due to a prolonged maintenance and refueling outage

Table 7. Estimated* number of lobsters impinged by month for Unit 1 and Unit 2 intakes and total impinged for 1983.

Month	Unit 1	Unit 2	Both Units
January	8	10	18
February	5	5	10
March	9	7	16
April	49	20	69
May	120	19	139
June	242	35**	277
July	132	13**	145
August	82	93**	175
September	37	62**	99
October	107	128**	235
November	117	50**	167
December	91***	55**	146
Total	999	497	1496

* These values, based on 3 days of sampling per week, are extrapolated based on flow rates to represent the estimated total number impinged per month.
** Refueling outage.
*** Unit 1 sluiceway operation December 16, 1983.

at Unit 2 (June-December). The annual total estimate (1496) for both units combined, was within the range of previous years (506-1979). The number of lobsters impinged varied seasonally, with highest impingement occurring during the summer months, concomitant with peak trap catches and increased water temperature.

The size frequency distribution and sex ratios for lobsters caught on Units 1 and 2 traveling screens in 1983 are presented in Figure 12. The mean CL at both units (58.9 mm) (Unit 1 59.9 mm; Unit 2 56.8 mm) was within the range reported in previous years (48.6-64.9 mm) but smaller than the trap catch value (NUSCo 1983b). Larger sized males were impinged more frequently than large females, thus the mean CL for impinged males was greater (Unit 1 61.9 mm; Unit 2 59.2 mm) than the mean CL for impinged females (Unit 1 56.3 mm; Unit 2 53.0 mm). The greater number of smaller sized lobsters impinged relative to the number caught in traps is because the traps allow for escapement of the smaller sized individuals. The sex ratio of 1.0:0.58 (M:F) was similar to the 1982 value of 1.0:0.50 (M:F) and reflects the higher abundance of males in near shore waters, also evident in the trap catches at JC and IN.

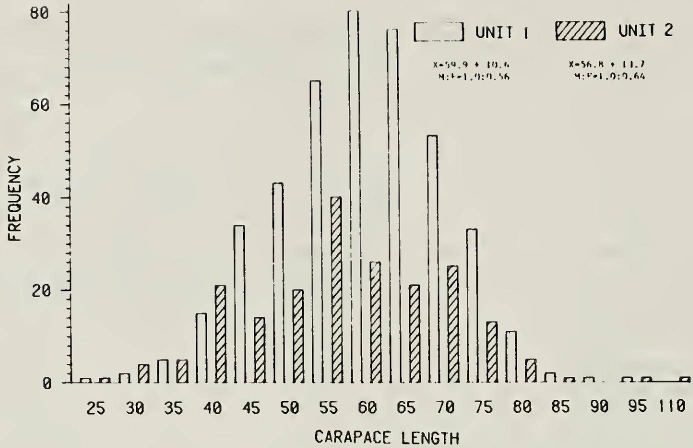


Figure 12. Size frequency distributions for impinged lobsters at each unit in 1983.

During 1983, 38.3% of all lobsters impinged were missing one or both claws. Of the total lobsters impinged at Unit 1 31.2% were missing 1 claw, 4.6% were missing both claws and at Unit 2 34.5% were missing 1 claw, 9.1% were missing both claws. Sublegal-sized impinged lobsters exhibited greater claw loss (38.7%) than legal-sized impinged lobsters (16.7%). The percent of culled lobsters observed in 1983 (impinged and pot caught) was higher than that observed in 1982.

Survival of impinged lobsters was greater in 1983 (79.8%) than in previous years (range 65.0-72.2%). No differences in survival were observed between lobsters $<$ 70 mm CL and $>$ 70 mm CL. The highest mortality of lobsters occurred in August-September when water temperatures were highest; this contrasts with the results of previous years when highest mortality occurred during the peak molting period (May-June).

CONCLUSION

The Millstone Point lobster population remains relatively constant from year to year. The 1983 values for total and legal CPUE, population size and total number caught were lower than the 1982 values but within the range of values reported since this investigation was initiated. The percentage of legal-sized individuals in our catch and the total landings reported in 1983 for the state of Connecticut were greater in 1983 than in 1982. This increase reflects the large number of prerecruits (one molt from legal size) observed in the 1982 catch.

The 1983 values for sex ratios, growth rates, number of berried females, incidence of culled lobsters, and molting patterns were similar to previous years and within the range reported throughout the northeastern coast of North America. Results indicate that the local population was highly exploited, with the commercial and recreational catch being highly dependent on the prerecruit size class.

Since lobsters are not fully vulnerable to our traps until at least year 4 and because they require 5-6 years to reach legal size, an impact on the larval and juvenile stages would not be evident until individuals grow to the size at which they become vulnerable to our sampling gear (>70mm CL). Therefore, it is essential that we continue monitoring this population to evaluate changes in the population during two and three unit operation. Potential changes in the lobster population due to the start-up and operation of Unit 3 in 1986 will be detected through the analysis of changes in the basic population parameters now being collected (population size, growth, movement, size structure, sex ratios, the number of egg-bearing females and culls). In addition to these population parameters, a lobster larvae study will be initiated in 1984 to provide more quantitative entrainment estimates. The stability of these parameters during Unit 1 and 2 operation and after the start up of Unit 3 will demonstrate the effects (if any) of operating plants on Millstone Point.

SUMMARY

1. The 1983 total catch (6376) was within the range of values reported since wire pots were first used 1978-82 (4266-9109).

2. Catch per unit effort (CPUE) per 100 pot hauls was 146 for all sizes of lobsters and 15 for legal-sized lobsters.

3. The catch of fish and crabs significantly affected the catch of lobsters. Accordingly, lobster catches per pot were adjusted for these effects to obtain unbiased mean CPUE estimates.

4. Overall population characteristics; size frequencies, sex ratios, molting patterns, growth per molt, and percentage of culls were within the range reported in previous years.

5. A higher percentage of egg-bearing females was found in 1983 (4.7%) than in any year since wire pots were first used (1978-82 range 3.1-4.2%).

6. Ninety-seven percent of our recaptures and 91% of the commercial recaptures were caught at the station where they were released, suggesting little migration out of the Millstone Point area.

7. The Jolly-Seber model provided a total population size estimate of 33,205 which was within the range reported since 1975 (16,506-44,761).

8. The estimated number of lobsters impinged at Units 1 and 2 was 1496. Population characteristics of impinged lobsters were similar to the values reported for impinged lobsters in previous years and to the values reported for trap catches at the inshore JC and IN stations, except for the higher percent culled associated with impingement.

REFERENCES CITED

Aiken, D.E. 1973. Proecdysis, setal development, and molt prediction in the American lobster (Homarus americanus). J. Fish. Res. Board Can. 30:1337-1344.

Briggs, P.T. and F.M. Mushacke. 1979. The American Lobster in Western Long Island Sound. New York Fish and Game J. 26:59-86.

Cooper, R.A. 1970. Retention of marks and their effects on growth, behavior, and migration of the American lobster, Homarus americanus Trans. Amer. Fish. Soc. 99:409-417.

_____, R.A. Clifford and C.D. Newell. 1975. Seasonal abundance of the American lobster, Homarus americanus, in the Boothbay Region of Maine. Trans. Amer. Fish. Soc. 104:669-674.

_____, and J.R. Uzmann. 1971. Migrations and growth of deep-sea lobsters, Homarus americanus. Science. 171:288-290.

_____. 1980. Ecology of Juvenile and Adult Homarus. Pages 97-142 in J.S. Cobb, and B.F. Phillips eds. The Biology and Management of Lobsters, Vol. II, Academic Press, Inc., New York.

Dow, R.L. 1966. The use of biological, environmental and economic data to predict supply and to manage a selected marine resource. The Amer. Biol. Teacher 28:26-30.

_____. 1969. Cyclic and geographic trends in sea water temperature and abundance of American lobster. Science. 164:1060-1063.

_____. 1976. Yield trends of the American lobster resource with increased fishing effort. Mar. Technol. Soc. 10:17-25.

Ennis, G.P. 1972. Growth per molt of tagged lobsters (Homarus americanus) in Bonavista Bay, Newfoundland. J. Fish. Res. Board Can. 29:143-148.

_____. 1980. Size-maturity relations and related observations in Newfoundland populations of the lobster (Homarus americanus). Can. J. Fish. Aquat. Sci. 37:945-956.

Fair, J.J., Jr. 1977. Lobster investigation in management area I; Southern Gulf of Maine. Mass. Div. of Mar. Fish. 8p.

Flowers, J.M. and S.B. Saila. 1972. An analysis of temperature effects on the inshore lobster fishery. J. Fish. Res. Board Can. 29:1221-1225.

Jolicoeur, P. 1975. Linear regressions in fisheries research: some comments. J. Fish. Res. Board Can. 32:1491-1494.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52:225-247.

Keser, M., D.F. Landers Jr. and J.D. Morris. 1983. Population characteristics of the American lobster, Homarus americanus, in Eastern Long Island Sound, Connecticut. NOAA Tech. Rep. NMFS SSRF-770, 7p.

Krouse, J.S. 1973. Maturity, sex ratio, and size composition of the natural population of American lobster, Homarus americanus, along the Maine coast. Fish. Bull. 71:165-173.

Lund, W.A., L.L. Stewart, and C.J. Rathbun. 1973. Investigation of the lobster. NOAA Tech. Rep. NMFS Project No. 3-130-R, 189p.

Marcello, R.A., Jr., W. Davis III, T. O'Hara and J. Hartley. 1979. Population statistics and commercial catch rate of American lobster (Homarus americanus) in the Charlestown-Manatuck, Rhode Island region of Block Island Sound. Yankee Atomic Electric Company. Submitted to New England Power Company YAEC1175, 40p.

McLeese, D.W. and D.G. Wilder. 1958. The activity and catchability of the lobster (Homarus americanus) in relation to temperature. J. Fish. Res. Board Can. 15:1345-1354.

NUSCo (Northeast Utilities Service Company). 1983a. Lobster Population Dynamics. Pages 1-23 in Monitoring the Marine Environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report 1982.

_____. 1983b. Monitoring the Marine Environment of Long Island Sound at the Millstone Nuclear Power Station, Resume 1968-1982. Northeast Utilities Service company, Waterford, CT.

Richards, R.A., J.S. Cobb, and M.J. Fogarty. 1983. Effects of behavioral interactions on the catchability of American lobster, Homarus americanus, and two species of Cancer crab. Fish. Bull. 81:51-60.

Russell, H.J., C.V.D. Borden, and M.J. Fogarty. 1978. Management studies of inshore lobster resources completion report. No. L074-1-RI(1):1. R.I. Fish and Game, 75p.

Scarratt, D.J. 1970. Laboratory and field tests of modified sphyrion tags on lobsters (Homarus americanus). J. Fish. Res. Board Can. 27:257-264.

_____, and P.F. Elson. 1965. Preliminary trials of a tag for salmon and lobsters. J. Fish. Res. Board Can. 2:421-432.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika 52:249-259.

Skud, B.E. and H.C. Perkins. 1969. Size composition, sex ratio and size at maturity of offshore northern lobsters. U.S. Fish Wildl. Spec. Sci. Rept. Fish. 598, 10p.

Smith, E.M. 1977. Some aspects of catch/effort, biology, and the economics of the Long Island lobster fishery during 1976. NOAA Tech. Rep. NMFS Project No. 3-253-R-1, 97p.

Thomas, J.C. 1973. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December 1970. NOAA Technical Report, NMFS SSRF-667, 57p.

Wilder, D.G. 1953. The growth rate of the American lobster (*Homarus americanus*). J. Fish. Res. Board Can. 10:371-412.

_____. 1963. Movements, growth, and survival of marked and tagged lobsters liberated in Egmont Bay, Prince Edward Island. J. Fish. Res. Board Can. 20:305-318.

_____, and R.C. Murray. 1958. Do lobsters move offshore and onshore in the fall and spring? Fish. Res. Board. Can. Atlantic Prog. Rpt. 69:12-15.

FISH ECOLOGY

Table of Contents

FISH ECOLOGY

INTRODUCTION

The purpose of the marine monitoring programs at Millstone is to determine if construction and operation of the nuclear power plants effect changes in the local marine biota beyond those expected due to natural variation. Plant operations may impact finfish in several ways. Larger fish may be removed from the population by impingement on the intake screens. Eggs, larvae and smaller fish may be adversely affected during entrainment through the condensor cooling water system. In addition, local fish distributions could change due to thermally or physically altered habitats. Physical changes would include bottom scouring in regions of high water velocity and riprap addition.

Several finfish sampling programs were established as part of the Millstone ecological monitoring effort. The shore-zone fish (seine) sampling program began in 1969. Unit 1 impingement sampling began in 1972 followed by the trawl and both offshore and entrainment plankton programs in 1973, and Unit 2 impingement sampling in 1976. The program objectives are:

1. To identify and enumerate finfishes found in the plankton, impingement, seine, and trawl samples collected from stations within the Greater Millstone Bight.

2. To determine which of the finfishes known to be present in the area around Millstone Point are potentially susceptible to entrainment, impingement and exposure to the thermal plume.

3. To describe historical fluctuations of potentially impacted finfishes as best estimated by egg or larval density or impingement, seine or trawl catches or by a combination of these methods.

4. To evaluate whether variations in the abundance estimates in the current year are within the normal variation as determined from historical data and to interpret such variations in relation to power plant operations.

To ensure that these objectives were met, study methods have been modified when necessary (NUSCo 1983a). Offshore ichthyoplankton and entrainment fish egg methods have been consistent since 1979; trawl, seine, impingement and entrainment larval programs have been consistent since 1976.

Observed changes in finfish abundance may be natural or power plant induced, so an understanding of fluctuations representing natural variability is important. Historical observations through 1982 provided a basis for predicting the kinds and relative numbers of organisms that might occur in a given area at a certain time of the year. We used harmonic regression analysis to model the observed abundance fluctuations and to forecast expected fluctuations for 1983. We compared the actual data collected to those values predicted and interpreted the differences relative to power plant impact. Model results and interpretations are included in this report.

MATERIALS AND METHODS

Trawl sampling

Demersal finfishes were sampled west of Twotree Island (TT), southwest of Bartlett Reef (BR), in Niantic Bay (NB), Jordan Cove (JC), Niantic River (NR) and in front of the intake structures (IN) (Fig. 1). Specimens were collected using a 9.1-m otter trawl with a 0.6-cm mesh cod-end liner. Triplicate tows, each covering 0.69 km of the bottom as measured by RADAR, were made biweekly at each station from October 1977 through September 1983. Prior to October 1977, the unit-effort was 15 min per tow. Although time is traditionally the unit-effort for trawls, it was felt that the demersal finfish abundance would be better

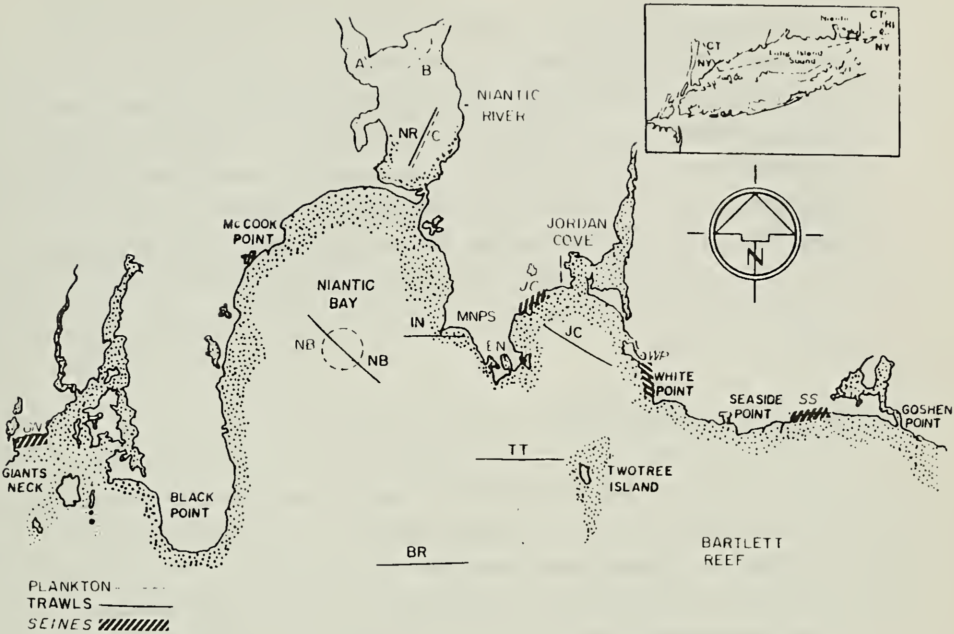


Figure 1. Location of plankton, trawl and seine sampling sites.

estimated by using a fixed distance per tow. The distance of 0.69 km was chosen because it is the maximum distance that can be covered at NR and JC. In addition, this was approximately the distance covered in 15 min when the boat was hauling a trawl net with the engine at idle speed without the influence of tidal currents. Thus, trawl data collected between February 1976 and October 1977 are considered comparable to those collected after October 1977. The data used in this report are from the period February 1976 through September 1982. Fish in each haul were identified to the lowest practical taxon, counted, and measured to the nearest mm of total length.

Seine sampling

The shore-zone fishes were sampled monthly at Seaside Point (SS), White Point (WP), Jordan Cove (JC), and Giants Neck (GN) (Fig. 1). They were collected with a 9.1 x 1.2-m knotless nylon mesh (1.3 cm) beach seine from October through December 1982, and from February through September 1983. Triplicate 30-m hauls were made parallel to the beach within the 2-h period before high tide at each station. These methods were comparable to those used since October 1976. Fish in each haul were identified to the lowest practical taxon, counted, and measured to the nearest mm. From 1969 through 1980, only standard length measurements were made. During 1981 through 1982 both standard and total lengths were measured. Linear regression equations fitted to the standard length data were used to estimate the total lengths for the period 1976-1980.

Ichthyoplankton sampling

The eggs and larvae of various finfish were sampled from October 1982 through September 1983 using 0.333-mm mesh plankton nets. Entrainment ichthyoplankton samples were collected at least weekly, alternating between Units 1 and 2 discharge (EN). Samples were collected with a 1.0 x 3.6-m conical plankton net deployed using a gantry system described previously (NUSCo 1978). Volumes filtered approximated 400 m^3 and were measured with four General Oceanic flowmeters (Model 2030G) arranged inside the net hoop to account for vertical and horizontal flow variations. Volumes were calculated from the four flowmeters and averaged for each sample. One day and night sample was collected per week in October through December and four day and four night samples per week in January through September. Offshore ichthyoplankton samples were collected at NB (Fig. 1) with paired 0.61 x 3.3-m cylinder-cone plankton nets, mounted on an unbridled bongo frame. Volumes filtered approximated 300 m^3 and were determined with General Oceanic (Model 2030G) flowmeters. Two bongo tows (1/day, 1/night) were made biweekly September through March. Four bongo tows (2/day, 2/night) were made weekly from April through August. One replicate of each tow was processed. The EN larval data used in this report are from the period October 1976 through September 1983; the NB larval data are from October 1978 through September 1983. Egg data are from May 1979 through September 1983.

Plankton samples were split using a NOAA-Bourne splitter (Botelho and Donnelly, 1978) and sorted for ichthyoplankton using dissecting microscopes. Samples were sorted for fish eggs and larvae during April through September. During all other months, egg abundance was low and samples were sorted only for larvae. Fish eggs and larvae were identified to the lowest practical taxon. The eggs of *Tautoglabrus adspersus* and *Tautoga onitis* were differentiated weekly using the criterion of bimodality of egg diameters (Williams 1967).

Impingement sampling

Finfish impinged on the traveling screens of Millstone Units 1 and 2 were sampled after each of three 24-h periods a week, usually on Tuesday, Wednesday and Friday. Organisms washed from the screens were collected in a metal basket measuring 1.5 x 0.8 x 1.75 m with 2.5-cm perforations. Screen washes were initiated manually at least once every 8 hours. During periods of heavy debris loading (e.g., storms), either automatic sensors started screen washes or the system was placed in continuous operation. Fish were sorted from the debris, identified to the lowest practical taxon, counted and measured to the nearest mm of total length.

Analytical Methods

The data collected from the programs described above were processed and analyzed in different ways depending on the type of data. When having a complete seasonal cycle was desirable, such as in species composition or spectral analysis described below, a "year" was considered to run from October through September. For instance, 1983 included data from October through December 1982 and January through September 1983. The data from all programs were standardized to some unit effort. The trawl data were reported as catch per 0.69-km tow; the seine data as catch per 30-m haul; the plankton data as number per 500 m^3; and impingement data as count per 24 h. Percent species composition was computed by summing the total catch (corrected for variations in sample size if necessary), of a particular taxon and dividing by the total number of fish caught.

Totals of fish impinged were determined by summing the counts on days sampled and the estimated numbers on days not sampled. The estimates for days not sampled were calculated by dividing the sum of the fish collected in a month by the sum of the condenser cooling water-flow on collection days to determine a monthly impingement rate (n/m^3). This rate was then multiplied by the flow during non-sampling days in each month to obtain estimates for those days. The actual and estimated daily totals were summed to provide monthly estimates. Annual totals were the sum of the estimated monthly totals.

Since previous studies (NUSCo 1982a, 1983a) have shown that the trawl, seine, plankton and impingement data came from highly skewed, non-normal distributions, all these data were log-transformed:

$Y_{sti} = \ln(\text{catch}*c + 1)$ for trawls and seines
$Y_{sti} = \ln(\text{count}*c + 1)$ for impingement
$Y_{sti} = \ln(\text{density} + 1)$ for ichthyoplankton

where 's' refers to a sampling station, 't' designates the sampling period, and 'i' indicates a sample within the sampling period. The constants, 'c', are multipliers (1, 10 or 100) to insure that incrementing the catch or count by 1 added less than 0.01%. When replicates were taken in a sampling period, the transformed data were averaged so that a single value was available for each sampling period and station combination. The sampling periods were weekly for impingement and plankton samples, biweekly for trawl samples and monthly for seine samples.

The general approach used to build the mathematical models for the observed fluctuations included the following steps. First, abundant species were selected and the data for these species were zero-filled. That is, a zero was recorded for every sampling period-station-replicate combination in which no individuals of a selected species were found. Second, the data on the selected species were limited to those stations where the species was most abundant. Third, the data were log-transformed as described above and the dominant periods for the biweekly trawl and weekly entrainment and impingement data were determined using spectral analysis (PROC SPECTRA, SAS 1982). Because the seine, offshore fish larvae and all the fish egg data were collected at unequal intervals, spectral analyses were not done on these data. Fourth, stepwise analyses were used to find the best set of variables (predictors) for each mathematical model.

Variables considered as potentially good predictors were time, water temperature, deviations from normal water temperatures, barometric pressure, species abundance at other stations, zooplankton abundance' season and flow (water volume entrained by the cooling system). Of these, time, season, and flow were the most useful. The latter was only considered for the impingement models. The variable "season" was a dummy variable that was set equal to 1 for those months corresponding to when at least 98% of the total annual abundance occurred for each species; it was set to 0 during other times (see Table 4). The variable "time" always appeared in the argument of the sine and cosine functions. The actual argument of these trigonometric functions is the time (in days) expressed as radians scaled for the period of the cycle being described by each harmonic component (see Bliss (1958) and Lorda (1983) for more details). The following periods (multiples or even fractions of a basic period of one year) were initially considered for possible harmonic components:

6 year cycle	6 months
5 year	4 months
4 year	3 months
3 year	2 months
2 year	
1 year	

Dummy predictor variables that represented interactions were created by multiplying the values of the interacting variables. In the impingement models, flow appeared as a multiplier of the other predictors and forced a low impingement prediction whenever flow was low. Three general classes of deterministic models were found most descriptive:

$$\text{time alone: } Z = I + \text{sin terms} + \text{cos terms}$$

$$\text{multiplicative: } Z = I + M + M(\text{sin terms} + \text{cos terms})$$

$$\text{multiplicative (no intercept): } Z = M + M(\text{sin terms} + \text{cos terms})$$

where: I = intercept

Z = mean of log-transformed catch, count or density

M = multiplier, flow (for impingement data) or season (for seasonally occurring taxa).

The best model, by definition, had 1) maximum R^2 and 2) all parameter estimates significantly different from 0. The residuals were then analyzed for autocorrelation if the data were equally spaced in time. If autocorrelation was evident, the order of the autoregressive process was determined. If the data were not equally spaced in time, the best harmonic regression model was used to provide values for the missing months or weeks in the following way. The variance ($\hat{\sigma}^2$) of the residuals from the best regression model was estimated and assumed to come from a $N(0,\sigma^2)$ distribution. A pseudoresidual, R*, was generated using a random number, η, from the standard normal distribution, and the estimated variance ($\hat{\sigma}^2$):

$$R^* = (\eta) * (\hat{\sigma}^2)$$

This was added to the predicted value for a week or month unless season for that time period had previously been determined to be 0. In that event, a 0 replaced the missing value. The parameters associated with the deterministic (harmonic) and autoregressive processes were estimated and forecasts for the 1982-1983 sampling period were generated by PROC ARIMA (SAS 1982).

The best regression models determined from 1976-1982 data were considered a description of average abundance fluctuations over those years. The models were used to generate a forecast for 1983. The actual 1983 data were compared to the forecast through the use of upper and lower 95% confidence intervals and percent error. Interpretations were then made as to how well the model forecasted the 1983 data.

RESULTS

From October 1976 through September 1983, organisms from over 100 different taxa were identified from trawl, seine, plankton and impingement monitoring programs. The relative abundance of these taxa is indicated by the percent species composition (Table 1). Clearly, all

Table 1. Finfish percent species composition from various MNPS sampling programs during October 1976 through September 1983 (complete listing is in Appendix 1).

Species	Impingement*	Plankton Entrainment Eggs	Plankton Entrainment Larvae	Plankton Niantic Bay Eggs	Plankton Niantic Bay Larvae	Trawl	Seine
Pseudopleuronectes americanus	17.87	0.12	10.96	0.03	6.91	45.09	0.05
Anchoa spp. (a)	16.76	10.86	56.07	10.99	58.06	2.45	0.02
Myoxocephalus aenaeus	11.09	0.20	3.84	0	2.13	2.37	0.01
Menidia spp. (b)	11.01	0.12	0.14	1.72	0.18	4.95	80.82
Gasterosteus wheatlandi	7.44	0	0.01	0	0	trace	0.03
Microgadus tomcod (p)	6.36	trace	0.07	trace	0.04	3.53	0.18
Gasterosteus aculeatus	5.15	0	0.02	0	0.01	0.34	0.64
Tautogolabrus adspersus	3.61	52.92	2.53	44.19	6.56	3.16	0.01
Scophthalmus aquosus	2.97	1.06	0.67	1.59	1.13	14.47	trace
Syngnathus fuscus	2.74	0	0.77	0	0.54	0.55	0.53
Peprilus triacanthus	1.87	0.07	1.10	0	1.70	0.63	trace
Alosa spp. (c)	1.58	5.18	0.06	1.45	0.19	0.28	0.01
Merluccius bilinearis	1.56	0	0.06	0	0.13	1.16	0
Tautoga onitis	1.52	23.77	2.34	31.60	3.99	0.91	0.02
Morone americana	1.46	trace	0	0	0	0.02	0
Cyclopterus lumpus	1.01	0	0.01	0	0.01	0.08	0
Osmerus mordax	0.90	0	0.02	0	0.02	0.43	0.02
Raja spp. (d)	0.81	0	0	0	0	4.00	0
Prionotus spp. (e)	0.45	2.68	0.44	2.76	0.98	1.87	0
Brevoortia tyrannus	0.40	0.06	0.78	0.14	1.41	0.01	0.18
Cynoscion regalis	0.36	0.19	0.45	1.19	0.57	0.05	0
Sphoeroides maculatus	0.35	trace	0.06	0	0.06	0.03	0.02
Anguilla rostrata	0.34	0	0.17	0	0.02	0.06	0.04
Fundulus spp. (f)	0.33	0.03	0.01	0	trace	trace	9.20
Liparis atlanticus (p)	0.33	0	1.80	0	0.53	0.06	0
Opsanus tau	0.31	0	0	0	0	0.09	0
Pollachius virens	0.29	0	0.01	0	0.03	0	0
Paralichthys dentatus	0.28	0.01	0.02	0.86	0.09	0.67	0
Pomatomus saltatrix	0.23	0	0	0	0	trace	0.26
Ammodytes americanus (p)	0.23	0.03	9.62	0	8.37	0.21	2.82
Urophycis spp. (g)	0.22	0.33	0.05	0.31	0.08	0.85	trace
Stenotomus chrysops	0.22	1.03	0.51	1.27	0.60	15.63	0

*Impingement percents have been corrected for variations in flow
trace= <0.01%
(p) indicates most probable identification
(a) includes A. mitchilli and A. hepsetus
(b) includes M. menidia and M. beryllina
(c) includes A. aestivalis, A. mediocris, A. pseudoharengus and A. sapidissima
(d) includes R. erinacea, R. ocellata and R. eglanteria
(e) includes P. carolinus and P. evolans
(f) includes F. majalis and F. heteroclitus
(g) includes U. regia, U. chuss and U. tenuis

of these taxa could not be discussed in the same detail. Approximately 90% of the taxa individually contributed less than 0.01% to any program. These taxa were not sufficiently abundant for analyses other than simple presence-absence summaries. The criterion used to select certain taxa for detailed analyses and discussion was that they be susceptible to entrainment or impingement. The basis used was that they appeared among the top 80% impinged or entrained taxa (see Appendix 2 for 1983 impingment estimates).

As a result, 10 taxa were selected for further study, 9 of which will be discussed in this report. The winter flounder (Pseudopleuronectes americanus) was the dominant finfish species in impingement (17.87%), and trawl collections (45.09%) and ranked second in entrainment (10.96%). This species has been the subject of extensive investigations detailed in the Winter Flounder Population Studies section. Anchovies (Anchoa spp.) ranked first among entrained larval taxa and second among impinged taxa. Eggs of the cunner (Tautogolabrus adspersus) and tautog (Tautoga onitis) were the two most abundant egg taxa entrained, but only cunner was well represented in the other collections. Silversides (Menidia spp.), ranked fourth among impinged and trawled finfish, and dominated the finfish catch from seines. Grubby (Myoxocephalus aenaeus), ranked third among impinged finfish as did American sand lance (Ammodytes americanus) among entrained larvae. Sticklebacks (Gasterosteus aculeatus and G. wheatlandi), and Atlantic tomcod (Microgadus tomcod), each contributed 5-8% to the impingement species composition. Windowpane (Scophthalmus aquosus), ranked ninth among the impinged finfish and third among trawled fish. Salient life history information on these taxa are summarized in Table 2.

The selection criterion eliminated three finfish taxa that were relatively abundant (> 4%) in the trawl and seine programs: skates (Raja spp.), killifishes (Fundulus spp.) and scup (Stenotomus chrysops). Since they were infrequently found (< 1%) in impingement or entrainment collections, these taxa were believed to be relatively unaffected by the impingement or entrainment processes. Although northern pipefish (Syngnathus fuscus) and sea robins (Prionotus spp.) contributed more than 2% to impingement and entrainment collections, respectively, they were not selected for detailed analyses because of otherwise low abundances.

Ammodytes americanus, American sand lance

The taxonomy of sand lance has not been resolved and the numbers of species found in the North Atlantic is questionable (Bigelow and Schroeder 1953; Leim and Scott 1966; Scott 1972; Fritzsche 1978). However, all specimens collected near MNPS were Ammodytes americanus.

Table 2. Summary of life history information for selected finfishes.

Species	Geographic Location	Habitat	Adult Seasonality	Reproductive Maturity	Spawning Season	Eggs
Ammodytes americanus	Artic to Cape Hatteras[1]	Large schools, over sandy bottoms from near shore to edge of shelf; burrows into sand[1]	January and February in Millstone trawls and impingement; spring in shore zone[1]	Unknown	Late November or early December to late March[2]	Demersal[1]; slightly adhesive[2]
Anchoa spp.	Atlantic coast of North America from Gulf of Maine to Yucatan, Mexico[1]	Ubiquitous euryhaline species in estuaries and coastal waters[1]	May to October in southern New England waters; moves offshore in winter[3]	2.5- 12 months (spawn once per generation)[1]	June through September in depths of less than 20 m[1]	Pelagic[1] 28 - 48 hour hatch time[4]
Gasterosteus aculeatus	Circumpolar distribution from northern Newfoundland to Chesapeake Bay[4]	Euryhaline, prefer estuarine eelgrass beds[4]	Year round resident[3]; offshore November to March; some anadromous spawning migrations in spring[5]	Most at age 2+; 50-70 mm[8]	June to July in northern climes[4]; many die after spawning; territorial[3]	Nest built in brackish or fresh water by males who guard and protect eggs and larvae[4]; eggs clumped in nest[3]
Gasterosteus wheatlandi	Newfoundland to Long Island Sound[9]	Restricted to coastal/ brackish waters only[8, 9]	Year-round resident; offshore November to March; spawning migration to brackish waters in spring[8]	Most at age 1+; 35-45 mm[8]	Late May to July after G. aculeatus[7]	Nest built in brackish by males who guard and protect eggs and larvae[4]
Menidia spp.	Atlantic silverside: Canada to Florida Inland silverside: Massachusetts to northern Mexico[3]	Tidal river mouths, creeks, channels and bays[10]	Shore zones in summer and fall; deeper water in winter[11]	1 year old (60-70 mm)[3]	April-July[3, 4, 12]	Demersal. Attached to eelgrass, adhering to sand and each other in clusters[10]
Microgadus tomcod	Coastal and freshwaters from Gulf of St. Lawrence[3]	Strictly coastal and inshore in estuaries, often in brackish water[3]	Near estuaries year round[3]	At 1 yr (Hudson River) to 4 yrs (Quebec) (>170mm)[6]	Entering streams and rivers October through January[6]	Demersal, attached in masses to seaweeds, stones or any available support[3]
Myoxocephalus aenaeus	New Jersey to the Gulf of St. Lawrence[3]	Coastal and estuarine over various bottoms, particularly abundant in eelgrass[4]	Present throughout the year, most abundant inshore during winter months[1]; deeper water in fall[4]	Mature in 3rd. year (2+ age group)[3]	December-March in Connecticut[4]	Large and demersal; occurring in clumps on various substrates[4]
Scophthalmus aquosus	Atlantic coast of North America from Gulf of St. Lawrence to South Carolina[3]	Coastal waters: sandy bottom (New England and southward), softer muddier grounds in the Gulf of Maine[3]	Year-round off of Southern New England attributed to wide temperature tolerance[3]	3-4 yrs at 230-254 mm[3]	Through October depending on location[1]; Bimodal, spring and summer[13]	Pelagic. Transparent, buoyant, spherical[3]
Tautoga onitis	Atlantic coast of North America Nova Scotia to South Carolina[3]	Steep rocky shores and around breakwaters, wrecks, piers, over mussel beds[3]	April to November, deeper water in winter and become dormant[14]	2 years old (when fish are 76 mm)[2]	June - August[2] May - Sept. at Millstone[1]	Pelagic; buoyant and without oil globule[3]
Tautogolabrus adspersus	Atlantic coast of North America; Newfoundland southward to Virginia[3]	Among seaweeds, stones or dock piles, in rock pools[3]	Year-round residents, may descend to slightly deeper water in winter[3]	At 2 yrs at 70-90 mm[3]	Chiefly May-June but can spawn as late as August 15[3]	Pelagic. Buoyant and transparent, without oil[3]

1. NUSCo. 1982b.
2. Frizsche, Ronald A. 1978.
3. Bigelow and Schroeder. 1953.
4. NUSCo. 1982a.
5. Morgan, J.P. and G. J. Fitzgerald. 1981.
6. Hardy, Jerry D., Jr. 1978.
7. Roland, W.J. 1983.
8. Craig, D. and G.J. Fitzgerald. 1982.
9. McInerney, J.E. 1969.
10. Johnson, G. David. 1978.
11. NUSCo. 1983.
12. Barkman, R.C., D.A. Bengtson and A. D. Beck. 1981.
13. Richards. 1959.
14. Olla et al. 1974.

Sand lance were found in the plankton, seine, trawl and impingement collections (Table 1). Larvae ranked second in plankton collections at NB and third at EN, and were found in these samples from January to May; eggs were not abundant in plankton collections. While sand lance was the third most abundant shore-zone species, it contributed less than 3% to the species composition from 1976-1983. Young-of-the-year (modal length of 80 mm) (Fig. 2) were most abundant in seine collections July to

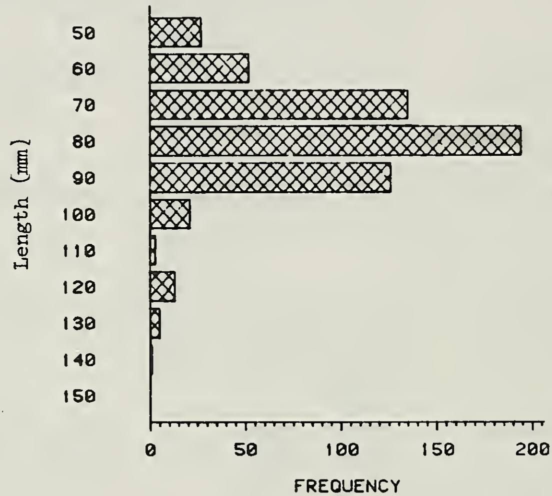


Figure 2. Length frequency of A. americanus in seines from October 1976 through September 1983.

October. Sand lance were not observed in great numbers in trawls or impingement. When found in trawls, they appeared primarily at NR and BR (Table 3) from January to March (Table 4).

Sand lance modeling was limited to larval log-transformed abundance data at EN and NB. Season was found to be a significant multiplicative regressor in the larval models (season was 0 from August through October and 1 at other times, Table 4). There was no evidence of long term (>12 mo) abundance cycles. Annual cycles were found at both plankton stations. The shorter term cycles (4 mo) were evidence of consistent fluctuations within each year. Harmonic regressions modeled the data reasonably well as evident from the R^2 values (Table 5). The forecast errors for the

Table 3. Geographic distribution (as percents) of selected finfish species at MNPS trawl stations October 1976 through September 1983.

Station	*A. americanus*	*Anchoa* spp.	*Gasterosteus* spp.	*Menidia* spp.	*M. tomcod*	*M. aenaeus*	*S. aquosus*	*T. onitis*	*T. adspersus*
NR	24.6	5.2	73.4	26.2	7.2	35.7	7.6	22.4	3.8
IN	1.6	33.2	1.2	34.5	18.2	19.6	10.9	25.1	59.7
JC	4.8	8.4	23.2	20.2	20.5	15.2	5.0	20.5	21.3
NB	0.8	47.8	1.0	12.7	37.9	6.4	7.8	13.1	7.4
TT	7.4	5.3	0.8	4.9	13.4	8.2	15.0	8.2	3.2
BR	60.8	0.1	0.3	1.5	2.8	14.8	53.7	10.8	4.7

Table 4. Seasonal distribution of selected finfish species from MNPS monitoring programs. Those percents marked by an asterisk (*) are the months for which the variable season was set equal to one in the model building procedure.

