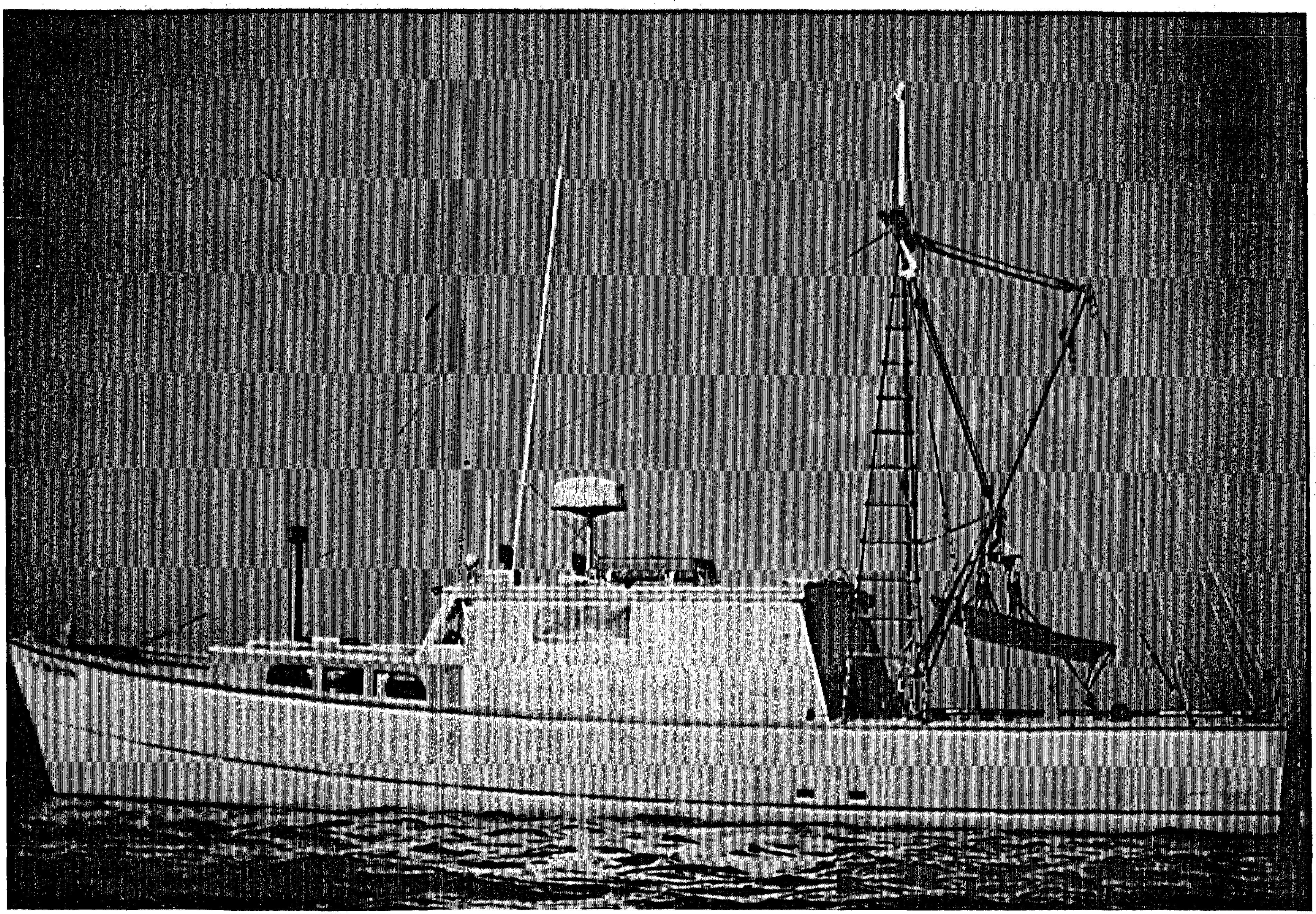
PILGRIM NUCLEAR POWER STATION
MARINE ENVIRONMENTAL MONITORING PROGRAM
REPORT SERIES NO. 7

FINAL REPORT ON BOTTOM TRAWL SURVEY AND IMPACT ASSESSMENT OF THE THERMAL DISCHARGE FROM PILGRIM STATION ON GROUNDFISH, 1970-1982

REGULATORY AFFAIRS DEPARTMENT
BOSTON EDISON COMPANY

Boston Edison



FRONTISPIECE. The R/V F.C. Wilbour used in the bottom trawl survey conducted in the western inshore sector of Cape Cod Bay, 1970 - 1982.

FINAL REPORT
ON
BOTTOM TRAWL SURVEY (1970-1982)
AND IMPACT ASSESSMENT OF THE
THERMAL DISCHARGE FROM PILGRIM STATION
ON GROUNDFISH

Robert Lawton, Vincent Malkoski
Brian Kelly, and John Chisholm

Department of Fisheries, Wildlife
and Environmental Law Enforcement
Massachusetts Division of Marine Fisheries
18 Route 6A
Sandwich, MA 02563

November 1, 1995

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

<u>Figure</u> <u>Page</u>

LIST OF PLATES

I. SUMMARY

We conducted a long-term bottom trawl survey in the environs of Pilgrim Station from 1970 to 1982. The occurrence, distribution, and relative abundance of groundfish were examined for spatio-temporal changes in response to the thermal discharge from the power station. Fixed stations were sampled biweekly in a standardized manner using a ½-Yankee trawl fished from the Division's 15.5 m (51 ft) research vessel, and catch per unit effort (CPUE) indices were generated.

The composition of finfish in the western inshore sector of Cape Cod Bay reflects a transition between species occurring in the Gulf of Maine and those found in the mid-Atlantic Bight. Fifty finfish species were collected during our 13 year sampling program, with only six taxa dominating the bottom catches numerically as follows: winter flounder (*Pleuronectes americanus*), yellowtail flounder (*Pleuronectes ferrugineus*), skates (*Raja* spp.), ocean pout (*Macrozoarces americanus*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), and windowpane (*Scophthalmus aquosus*). An assemblage of these dominants has been referred to as shallow-water sedentary species elsewhere by Murawski (1993). They are characterized by showing little directional movement and are not especially sensitive to natural temperature variations.

Winter flounder ranked first in our catch. Local flounder may belong to a discrete population. Ranging in age from 0+ to >9+ years old, they were caught in highest abundance at Station 1 in Warren Cove. A unimodal (occurring in mid-to-late summer) intra-

year distribution of catches was seen at the latter site and Station 2 (surveillance), indicating a pronounced seasonality in abundance, but not at the deepest site sampled - Station 3, where catches were fairly uniform.

Trends in winter flounder relative abundance were evident. The CPUE fell markedly at all stations from 1970 to 1975 (includes preoperational and operational years), indicating a drop in numbers in the population. A region-wide decline also occurred concurrently, with distant populations involved. A resurgence in local abundance followed between 1976 and 1981, as CPUE steadily increased in the Pilgrim study area. Other research surveys and commercial landings reflected an analogous pattern. The widespread spatio-temporal agreement in inter-annual variability in abundance suggests that similar regulating processes and causal mechanisms were ongoing in various winter flounder populations. Far reaching is the effect of overfishing on stock size which occurred as far back as 1975 with the Plymouth flounder population.

There is no evidence that occurrence, distribution, or relative abundance of winter flounder were significantly affected by Pilgrim Station's thermal plume. The decline in flounder abundance ensued prior to operation of Pilgrim Station, while an upswing occurred during operational years. At the time of the population decline, the rate of change in CPUE was greatest at reference Station 1, while changes at Stations 2 (surveillance) and 3 were one-third and one-fourth, respectively, that at Station 1.

Yellowtail flounder in the Pilgrim study area are members of a discrete Cape Cod stock. Overall, they ranked second in catch. Spatially, relative abundance varied directly with depth. Although caught throughout the year off the power plant, seasonal variation occurred preeminently at Stations 2 and 3, where marked mid-to-late-summer unimodal distributions of relative abundance were seen.

The CPUE indices for yellowtail from our trawl survey in the inshore sector of western Cape Cod Bay mirrored well the overall regional findings in the Bay as obtained from commercial landings and bay-wide stock assessment surveys. There is no indication that the occurrence, distribution, or abundance of yellowtail flounder were significantly affected by the thermal discharge from Pilgrim Station. Overfishing likewise has played a major role in recent declines in yellowtail flounder stocks. In the Pilgrim study area during the late 1970's and early '80's, there is an indication of lower recruitment, in addition to a drop in adult abundance.

Little skate and winter skate were captured, but the former, by far, predominated. Highest catches were obtained during summer at Station 1 in Warren Cove. Catches generally were lowest at Station 3. Relative abundance was relatively low throughout most of the 1970's but increased into the 1980's. This trend mirrored what was happening region-wide at the time. Skate CPUE in the Pilgrim study area began to increase during operational years at all sampling stations, and no adverse power plant effect is evident.

Catch abundance of ocean pout varied seasonally in the Pilgrim area, being relatively low in late summer and fall and more abundant in late winter and spring. This is related to their seasonal movements to hard-bottom spawning grounds, where they are ostensibly unavailable to trawlers, and their return to sand-bottom feeding grounds. Highest catches, by far, came from Station 2 off the discharge canal, while lowest catches generally came from Station 1. Between 1970 and 1982, a 95% decline in relative abundance occurred in the Pilgrim study area, where CPUE fell concurrently at each sampling station. This decline was region-wide, however, and no significant thermal impact from Pilgrim Station was indicated.

Longhorn sculpin catches were highest during summer, with over half their numbers taken at Station 3, the deepest site sampled at 12 m (40 ft). There was an 89% decrease in relative abundance from 1973 to 1976, with mean catch rates falling at all stations sampled. This decline was not limited to the Plymouth area but also was documented in Nantucket Sound at the time.

Windowpane were most abundant in the Pilgrim study area during summer and early fall in Warren Cove (Station 1). Annual abundance fluctuated during the years of our survey both in the Plymouth area and throughout southern New England generally, following a similar downward pattern overall, with overfishing implicated as a causal agent. Annual catch rates did not differ significantly at the sampling stations over the survey or between preoperational and operational years at each site.

Over the 13 year groundfish survey, species replacement in the dominance hierarchy was evident, with ocean pout falling from ranking second to fourth in the trawl catch, while skates rose from sixth to third. The thermally-impacted benthic area off Pilgrim Station is relatively small (~ 4,000 m^2 ~ 1 acre). We conclude that there was a general decline in relative abundance of most groundfish, which also occurred over a larger geographical area. Evidently, over-fishing was a primary causative factor.

II. INTRODUCTION

The Massachusetts Division of Marine Fisheries, funded by Boston Edison Company, conducted research vessel, otter trawl sampling in coastal waters of Cape Cod Bay from 1970 to 1982 as part of a comprehensive marine environmental impact assessment of an electric power plant operation. Bottom surveys were targeted to the inshore sector of the western Bay, in the environs of the Pilgrim Nuclear Power Station. Three years of pre-operational data (1970-1972), which were collected while this power plant was under construction, gave us a limited baseline to compare with 10 years of operational data (1973-82). Long time series, particularly before a planned disturbance, are not the norm in environmental investigations because of logistical and/or financial constraints. Nevertheless, our data base provides a valuable source of information on population trends. Specifically in this study, we looked to see if there were changes in the occurrence, distribution or abundance of benthic fish in response to alterations of temperature and current elevations by the thermal effluent.

Bigelow and Schroeder (1953), reported on groundfish in the Gulf of Maine including Cape Cod Bay, which detailed species' distributions and general abundances. More specifically, the seasonal occurrence and catch abundance of fishes north of Cape Cod, within the demarcation of Cape Cod Bay and its tributaries, were documented for Wellfleet Harbor (Curley et al. 1972), Plymouth-Kingston-Duxbury Bay (Iwanowicz et al. 1974), and Cape Cod Bay (Howe and Germano 1982; Lawton, Anderson et al. 1984).

Groundfish abundance in Gulf of Maine waters has been monitored by both the National Marine Fisheries Service (1976) and the Massachusetts Division of Marine Fisheries (Witherell and Burnett 1993) via seasonal bottom trawl surveys. Environmental impact assessments of coastal power plant operations on marine fish in Massachusetts waters were undertaken by Fairbanks et al. (1971), Anderson et al. (1975), Collings et al. (1981), Marine Research, Inc. (1981), and Lawton, Anderson et al. (1984).