SPECIES	PROGRAM	MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A. americanus	Larvae	19.5*	6.1*	23.5*	36.5*	7.9*	0.0*	0.3*	0.3	0.4	0.1	0.1*	5.1*
	Impingement	10.0	3.1	6.6	12.7	10.7	4.4	6.9	0.2	0.8	2.2	13.6	28.7
	Seine	00.0	00.0	00.0	00.0	00.0	0.5	71.1	1.3	6.3	10.8	00.0	00.0
Anchoa spp.	Egg	0.0	0.0	0.0*	0.0*	0.1*	19.2*	73.3*	7.4*	0.0*	0.0	0.0	0.0
	Larvae	0.0	0.0	0.0	0.0	0.0*	1.0*	72.4*	22.7*	3.5*	0.3*	0.0*	0.0
	Impingement	0.1	0.1	0.0	0.2	17.8	68.9	5.8	0.7	1.7	3.3	0.8	0.4
	Trawl	0.1	00.0	00.0	00.0	00.0	0.1	00.0	12.6	63.9	21.0	0.7	1.6
G. aculeatus	Impingement	21.6	12.3	16.1	33.5	1.2	0.2	0.1	0.0	0.0	0.4	5.4	9.2
	Seine	0.0	0.0	0.0	0.9	8.9	44.4	41.8	0.6	0.3	3.2	0.0	0.0
G. wheatlandi	Impingement	0.2	0.1	10.8	87.6	0.6	0.1	0.0	0.0	0.0	0.0	0.4	0.2
Menidia spp.	Impingement	43.7	7.3	10.7	4.9	0.9	0.2	0.5	0.0	0.1	0.2	0.6	30.8
	Trawl	19.1*	1.6*	1.3*	0.3	0.0	0.0	0.0	1.0*	1.5*	1.7*	11.2*	62.2*
	Seine	0.0	0.0	0.0	0.0	0.9*	4.4*	40.8*	31.6*	13.6*	6.2*	0.9*	1.5*
M. tomcod	Impingement	13.1	1.5	1.0	1.0	2.9	4.1	0.5	0.6	0.8	1.2	4.9	68.3
M. aenaeus	Larvae	0.7*	6.9*	36.3*	46.2*	9.9*	0.0*	0.0	0.0	0.0	0.0	0.0	0.0
	Impingement	31.4	6.4	5.5	10.4	6.7	1.4	0.3	0.2	0.4	0.3	0.5	36.6
	Trawl	20.0	15.9	9.5	14.3	8.9	2.6	1.4	2.1	1.5	1.4	4.4	18.0
S. aquosus	Impingement	9.8	2.3	6.9	14.5	13.4	8.8	15.7	7.9	3.0	2.5	5.8	9.3
	Trawl	6.9	2.6	1.8	3.9	7.6	9.3	9.4	12.0	13.2	6.9	14.5	12.0
T. onitis	Egg	0.0	0.0	0.0	0.0*	8.4*	44.6*	36.8*	9.7*	0.4*	0.0	0.0	0.0
	Larvae	0.0	0.0	0.0	0.0	0.2*	14.9*	78.5*	5.6*	0.7*	0.0	0.0	0.0
	Impingement	2.0	0.1	0.3	2.9	33.8	19.0	10.5	10.5	9.6	5.7	2.4	3.2
	Trawl	0.9	0.1	0.3	1.6	6.4	17.8	28.0	18.1	10.5	7.5	5.3	3.4
T. adspersus	Egg	0.0	0.0	0.0	0.0*	13.1*	64.8*	21.4*	0.6*	0.0*	0.0	0.0	0.0
	Larvae	0.0	0.0	0.0	0.0	0.2*	22.9*	73.5*	3.3*	0.0*	0.0*	0.0	0.0
	Impingement	5.2	0.7	0.9	1.9	8.4	22.2	16.2	18.4	17.0	9.1	2.3	2.5
	Trawl	0.1	0.0	0.0	0.3	8.0*	38.7*	31.9*	12.4*	6.0*	1.7	0.6	0.2

Table 5. Sand lance; summary of time-based regression models selected to describe their occurrance in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Entrainment (larvae)	EN	$Z_t = B_1S + B_2S\sin(tK_{12}) + B_3S\cos(tK_{12}) - B_4S\sin(tK_4) + A_1e_{t-1} + A_2e_{t-2} - A_3e_{t-43} + A_4e_{t-51}$	0.92	8.9	314	28.7	52
Ichthyoplankton (larvae)	NB	$Z = B_1S + B_2S\sin(tK_{12}) + B_3S\cos(tK_{12}) - B_4S\sin(tK_4)$	0.93	6.6	224	11.1	52

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
S = seasonal coefficient
n = number of observations contributing to the %error

1983 data were low and observed data fell within the 95% confidence intervals for both models (Fig. 3).

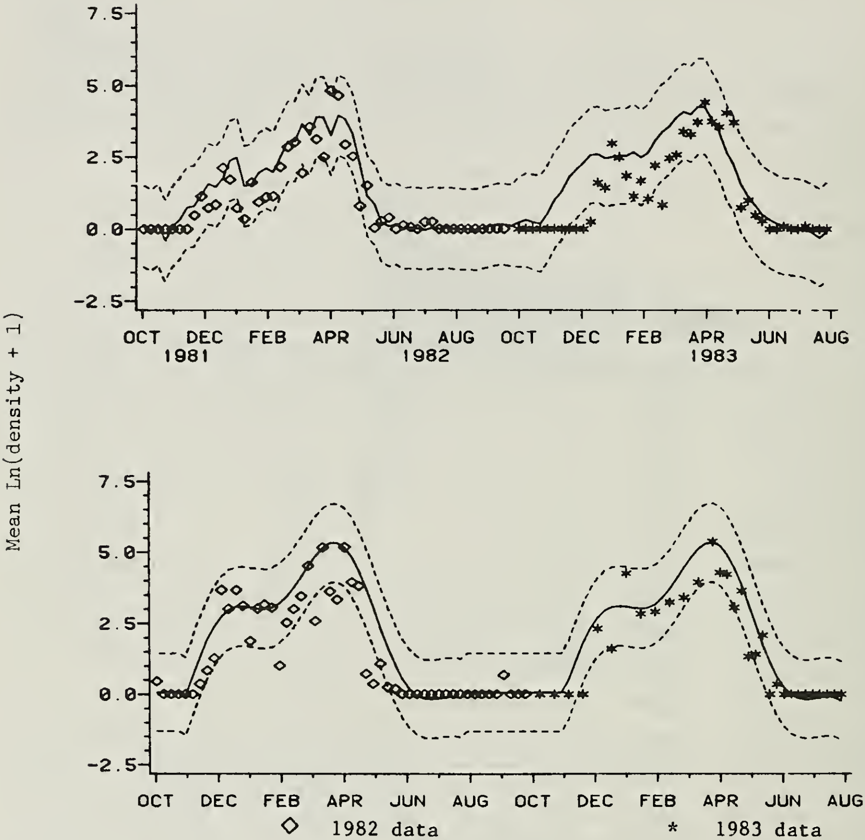


Figure 3. Forecast (———) and 95% confidence limits (---) for A. americanus larvae at EN (top figure) and NB (bottom figure). The EN model was fit to data from October 1976 through September 1982; the NB model was fit to data from October 1978 through September 1982.

Sand lance were most prevalent as larvae in the plankton programs. They were present, but not abundant, in other finfish monitoring programs; eggs are demersal (Table 2) and were not found in plankton samples. Larger sand lance burrow into the sand (Table 2) and this behavior may account for the low numbers of post-larval sand lance.

Adult sand lance were found in the trawl collections in the winter (January - March) during their spawning season (Table 2). Larvae were in the plankton samples during this time as well. Young-of-the-year sand lance were found in the shore zone July through October where they were caught in seines. Harmonic regressions of larval data seemed to accurately model fluctuations. Most of the 1983 data fell well within the 95% confidence intervals showing no change over time.

Anchoa spp., anchovies

Two anchovies, the bay anchovy (*Anchoa mitchilli*) and the striped anchovy (*Anchoa hepsetus*), have been collected in the waters off Millstone Point. The bay anchovy was by far the most common of the two species and made up over 99% of all anchovies collected.

Ichthyoplankton was comprised largely of anchovies; their larvae ranked first and eggs ranked third (Table 1). While anchovies ranked fifth in impingement during the 1977-1982 period (NUSCo 1983b) they ranked second in the 1977-1983 period due to a 90% increase in 1983 (Fig. 4).

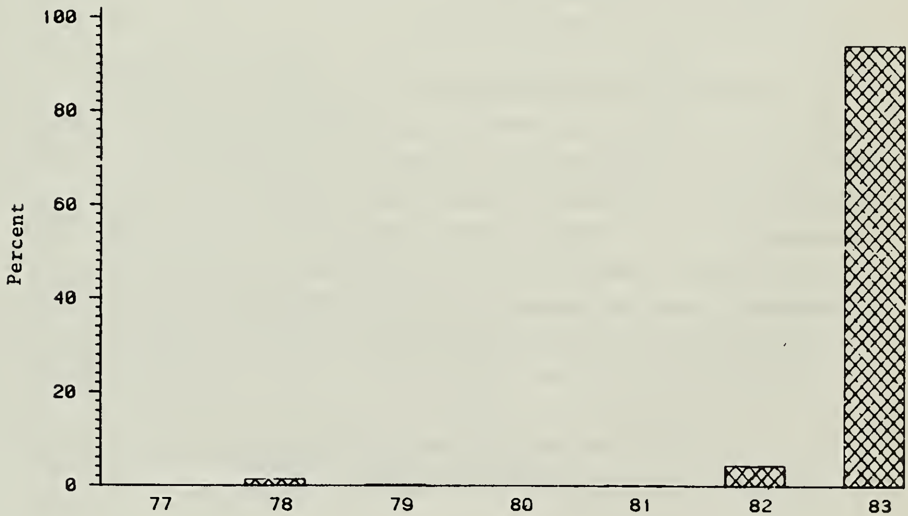


Figure 4. Annual percents of all Anchoa spp. impinged.

They ranked eighth among trawl-caught fish. Anchovies were most abundant in trawl catches at NB and IN (Table 3). Impinged fish (modal length of 80 mm) were primarily adults, while trawled fish (modal length of 30 mm) were young of the year (Fig. 5).

Table 6. Anchovies; summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F-B_2FCos(tK_{72})-B_3FCos(tK_{12})-B_4FSin(tK_6)+B_5FCos(tK_6)+B_6FSin(tK_4)+A_1e_{t-1}+A_2e_{t-2}$	0.73	27.0	353	42.2	52
Imoingement	Unit 2	$Z_t = B_1F-B_2FCos(tK_{72})-B_3FCos(tK_{12})-B_4FSin(tK_6)+B_5FCos(tK_6)+B_6FSin(tK_4)+A_1e_{t-1}+A_2e_{t-2}$	0.76	24.3	353	47.8	52
Entrainment (larvae)	EN	$Z_t = B_1S+B_2SSin(tK_6)+B_3SCos(tK_6)-B_4SSin(tK_3)+A_1e_{t-1}-A_2e_{t-8}-A_3e_{t-49}$	0.95	5.0	314	7.9	52
Entrainment (eggs)	EN	$Z_t=-B_1SCos(tK_{12})+B_2SSin(tK_6)-B_3SCos(tK_4)+B_4SCos(tK_3)$	0.93	7.3	209	10.6	52
Ichthyoplankton (larvae)	NB	$Z_t= B_1S+B_2SSin(tK_6)+B_3SCos(tK_6)+B_4SSin(tK_3)$	0.91	8.6	224	9.1	52
Ichthyoplankton (eggs)	NB	$Z_t=-B_1SCos(tK_{12})+B_2SSin(tK_6)-B_3SCos(tK_4)+B_4SSin(tK_3)$	0.90	9.7	211	20.8	52

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
S = seasonal coefficient
n = number of observations contributing to the %error

Fluctuations in log-transformed anchovy catches in various monitoring programs were modeled using harmonic regression techniques. Data from the trawl and seine programs were insufficient for modeling. The egg and larval models included season (see Table 4) and the impingement models included flow, as multiplicative regressors (Table 6). The models of egg and larval abundance explained over 90% of the variation during the modeling period; the impingement models explained less variation (73-76%). The forecast errors for the impingement models (42-48%) were higher than those resulting from the egg and larval models (8-21%). Some 1983 data exceeded the 95% confidence limits; the eggs appeared earlier than predicted and impingement levels were two orders of magnitude higher than forcasted (Figs. 6 and 7).

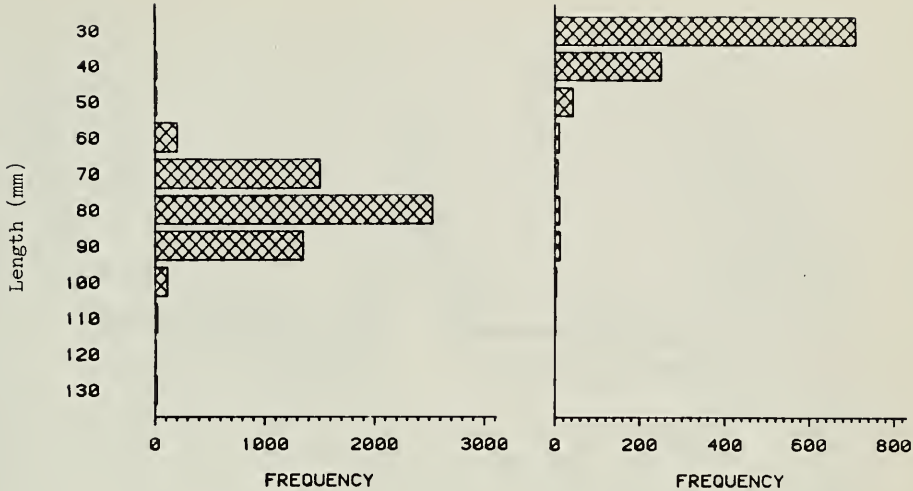


Figure 5. Length frequency of Anchoa spp. in impingement (left) and trawl (right) samples from October 1976 through September 1983.

McHugh (1977) states that the bay anchovy is perhaps the most numerous fish found along the Atlantic Coast of the United States. Near MNPS anchovies migrated inshore in spring and were only briefly available to capture by the monitoring programs. They were caught in the following time sequence (Table 4). From May through July (the time of their offshore spawning migration, Table 2) they were impinged as adults. Eggs and larvae were found July through August at EN and NB. Finally, young-of-the year were caught in trawls August through October. The trawl catch of anchovies varied greatly from year to year, depending on a chance match of our sampling efforts and the sporadic spatial and temporal presence of anchovies. The actual 1983 egg and larvae data were close to the values forecast by the model; the actual impingement data followed the pattern forecast, but were well above the upper confidence limit.

Gasterosteus wheatlandi (blackspotted stickleback) and
Gasterosteus aculeatus (threespine stickleback)

Two stickleback species were found almost exclusively in Millstone impingement samples. Only since 1981 have we distinguished the

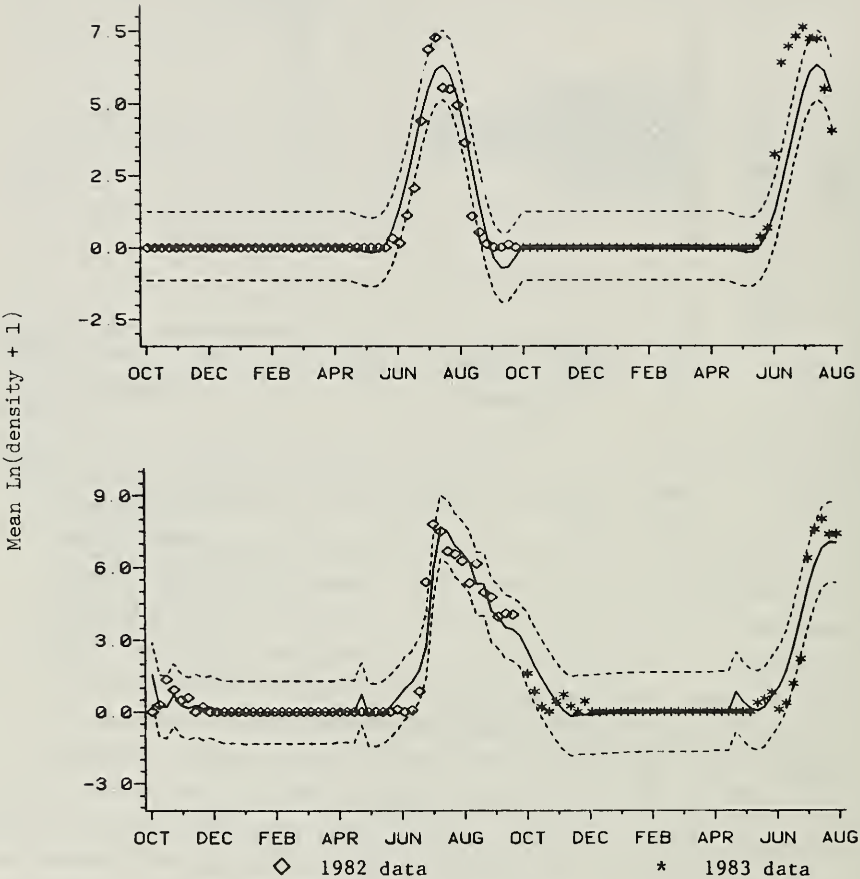


Figure 6. Forecast (——) and 95% confidence limits (---) for <u>Anchoa</u> spp. eggs (top) and larvae (bottom) at EN. The egg model was fit to data from May 1979 through September 1982; the larval model was fit to data from October 1976 through September 1982.

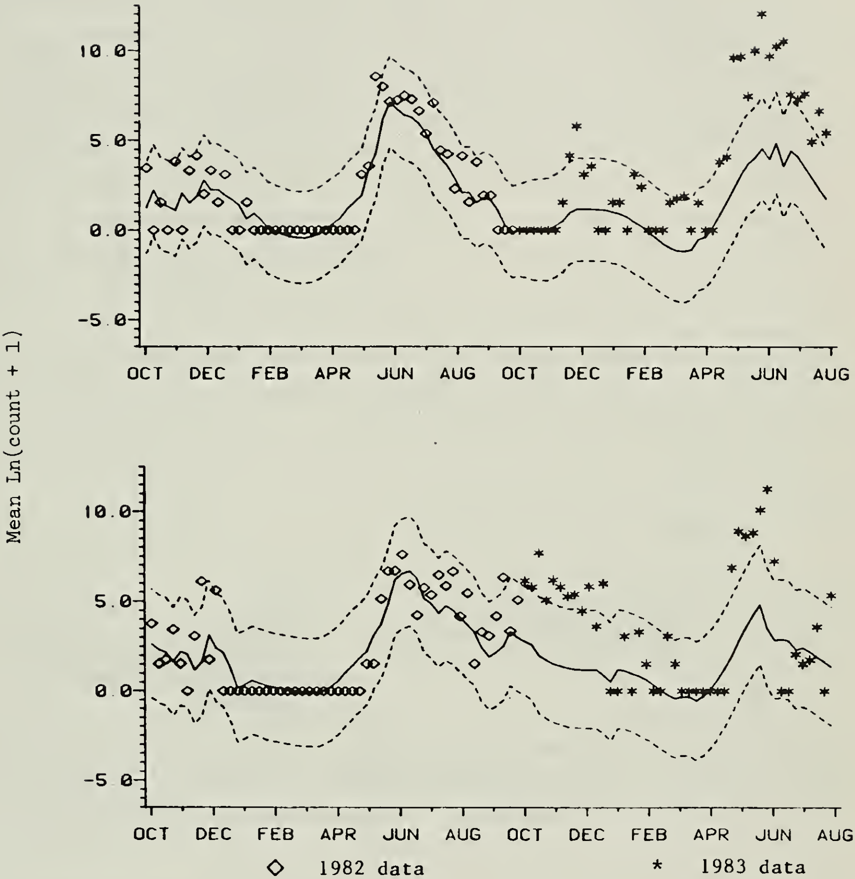


Figure 7. Forecast (———) and 95% confidence limits (---) for Anchoa spp. impinged at Units 1 (top) and 2 (bottom). Both models were fit to data from January 1976 through September 1982.

blackspotted stickleback (Gasterosteus wheatlandi) from the threespine stickleback (G. aculeatus). Thus, the impingement percent species composition of both species was based on samples collected since October 1981. The blackspotted stickleback was rarely found in trawls at MNPS, while the threespine stickleback was occasionally found in trawls from JC and NR (Tables 1 and 3). Sticklebacks were absent or infrequently found in plankton and seine programs. Even though sticklebacks ranked fifth in seines, they accounted for less than 1% of the total abundance (Table 1). Of all impinged threespine stickleback, 90% occurred from November through April. Blackspotted stickleback was present in impingement samples during a much shorter season; over 90% occurred in March and April (Table 4). The length frequency distributions of both species taken from impingement samples were dominated by mature individuals. The length distribution of blackspotted stickleback had a narrow peak from 40-50 mm, while the distribution of threespine stickleback, the larger of the two species, had a broader peak (50-60 mm) (Fig. 8).

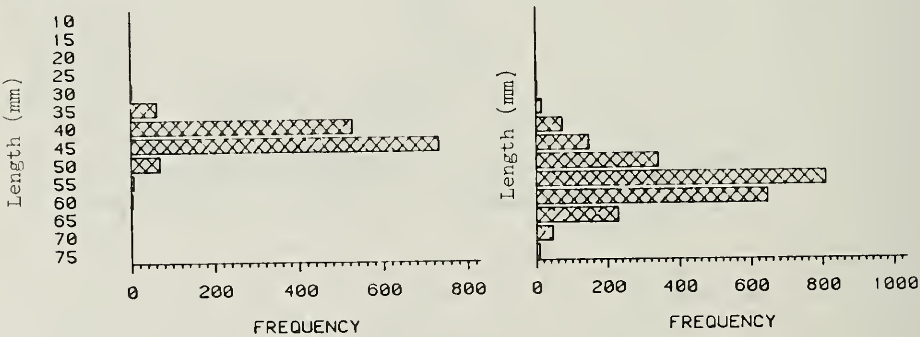


Figure 8. Length frequency of G. wheatlandi (left) and G. aculeatus (right) in impingement collections from October 1981 through September 1983.

To describe changes in log-transformed abundance of sticklebacks, harmonic regression models of weekly catch data from impingement programs were developed. The two species were combined for constructing these models. Impingement catch was described as a function of cooling-water flow and time. The harmonic components were the same for both units and reflected cycles of 12 and 4 months (Table 7).

Table 7. Sticklebacks (blackspotted and threespine combined); summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F + B_2F\mathrm{Sin}(tK_{12}) + B_3F\mathrm{Cos}(tK_{12}) - B_4F\mathrm{Sin}(tK_4) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-50}$	0.88	12.2	353	12.2	52
Impingement	Unit 2	$Z_t = B_1F + B_2F\mathrm{Sin}(tK_{12}) + B_3F\mathrm{Cos}(tK_{12}) - B_4F\mathrm{Sin}(tK_4) + A_1e_{t-1} + A_2e_{t-25} - A_3e_{t-42}$	0.88	12.4	353	9.6	52

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
n = number of observations contributing to the %error

The coefficients of determination (R^2) of both models were high (0.88 and 0.86) demonstrating the reliability of the models. In addition, the forecast errors were low, and few observations in 1983 were outside the 95% confidence limits (Fig. 9).

In the Millstone area, sticklebacks spawn and care for their eggs and young in fresh- or brackish-water nests from May through October (Table 2). Because these habitats were not sampled by any MNPS programs, sticklebacks were missing from samples or found in low numbers during this period. Their abundance increased in trawl and impingement samples as young-of-the-year moved to deeper waters after spawning. After mid-winter, their abundance increased in impingement as they returned inshore to spawn. Models of impinged sticklebacks accurately described the historical data, and showed that 1983 impingement levels were similar to previous years.

Menidia spp., silversides

Two silverside species are found in the Millstone area, the Atlantic silverside (*Menidia menidia*) and the inland silverside (*M. beryllina*). Since 1980, silversides have been separated by species; most were Atlantic silverside.

Silversides were the dominant (81%) shore-zone fish taxon in the Millstone area (Table 1). They ranked fourth in both impingement and trawl samples but were rarely found in the ichthyoplankton programs.

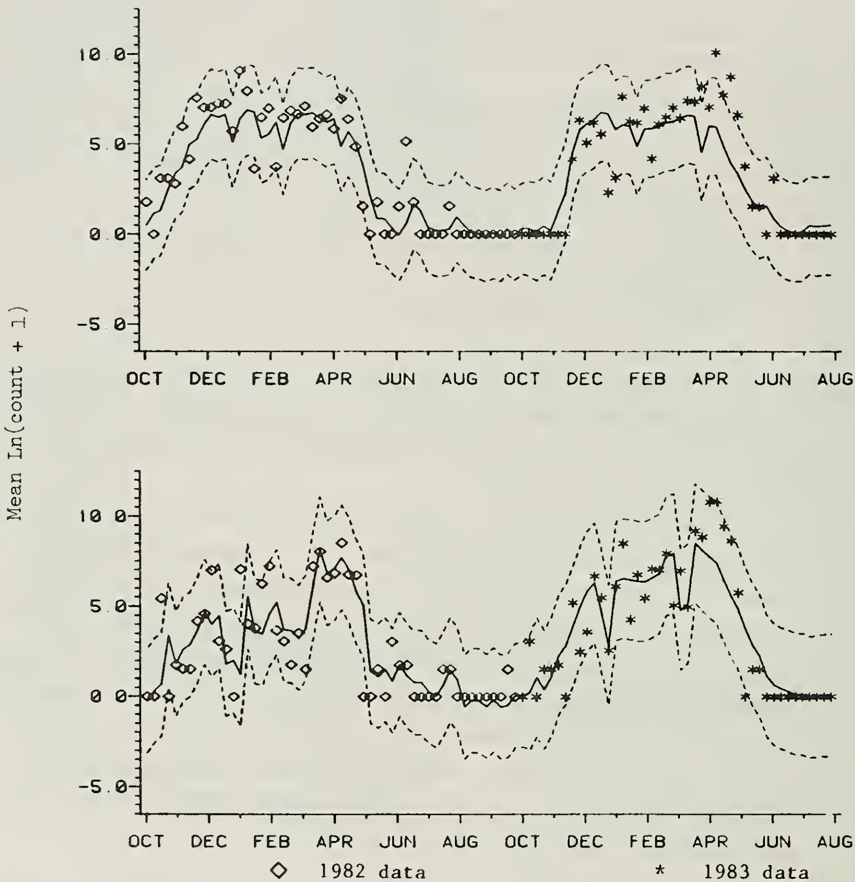


Figure 9. Forecast (——) and 95% confidence limits (---) for G. aculeatus and G. wheatlandi (combined) impinged at Units 1 (top) and 2 (bottom). Both models were fit to data from January 1976 through September 1982.

Silversides were trawled primarily (93%) from four stations (NR, JC, 1N, NB; Table 3), but were seined primarily (80%) from JC. Seined, trawled and impinged silversides had pronounced seasonal patterns of abundance (Table 4). They were found in the shore zone primarily from June through October and in trawls and impingment from November through May. Young-of-the-year (20-50 mm) silversides dominanted summer seine catches while adult fish (60-120 mm) were abundant in the trawl and impingement collections (Fig. 10).

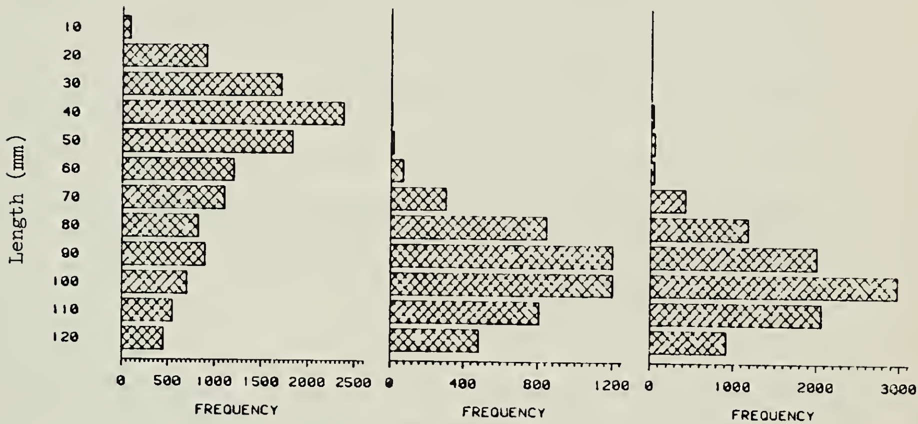


Figure 10. Length frequency of Menidia spp. in seine (left), impingement (middle) and trawl (right) collections from October 1976 through September 1983.

Fluctuations in log-transformed catches were modeled for several monitoring programs (Table 8). Only one model (JC) had a significant long-term (>12 mo) harmonic component (3-yr). All seine and trawl models had a 6-mo cycle and some also had 4- and 3-mo cycles. Impingement models included flow and 12-mo harmonic components and realistically described fluctuations of impinged silversides. Forecast error for the 1983 data was low at Unit 2 (18%); Unit 1 forecast error was higher (39%). Most of the 1983 data fell within the 95% confidence

Table 8. Silversides; summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F+B_2FSin(tK_{12})+B_3FCos(tK_{12})+A_1e_{t-1}+A_2e_{t-3}+A_3e_{t-50}$	0.83	16.9	353	39.2	52
Impingement	Unit 2	$Z_t = B_1F+B_2FSin(tK_{12})+B_3FCos(tK_{12})+A_1e_{t-1}+A_2-e_{t-2}-A_3e_{t-6}$	0.82	18.2	353	18.1	52
Seines	GN	$Z_t = B_1S-B_2SSin(tK_{12})+B_3SSin(tK_6)$	0.89	11.2	162	17.7	12
Seines	JC	$Z_t = B_1S-B_2SSin(tK_{36})+B_3SSin(tK_6)-B_4SCos(tK_4)$	0.86	13.9	162	6.9	12
Seines	SS	$Z_t = B_1S-B_2SCos(tK_6)+B_3SCos(tK_3)$	0.59	41.2	162	24.6	12
Seines	WP	$Z_t = B_1S-B_2SSin(tK_{12})+B_3SSin(tK_6)+B_4SCos(tK_4)$	0.89	11.2	162	12.0	12
Trawls	IN	$Z_t =-B_1SSin(tK_{12})+B_2SCos(tK_{12})+B_3SSin(tK_6)+B_4SCos(tK_6)-B_5SSin(tK_4)+$ $B_6SCos(tK_3)$	0.70	30.4	176	85.6	26
Trawls	JC	$Z_t = B_1S-B_2SSin(tK_6)+B_3SCos(tK_6)+B_4SSin(tK_4)+B_5SCos(tK_4)-B_6SSin(tK_3)+$ $A_1e_{t-1}-A_2e_{t-4}$	0.61	38.5	176	91.3	26
Trawls	NB	$Z_t =-B_1SSin(tK_{12})+B_2SCos(tK_{12})+B_3SSin(tK_6)+B_4SCos(tK_6)-B_5SSin(tK_4)+$ $B_6SCos(tK_3)+A_1e_{t-2}-A_2e_{t-24}$	0.72	27.7	176	57.8	26
Trawls	NR	$Z_t = B_1SSin(tK_{12})+B_2SCos(tK_{12})+B_3SCos(tK_6)-B_4SSin(tK_4)-B_5SSin(tK_3)-$ $A_1e_{t-24}+A_2e_{t-27}$	0.69	30.9	176	35.5	26

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit

intervals for the impingement models (Fig. 11). Because the seine data were not equally spaced in time as needed to forecast fluctuations using time-series techniques, estimates were made for months not sampled using techniques described in the Analytical Methods section. All seine models included 6-mo harmonic components. Seine models had high R^2 values with only the model for station SS accounting for less than 80% of the variation. Forecast errors were low for the 1983 seine data. In two cases (JC, and SS) the forecast error was lower than the model error. The 1983 seine data were all within the 95% confidence intervals. Models for trawl-caught silversides showed lower R^2 than seine or impingement models. Because few silversides were trawled at BR and TT, modeling was not done for these two stations. Annual cycles were significant at all trawl stations modeled except JC and this station had the highest model and forecast errors. The 1983 trawl data for silversides exceeded the 95% confidence range at NR and IN (Fig. 12).

In both cases catches were higher than the upper confidence interval and never fell below the lower limits.

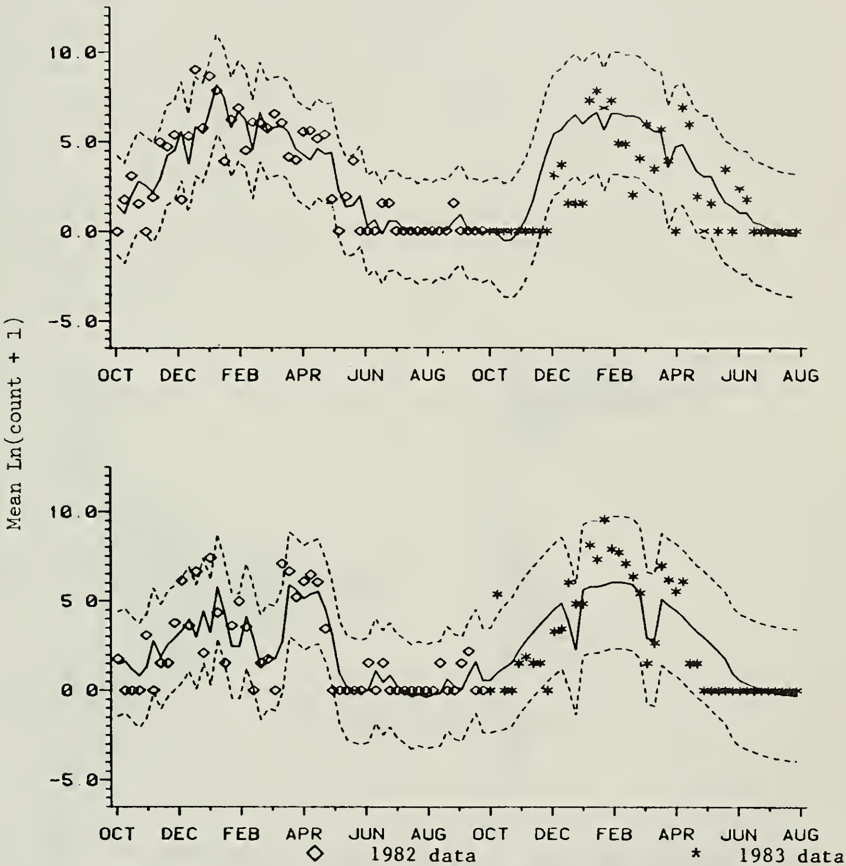


Figure 11. Forecast (———) and 95% confidence limits (---) for Menidia spp. impinged at Units 1 (top) and 2 (bottom). Both models were fit to data from January 1976 through September 1982.

Silversides were common in the Millstone area. They were found along sandy shores during their spawning season (May-July) and their eggs and larvae were not suseptible to entrainment. The presence of silversides in the winter trawl and impingement catches was evidence of migrations into deeper water. Models of silversides described the pattern of observed fluctuations reasonably well; in some cases the 1983 forecast error was lower than the actual model error, indicating little deviation from historical average variability.

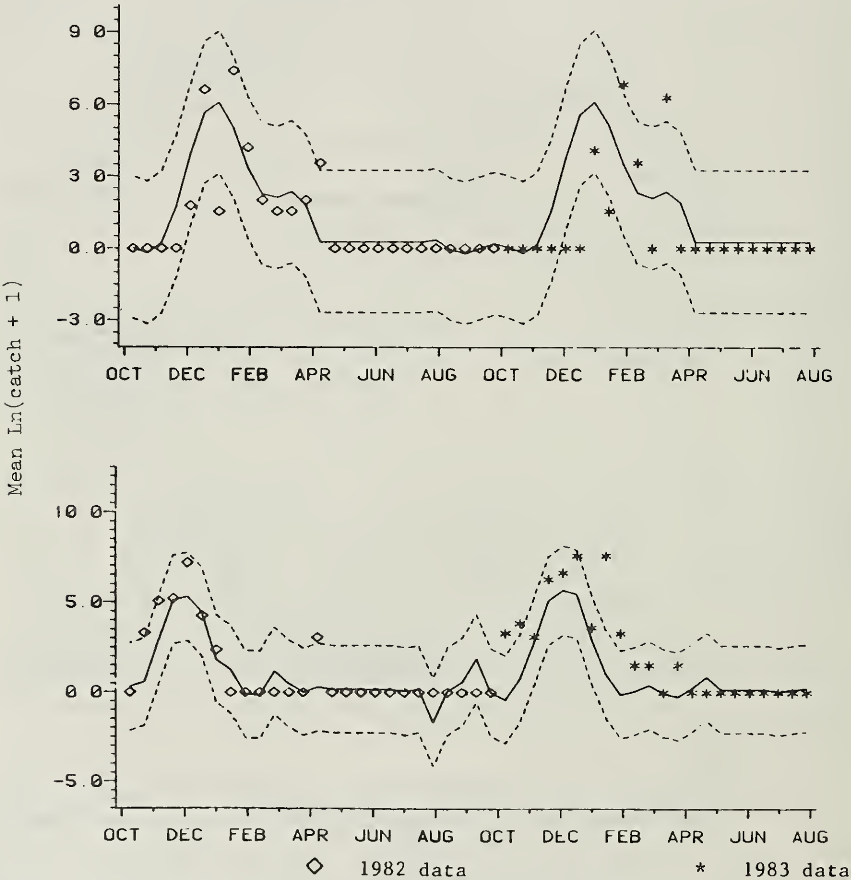


Figure 12. Forecast (———) and 95% confidence limits (---) for Menidia spp. trawled at IN (top) and NR (bottom). Both models were fit to data from January 1976 through September 1982.

Microgadus tomcod, Atlantic tomcod

Atlantic tomcod were abundant in only two programs at MNPS. The taxon ranked sixth in both trawl and impingement collections and was rarely found in seine or plankton programs (Table 1). In trawls, 90% of all tomcod were found at four stations (JC, NB, IN, and TT) (Table 3). They were impinged most frequently from December through January (Table 4). During this period, the tomcod catches were dominated by mature fish (>160 mm) (Fig. 13); many of these were gravid. Of all tomcod impinged since 1977, greater than 85% were impinged in 1982 and 1983 (Fig. 14). In trawls, tomcod were seen most frequently from April through June, and catches were dominated by young-of-the-year fish (<50 mm) (Fig. 13).

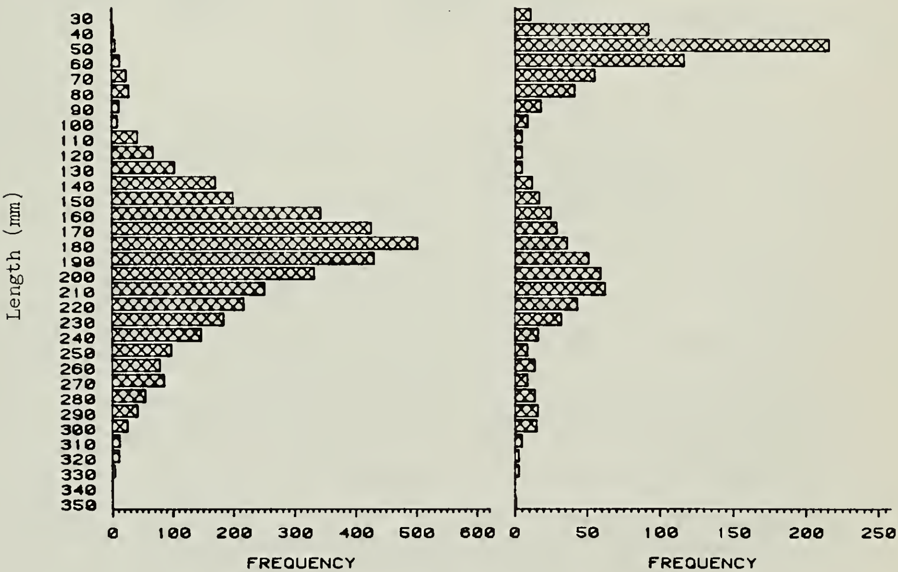


Figure 13. Length frequency of M. tomcod in impingement (left) and trawl (right) collections from October 1976 through September 1983.

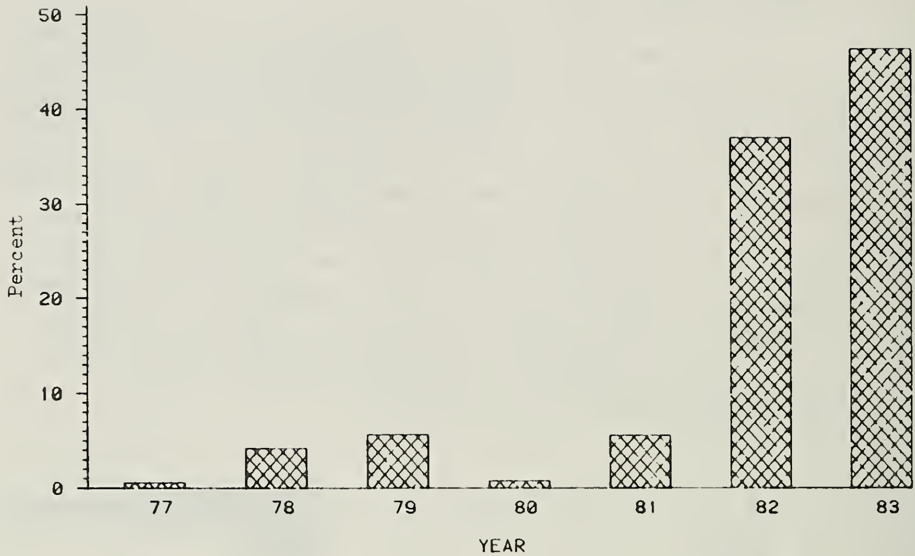


Figure 14. Percentage of impinged M. tomcod caught in each year since October 1976. Counts were corrected for variations in cooling-water flow rates.

Modeling of tomcod abundance in the trawl and impingement programs using harmonic regression techniques was moderately successful. Cycles of 6- and 12-mo duration were common to both program models; JC and IN trawl models also had 3- and 4-mo harmonic components (Table 9). Model R^2 values ranged from 0.71 to 0.77 for trawl and impingement data. Forecast errors from trawl and impingement models were low except at TT (161.2%). Examination of data from TT revealed that some 1983 catches were below the 95% confidence limits during the predicted peak (Fig. 15). Catch data from other stations and impingement data were within the 95% confidence limits except for Unit 2 impingement where recent estimates have increased relative to historical data (Fig. 15).

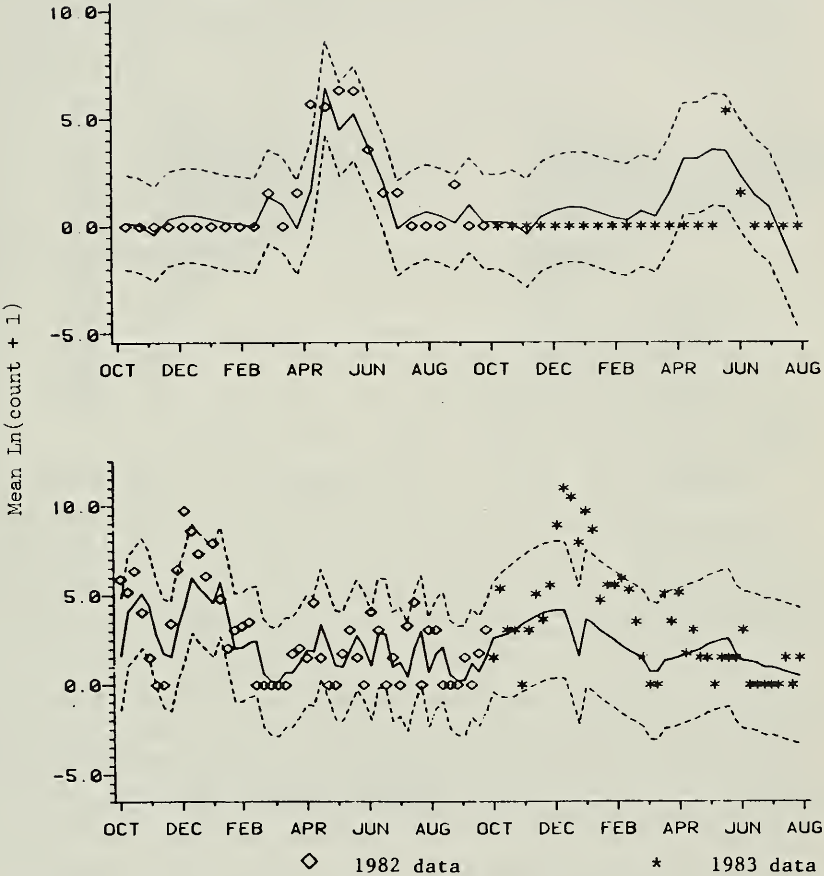


Figure 15. Forecast (———) 95% confidence limits (-----) for M. tomcod trawled at TT and impinged at Unit 2. Both models were fit to data from January 1976 through September 1982.

Table 9. Atlantic tomcod: summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F + B_2FCos(tK_{12}) - B_3FSin(tK_6) + B_4FCos(tK_6) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-14}$	0.71	28.5	353	31.5	52
Impingement	Unit 2	$Z_t = B_1F + B_2FCos(tK_{12}) - B_3FSin(tK_6) + B_4FCos(tK_6) + A_1e_{t-1} + A_2e_{t-2}$	0.71	29.0	353	38.9	52
Trawls	IN	$Z_t = B_1S - B_2SCos(tK_{12}) - B_3SCos(tK_6) + B_4SCos(tK_4) - B_5SSin(tK_3) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-3}$	0.76	23.7	176	23.1	26
Trawls	JC	$Z_t = B_1S - B_2SCos(tK_{12}) - B_3SCos(tK_6) + B_4SCos(tK_4) - B_5SSin(tK_3) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-3}$	0.71	29.2	176	25.1	26
Trawls	NB	$Z_t = B_1SSin(tK_{12}) - B_2SSin(tK_6) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-20}$	0.77	22.5	176	16.5	26
Trawls	TT	$Z_t = B_1SSin(tK_{12}) - B_2SSin(tK_6) + B_3SCos(tK_6) + A_1e_{t-1} + A_2e_{t-6} + A_3e_{t-26} - A_4e_{t-27}$	0.71	28.7	176	161.2	26

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
n = number of observations contributing to the %error

Historically, levels of tomcod abundance have fluctuated greatly in impingement and trawls (NUSCo 1982a). Tomcod were impinged primarily from December through January and caught in trawls from April through June. Because tomcod spawn and mature in fresh or brackish waters, and their eggs are demersal (Table 2), they were infrequently seen in plankton samples. All models except for TT seemed to predict the patterns of catch fluctuations reasonably well. Tomcod catches in 1983 were higher than predicted in most cases. The decrease in catch at TT was a result of the high variability in catches at that station and not a reflection of the general tomcod population variability.

Myoxocephalus aenaeus, grubby

The grubby, a nearshore demersal fish, was well represented in all programs at Millstone except seines (Table 1). It ranked ninth in trawl samples and was most abundant from December through May (Table 4). Over one-third of all trawl-caught grubby came from NR (Table 3). Larval grubby, collected from January through May, ranked fourth in entrainment samples and fifth in offshore plankton samples. Eggs were not abundant in either plankton collection (0.2%). Grubby ranked third among impinged species and was collected predominantly from December through May (Table 4). Length frequency histograms from both trawl and impingement programs were very similar, with major peaks occurring between 60-100 mm (Fig. 16).

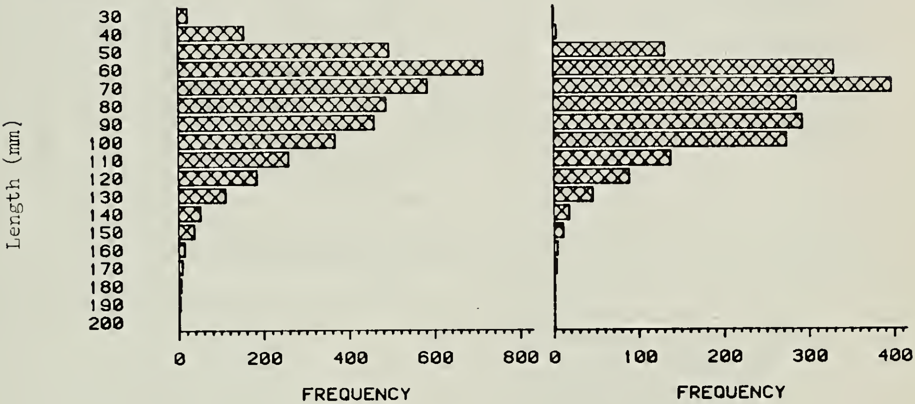


Figure 16. Length frequency of M. aenaeus in trawl (left) and impingement (right) collections from October 1976 through September 1983.

Descriptive models of grubby had various combinations of harmonic components (Table 10). In general, all models had 12-mo cycle terms; those from NR and TT also had significant 6-yr cycle term. Other statistically significant cycles were 6-, 4-, and 3-mo. Cooling-water flow was a significant multiplicative variable in models describing impingement counts. Entrainment and impingement models were the most accurate with R^2 greater than 0.89 (Table 10). Models of the trawl data were less accurate with R^2 values ranging from 0.29 for BR to 0.68 for JC. Model errors were high for trawl and low for entrainment and impingement models and few 1983 data points were beyond the 95% confidence limits (Figs. 17). In addition, forecast errors of the trawl models ranged from 38% at JC to 294% at NR, but most of the data points were within the 95% confidence limits except for NR (Fig. 18). At this

Table 10. Grubby: summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[e]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F + B_2FSin(tK_{12}) + B_3FCos(tK_{12}) + B_4FCos(tK_4) + A_1e_{t-1} + A_2e_{t-3} + A_3e_{t-22}$	0.90	10.1	393	7.9	52
Impingement	Unit 2	$Z_t = B_1F + B_2FSin(tK_{12}) + B_3FCos(tK_{12}) + B_4FCos(tK_4) +$ $A_1e_{t-1} + A_2e_{t-3} + A_3e_{t-23} + A_4e_{t-51}$	0.89	11.0	393	11.3	52
Entrainment (larvae)	EN	$Z_t = B_1SSin(tK_{12}) - B_2SSin(tK_4) + A_1e_{t-1} - A_2e_{t-3} + A_3e_{t-6} + A_4e_{1-52}$	0.97	2.9	314	5.1	52
Ichthyoplankton (larvae)	NB	$Z_t = B_1SSin(tK_{12}) + B_2SSin(tK_4)$	0.94	5.7	224	11.2	52
Trawls	BR	$Z_t = B_0 + B_1Sin(tK_{12}) + B_2Cos(tK_{12}) + B_3Sin(tK_6) + B_4Sin(tK_4) +$ $A_1e_{t-1} + A_2e_{t-2} - A_3e_{t-22} + A_4e_{t-24} - A_5e_{t-27}$	0.68	31.7	176	119.7	26
Trawls	IN	$Z_t = B_0 + B_1Sin(tK_{12}) + B_2Cos(tK_{12}) + B_3Cos(tK_6) + B_4Cos(tK_4) + A_1e_{t-22}$	0.49	51.0	176	63.0	26
Trawls	JC	$Z_t = B_0 + B_1Cos(tK_4) + B_2Cos(tK_3) + A_1e_{t-2} + A_2e_{t-3} - A_3e_{t-21} + A_4e_{t-24}$	0.29	71.2	176	37.7	26
Trawls	NB	$Z_t = B_0 + B_1Sin(tK_{12}) + B_2Cos(tK_{12}) + B_3Sin(tK_6) + B_4Cos(tK_4) + A_1e_{t-1} + A_2e_{t-2}$	0.50	50.5	176	65.4	26
Trawls	NR	$Z_t = B_0 - B_1Cos(tK_{72}) + B_2Sin(tK_{12}) + B_3Cos(tK_{12}) - B_4Sin(tK_6) + B_5Cos(tK_4) +$ $A_1e_{t-1} - A_2e_{t-5} + A_3e_{t-20}$	0.55	45.3	176	294.3	26
Trawls	TT	$Z_t = B_0 - B_1Sin(tK_{72}) + B_2Sin(tK_{12}) + B_3Cos(tK_{12}) + B_4Sin(tK_6) + B_5Sin(tK_4) +$ $B_6Sin(tK_3) + A_1e_{t-3}$	0.61	39.1	176	72.9	26

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
S = seasonal coefficient
n = number of observations contributing to the %error

station, which had the highest forecast error, the 1983 data were above the 95% confidence interval.

The grubby was found throughout the year near MNPS. They spawn locally throughout the winter and attach eggs to bottom substrates (Table 2). Thus, grubby eggs were not identified in plankton samples although larvae were abundant. Abundance of grubby in the trawl and impingement programs was seasonal with high numbers occurring during winter. All regression models provided a description of the observed fluctuations of grubby. However, the high model errors associated with trawl models produced very wide confidence intervals and limited the validity of these models. Entrainment and impingement models were more accurate and suggested no change had occurred in the 1983 abundance of grubby compared to previous years.

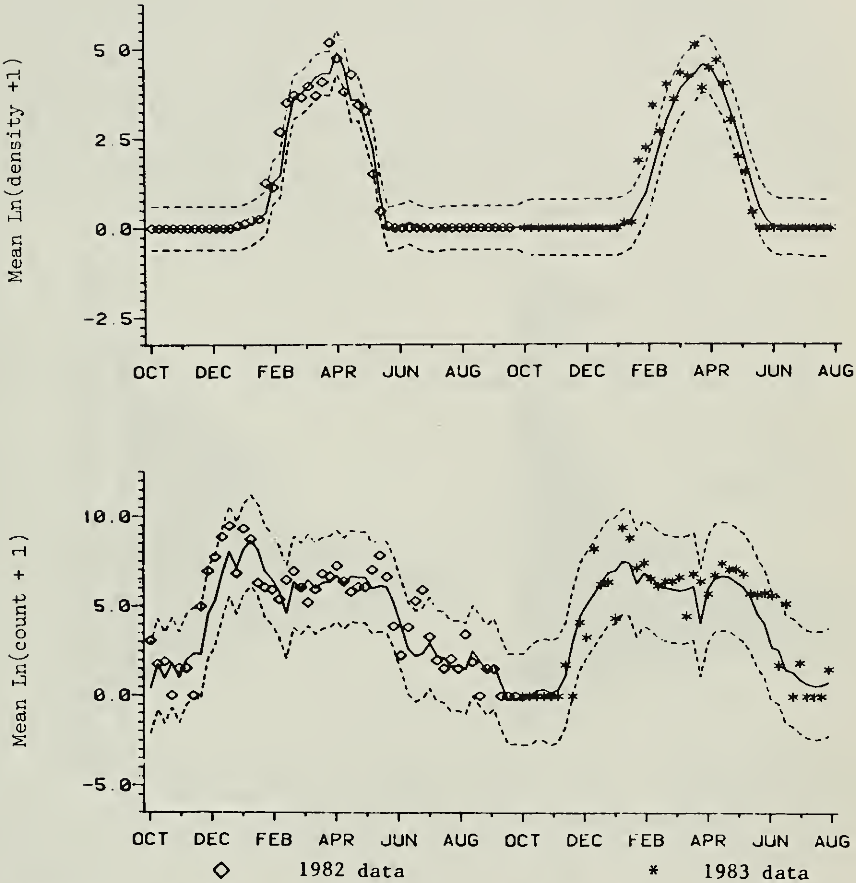


Figure 17. Forecast (———) and 95% confidence limits (-----) for M. aenaeus larvae at EN (top) and impinged at Unit 1 (bottom). The EN model was fit to data from October 1976 through September 1982; the impingement model was fit to data from January 1976 through September 1982.

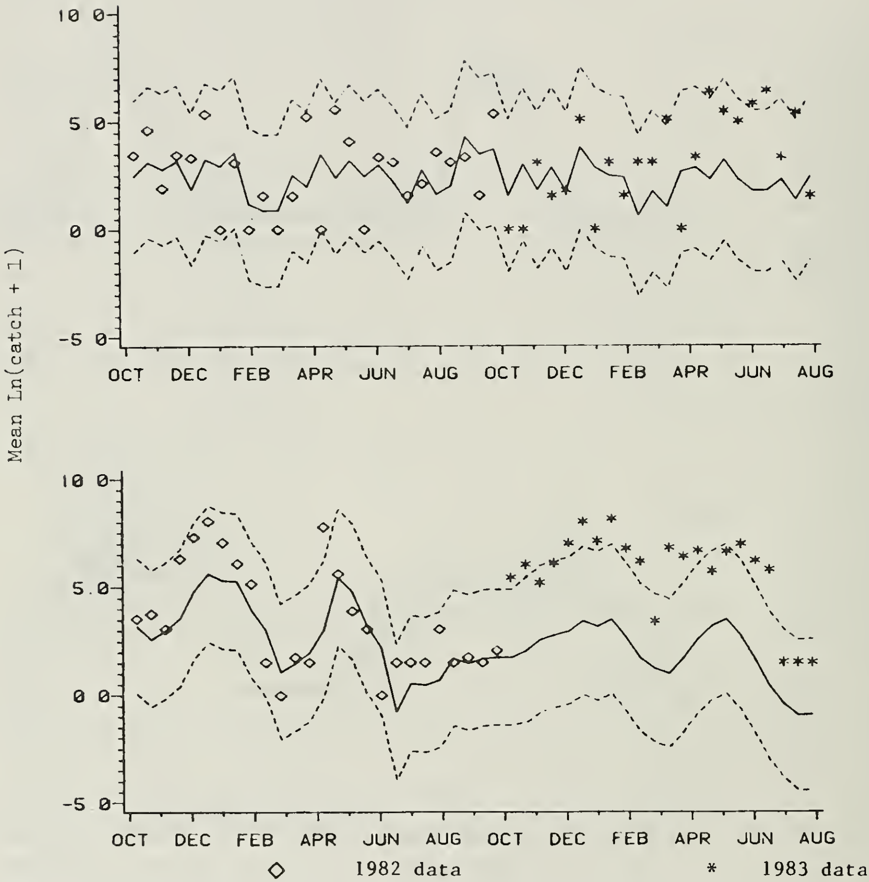


Figure 18. Forecast (———) and 95% confidence limits (-----) for M. aenaeus trawled at JC (top) and NR (bottom). Both models were fit to data from January 1976 through September 1982.

Scophthalmus aquosus, windowpane

The windowpane was represented in the trawl, impingement and plankton programs (Table 1). It ranked third in trawls, eighth in impingement but was nearly absent from the seine program. Eggs ranked sixth at both EN and NB, although larvae were rare. Windowpane were year-round residents of the Millstone area (Table 4). More than half of the windowpane were caught by trawl at the deep-water BR station (Table 3). The modal length of trawled windowpane was 260 mm (Fig. 19). The

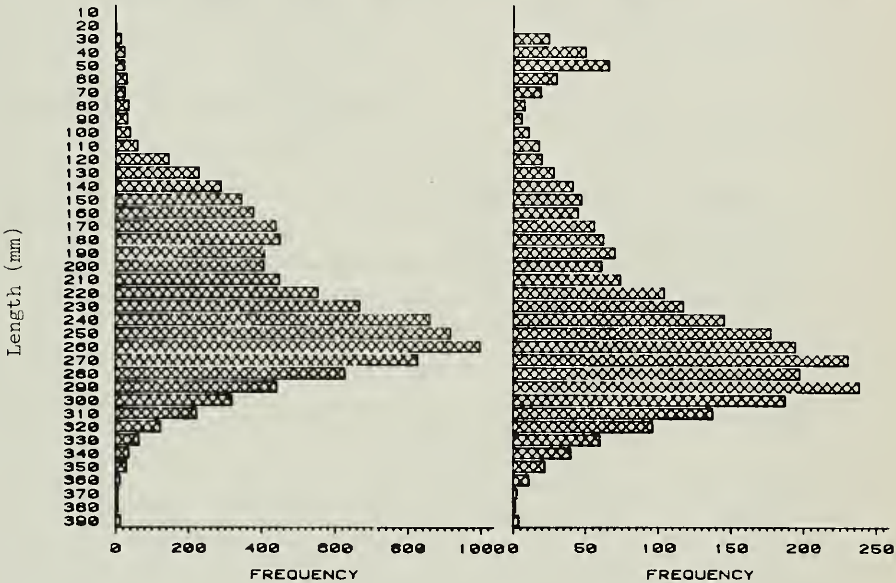


Figure 19. Length frequency of S. aquosus in trawl (left) and impingement (right) collections from October 1976 through September 1983.

length frequency distribution of impinged windowpane had a small peak at 50 mm and a much larger peak from 270 to 290 mm (Fig. 19). More windowpane were collected by trawl and impinged in 1983 than during previous years (Fig. 20).

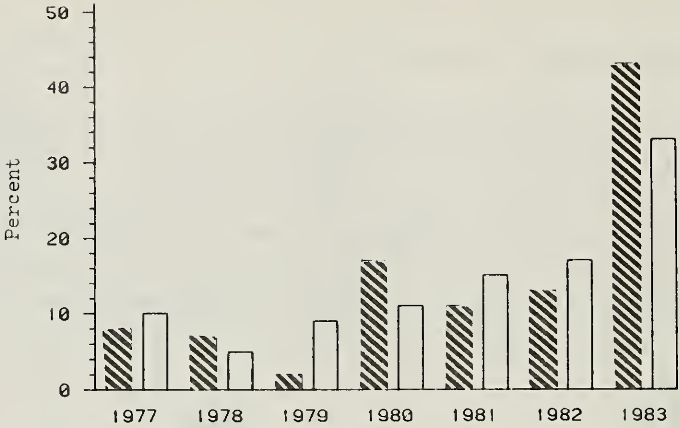


Figure 20. Annual percents of all S. aquosus impinged (▨) and trawled (□).

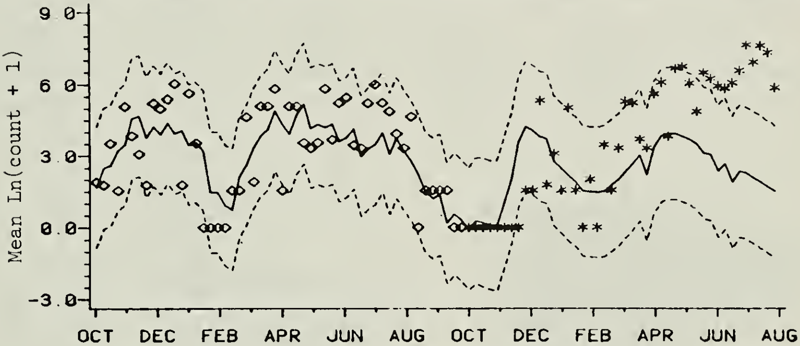
Harmonic regression techniques were used to model the trawl and impingement data; windowpane eggs and larvae were not modeled because of their low densities. All models had significant terms for 12-mo cycles (Table 11). Longer (72-mo) and shorter (6- and 4-mo) cycles were also

Table 11. Windowpane; summary of time-based regression models selected to describe their occurrence in the various MNPS monitoring programs.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F - B_2F\mathrm{Cos}(tK_{72}) + B_3F\mathrm{Sin}(tK_{12}) - B_4F\mathrm{Sin}(tK_6) - B_5F\mathrm{Sin}(tK_4) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-4} - A_4e_{t-5} + A_5e_{t-19}$	0.42	18.5	353	41.7	52
Impingement	Unit 2	$Z_t = B_1F - B_2F\mathrm{Cos}(tK_{72}) + B_3F\mathrm{Sin}(tK_{12}) - B_4F\mathrm{Sin}(tK_6) - B_5F\mathrm{Sin}(tK_4) + A_1e_{t-1} + A_2e_{t-3} + A_3e_{t-5} + A_4e_{t-14}$	0.79	21.3	353	25.9	52
Trawls	BR	$Z_t = B_0 - B_1\mathrm{Sin}(tK_{72}) - B_2\mathrm{Cos}(tK_{72}) - B_3\mathrm{Sin}(tK_{12}) + A_1e_{t-1} + A_2e_{t-2} - A_3e_{t-21}$	0.39	61.5	176	279.1	26
Trawls	IN	$Z_t = B_0 - B_1\mathrm{Sin}(tK_{72}) - B_2\mathrm{Cos}(tK_{12}) - B_3\mathrm{Sin}(tK_6) + B_4\mathrm{Cos}(tK_4) + A_1e_{t-1} - A_2e_{t-10} - A_3e_{t-15}$	0.33	66.5	176	191.6	26
Trawls	JC	$Z = B_0 + B_1\mathrm{Cos}(tK_{12}) - B_2\mathrm{Sin}(tK_6) - B_3\mathrm{Sin}(tK_4) + B_4\mathrm{Cos}(tK_4) + A_1e_{t-1} + A_2e_{t-2}$	0.43	56.5	176	119.9	26
Trawls	NB	$Z_t = B_0 + B_1\mathrm{Cos}(tK_{72}) + B_2\mathrm{Cos}(tK_{12}) + A_1e_{t-1} - A_2e_{t-7}$	0.17	83.1	176	103.4	26
Trawls	NR	$Z_t = B_0 - B_1\mathrm{Cos}(tK_{72}) - B_2\mathrm{Sin}(tK_{12}) - B_3\mathrm{Cos}(tK_{12}) - B_4\mathrm{Sin}(tK_4) + B_5\mathrm{Cos}(tK_4) - A_1e_{t-1} + A_2e_{t-10}$	0.60	40.3	176	106.2	26
Trawls	TT	$Z_t = B_0 - B_1\mathrm{Sin}(tK_{12}) - B_2\mathrm{Cos}(tK_{12}) - B_3\mathrm{Sin}(tK_6) + B_4\mathrm{Cos}(tK_6) + A_1e_{t-1}$	0.19	80.9	176	317.3	26

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
n = number of observations contributing to the %error

significant at some stations. Cooling-water flow was a significant multiplicative regressor in the impingement models. The 6-yr cycle found in impingement and four out of the six trawl models could be an artifact of the 6-yr database (1976-82). The shorter 6-mo and 4-mo cycles were evidence of consistent fluctuations within a year. The impingement models had high R^2 values and explained 80% of the variation (Table 11). Even though these models described observed patterns, the 1983 data exceeded the upper 95% confidence limit (Fig. 21). Among the



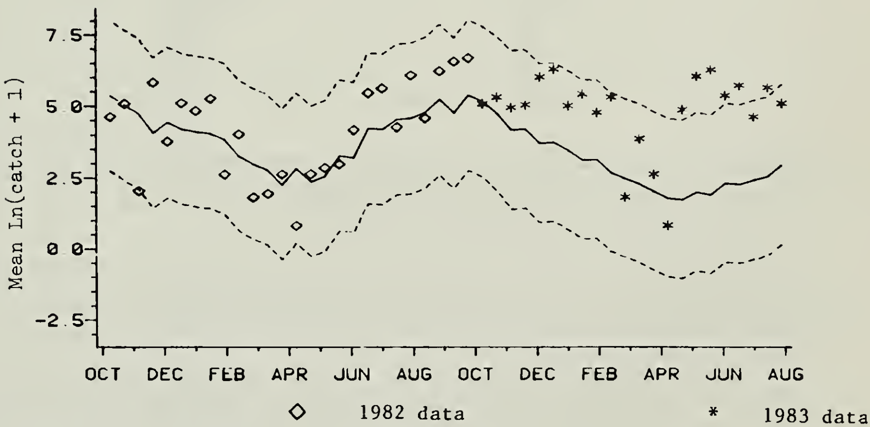


Figure 21. Forecast (———) and 95% confidence limits (-----) for *S. aquosus* impinged at Unit 1 (top) and trawled at BR (bottom). Both models were fit to data from January 1976 through September 1982.

trawl models only NR had an R^2 exceeding 0.50. The forecast errors for all the trawl models were high, and the actual 1983 data for trawls fell within the 95% confidence interval for only the NB model.

Catches of windowpane in both trawls and impingement were at a 6-yr high in 1983. This peak could be accounted for in several ways. First, the windowpane population may have a cycle of abundance longer than 6 years (the length of MNPS database). Secondly, unusually warm winter water temperatures in 1983 (Fig. 22) may have made it unnecessary for

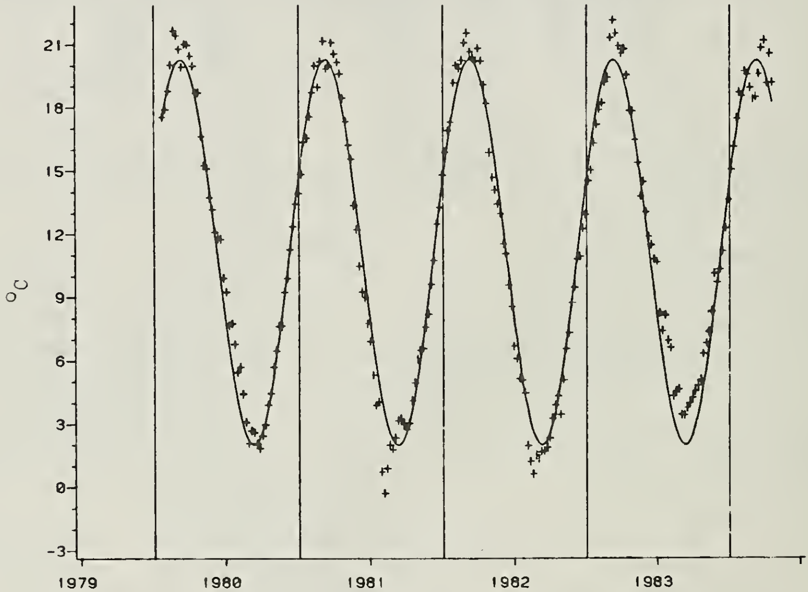


Figure 22. Predicted (———) and actual weekly means (+) of daily intake water temperatures. The equation for the predicted values is T=11.13-6.47*cos(time * 365.25/12)-6.46*sin(time * 365.25/12) with R^2 = 0.97.

the windowpane to migrate offshore to avoid cold inshore temperatures as usual (Austin 1973). Model errors for trawl-caught windowpane were high, although impingement models seemed to accurately describe the pattern of windowpane fluctuations. Actual 1983 data exceeded the upper 95% confidence interval for both trawls and impingement models. More years of data may be needed to accurately describe catch fluctuations for this species.

Tautoga onitis, tautog

Tautog were found in all programs except seines, but the taxon ranked among the top ten species only in the plankton programs (Table 1). Tautog, second ranked among the eggs, made up 32% of all eggs identified during 1979-1983 at EN and 24% at NB. Larvae ranked fifth (4% of total abundance) at NB and sixth (2%) at EN. Post-larval tautog were found in low numbers in trawl and impingement collections. They were most abundant at the nearshore trawl stations (JC, IN and NR) (Table 3) May through October (Table 4). The length frequency distribution of trawl-caught tautog was bimodal with peaks at 50 and 170 mm, while the impingement length frequency was unimodal peaking between 110 and 170 mm (Fig. 23).

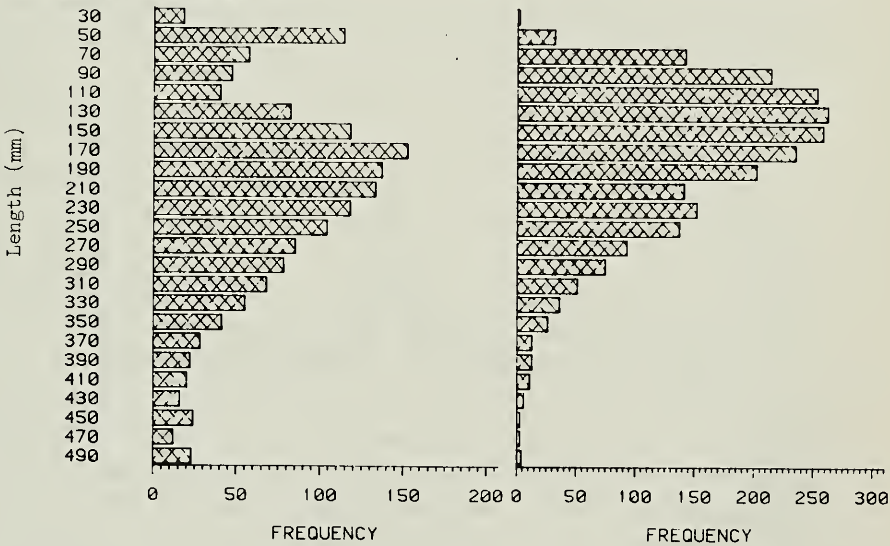


Figure 23. Length frequency of T. onitis in trawl (left) and impingement (right) collections from October 1976 through September 1983.

The fluctuations in the density of tautog eggs and larvae in the plankton programs were modeled using harmonic regression techniques. In all other sampling programs the catch of tautog was too low to obtain a representative model. All models contained terms describing a 12- and 6-mo cycle (Table 12). The models of the log-transformed plankton

Table 12. Tautog: summary of time-based regression models selected to describe their occurrence in the various monitoring programs at MNPS.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Entrainment (larvae)	EN	$Z_t = B_1 S\mathrm{Sin}(tK_{60}) - B_2 S\mathrm{Cos}(tK_{12}) + B_3 S\mathrm{Sin}(tK_6) - B_4 S\mathrm{Cos}(tK_4) + B_5 S\mathrm{Sin}(tK_2) + A_1 e_{t-1} - A_2 e_{t-2} - A_3 e_{t-5} + A_4 e_{t-52}$	0.76	23.9	314	23.9	52
Entrainment (eggs)	EN	$Z_t = -B_1 S\mathrm{Cos}(tK_{12}) + B_2 S\mathrm{Sin}(tK_6) + B_3 S\mathrm{Cos}(tK_6)$	0.97	2.8	279	2.0	52
Ichthyoplankton (larvae)	NB	$Z_t = -B_1 S\mathrm{Cos}(tK_{12}) + B_2 S\mathrm{Sin}(tK_6) - B_3 S\mathrm{Cos}(tK_4) + B_4 S\mathrm{Sin}(tK_2)$	0.86	14.4	224	23.7	52
Ichthyoplankton (eggs)	NB	$Z_t = -B_1 S\mathrm{Cos}(tK_{12}) + B_2 S\mathrm{Sin}(tK_6) - B_3 S\mathrm{Cos}(tK_4) - B_4 S\mathrm{Sin}(tK_3) - B_5 S\mathrm{Cos}(tK_2)$	0.96	4.0	211	2.8	52

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
S = seasonal coefficient
n = number of observations contributing to the %error

density data included season as a significant multiplicative regressor (see Table 4). The only long-term cycle (5-yr) was in the larval entrainment model. The harmonic regressions had high R^2 values and low forecast errors. The 1983 egg data followed model predictions very closely; the actual larval data were not predicted as well (Fig. 24).

The tautog is a popular sport fish in Connecticut (Sampson 1981). Fish from this taxon prefer rocky shores such as those surrounding Millstone. This type of habitat cannot be sampled effectively by either trawl or seine and therefore tautog were not found in these programs. Even though the intakes are located near preferred habitat, the fish was not impinged in large numbers. Locally spawning tautog produced abundant pelagic eggs and both eggs and larvae were numerous in plankton samples. We believe that tautog egg and larval abundance are the best population indicators for this species. The historical egg and larval catches produced reliable models with high R^2 values. Low forecast errors indicated that the actual 1983 data did not deviate greatly from the past years.

Tautogolabrus adspersus, cunner

The cunner was within the top ten ranked species from all Millstone monitoring programs except seines. This species had the most abundant eggs found in plankton samples and larvae ranked fourth and fifth at NB

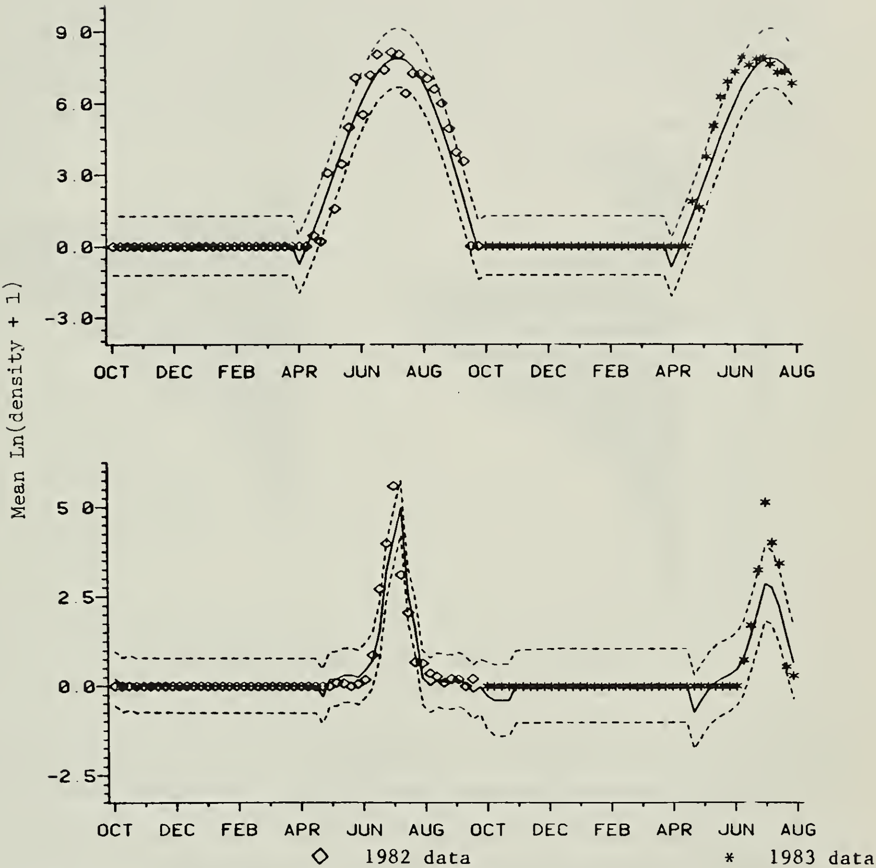


Figure 24. Forecast (———) and 95% confidence limits (-----) for T. onitis eggs (top) and larvae (bottom) at EN. The egg model was fit to data from May 1979 through September 1982; the larval model was fit to data from October 1976 through September 1982.

and EN, respectively (Table 1). It ranked seventh in abundance among the trawl catches and eighth among the impinged finfish. Over 80% of trawled cunner were caught at IN and JC (Table 3). The cunner was most abundant in the catches from various programs from May through September (Table 4). Length frequency histograms of cunner from the trawl and impingement programs differed. The length distribution of trawled cunner was bimodal with a small peak at 30 and a larger one at 110 mm; the impingement distribution had a single mode at 90 mm (Fig. 25).

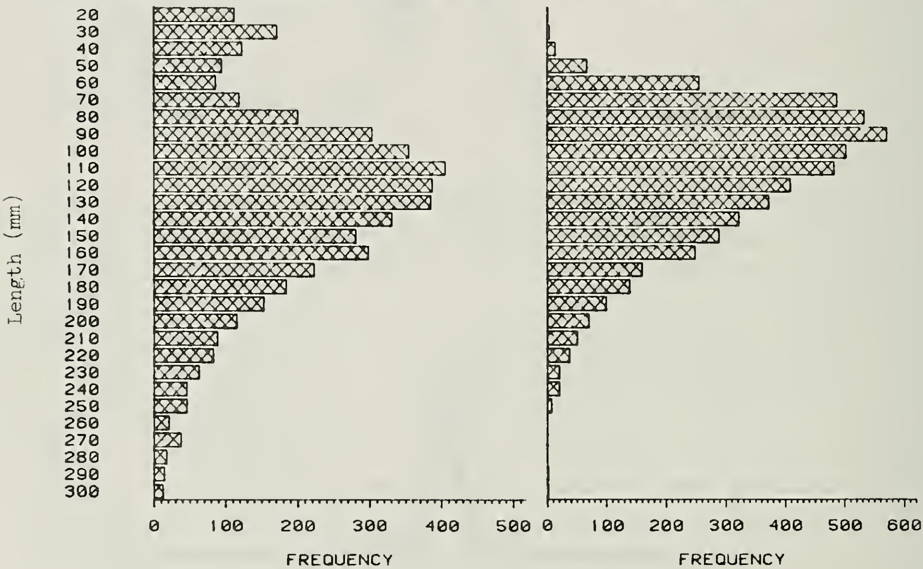


Figure 25. Length frequency of T. adspersus in trawl (left) and impingement (right) collections from October 1976 through September 1983.