III. STUDY AREA

Bottom trawling was conducted at from three to five fixed sampling stations in marine waters located 4.5 - 6.5 km (2.8 - 4.0 mi) off the entrance of the nearby estuary - Plymouth Harbor, Kingston, and Duxbury Bay (PKDB) and, within a 3.2 km (2.0 mi) radius of the Pilgrim Nuclear Power Station (Figure 1). Three of these sampling sites were selected prior to power plant operation, predicated on the criteria of suitable substrate for trawling and patterns of the thermal plume as predicted by modelling (Bechtel Corporation 1968). It is helpful to know the spatial scale of a reputed environmental impact before it occurs, in that a proposed warm-water outfall into a receiving water body may have only a localized effect on the surrounding few hundred square meters of bottom.

Station 1 (6 m (20 ft) depth, MLW) in Warren Cove is located 3.0 km (1.9 mi) northwest of Pilgrim Station and is closest to PKDB. Commercial trawling for groundfish in the area occurs seasonally followed by an area closure; intense fishing occurs especially in Warren Cove beginning in November. Station 2 (9 m (30 ft) depth, MLW) is nearest the discharge canal, located 0.9 km (0.6 mi) northeast of the plant. It was believed at the time of station selection that this site would be impacted on the bottom by the thermal plume and was designated as the surveillance location. In reality, the spatial scale of thermal impact on the bottom at Pilgrim Station was not well defined in advance of or even after plant startup. Station 3 (12 m (40 ft) depth, MLW) is 1.7 km (1.1

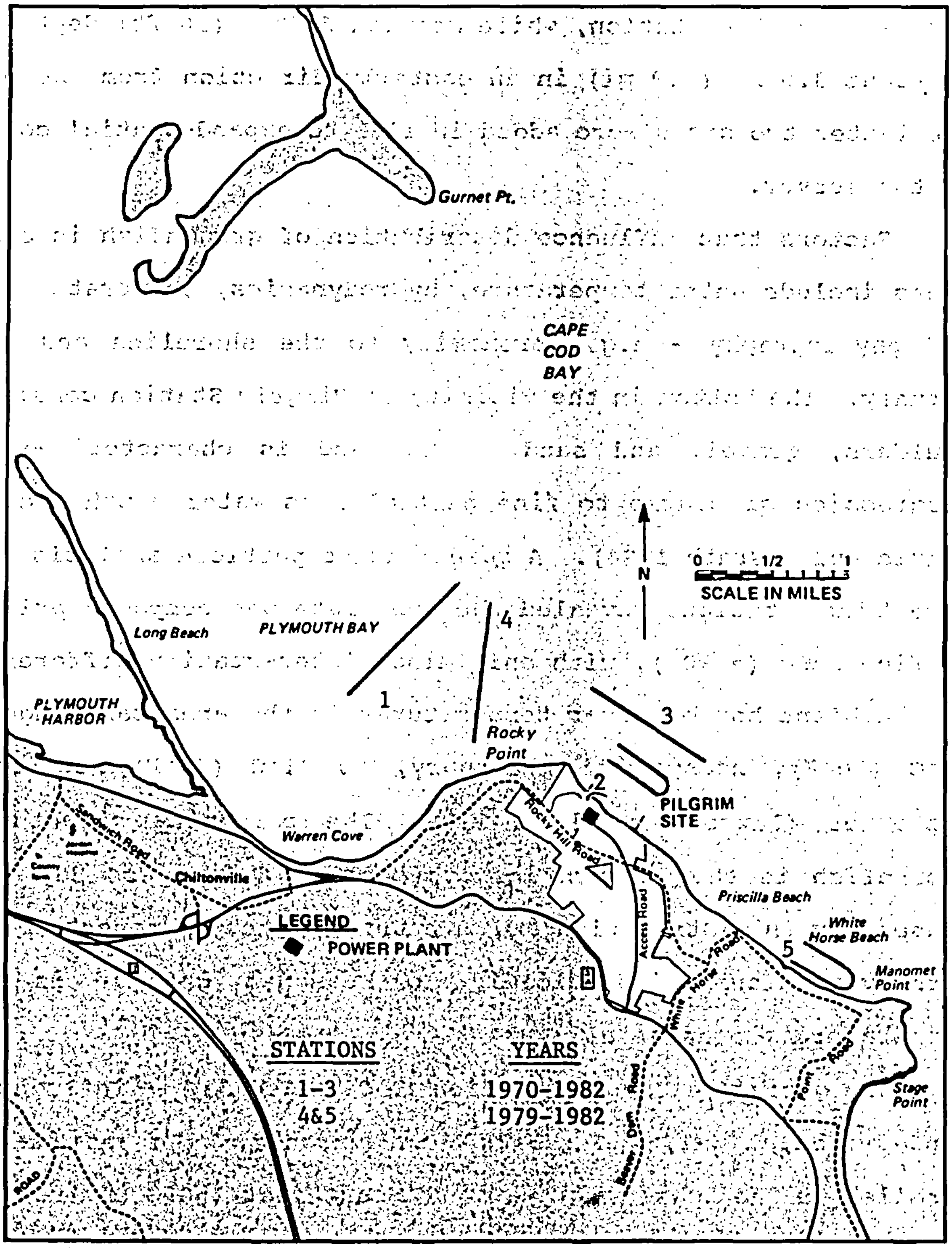


Figure 1. Bottom otter-board trawl sampling stations on the inshore grounds of western Cape Cod Bay in the vicinity of the Pilgrim Nuclear Power Station, 1970-1982.

mi) northeast of the discharge canal and seaward of Station 2. Station 4 (6 m (20 ft) depth, MLW) is situated 1.9 km (1.2 mi) northeast of the station, while Station 5 (3 m (10 ft) depth, MLW) is about 3.0 km (1.9 mi) in an easterly direction from the plant. The latter two sites were added in 1979 to expand spatial coverage of the survey.

Factors that influence distribution of groundfish in coastal areas include water temperature, hydrodynamics, substrate, cover, and physiography - e.g., proximity to the shoreline and nearby estuary. The bottom in the vicinity of Pilgrim Station consists of boulders, gravel, and sand. The sand is characterized by a progression of coarse to fine particles as water depth increases (Davis and McGrath 1984). A quantitative particle analysis at our five trawl stations revealed the substrate was composed primarily of fine sand (> 90%), with only minor inter-station differences.

Ambient bottom water temperatures in the area can range from -1°C (30°F), measured in February, to 21°C (70°F) recorded in September (Lawton et al. 1983). The community structure of groundfish in the western inshore sector of Cape Cod Bay varies seasonally in distribution and abundance of the component species, with variations tied closely to seasonal changes in water temperature (Horst et al. 1984).

The overall water circulation in Cape Cod Bay is influenced by wind-driven, tidal, and geostrophic currents, with residual flow parallel to the coast and toward the southeast (EG&G Environmental Consultants 1975). Efficient tidal flushing (estimated tidal prism of about 9.3% of the water volume) of Cape Cod Bay results in its waters showing little salinity variation from Massachusetts Bay and the Gulf of Maine (Davis 1984), with salinities generally in the high 20's to the low 30's parts per thousand.

IV. METHODS AND MATERIALS

Biweekly duplicate 20-minute bottom trawl tows were made at stations from aboard the Division's 15.5m (51 ft) R/V *F.C. Wilbour* (rigged as a side trawler). Using a standard survey method, tows were completed during daylight hours. In the Frontispiece and in Plates 1 to 4 are pictured the research vessel and various aspects of the trawl sampling. The sampling gear consisted of a ½-Yankee 35 bottom otter trawl with the following specifications:

- doors - 0.8 x 1.5 m (2.6 x 4.9 ft), 68 kg (150 lb) each of two;
- bridles - 0.9 m (3.0 ft);
- headrope - 7.6 m (25 ft);
- footrope - 10.7 m (35 ft), with 4.8 mm (0.2 in) chain, and 7.6 cm (3.0 in) rubber discs;
- mesh size - all sections: 11.4 cm (4.5 in) bar mesh, with a 3.8 cm (1.5 in) bar-mesh liner in the codend.

The wire towing cable was deployed according to water depth as follows - 30.5 m (100 ft) of cable for ≤ 9.1 m (30 ft) of water and 45.7 m (150 ft) for depths > 9.1 m (30 ft). The setting and hauling of the cable was done with a hydraulic winch.

The vessel was operated at a constant rpm, and the towing speed was estimated to be 4.6 km/hr (2.9 mph). The distance towed in 20 minutes was influenced by the direction and speed of the wind, tide, and other flow (current) patterns in the Bay. On average, a distance of 1.4 km (0.87 mi) was covered over the bottom

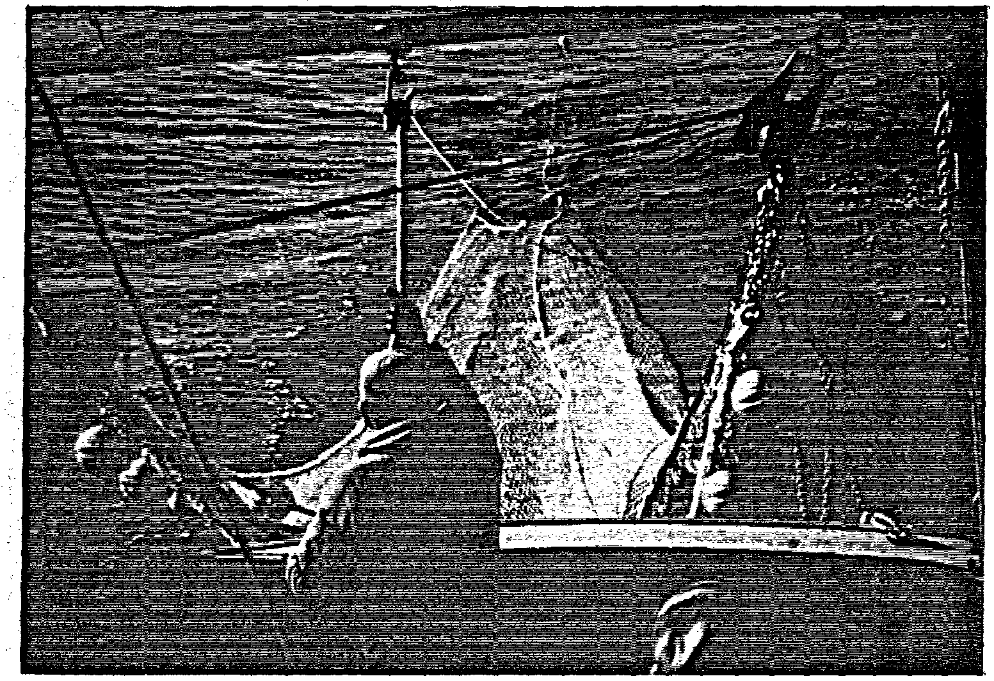


Plate 1. Bottom otter-door trawl being retrieved following a 20-minute bottom tow to quantitatively sample groundfish in the Pilgrim Station area.

Plate 2. Sample catch of bottom fish is dumped from the cod-end of the otter trawl on the deck of the research vessel for processing.

Plate 3. Typical bottom trawl collection of groundfish endemic to the inshore region of western Cape Cod Bay.

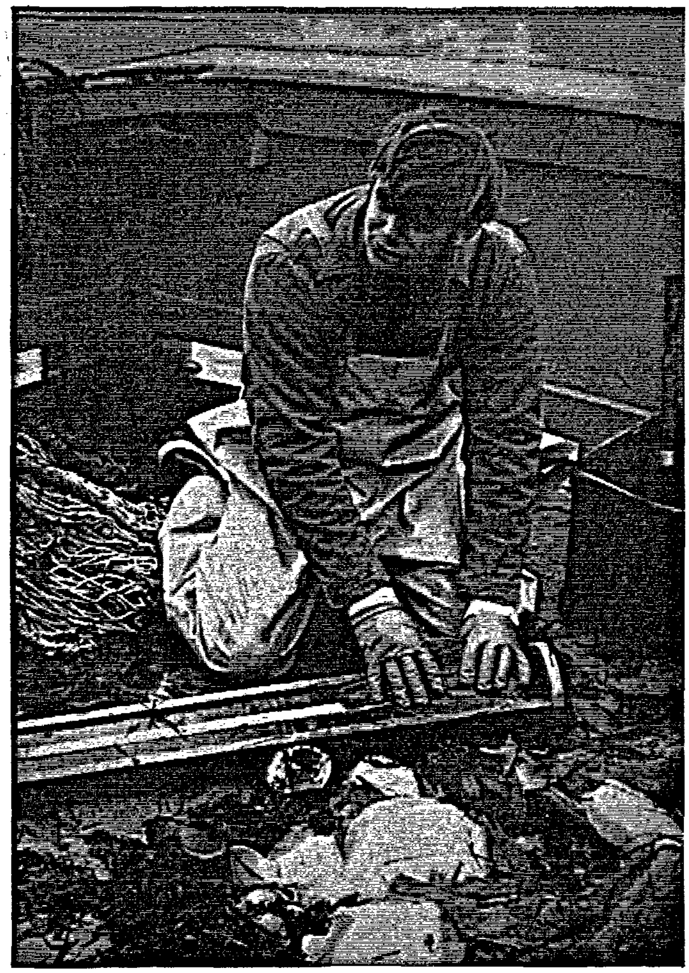


Plate 4. Sample trawl catch, including flatfish pictured here, is processed, which includes identifying, enumerating, and measuring all finfish captured.

in 20 minutes. Whenever possible, the order of station sampling was altered to randomize variation in catch related to gear use, e.g., the accumulation of macro-algae in the net can add to gear selectivity.