The fluctuations in the catch of cunner were modeled using harmonic regression techniques (Table 13). Flow (for impingement) and season (for plankton and trawls) were significant multiplicative regressors (see Table 4 for the months when season was 0 or 1). Terms describing 12-mo cycles were present in all models, and were the only harmonic components present in impingement models. Components for both longer and shorter cycles were found useful in modeling the catches of cunner in other programs. The trawl models included 6-yr cycles. Since only 6 years of data were modeled it was difficult to determine if these cycles

Table 13. Cunner; summary of time-based regression models selected to describe their occurrence in the various monitoring programs at MNPS.

Monitoring Program	Station	Model[a]	Model R^2	Model %Error	n[a]	Forecast %Error	n
Impingement	Unit 1	$Z_t = B_1F - B_2FCos(tK_{12}) + A_1e_{t-1} + A_2e_{t-3} + A_3e_{t-14}$	0.77	23.2	353	17.0	52
Impingement	Unit 2	$Z_t = B_1F - B_2FCos(tK_{12}) + A_1e_{t-1} + A_2e_{t-2} + A_3e_{t-3} + A_4e_{t-4}$	0.77	22.8	353	48.0	52
Entrainment (larvae)	EN	$Z_t = -B_1SCos(tK_{12}) + B_2SSin(tK_6) - B_3SCos(tK_4) + A_1e_{t-1} - A_2e_{t-5} - A_3e_{t-8}$	0.82	17.7	314	26.2	52
Entrainment (eggs)	EN	$Z_t = -B_1SCos(tK_{12}) - B_2SSin(tK_6) - SCos(tK_4)$	0.96	4.0	209	6.0	52
Ichthyoplankton (larvae)	NB	$Z_t = -B_1SCos(tK_{12}) - B_2SCos(tK_4) - B_3SSin(tK_4) + B_4SCos(tK_3)$	0.91	9.4	224	11.8	52
Ichthyoplankton (eggs)	NB	$Z_t = -B_1SCos(tK_{12}) - B_2SSin(tK_6) - B_3SCos(tK_4)$	0.94	6.1	211	5.4	52
Trawls	IN	$Z_t = B_1SSin(tK_{72}) - B_2SCos(tK_{72}) - B_3SSin(tK_{12}) - B_4SCos(tK_{12}) - B_5SCos(tK_4) + A_1e_{t-1} + A_2e_{t-27}$	0.90	10.2	176	18.9	26
Trawls	JC	$Z_t = -B_1SCos(tK_{72}) - B_2SSin(tK_{12}) - B_3SCos(tK_{12}) + A_1e_{t-1} + A_2e_{t-2} - A_3e_{t-6}$	0.87	13.0	176	12.7	26

[a] Z_t = mean of the ln transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m (months)
A = autoregression coefficients
e = residual (predicted-observed)
F = cooling water flow rate at indicated Unit
S = seasonal coefficient
n = number of observations contributing to the %error

were real. The models for all programs explained over 75% of the variation during the modeling period. The egg models had the largest R^2 value (0.94 and 0.96, respectively). The 1983 egg data were very close to the predicted values while the larval data were two orders of magnitude higher than predicted (Fig. 26). Most 1983 data fell within the 95% confidence interval predicted by trawl and impingement models (Fig. 27).

Cunner were common in all monitoring programs except seines. They were most abundant in rocky inshore regions during June through July. The harmonic regression models described fluctuations in catch reasonably well as indicated by R^2 values greater than 0.77. The 1983 forecasts did not deviate greatly from model predictions.

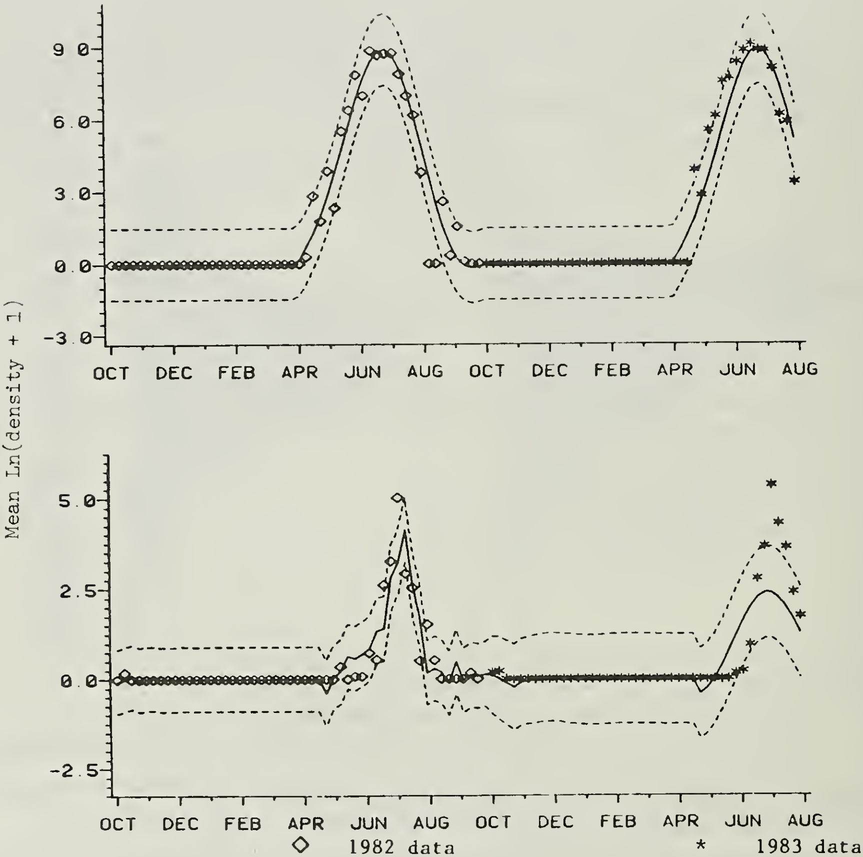


Figure 26. Forecast (———) and 95% confidence limits (-----) for T. adspersus eggs (top) and larvae (bottom) at EN. The egg model was fit to data from May 1979 through September 1982; the larval model was fit to data from October 1976 through September 1982.

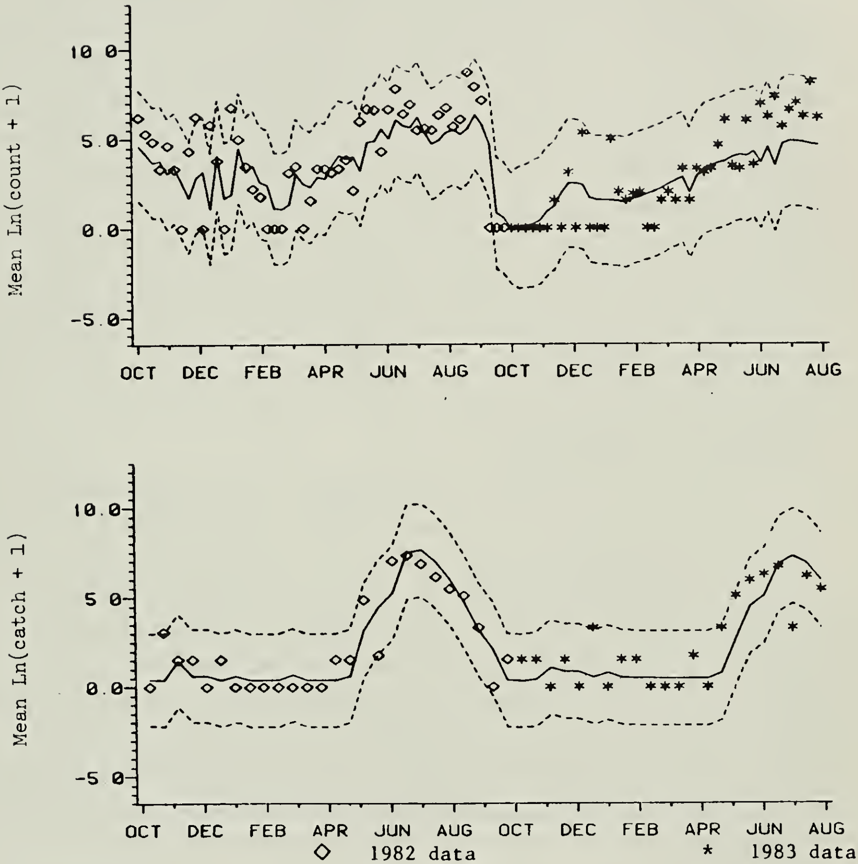


Figure 27. Forecast (———) and 95% confidence limits (---) for T. adspersus impinged at Unit 1 (top) and trawled at IN (bottom). Both models were fit to data from January 1976 through September 1982.

DISCUSSION

This report examined finfish data from the impingement, plankton, trawl and seine monitoring programs at MNPS. Of the numerous species recorded, 10 were discussed in detail. Winter flounder was discussed extensively in the the Winter Flounder Population Studies section and the remaining nine (American sand lance, anchovies, sticklebacks, silversides, Atlantic tomcod, grubby, windowpane, tautog and cunner) were discussed here. All taxa except anchovies were considered permanent residents that make limited movements or have some behavioral pattern that makes them unavailable to capture during certain times. Anchovies were seasonal residents in the greater Millstone Bight, and were sporadically present in monitoring collections. Young sand lance, sticklebacks and silversides, use the shore zone in summer and other nearby habitats in colder seasons. Cunner and tautog are both year-round residents that become torpid in winter and are less susceptible to collection.

In this report, we tried a new approach for assessing impacts. It involved building harmonic regression models that described the observed patterns of finfish catch fluctuations. All models had deterministic components. Besides time (used to describe periodicities through harmonic terms), season and flow were found to be useful predictor variables that determined the basic shape of the predicted curves. Some models also included stochastic autoregressive terms which modified the basic shape of the curve to account for autocorrelated deviations. Previous modeling efforts used only stochastic components (NUSCo 1983a) and produced less reliable descriptions of fluctuation patterns in the forecast year.

The reliability (as measured by R^2) of 41 out of the 56 models produced from historical data was good (> 0.70). The models fitted to plankton and impingement data provided more accurate descriptions of historical conditions than those fitted to trawl data. The higher R^2 values were associated with models that described very seasonal patterns of occurrence; e.g. the times of the year when eggs and larvae were present near MNPS were very well defined. When season interacted with the sine and cosine terms in a multiplicative sense, the models were forced to predict 0 during periods of non-occurrence; the harmonic terms described the curves otherwise. Among the trawl models, low R^2 values were associated with descriptions of species that were present throughout the year, and had no seasonal pattern of occurrence. The relationship between cooling-water-flow rate and impingement is well establish in the literature (Murarka 1977; NUSCo 1981). Thus, including flow as a multiplicative variable forced the impingement models to predict low counts during plant shutdowns, but interacted with the harmonic terms to allow for seasonality during normal operations. While storms also influence daily impingement counts (NUSCo 1980), these affects were minimized by taking a weekly average of daily counts. Some models included harmonic terms that described 5- or 6-yr cycles. Frequently, these models described the 1983 pattern of occurrence well, but some actual data were outside the 95% confidence interval. Also, our data base was too short (six years) for us to observe a repeatable five or six year pattern. Thus these harmonic terms described the existing data reasonably well, but the period will probably change as more data are added to the series.

The results of the forecasting procedure produced bounds (95% confidence limits) for what the 1983 abundances would be if they followed historical patterns. Most of the 1983 catches did not deviate greatly from what was predicted based on six years of data and therefore had not been affected by power plant operations. Of those species whose abundances fell outside the confidence interval, only tomcod fell below the lower limit; apparently the 1983 tomcod peak abundance was delayed somewhat. The 1983 data for anchovies, windowpane and cunner were above the upper limit forecasted for these species. These discrepencies could be the result of insufficient data (e.g. the length of the available series was shorter than some natuarally occurring fluctuations) or unusal climatic events (warm winter), but could not be attributed to power plant operations.

The models resulting from the harmonic regression and autoregression techniques used here for the first time provided the necessary framework for future applications such as impact assessment under 3 unit operation. As we gain experience using these techniques and as more data become available, we will be able to provide even better descriptions of natural fluctuations. With these bases, ecological changes can be interpreted relative to power plant impact.

CONCLUSIONS

The patterns of abundance of nine finfishes (American sand lance, anchovies, sticklebacks, silversides, Atlantic tomcod, grubby, windowpane, tautog and cunner) were described with harmonic regression models that had been fit to historical data through 1982. The 1983 patterns of abundance were compared to those forecasted for 1983 by the models. None of the observed 1983 fluctuations could be attributed to the operations of the power plants at MNPS. The models will continue to provide the basis for impact assessment in the future.

REFERENCES

Austin, H.M. 1973. The ecology of Lake Montauk: planktonic fish, eggs and larvae. New York Ocean Science Laboratory. Tech. Rep. 21.

Barkman, R.C., D.A. Bengtson, and A.D. Beck. 1981. Daily growth of the juvenile fish (Menidia menidia) in the natural habitat compared with juveniles reared in the laboratory. Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 178:324-326.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv. Bull. 53:1-577.

Bliss, C.I. 1958. Periodic regression in biology and climatology. The Connecticut Agricultural Experiment Station, Bull. 615, 55 pp.

Bothelho, V.M., and G.T. Donnelly. 1978. A statistical analysis of the performance of the Bourne plankton splitter, based on test observations. NMFS unpub. ms.

Craig, D., and G.J. Fitzgerald. 1982. Reproductive tactics of four sympatric sticklebacks (Gasterosteidae). Env. Biol. Fish. 7(4):369-375.

Fritzsche, R.A. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol V. Chaetodontidae through Ophidiidae. Power Plant Project, Off. Biol. Serv., U.S. Fish Wildl. Serv., U.S. Dept. of the Interior, FWS/OBS-78/12. 340 pp.

Hardy, J.D., Jr. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol II. Anguillidae through Syngnathidae. Power Plant Project, Off. Biol. Serv., U.S. Fish Wildl. Serv., U.S. Dept. of the Interior, FWS/OBS-78/12. 458 pp.

Johnson, G.D. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol. IV. Carangidae through Ephippidae. Power Plant Project, Off. Biol. Serv., U.S. Fish Wildl. Serv., U.S. Dept. of the Interior, FWS/OBS-78/12. 314 pp.

Leim, A.H., and W.B. Scott. 1966. Fishes of the Atlantic coast of Canada. Bull. Fish. Res. Board Can. 155:1-485.

Lorda, E. 1983. Biological rhythms and the estimation and comparison of the abundance of marine organisms. University of Rhode Island Graduate School of Oceanography Tech. Rep. No. 159. 16 pp.

McHugh, J.L. 1977. Fisheries and fishery resources of New York Bight. NOAA Tech. Rep. NMFS Circ. 401. 51 pp.

McInerney, J.E. 1969. Reproductive behaviour of the blackspotted stickleback, Gasterosteus wheatlandi. J. Fish. Res. Board Can. 26:2061-2075.

Murarka, I.P. 1977. A model for predicting fish impingement at cooling water intakes. ANL/AA-8. Argonne National Laboratories, Argonne, Illinois.

NUSCo (Northeast Utilities Service Company). 1978. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1977.

______. 1980. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1979.

______. 1981. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1980.

______. 1982a. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1981.

______. 1982b. Millstone Nuclear Power Station, Unit 3. Interim environmental report, operating license stage.

______. 1983a. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Resume 1968-1981.

______. 1983b. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1982.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1974. Daily activity, movements, feeding, and seasonal occurrence in the tautog, *Tautoga onitis*. Fish. Bull., U.S. 72:27-35.

Richards, S.W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17:95-124.

Roland, W.J. 1983. Interspecific aggression and dominance in *Gasterosteus*. Env. Biol. Fish. 8(3/4):269-277.

Sampson, R. 1981. Connecticut marine recreational fisheries survey 1979-1980. Connecticut Dept. of Environmental Protection. Mar. Fish. 49 pp.

SAS Institute, Inc. 1982. SAS/ETS User's Guide: Econometric and time-series library. SAS Institute, Inc. Cary, N.C. 584 pp.

Scott, J.S. 1972. Morphological and meristic variation in northwest Atlantic sand lances (*Ammodytes*). J. Fish. Res. Board Can. 29:1673-1678.

Williams, G.C. 1967. Identification and seasonal size changes of eggs of the labrid fishes, *Tautogolabrus adspersus* and *Tautoga onitis*, of Long Island Sound. Copeia 1967(2):452-453.

Worgan, J.P., and G.J. Fitzgerald. 1981. Habitat segregation in a salt marsh among adult sticklebacks (Gasterosteidae). Env. Biol. Fish. 6:105-109.

Appendix 1. Finfish percent species composition as recorded from various environmental programs during the period October 1976 through September 1983.

Species	Impingement*	Plankton: Entrainment Eggs	Plankton: Entrainment Larvae	Plankton: Niantic Bay Eggs	Plankton: Niantic Bay Larvae	Trawl	Seine
Pseudopleuronectes americanus	17.87	0.12	[illegible]	0.03	6.91	45.09	0.05
Anchoa spp.(a)	16.76	10.86	56.07	10.99	58.06	2.45	0.02
Myoxocephalus aenaeus	11.09	0.20	3.84	0	2.13	2.37	0.01
Menidia spp. (b)	11.01	0.12	0.14	1.72	0.18	4.95	80.82
Gasterosteus wheatlandi	7.44	0	0.01	0	0	trace	0.03
Microgadus tomcod (p)	6.36	trace	0.07	trace	0.04	3.53	0.18
Gasterosteus aculeatus	5.15	0	0.02	0	0.01	0.34	0.64
Tautogolabrus adspersus	3.61	52.92	2.53	44.19	6.56	3.16	0.01
Scophthalmus aquosus	2.97	1.06	0.67	1.59	1.13	14.47	trace
Syngnathus fuscus	2.74	0	0.77	0	0.54	0.55	0.53
Peprilus triacanthus	1.87	0.07	1.10	0	1.70	0.63	trace
Alosa spp. (c)	1.58	5.18	0.06	1.45	0.19	0.28	0.01
Merluccius bilinearis	1.56	0	0.06	0	0.13	1.16	0
Tautoga onitis	1.52	23.77	2.34	31.60	3.99	0.91	0.02
Morone americana	1.46	trace	0	0	0	0.02	0
Cyclopterus lumpus	1.01	0	0.01	0	0.01	0.08	0
Osmerus mordax	0.90	0	0.02	0	0.02	0.43	0.02
Raja spp. (d)	0.81	0	0	0	0	4.00	0
Prionotus spp. (e)	0.45	2.68	0.44	2.76	0.98	1.87	0
Brevoortia tyrannus	0.40	0.06	0.78	0.14	1.41	0.01	0.18
Cynoscion regalis	0.36	0.19	0.45	1.19	0.57	0.05	0
Sphoeroides maculatus	0.35	trace	0.06	0	0.06	0.03	0.02
Anguilla rostrata	0.34	0	0.17	0	0.02	0.06	0.04
Fundulus spp. (f)	0.33	0.03	0.01	0	trace	trace	9.20
Liparis atlanticus (p)	0.33	0	1.80	0	0.53	0.06	0
Opsanus tau	0.31	0	0	0	0	0.09	0
Pollachius virens	0.29	0	0.01	0	0.03	0	0
Paralichthys dentatus	0.28	0.01	0.02	0.86	0.09	0.67	0
Pomatomus saltatrix	0.23	0	0	0	0	trace	0.26
Ammodytes americanus (p)	0.23	0.03	9.32	0	8.37	0.21	2.82
Urophycis spp. (g)	0.22	0.33	0.05	0.31	0.08	0.85	trace
Stenotomus chrysops	0.22	1.03	0.51	1.27	0.60	15.63	0
Pholis gunnellus	0.20	0	2.18	0	1.06	0.71	0
Hemitripterus americanus	0.14	0.20	0.01	0	0.02	0.88	0
Myoxocephalus spp.	0.13	0.01	[illegible]	0	0.11	0	0
Trinectes maculatus	0.09	0.24	0.12	0	0.07	trace	0
Morone saxatilis	0.06	0	0	0	0	trace	0
Clupea harengus	0.06	0	0	0	0	0.01	trace
Apeltes quadracus	0.06	0	trace	0	0	0.65	2.65
Leiostomus xanthurus	0.06	0	0.01	0	0	trace	0
Melanogrammus aeglefinus	0.05	0	0	0	0	trace	0
Caranx hippos	0.05	0	0	0	0	trace	trace
Monacanthus hispidus	0.04	0	0	0	0	0.01	0
Gadus morhua	0.03	trace	0.06	0	0.10	0	0
Mugil cephalus	0.03	0	trace	0	0	trace	0.12
Centropristis striata	0.03	0	0.05	0	0.21	0.16	0
Sphyraena borealis	0.02	0	0	0	0	0	0
Scomber scombrus	0.02	0.12	0.50	0.09	0.30	trace	0
Aluterus schoepfi	0.01	0	0	0	0	trace	0
Mustelis canis	0.01	0	0	0	0	0.04	0
Paralichthys oblongus	0.01	0.05	0.15	0	0.44	0.16	0
Etropus microstomus	0.01	0	0.03	0	0.09	0.15	0
Pungitius pungitius	0.01	0	0.01	0	0	trace	0.14
Selene vomer	0.01	0	0	0	0	trace	0
Selene setapinnis	0.01	0	0	0	0	0	0
Myoxocephalus octodecemspinosus	0.01	0.01	0.23	0	0.39	0.29	0
Ulvaria subbifurcata	0.01	0	1.14	0	0.73	trace	0
Conger oceanicus	0.01	0	0.01	0	trace	trace	0

Appendix 1. Finfish percent species composition as recorded from various environmental programs during the period October 1976 through September 1983.

Species	Impingement*	Plankton				Trawl	Seine
		Entrainment		Niantic Bay			
		Eggs	Larvae	Eggs	Larvae		
Trachurus lathami	trace	0	0	0	0	trace	0
Ophidion marginatum	trace	0	0.01	0	0.03	0	0
Alectis ciliaris	trace	0	0	0	0	0	0
Caranx crysos	trace	0	0	0	0	trace	0
Mugil curema	trace	0	0	0	0	0	trace
Fistularia tabacaria	trace	0	0	0	0	trace	0
Cyprinodon variegatus	trace	0.02	0	0.05	0	0	2.05
Chaetodon ocellatus	trace	0	trace	0	0	trace	0
Etrumeus teres	trace	0	trace	0	0	0	0
Squalus acanthias	trace	0	0	0	0	trace	0
Dactylopterus volitans	trace	0	0	0	0	trace	0
Decapterus punctatus	trace	0	0	0	0	0	0
Lophius americanus	trace	0	0.05	0	0.02	trace	0
Seriola zonata	trace	0	0	0	0	0	0
Chilomycterus schoepfi	trace	0	0	0	0	0	0
Hippocampus erectus	trace	0	trace	0	0	0	0
Menticirrhus saxatilis	trace	0	0.31	0	0	trace	trace
Priacanthus cruentatus	trace	0	0	0	0	trace	0
Salmo trutta	trace	0	0	0	0	trace	0
Macrozoarces americanus	trace	0	0	0	0	0.01	0
Aulostomus maculatus	trace	0	0	0	0	0	0
Selar crumenopthalmus	trace	0	0	0	0	0	0
Ophidion welshi	trace	0	0	0	0	0	0
Priacanthus arenatus	trace	0	0	0	0	0	0
Ophidiidae	trace	0	0	0	0	0	0
Ictalurus catus	trace	0	0	0	0	0	0
Bairdiella chrysoura	trace	0	0.69	0	0.34	0	0
Monocanthus spp.	trace	0	0	0	0	0	0
Petromyon marinus	trace	0	0	0	0	0	0
Brosme brosme	trace	0	0	0	0	0	0
Rhinoptera bonasus	trace	0	0	0	0	0	0
Pristigenys alta	trace	0	0	0	0	trace	0
Acipenser oxyrhynchus	0	0	0	0	0	trace	0
Bothus ocellatus	0	0	trace	0	0	trace	0
Clupeidae	0	trace	0.17	0	0.10	trace	0
Enchelyopus cimbrius	0	0.37	0.65	0.42	0.86	trace	0
Engraulus eurystole	0	0	trace	0	0	0	0
Gasterosteidae	0	0	0	0	0	trace	0
Gobiidae	0	0	0.18	0	0.07	trace	0
Labridae	0	0.21	0.08	1.26	0.03	0	0
Limanda ferruginea	0	0	0.01	0	0.02	0.02	0
Lucania parva	0	0	0	0	0	0	0.01
Lumpenus lumpretaeformis	0	0	0.04	0	0	0	0
Micropogon undulatus	0	0	trace	0	0.03	0	0
Mullus auratus	0	0	0	0	0	trace	0
Myliobatis freminvillei	0	0	0	0	0	trace	0
Peprilis alepidotus	0	0	trace	0	0	0	0
Sciaenidae	0	0	0.17	0	0.32	0	0
Scyliorhinus retifer	0	0	0	0	0	trace	0
Strongylura marina	0	0	0	0	0	0	trace
Synodus foetens	0	0	0	0	0	trace	0
Trachinotus falcatus	0	0	0	0	0	0	0.02

*Impingement percents have been corrected for variations in flow
trace=<0.01%
(p) indicates most probable identification
(a) includes A. mitchilli and A. hepsetus
(b) includes M. menidia and M. beryllina
(c) includes A. aestivalis, A. mediocris, A. pseudoharengus and A. sapidissima
(d) includes R. erinacea, R. ocellata and R. eglanteria
(e) includes P. carolinus and P. evolans
(f) includes F. majalis and F. heteroclitus
(g) includes U. regia, U. chuss and U. tenuis

Appendix 2. Estimated total number of fish and shellfish impinged at units 1 and 2 (combined) between October 1, 1982 and September 31, 1983.

SCIENTIFIC NAME	TOTAL	SCIENTIFIC NAME	TOTAL
Anchoa mitchilli	50,535	Fundulus majalis	45
Loligo pealei	23,769	Libinia spp.	38
Ovalipes ocellatus	23,762	Centropristis striata	37
Gasterosteus wheatlandi	14,747	Etropus microstomus	35
Microgadus tomcod	12,260	Squilla empusa	32
Pseudopleuronectes americanus	10,769	Leiostomus xanthurus	30
Myoxocephalus aenaeus	10,258	Penaeus aztecus	28
Cancer irroratus	8,995	Menidia beryllina	26
Gasterosteus aculeatus	6,972	Ophidion marginatum	23
Syngnathus fuscus	6,687	Mugil cephalus	21
Menidia menidia	4,833	Pungitius pungitius	21
Tautogolabrus adspersus	3,610	Argopecten irradians	21
Alsoa aestivalis	3,534	Cancer borealis	20
Carcinus maenus	3,067	Urophycis tenuis	16
Anchoa spp.	3,032	Conger oceanicus	16
Scophthalmus aquosus	2,481	Ammodytes spp.	14
Callinectes sapidus	2,062	Myoxocephalus octodecemspinosus	14
Osmerus mordax	1,467	Gadidae	13
Tautoga onitis	1,397	Fundulus heteroclitus	11
Peprilus triacanthus	1,365	Monacanthus hispidus	11
Homarus americanus	1,175	Callinectes similis	9
Pollachius virens	943	Pagurus pollicaris	9
Morone americana	872	Scomber scombrus	9
Cyclopterus lumpus	854	Hippocampus erectus	7
Raja spp.	772	Paralichthys oblongus	7
Libinia emarginata	769	Squalus acanthias	7
Merluccius bilinearis	765	Priacanthus cruentatus	7
Brevoortia tyrannus	628	Selene vomer	7
Sphoeroides maculatus	622	Dactylopterus volitans	7
Neopanope texana	533	Trachurus lathami	5
Anguilla rostrata	494	Caranx crysos	5
Alosa pseudoharengus	460	Fistularia tabacaria	5
Urophycis regia	432	Menidia spp.	5
Pomatomus saltatrix	411	Decapterus punctatus	5
Stenotomus chrysops	343	Ophidiidae	5
Paralichthys dentatus	236	Apeltes quadracus	5
Opsanus tau	235	Anchoa hepsetus	4
Hemitripterus americanus	226	Mustelis canis	4
Pholis gunnellus	225	Lepomis macrochuris	2
Limulus polyphemus	161	Urophycis spp.	2
Ammodytes americanus	159	Aluterus schoepfi	2
Liparis spp.	148	Cyprinodon variegatus	2
Raja ocellata	142	Etrumeus teres	2
Prionotus evolans	136	Pristigenys alta	2
Upogebia affinis	128	Rana pipens	2
Liparis atlanticus	109	Chaetodon ocellatus	2
Cynoscion regalis	96	Bairdiella chrysoura	2
Caranx hippos	82	Monocanthus spp.	2
Urophycis chuss	81	Macrozoarces americanus	2
Sphyraena borealis	71	Lunatia heros	2
Trinectes maculatus	69	Menticirrhus saxatiliis	2
Gadus morhua	68	Brosme brosme	2
Morone saxatilis	64	Illex illecebrosus	2
Prionotus carolinus	63	Ophidion welshi	2
Alosa sapidissima	55	Mugil curema	2
Clupea harengus	48	Ulvaria subbifurcata	2

WINTER FLOUNDER POPULATION STUDIES

Table of Contents

WINTER FLOUNDER POPULATION STUDIES

INTRODUCTION

The winter flounder (Pseudopleuronectes americanus) ranges from Labrador to Georgia (Leim and Scott 1966). It is one of the most common demersal fishes along the northeastern coast from Nova Scotia to New Jersey (Perlmutter 1947) and is particularly abundant in Long Island Sound. It is one of the most valuable commercial species in Connecticut with annual landings from 1973 through 1983 between 221,807 and 413,537 kg (Connecticut Department of Environmental Protection, unpublished data). It is also one of the most sought-after marine sport fishes in the state with an estimated annual catch in 1979 of 190,626 kg (Sampson 1981).

The abundance of the winter flounder in the Greater Millstone Bight has been evident from the beginning of environmental studies conducted at the Millstone Nuclear Power Station (MNPS). The species dominates the trawl catch of demersal fishes and is the most numerous fish impinged on the traveling screens of the MNPS cooling-water intakes. Its larvae are very abundant in spring, particularly in the Niantic River, and many are entrained through the MNPS cooling-water system.

Winter flounder populations are composed of geographically isolated stocks which spawn in specific estuaries and coastal areas (Lobell 1939; Perlmutter 1947; Saila 1961). Other local fish stocks have greater geographical range and abundance or life histories making them less susceptible to impact by MNPS. Special emphasis has therefore been placed on understanding the dynamics of the winter flounder stock spawning in the nearby Niantic River. The dynamics of this population have been studied extensively to determine if MNPS impacts have or would cause changes in local abundance beyond those expected from natural variation.

Studies of the winter flounder began at Millstone in 1973 and included the development of a predictive mathematical population dynamics model (Sissenwine et al. 1975; Saila 1976). Preliminary field studies to estimate population abundance began in 1973 and were expanded in scope in 1975 (Table 1). Studies of age structure, reproductive

Table 1. Summary of Niantic River adult winter flounder studies from 1975 through 1983.

Year	Dates Sampled	Marking method	Method of abundance estimation	Types of studies	Comments
1975	March 31 - May 13	Fin clipping	Triple Trellis (Ricker 1958) and Jolly (1965)	Population abundance.	Study set up for triple trellis method of abundance estimation; Jolly method also applied to data.
1976	March 1 - May 4	Fin clipping	Jolly (1965)	Population abundance.	Study set up for Jolly method to obtain improved estimate.
1977	March 7 - May 10	Freeze branding	Jolly (1965)	Abundance, age, sex ratio, length-fecundity and length-weight relationships.	Used freeze branding to improve the method of marking and to increase the variety of marks used. Age determined by examination of both scales and otoliths.
1978	March 6 - May 16	Freeze branding	Jolly (1965)	Abundance, age, sex ratio, and length-weight relationship.	Aging by scales and otoliths and scales alone to compare aging methods. Scales alone used henceforth.
1979	March 12 - May 15	Freeze branding	Jolly (1965)	Abundance, age, sex ratio, and survival.	Fish assigned ages 1 through 3; older specimens combined as age 3+.
1980	March 17 - May 6	Freeze branding	Jolly (1965), Manly-Parr and Fisher-Ford	Abundance, age, sex ratio, and survival.	An age was assigned to each fish using an age-length key.
1981	March 2 - May 3	Freeze branding	Jolly (1965)	Abundances, age, sex ratio, and movements.	An age was assigned to each fish using an age-length key. Petersen discs used to mark fish for studies of movements and exploitation.
1982	February 22 - May 11	Freeze branding	Jolly (1965)	Abundance, age sex ratio, movements, and survival.	An age was assigned to each fish using an age-length key. Petersen discs used to mark fish for studies of movements and exploitation.
1983	February 21 - April 6	Freeze branding	Jolly (1965)	Abundance, age, sex ratio, movements, and survival.	An age was assigned to each fish using an age-length key. Petersen discs used to mark fish for studies of movements and exploitation. Growth calculated by measurements to scale annuli.

activity, length-weight relationships, survival, movements, early life history, and entrainment were conducted in following years and were reported in greater detail in Battelle-William F. Clapp Laboratories (1978-79) and in NUSCo (1975, 1980-83). This report summarizes results of the 1983 adult, larval, and juvenile surveys, and data from the trawl, impingement, and entrainment monitoring programs.

MATERIALS AND METHODS

Adult population studies

Abundance estimates

Preliminary sampling for adult winter flounder in the Niantic River started on January 12 and continued weekly or biweekly to ascertain abundance and spawning condition. After iceout in the upper river, enough winter flounder were present for mark and recapture studies and the 1983 adult population abundance survey began on February 22. The survey was conducted for 2 days each week through April 6 when the criterion was met that the weekly percentage of ripe females was less than 10% of all females for 2 successive weeks. Six stations were sampled in 1983 (Fig. 1). Station 5, sampled from 1975 through 1982

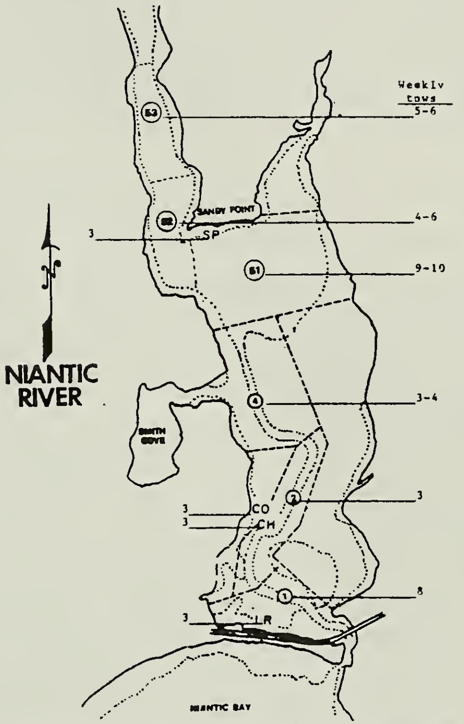


Figure 1. Location of Niantic River winter flounder sampling stations and number of weekly tows at each station (see text for tow allocation criteria).

(NUSCo 1983), was subdivided into stations 51, 52 and 53 during 1983. The 32 to 35 tows made weekly were allocated to each station based on area and expected abundance of winter flounder; more tows were taken at stations having greater catches.

Winter flounder were captured with a 9.1-m otter trawl (6.4-mm bar mesh codend liner) towed 0.55 km. This distance was chosen because it represented the maximum tow length at station 1 and its use at all stations was expected to reduce variability in calculating catch-per-unit-effort (CPUE). However, since catch data from station 2 was also used for the trawl monitoring program, tows there were maintained at the 0.69 km distance used for that program. Because of tidal currents, wind, and varying amounts of material collected in the trawl, tow times for the standardized distances varied slightly and were usually greater in the lower than in the upper river. Tows made during previous years were not standardized by distance or time. Distribution of tow times were examined at each station from 1976 through 1982; mean duration for stations 1 and 2 was 14.7 min and for other stations was 9.8 min. Tows with duration greater or less than two standard deviations of the mean were deleted from analysis and calculation of CPUE. For comparisons among years, all catches of winter flounder larger than 15 cm were standardized to either 15-min tows (stations 1 and 2) or 10-min tows (all other stations). The CPUE for each year were plotted and distributions tested for normality with the Kolmogorov D-statistic (SAS Institute Inc. 1982a). The annual mean and median CPUE were determined and a 95% confidence interval was calculated for each median using a distribution-free method (Snedecor and Cochran 1967).

The winter flounder caught in each tow were held in water-filled containers until processed. All fish 20 cm or larger were marked with a number made by a 15.9-mm brass brand cooled in a container of liquid nitrogen; the number was changed weekly. Fish recaptured were noted and remarked with a number designating the latest week of the survey. During the third week of the study, all specimens were double-branded to evaluate the loss of marks during the survey period.

Using the mark and recapture data, the Jolly (1965) model was used to estimate the abundance of all winter flounder 20 cm or larger in the Niantic River during the spawning season. The estimates were obtained using the computer program of Davies (1971) with minor modifications as described in NUSCo (1982). Total abundance estimates were obtained by starting with an initial estimate and then adding the total number of fish joining during subsequent weeks. The estimated abundance of fish less than 20 cm was determined from the following proportion:

$$\frac{\text{Jolly estimate of fish} \geq 20\text{ cm}}{\text{total trawl catch of fish} \geq 20\text{ cm}} = \frac{\text{estimate of fish} < 20\text{ cm}}{\text{total trawl catch of fish} < 20\text{ cm}}$$

The occurrence of non-permanent or temporary outmigration during the population abundance survey was examined using a series of 2 X 2 tables and the chi-square statistic (NusCo 1980; Balser 1981). The log-likelihood ratio test (G-test of Sokal and Rohlf 1969) was used to examine the proportions of winter flounder marked and recaptured by sex, length interval, and station. The probability level chosen to reject the null hypothesis in these and all other statistical tests was $p \leq 0.05$.

Length, age, reproduction, and survival

Each week of the population abundance survey in the Niantic River all winter flounder larger than 20 cm and at least 200 smaller fish were measured to the nearest mm in total length. The sex and reproductive condition of all mature winter flounder were determined either by observing eggs or milt or by the presence (males) or absence (females) of ctenii on the caudal peduncle scales of the left side. Based on previous data, stratified sampling was used for aging (Ketchen 1950; Ricker 1975). From five to ten scale samples were allocated to each 1-cm size interval of both sexes starting with 20 cm. Within each length interval, scales from random individuals were removed from the right side between in the dorsal fin and the lateral line. Scales from some fish less than 20 cm were also taken for the growth calculations. After processing in the field, all fish were returned to the general area of capture. Information on reproductive condition was recorded for a subsample of winter flounder impinged at MNPS from December through April and for those taken in the trawl monitoring program from February through April.

Five or more scales from specimens selected for aging were cleaned and mounted in plastic resin on a slide and examined by at least two people using a Bausch and Lomb trisimplex projector or a compound microscope. Except for the first year, winter flounder have a zone of widely spaced circuli (fast spring and summer growth) followed by a zone of closely spaced circuli (slow fall and winter growth). The outer edge of the zone of closely spaced circuli was considered the annulus (Lux and Nichy 1969; Lux 1973). Fish age 7 and older were assigned age 7+

because of the uncertainty in aging these larger and slower growing fish. An age-length key was constructed by determining the percentage that each of the ages 1 through 7+ made up of every 1-cm length increment in the sample of aged fish. This key was used to assign an age to all fish measured during the abundance survey. The percentages of the age-length distribution together with the abundance estimates were used to compute the population age structure.

The growth rate of Niantic River winter flounder was found by additional examination of one of the scales used in age determination. Measurements were taken from the midpoint of the scale focus to each annulus and to the anterior margin of the projected scale image along a standard axis (Tesch 1968; Everhart et al. 1975). For the back-calculation of length-at-age, the relationship between scale size and fish length was examined using a functional regression (Jolicoeur 1975; Sprent and Dolby 1980). Annuli measurements for each fish were substituted into the appropriate regression equation for back-calculation of growth. Mean lengths-at-age with 95% confidence intervals were then computed.

Using the above length-at-age data, the von Bertalanffy growth model (Ricker 1975; Gallucci and Quinn 1979) was used to describe the growth of Niantic River winter flounder:

$$L_t = L_\infty(1-\exp(-K(t-t_0)))$$

where

L_t = length in mm at age t in years

K = growth coefficient

L_∞ = asymptotic maximum length in mm

t_0 = hypothetical age in years at which a fish would have zero length if it had always grown in the manner described by the equation

A nonlinear procedure using the modified Gauss-Newton iterative method (SAS Institute Inc. 1982b) was used to estimate the growth model parameters from the length-at-age data. The ω parameter (the product of $L\infty$ and K) of Gallucci and Quinn (1979) was calculated and their graphical procedure was used to compare the theoretical growth of females and males. This involved plotting two standard errors on each side of the point estimates of $L\infty$ and K and joining the lines to form a rectangle. If the resultant rectangles had little or no overlap, it was inferred that a significant difference existed between the female and male growth parameters.

Probit analysis (SAS Institute Inc. 1982b) was used to determine the median (50%) length of sexually mature females. The number of females reproducing in the Niantic River each year was estimated by determining their abundance in each 2-cm length increment starting with 25 cm. Fecundity (annual egg production per female) was estimated using the length-frequency data with the length-fecundity relationship described by a functional regression for Niantic river winter flounder:

$$\text{fecundity} = 2.4837(\text{length})^{4.4124} \quad (n=49,\ R^2=0.76).$$

The mean fecundity was the sum of all individual fecundities divided by the number of spawning females. The sum of the fecundities gave total egg production for the year.

Estimates of survival (S) were made using the abundance and age data from 1977 through 1983 with the method of Robson and Chapman (Ricker 1975):

$$S = \frac{T}{\Sigma N + T - 1}$$

$$\text{where } T = N_1 + 2N_2 + 3N_3 \ldots$$

$$\Sigma N = N_0 + N_1 + N_2 \ldots$$

<u>Movements</u>

Since 1980, 4,978 winter flounder were each tagged with a Petersen disc to determine their movements and exploitation by fishermen. Most fish in 1983 were tagged in the Niantic River during the first week of March; these fish were also branded as part of the population abundance survey. During tagging operations, winter flounder larger than 20 cm were sexed, scales removed for aging, and length recorded to the nearest mm. A white 1.3-cm diameter disc uniquely numbered and printed with information for its return was positioned on the nape of the right side of the fish and a red disc with additional information was used on the left side. A nickel pin was pushed through the musculature, cut to size, and its end was crimped over to connect the tags and hold them in place. Except for some specimens released specifically at the MNPS intakes, winter flounder were returned to the same location as their capture. Information requested at recapture included date, location, method of capture, length, sex, and additional scales. A reward was given to all persons returning a tag.

Early life history studies

Larval stage

Samples examined for winter flounder larvae were taken at the MNPS discharge (station EN, formerly designated as DIS; NUSCo 1983); at Station NB in mid-Niantic Bay (formerly NB 5); and at stations A (new in 1983), B (realignment of former station NR 1), and C (formerly NR 2) in the Niantic River (Fig. 2). Entrainment samples at EN were collected on

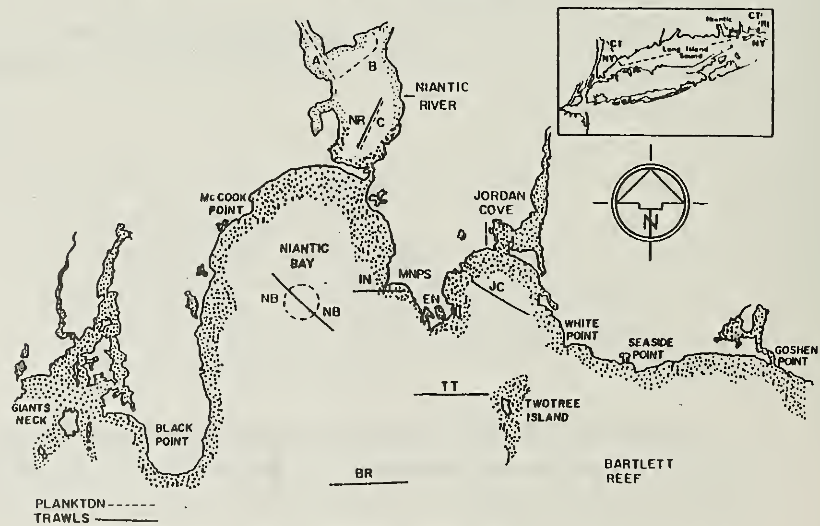


Figure 2. Location of stations sampled for winter flounder in the trawl and ichthyoplankton monitoring programs.

4 days and 4 nights each week, alternating weekly at the discharge of Units 1 and 2. Approximately 400 m^3 of water were filtered through a 1.0-m diameter, 3.6-m long, 0.333-mm mesh conical plankton net. Additional details may be found in the Fish Ecology section.

Ichthyoplankton samples were taken in Niantic River and Bay with a 60-cm bongo sampler with 3.3-m long nets of 0.333-mm mesh towed at 2 knots and weighted with a 28.2-kg oceanographic depressor. Volume filtered was determined with General Oceanics flowmeters (Model 2030) and approximated 300 m^3 per sample. Single tows (one replicate processed) were taken both day and night using a stepwise oblique tow pattern with equal sampling duration of 5 min in surface, midwater, and bottom strata. The length of tow line necessary to sample the mid-water and bottom strata was based on water depth and the tow line angle as measured with an inclinometer and was determined by the following relationship:

tow line length = desired sampling depth/cosine of tow angle.

Tow duration was reduced to 2 min per strata at station A starting on May 28 due to net clogging by lion's mane jellyfish (*Cyanea* sp.). At NB, single bongo tows (both replicates processed) were made biweekly from January through March. From April through the end of the larval winter flounder season in mid-June, single bongo tows (one replicate processed) were taken twice weekly (Monday and Thursday or Tuesday and Friday) during day and night. In the Niantic River, preliminary tows were made during the day in February at stations A, B, and C at about weekly intervals to determine when larval winter flounder were present. From March through the disappearance of larvae at each station, single bongo tows (one replicate processed) were made twice weekly (Monday and Thursday or Tuesday and Friday) day and night.

Sampling time in the Niantic River during daylight and night was systematically varied between two daily periods (prior to 1200 and after 1200) and two nightly periods (prior to 2400 and after 2400) since the effect of time of day on collection densities was not known. No sampling was conducted 30 min before or after sunrise or sunset. The two daylight and two night sampling periods were alternated weekly.

Station C was the only one in the Niantic River with strong tidal currents (Marshall 1960) and the effect of tide on collection densities was not known. Therefore, sampling at station C was systematically varied over four tidal stages (high, low, mid-ebb, and mid-flood). By collecting day and night samples approximately 6 h apart on one date, two opposing tidal stages were collected (e.g., high and low). The second weekly collection trip was 3 days later at approximately the same time and collections were taken during the other two tidal stages (e.g., mid-flood and mid-ebb). All 16 combinations of sampling periods and tidal stages were collected during every 4-wk period at station C. Two 24-h tidal studies were conducted at station C on April 28-29 and May 8-9. Samples were collected at 2-h intervals during a 24-h period.

Tidal export and import of larvae was examined at the mouth of the Niantic River during maximum ebb and flood currents. Two ebb and flood tides were sampled on May 9 and one ebb and flood tide was sampled on May 16. Stationary tows were taken in the middle of the channel adjacent to the Niantic River Highway Bridge. The bongo samplers described previously were used except an additional 40 kg of weight was added as ballast to increase the vertical tow line angle. Two bongo samplers were deployed for 15 min off each side of the boat with one at mid-water and the other near bottom. Two tows were made at each depth for a total of four replicates at each depth per tidal stage.

All ichthyoplankton samples were preserved with 10% formalin and processed in the laboratory. Samples were split to at least one-half volume and larvae identified and counted using a dissecting microscope. Up to 50 winter flounder larvae were measured to 0.1-mm in standard length (snout tip to notochord tip). The developmental stage of each larvae measured was recorded. The five possible stages were defined as:

Stage 1. The yolk sac was present or the eyes were not pigmented (yolk-sac larvae)

Stage 2. The eyes were pigmented, no yolk sac was present, and no fin ray development

Stage 3. Fin rays were present but the left eye had not migrated to the mid-line

Stage 4. The left eye had reached the mid-line but juvenile characteristics were not present

Stage 5. Transformation to juvenile was complete and intense pigmentation was present near the caudal fin base

Larval collection frequency and density (n/500 m^3) were used for data analyses. Collection frequency was adjusted for the number of samples at each station and sample volume. Density distribution plots were smoothed using the spline function (SAS Institute Inc. 1981).

Post-larval stage

During 1983, information was gathered on post-larval juvenile winter flounder in the Niantic River. Four stations were sampled including Sandy Point (SP), Lower River (LR), Camp O'Neill (CO), and Channel (CH) (Fig. 1). SP, CO, and LR were selected because they had good juvenile winter flounder habitat, with sandy to muddy bottoms in shallow water adjacent to eelgrass beds (Bigelow and Schroeder 1953). Station CH was in a slightly deeper area between stands of eelgrass and the navigation channel. Depths sampled at all stations ranged from about 1 to 3 m. The stations were sampled once each week from May 18 through October 12 during daylight from 2 h before to 1 h after high tide. A 1-m beam trawl which had interchangable nets of 0.8-, 1.6-, 3.2-, and 6.4-mm bar mesh was used; the nets were changed as fish grew and became available to the next largest size. A tickler chain was added to the net for use with the three largest meshes. Three replicates were made at each station and distance of each tow was estimated by letting out a measured line attached to a lead weight. Tows of 40 and 50 m made initially were increased to 75 and 100 m as the number of fish decreased throughout the summer and early fall. For data analysis and calculation of CPUE, the catch at each station was adjusted to 100 m^2 of bottom covered by the beam trawl.

Juveniles were measured to the nearest 0.5 mm in total length. During the first 5 weeks of the study, standard length was also measured as many of specimens had damaged caudal fin rays and total length could not be taken. The relationship between the two was determined by a functional regression and used to convert standard to total length for data analysis.

The mortality rate of juveniles was calculated using a method described by Jones (1981). The natural logarithms of the total number of fish caught that were equal to or larger than a series of specific lengths were plotted against the logarithms of L_∞ minus those lengths; the slope was Z/K. Both L_∞ and K are parameters of the von Bertalanffy growth model and Z is the instantaneous rate of total morality. The growth model was fit by methods outlined previously in this section using the weekly length measurements of specimens from station LR. As weekly data were used, the time unit for the model parameters was 1 week and Z represented the weekly rate of instantaneous mortality. Asymptotic maximum length was assumed to be the length achieved as growth ceased in early fall. Length-frequency distributions were examined for each of the four tow lengths (40-100 m) used during the sampling and numbers per each 2.5-mm interval were adjusted upwards as necessary to give the catch per 100 m^2. Total catch for each 2.5-mm interval was found by summing across all the length frequencies. These data were used with the growth model parameters in a regression to calculate Z; annual survival was estimated as exp((-Z)(52)) and daily survival as exp(-Z/7).

Impingement

The number of winter flounder impinged on the traveling screens of MNPS from October 1972 through September 1983 was estimated using techniques described in detail in the Fish Ecology section of this report. Length-frequency data of fish impinged from 1976-77 through 1982-83 were also examined.

Entrainment

Annual entrainment estimates from 1976 through 1983 were calculated using the median density (n/500 m^3) of winter flounder larvae collected at station EN during the larval season. The entrainment estimate was the median value times the total number of 500 m^3 units of seawater withdrawn by MNPS during the larval period for each year. A distribution-free (nonparametric) method (Snedecor and Cochran 1967) was used to construct a 95% confidence interval around each median and entrainment estimate.

An entrainment mortality study was conducted from April 25 through May 17. Samples of entrained winter flounder larvae were collected in a slow current area of the Millstone quarry downstream from the MNPS discharges. A 0.5-m diameter, 1-m long, 0.333-mm mesh bridled plankton net was lowered from a boat to the bottom (ca. 15 m) and slowly hauled to the surface to minimize net damage. Samples were transported to the laboratory and gently poured into 2-liter white porcelain trays. Dead specimens were counted and removed. Test groups of five live larvae each were transferred using wide-bore pipettes to 0.333-mm mesh 1-liter holding chambers in flow-through effluent water. Effluent holding time was 2 or 4 h to simulate retention in the quarry with three or two units of MNPS in operation, respectively. Following effluent holding, chambers were moved to ambient flow-through water and observed daily for latent mortality over a 96-h period. All dead larvae or larvae surviving the latent mortality holding period were classified by developmental stage and measured.

Harmonic regression models

Fluctuations in the log-transformed catches of winter flounder taken in various monitoring programs were analyzed using harmonic regression techniques described in the Fish Ecology section. Data from the trawl monitoring program were used to calculate the catch of winter flounder for a standard tow of 0.69 km at six stations (Fig. 2), including Niantic River (NR), Niantic Bay (NB), Intake (IN), Twotree Island Channel (TT), Jordan Cove (JC), and Bartlett Reef (BR). Three replicate tows were taken every other week and the log-transformed catches were averaged to produce a single value for every sampling period. Weekly means of the log-transformed catches were calculated from the impingement, entrainment (station EN), and ichthyoplankton (NB) monitoring programs. These values were used to construct various models describing catches from October 1976 through September 1982. The models were used to forecast log-transformed catches for October 1982 through September 1983. Comparisons were then made between the predicted and the actual catches made during the past year.

RESULTS AND DISCUSSION

Adult population studies

Abundance

The 1983 population abundance survey took place during a 7-week period; 5,196 adults larger than 20 cm were marked and 363 of these were subsequently recaptured (Table 2). The number marked in 1983 was about

Table 2. Yearly mark and recapture data for Niantic River winter flounder from 1976 through 1983.

Year	Number of weeks sampled	Number marked	Number recaptured	Percent recaptured	Percent of population sampled
1976	10	9,856	699	7.1	11.2
1977	10	6,860	623	9.1	13.3
1978	11	8,403	729	8.7	16.1
1979	10	8,105	491	6.1	15.1
1980	8	7,625	961	12.6	23.4
1981	10	10,458	822	7.9	11.8
1982	12	11,076	901	8.1	10.9
1983	7	5,196	363	7.0	12.4

one-half that of 1981 and 1982 because the minimum size for marking was raised from 15 to 20 cm. This change was made to focus effort on the adult spawning population and eliminate labor involving smaller winter flounder. Unlike earlier years, the survey in 1983 did not extend beyond the spawning period, but the percentages of fish recaptured (7%) and of the estimated population sampled (12%) were similar to previous years (6-13%; 11-23%). Except for the third week of March, the number marked was very consistent from week to week (Table 3); this was probably because of the more uniform temporal and spatial sampling effort made during 1983. These data were used with the Jolly mark and recapture model to produce an estimate of 41,980 ± 15,564 winter flounder larger than 20 cm in the Niantic River (Table 4).

Table 3. Weekly catch data used for estimating population abundance of Niantic River winter flounder during 1983.

Week no.	Date (week of)	Total catch	Number unmarked	Number marked	Number removed	Number examined	Recap. 1977-82	Recaptures (week marked) 3	4	5	6	7	8	9	Total recap	Week no.
3	2/21	1,461	638	823	0	823	43	-							-	3
4	2/28	1,740	962	777	1	778	52	31	-						31	4
5	3/7	1,633	741	869	23	892	46	15	28	-					43	5
6	3/14	1,586	718	855	13	868	40	8	22	20	-				50	6
7	3/21	2,380	1,364	1,015	1	1,016	29	14	14	22	24				74	7
8	3/28	1,969	1,081	857	31	888	33	11	8	14	23	29	-		85	8
9	4/4	2,014	1,226	-	7	788	31	11	12	9	12	17	19	-	80	9
Total		12,783	6,730	5,196	76	6,053	274	90	84	65	59	46	19	-	363	Total

Table 4. The 1983 abundance estimate of winter flounder larger than 20 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
3	2/21			0.701	0.108			14,475
4	2/28	14,475	3,312	1.043	0.136	13,526	5,473	13,526
5	3/7	28,625	5,970	0.778	0.178	7,542	5,456	7,542
6	3/14	29,799	6,020	0.904	0.246	4,372	5,236	4,372
7	3/21	31,311	6,301			2,065	4,518	2,065
8	3/28	29,632	8,052					
Total abundance ± 2 standard errors								41,980 ±15,564

The 1983 data were examined for potential sources of bias or error in the abundance estimates by comparing proportions of marked and recaptured fish by sex, length, and station. More females were marked (n=3,127; 60%) and recaptured (n=247; 68%) than males (2,069, 40%; 116, 32%). The increase in proportion of females recaptured in comparison to those tagged was significantly different, although no plausible explanation can be offered for this phenomenon. One possible reason was that males left the river at a greater rate than females. However, other data seemed to indicate the opposite effect as 54% of the returns of disc-tagged males were from the river while only 39% of the females were. Another possibility was that after spawning, when emission of eggs and milt ceased, more males than females were misclassified by sex. For instance, a change of 10 females to males (3% of the recaptures) would have made the difference non-significant. Errors in classification by sex did not affect the abundance estimate since the sexes were combined for the calculation, but could have slightly influenced egg production estimates. No differences were found in the length-frequency distribution of males and females tagged as compared to those recaptured. Thus, recapture probabilities were not biased by size selectivity.

A significant difference was found in the proportions branded and recaptured at the stations sampled. The proportions were significantly different between a group comprised by stations 52 (16% branded and 20% recaptured), 2 (5%, 7%), and 1 (17%, 19%) and that by 53 alone (17%, 11%). This was not unexpected as winter flounder concentrated in the channels of the lower river before leaving the estuary and were more available for recapture there. They also probably withdrew from the northern portion (station 53) of the upper river arm into the southern portion (52) as well.

Two sources of information were available to examine for loss of marks during the survey. Two of the 67 fish that were double-branded and recaptured one or more times had only one brand visible. Of the fish both branded and disc-tagged, only 1 of the 91 fish re-examined had a missing brand. These data indicated that the number of recaptures was perhaps underrepresented by about 2 to 3%. According to Arnason and Mills (1981), the small loss of brands should not have biased the abundance estimate (N) nor its standard error, although it could have affected the number joining (B) and its standard error. They also noted that the precision of the estimates might have been reduced slightly, but in our study corrections were unnecessary since the bias was small and precision (CV=19% for 1983) was relatively good. No bias occurred because of capture-prone fish; only 15 fish were recaptured twice (4% of total) and 1 specimen was taken 3 times (0.2%).

Any movement of marked fish out of and back into the Niantic River during the abundance survey could have introduced serious bias into the Jolly estimate (NUSCo 1980; Balser 1981). Several significant differences were found in the proportions of fish marked and recaptured during various weeks. As in previous years, the significant differences were thought to have been due to sampling error rather than from an acutal temporary outmigration of branded winter flounder. The differences in 1983 were associated with a decrease in the number of fish marked in week 3 and recaptured in week 6 (n=8; Table 3) as compared to recaptures of the same group of fish in the previous and following weeks (15 and 14, respectively). Further examination of the data showed that this decline took place at station 51, but no explanation can be offered for this unusual decline in recaptures. The Jolly abundance estimate was recalculated as if the number of week 3 recaptures in week 6 was 14 instead of the 8 recaptures actually used. The resulting increase in estimated abundance was less than 2%, so the error had only minor consequences in the calculation.

For comparison with previous years, the annual abundance estimates were adjusted to account for the 5-cm difference in size of winter flounder marked between 1983 and previous years. Adjustments were also made to account for differences in the number of weeks sampled among years. Some differences were reduced by comparing estimates for just the spawning period (Table 5; Appendices 1-7). The total number of

Table 5. Annual estimates of spawning population abundances and total egg production for Niantic River winter flounder from 1976 through 1983.

Year	Number of weeks for estimates	Population of winter flounder $\geq$ 15 cm ($x10^3$)	±2 standard errors ($x10^3$)	Population of winter flounder $\geq$ 20 cm ($x10^3$)	±2 standard errors ($x10^3$)	Number of spawning females ($x10^3$)	Mean fecundity ($x10^5$)	Total egg production ($x10^9$)
1976	5	48.2	11.5	38.8	-	-	-	-
1977	4	37.4	19.4	27.7	-	12.4	5.7	7.0
1978	3	25.4	12.1	17.3	-	9.9	6.2	6.1
1979	2	26.7	-	14.0	-	7.4	6.3	4.6
1980	3	27.2	15.3	13.1	-	6.0	5.4	3.3
1981	5	62.9	10.8	49.3	-	25.1	6.3	15.8
1982	5	77.5	13.4	58.8	-	30.3	7.0	21.2
1983	5	49.4	-	42.0	15.6	22.0	6.8	15.0

winter flounder larger than 20 cm in 1983 apparently declined about 28% from 1982 and 15% from 1981, but remained larger than estimates made during the late 1970's.

Based on the proportional method of calculation, the number of winter flounder smaller than 20 cm was 45,789; 38,482 of these were smaller than 15 cm, a decline of more than a third from 1982. Fewer winter flounder between 15 and 20 cm were taken in 1983 than in previous years (Table 5). One explanation for this difference may have been the earlier completion of the survey in 1983. Smaller winter flounder were more abundant later in spring during previous years as surveys then included all of April and part of May. The abundance estimate of immature winter flounder in the Niantic River may not have accurately reflected their absolute abundance as data from the trawl monitoring program indicated that they were present throughout the area during this time. Their presence in the river may have been influenced by other factors such as water temperature.

Abundance of winter flounder 15 cm and larger was also measured by trawl CPUE during the survey (Table 6). The trawl data were determined

Table 6. Mean and median CPUE of Niantic River winter flounder from 1976 through 1983.

Year	1976	1977	1978	1979	1980	1981	1982	1983
Total tows made	390	412	289	265	228	286	322	233
Tows used for CPUE	349	355	260	247	173	273	285	228
% of tows used	89	86	90	93	76	95	89	98
Mean CPUE	37.5	22.1	38.2	38.4	34.2	41.3	30.6	26.9
Standard deviation	36.9	19.6	33.1	33.7	27.3	31.2	31.3	13.8
Coefficient of variation	98%	89%	87%	88%	80%	76%	102%	51%
Median CPUE	27.5	16.7	27.1	26.7	26.3	35.0	19.5	26.4
95% CI	24-31.5	15-18	24-31	22-32	22-31	31-38	16-24.4	24-28
Coefficient of skewness[a]	2.51	2.09	1.45	1.33	1.40	2.96	1.94	1.26

[a] Zero when data is distributed symetrically

to be non-normally distributed and positively skewed, so the median was chosen as the most representative catch statistic; the means were included as a comparison. Standardization of the trawling lessened the variability of the 1983 data. The coefficient of variation was reduced (51%; half that of 1982) and skewness lessened, resulting in a close correspondence between the median and the mean. Nevertheless, the 95% confidence interval around each annual median was generally similar in magnitude for all years. Comparisons between annual median CPUE and abundance estimates (Fig. 3) showed different trends in several years. The most striking difference occurred in 1982, which had a similarly large abundance estimate but a significantly smaller median catch than 1981. The smallest median CPUE and 95% confidence interval was in 1977 but the abundance estimate that year had the largest confidence interval and was similar in magnitude to that found for 1978 through 1980.

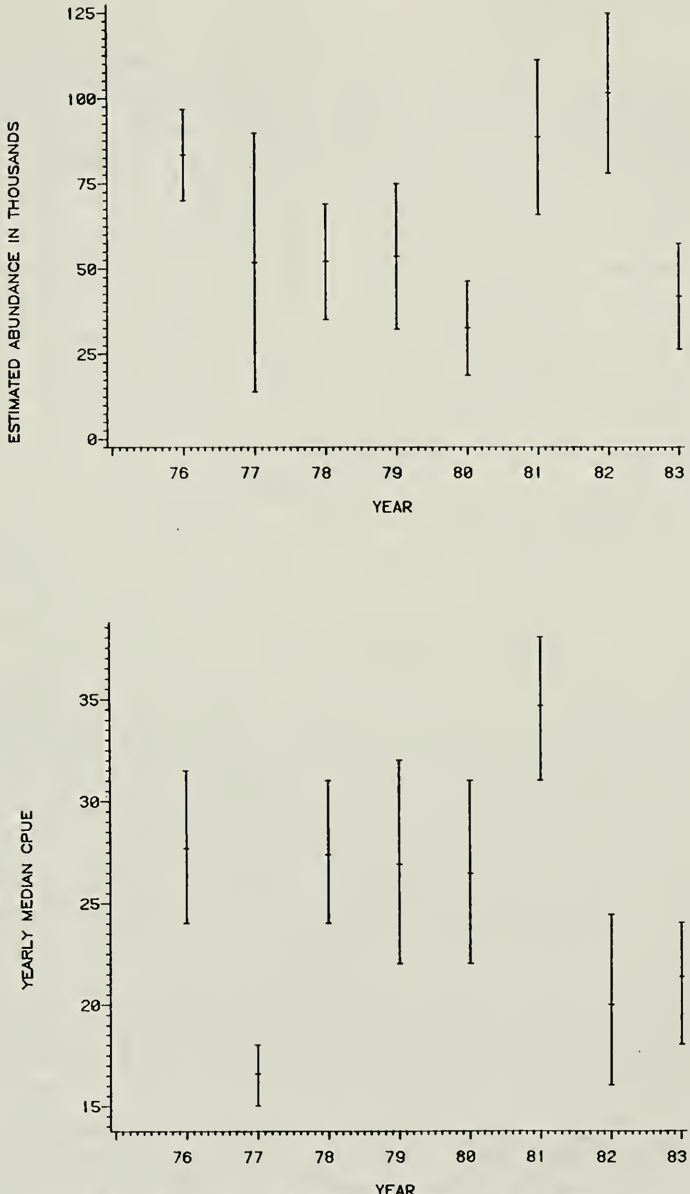


Figure 3. Population abundance estimates and median CPUE ($\pm$ 2 standard errors) for winter flounder taken during surveys in the Niantic River from 1976 through 1983.

Reproductive activity

The spawning period for winter flounder was determined by examining the weekly percentage of gravid females. When the proportion of spawning females fell below 10%, spawning was considered to have been completed (Fig. 4). This typically occurred by early to mid-April.

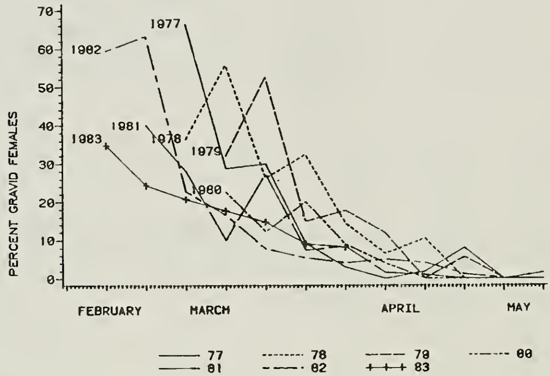


Figure 4. Percentage of female adult winter flounder in spawning condition by week in the Niantic River from 1977 through 1983.

Apparently spawning in the Niantic River begins in January or early February and in 1983 was initiated under the ice in the upper river. Usually more than 50% of the females were spent at the start of each annual survey as ice and weather conditions precluded an earlier start of the sampling. Little evidence was found that significant spawning occurred elsewhere in the study area. Examination of adults taken by the trawl monitoring program from February through April of 1983 showed that only a few (5%) of the adult females were gravid at stations outside the river but 48% were in spawning condition at station NR.

Sex ratios during the spawning period ranged from 1.21 to 2.03 in favor of females when fish larger than 20 cm were considered (Table 7).

Table 7. Female to male sex ratios of winter flounder taken during the spawning period in the Niantic River from 1977 through 1983.

	1977	1978	1979	1980	1981	1982	1983	Mean	C.V.
All fish captured	1.03	2.23	1.37	2.66	1.42	1.16	1.52	1.67	36%
Measured fish larger than 20 cm	1.26	1.95	1.21	2.03	1.61	1.50	1.52	1.58	20%

The observed ratios were similar to those reported by Saila (1962a, b) and Howe and Coates (1975). Observations of female winter flounder spawning in the Niantic River during recent years indicated that sexual maturity was achieved at about 25 cm, when the fish were from 3 to 5 years old (NUSCo 1983). This was confirmed by a probit analysis of the 1983 data, which produced a 50% sexual maturation estimate of 25.1 cm with a 95% confidence interval of 24.2 to 25.9 cm. Based on oocyte development time, the minimum age of reproduction for winter flounder was reported as 3 years (Dunn and Tyler 1969; Dunn 1970). However, maturity in many flatfishes is probably governed by size as well as age (Roff 1982). The 25-cm median size of maturity found for the Niantic River winter flounder was the same as that reported by Kennedy and Steele (1971) for a Canadian population with an average age of maturity of 7 years. Thus, the Niantic River stock probably has reached lower limits for age and size of first reproduction. Accelerated maturation, which may be found in reduced or stressed populations (Nikolsky 1963; Roff 1982), probably cannot occur any further in the Niantic River stock.

In previous years some of the information used to estimate reproduction was gathered by individuals in the field who noted spawning condition of each female; fish were recorded as ripe, spent, or non-classified. Only the proportion of females in the first two categories was used to estimate the abundance of spawners and egg production. This procedure probably caused an underestimation in the number of spawners because of individual bias and errors in observation and classification; over the years varying percentages of females of different size-classes were classified as non-spawning regardless of their length or age. For this report it was assumed that most, if not all, adult females found in the Niantic River during the spawning period reproduced there. All females larger than 25 cm were used in estimating the number of spawners and total egg production found in Table 5. This change as well as increases in estimated numbers of female spawners resulted in generally larger estimates of eggs produced from 1977 through 1982 than reported in NUSCo (1982). The largest yearly increase in number of spawning females and in egg production occurred from 1980 to 1981; however, this was partly due to improvements in survey design (NUSCo 1983). Female spawners and egg production peaked in 1982 with the 1983 and 1981 estimates comparable in magnitude.

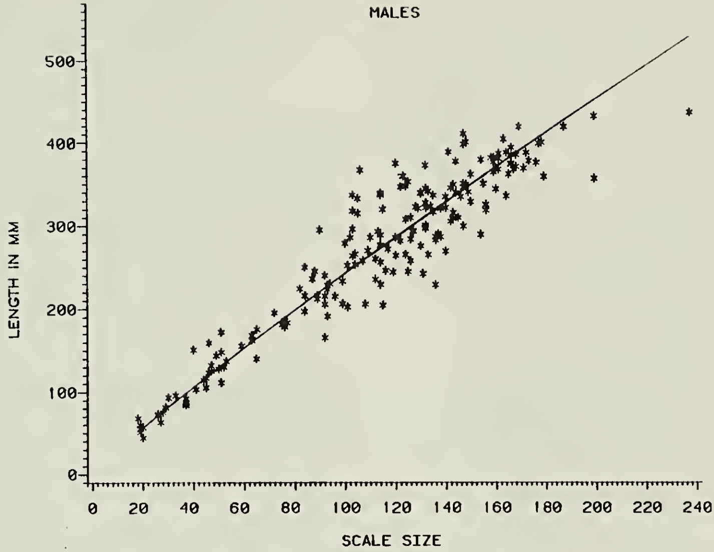
Age and growth

During 1983, the scales of 214 females and 188 males ranging from 44 to 465 mm were examined for age and measurements were made to each annulus for the purposes of calculating growth. Some curvilinearity was seen in a linear regression of scale and length, especially with larger specimens, indicating probable heterogeneous growth of the scale and fish (Fig. 5). A non-linear length-scale relationship was used in the back-calculation of length-at-age because it provided a better fit to the data. Length at each annulus was calculated by the relationship:

$$\text{length} = 3.557\ (\text{scale size})^{0.908} \text{ for females, } (n=216,\ R^2=0.93)$$

$$\text{length} = 3.777\ (\text{scale size})^{0.904} \text{ for males, } (n=193,\ R^2=0.94)$$

The mean calculated lengths-at-age (Tables 8 and 9) were larger than the observed lengths except for ages 1 and 2 where resumption of seasonal growth probably occurred before the scales were collected. The calculated growth estimates were probably less reliable for older specimens, particularly males, as calculated lengths became considerably greater than observed lengths-at-age. A reverse Lee's phenomenon was also observed where the calculated lengths of fish increased as age increased. This may have been the result of size-selective mortality that was greater on smaller fish of an age group (Tesch 1968) or due to a bias in sample selection if only faster-growing larger specimens were chosen for aging and scales from slower-growing fish were rejected as unreadable. This may also have resulted in the apparent anomalous increase in growth at age 9 in females and 8 in males. The smaller number of older specimens examined also made their mean growth estimates less reliable.



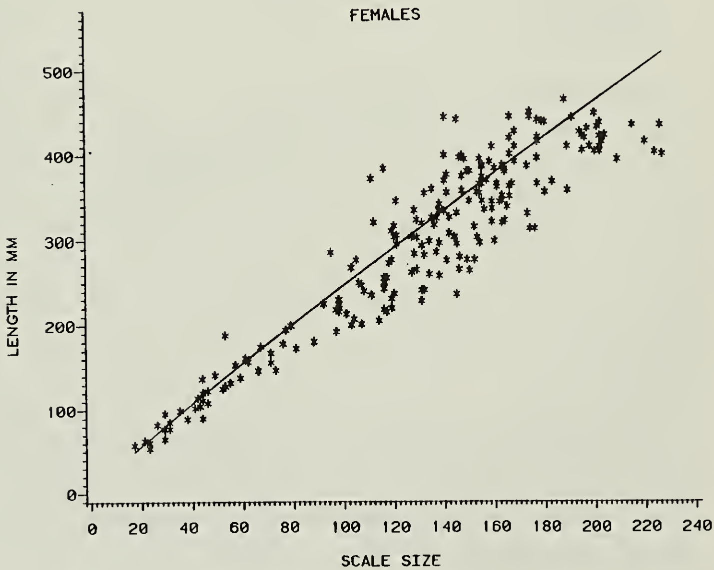


Figure 5. Functional regression of length and scale size of winter flounder taken in the Niantic River from February through April 1983.

Table 8. Average back-calculated lengths (mm) at age for female winter flounder taken in the Niantic River.

Age class	Number	Mean length at capture ± 95% CI	Mean calculated length (± 95% CI) Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
I	10	107±14	80±8								
II	26	195±13	67±9	178±16							
III	43	277±11	78±7	182±12	285±12						
IV	25	315±13	87±10	185±14	278±12	318±14					
V	23	349±10	88±9	182±16	276±18	321±18	343±18				
VI	13	366±19	75±15	163±23	269±21	309±16	331±15	345±14			
VII	27	395±10	90±7	205±13	296±14	332±16	354±17	369±18	380±18		
VIII	19	418±9	86±11	202±24	296±25	345±21	370±21	383±21	393±21	402±22	
IX	8	442±10	86±10	186±26	292±33	361±26	389±25	406±27	419±25	428±27	435±26
Mean calculated length			81±4	186±6	285±6	329±8	355±8	373±10	391±12	410±16	435±26
Average growth increment			81	105	99	44	26	18	18	19	25

Table 9. Average back-calculated lengths (mm) at age for male winter flounder taken in the Niantic River.

Age class	Number	Mean length at capture ± 95% CI	Mean calculated length (± 95% CI) Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
I	28	96±13	80±8							
II	18	177±16	70±13	166±19						
III	43	246±10	81±7	181±10	262±12					
IV	19	285±15	75±10	171±19	248±20	281±21				
V	26	327±12	92±12	181±18	259±18	301±16	322±16			
VI	20	348±12	84±9	185±17	257±18	302±17	322±17	334±18		
VII	27	370±10	81±9	189±20	260±21	300±21	320±20	337±19	349±19	
VIII	7	378±28	91±17	209±28	305±46	351±45	369±42	380±41	389±40	397±39
Mean calculated length			82±4	182±6	261±8	302±10	325±10	341±12	357±18	397±39
Average growth increment			82	100	79	41	23	16	16	40

The mean length of females was significantly greater than males for fish age 3 and older; this was also noted by a number of others (Berry et al. 1965; Poole 1966; Lux 1973; Howe and Coates 1975; Danila 1978). Largest differences between the sexes in average yearly growth increment occurred during the third year of life. Growth of the Niantic River stock was compared in Figure 7 to that of other populations in nearby areas, including Charlestown Pond (Berry et al. 1965), Peconic Bay (Poole 1966), and south of Cape Cod (Howe and Coates 1975). The Niantic River fish grew less during their first 2 years than these and other populations (Poole 1966; Kurtz 1975; Danila 1978) with the exception of the nearby Mystic River (Pearcy 1962). However, the Niantic River fish caught up to or surpassed other stocks at age 3 and older. Although the winter flounder is an omnivorous feeder (Pearcy 1962; Richards 1963), perhaps conditions in the Niantic River and Bay are not as favorable for growth of immature fish as other areas.

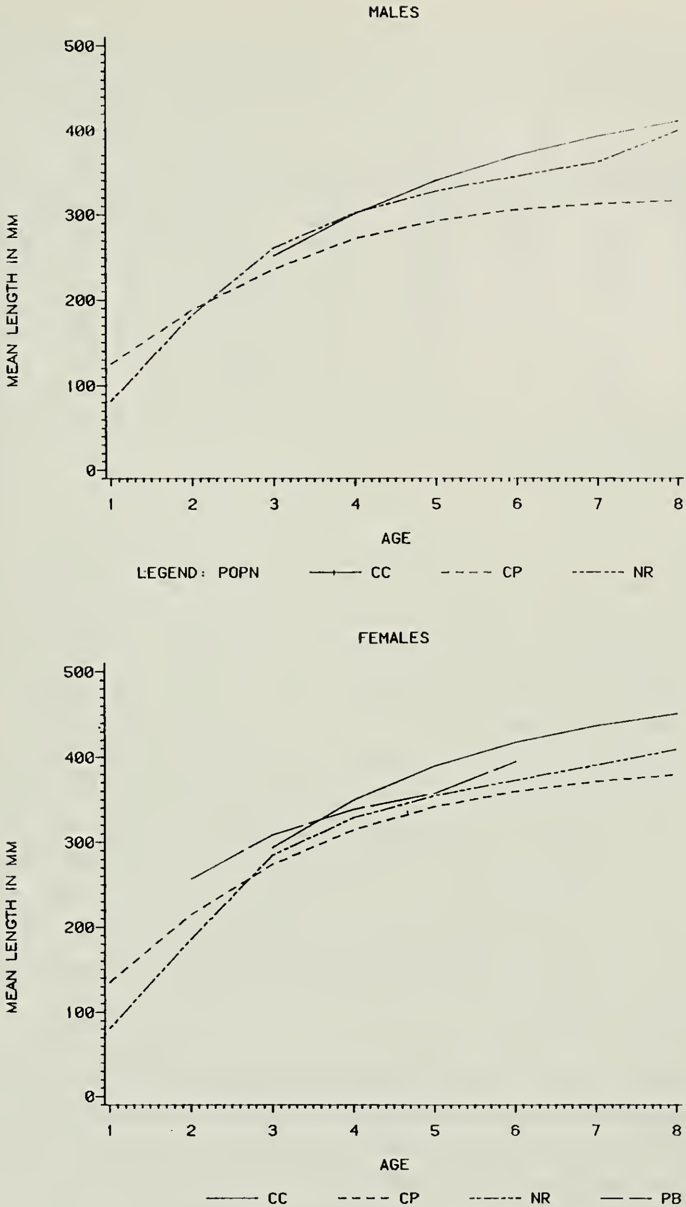


Figure 6. Calculated mean lengths of winter flounder from various locations in the northeastern United States (CC = south of Cape Cod, CP = Charlestown Pond, NR = Niantic River, PB = Peconic Bay).