Although we followed a standardized sampling scheme, inclement weather, vessel breakdown, and interference with lobster gear resulted in aborted tows or tow omissions. Each trawl catch was sorted - fish were identified, enumerated, and most were measured. Catches too large to process (ca. one percent) were sub-sampled representatively, and data were extrapolated. During the early years of the survey, hakes (*Urophycis* spp.) and skates (*Raja* spp.) were not identified to species but were later in the study. Scientific nomenclature was according to Robins et al. (1980, 1991). Water temperatures (surface and bottom) were measured on station at the time of sampling.

Our trawl data were collected to monitor the area's dominant groundfish over time and space for occurrence, distribution, and relative abundance. We fished standard tows to equate usage with a standard unit of effort. Catch per unit effort (CPUE) in time, i.e., catch (mean number) per standard 20-minute tow, was our measure of abundance, and the relative change in the annual index was the information of interest.

Commercially/recreationally important and numerically dominant in the groundfish community off Pilgrim Station, winter flounder were selected for additional analyses. Winter flounder were sexed (n = 946), and scale samples collected for aging (n = 1,089 fish) over the course of one survey year (1975). Samples were stratified on a quarterly basis for the year, and a total of 440 samples (241 females, 199 males) was selected randomly and aged by Division personnel to provide an even quarterly distribution (Howe and Pierce 1976). Scales from each sample were water soaked, cleaned, and non-regenerated ones were mounted between glass slides. Each sample was aged independently twice under magnification (43 X) of a microprojector. Length frequencies by centimeter (0.4 in) interval were compiled. A catch-at-age matrix (annual mean CPUE for each age group sampled by the trawl) was derived from age-length keys and catch data.

V. DATA ANALYSES

If trawl sampling is too frequent, data may not be independent, which can be problematic in statistical analyses. In addition, our selection of permanent stations ruled out randomness as part of the sampling design. We chose to consider a population as the appropriate unit to investigate. Data were used to measure changes in population abundance over time and between stations. Implicit in this are two assumptions: one, that changes seen at the standard index sites reflect overall changes in the Pilgrim area, and second, that catch per tow is linearly related and proportional to absolute abundance of the species' population of concern.

As there were definite seasonal changes in our trawl catches (Horst et al. 1984), we endeavored to overcome differences in sampling effort (number of tows) at each of the stations by weighting catch per effort data to generate an even sample size. This did not meet with success because of data gaps that occurred during several summers when interference with lobster gear precluded trawl sampling.

The spatial distribution of many marine fish is patchy, i.e., overdispersed. Trawl CPUE data for many species tend to follow a lognormal distribution, in that trawl catches render skewed frequency distributions. Therefore, log transformation was used in an attempt to normalize data and stabilize variances for numerically dominant groundfish. With winter flounder, there was only the occasional zero catch in our samples, and we used the natural log [ln (x+1)] transformation. The geometric mean was calculated, retransformed, and reported on a linear scale. For yellowtail flounder, skates, windowpane, and ocean pout, a large number of tows consisted of zero catches of these species; therefore, we employed the delta-distribution (Δ), which is lognormal but contains a proportion of zeros (Pennington 1986). McConnaughey and Conquest (1992) advocate the use of the geometric mean as an estimator of central tendency to index the abundance of species where individuals aggregate. Because of high variability generally in trawl data, the geometric or delta mean is more efficient than the arithmetic mean.

Because log transformations of the catch-effort data for the dominant species did not entirely solve the problem of non-normality of distribution or heteroscedastic variances, besides making use of parametric tests, we employed the non-parametric Kruskal-Wallis analysis of variance statistical test, which is distribution free. When the latter gave significant results, differences among means were ascertained using nonparametric multiple comparison procedures described by Zar (1984). We examined statistical power of a multi-way analysis of variance in order to determine our ability to detect differences in annual relative abundance of the dominant species taken in our trawl study.

VI. RESULTS AND DISCUSSION

The composition of groundfish in western Cape Cod Bay reflects a transition between species assemblages found in the Gulf of Maine and those in the mid-Atlantic Bight (Horst et al. 1984). Bottom water temperatures in western Cape Cod Bay can range from - 1°C (30°F) to 21°C (70°F). A thermocline often is present from June to November. Salinities ranged from 28 to 33 ‰, influenced primarily by the ocean and to a lesser extent, watershed drainage as from PKDB.

Fifty finfish species (not all groundfish) were sampled in our trawl survey, which consisted of 1,322 standard tows made over the years, 1970 to 1982 (Table 1). Six groundfish taxa were numerically dominant comprising 92.1% of the 74,266 fish caught. In descending order of abundance were: winter flounder (*Pleuronectes americanus*), yellowtail flounder (*Pleuronectes ferrugineus*), skates (*Raja* spp.), ocean pout (*Macrozoarces americanus*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), and windowpane (*Scophthalmus aquosus*) (Figure 2). The numerical importance of winter flounder relative to various benthic fish assemblages in northern temperate fish communities is quite evident (Fairbanks et al. 1971; Tyler 1971; Iwanowicz et al. 1974; Anderson et al. 1975; Greenstein

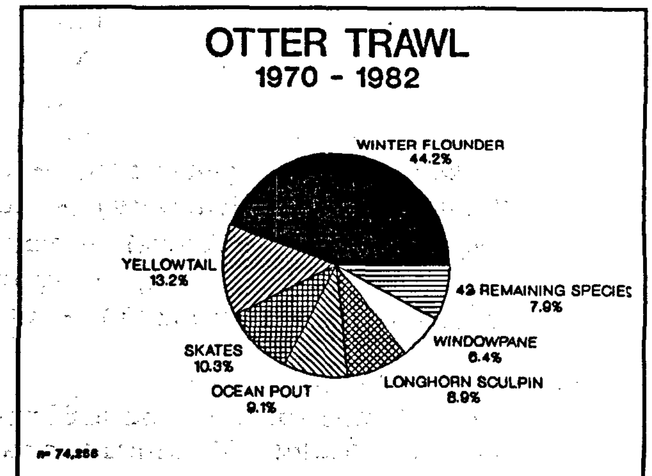


Figure 2. Catch (percent composition) of groundfish obtained by otter trawl from the western sector of Cape Cod Bay in the vicinity of the Pilgrim Nuclear Power Station, 1970-1982.

Table 1. Check list of finfish species captured by otter trawl in the western sector of Cape Cod Bay, 1970-1982.

Class: Elasmobranchiomorphi
Order: Lamniformes
Family: Carcharhinidae - requiem sharks
Mustelus canis (Mitchill) - smooth dogfish

Order: Squaliformes
Family: Squalidae - dogfish sharks
Squalus acanthias Linnaeus - spiny dogfish

Order: Rajiformes
Family: Rajidae - skates
Raja erinacea (Mitchill) - little skate
Raja ocellata Mitchill - winter skate

Class: Osteichthyes
Order: Clupeiformes
Family: Clupeidae - herrings
Alosa aestivalis (Mitchill) - blueback herring
Alosa pseudoharengus (Wilson) - alewife
Alosa sapidissima (Wilson) - American shad
Brevoortia tyrannus (Latrobe) - Atlantic menhaden
Clupea harengus Linnaeus - Atlantic herring

Order: Salmoniformes
Family: Osmeridae - smelts
Osmerus mordax (Mitchill) - rainbow smelt

Order: Gadiformes
Family: Gadidae - codfishes
Gadus morhua Linnaeus - Atlantic cod
Melanogrammus aeglefinus (Linnaeus) - haddock
Merluccius bilinearis (Mitchill) - silver hake
Microgadus tomcod (Walbaum) - Atlantic tomcod
Pollachius virens (Linnaeus) - pollock
Urophycis chuss (Walbaum) - red hake
Urophycis regia (Walbaum) - spotted hake
Urophycis tenuis (Mitchill) - white hake

Order: Lophiiformes
Family: Lophiidae - goosefishes
Lophius americanus Valenciennes - goosefish

Order: Atheriniformes
Family: Atherinidae - silversides
Menidia menidia (Linnaeus) - Atlantic silverside

Table 1. (cont.)

Order: Gasterosteiformes
Family: Gasterosteidae - sticklebacks
Gasterosteus aculeatus Linnaeus - threespine stickleback

Family: Sygnathidae - pipefishes and seahorses
Sygnathus fuscus Storer - northern pipefish

Order: Scorpaeniformes
Family: Triglidae - searobins
Prionotus carolinus (Linnaeus) - northern searobin
Prionotus evolans (Linnaeus) - striped searobin

Family: Cottidae - sculpins
Hemitripterus americanus (Gmelin) - sea raven
Myoxocephalus aenaeus (Mitchill) - grubby
Myoxocephalus octodecemspinosus (Mitchill) - longhorn sculpin
Myoxocephalus scorpius (Linnaeus) - shorthorn sculpin

Family: Cyclopteridae - lumpfishes and snailfishes
Cyclopterus lumpus Linnaeus - lumpfish
Liparis atlanticus (Jordan & Evermann) - Atlantic seasnail

Order: Perciformes
Family: Serranidae - sea basses
Centropristis striata (Linnaeus) - black sea bass

Family: Pomatomidae - bluefishes
Pomatomus saltatrix (Linnaeus) - bluefish

Family: Sparidae - porgies
Stenotomus chrysops (Linnaeus) - scup

Family: Carangidae - jacks
Selene vomer (Linnaeus) - lookdown

Family: Sciaenidae - drums
Menticirrhus saxatilis (Bloch & Schneider) - northern kingfish

Family: Labridae - wrasses
Tautoga onitis (Linnaeus) - tautog
Tautogolabrus adspersus (Walbaum) - cunner

Family: Zoarcidae - eelpouts
Macrozoarces americanus (Schneider) - ocean pout

Table 1 (cont.)

Family: Pholidae - gunnels
Pholis gunnellus (Linnaeus) - rock gunnel

Family: Scombridae - mackerels
Scomber scombrus Linnaeus - Atlantic mackerel

Family: Stromateidae - butterfishes
Peprilus triacanthus (Peck) - butterfish

Order: Pleuronectiformes
Family: Bothidae - lefteye flounders
Paralichthys dentatus (Linnaeus) - summer flounder
Paralichthys oblongus (Mitchill) - fourspot flounder
Scophthalmus aquosus (Mitchill) - windowpane

Family: Pleuronectidae - righteye flounders
Hippoglossus hippoglossus (Linnaeus) - Atlantic halibut
Pleuronectes americanus Walbaum - winter flounder
Pleuronectes ferrugineus (Storer) - yellowtail flounder

Order: Tetraodontiformes
Family: Balistidae - leatherjackets
Aluterus schoepfi (Walbaum) - orange filefish
Monacanthus hispidus (Linnaeus) - planehead filefish

Family: Tetraodontidae - puffers
Sphoeroides maculatus (Bloch & Schneider) - northern puffer

1978; Marine Research, Inc. 1980; and GEOMET Technologies, Inc. 1981).

Considering the hierarchy in catch, winter flounder ranked first in each of the 13 survey years. Ocean pout was second in the early years but fell to fourth by the end of the time series. Yellowtail flounder initially ranked third but by the end of the study averaged second overall. Longhorn sculpin and windowpane each fell a rank overall in catch from the early years of the survey, placing fifth and sixth, respectively. Skates made the biggest increase climbing from sixth to third position, apparently filling the void caused by the declining numbers of ocean pout and longhorn sculpin in the local groundfish community.

Murawski (1993) identified components in fish distribution from the seasonal patterns of temperature, depth, and latitude. He defined three major types of life history adaptions to seasonal temperature fluctuations seen in the ichthyofauna. One type describes the groundfish community in the Pilgrim area and includes the same group of dominant species. Referred to as shallow-water sedentary species, they are characterized by showing little directional movement and are not especially sensitive to the range of natural temperature fluctuations encountered.

Winter Flounder

Common in the Northwest Atlantic from the Gulf of St. Lawrence to Chesapeake Bay, winter flounder are eurythermal and euryhaline, being found in waters of temperatures from 0° to 25°C (32° to 77°F) and salinities from 4 to 30 ‰. Comprised of several stocks that, in turn, can consist of estuarine associated populations (Saila 1961; Pierce and Howe 1977), this species is population rich (Sinclair 1992). In addition to exhibiting geographic reproductive isolation, various life stages from a population are often discrete from nearby populations. Saila (1961) found adult winter flounder to show fidelity to the same spawning grounds in consecutive years. Spawning/retention areas are known to be located in estuaries, over shoals outside estuaries, and on offshore banks. Nursery areas occur in the general vicinity of spawning and include such places as saltwater coves, coastal salt ponds, embayments, and estuarine river systems. Young-of-the-year (YOY) winter flounder are reported to remain in or near their natal waters (Buckley 1982). Behavior of the early life stages offsets drift dispersal, which is linked to physical oceanographic processes, leading to retention of a population in a specific area (Sinclair 1992).

For management purposes in Massachusetts, three groups of winter flounder have been identified: a stock north of Cape Cod, another south and east of the Cape, and a third on Georges Bank (Howe and Coates 1975). Winter flounder in Cape Cod Bay may occur as estuarine related population units (Stone and Webster 1975). PKDB is a known winter flounder spawning ground and nursery area that contributes to the production of local fish in the environs of Pilgrim Station. There are seasonal inshore and offshore movements of flounder in this area, as adults disperse to and from winter-spring spawning aggregations. When the water temperature exceeds

15°C, flounder generally move seaward to deeper waters within Cape Cod Bay.

Our trawl survey catches of winter flounder included fish from 2 cm (0.8 in) to 52 cm (20.5 in) in total length (TL), and based on age-length keys developed for flounder north of Cape Cod (Witherell et al. 1990), the fish ranged in age from YOY to >9 years old. In 1975 when the catch of flounder from our study area was sexed (Howe and Pierce 1976), the ratio of females to males was 3:2; this was a time of low stock abundance. Witherell and Burnett (1993) found that sex ratios of winter flounder favored females at older ages, indicating a higher natural mortality rate for males.

We assumed that our trawl CPUE provided unbiased estimates of relative abundance (Lawton, Anderson et al. 1984). Edwards (1968) reported that winter flounder are vulnerable to the Yankee trawl, while Oviatt and Nixon (1973) found them to be uniformly distributed on the bottom with high availability to this gear. Catch at age data revealed that winter flounder became fully available to our sampling gear generally as adults, i.e., by ages 3 to 4 (Howe and Pierce 1976). For the Cape Cod Bay stock for both sexes, maturation generally begins at age 3 and is nearly complete at age 5 (Witherell and Burnett 1993).

Winter flounder were most abundant at Station 1 in Warren Cove (Figure 3), where over half the total catch was obtained during many years of the survey. Relative abundance generally was lowest at Station 3 (Figures 3 and 4). A unimodal intra-year distribution of catches was seen at Stations 1 and 2 which indicates a

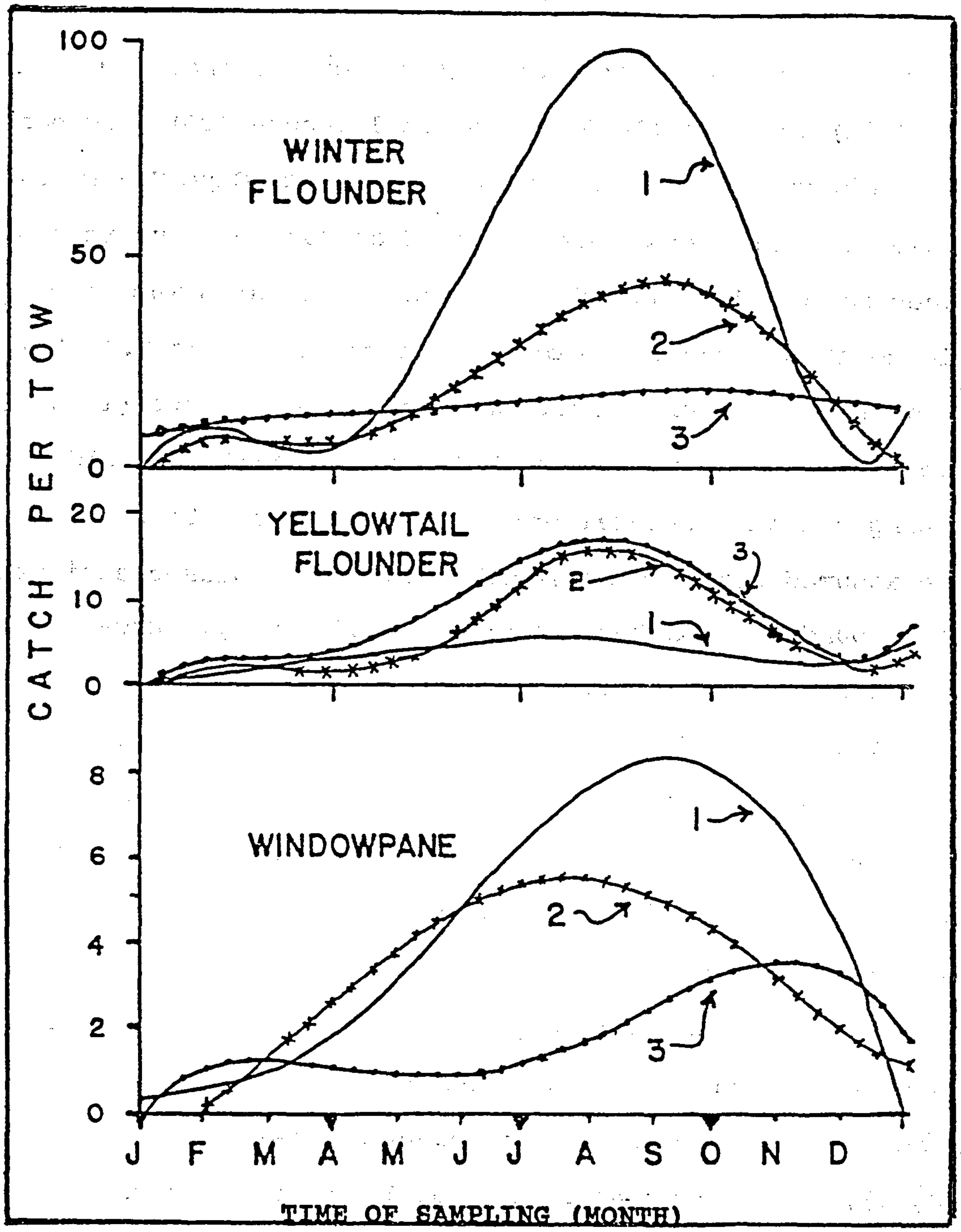


Figure 3. Intra-year relative abundance (pooled yearly data) for flounder in the Pilgrim Station study area at the original three fixed stations: 1- Warren Cove, 2- 9m depth contour, 3- 12m contour.

pronounced seasonality in abundance at those locations (Figure 3). Catches peaked in mid-summer at the former location and about 30 days later for the latter site, possibly resulting from a shift in a segment of the population from spawning habitat to Plymouth Bight and beyond as the waters warmed. The spring/summer migration produces a dispersal of the population, with larger fish distributing beyond the headlands. Howe and Coates (1975), nevertheless, concluded from a tagging study that seasonal movements of winter flounder north of Cape Cod are in general relatively localized, being limited to deeper, cooler inshore waters.

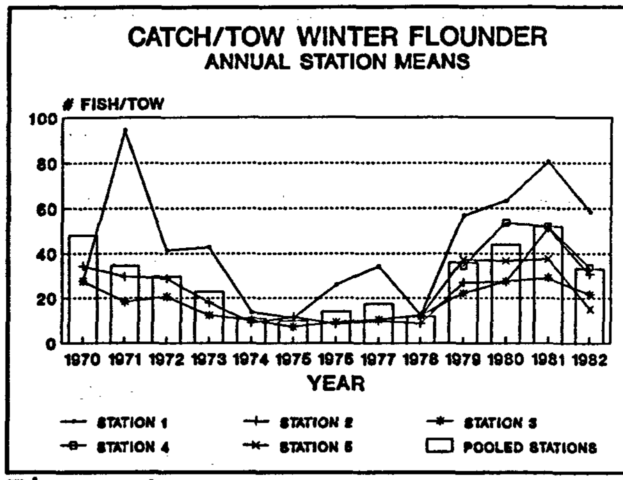


Figure 4. Annual mean catch per standard trawl tow of winter flounder at fixed stations in western Cape Cod Bay, 1970-1982.

Although winter flounder (juveniles and adults) were captured all seasons of the year, abundance nearshore was highest in summer, lowest in winter. Abundance inside PKDB was found to peak in early autumn, with most being juveniles (Iwanowicz et al. 1974). There appeared to be no defined seasonal peak at Station 3, however (Figure 3). Catches there were relatively constant throughout the year, suggesting an increased stability of the environment for flounder with increasing depth. This provided the first intimation that some members of the population may not utilize the nearby estuary to spawn. In fact, Chau and Pearce (1977) from their analysis concluded that winter flounder larvae arriving at Pilgrim Station likely originate from other sources besides aduction from PKDB. Marine Research, Inc. (1986) aged winter flounder eggs entrained at Pilgrim Station and concurred that spawning occurs near the plant in addition to the acknowledged estuarine spawning area.

When Stations 4 (Rocky Point) and 5 (Priscilla Beach) were added to the sampling regime in 1979, the former recorded the second highest catch rates through 1982. Stations 2, 3, and 5 showed less inter-year variations than did 1 and 4 (Figure 4).

From 1970 to 1975, there was a marked decline in catch at the three stations sampled at the time (Figure 4), with a 79% decrease noted overall in the annual mean CPUE for pooled station data. In 1976, the downward trend apparently was arrested, and an upward swing began which continued through 1981, during which time relative abundance increased more than fourfold overall in the study area.

A downward trend in our survey indices from 1970 to 1975 reflected a decline in local population abundance. This decline, however, was seen region-wide in winter flounder population units during the period. Catches also were down in populations from Salem Harbor (Chesmore et al. 1974; Anderson et al. 1975), Narragansett Bay and Block Island Sound (Jeffries and Johnson 1974), Niantic Bay (Battelle unpublished), Nantucket Sound (Howe 1975), and Mount Hope Bay (Marine Research, Inc. 1980).

The abundance trends in our survey parallel those flagged by annual commercial fishery landings. Historically, it appears that winter flounder landings in Massachusetts followed a 20-year cycle (Howe 1975). Highs occurred in 1947 and 1966 which were interspersed with a low in 1955. The mid-1970's corresponded to another cyclic low which was reflected in our catch/effort records. A resurgence in abundance indicated in our research survey from 1976 to 1981 (Lawton et al. 1981) also was detected in research catches elsewhere - Mount Hope Bay (Marine Research, Inc. 1980), Niantic River and Bay (Northeast Utilities 1980), and northern Long Island (GEOMET Technologies, Inc. 1981). US commercial winter flounder landings likewise increased in the late 1970's reaching an all-time high of 14.0 x 10^6 kg (30.9 million lbs) in 1981 but then fell over the next 7 years totaling only 5.6 x 10^6 kg (12.3 million lbs) in 1988 (Witherell et al. 1990). Although the data base from our Yankee-trawl survey ended in 1982, we recorded an overall decline of 36% in interannual winter flounder relative abundance from 1981 to 1982. The decline of the 1980's is counter to the cyclic abundance pattern of earlier years, in that another high would have been expected in the mid-1980's.

The widespread spatio-temporal agreement in interannual variability in abundance suggests that similar regulating processes were ongoing in geographically distinct winter flounder populations. One thing is certain, overfishing has been instrumental in stock declines (Witherell et al. 1990). Howe and Pierce (1976) demonstrated back in 1975 that stock overfishing of the local Plymouth flounder population was occurring. Commercial catches exceeded annual sustainable yields, and the population was estimated to be only 20% of the 1970 abundance level.

When examining catch at length and age data over the survey, we found that annual fluctuations in relative abundance were age (size) related. Catch rates for age groups 1 and 2 (mostly juveniles) were similar until after 1978 when many more small fish appeared in our catches. It appears that inter-year variability in catch rates is driven by year-class strength variation in this age-structured population. Another example of this is the relative abundance of age-3 flounder which fell from a high in 1970 to a low in 1975, followed by a marked increase from 1976 to 1981. Catches of age 4 flounder declined noticeably after 1972, followed by a slight upswing from 1979 to 1982. The number of age 5 and older fish in our research catches also declined markedly following 1972 but remained low thereafter, no doubt a result of fishing pressure as these older age groups were 100% vulnerable to the nets of commercial trawl exploitation.