Calculated lengths-at-age were used to estimate the von Bertalanffy growth parameters (Table 10; Fig. 7). The growth models for females and

Table 10. The von Bertalanffy growth parameters for Niantic River winter flounder and comparisons with other areas.

Area	No. of fish examined	K value	Asymptotic 95% CI	L_∞ (mm)	Asymptotic 95% CI	ω[a]	t_0 (year)	Asymptotic 95% CI	R^2
				Females					
Niantic River	214	0.42	0.39–0.45	423	412–433	177.7	+0.51	0.46–0.56	0.90
Charlestown Pond[b]	104	0.41	-	396	-	162.4	-	-	-
South of Cape Cod[c]	839	0.34	-	487	-	165.6	-	-	-
North of Cape Cod[c]	114	0.37	-	455	-	168.4	-	-	-
Georges Bank[c]	126	0.44	-	622	-	273.7	-	-	-
Georges Bank[d]	163	0.31	-	630	-	195.3	–0.05	-	-
				Males					
Niantic River	188	0.44	0.39–0.48	381	367–395	165.7	+0.46	0.39–0.53	0.85
Charlestown Pond[b]	49	0.54	-	323	-	174.4	-	-	-
South of Cape Cod[c]	298	0.25	-	477	-	119.3	-	-	-
Georges Bank[c]	113	0.37	-	534	-	197.6	-	-	-
Georges Bank[d]	184	0.37	-	550	-	203.5	+0.05	-	-

[a] $\omega = K \times L_\infty$ (Gallucci and Quinn 1979)

[b] Berry et al. (1965); parameter K calculated from their k ($= e^{-K}$)

[c] Howe and Coates (1975); parameter K calculated from their k

[d] Lux (1973)

males had good fits (n=917, R^2=0.90; n=764, R^2=0.85) and represented theoretical growth of the population. The ω parameter was used for statistical comparisons of growth as suggested by Gallucci and Quinn (1979). Their graphical procedure was applied to Niantic River fish and showed significant differences between the sexes (Fig. 8); it was not possible to make comparisons with other winter flounder populations because of the lack of published estimates of variability. However, the ω parameter of female Niantic River winter flounder was similar to those of other stocks or geographical groups examined with the exception of Georges Bank, which has a racially distinct population with much faster growth (Lux 1973; Howe and Coates 1975). The value for males most closely corresponded to the Charlestown Pond stock (Berry et al. 1965); greater asymptotic maximum length was achieved by winter flounder stocks in other areas to the east.

The estimates of L_∞ were actually less than the lengths of some specimens examined from the Niantic River. However, this should not be considered unusal and was also reported by Lux (1973). This could have been a result of the sample used and the addition of larger and older specimens could have altered the curve upwards. Nevertheless, since 1977 only 1% each of more than 8,330 female and 5,331 male winter flounder larger than 20 cm exceeded the calculated asymptotic maximum lengths. Thus, the parameters should be adequate for use in our winter flounder population dynamics model which is currently under development.

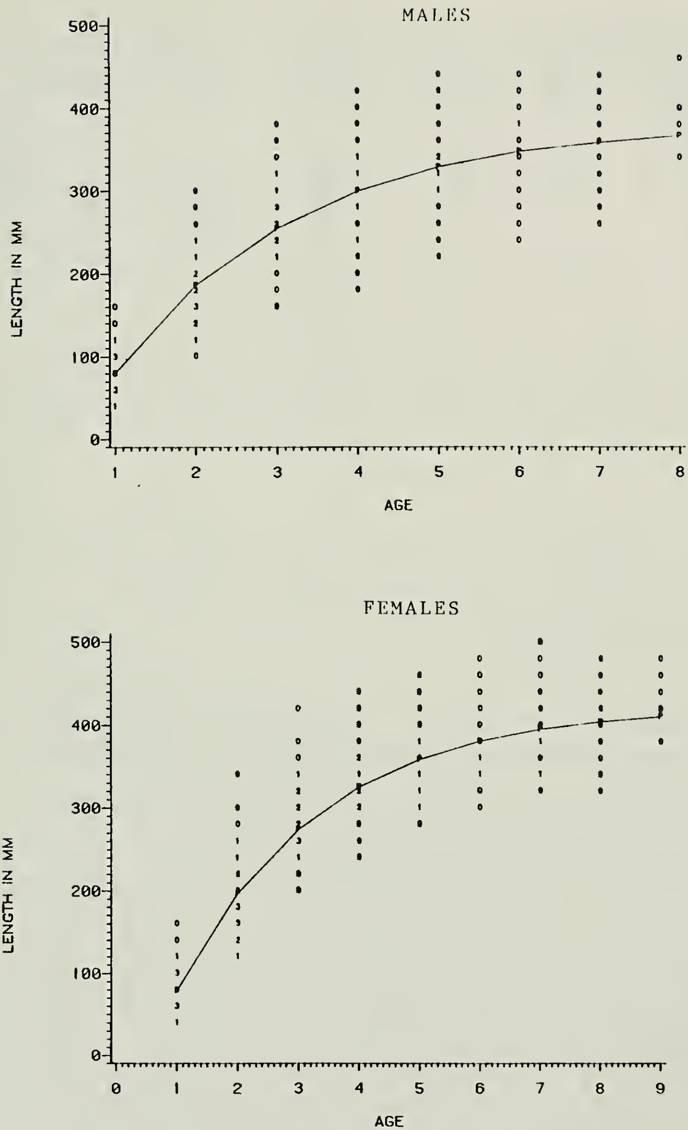


Figure 7. The von Bertalanffy growth curve for Niantic River winter flounder (P = predicted, 0 = 1-9 observations, 1 = 10=19, 2 = 20-29, 3 = 30+).

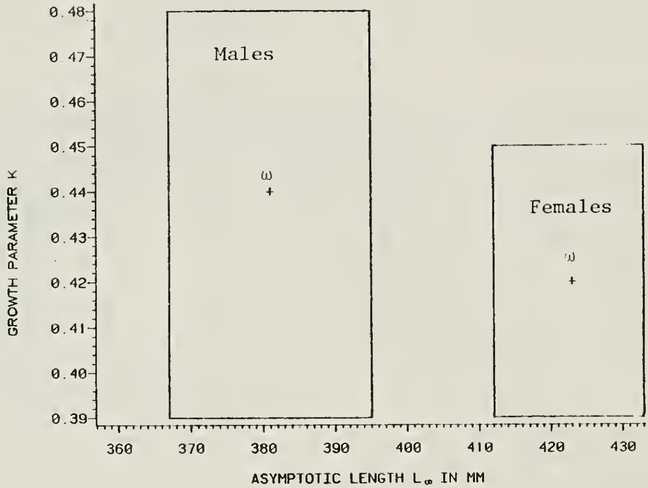


Figure 8. Calculated value of ω and rectangles showing two standard errors about each estimate of the theoretical growth parameters L∞ and K.

Mortality and survival

Survival was calculated by using a time-specific method. Because of large apparent variability in estimated abundance of individuals of specific year-classes, most likely due to changes in survey methodologies and sampling errors, the cohort-specific methods of estimating survival were considered less reliable (NUSCo 1983). Time-specific methods have advantages in that the age determinations of older fish do not have to be known with certainty, although the representativeness of the youngest age used in very important (Ricker 1975). Since immature winter flounder (mostly ages 1 and 2) were found both inside and outside the river during the survey period, their relative abundance in the population age structure was not known with certainty. Therefore, only ages 3 and older were used in the calculations. The mean annual survival estimates for the 7-year period was 0.565 (Table 11). This figure was somewhat larger than the estimates reported in NUSCo (1983), which used age 2 fish in the calculations and were not restricted to fish taken only during the

Table 11. Population age structure and estimated survival (S) of winter flounder taken during the spawning period in the Niantic River from 1977 through 1983.

1977		1978		1979		1980		1981		1982		1983		1977-83	
Age	Estimated abundance	Age	Estimated abundance	Age	Estimated abundance	Age	Estimated abundance	Age	Estimated abundance	Age	Estimated abundance	Age	Estimated abundance	Mean	C.V.
												3	13,983		
										3	12,692	4	8,379		
								3	14,835	4	11,678	5	7,029		
						3	4,652	4	8,388	5	8,911	6	3,347		
				3	4,262	4	2,095	5	10,350	6	11,277	7+	7,304		
		3	4,233	4	2,014	5	850	6	5,559	7+	6,352				
3	12,600	4	3,766	5	2,168	6	894	7+	3,168						
4	5,850	5	3,382	6	2,059	7+	901								
5	1,885	6	1,594	7+	1,313										
6	1,731	7+	1,385												
7+	430														
S	0.424		0.592		0.601		0.518		0.580		0.635		0.606	0.565	13%

spawning period. The estimate was similar to that determined by Howe and Coates (1975) for winter flounder found south of Cape Cod and was somewhat higher than those for fish from Great South Bay, New York (Poole 1969) and Rhode Island (Saila et al. 1965).

Movements

From December 1980 through September 1983, 4,978 winter flounder were tagged with Petersen discs (Table 12). Most of the fish were released in the Niantic River (46%), including nearly all fish tagged during 1983, and in Niantic Bay (31%). Rates of recapture were similar among years and ranged from 17 to 23% of those tagged. Discounting recaptures from NUSCo sampling activities, which accounted for about one-third of the total (97% of these were released alive again), the recapture rates were 13 to 15% for each year. The non-NUSCo returns were mostly from the sport (59%) and commercial (36%) fisheries. Very few (0.5%) of the tagged winter flounder were impinged on the MNPS screens and more than half of these were fish released very close to the Unit 1 intake structure. Sport fishermen took most of the tagged winter flounder removed from the Niantic River and Jordan Cove; nearly equal numbers were taken by the sport and commercial fisheries for all other stations except Bartlett Reef, where twice as many were taken by commercial fishermen.

Sport fishing catches mostly occurred during spring and summer in Niantic River and Bay and in New London County waters. The commercial fishing returns for Niantic Bay and River fish were greater in 1980 and 1981 because a trawler was then operating extensively in Niantic Bay and

Table 12. Summary of winter flounder disc tagging and recapture data from December 1980 through September 1983.

		Niantic Bay	Niantic River	Twotree	Millstone Intakes	Bartlett Reef	Jordan Cove	Miscellaneous[a]	Total
Number tagged	1980	309	410	47	0	68	10	0	844
	1981	970	108	29	198	4	0	0	1,309
	1982	280	1,015	294	61	206	131	10	1,997
	1983	0	770	0	40	12	6	0	828
	Total	1,559	2,303	370	299	290	147	10	4,978
Number recaptured[b]	1980	73	88	15	0	8	0	0	184
	1981	177	22	3	27	0	0	0	229
	1982	46	306	43	8	18	37	2	460
	1983	0	162	0	4	0	1	0	167
	Total	296	578	61	39	26	38	2	1,040
Method recaptured									
Sport fishing	1980	31	28	7	0	1	0	0	67
	1981	63	8	0	8	0	0	0	79
	1982	25	132	18	4	7	23	1	210
	1983	0	53	0	0	0	0	0	53
	Total	119	221	25	12	8	23	1	409
Commercial fishing	1980	21	20	7	0	7	0	0	55
	1981	90	9	3	2	0	0	0	104
	1982	12	36	15	1	9	6	1	80
	1983	0	13	0	0	0	0	0	13
	Total	123	78	25	3	16	6	1	252
NUSCo sampling	1980	18	38	1	0	0	0	0	57
	1981	21	5	0	7	0	0	0	33
	1982	9	134	7	0	0	7	0	157
	1983	0	93	0	2	0	1	0	96
	Total	48	270	8	9	0	8	0	343
Impingement	1980	1	2	0	0	0	0	0	3
	1981	0	0	0	10	0	0	0	10
	1982	0	3	0	3	1	1	0	8
	1983	0	3	0	2	0	0	0	5
	Total	1	8	0	15	1	1	0	26
Miscellaneous[c]	1980	2	0	0	0	0	0	0	2
	1981	3	0	0	0	0	0	0	3
	1982	0	1	3	0	1	0	0	5
	1983	0	0	0	0	0	0	0	0
	Total	5	1	3	0	1	0	0	10

[a] Includes various locations along shoreline west of Black Point to the Connecticut River.

[b] Year here and following refers to year in which fish were tagged. Number recaptured includes 341 released alive (mostly by NUSCo), 66 of which were caught again.

[c] Includes recaptures from the CT DEP, Project Oceanology, and unknown sources.

adjacent waters; local commercial fishing effort declined greatly in 1982 and 1983. Most other commercial catches were made during summer in deeper waters of Long Island and Fishers Island Sounds and locations off Rhode Island and Massachusetts where many winter flounder were concentrated and unavailable to the sport fishery.

Not unexpectedly, most (70%) of the recaptures were made in local waters. Of the remainder, more than three times as many returns were received from locations to the east than to the west of Millstone (Table 13). A number of winter flounder released in Niantic Bay and River interchanged locations, showing the movement of fish between these areas. However, relatively few fish from other tagging locations entered the river. Few Bartlett Reef fish were caught locally; about half were taken by fishermen to the east. Specimens released near the MNPS intakes and in Jordan Cove tended to remain near Millstone. Most fish released at the intakes were impinged at MNPS or caught in Niantic

Table 13. Location of recaptures of disc-tagged winter flounder from December 1980 through September 1983.

Recapture location	Tagging location: Niantic Bay	Niantic River	Twotree	Millstone Intakes	Bartlett Reef	Jordan Cove	Miscellaneous	Total
Local								
Niantic Bay	99	47	20	15	3	3	-	187
Niantic River	34	397	4	3	-	2	-	440
Twotree	1	-	9	2	-	-	-	12
Millstone Intakes	1	8	-	15	1	1	-	26
Bartlett Reef	7	4	-	1	1	-	-	13
Jordan Cove	5	13	-	-	-	21	-	39
East								
New London Co., CT	42	27	14	2	8	8	1	102
Suffolk Co., NY	5	12	3	-	2	-	-	22
Washington Co., RI	25	23	7	1	1	-	-	57
Newport Co., RI	10	9	-	-	1	-	-	20
Barnstable Co., MA	1	1	-	-	1	-	-	3
Dukes Co., MA	3	2	1	-	-	-	1	7
Nantucket Co., MA	3	6	1	-	1	-	-	11
West								
New London Co., CT	10	5	1	1	1	1	-	19
Middlesex Co., CT	4	10	1	2	-	-	-	17
Suffolk Co., NY	9	4	1	-	2	-	-	16
New Haven, Co., CT	7	2	8	-	3	-	-	20
Fairfield Co., NY	2	1	-	-	-	1	-	4
Bronx Co., NY	-	-	-	-	1	-	-	1
Unknown								
Connecticut	1	-	-	-	-	-	-	1
New York	1	-	-	-	-	-	-	1
Rhode Island	4	4	-	-	1	-	-	9
Massachusetts	5	6	-	-	-	1	-	12
Virginia	-	1	-	-	-	-	-	1
Total	279	582	20	42	22	38	2	1,040

Bay. Most Jordan Cove fish were taken within the cove and in adjacent New London County waters; only one return was received further to the east.

Some 61% of all tagged fish were females, 20% males, and 10% fish of unknown sex. Of the recaptured fish, 68% were females, 27% males, and 5% unknown. Recapture rates were 23% for females, 20% for males and 9% for fish of unknown sex; significantly fewer fish of unknown sex were recaptured. More males tended to remain near Millstone than females. Over three-quarters of the males were caught in local waters (about half of these in the Niantic River) as opposed to about two-thirds of the females. Males made up 30% of the local catch but only 17% of the catch from the east, whereas females made up about 65% and 76%, respectively.

Two special studies were initiated in 1982 which involved the simultaneous tagging and branding of winter flounder (NUSCo 1983). The first study included fish larger than 23 cm that were both disc-tagged and branded. The second had 50% of them branded and tagged and 50% just branded. Recaptures were made of some of these fish as well as the group both tagged and branded during 1983. Twenty-two of the fish from the first experiment were recaptured and had both brands and tags. Five additional fish had a brand similar to that used but no tag. However, two of these may have been under 23 cm in 1982 and although branded would not have been tagged then and another one was probably branded in 1980; only two fish definitely had scars that indicated a tag loss. Twenty-two fish from the second experiment were also recaptured; 12 had tags (2 lost brands) and 10 had just brands, a ratio similar to the one in the original marking experiment. Combining data, the best estimate of disc-tag loss was about 6% after 1 year. Two of the 91 fish branded and tagged during 1983 had lost tags; the 2% rate of immediate tag loss was similar to that reported in NUSCo (1983).

Early life history studies

Larval stage

Abundance and distribution

A successive pattern of winter flounder larval abundance was found in Niantic River and Bay in 1983 (Fig. 9). Larval densities reached peak abundance in the mid and upper portion of the river during the first 2 weeks of March at stations A (> 300/500 m^3) and B (> 600/500 m^3). Peak abundance at station C (> 600/500 m^3) occurred later during the last half of April and the first part of May. Coincident with high abundance at station C, a second peak was noted at B (> 400/500 m^3) and maximum abundance occurred in Niantic Bay at stations NB (> 600/500 m^3) and EN (> 500/500 m^3). A decline in larval abundance began at station A in late March, followed by station B during late April. Stations C, NB, and EN showed a similar decline from May through June. The successive temporal pattern in peak abundance was followed by a decline from the upper to the lower river; Niantic Bay was similar to the lower river. In the Mystic River, Pearcy (1962) found approximately the same upper to lower river pattern, which was attributed to seaward flushing.

Weekly fluctuations in larval densities have usually been attributed to sampling variability or error. These short-term fluctuations were evident in the winter flounder larval densities found in the Niantic River and Bay (Fig. 9). An almost identical pattern of change in weekly densities was found at B, C, and NB beginning in the first week of

April. In addition, a decrease in larval densities occurred during the week of May 22 at B, C, NB, and EN. The consistent fluctuations

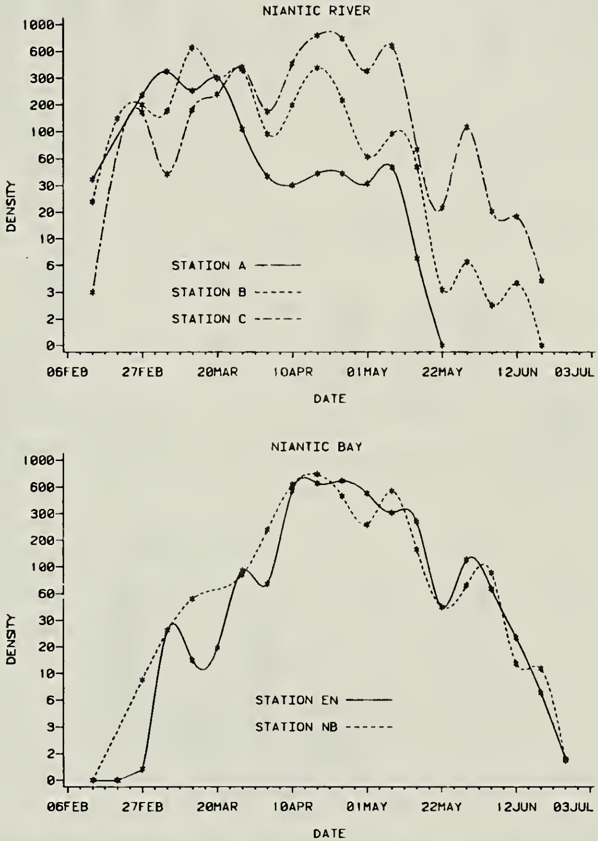


Figure 9. Weekly mean density per 500 m^3 of larval winter flounder during 1983.

suggested that sampling error was not the primary source of short-term variability, but most likely changes in environmental factors affected collection densities.

Spatial differences were found in the frequency of different developmental stages (Fig. 10). Almost all Stage 1 larvae were

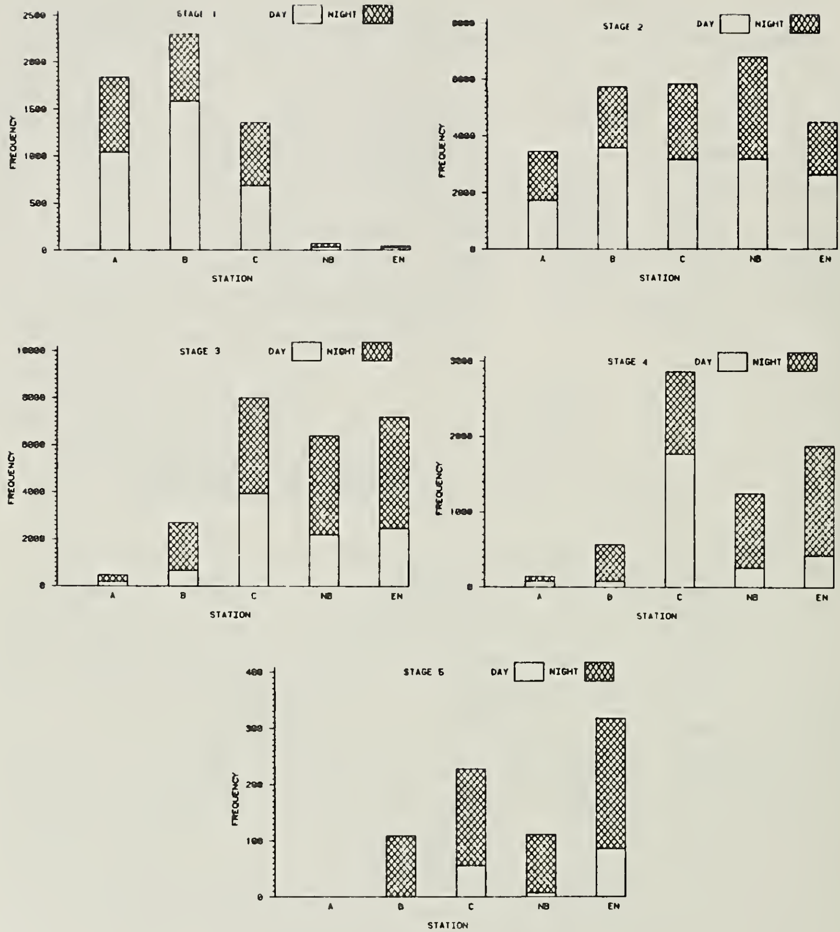


Figure 10. Frequency distribution by developmental stage for larval winter flounder collected in day and night samples at each station during 1983.

collected in the Niantic river, mostly in the mid and upper portion at stations A and B. Laboratory studies (Dr. G. Klein-MacPhee, USEPA-URI, Narragansett, RI, personal communication) have shown an approximate 50% mortality during the transition from yolk-sac absorption to first feeding, so the much lower frequency of Stage 1 larvae compared to Stage

2 indicated that the younger larvae were greatly undersampled. Stage 2 larvae were more evenly dispersed throughout Niantic River and Bay. The frequency of Stage 3 larvae, low in the mid and upper river, was high at station C and at NB and EN in Niantic Bay. Stage 4 frequency was highest at C and in Niantic Bay with EN having a greater frequency than NB. At all stations an approximate six to ten-fold reduction in frequency occurred from Stages 4 to 5; most were collected at EN. This reduction was expected due to the predominantly benthic habits of the later developmental stages. The spatial distribution of developmental stages agreed with patterns of larval abundance noted above, with early stages found in the mid and upper river and later stages concentrated in the lower river and Niantic Bay.

Larval frequencies in day and night collections were examined by developmental stage and station (Fig. 10). No apparent differences were found for Stages 1 and 2. For Stages 3 and 4, frequencies were higher during the night than the day at stations B, NB, and EN, but not at C. Frequencies of Stage 5 larvae were higher during night at all stations. Previously, this diel difference in larval abundance had been attributed to vertical movement of larvae from on or near bottom into the water column at night (NUSCo 1983). The lack of diel vertical movement of Stage 3 and 4 larvae at station C suggested that other factors in the lower river must have affected their behavior.

A comparison of the temporal distribution of developmental stages in the Niantic River and Bay was made by examining the cumulative percentage of each stage over time (Fig. 11). Stage 1 larvae in the Niantic River were collected in fairly consistent densities throughout March, as indicated by the linearity of the cumulative percent curve, and then declined at the end of the month. Data for this stage was not plotted for Niantic Bay because so few were collected. In the Niantic River, most of the Stage 2 larvae were collected from March to mid-April. In Niantic Bay, Stage 2 larvae were abundant from April through May. Stage 3 larvae were abundant in the river and bay from mid-April to mid-May. Stage 4 larvae increased in abundance during the last week of April at both locations and declined in the river during mid-May and in the bay during late May. The cumulative percent curve of Stage 5 larvae was more erratic, probably due to low collection

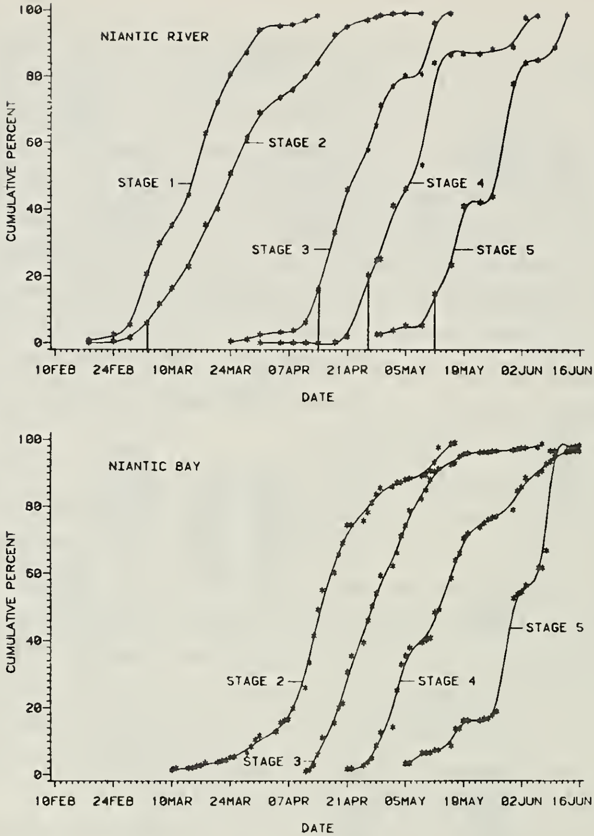


Figure 11. Cumulative percent of larval winter flounder for each developmental stage in the Niantic River (stations A, B, and C) and Niantic Bay (stations NB and EN) during 1983.

densities. Over 65% of the Stage 5 larvae were collected in the river on 4 sampling dates and over 78% of the Stage 5 larvae in the bay were taken on 2 dates. In Niantic River and Bay, Stage 5 larvae were abundant in the second half of May through early June. A comparison of Niantic River and Bay showed that Stage 2 larvae were abundant in the bay approximately 30 days later than in river. This 30-day lag agreed with Moore and Marshall (1967) who calculated that approximately 25 days were required for water entering the Niantic River from a tributary to reach Niantic Bay. The seaward flushing during Stage 2 development appeared to be the primary dispersal mechanism into Niantic Bay. The temporal occurrence of Stage 3, 4, and 5 larvae was similar in both locations, except that Stage 5 larvae were abundant approximately 2 weeks longer in the bay.

Growth

The length of time for a winter flounder larvae to pass through a particular developmental stage was estimated by determining the number of days between the first increase in abundance for successive developmental stages, as if following a cohort. In the Niantic River, the sampling dates for first rapid increases in abundance were March 4 for Stage 2, April 14 for Stage 3, April 26 for Stage 4, and May 12 for Stage 5 (Fig. 11). The number of days between these dates was an estimate of developmental time and totaled 41 days for Stage 2, 12 days for Stage 3, and 16 days for Stage 4. Stage 1 developmental time was not estimated from the field collection data because of the obvious undersampling of these larvae. Based on laboratory rearing of yolk-sac larvae (Buckley 1982), the yolk-sac stage ranged from 9 to 13 days at temperatures of 5 and 2 C, respectively. Water temperatures in the Niantic River during the last 2 weeks of February ranged from 2 to 4 C and the estimated yolk-sac stage developmental time was about 11 days. The estimated total larval development time in 1983 from hatching to transformation into a juvenile was approximately 80 days.

Examination of the length-frequency distributions within developmental stages by 0.5-mm size-classes showed a distinct progression in successive stages (Fig. 12). The predominant size-classes were 2.5 to 3.0 mm (89% of the total) for Stage 1, 3.0 to 5.0 mm (85%) for Stage 2, 5.0 to 7.5 mm (90%) for Stage 3, 6.5 to 8.5 mm (88%) for Stage 4, and 6.5 to 8.5 mm (89%) for Stage 5. The predominant size-classes for each developmental stage were clearly separated for Stages 1 though 3, but overlapped for Stages 4 and 5. Apparently, growth during Stages 4 and 5 occurred mostly in body depth with little increase in length. Laroche (1981) reported that for winter flounder

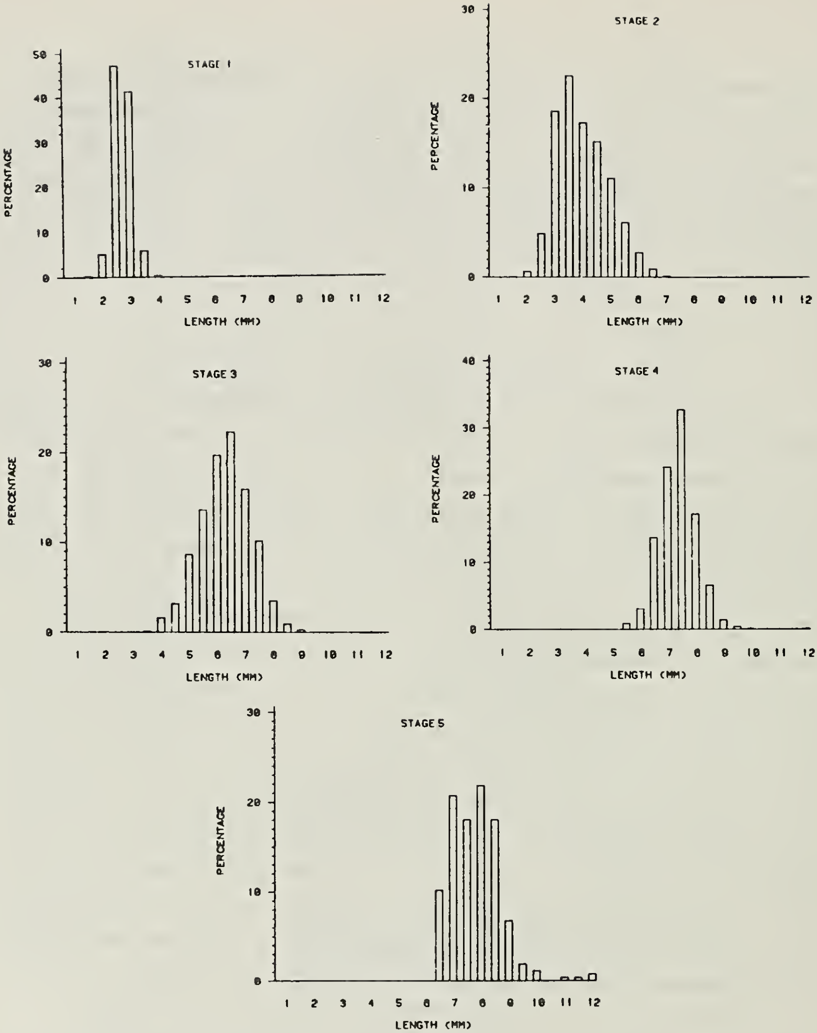


Figure 12. Length-frequency distribution of larval winter flounder in 0.5-mm size classes for all stations combined during 1983.

the percentage of body depth at the pectoral fin base to standard length increase from 9% for yolk-sac larvae to 31% for transformed larvae. Few individuals larger than 8.5 mm were collected, which indicated that at this size winter flounder change from a pelagic to a benthic habitat and thus were not susceptible to the plankton sampling gear.

The mean length at each station for different developmental stages provided additional insight into larval dispersion (Table 14). Although

Table 14. Mean length by stage of all measured larval winter flounder taken at stations in the Niantic River and Bay and at MNPS.

Developmental stage	Station	Number measured	Mean length (mm)	Standard error
1	A	239	2.7	0.02
	B	217	2.8	0.02
	C	171	2.7	0.02
	EN	29	2.9	0.10
	NB	11	3.1	0.10
2	A	480	3.4	0.03
	B	658	3.7	0.03
	C	655	3.8	0.03
	EN	974	4.3	0.03
	NB	780	4.3	0.03
3	A	64	6.5	0.11
	B	342	6.4	0.05
	C	646	6.4	0.04
	EN	1,333	6.1	0.02
	NB	605	6.4	0.03
4	A	14	6.6	0.20
	B	137	7.2	0.05
	C	255	7.4	0.03
	EN	599	7.3	0.03
	NB	210	7.6	0.05
5	A	0	-	-
	B	27	7.7	0.13
	C	67	7.8	0.10
	EN	149	7.8	0.07
	NB	23	8.7	0.57

Stage 2 larvae were fairly evenly distributed in Niantic River and Bay (Fig. 10), the lag in temporal occurrence in Niantic Bay (Fig. 11) was reflected in the larger mean lengths at station NB and EN. For Stages 3 to 5, the mean length was similar at all stations except NB, which had a larger mean length for Stages 4 and 5. Based on these data, it appeared that most of the dispersion from the Niantic River to Niantic Bay occurred during the Stage 2 developmental period.

Special studies

Primarily Stage 3 (62% of total) and 4 (30%) winter flounder larvae were collected during the two 24-h studies at station C. No apparent day-night relationship was found (Fig. 13). However, the bimodal cycle over the 24-h period suggested a tidal influence. The tidal period observed during both studies was 12 h. A harmonic regression as described by Lorda (1983) using terms of sin(hours) and cos(hours) over a 12-h period with slack ebb occurring at hours 0 and 12 and slack high at hour 6 was fit to log-transformed ($n/500\ m^2 + 1$) data (Fig. 14). The harmonic regression accounted for about 45% of the total corrected sums of squares (TCSS) with the two sampling dates combined. Based on this model, collection densities increased on a flood tide with a peak prior to slack high and then declined during ebb tide. Analyses of covariance, with tidal effect as described by the sine-cosine function as the covariate, was used to examine sampling data and day-night effects (Table 15). An interaction term for sampling date by day-night effect accounted for less than 1% of the TCSS and was pooled with the error. The two sampling dates were significantly different and accounted for an additional 19% of the TCSS. In agreement with the 24-h plot (Fig. 13), the day-night effect was not significant. Weinstein et al. (1980) reported that three post-larval fish taxa (spot, Atlantic croaker, and Paralichtys spp. flounders) used vertical migration in response to tides as a retention mechanism in the Cape Fear River estuary. The day and night differences in frequency of Stages 3 and 4 larvae at stations B, NB, and EN (Fig. 10) showed that winter flounder larvae of these developmental stages were capable of vertical movements. At station C the lack of diel differences for Stages 3 and 4 larvae suggested a modification of behavior in response to tidal currents. The vertical movement from the bottom during during a flood tide would act as a retention mechanism in the Niantic River.

Table 15. Summary of analysis of covariance for 24-h diel study with harmonic components of the tidal effect used as covariates.

Sources	Sum of squares	% of total	
Tidal[a]	25.003	44.6	*[b]
Sampling date	10.882	19.4	*
Diel	1.986	3.5	ns
Model	37.871	65.5	
Corrected Total	56.087	-	

[a] - Includes both sine and cosine components

[b] * - significant at $p \leq 0.05$
ns - not significant

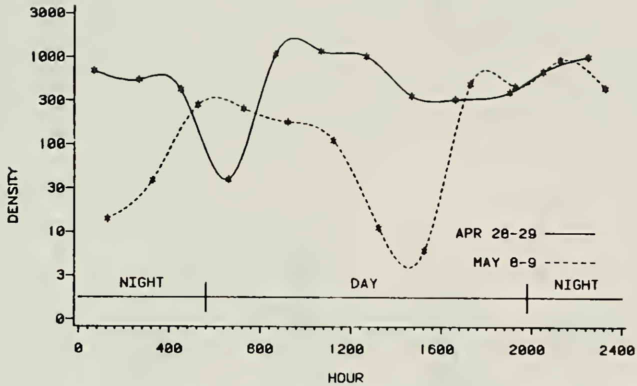


Figure 13. Larval winter flounder density per 500 m^3 during the two 24-hr tidal studies at station C.

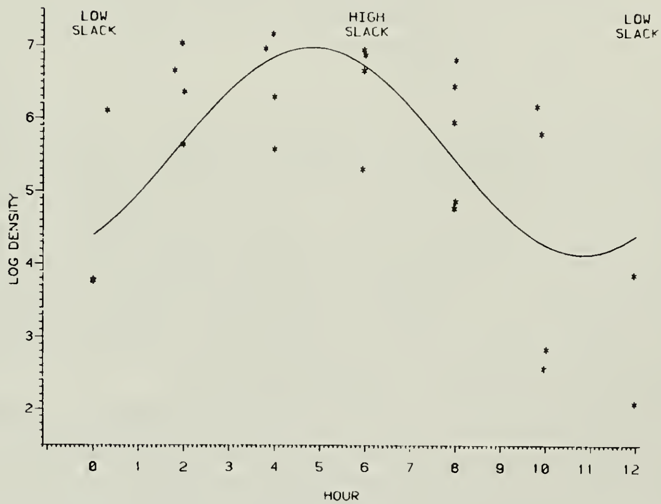


Figure 14. Larval winter flounder abundance (log density per 500 m^3) for the two tidal studies conducted at station C with the line fitted from the haromic regression (log density = 5.555 - 1.158 cos(hr) + 0.832 sin (hr)).

The potential export or import of winter flounder larvae from the Niantic River was investigated by sampling three ebb and three flood tides at the river mouth. Most of the larvae collected during this study were Stages 3 (45%) and 4 (48%). Many more larvae were collected during flood tide (Fig. 15). No consistent difference in collection

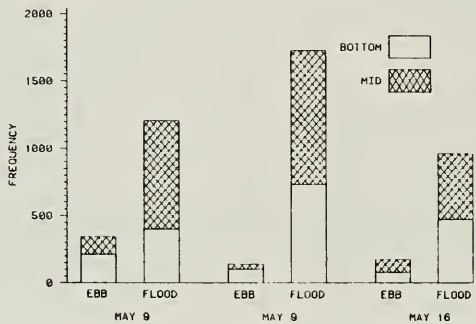


Figure 15. Frequency and collection times of larval winter flounder taken at the mouth of the Niantic River during maximum ebb and flood tidal currents.

frequency was found between mid and bottom depths. During the period of sampling, there was a net increase in the number of winter flounder larvae entering the Niantic River. The larval dispersion model for the Niantic River (Saila 1976), which assumed larvae behaved as passive particles, simulated an approximate 4% loss from the river per tidal cycle. Stage 3 and 4 larvae, which have developing or developed fins, may have used vertical movements in response to tidal currents for transport into the Niantic River from the bay.