Using the Kruskal-Wallis nonparametric statistical test (an analogue of the parametric single classification analysis of variance) we found no significant difference ($P > 0.05$) in annual catch rates amongst Stations 1, 2, and 3 during preoperational years (1970 to 1972). However, there was a highly significant difference ($P < 0.01$) between stations during operational years. Specifically, Stations 1 (reference) and 2 (surveillance) had significantly different ($P < 0.01$) catch rates, while Stations 2 and 3 (reference) did not ($P > 0.50$). The data at Stations 2 and

3 were most alike, while the catch rates at Stations 1 and 3 differed as follows: $0.10 < P > 0.05$, i.e., not at the conventional alpha of ≤ 0.05 for significance.

Employing a multi-way analysis of variance, we examined for power of the test when measuring for differences in log transformed catch rates between stations and at a station over the years. We set alpha at 0.05 and found that beta (i.e., the probability of making a type II error) for inter-station comparisons was 0.56 and for station by year was 0.21. There is obviously a real problem of insensitivity when testing for spatial differences between stations, but not at a station for inter-year comparisons.

For the period of declining flounder abundance in the early 1970's, which began prior to power plant operation, a parametric linear regression analysis of catch rates over time revealed a marked downward trend, with the greatest change occurring at reference Station 1 (Figure 5). The rate of change at Stations 2 and 3 was about one-third and one-fourth, respectively, that at Station 1. This reduces the potential of the power plant having a thermal effect on winter flounder abundance. A fifth order polynomial was fitted to the inter-year data of relative abundance by the method of least squares in order to investigate change during power plant pre-operational and operational time periods (Figure 5). Over the early years of the survey, there were peaks and subsequent declines in relative abundance at Stations 1 and 2 prior to the commencement of operation at Pilgrim Station. Variation in relative abundance was less at Station 3.

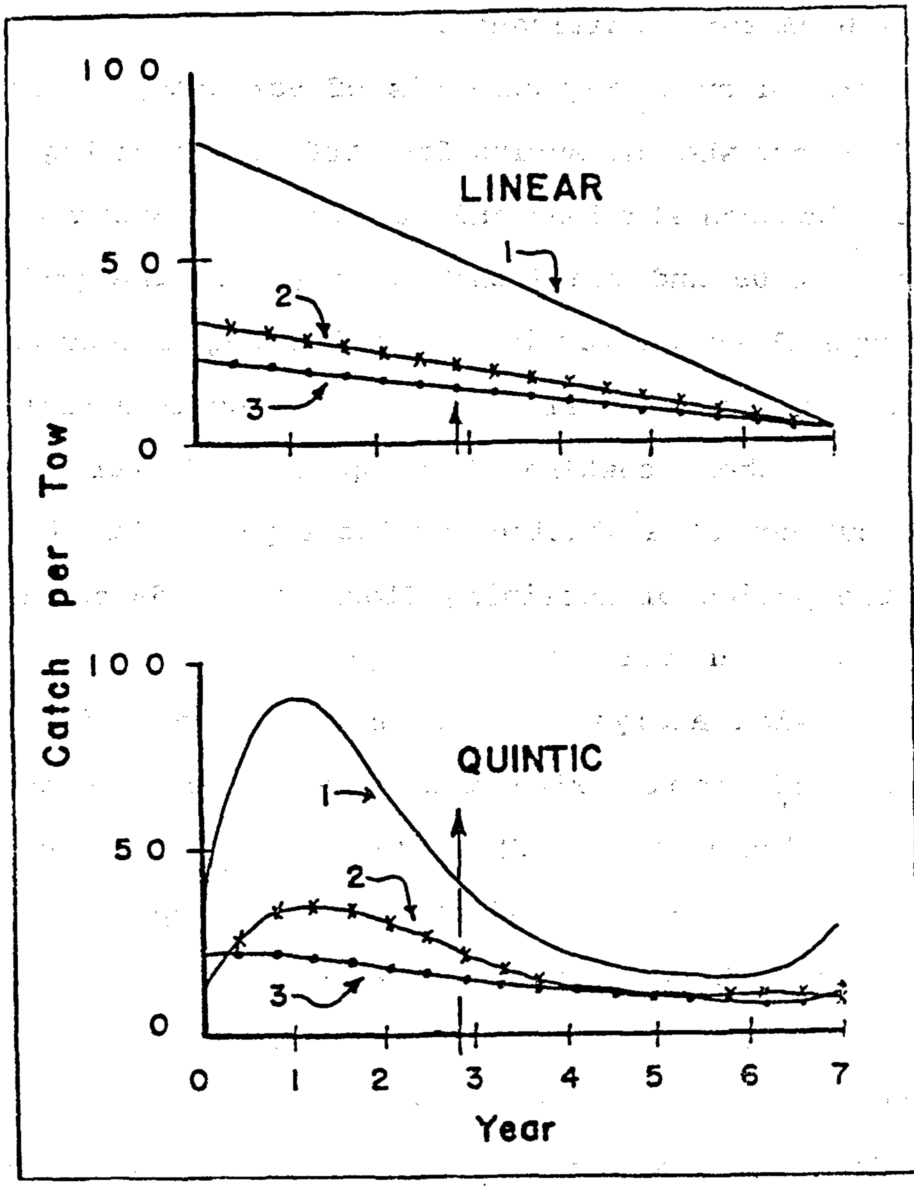


Figure 5. Annual trawl catch rates over time (1970-1976) for winter flounder: top, estimated linear trend for stations 1-3; bottom, estimated quintic trend (5th order polynomial) for the same stations. (Arrow indicates commencement of PNPS operation).

There is no indication that occurrence, distribution, or abundance of winter flounder were significantly altered by the PNPS thermal plume based on the stations sampled. Furthermore, no direct mortalities of flounder have been documented in the thermal plume. Based on our SCUBA diving surveys, it is evident, however, that flounder are seasonally excluded by high temperatures from the immediate vicinity of the Pilgrim discharge. Current may also be a contributing factor. This impact area is relatively small (~ 4,000 m^2 - 1 acre).

Yellowtail Flounder

This flatfish ranges from Labrador to Chesapeake Bay. Tagging and other studies on juvenile and adult characteristics and on migrations and movements (Lux 1963) indicate that yellowtail flounder are generally sedentary and occur as relatively discrete groups. Separate stocks are found on Georges Bank, in Southern New England, the Mid-Atlantic Bight, off Cape Cod and in the Gulf of Maine. Spawning, which occurs during spring and summer at temperatures between 4° and 9°C (39° to 48°F), peaks in May. The eggs are pelagic, as is the larval stage; the latter lasts for a month or more. However, because of their vertical distribution, concomitant with ontogenetic changes in behavior, dispersal of the larvae, via surface-layer, wind-driven circulation, is limited prior to their metamorphosis and settlement to the bottom (Smith et al. 1978).

Although yellowtail flounder - both juveniles and adults -, which are congeners of winter flounder, are found in shoal water and overlap winter flounder in distribution, overall they inhabit greater depths. Their depth range is from about 9 m (30 ft) to 110 m (360 ft). Sand or a mixture of sand and silt are the preferred bottom habitat for this demersal fish.

Yellowtail flounder ranked second overall in catch over the survey years: 1970 to 1982 (Figure 2). Size composition of the catch ranged from 3 cm (1.2 in) (YOY) to 51 cm (20.1 in) TL. Catches generally were lowest at Station 1 and highest at Station 3 (Figures 6 and 7), which is likely related to depth preference. Although they were caught throughout the year, seasonal abundance variation was evident. At Stations 2 and 3, there were marked unimodal distributions in relative abundance (Figure 3), with modes in mid-to-late-summer, similar to winter flounder abundance peaks in the same area. No mode was particularly noted at Station 1.

Availability and vulnerability coefficients for this species were similar to those for winter flounder (Edwards 1968). For the study area, using pooled station data (Figure 6), we found that CPUE fell in 1972 (pre-operational), reaching a low in 1974. This was followed by an increase in the annual catch rate which began in 1975, culminating in the high levels of 1979 to 1981. In 1982, the final survey year, the overall catch rate markedly declined again to the former low of 1974. Area findings (pooled data) generally were mirrored at each sampling station. A fifth order polynomial distributional plot of catch data suggests that annual abundance fluctuations might have a cyclical component (Figure 7). For the

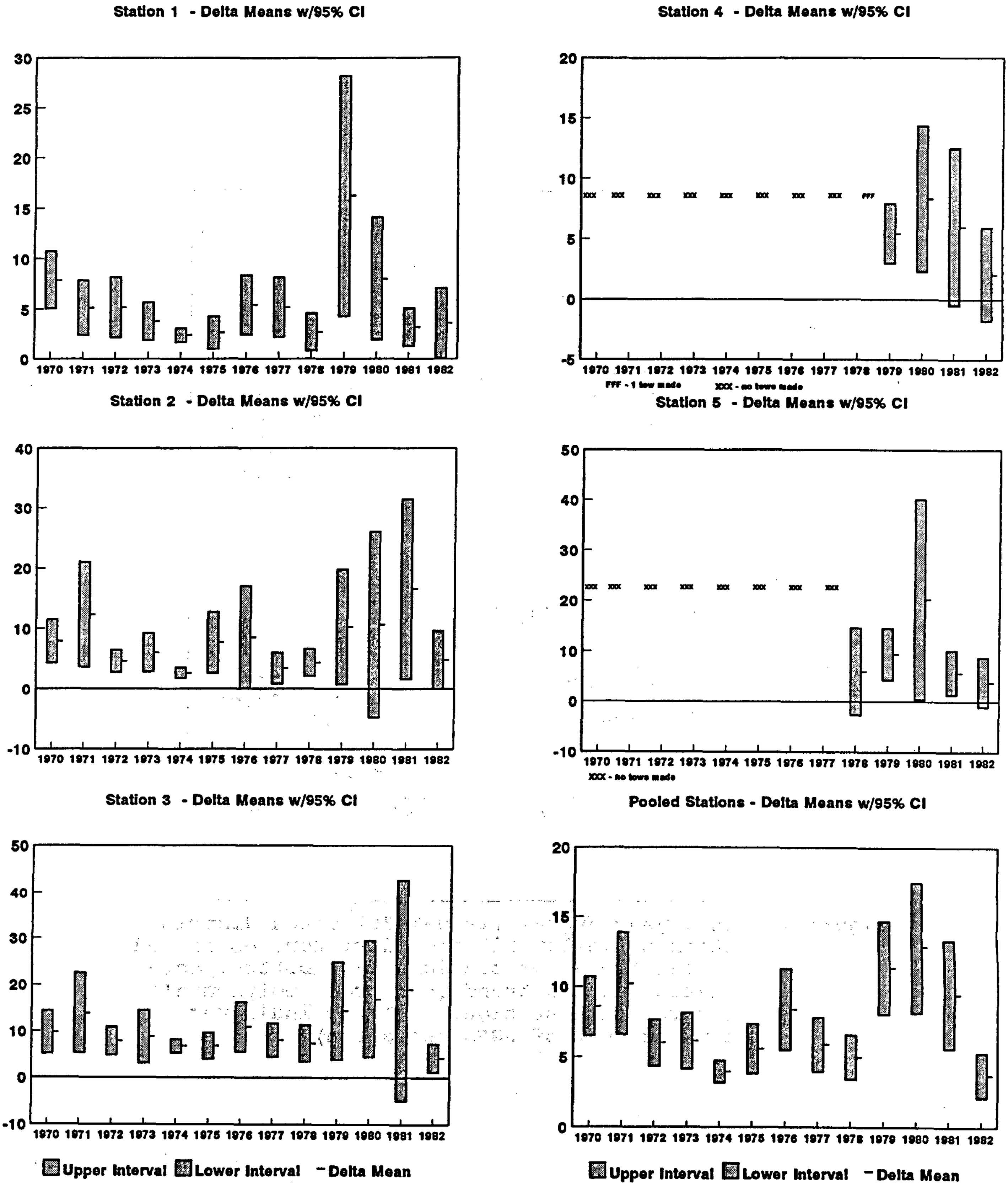


Figure 6. Mean annual catch per standard trawl tow and estimates of precision ($\bar{X} \pm 2SE$) for yellowtail flounder at fixed stations in western Cape Cod Bay, 1970 - 1982.

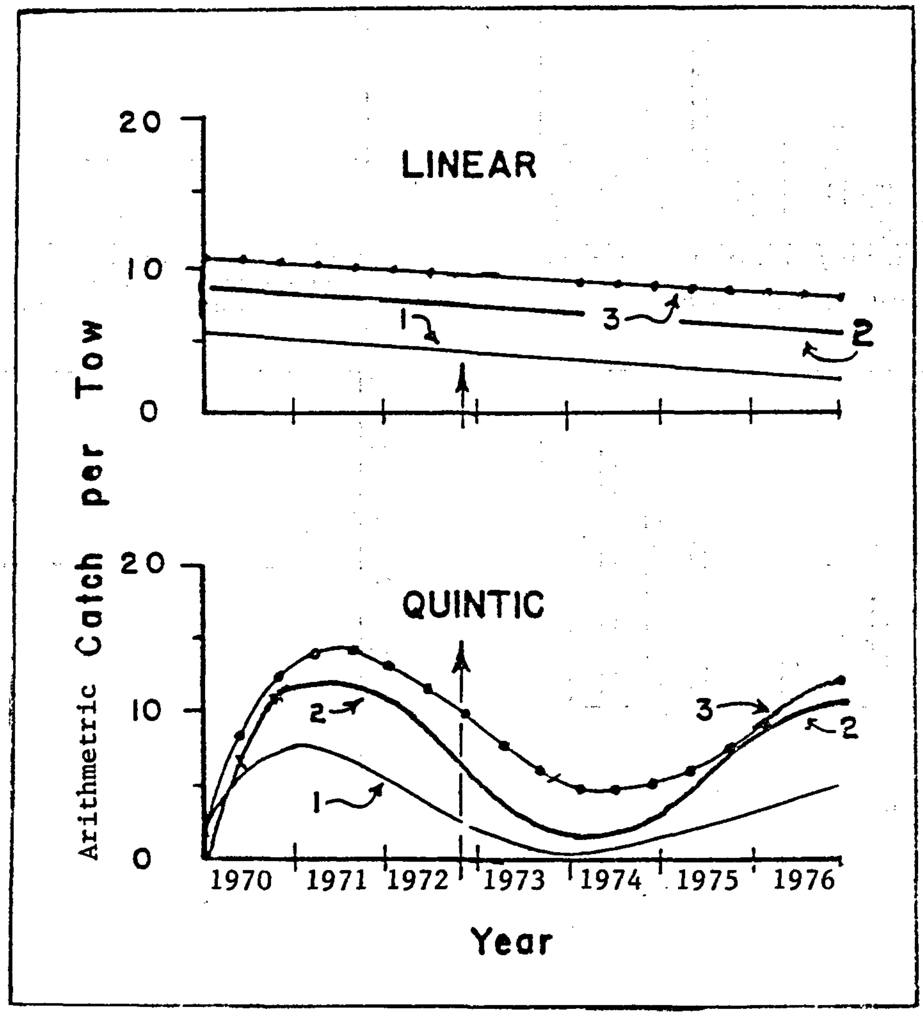


Figure 7. Interyear annual (1970-1976) catch distribution of yellowtail flounder: top, estimated linear trend for stations 1-3; bottom, estimated quintic trend (5th order polynomial) for the same stations. (Arrow indicates commencement of PNPS operation).

first seven years of the survey, the overall trend (linear regression) was for relative abundance to decrease at about the same negative rate of change for all stations (Figure 7).

Using the Kruskal-Wallis and multiple comparisons' tests, we found no significant ($P > 0.05$) difference in catch rates between pre-operational and operational periods at the stations sampled. As for station pairs during the preoperational period, CPUE at Stations 1 and 3 were significantly different ($P < 0.05$) and were deleted from further analysis. Stations 1 and 2 ($P > 0.5$) and 2 and 3 ($P > 0.2$) were not significantly different for CPUE. During operational years, CPUE at Stations 1 and 2 were not significantly different ($P > 0.1$), but Stations 2 and 3 were ($P < 0.001$). Thus Station 3 was statistically different from the reference and surveillance stations in catch rate of yellowtail flounder. Comparing the preoperational and operational periods, we found no significant ($P > 0.05$) difference in relative abundance at each station.

When examining for statistical power, with alpha set at 0.05, beta was found to be 0.05 for analysis of variance of density comparisons at a station over time, and conversely power was 0.95, which is very sensitive to measure differences if they exist. Whereas, beta was 0.71 (power = 0.29) for comparisons between stations which is insensitive, evidently because of the high level of variation amongst sites.

Commercial landings from Cape Cod Bay fluctuated in the early 1970's, but increased markedly in the latter part of that decade, with a high reached in 1980. This was followed by a decline to record lows in the 1980's (Northeast Fisheries Science Center 1992). The stock assessment survey of the Northeast Fisheries Science Center (1992, 1993) reflected the general pattern of commercial landings but also flagged a low in 1974, as we found in our survey. Our indices from the inshore sector of western Cape Cod Bay mirrored well the overall picture in the Bay. Declining commercial landings and corresponding general downward trends in research survey indices have been attributed to overfishing. The Cape Cod Bay stock is considered overexploited.

An examination of length frequencies in our trawl catches revealed the modal catch by length was from 10 to 15 cm (3.9 to 5.9 in) TL for the years 1970 to 1976, but from 1977 through the end of the survey in 1982, the mode ranged from 29 to 32 cm (11.4 to 12.6 in) TL. Reduced abundance of small fish in our catches suggests there was lower recruitment in the late 1970's and early 1980's. Overfishing can impact the size of a spawning stock which, in turn, can adversely affect recruitment.

There is no indication that yellowtail flounder occurrence, distribution, or abundance were significantly impacted by the PNPS thermal discharge. Although, yellowtail flounder eggs are entrained at Pilgrim Station each spring, the numbers are not particularly high.

Skates

Skates, primarily little skate (98%) with small numbers of winter skate, ranked third overall, comprising about 10% of the trawl survey catch. Skates are widely distributed throughout the Northwest Atlantic from near shore to depths exceeding 700 m (393 fathoms). The center of distribution of little and winter skates is Southern New England/Georges Bank, but the former species is also a common resident in Cape Cod Bay. Skates are not known to make large-scale migrations but do move inshore and offshore in response to water temperature changes.

Temporally, our trawl catches of skates were highest in summer. Spatially, forty-four percent of the survey's catch came from Station 1 in Warren Cove, where consistently the highest catches were garnered. Edwards (1968) reported that skate species of this region are considered fully available to the Yankee trawl (i.e., with a coefficient of 1.0), but, in general, skates have low vulnerability to a trawl, for they tend to be herded ahead of a bottom-towed net.

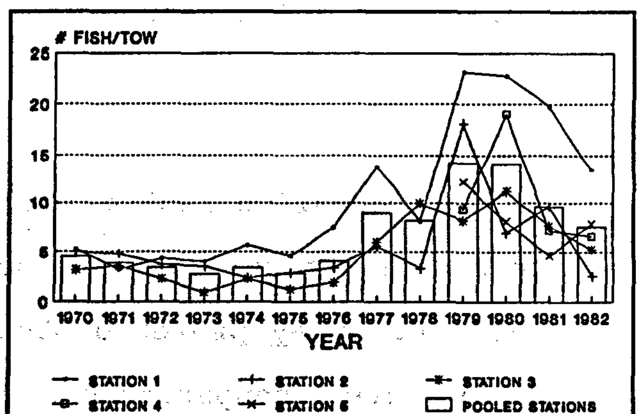


Figure 8. Trawl catch per tow (delta mean) of skates at fixed stations in the vicinity of Pilgrim Station, 1970-1982.

Abundance indices were low in our survey throughout most of the 1970's but then showed signs of increasing in the late 1970's and early 1980's (Figure 8). New England commercial fishery landings of skates peaked in 1969 but declined steadily during the 1970's, bottoming out in 1981; landings subsequently increased. Northeast Fisheries

Science Center (1990) research bottom trawl surveys revealed that skate abundance indices declined modestly in the 1970's reaching a series low in 1979. This was followed by a marked increased into the 1980's. Skates have limited reproductive capacity, and stocks potentially could collapse through extensive exploitation.

Skate catch rates began to increase at all sampling stations during the operational period, and no negative power plant effect was indicated. With the Kruskall-Wallis test, we found no significant differences ($P > 0.05$) in CPUE at any of the stations comparing the preoperational and operational periods. During the preoperational period, CPUE was not significantly different ($P > 0.05$) amongst the stations sampled. During the operational years, Stations 1 and 3 had significantly different catch rates ($P < 0.05$). This in no way, however, implicates Pilgrim Station as the cause. Power of yearly comparisons at a station via multi-way ANOVA was excellent (0.94), but for station comparisons, power was only 0.45 with a 55% chance (beta) of making a Type II error.

<u>Ocean Pout</u>

This groundfish ranked fourth in overall trawl totals (9.1%) by the end of the survey. The ocean pout's range is from Labrador to Delaware. They prefer depths of 15 to 80 m (8 to 44 fathoms) and cool water temperatures of 6° to 7° C (43° to 45° F). Population identification studies point to the existence of two stocks of ocean pout: one in the Bay of Fundy - northern Gulf of Maine region east of Cape Elizabeth, and the other occupying the region from Cape Cod Bay south to Delaware. Mark and capture/recapture studies combined with research bottom-trawl surveys reveal that adult ocean pout do not carry out extensive migrations but do move seasonally between different substrates (Northeast Fisheries Science Center 1990).

Seasonally, ocean pout were scarce in our late summer and fall trawl catches, being caught in highest abundance in late winter and spring. Olsen and Merriman (1946) found that in late summer, adults cease feeding and congregate over rocky substrate which may be untrawlable. Spawning occurs on hard bottom in September and October. The demersal eggs, in turn, are guarded by both parents until hatchout. Conversely, during winter and spring, ocean pout disperse over smoother grounds (sand or sand-gravel) to feed, where they become more susceptible to commercial trawling.

Our survey CPUE data provided estimates of ocean pout relative abundance. Edwards (1968) reported ocean pout have fairly high availability (0.9) and vulnerability (0.7) coefficients Highest catches, by far, were made at Station 2, which garnered 62% of the total. CPUE data from the study area reflected a long-term marked downward trend in relative abundance (Figure 9). From 1970 to 1982, overall relative abundance (pooled station data) in the

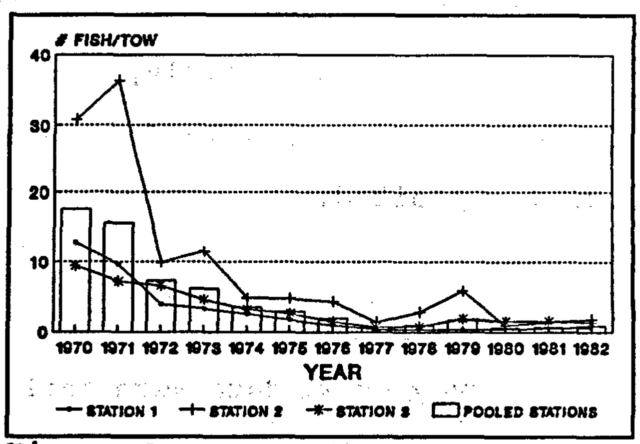


Figure 9. Research bottom trawl catch per tow (annual delta mean) of ocean pout at fixed stations in the environs of Pilgrim Station, 1970-1982.

Pilgrim study area steadily declined (95% overall), with Stations 1, 2, and 3 all showing substantial decreases. There were statistically significant differences ($P < 0.01$) across years for these stations. For a multi-way ANOVA, alpha was 0.05, and beta was 0.38. Limited data were collected at Stations 4 and 5, and the catches there also were low. Declining CPUE persisted at all stations throughout the survey, during both pre-operational and operational study years. The numerical decrease in abundance was greatest at Station 2 (surveillance location). However, no power plant discharge effect can be construed from our trawl data.

Commercial interest in ocean pout has fluctuated widely. From 1964 to 1974 a domestic industrial fishery developed, and nominal catches by our U.S. fleet averaged 4,700 mt. Commercial catches declined to average 600 mt annually for the years 1975 to 1983. From 1968 to 1975, both commercial landings and Northeast Fisheries Science Center spring survey data followed similar trends; declines occurred from historic highs in 1968 and 1969 to lows of 300 mt and 1.6 kg/tow, respectively, in 1975 (Northeast Fisheries Science Center 1990). The population even at that time appeared to be fully exploited.

Longhorn Sculpin

Survey trawl data were analyzed through 1976, with the catches so low thereafter no further analysis was undertaken. Ranking fifth, this species was captured in highest abundance during the warmer months, with over half the total catch obtained at Station

3. Annual trawl-survey data (Table 2) disclosed an 89% decrease in relative abundance during plant operational years (1973 to 1976),

Table 2. Arithmetic mean annual trawl catch per tow and standard deviation (pooled catch) for longhorn sculpin at fixed stations in the environs of Pilgrim Station, 1970-1976.