The abundance of lion's mane jellyfish (Cyanea sp.) medusae in the Niantic River samples was measured volumetrically (Fig. 16). Volumes of medusae increased at station A during late March and at station B during early May. Marshall and Hicks (1962) also found that medusae were more abundant in the upper river compared to the lower portion during May and June. A peak occurred at stations A and B during mid-May. At station C, jellyfish were most abundant in the last week of May. Although no

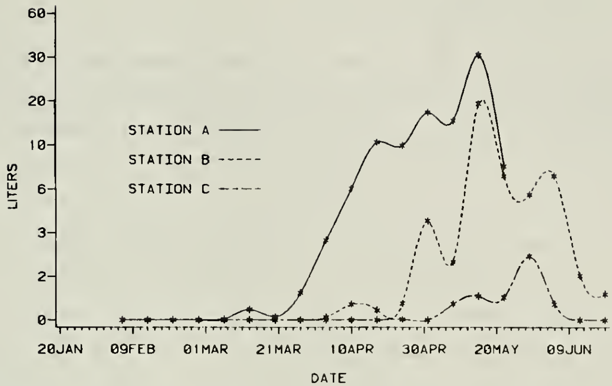


Figure 16. Weekly mean volume (liters per 500 m^3) of lion's mane jellyfish collected in the Niantic River during 1983.

causal predator-prey relationship was established, the increase in medusae at stations A and B was coincident with a decline in larvae at these stations (Fig. 9). Arai and Hay (1982) reported that several species of hydromedusae were present and preyed upon Pacific herring larvae when the latter were most abundant. Pearcy (1962) stated that Sarsia tubulosa medusae were important predators of winter flounder larvae in the Mystic River and had greatest impact on the less motile younger individuals. Over 40% of the Cyanea sp. medusae from the Niantic River examined during a 1982 study (Dr. R. Brewer, Trinity College, Hartford, CT, personal communication) contained unidentified fish larvae in their gastrovascular cavity during mid-April, a time when winter flounder larvae were abundant. If medusae were a significant predator on larval winter flounder, the successive temporal decline in larval abundance from the upper to the lower river could have been partly due to predation. Since the larval dispersion model (Saila 1976) showed the retention of many larvae in the upper arm of the Niantic River, a potentially high predation by medusae may have occurred which was not accounted for in the model.

Post-larval stage

Abundance and distribution

The abundance and distribution of post-larval juvenile winter flounder were examined at four stations in the Niantic River. By design, nets of four increasing mesh sizes and four increasing tow lengths were used with the 1-m beam trawl in order to maximize efficiency in catching juveniles as they grew in length and declined in number. One factor which may have influenced catches was the lack of a tickler chain used with the smallest (0.8-mm) mesh. Catches with this net declined from mid-May through the end of June when it was replaced by the 1.6-mm mesh net and a tickler chain was added to the beam trawl. Following these changes an immediate four to five-fold increase in catch occurred at the LR and CO stations. Even as catches declined throughout the summer they remained higher than those in June. This indicated that the number of juveniles was probably underestimated early in the season, perhaps due to lesser catch efficiency of the first net used.

Juvenile winter flounder were most abundant at LR (Fig. 17).

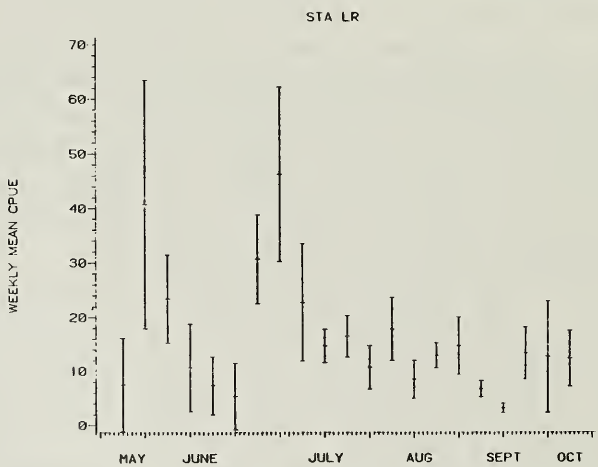


Figure 17. Weekly mean CPUE ($\pm$ 2 standard errors) for juvenile winter flounder taken at station LR in the Niantic River during 1983.

Excluding the first 6 weeks, catches were largest from early to mid-July (31-46/100 m^2) followed by a decline and densities that fluctuated around 10/100 m^2 until sampling terminated in early October. Catches at CO were more variable and showed several peaks until leveling off at about 8/100 m^2 in late August (Fig. 18). Sampling at CO was hampered on

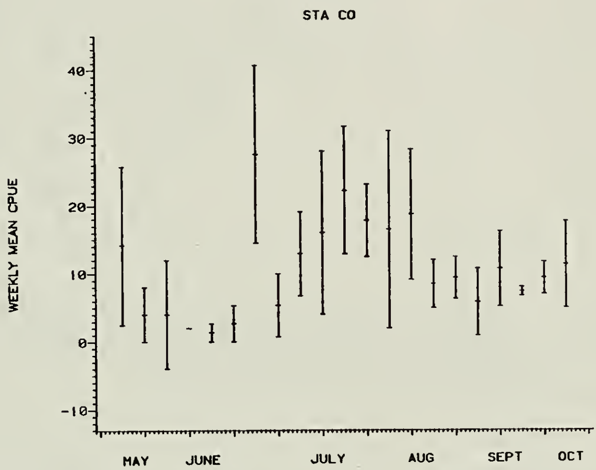


Figure 18. Weekly mean CPUE (± 2 standard errors) for juvenile winter flounder taken at station CO in the Niantic River during 1983.

several occasions by dense mats of algae (Enteromorpha clathrata) which built up on the tickler chain and trawl frame and partially clogged the net. Densities at CH were even more erratic and after fluctuating between 5 and 10/100 m^2 from early July through mid-August, they declined to about 3-4/100 m^2 until completion of sampling (Fig. 19). Catches at SP were not plotted as only a few winter flounder were caught there before August and densities remained low thereafter (maximum of 4/100 m^2 on August 21). These densities were considerably less than those reported for the Mystic River (Pearcy 1962), but perhaps differences were due to variable carrying capacities of the two estuaries as well as in the year-class strength of winter flounder for the years examined.

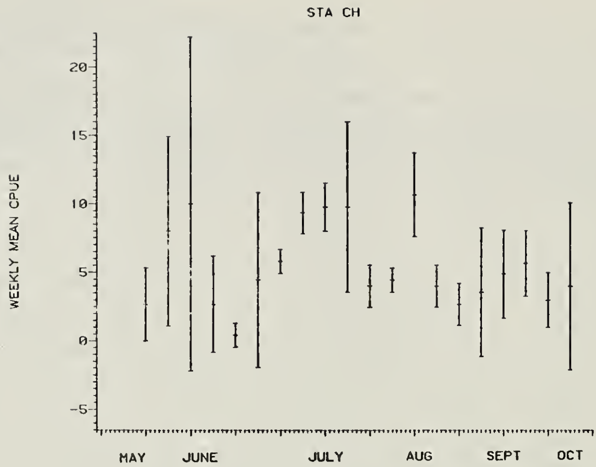


Figure 19. Weekly mean CPUE (± 2 standard errors) for juvenile winter flounder taken at station CH in the Niantic River during 1983.

Growth

Standard lengths of many juveniles taken early in the study were converted to total lengths by the relationship:

$$SL = 0.007 + 1.206(TL) \quad (n=305,\ R^2=0.99)$$

Growth of juveniles was examined by observing changes in weekly mean length at the lower river station (Fig. 20). Weekly mean lengths at LR increased fairly rapidly until early August when growth slowed and in September when no further increases were seen. Relatively little variability was seen in the length distributions. Although two to three modes were usually observed in weekly length-frequency distributions, the modes were close together and lengths were clustered about them.

Length data at CO were more variable than at LR. Probably two or three cohorts were also present at CO with greater spread about the modes. The smallest group contained most of the specimens and was joined by one

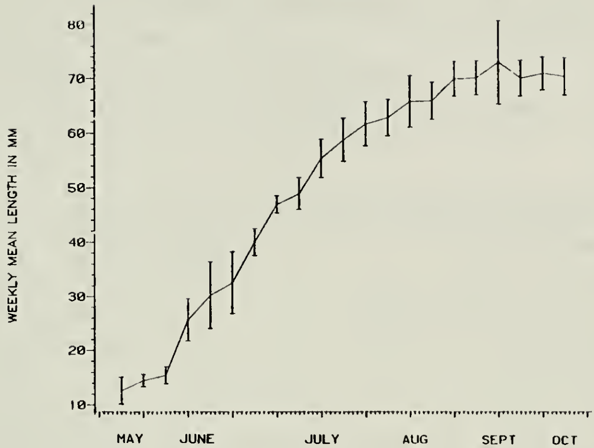


Figure 20. Weekly mean length (± 2 standard errors) of juvenile winter flounder taken at station LR in the Niantic River during 1983.

or two groups of a few larger individuals each week. Juveniles were significantly smaller at CO than those at LR because little or no overlap occurred in the error bars around the weekly mean lengths. By August the smallest individuals at LR were larger than 50 mm whereas specimens of 30 to 40 mm were still being taken at CO.

Weekly mean lengths at CH were generally similar to or somewhat less than those at LR; smaller sample sizes resulted in greater observed variability. The few juveniles taken at SP included some of the largest specimens taken during the sampling (up to 104.5 mm). This was similar to Pearcy (1962) who also found largest juveniles farthest upriver.

Since a plot of the mean weekly lengths of juveniles at LR appeared to follow a classic form of a growth curve, the von Bertalanffy growth model was fit to the data (Table 16). A good fit was obtained (n=716; R^2=0.80) and the L_∞ (coincidentally, the same as the calculated lengths for age 1) and K parameters were used with length frequencies to calculate the instantaneous mortality coefficient (Z) according to the method of Jones (1981). A daily total mortality rate of 2.97% was derived from these calculations. This value, equivalent to an average

Table 16. Growth and mortality calculations for juvenile winter flounder taken at station LR in the Niantic River during 1983.

Growth

Parameter	Value	Asymtotic 95% CI
L_∞	82 mm	78–86 mm
K	0.11 (weekly units)	0.10–0.12
t_0	0.47	0.15–0.80

Mortality

Slope of ln(number of fish >specific length interval) vs $\ln(L_\infty - \text{specific length}) = 1.9124$

K = –.11065

Slope = Z/K so Z = 0.21157

Annual survival = $e^{(-Z)(52)} = 0.0000167$

Daily survival = $e^{(-Z/7)} = 0.97023$

Daily mortality = 2.97%

monthly survival of 40.3%, and lower than the monthly survival of 69% reported by Pearcy (1962). Our estimate may have included a component of emigration if off-station movement of large individuals occurred.

Impingement

The estimated impingement of winter flounder at MNPS during 1982-83 (10,769) was the second highest annual total for the 11-year period examined (Table 17). However, this large number of impinged winter

Table 17. Estimated total number of winter flounder impinged on the intake screens of Millstone Nuclear Power Station Units 1 and 2 by month and year from October 1972 through September 1983.

	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sep	Total	% by year	% of all fish
1972-73	249	37	119	1,200	1,530	1,674	818	276	90	36	71	63	6,163	6.8	37.9
1973-74	93	96	273	883	859	921	326	199	39	85	23	16	3,813	4.2	28.9
1974-75	20	223	141	667	477	522	150	149	55	55	23	107	2,589	2.9	27.0
1975-76	38	106	613	686	733	990	366	283	115	73	22	12	4,037	4.5	15.6
1976-77	25	47	2,316	752	1,127	2,978	1,484	615	144	39	61	42	9,630	10.6	32.4
1977-78	42	100	231	2,973	783	228	615	497	561	48	37	67	6,182	6.8	16.9
1978-79	78	283	1,351	3,866	9,754	3,814	2,427	398	984	509	306	308	24,078	26.6	32.9
1979-80	162	146	391	476	834	1,679	1,368	839	145	105	213	62	6,420	7.1	20.4
1980-81	81	65	862	593	2,395	1,377	743	354	263	207	89	82	7,091	7.8	12.5
1981-82	99	166	1,228	3,626	1,313	1,286	805	244	459	256	143	126	9,751	10.8	15.7
1982-83	43	95	448	3,834	1,558	2,108	778	586	598	242	189	289	10,769	11.9	7.4
Total	910	1,364	7,973	19,556	21,363	17,577	9,880	4,440	3,453	1,655	1,177	1,174	90,523	100.0	18.1
% by month	1.0	1.5	8.8	21.6	23.6	19.4	10.9	4.9	3.8	1.8	1.3	1.3	100.0	-	-
% of all fish	7.8	7.9	9.9	26.6	49.7	37.8	15.6	9.4	4.8	8.5	6.7	9.3	18.1	-	-

flounder contributed the least to the overall percent composition of impinged fish because a very large number of bay anchovy was taken during the summer of 1983. In general, the monthly pattern of impingement was similar to the other years.

The length-frequency distribution of impinged winter flounder has varied to some extent over the past 7 years (Table 18). The greatest

Table 18. Annual mean length and percent length-frequency distribution by 5-cm size intervals of winter flounder impinged at MNPS Units 1 and 2 from October 1976 through September 1983.

Year	Number	Mean length (cm)	CV	% length-frequency <10	10-14	15-19	20-24	25-29	> 29
1976-77	5,247	19.7	45%	22	16	15	17	17	13
1977-78	2,670	16.9	43%	22	21	29	16	8	4
1978-79	5,040	16.2	51%	31	25	14	14	11	5
1979-80	2,935	22.3	36%	5	21	19	16	21	18
1980-81	2,197	20.0	45%	19	19	14	16	17	15
1981-82	2,945	20.0	42%	11	24	23	16	12	14
1982-83	3,374	17.7	52%	27	25	11	11	12	14

change seen in 1982-83 was that small (less than 15 cm) winter flounder made up 52% of the total, the largest percentage since 1978-79. Mid-size fish (15-24 cm) comprised only 22%, the smallest proportion found to date. The large number of small fish was probably indicative of a large year-class of winter flounder produced in 1982 with perhaps changes in other conditions such as weather or level of plant operations that may have increased their impingement.

The sex and reproductive condition of 1,675 specimens impinged from December through April were recorded; 65% were males and 35% were females. This ratio was the opposite of that seen for the spawning population in the Niantic River. Of the 375 females examined that were larger than 25 cm, 69% were gravid and 31% were spent or had not yet come into spawning condition. This was contrary to the data obtained from the trawl monitoring program during the same period which showed relatively few ripe females outside the Niantic River. Their occurrence at MNPS may have been related, in part, to behavior. The environmental cues used by winter flounder to successfully return to the Niantic River from distant areas for spawning are not known. Beverton and Holt (1957) noted that current direction is an important guiding factor in oriented migration of marine demersal fishes. If adults were moving along the shoreline in search of a particular estuary, then the intake currents at MNPS may have attracted individuals seeking to enter the river for spawning. The larger number of males impinged than females may have been related to their generally smaller size and therefore lower sustained swimming speeds (Beamish 1966; Terpin et al. 1977) which would have allowed fewer of them to escape from the intake area.

Entrainment

Winter flounder larvae were present in entrainment samples at EN from late February through late June with the highest densities in April and May (Fig. 11). Most of the larvae entrained were developmental Stage 3 (Fig. 12). The 1983 median entrainment density (47.5 per 500 m^3) and total entrainment estimate (54.7 million) were the second highest estimates since 1976 (Table 19). However, due to the overlap in

Table 19. Yearly median densities of winter flounder larvae in entrainment samples during their season of occurrence and annual entrainment estimates with 95% confidence intervals for MNPS Units 1 and 2 from 1976 through 1983.

Year	Median[a]	95% CI	estimate ($\times 10^6$)	95% CI ($\times 10^6$)
1976	38.8	25.9-83.3	45.5	30.4-97.7
1977	23.4	12.0-43.8	20.8	10.7-39.0
1978	46.9	23.2-84.9	47.5	23.5-85.9
1979	28.7	14.2-56.8	24.5	15.1-57.7
1980	58.6	31.7-116.4	72.7	32.9-117.6
1981	20.1	9.8-47.6	14.1	10.5-48.3
1982	33.7	19.1-49.8	47.6	20.5-51.2
1983	47.5	31.0-109.6	54.7	35.7-126.1

[a] $n/500m^3$

confidence intervals, no significant differences were found in annual entrainment estimates among the years.

A total of 135 winter flounder larvae were collected in the entrainment mortality studies during 11 sampling sessions (Table 20). During the study the effluent ΔT ranged from 8.0 to 11.5 C. Of the 24

Table 20. Results of larval winter flounder entrainment mortality study.

Stage	Number captured	Alive at capture	Surviving effluent holding	Surviving 96-h latent holding
2	24	8	0	0
3	87	69	15	0
4	24	24	19	19
Total	135	101	34	19

Stage 2 larvae collected, 8 were alive following capture but none survived the 2 to 4-h effluent holding period. Stage 3 larvae had greater survival than Stage 2 following capture and the effluent holding period, but all survivors died during the first 24 h of the 96-h latent holding period. All 24 Stage 4 larvae were alive following capture, with 19 (79%) surviving effluent and 96-h latent holding periods. No Stage 5 larvae were collected but their survival most likely would have been at least as great as that of Stage 4. It appeared that a large portion of Stage 4 and 5 larvae could survive entrainment and passage through the Millstone quarry. Approximately 15% of all winter flounder larvae entrained during 1983 were in these later stages of development. Pearcy (1962) found the winter flounder mortality rates decreased with increasing larval development. Therefore, the later stages would have had a greater probability of being recruited to the adult stock than earlier stages. Survival of larger winter flounder larvae passing through the MNPS cooling-water system would have reduced the effects of entrainment as estimated in previous assessments (Sissenwine et al. 1975; Saila 1976) which assumed 100% mortality for entrained larvae.

Harmonic regression models

The fluctuations in the catch of winter flounder in several monitoring programs from October 1976 through September 1982 were analyzed using time-based harmonic regressions (Table 21). All models contained terms describing a 12-month cycle, although both longer (72-mo) and shorter (4-, 6-mo) period harmonic terms were also significant in some models. The best models of the log-transformed impingement counts included a 12-mo cycle and MNPS cooling-water flow as

Table 21. Summary of time-based regression models selected to best describe the occurrence of winter flounder in various monitoring programs at MNPS.

Monitoring Program	Station	Model[a]	Model R^2	Model % error	n[a]	Forecast % error	n
Impingement	Unit 1	$Z_t = B_1F+B_2FSin(tK_{12})+B_3FCos(tK_{12})+A_1e_{t-1}+A_2e_{t-2}+A_3e_{t-3}$	0.91	9	353	9	52
Impingement	Unit 2	$Z_t = B_1F+B_2FSin(tK_{12})+B_3FCos(tK_{12})+A_1e_{t-1}+A_2e_{t-2}+A_3e_{t-3}$	0.92	8	353	12	52
Entrainment	EN	$Z_t = B_1S-B_2SCos(tK_6)-B_3SSin(tK_6)-B_4SCos(tK_3)+ A_1e_{t-1}-A_2e_{t-3}+A_3e_{t-7}-A_4e_{t-8}-A_5e_{t-45}-A_6e_{t-49}+A_7e_{t-50}$	0.96	4	314	7	52
Ichthyoplankton	NB	$Z_t = B_1SSin(tK_{72})+B_2SSin(tK_{12})-B_3SCos(tK_{12})-B_4SSin(tK_4)$	0.90	10	224	15	52
Trawl	BR	$Z_t = B_0-B_1Cos(tK_{72})+B_2Sin(tK_{12})+A_1e_{t-1}+A_2e_{t-4}+A_3e_{t-15}$	0.44	56	176	246	26
Trawl	IN	$Z_t = B_0-B_1Cos(tK_{72})-B_2Sin(tK_{12})-B_3Cos(tK_{12})-B_4Sin(tK_6)+ A_1e_{t-8}-A_2e_{t-28}$	0.37	63	176	413	26
Trawl	JC	$Z_t = B_0-B_1Cos(tK_{72})-B_2Sin(tK_{12})-B_3Sin(tK_6)-B_4Cos(tK_6)- B_5Sin(tK_4)+B_6Cos(tK_4)+A_1e_{t-1}$	0.39	61	176	140	26
Trawl	NB	$Z_t = B_0-B_1Cos(tK_{12})-B_2Sin(tK_6)+A_1e_{t-1}+A_2e_{t-7}$	0.41	59	176	71	26
Trawl	NR	$Z_t = B_0-B_1Cos(tK_{72})-B_2Sin(tK_{12})-B_3Cos(tK_{12})-B_4Sin(tK_6)- B_5Sin(tK_4)+A_1e_{t-1}-A_2e_{t-3}-A_3e_{t-10}$	0.61	33	176	581	26
Trawl	TT	$Z_t = B_0-B_1Cos(tK_{72})-B_2Cos(tK_{12})+A_1e_{t-1}$	0.41	59	176	466	26

a Z_t = mean of the log transformed catches in a sample period
B = regression coefficients
t = time in days
K_m = constant to use for period of duration m in months
A = autoregression coefficients
e = residual (predicted - observed)
F = cooling-water flow rate at specific unit
S = seasonal coefficient (1 from January through July, 0 at other times)
n = number of observations contributing to the % error

a significant multiplicative regressor. Because of the large number of observations available, the impingement models for MNPS Units 1 and 2 had large R^2 values (0.91 and 0.92, respectively). Similarly, the entrainment and NB ichthyoplankton station models also explained over 90% of the variation during the model period; a seasonal component was used in these models as winter flounder larvae were only available for a maximum of 7 months of the year. These models were used to forecast catches for the period October 1982 through September 1983. The actual catches were then compared to those forecasted. The percent error for the impingement and larval models remained low during the forecast year, which suggested a reasonably accurate forecast of the data not used to build the model. Examples of these particular models shown in Figures 21 and 22 tended to have relatively narrow confidence intervals. Although data from 6 years were used in building the models, only 2

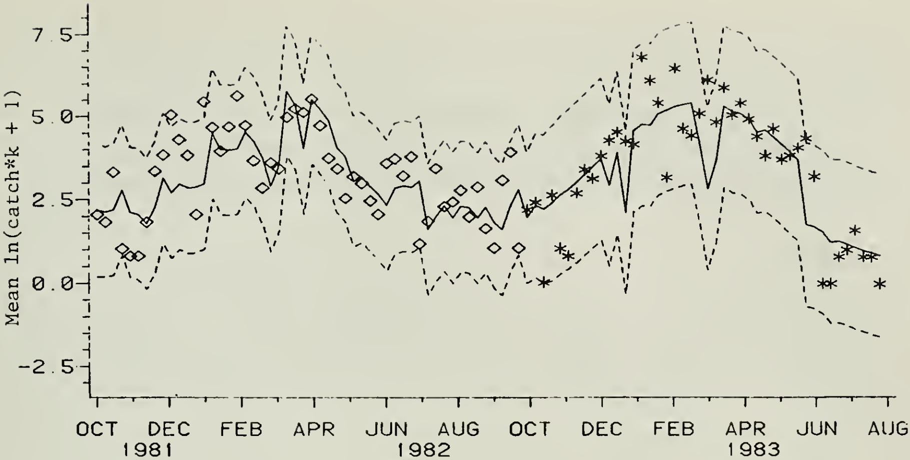


Figure 21. Harmonic regression forecast (——) and 95% confidence limits (---) for winter flounder at MNPS Unit 2. Data from 1976-82 were used in building the model (◇) and compared to data from 1982-83 (*).

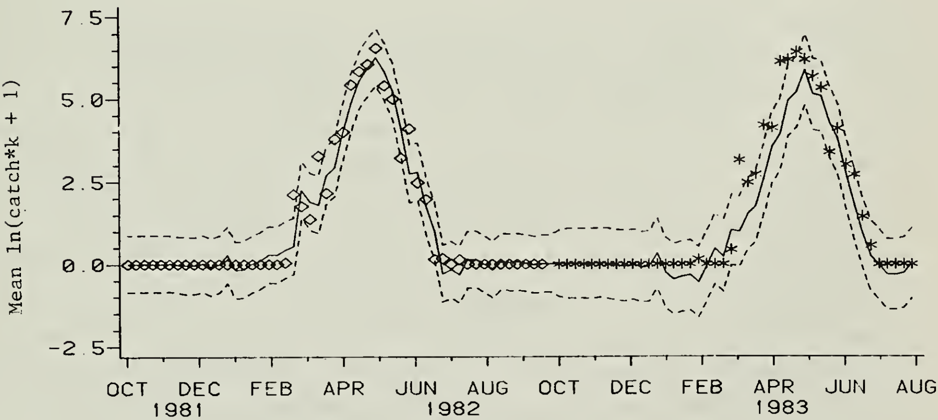


Figure 22. Harmonic regression forecast (——) and 95% confidence limits (---) for winter flounder at entrainment station EN. Data from 1976-82 were used in building the model (◇) and compared to data from 1982-83 (*).

years of each harmonic regression model and the forecast for 1982-83 are shown for clarity.

In contrast, models built from the trawl monitoring program data accounted for more than half of the variation at only the NR station (Fig. 23). The forecast percent error for this particular model was

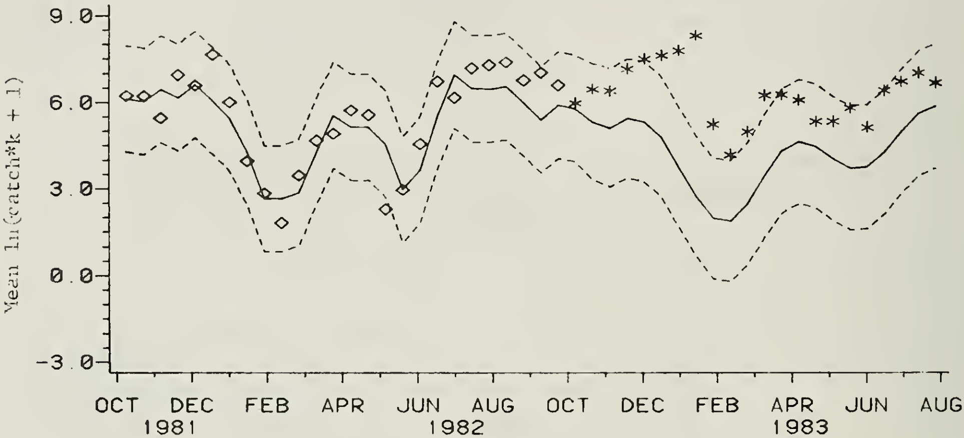


Figure 23. Harmonic regression forecast (——) and 95% confidence limits (---) for winter flounder at trawl station NR. Data from 1976-82 were used in building the model (◇) and compared to data from 1982-83 (*).

very high; the seasonal pattern was modeled adequately but the magnitude of the catches was underestimated considerably for 1983. It remained unclear whether the inadequacies of the trawl models were due to inappropriate choices for the models, insufficient data, or the inherent variability of the trawl data. Except for the NB station, models developed from these data had terms including 72- and 12-mo periods as well as shorter time intervals. The presence of 12-mo and shorter terms in the models were not unreasonable and represented the yearly cycle of abundance caused by patterns of movement and recruitment of juveniles into the trawl catch. However, the 72-mo long-term harmonics may have been an artifact of the data base and additional years of study will probably be necessary to improve the models if the winter flounder has a longer-term cycle of abundance. Even though the forecast percent error for each of these models was high, the actual 1982-83 data fell within the 95% confidence interval in most cases. However, the confidence intervals themselves were fairly wide because of the variability of the data.

Yearly changes in abundance were noted both in the Jolly population estimates and in the harmonic regression models of the trawl monitoring program data. These changes were not unusual for the winter flounder and most likely reflected long-term natural fluctuations. Jeffries (1983) noted an 11-yr cycle of abundance for Narragansett Bay winter flounder. He reported a decline of 86% in his standardized trawl catch from 1968 to 1976, a rapid recovery culminating in a peak in 1979 similar in magnitude to 1968, and yet another rapid decrease of 58% by 1982. He attributed the cyclic changes in number to a subtle warming and cooling trend which may have caused the observed changes in number; his temperature model accounted for 92% of the variability. Jeffries hypothesized that temperature variability affected predation on larvae during metamorphosis in April, which he termed a critical month. Similar correlations of year-class strength with environmental factors have been summarized for other flatfishes by Roff (1981). Nisbet and Gurney (1982) noted that fish populations can experience fluctuations in abundance approximately two to four times longer than the length of time it takes the species to mature, depending upon the population age-structure of the species in question. Since the winter flounder typically matures in 3 to 4 years, a 6- to 12-yr cycle of abundance could be expected.

SUMMARY

1. The minimum size for marking winter flounder during the population abundance survey in the Niantic River was increased from 15 to 20 cm in 1983 and the sampling was completed after most spawning occurred. The number of adult winter flounder was estimated as 41, 980 ± 15,564. The 1983 data were examined for potential sources of bias or error; the estimate was relatively unbiased and precision good.

2. The total number of winter flounder larger than 20 cm declined 28% from 1982 and 15% from 1981, but remained greater than those of the late 1970's. The estimated number of smaller winter flounder decreased more than a third from 1982, but this may have been partly related to differences in sampling among years.

3. The median was chosen as the most representative catch statistic for trawl CPUE during the surveys. Standardization of the tows lessened the variability of the 1983 data as compared to previous years.

4. Spawning apparently began in January or early February under the ice in the upper river and was completed by mid-April. Little spawning apparently took place outside of the river. The median size of mature females was 25.1 cm. The number of spawning females and egg production peaked in 1982 with 1983 and 1981 estimates comparable in magnitude.

5. Calculated lengths-at-age were greater for females than males at age 3 and older. Niantic River fish grew slower than other nearby populations during their first 2 years of life, but caught up to or surpassed other stocks beginning at age 3. The von Bertalanffy theoretical growth parameters were calculated and were also similar to those of other New England stocks.

6. Tagging studies showed that most movement out of the Millstone area was to the east. More females tended to leave the area than males and more returns were received from the sport than the commercial fishery.

7. Winter flounder yolk-sac larvae were collected almost exclusively in the Niantic River. The seaward flushing of larvae into Niantic Bay primarily occurred during their second developmental stage. Transforming larvae (Stages 3-5) were concentrated in Niantic Bay and the lower portion of the Niantic River.

8. The estimated larval developmental time in 1983 from hatching to transformation into a juvenile was approximately 80 days.

9. Stage 3 to 5 larvae were collected at the mouth of the Niantic River in greatest abundance during a late flood tide. Many of these larvae apparently used tidal currents to re-enter and remain in the river.

10. Medusae of the lion's mane jellyfish were identified as a potentially important predator of winter flounder larvae, particularly in the upper Niantic River.

11. Post-larval juveniles were most common in the lower Niantic River. Absolute abundance estimates were uncertain because of sampling problems, but densities of 8 to 10 juveniles per 100 m^2 were found during late summer. Growth of juveniles at the Lower River station was examined. An average monthly survival of 40.3% was calculated for these fish.

12. The estimated annual impingement of winter flounder at MNPS was the second highest total during the past 11 years. More than half of the individuals impinged were smaller than 15 cm. More males than females were impinged, perhaps because of a lesser ability to escape intake currents.

13. Winter flounder larvae were entrained at MNPS from late February through late June and the 1983 estimate was the second highest since 1976. Entrainment survival for later developmental studies was approximately 80%, but was 100% for earlier stages.

14. Fluctuations in the catch of winter flounder in several monitoring programs were analyzed using time-based harmonic regression models. The best models were developed with impingement and entrainment data. Models using data from the trawl monitoring program were inadequate, which may have been a result of variability in the data or because the winter flounder has a cycle of abundance greater than the 6-year period used in the models.

REFERENCES CITED

Arai, M.N., and D.E. Hay. 1982. Predation by medusae on Pacific herring (Clupea harengus pallasi) larvae. Can. J. Fish. Aquat. Sci. 39:1537-1540.

Arnason, A.N., and K.H. Mills. 1981. Bias and loss of precision due to tag-loss in Jolly-Seber estimates for mark-recapture experiments. Can. J. Fish. Aquat. Sci. 38:1077-1095.

Balser, J.P. 1981. Confidence interval estimation and tests for temporary outmigration in tag-recapture studies. Ph.D. Thesis, Cornell University. 205 pp.

Battelle-William F. Clapp Laboratories. 1978. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual report, 1977. Presented to Northeast Utilities Service Company.

______. 1979. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual report, 1978. Presented to Northeast Utilities Service Company.

Beamish, F.W.H. 1966. Swimming endurance of some northwest Atlantic fishes. J. Fish. Res. Board Can. 23:341-347.

Berry, R.J., S.B. Saila, and D.B. Horton. 1965. Growth studies of winter flounder, Pseudopleuronectes americanus (Walbaum), in Rhode Island. Trans. Am. Fish. Soc. 94:259-264.

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. London, Ser. 2, 19:1-533.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish. Wildl. Serv., Fish. Bull. 53:1-577.

Buckley, L.J. 1982. Effects of temperature on growth and biochemical composition of larval winter flounder Pseudopleuronectes americanus. Mar. Ecol. Prog. Ser. 8:181-186.

Danila, D.J. 1978. Age, growth, and other aspects of the life history of the winter flounder, Pseudopleuronectes americanus (Walbaum), in Southern New Jersey. M.S. Thesis, Rutgers University. 79 pp.

Davies, R.G. 1971. Computer programming in quantitative biology. Academic Press, New York, N.Y.

Dunn, R.S. 1970. Further evidence for a three-year oocyte maturation time in the winter flounder (Pseudopleuronectes americanus). J. Fish. Res. Board Can. 27:957-960.

______, and A.V. Tyler. 1969. Aspects of the anatomy of the winter flounder ovary with hypothesis on oocyte maturation time. J. Fish. Res. Board Can. 26:1943-1947.

Everhart, W.H., A.W. Eipper, and W.D. Youngs. 1975. Principles of fishery science. Comstock Publishing Associates, Ithaca, N.Y. 288 pp.

Gallucci, V.F., and T.J. Quinn II. 1979. Reparameterizing, fitting, and testing a simple growth model. Trans. Am. Fish. Soc. 108:14-25.

Howe, A.B., and P.G. Coates. 1975. Winter flounder movements, growth, and mortality off Massachusetts. Trans. Am. Fish. Soc. 104:13-29.

Jeffries, H.P. 1983. An 11-year cycle of abundance in the fishes of the Narragansett Bay area. 7th Biennial International Estuarine Research Conference, Oct. 22-26, 1983. Virginia Beach, VA.

Jolicoeur, P. 1975. Linear regressions in fisheries research: some comments. J. Fish. Res. Board Can. 32:1491-1494.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with death and immigration stochastic model. Biometrika 52:225-247.

Jones, R. 1981. The use of length composition data in fish stock assessments (with notes on VPA and cohort analysis). FAO Fish. Circ. 734:1-60.

Kennedy, J.S., and D.H. Steele. 1971. The winter flounder (Pseudopleuronectes americanus) in Long Pond, Conception Bay, Newfoundland. J. Fish. Res. Board Can. 28:1153-1165.

Ketchen, K.S. 1950. Stratified subsampling for determining age distributions. Trans. Am. Fish. Soc. 79:205-212.

Kurtz, R.J. 1975. Stomach content analysis in relation to differences in growth rate of winter flounder (Pseudopleuronectes americanus) from two Long Island bays. M.S. Thesis, Long Island University, C.W. Post College. 60 pp.

Laroche, W.A. 1981. Development of larval smooth flounder, Liopsetta putnami, with a redescription of development of winter flounder, Pseudopleuronectes americanus (Family Pleuronectidae). Fish. Bull, U.S. 78:897-909.

Leim, A.H., and W.B. Scott. 1966. Fishes of the Atlantic coast of Canada. Bull. Fish. Res. Board Can. 155:1-485.

Lobell, M.J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes. Winter flounder (Pseudopleuronectes americanus). Suppl. 28th Ann. Rep., N.Y. Cons. Dep., Pt. I:63-96.

Lorda, E.C. 1983. Biological rhythms and the estimation and comparison of the abundance of marine organisms. University of Rhode Island Graduate School of Oceanography Tech. Rep. No. 159. 16 pp.

Lux, F.E. 1973. Age and growth of the winter flounder, (Pseudopleuronectes americanus), on Georges Bank. Fish. Bull., U.S. 71:505-512.

_____, and F.E. Nichy. 1969. Growth of yellowtail flounder, Limanda ferruginea (Storer), on three New England fishing grounds. Int. Comm. Northwest Atl. Fish., Res. Bull. 6:5-25.

Marshall, N. 1960. Studies of the Niantic River, Connecticut, with special reference to the bay scallop, Aequipecten irradians. Limnol. Oceanogr. 5:86-105.

_____, and S.D. Hicks. 1962. Drift of medusae and their distribution in relation to the hydrography of the Niantic River, Connecticut. Limnol. Oceanogr. 7:268-269.

Moore, J.K., and N. Marshall. 1967. The retention of lamellibranch larvae in the Niantic estuary. The Veliger 10:10-12.

Nikolsky, G.V. 1963. The ecology of fishes. Academic Press, Inc., New York. 352 pp.

Nisbet, R.M., and W.S.C. Gurney. 1982. Modelling fluctuating populations. John Wiley and Sons, New York. 379 pp.

NUSCo (Northeast Utilities Service Company). 1975. Summary report, ecological and hydrographic studies, May 1966 through December 1974, Millstone Nuclear Power Station.

_____. 1980. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1979.

_____. 1981. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1980.

_____. 1982. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1981.

_____. 1983. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual report, 1982.

Pearcy, W.G. 1962. Ecology of an estuarine population of winter flounder Pseudopleuronectes americanus (Walbaum). Bull. Bingham Oceanogr. Coll. 18(1):1-78.

Perlmutter, A. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Oceanogr. Coll. 11:1-92.

Poole, J.C. 1966. Growth and age of winter flounder in four bays of Long Island. N. Y. Fish Game J. 13:206-220.

_____. 1969. A study of winter flounder mortality rates in Great South Bay, New York. Trans. Am. Fish. Soc. 98:611-616.

Richards, S.W. 1963. The demersal fish population of Long Island Sound. Bull. Bingham Oceanogr. Coll. 18(3):1-101.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191:1-382.

Roff, D.A. 1981. Reproductive uncertainty and the evolution of iteroparity: why don't flatfish put all their eggs in one basket? Can. J. Fish. Aquat. Sci. 38:968-977.

_____. 1982. Reproductive strategies in flatfish: a first synthesis. Can. J. Fish. Aquat. Sci. 39:1686-1698.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

_____. 1962a. The contribution of estuaries to the offshore winter flounder fishery in Rhode Island. Proc. Gulf Caribb. Fish. Inst. 14th Annu. Sess. 1961:95-109.

_____. 1962b. Proposed hurricane barriers related to winter flounder movements in Narragansett Bay. Trans. Am. Fish. Soc. 91:189-195.

_____. 1976. Effects of power plant entrainment of winter flounder populations near Millstone Point, Connecticut. URI-NUSCo Rep. No. 5. 134 pp.

_____, D.B. Morton, and R.J. Berry. 1965. Estimates of the theoretical biomass of juvenile winter flounder, Pseudopleuronectes americanus (Walbaum), required for a fishery in Rhode Island. J. Fish. Res. Board Can. 22:945-954.

Sampson, R. 1981. Connecticut marine recreational fisheries survey 1979-1980. Connecticut Dept. of Environmental Protection, Mar. Fish. 49 pp.

SAS Institute Inc. 1981. SAS/Graph user's guide, 1981 edition. SAS Institute Inc., Cary, N.C. 126 pp.

_____. 1982a. SAS user's guide: basics, 1982 edition. SAS Institute Inc., Cary, NC. 923 pp.

_____. 1982b. SAS user's guide: statistics, 1982 edition. SAS Institute Inc., Cary, NC. 584 pp.

Sissenwine, M.B., K.W. Hess, and S.B. Saila. 1975. A mathematical model for evaulating the effect of power plant entrainment of populations near Millstone Point, Connecticut. MES-NUSCo Rep. No. 1. 77 pp.

Snedecor, G.W., and W.C. Cochran. 1967. Statistical methods. The Iowa State University Press, Ames, Iowa. 593 pp.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 775 pp

Spent, P., and G.R. Dolby. 1980. Query: the geometric mean functional relationship. Biometrics 36:547-550.

Terpin, K.M., M.C. Wyllie, and E.R. Holmstrom. 1978. Temperature preference, avoidance, shock, and swim speed studies with marine and estuarine organisms from New Jersey. Ichthyological Associates, Inc. Ithaca, N.Y. Bull. No. 17. 86 pp.

Tesch, F.W. 1968. Age and growth. Pages 93-123 in W.E. Ricker, ed. Methods for assessment of fish production in fresh waters. I.B.P. Handbook No. 3. Blackwell Scientific Publications, Oxford and Edinburgh, U.K.

Weinstein, M.P., S.L., Weiss, R.G. Hodson, and L.R. Gerry. 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. Fish. Bull., U.S. 78:419-436.

Appendix 1. The 1976 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
4	3/1			0.663	0.093			28,596
5	3/8	28,596	5,870	0.937	0.142	-1,411	5,474	0
6	3/15	25,353	4,511	0.578	0.110	4,292	2,535	4,292
7	3/22	18,939	3,524	0.527	0.102	11,116	3,373	11,116
8	3/29	21,094	4,286	0.728	0.164	4,148	3,012	4,148
9	4/5	19,514	4,371					
Total abundance ±2 standard errors								48,152 ±23,050

Appendix 2. The 1977 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
5	3/7			0.520	0.119			29,470
6	3/14	29,470	11,666	0.656	0.110	-2,874	7,554	0
7	3/21	16,425	3,462	0.694	0.124	7,895	3,496	7,895
8	3/28	19,245	4,097	1.157	0.331	-3,383	4,015	0
9	4/4	18,879	5,429					
Total abundance ±2 standard errors								37,365 ±38,701

Appendix 3. The 1978 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
5-8	3/6-3/27			0.476	0.078			15,733
9	4/3	15,733	3,513	0.634	0.096	9,154	3,318	9,154
10	4/10	19,126	3,601	0.442	0.070	543	1,463	543
11	4/17	9,000	1,470					
Total abundance ±2 standard errors								25,430 ±12,085

Appendix 4. The 1979 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
6-8	3/12-3/26			0.559	-			26,658
9	4/2	26,658	-	0.433	-	-793	-	0
10	4/9	10,760	-					
Total abundance ±2 standard errors								26,658 -

Appendix 5. The 1980 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
6	3/17			0.664	0.102			18,276
7	3/24	18,276	4,293	0.766	0.096	7,393	3,969	7,393
8	3/31	21,345	3,542	0.624	0.085	1,536	2,116	1,536
9	4/7	14,856	2,146					
Total abundance								27,205
±2 standard errors								±15,253

Appendix 6. The 1981 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
4	3/2			0.791	0.119			25,674
5	3/9	25,674	5,636	0.681	0.109	2,955	4,122	2,955
6	3/16	20,378	3,932	0.583	0.091	5,963	2,747	5,963
7	3/23	17,842	3,068	1.097	0.171	28,288	7,214	28,288
8	3/30	47,858	8,622	0.757	0.150	-2,988	5,444	0
9	4/4	33,218	6,553					
Total abundance								62,880
±2 standard errors								±21,554

Appendix 7. The 1982 abundance estimate of winter flounder larger than 15 cm during the spawning period in the Niantic River.

Week no.	Date (week of)	Total number (N)	Standard error of N	Probability of survival (phi)	Standard error of phi	Calculated number joining (B)	Standard error of B	Actual number joining
3	2/22			1.213	0.335			8,806
4	3/1	8,806	3,458	0.939	0.226	50,683	19,838	50,683
5	3/8	58,950	20,594	0.612	0.102	15,510	15,121	15,510
6	3/15	51,600	12,397	0.754	0.122	-1,142	8,971	0
7	3/22	37,768	6,868	0.578	0.110	2,510	3,772	2,510
8	3/29	24,340	4,896					
Total abundance								77,509
±2 standard errors								±26,706

HEAVY METALS

Table of Contents

FINAL REPORT

TRACE METAL CONCENTRATIONS IN COOLING WATER EFFLUENT, SEAWATER, SUSPENDED MATTER, OYSTERS, AND MUSSELS NEAR MILLSTONE POINT, 1983

to

NORTHEAST UTILITIES SERVICE COMPANY

March 5, 1983

by

Dennis G. Waslenchuk
Aquademia
50 Center Street
New London, Connecticut 06320

TRACE METAL CONCENTRATIONS IN COOLING WATER EFFLUENT, SEAWATER, SUSPENDED MATTER, OYSTERS, AND MUSSELS NEAR MILLSTONE POINT, 1983

INTRODUCTION

The concentrations of chromium, copper, iron, lead, and zinc in the dissolved and particulate states in seawater and in the cooling water effluent of the Millstone Nuclear Power Station were determined on five occasions during 1983, at approximately 10-week intervals. With the exception of lead, concentrations of the same metals were determined in oyster (*Crassostrea virginica*) and mussel (*Mytilus edulis*) tissue, on the same sampling occasions. This 1983 work continues along the lines of a monitoring program for metals that began in 1971. During this same period, geochemical researchers have made large advances in their abilities to accurately measure trace concentrations of metals in seawater and tissue, especially in their ability to control sample contamination. It is of doubtful value, therefore, to make strict comparisons between the earliest and the most recent data, but of greater value to compare results of the past few years only. Analytical problems have been greater for seawater determinations than for tissue determinations, such that similar metal levels in oysters and mussels have now been reported for the past several years. The present report is this investigator's second contribution to the monitoring program, although he has conducted special studies of metals in the Millstone Power Station cooling water plume in 1979 and 1980 (Waslenchuk, 1982).

The sampling locations represent: an environment apparently remote from any power station influence (Giant's Neck); areas proximal to the discharge to Long Island Sound which may be affected to some degree on some occasions by power station cooling waters (Niantic Bay, Twotree Island, Fox Island, White Point), and the undiluted cooling waters themselves (Quarry Cut). Any impacts of power station operations on the metal burdens in Long Island Sound waters and mollusc tissues may therefore be revealed as systematic concentration anomalies (with respect to the remote location), related to proximity to the cooling water plume.

As shown in a previous detailed study (Waslenchuk, 1982), cooling waters can have metal concentrations higher than ambient Long Island Sound waters, due to corrosion and erosion of condenser pipes. The present study provides results generally consistent with those earlier observations, in that the cooling waters are enriched in copper and zinc. The present study also shows that oysters growing naturally, or deployed in exposure cages, in the quarry (the immediate receiving basin for effluent) have somewhat elevated levels of metals compared to oysters deployed in exposure cages elsewhere in the vicinity. Metal concentrations in oysters and mussels from locations outside the quarry show no discernable relationship to proximity to the effluent outfall, in agreement with the results of the 1981 and 1982 monitoring programs (NUSCo, 1981, 1982 Annual Report). Unlike the past two years' results, however, concentrations are not seen to vary systematically by season, in molluscs outside the quarry. Finally, considering the most distal sampling location (Giant's Neck) to be representative of natural conditions, there is no evidence that the Millstone Power Station effluent causes additional bioaccumulation of metals in molluscs near Millstone Point.

MATERIALS AND METHODS

Contemporary oceanographic techniques for non-contaminating sampling and sample handling were employed, along with clean-laboratory techniques for low-level metal analyses. Table 1 lists the specific procedures followed to ensure accurate work.

Seawater samples were collected on February 25, May 13, July 26, September 23, and December 20. Sampling times and tidal stages are listed in Table 2. Molluscs were collected on February 26, May 14, July 24, September 24, and December 20.

Sample Collection.

1) Seawater

Collection was accomplished off the bow of the vessel while it made slight headway into uncompromised waters. A two meter PVC sampling pole with 3 one-liter CPE bottles taped to one end was plunged through the surface layer to about 0.5m depth. The bottles collected three samples from a swath about 30cm wide; if the water mass were completely homogeneous the three samples would be exact replicates. The bottles were allowed to half fill for a rinse, then were submerged again for the sample. Adjacent water temperature was noted during filling. The position of the cooling water plume is readily detected by temperature anomalies; in this past year, the plume itself was not sampled. About 250 mls of seawater from each sampling bottle was immediately filtered through 0.45 micron Nuclepore membranes held in a Millipore filtering apparatus. Each filtrate was collected in a CPE storage bottle, and was acidified to pH 2 with concentrated HCl. The used membranes were stored in CPE vials.

Samples were taken at the quarry cut, near Twotree Island (outside the obvious temperature anomaly of the plume), in front of Millstone Intake #1, and at Giant's Neck, during mid-ebb tide stage.

2) Molluscs

Oysters were deployed in mid-January, 1982, in cages made of vinyl-coated wire, at White Point, at the Northeast Utilities Environmental Lab (NUEL) dock near Fox Island, from the floating laboratory in the quarry, and at Giant's Neck. A natural population that grows on the steel frame of the floating laboratory was also sampled on each occasion.

On each sampling occasion, three replicate groups of 8 oysters were collected from each site (three groups of 4 individuals were taken from each of two cages). It was possible to collect only three to eight individuals at any time from the natural population. These were divided into two or three replicates, but with so few individuals, such replicates can be expected to show larger inter-group variability than those from the exposure cages. Three replicate groups of fifteen individual mussels were collected from the rocky intertidal zone at Giant's Neck, at Fox Island South (adjacent to the effluent discharge at quarry cut), and at Fox Island North (opposite the NUEL Dock).

The molluscs were scrubbed on-site with nylon brushes, in local seawater, then placed in bags and put on ice. At the end of the day, the molluscs were deep-frozen until processing.

Table 1a: Contamination Control Procedures: Seawater

ITEM	PROCEDURE
Sampling	Performed outside of zone of influence of vessel; sub-surface sample taken to avoid highly fractionated surface film; workers wear plastic gloves.
Sampling Apparatus: CPE collection bottles, Millipore filtering apparatus, 0.4μ Nucleopore membranes, polyethylene forceps.	Three stage acid leaching (Conc. reagent grade HNO_3, three days exposure at 60°C; 2N HNO_3, three days exposure at 60°C; 0.2N ultrapure HNO_3, three days exposure at 60°C; intermediate rinses with distilled deionized water (DDIW), final rinse with sub-boiling quartz-distilled water (Q-DDIW); air drying under particle free ultra-clean hood in Class 100-A Clean Laboratory.
Storage bottles (CPE), membrane storage vials (CPE).	Three-stage acid-leaching; bottles taken to field in double plastic bags, filled in bags, returned to clean lab in bags.
Acids for sample preservation (HCl), for third stage cleaning (HNO_3), for chelation-extraction preconcentration (HNO_3).	Purification of Baker Analysed Reagent Grade acids by two sub-boiling distillations in Teflon apparatus.
Extraction Materials: (i) handling: Teflon beakers, separatory funnels, CPE micro-pipette tips, polyvials for AAS, (ii) reagents:	Three-stage acid leaching.
APDC-DDDC	Triple freon extraction.
acids	As described earlier
Freon	No purification required; frequent reagent blank analyses performed
NH_4OH	Q-DDIW equilibrated with conc. NH_4OH in dessicator jar
Extractions, acid-cleaning, reagent purification	Carried out in Class 100-A ultra-clean laboratory; workers wear plastic gloves, changed frequently to avoid cross-contamination.

Table 1b: Contamination Control Procedures: Molluscs

ITEM	PROCEDURE
Sampling	Workers wore plastic gloves, fouling organisms removed from shells.
Shucking Tools	Rinsed with 10% Baker Instra-analysed Trace Metal HNO_3 (HNO_3); DDIW rinses.
Tissue homogenizer, mortar and pestle.	Rinsed with 10% HNO_3; Q-DDIW rinses.
Digestion Materials:	
tissue drying beakers	Acid leaching with 10% HNO_3 for 24 hours at 60^{o}C; DDIW rinses.
erlenmyer flasks, watch glasses	Acid leaching with conc. HNO_3 for 24 hours at 70^{o}C; rinsed with Q-DDIW.
digestion acid	Baker Ultrex HNO_3; reagent blank analyses performed.
Millipore filtering apparatus	Acid leaching with 10% HNO_3 for 24 hours at 60^{o}C; Q-DDIW rinses.
glass fiber filters	100 mls of 20% HNO_3 drawn through filter followed by 100 mls Q-DDIW.

Table 2: Sampling Dates and Timing of the Tide

Date	High Tide/Low Tide	Sampling Period
2/25/83	0822 / 1412	1125 - 1230
5/13/83	0938 / 1547	1422 - 1535
7/26/83	1024 / 1632	1345 - 1445
9/23/83	0953 / 1623	1230 - 1405
12/20/83	0905 / 1554	1230 - 1355

Note: Order of sampling was Quarry Cut, Giant's Neck, Intake #1, Twotree Island, except on 5/13/83 when Quarry Cut was sampled last.

Sample Pretreatment.

1) Seawater and suspended matter

No preparation was required for the filtrate. The filtrate weight was determined so that the particulate metal fraction could be normalized to volume of sample filtered.

Particulate matter on membranes was dried for 72 hours in a desiccator. The dried filters were placed in vials, submerged in 3 ml of 1.0N Ultrex HNO_3, and leached for at least 48 hours at 70°C.

2) Molluscs

Individuals from replicate groups were shucked with acid-rinsed stainless steel tools, rinsed with distilled-deionized water, and homogenized with a stainless steel and Teflon tissue grinder. The homogenate was dried for 72 hours at 80°C and ground with quartz mortar and pestle.

Sample Analyses.

1) Seawater and suspended matter

Dissolved metal determinations were made on 250 ml aliquots of seawater after preconcentration and isolation of the metals of interest by organic complexation/extraction (Danielsson et al., 1978). Instrumental determinations were done by graphite-furnace atomic absorption spectrophotometry for Cr, Cu, Fe, Pb, and Zn. Analytical precisions are listed in Table 3. One extraction was done with each sample collected. Metal concentrations in the leachate of particulate matter were determined directly by graphite-furnace atomic absorption spectrophotometry.

2) Molluscs

Analyses were performed on three replicate samples from each collection site. Approximately one gram (accurately weighed) of dried and ground homogenate was covered with 5 ml Ultrex HNO_3, and reflux digested at 70°C for six hours. Digests were filtered through acid-rinsed glass fiber filters and diluted to volume (50ml for oysters, 25ml for mussels). Duplicate one-gram samples of NBS Standard Reference Oyster Tissue were included with each group of digests for quality control demonstration. Table 4 summarizes the similar results of the NBS Oyster Tissue determinations from the past two years, which compare acceptably with limits given by NBS. Reagent blanks and procedural blanks were run with each group, but were everywhere either less than 1% of the analytical levels or below the level of detection. Instrumental determinations for Cr, Cu, Fe, and Zn were made by flame atomic absorption spectrophotometry, with an Instrumentations Laboratory Video 12 AAS.

Table 3: Analytical Precisions

METAL	MATRIX	% STD DEV	N
Copper	Seawater*, previously extracted, spiked 1ppb	0.0	3
	Tissue**, replicate NBS Oyster Tissue preparations	2.6	8
Zinc	Seawater, Intake 2/83	25	3
	Tissue, as above	3.6	8
Iron	Seawater, 5 ppb spike	27	3
	Tissue, as above	5.9	5
Chromium	Seawater, .01 ppb spike	8.7	4
	Tissue, as above	6.5	3
Lead	Seawater, 1 ppb spike	31	4

* Instrumental determination by Perkin-Elmer AAS with Heated Graphite Atomizer
**Instrumental determination by Instrumentations Laboratory Video 12 AAS-flame

Table 4: Metal Concentrations (± Standard Deviation) in mg/kg, of National Bureau of Standards Oyster Tissue, Tested in 1982 and 1983.

	NBS Reported Value	Measured Value
COPPER	63.0 ± 3.5	64 ± 2.0 (1982) 63.2 ± 1.2 (1983)
ZINC	852 ± 14.0	860 ± 14.6 (1982) 833 ± 6.6 (1983)
IRON	195 ± 34.0	155 ± 5.0 (1982) 146 ± 2.9 (1983)
CHROMIUM	0.69 ± 0.27	0.77 ± 0.15 (1982) 0.62 ± 0.13 (1983)

RESULTS AND DISCUSSION

Seawater and Suspended Matter.

The metal concentrations found in the dissolved and particulate phases of seawater samples taken during 1983 are reported in Tables 5a and 5b, and for comparison purposes, the comparable data from 1982 are reproduced in Table 5c.

A comparison of 1982 and 1983 levels of dissolved metals shows close agreement. As expected from earlier work (Waslenchuk, 1982), quarry and plume waters are usually slightly enriched with dissolved Cu. Dissolved zinc enrichments are sometimes seen, but as in earlier observations there is less consistency than for copper. Cooling water is not evidently an enriched source of the other metals. This would be anticipated since the condenser tubes are essentially Cu-Ni alloys. Zn may be provided by sacrificial Zn blocks used for corrosion protection, and by Cu-Ni-Zn alloy pipes in auxiliary systems.

The particulate copper load associated with cooling waters is somewhat elevated above Long Island Sound waters near the discharge plume, as found in earlier studies, but this is not the case for other metals. As before (1982), particulate copper levels are about 1/10 the dissolved load, zinc is more evenly distributed between the two phases, whereas iron, chromium, and lead are everywhere preferentially partitioned to the particulates.

Molluscs.

Metal concentrations found in oysters in 1982 are presented in Table 6, and those found in mussels are presented in Table 7. In general, the levels of chromium, copper, and zinc in oysters from Giant's Neck, Fox Island, and White Point were spatially uniform for each sampling date. There is no indication of excess metal burdens in oysters that grew near the cooling water outfall.

All metal levels in oysters from the quarry exposure cages and the natural population were about 1.5 or more times higher than levels in oysters from other cages outside the quarry, probably reflecting slight long-term enrichment of the dissolved metals in quarry waters.

A comparison of bivalve metal levels reported for the 1982 program, covering 1980, 1981, and 1982 results, showed that overall levels of Cu and Zn had been constant. The 1983 values are similar again. However, the 1982 reported values of iron and chromium were up to 5 times higher than earlier ones; no apparent reason was offered other than the suggestion that the differences might be due to dissimilar instrumentation (an atomic fluorescent spectrophotometric (AFS) technique was first used in the 1982 study). Subsequent to the 1982 report it was determined that previous investigators had depurated the shellfish samples prior to analysis, and that our inclusion of gut contents might explain the higher iron and chromium concentrations. On one occasion (May/83), therefore, we depurated two groups of mussels from Giant's Neck for comparison with the three groups from that location that were handled in the usual manner (ie. not depurated). Although the two depurated groups had quite different metal loads, they were less than those of the non-depurated groups: for iron, non-depurated groups averaged 700 ppm, depurated group #1 had 330 ppm, depurated group #2 had 53 ppm; for chromium, non-depurated samples averaged 14.5 ppm, whereas the two depurated samples had 9.3 and 1.5 ppm. Hence at least part of the differences amongst results of the past few years can reasonably be attributed to this differing methodology.

Table 5a: Trace Metal Concentrations in the Soluble Fraction of Seawater Samples Collected from Locations Near Millstone Point During 1983 (ug/kg, or parts per billion).

	FEB	MAY	JULY	SEPT	DEC
COPPER					
Intake #1	1.1	0.35	0.58	1.1	0.31
Quarry Cut	1.9	1.1	0.84	1.4	1.1
Giant's Neck	1.1	0.80	0.66	0.98	0.98
Twotree I.	1.2	0.61	0.67	1.2	0.76
ZINC					
Intake #1	1.7	-	3.6*	-	7.3*
Quarry Cut	3.5	-	6.4*	-	12.2*
Giant's Neck	2.2	-	-	12.1*	7.2*
Twotree I.	3.3	-	-	-	5.0*
IRON					
Intake #1	1.3	3.2	2.8	11.6	1.2
Quarry Cut	9.0	2.2	2.3	8.1	7.9
Giant's Neck	4.6	2.8	1.8	21.1	3.7
Twotree I.	7.0	3.3	6.2	9.0	4.4
CHROMIUM					
Intake #1	.004	.006	.008	.004	.006
Quarry Cut	.025	.008	.004	.009	.003
Giant's Neck	.013	.026	.005	.006	.005
Twotree I.	.007	.007	.015	.007	.004
LEAD					
Intake #1	.030	.030	.064	.034	.010
Quarry Cut	.089	.020	.014	.443	.084
Giant's Neck	.134	.339	.035	.072	.055
Twotree I.	.132	.055	.067	.058	.125

*
A pervasive but unidentified source of zinc contaminated most samples from the latter four sampling dates. Quality control 'blanks' for these contained between 1.1 and 20 ppb, masking the expected sample concentrations of 1 -7 ppb, and making correction for the blank impossible. Hence for most samples, zinc concentrations cannot be reported. The values that are given (marked with *) are uncorrected for the blank, hence they represent only maximum values for the possible concentrations, and should not be taken as absolute or relative estimates.

Table 5b: Trace Metal Concentrations in the Particulate Fraction of Seawater Samples Collected from Locations Near Millstone Point During 1983 (parts per billion, ie. ug Metal/kg of Filtrate). These values may be directly compared to those of the soluble load in Table 5a.

	FEB	MAY	JULY	SEPT	DEC
COPPER					
Intake #1	.054	.099	.144	.099	.171
Quarry Cut	.081	.207	.198	.160	.207
Giant's Neck	.072	.063	.072	.108	.171
Twotree I.	.081	.117	.063	.072	.090
ZINC					
Intake #1	2.4	1.4	1.3	2.7	2.4
Quarry Cut	2.3	1.6	1.2	2.7	2.3
Giant's Neck	2.9	1.6	1.1	1.0	2.7
Twotree I.	2.2	1.5	1.4	1.0	2.9
IRON					
Intake #1	21.6	41.4	36.0	21.6	26.1
Quarry Cut	27.0	24.3	30.6	42.9	36.9
Giant's Neck	36.0	27.9	20.7	23.4	35.1
Twotree I.	33.3	28.8	18.9	14.4	22.5
CHROMIUM					
Intake #1	.08	.15	.19	.12	.17
Quarry Cut	.09	.17	.16	.10	.22
Giant's Neck	.11	.13	.12	.12	.21
Twotree I.	.17	.18	.14	.07	.13
LEAD					
Intake #1	.14	.25	.17	.19	.29
Quarry Cut	.13	.30	.18	.35	.36
Giant's Neck	.16	.13	.14	.18	.40
Twotree I.	.18	.32	.14	.18	.23

Table 5c Trace Metal Concentrations of Soluble (μg/l) and Particulate (μg/kg) Fractions of Seawater Samples Taken from Selected Locations Near Millstone Point During 1982.

		SOLUBLE					PARTICULATE				
		Feb	May	July	Sept	Dec	Feb	May	July	Sept	Dec
COPPER											
Intake:	Ebb	1.6	1.1	0.9	1.2	0.9	0.11	0.81	0.09	0.12	0.13
	Flood	1.1	1.0	1.0	1.1	0.9	0.06	0.11	0.10	0.29	0.10
Quarry		1.9	1.6	2.3	2.0	1.9	0.12	0.22	0.19	0.31	0.17
50% Plume		1.5	1.9	1.3	1.7	1.4	0.12	0.21	0.16	0.18	0.11
Giants Neck:	Ebb	1.2	0.9	0.9	1.1	1.0	-	0.23	0.16	0.12	0.17
	Flood	-	1.1	1.3	1.1	1.9	-	0.22	0.15	0.26	0.10
Twotree I.:	Ebb	0.8	1.0	1.0	1.2	0.8	0.13	0.11	0.10	0.17	0.11
	Flood	-	0.9	1.2	1.6	1.0	-	0.08	0.11	0.16	0.29
ZINC											
Intake:	Ebb	0.9	4.1	2.3	3.9	4.9	0.41	0.23	0.27	0.31	0.29
	Flood	1.2	4.3	1.9	19.3	1.6	0.21	0.23	0.28	0.67	0.32
Quarry		11.6	2.5	1.9	9.6	3.6	0.21	0.32	0.29	0.41	0.28
50% Plume		10.0	8.0	0.9	5.7	9.3	0.23	0.32	0.31	0.26	0.22
Giants Neck:	Ebb	14.8	4.5	-	4.4	5.2	-	0.68	0.47	0.33	0.23
	Flood	-	4.0	2.1	3.1	-	-	0.41	0.41	0.36	0.20
Twotree I.:	Ebb	-	3.1	1.3	7.7	7.1	0.39	0.30	0.28	0.30	0.31
	Flood	-	2.5	2.3	1.5	3.6	-	0.20	0.27	0.35	0.45
IRON											
Intake:	Ebb	8.4	4.4	3.3	4.4	2.2	32.3	35.1	45.5	50.9	54.5
	Flood	9.7	5.8	3.2	3.6	1.8	21.9	36.7	46.5	95.4	57.9
Quarry		5.4	4.4	2.7	2.1	1.9	32.9	50.4	42.2	72.4	53.2
50% Plume		3.9	7.3	4.8	2.6	2.5	31.9	52.4	48.4	41.1	40.3
Giants Neck:	Ebb	6.7	6.1	2.1	2.2	4.8	-	54.3	64.8	59.6	44.8
	Flood	-	3.8	3.9	1.9	3.9	-	50.3	62.0	59.2	40.6
Twotree I.:	Ebb	3.7	4.6	2.1	2.9	1.8	45.3	37.1	43.5	48.1	57.5
	Flood	-	6.9	2.6	2.8	2.6	-	28.4	39.2	51.8	85.2
CHROMIUM											
Intake:	Ebb	≤0.02	0.03	≤0.02	0.02	≤0.02	≤0.10	0.13	0.15	0.18	0.13
	Flood	≤0.02	≤0.02	≤0.02	≤0.02	≤0.02	0.10	0.13	0.11	0.30	0.21
Quarry		0.02	0.01	0.02	0.02	0.01	0.24	0.18	0.16	0.23	0.14
50% Plume		0.02	≤0.02	≤0.02	≤0.02	≤0.02	0.09	0.17	0.16	0.14	≤0.10
Giants Neck:	Ebb	0.02	≤0.02	0.04	≤0.02	0.10	-	0.19	0.26	0.19	0.14
	Flood	≤0.02	≤0.02	≤0.02	≤0.02	≤0.02	-	0.26	0.22	0.20	0.16
Twotree I.:	Ebb	≤0.02	≤0.02	≤0.02	0.01	≤0.02	≤0.10	0.04	0.10	0.13	0.07
	Flood	≤0.02	0.03	0.02	≤0.02	≤0.02	-	0.17	0.15	0.18	0.29
LEAD											
Intake:	Ebb	0.05	0.02	0.03	0.03	0.04	≤0.1	3.6	5.1	3.2	2.4
	Flood	0.08	0.02	0.02	0.02	0.05	≤0.1	3.4	5.1	7.0	4.3
Quarry		0.09	0.01	0.03	0.03	0.04	7.3	5.7	4.2	3.5	4.6
50% Plume		-	0.04	-	0.03	0.04	7.6	3.1	4.7	1.5	3.1
Giants Neck:	Ebb	0.06	0.02	0.07	0.03	0.02	-	4.9	6.9	4.3	2.7
	Flood	-	0.03	0.02	0.03	0.07	-	5.3	3.4	4.5	3.5
Twotree I.:	Ebb	0.03	0.03	0.01	0.03	0.02	≤0.1	3.4	3.0	3.6	3.7
	Flood	-	0.04	0.06	0.04	0.04	-	5.0	2.7	3.7	5.6

Table 6: Trace Metal Concentrations in mg/kg Dry Weight in Oysters Obtained During 1983 from Exposure Cages Deployed in January.

		GIANT'S NECK	QUARRY	FOX ISLAND-N	WHITE POINT	NATURAL STOCK in QUARRY
COPPER	Jan * (390)					
	Feb	370 ± 25	430 ± 76	380 ± 47	380 ± 46	270 ± 170
	May	510 ± 66	430 ± 176	480 ± 55	540 ± 81	1060 ± 279
	Jul	350 ± 29	180 ± 15	420 ± 83	410 ± 57	410 ± 131
	Sept	520 ± 40	840 ± 375	500 ± 95	550 ± 155	420 ± 255
	Dec	470 ± 50	710 ± 84	450 ± 15	450 ± 23	850 ± 49
	mean	444 ± 79	518 ± 260	446 ± 48	466 ± 76	602 ± 336
ZINC	Jan * (5500)					
	Feb	6600 ± 830	7200 ± 950	7300 ± 64	6900 ± 580	10600 ± 131[illegible]
	May	7300 ± 1050	12100 ± 1920	6900 ± 570	8200 ± 1330	9600 ± 2320
	Jul	4000 ± 550	12600 ± 330	6000 ± 2190	4700 ± 1170	10000 ± 3420
	Sept	7100 ± 440	12700 ± 1490	7200 ± 1210	8300 ± 2130	10400 ± 3030
	Dec	7200 ± 190	9800 ± 1520	6500 ± 900	7200 ± 1140	7900 ± 730
	mean	6440 ± 1390	10880 ± 2370	6780 ± 536	7060 ± 1454	9700 ± 1077
IRON	Jan * (85)					
	Feb	80 ± 0	200 ± 49	80 ± 35	90 ± 0	370 ± 51
	May	170 ± 30	220 ± 12	230 ± 17	230 ± 15	560 ± 23[illegible]
	Jul	150 ± 23	250 ± 46	230 ± 60	170 ± 35	580 ± 270
	Sept	260 ± 35	460 ± 170	150 ± 6	200 ± 23	760 ± 240
	Dec	80 ± 6	170 ± 6	70 ± 15	90 ± 10	1085 ± 1140
	mean	148 ± 75	260 ± 116	152 ± 78	156 ± 64	671 ± 269
CHROMIUM	Jan * (3.5)					
	Feb	4.7 ± 1.0	9.0 ± 4.3	5.0 ± 0.7	5.7 ± 2.3	8.5 ± 1.0
	May	6.8 ± 2.0	15.2 ± 2.1	4.2 ± 0.8	7.0 ± 1.7	23.4 ± 9.2
	Jul	5.7 ± 1.5	11.8 ± 2.3	8.7 ± 2.3	8.2 ± 2.4	19.0 ± 8.9
	Sept	8.3 ± 1.2	15.5 ± 5.8	6.2 ± 0.3	10.3 ± 2.5	23.5 ± 5.7
	Dec	5.5 ± 0.7	5.0 ± 1.8	3.5 ± 1.0	5.8 ± 2.1	27.0 ± 29.0
	mean	6.8 ± 1.7	11.3 ± 4.4	5.5 ± 2.0	7.4 ± 1.9	20.3 ± 7.2

* Metal contents in oysters before deployment in exposure cages. Not included in "mean" calculation.

Table 7: Trace Metal Concentrations in mg/kg Dry Weight in Mussels Obtained During 1983 From Rocky Intertidal Areas of Niantic Bay

		GIANT'S NECK	FOX ISLAND-N	FOX ISLAND-S
COPPER	February	9.8 ± 1.4	10.6 ± 1.8	8.9 ± 2.0
	May	8.2 ± 2.5	6.7 ± 2.3	7.6 ± 2.5
	July	10.6 ± 0.4	10.4 ± 1.7	8.0 ± 0.5
	September	8.0 ± 2.8	8.4 ± 2.7	7.5 ± 1.8
	December	10.8 ± 1.8	7.5 ± 0.7	13.4 ± 0.3
	mean ± std deviation	9.2 ± 1.4	8.7 ± 1.7	9.1 ± 2.5
ZINC	February	140 ± 0	170 ± 12	150 ± 12
	May	150 ± 20	210 ± 26	270 ± 40
	July	150 ± 23	150 ± 6	170 ± 21
	September	150 ± 10	140 ± 0	180 ± 4
	December	211 ± 19	160 ± 6	230 ± 45
	mean ± std deviation	156 ± 33	166 ± 27	200 ± 49
IRON	February	1230 ± 360	1350 ± 150	1190 ± 320
	May	700 ± 130	570 ± 30	530 ± 100
	July	420 ± 19	340 ± 50	140 ± 34
	September	200 ± 7	140 ± 12	340 ± 23
	December	540 ± 110	350 ± 45	510 ± 16
	mean ± std deviation	618 ± 388	550 ± 470	542 ± 395
CHROMIUM	February	17.5 ± 0.0	17.9 ± 4.2	13.1 ± 0.4
	May	14.5 ± 2.2	14.0 ± 1.6	10.4 ± 1.7
	July	11.6 ± 0.7	6.5 ± 4.4	7.0 ± 1.9
	September	4.4 ± 0.6	2.2 ± 0.7	7.5 ± 3.2
	December	12.5 ± 2.0	12.7 ± 1.7	13.2 ± 3.7
	mean ± std deviation	11.5 ± 4.2	10.7 ± 6.3	10.2 ± 3.0

For mussels, on any particular date and for a given metal, the standard error bars generally overlap amongst locations. Unlike the previous year, the Fox Island South mussels did not have mean concentrations consistently greater than the other two stations, at any time. As was the case for oysters, then, there is no evident relationship between metal levels in mussels and proximity to the cooling water plume.

REFERENCES

Danielsson, L-G., B. Magnusson and S. Westerlund. 1978. An improved metal extraction procedure for the determination of trace metals in seawater by atomic absorption spectrometry with electrothermal atomization. Anal. Chim. Acta, 98: 47-57.

NUSCo, 1981, 1982. Annual Report, Millstone Environmental Laboratory.

Waslenchuk, D.G. 1982. The concentration, reactivity, and fate of copper, nickel, and zinc associated with a cooling water plume in estuarine waters. Environmental Pollution (Chemistry and Physics, Series B), 3(4): 271-287.

OSPREY

Table of Contents

Osprey

The numbers of American osprey (Pandion haliaetus) declined along the coast of Connecticut in the 1950's and 1960's due to the use of pesticides. Grier (1982) identified the pesticide DDE as one of the most persistent contaminants in the environment and one which posed the greatest physiological threat to the osprey. Osprey populations along the Connecticut River estuary decreased by as much as 30% per year (Ames 1966), and nests in other areas averaged only 0.2-0.4 young fledged per active nest between 1957-1962 (Ames and Musereau 1964). After the ban of DDT in 1972, reproduction rates of osprey from New York City to Boston increased, reaching levels of 1.55/nest by 1981 (Spitzer et al. 1983). The increase was attributed to reduced DDE concentrations in osprey eggs (Spitzer et al. 1978). Osprey populations can recover if young are produced at a rate of 0.8-1.30 per active nest (Henny and Wright 1969; Spitzer et al. 1983) (Fig. 1).

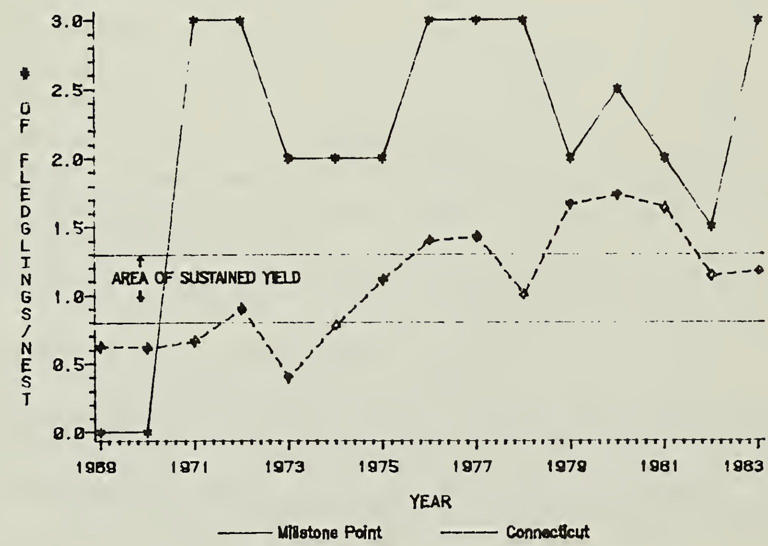


Figure 1. Average number of fledgelings per active nest for Millstone Point compared to all of Connecticut.

Natality in the area of the Millstone Nuclear Power Station (MNPS) began to increase when an egg transfer plan was implemented in 1969. Eggs from the nests of less threatened osprey of the Chesapeake Bay were exchanged for those of local birds. Since then, osprey production at MNPS has been enhanced by increasing the number of available nesting platforms. Current rates of reproduction are equal to those of the pre-DDT era; this increase in the osprey population appears strongly dependent on the number of artificial nesting sites erected to attract nesting pairs (Spitzer et al. 1983). The oldest nesting platform at MNPS, erected in 1967, is located atop the eastern rim of the granite quarry. A second platform was erected in 1974 on the southern edge of the wildlife refuge, a 50 acre site set aside by Northeast Utilities as a conservation area. These platforms have attracted ospreys and these birds have produced young every year since 1976. In 1979, a nesting platform was erected on Fox Island. To date, this site has not attracted a nesting pair of osprey; however, it is used quite frequently as a roosting and feeding site for the adults and young of the Quarry nest.

This year, two additional nesting platforms were erected on the Millstone site, bringing the number of platforms to five. These new platforms differ slightly from the existing three in that they are set on top of a 14' X 4" X 4" pressure treated post rather than a 30' utility pole. The new platforms are similar to those used by the State of Connecticut in their nesting program. One of the new platforms was located in a marsh on the eastern edge of the wildlife refuge. The second platform was placed on the west side of the plant near Niantic Bay just north of Bay Point.

In 1983, osprey returned to MNPS on March 28; one individual was observed in the nest located in the Wildlife area; on April 4, a pair returned to the Quarry nest. Nest rebuilding and mating attempts were observed at the Quarry nest shortly thereafter. The mate of the bird observed in the Wildlife area was not seen until late April. All other platforms remained inactive.

Three young were counted in the Wildlife area nest on June 16, using a bucket truck to make observations. The Quarry nest is relatively inaccessable to observations using the bucket truck, therefore it wasn't until July 1 that an accurate count could be made of the 3 young in this nest. The young from all nests had fledged by the end of July except for 1 individual in the Quarry Nest that didn't fledge until the second week of August. By mid September all the birds had left the Millstone site, marking the end of the 1983 breeding season.

During 1983, Millstone sites produced the highest number of fledglings since observations began in 1969. Two active nests produced three young each, raising the average annual production rate to 2.4/nest. Even though the two new platforms remained inactive, a pair of osprey did build a nest atop channel marker #4 outside the Niantic River, 1 km away from the Bay Point nest. This nest failed, presumably due to the boating activity.

This year in Connecticut, osprey produced 40 young in 34 active nests, slightly above last years annual production of 1.1/nest (Greg Chasko, Franklin Hill Wildlife Area, Personal Communication). This is the highest number of fledgings produced since the decline in the 1950-60 period (Table 1).

REFERENCES CITED

Ames, P.L. 1966. DDT residues in the eggs of the osprey in the northeastern United States and their relation to nesting success. J. Appl. Ecol. 3 (Suppl.) 87-97.

______, and G. S. Mersreau, 1964. Some factors in the decline of the osprey in Connecticut. Auk 81:173-185.

Grier, J.W. 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Science 218. 1232

Henny, C.J. and J.Y. Wright. 1969. Endangered osprey populations; Estimates of mortality and production. Auk 86:188-198.

Spitzer, P.R., A. Poole, and M. Scheibel. 1983. Proceedings, first international osprey-bald eagle conference. David Bird editor, McGill University Press. Montreal, Canada

______, R.W. Resebrough, W. Walker II. R. Hunandez, A. Poole, D. Puleston and I.C.T. Nesbet. 1978. Productivity of opsprey in Connecticut-Long Island rises as DDE residues decline. Science 202:333-335.

Table 1. Number of active nests and number of fledglings produced in Connecticut and Millstone Point.

Year	Millstone Point Active Nests	Millstone Point Fledglings	Connecticut Active Nest	Connecticut Fledglings
1969	1	0	16	10
1970	1	0	13	8
1971	1	3	12	8
1972	1	3	10	9
1973	1	2	10	4
1974	1	2	9	7
1975	1	2	9	10
1976	1	3	10	14
1977	1	3	14	20
1978	1	3	15	15
1979	1	2	15	25
1980	2	5	15	26
1981	2	4	22	36
1982	2	3	29	33
1983	2	6	34	40
Total		41		265