	Stations 1 Warren Cove		2 9-m Contour		3 12-m Contour		Pooled		
Year	Number of Tows	Mean CPUE	Number of Tows	Mean CPUE	Number of Tows	Mean CPUE	Number of Tows	Mean CPUE	Standard Deviation
1970	42	3.38	42	7.79	39	20.03	123	10.16	15.40
1971	43	2.49	42	5.83	42	9.95	127	6.06	8.54
1972	41	4.83	41	6.46	41	9.49	123	6.98	7.51
1973	22	2.27	22	3.73	22	10.00	66	5.33	5.96
1974	44	1.68	40	1.95	42	3.76	126	2.46	3.09
1975	45	0.78	38	0.89	45	1.49	128	1.06	1.61
1976	36	0.49	28	0.25	39	1.46	206	0.78	1.25

with mean catch rates falling 90%, 96%, and 85% at Stations 1 through 3, respectively. A downward trend is obvious at all sites, despite the fact that longhorn sculpin seasonally school on the bottom, which influences their availability to capture by trawl.

Declining abundance of this species was not limited to the Plymouth area. Howe and Estrella (1977), conducting a groundfish trawl survey in Nantucket Sound, likewise found a downward trend for longhorn sculpin during the years: 1974 to 1976, where there was an 85% decline overall in CPUE (pooled data). This is comparable to our finding for the period.

Windowpane

Distributed along the Northwest Atlantic from Florida north to the Gulf of St. Lawrence, windowpane occupy a large geographical range but concentrate in waters less than 46 m (25 fathoms) deep. Highest abundance is found from Georges Bank to Chesapeake Bay.

Maturity is reached between 3 and 4 years old, with spawning occurring from late spring to fall. Although this flatfish has a high availability coefficient (Edwards 1968) because of its fairly uniform distribution (Oviatt and Nixon 1973), their vulnerability to bottom trawling is lower than for winter flounder. Windowpane tend to rise high off the bottom when disturbed, which facilitates escape over a trawl net (Edwards 1968).

Of the top six groundfish in the Pilgrim study area, windowpane ranked last in catch at 6.4% of the trawl total. Occurring most of the year in the western inshore sector of Cape Cod Bay, windowpane, nevertheless, were most abundant during warmer months. This implies there are seasonal movements. Spatially, like winter flounder, highest catches (45% of the total) came from Warren Cove at Station 1.

Presently, there is no stock structure information available for this species. For sake of discussion, fish from Cape Cod Bay are grouped with Gulf of Maine-Georges Bank windowpane flounder. Our survey trawl data suggest overall abundance declined in the study area from 1970 to 1974 (Figure 10). Relative abundance generally increased at the sampling stations beginning in 1975 and peaked in 1979. This was followed by a decline.

Windowpane have fluctuated widely in abundance in southern New England. Trends similar to that described for the Plymouth area were reported for lower Narragansett Bay, Rhode Island (Jeffries and Johnson 1974); upper Mount Hope Bay (Marine Research, Inc. 1980); and Salem Harbor (Chesmore et al. 1972, 1973, 1974). The

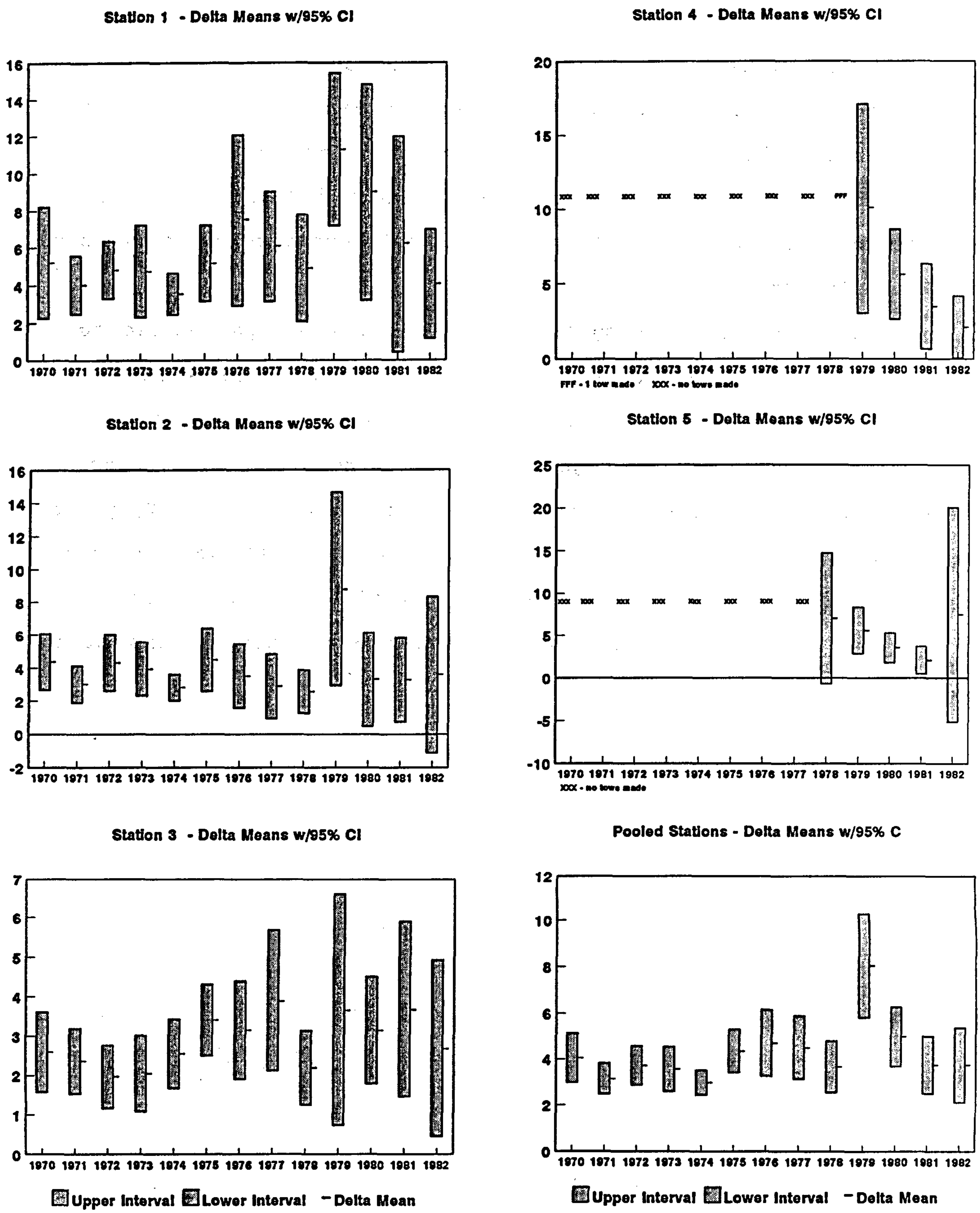


Figure 10. Mean annual catch per standard trawl tow and estimates of precision (X ± 2SE) for windowpane at fixed stations in western Cape Cod Bay, 1970 - 1982.

Northeast Fisheries Science Center (1992) autumn research survey indices for the Gulf of Maine-Georges Bank area were highly variable during the time of our survey but generally paralleled our findings. However, commercial catch-effort indices have shown a declining trend since 1975, which suggests overfishing (Northeast Fisheries Science Center 1990).

Statistically, using the Kruskal-Wallis non-parametric test (Zar 1984), we found no significant ($P > 0.05$) difference in annual catch rates at each station over the years: 1970 to 1982. In addition, there were no significant differences ($P > 0.05$) between preoperational (1970 to 1972) and operational (1973 to 1982) years at each site. In a multi-way ANOVA analysis of CPUE, we found that power was low (0.26) to detect spatial differences (between stations) but was high (0.89) for inter-year comparisons at a station.

IMPACT ASSESSMENT OF THE HEATED DISCHARGE CURRENT FROM PILGRIM STATION

To reliably detect ecological impact of anthropogenic activities, one must isolate observed effects from natural variability - both spatial and temporal. For many finfish populations, the high level of variation over time or especially space in abundance estimates results in the collection of "noisy" sampling data, where often the power of a statistical test is low when testing a null hypothesis. For some species populations, there may be a lack of agreement in temporal projections from place to place. Consequently, there often is considerable statistical interaction between changes in mean abundance spatio-temporally (Underwood 1994).

During the 13 year groundfish survey, species replacement in the dominance hierarchy was evident in the local benthic finfish community. Ocean pout, for example, fell from ranking second in the trawl catch to fourth by study's end, while skates climbed from sixth to third position overall. This reversal, where a dominant species declines in abundance to a lower level and is succeeded by another dominant, can produce cascading effects among other local biota (Fogarty et al. 1991).

Natural spatial variability, together with fishing mortality, limited our power to single out Pilgrim Station effects. The release of a large volume of waste-heat water at considerable velocity was expected to alter the composition of the benthos near the Pilgrim Station discharge (Bridges and Anderson 1984). This impact was realized, but on a much smaller scale than anticipated, resulting in insignificant effects on groundfish species. From SCUBA observations and measurements made after the conclusion of this survey, it was determined that Pilgrim's outfall has a local effect on no more than the surrounding several thousand square meters (~ 4,000 m^2 - 1 acre) of bottom outside the discharge canal via waste heat and current. This is a relatively small area to impact demersal fish whether by thermal kills or changes induced in occurrence and distribution.

We conclude from this survey that there was a general decline in relative abundance for most of the dominant groundfish in the Pilgrim study area, but this occurred over large geographical areas and evidently was strongly linked to other factors, such as fishing mortality and recruitment failures. In addition, overfishing can cause biomass flips via species shifts in groundfish communities resulting in yield losses of potential valuable biomass. Large marine ecosystems have exhibited marked changes when stressed, such as by exploitation. Groundfish have been replaced on Georges Bank by elasmobranchs and certain pelagic species (NEFSC 1994), despite total abundance remaining relatively stable as production is channeled into other species forms. Murawski and Idoine (1992) reported that biomass, species complements, and size structure are conservative properties of large marine systems.

VII. CONCLUSIONS

Of the 50 finfish species collected in our 13-year bottom trawl survey, 6 groundfish taxa predominated numerically. In descending order of abundance, they were winter flounder, yellowtail flounder, skates, ocean pout, longhorn sculpin, and windowpane.

As to the hierarchy of catch (percent composition), species shifts were evident over the survey. Although winter flounder ranked first each year, ocean pout fell markedly from second in the early years to fourth by the survey's end, being replaced by yellowtail flounder. Longhorn sculpin and windowpane each fell a rank in catch, while skates climbed from sixth to third position overall.

This assemblage of dominant groundfish has been characterized as exhibiting little directional movement or sensitivity to natural temperature fluctuations.

There is ample evidence that adult winter flounder spawn both inside and outside Plymouth, Kingston, Duxbury Bay which includes the vicinity of Pilgrim Station.

There was a region-wide decline in numbers of winter flounder throughout the mid-1970's which was followed by a resurgence through the early '80's. Then another decline followed. Our CPUE data from the inshore sector of western Cape Cod Bay mirrored these trends locally.

The widespread temporal agreement in abundance trends for flounder suggests that similar regulating processes were ongoing in different flounder populations. There is also evidence of cyclic abundance, with overfishing superimposed, which evidently caused a malapropos decline within the abundance pattern.

Our trawl data did not implicate the power plant's thermal discharge as significantly impacting winter flounder. In addition, no direct mortalities of flounder have been documented in the thermal plume. However, it is evident from diving observations that flounder are excluded, at least, seasonally from the immediate vicinity of the discharge because of heat, with current always being a factor.

Yellowtail flounder ranked second in overall trawl catch, and, although they are congeners and share the waters with winter flounder, yellowtail flounder abundance increased with depth.

Our trawl indices of yellowtail flounder abundance mirrored well the bigger picture of the Cape Cod Bay stock which fluctuated in abundance in the early 1970's reaching a high in the early '80's and then plummeting to record low levels the rest of the latter decade.

Statistically, we found no significant ($P > 0.05$) differences in catch rates of yellowtail flounder between the pre-operational and operational years at the fixed stations sampled. It is evident, however, that overfishing has deleteriously impacted yellowtail via adult stock reductions.

For the last six years of the survey there was evidence of reduced yellowtail flounder recruitment in the Pilgrim area. Overfishing also can cause stock-recruit failures.

Skates (primarily little skate) declined in abundance region-wide in the 1970's, but then catches increased into the 1980's. There is no evidence of power plant effects from the operation of Pilgrim Station impacting the occurrence, distribution, or abundance of this species.

Relative abundance of ocean pout declined dramatically long-term over the 13 year survey, steadily decreasing throughout the preoperational and operational years at each station; the overall reduction was 95% for the study area.

Longhorn sculpin abundance fell at each sampling station over the trawl survey. However, this species experienced a similar temporal decline of the same magnitude in Nantucket Sound.

Windowpane catches declined during the preoperational study period but generally increased within the operational period.

Species shifts in the dominance hierarchy of abundance (in numbers) occurred in the local groundfish community off Pilgrim Station.

There was a general decline in relative abundance for most of the numerically dominant groundfish, but this occurred over large geographical areas. Overfishing was implicated with several of the species, while Pilgrim Station thermal impact was determined not to be significant.

VIII. ACKNOWLEDGEMENTS

The authors thank the staff of the Division of Marine Fisheries (DMF) who contributed to the successful completion of the survey over the years, both in the field and at the office. A special thanks to Shirley Mitchell and Lewis Emerald for their assistance in sampling operations aboard the R/V *F.C. Wilbour*. Robert O'Hagan calculated trend equations and prepared several initial figures. We specifically extend appreciation to Mando Borgatti and Wendell Sides for their field work over the years. Finally, we acknowledge Kim Trotto for word processing various drafts of the manuscript, and Randall Fairbanks and W. Leigh Bridges of DMF, Robert D. Anderson of Boston Edison Company, and the Pilgrim Administrative-Technical Committee for guiding the study and for editorial reviews.

IX. LITERATURE CITED

Anderson, C.O., Jr., D.J. Brown, B.A. Ketschke, and E.M. Elliott. 1975. Semi-Annual Report, Number 1A. Investigations of the effects of electrical power generation on marine resources in Salem Harbor. Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Bechtel Corporation. 1968. Salt water use and waterfront development for Pilgrim Nuclear Power Station. Pilgrim Station Report Number 600. Boston Edison Company, Boston, Massachusetts.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. United States Fish and Wildlife Service, Fishery Bulletin 53:1-577.

Bridges, W.L., and R.D. Anderson. 1984. A brief survey of Pilgrim Nuclear Power Plant effects upon the marine aquatic environment, p. 263-271. *In:* J.D. Davis and D. Merriman (editors), Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, Berlin, FRG. 289 pp.

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.

Chau, T.S., and B.R. Pearce. 1977. Real time simulation of the winter flounder larvae entrainment near Pilgrim Nuclear Power Station. (Ralph M. Parsons Laboratory, M.I.T.) *In:* Marine Ecology Studies Related to the Operation of Pilgrim Station. Semi-annual Report No. 10. Boston Edison Company.

Chesmore, A.P., D.J. Brown, and J.C. Kinch. 1972. Progress Report - Numbers 1-4. Investigations of the effects of electrical power generation on marine resources in Salem Harbor. Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Chesmore, A.P., D.J. Brown, and B.A. Ketschke. 1973. Progress Report - Numbers 5 and 6. Investigations of the effects of electrical power generation on marine resources in Salem Harbor. Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Chesmore, A.P., D.J. Brown, B.A. Ketschke and E.M. Sawin. 1974. Progress Report - Numbers 7-9. Investigations of the effects of electrical power generation on marine resources in Salem Harbor. Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Collings, W.S., C. Sheehan, S. Hughes, and J. Buckley. 1981. Biological investigations relative to the effects of a second electrical generating unit upon some of the marine resources of northern Buzzards Bay and the Cape Cod Canal. Massachusetts Division of Marine Fisheries. 423 pp.

Curley, J.R., R.P. Lawton, D.K. Whittaker, and J.M. Hickey. 1972. A study of the marine resources of Wellfleet Harbor. Monograph Series Number 12. Massachusetts Division of Marine Fisheries. 37 pp.

Davis, J.D. 1984. Western Cape Cod Bay: hydrographic, geological, ecological, and meteorological backgrounds for environmental studies, p. 1-18. *In:* J.D. Davis and D. Merriman (editors), Observations on the Ecology and Biology of Western Cape Cod Bay, Mass. Springer-Verlag, Berlin, FRG. 289 pp.

Davis, J.D., and R.A. McGrath, 1984. Some aspects of nearshore benthic macrofauna in western Cape Cod Bay; p. 77-102. In: J.D. Davis and D. Merriman (editors), Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, Berlin, FRG. 289 pp.

Edwards, R.L. 1968. Fishing resources of the North Atlantic area: the future of the fishing industry of the United States. University of Washington Publication in Fisheries, No. 4:52-60.

E.G. and G., Environmental Consultants. 1976. Forecasting power plant effects on the coastal zone. Waltham, Massachusetts. 187 pp.

Fairbanks, R.B., W.S. Collings, and W.T. Sides. 1971. An assessment of the effects of electrical power generation upon marine resources in the Cape Cod Canal. Massachusetts Division of Marine Fisheries. 48 pp.

Fogarty, M., E.B. Cohen, W.L. Michaels, and W.W. Morse. 1991. Predation and the regulation of sand lance populations: an exploratory analysis. ICES Mar. Sci. Symp. 193:120-124.

Geomet Technologies, Inc. 1981. Preoperational aquatic ecology study, Shoreham Nuclear Power Station, Unit 1. Broadhollow Road, Melville, New York.

Greenstein, D. 1978. Abundance and distribution of demersal fish in the vicinity of Cousins Island, Casco Bay, Maine. Environmental Studies Department, Central Maine Power Company, Augusta, Maine.

Horst, T., R. Lawton, R. Toner, and M. Scherer. 1984. Seasonal abundance and occurrence of some planktonic and ichthyofaunal communities in Cape Cod Bay: evidence for biogeographical transition, p. 241-261. *In:* J.D. Davis and D. Merriman (editors), Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, Berlin, FRG. 289 pp.

Howe, A.B. 1975. Fishery resource assessment: winter flounder and other species. Massachusetts Division of Marine Fisheries, Boston, Massachusetts.

Howe, A., and P. Coates. 1975. Winter flounder movement, growth, and mortality off Massachusetts. Transactions of the American Fisheries Society. 104:13-29.

Howe, A.B., and D.E. Pierce. 1976. Fishery Resource Assessment: winter flounder and other species. Massachusetts Division of Marine Fisheries. Boston, Massachusetts.

Howe, A.B., and B.T. Estrella. 1977. Fishery resource assessment: winter flounder and other species. Massachusetts Division of Marine Fisheries. Boston, Massachusetts.

Howe, A.B., and F.J. Germano. 1982. Fisheries and environmental baselines relative to dredge spoil disposal, Cape Cod Bay, 1981. Massachusetts Division of Marine Fisheries. 19 pp.

Iwanowicz, H.R., R.D. Anderson, and B.A. Ketschke. 1974. A study of the marine resources in Plymouth, Kingston, and Duxbury Bay. Monograph Series Number 17. Massachusetts Division of Marine Fisheries. 37 pp.

Jeffries, H.P., and W.C. Johnson. 1974. Seasonal distributions of bottom fishes in the Narragansett Bay area: seven-year variations in the abundance of winter flounder (*Pseudopleuronectes americanus*). Journal of the Fisheries Research Board of Canada 31:1057-1066.

Lawton, R.P., P. Brady, C. Sheehan, M. Borgatti, J. Egan, H. Davis and B. Doyle. 1981. Progress report on studies to evaluate possible effects of the Pilgrim Nuclear Power Station on the marine environment. Project Report Number 30. *In:* Marine Ecology Studies Related to Operation of Pilgrim Station. Semi-Annual Report Number 17. Boston Edison Company, Boston, Massachusetts.

Lawton, R., E. Kouloheras, P. Brady, W. Sides, and M. Borgatti. 1983. Distribution and abundance of larval American lobsters, *Homarus americanus* Milne-Edwards, in the western inshore region of Cape Cod Bay, Massachusetts, p. 47-52. *In:* M.J. Fogarty (ed.), Distribution and relative abundance of American lobster, *Homarus americanus*, larvae: New England investigations during 1974-79, 64 pp. NOAA Technical Report. NMFS SSRF-775.

Lawton, R.P, R.D. Anderson, P. Brady, C. Sheehan, W. Sides, E. Kouloheras, M. Borgatti, and V. Malkoski. 1984. Fishes of western inshore Cape Cod Bay: studies in the vicinity of the Rocky Point shoreline, p. 191-230. *In:* J.D. Davis and D. Merriman (editors), Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts. Springer-Verlag, Berlin, FRG. 289 pp.

Lux, F.E. 1963. Identification of New England yellowtail flounder groups. Fish. Bull. (U.S.). 63:1-10.

Marine Research, Inc. 1980. Brayton Point Generating Station, Mount Hope Bay, Somerset, Massachusetts. Section 316 (b) Demonstration. 35 pp.

Marine Research, Inc. 1986. Winter flounder early life history studies related to operation of Pilgrim Station - A review, 1975-1984. Pilgrim Nuclear Power Station Marine Environmental Monitoring Program - Report Series No. 2 Boston Edison Company. 111 pp.

McConnaughey, R.A., and L.L. Conquest. 1992. Trawl survey estimation using a comparative approach based on lognormal theory. Fish. Bull., U.S. 91:107-118.

Murawski, S.A. 1993. Climate change and marine fish distributions: forecasting from historical analogy. Trans. Am. Fish. Soc. 122 (5): 647-658.

Murawski, S.A., and J.S. Idoine. 1992. Multi-species size composition: a conservative property of exploited fishery systems. Northwest At. Fish. Sci. 14:79-86.

National Marine Fisheries Service. 1976. Current fisheries statistics, Number 7179, Massachusetts landings, December, 1976. National Oceanic and Atmospheric Administration.

Northeast Fisheries Science Center (NEFSC). 1990. Report of the 11th NEFC Stock Assessment Workshop. NEFSC reference document 90-09. U.S. Dept. of Commerce, NOAA, NMFS, Woods Hole, Mass.

Northeast Fisheries Science Center (NEFSC). 1992. Status of Fishery Resources off the Northeastern United States for 1991. U.S. Dept. of Commerce, NOAA, NMFS, Woods Hole, Mass. 133 pp.

Northeast Fisheries Science Center (NEFC). 1993. Status of the Fisheries Resources off the Northeastern United States for 1992. National Marine Fisheries Service, Woods Hole, MA. 133 pp.

Northeast Fisheries Science Center (NEFC). 1994. Status of the Fisheries Resources off the Northeastern United States for 1993. NOAA Technical Report. NMFS-F/NEC-101. National Marine Fisheries Service, Woods Hole, MA.

Northeast Utilities Service Co. (NUSCO). 1980. Monitoring the Marine Environment of Long Island at Millstone Nuclear Power Station. Waterford, CT. 269 pp.

Olsen, Y.H., and D. Merriman. 1946. The biology and economic importance of the ocean pout (*Macrozoarces americanus*). Bulletin of the Bingham Oceanographic Collection 9(4):1-184.

Oviatt, C.A. and S.W. Nixon. 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution, and abundance. Estuarine and Coastal Marine Science: 361-378.

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fish. Bull., U.S. 84: 519-525.

Pierce, D., and A. Howe. 1977. A further study on winter flounder group identification off Massachusetts. Trans. Amer. Fish. Soc. 106(2):131-139.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.M. Lea, and W.B. Scott. 1980. A List of Common and Scientific Names of Fishes From the United States and Canada. 4th Edition. Special Publication Number 12, American Fisheries Society. 174 pp.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.M. Lea, and W.B. Scott. 1991. Common and Scientific Names of Fishes from the United States and Canada. 5th Edition. Special Publication No. 20. American Fisheries Society. 183 pp.

Saila, S.B. 1961. A study of winter flounder movements. Limnol. Oceanogr. 6:292-298.

Science Applications International Corporation (SAIC). 1992. Marine Ecology Studies Related to Operation of Pilgrim Station. Semi-annual report No. 40 (January-June, 1992). Boston Edison Co., Boston, MA, USA.

Sinclair, M. 1992. Marine Populations: An Essay on Population Regulation and Speciation. University of Washington Press. 252 pp.

Smith, W.G., J.D. Sibunka, and A. Wells. 1978. Diel movements of larval yellowtail flounder, *Limanda ferruginea*, determined from discrete depth sampling. Fisheries Bulletin (U.S.). 76:167-178.

Stone and Webster Engineering Corporation. 1975. 316 (a and b) Demonstration for Pilgrim Nuclear Power Station - Units 1 and 2. Boston, Massachusetts.

Tyler, A.B. 1971. Periodic and resident components in communities of Atlantic fishes. Journal of the Fisheries Research Board of Canada. 28(7):935-946.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4(1):1-15.

Witherell, D.S., S. Correia, A. Howe, and T. Currier. 1990. Stock assessment of winter flounder in Massachusetts waters. Massachusetts Division of Marine Fisheries. 46 pp.

Witherell, D.B., and J. Burnett. 1993. Growth and maturation of winter flounder, *Pleuronectes americanus*, in Massachusetts. Fishery Bulletin. 91:816-820.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs. 718 pp.