SUPPLEMENTAL ASSESSMENT IN SUPPORT OF THE 316 DEMONSTRATION PILGRIM NUCLEAR POWER STATION UNITS 1 AND 2 BOSTON EDISON COMPANY

SEPTEMBER 1977

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I INTRODUCTION

This is a report on supplemental analyses which have been performed in support of the "316 Demonstration for the Pilgrim Nuclear Power Station Units 1 and 2, Boston Edison Company," which was published in July of 1975. Since the publication of the 316 Demonstration report, additional ecological and hydrographic data have been collected at the Pilgrim site. These data are similar in nature to those used in the original 316 Demonstration report; therefore, although they utilize an expanded data base by the inclusion of 1975 and 1976 study results, the present analyses are similar to the original analyses reported in July 1975.

The analyses contained in this supplemental analysis are also similar to those applied in the 316 Demonstration in that conservative assumptions are used which result in overestimation of the prediction of impact. Therefore, the predictions in this supplement should be viewed as upper bounds in that the impact should be no greater than predicted and in many situations will probably be less than predicted. Some examples of the conservative assumptions are discussed below.

In estimating entrainment impact, it is assumed that 100 percent of the organisms die upon passage through the cooling system. Some information on mortality through the Pilgrim cooling system, which has a relatively brief transit time, supports the idea that some organisms survive passage. This mortality will depend upon species, life stage and time of the year. Onsite studies for gastropod and bivalve larvae indicate, for example, that 90 percent or more may survive passage. In assessing impingement, it is assumed that all organisms which are impinged die.

The prediction of the temperature increase in the thermal plume, which may cause mortality, is taken as the lowest temperature indicated by available information as having an adverse effect. This temperature may be the critical thermal maximum, the LT_{50}, or the lethal temperature (see Appendix A for an explanation of these temperature criteria). That is, when information on all temperature indices is available, the lowest among them is used.

In projecting the effects of Units 1 and 2 operation, it is assumed that Units 1 and 2 will operate at full load each day of the year.

In predicting the effects of the thermal plume, and of entrainment and impingement on the populations of certain species, it is assumed that the organisms effected are members of localized populations. This assumption tends to concentrate the effect and increase the predicted impact.

In situations where limitations in the present taxonomic ability preclude positive identification to the species level, all

organisms belonging to the larger taxonomic category were assumed to belong to the species being analyzed. This assumption also inflates the effect of the power station.

In most cases the assessments of impact at the population level do not use the concept of biological compensation. This concept is the mechanism by which populations respond to exploitation and maintain a viable population. Therefore, the absence of compensation in the impact assessment methodology results in an overestimated impact.

In general, the assessments contained in the 316 Demonstration and this analysis are conservative and the actual effects should probably be smaller than those predicted. Indeed, the field data collected during Unit 1 operation indicate that the actual effects are less than those predicted for Unit 1 operation.

The results of the studies conducted at the Pilgrim site have been reported in the Boston Edison Semi-Annual Marine Ecology Series, which presently consists of nine volumes. The list of ecological and hydrological studies associated with Pilgrim Station was represented in Appendix B of the original July 1975 report. This material has been updated and is presented in Appendix B of this supplemental report.

The analyses which are contained in this report consider the effects of both the Pilgrim discharge and intake. Consequently, the analyses address both the Section 316(a) and 316(b) requirements of the Federal Water Pollution Control Act Amendments of 1972. The analyses also consider the effects of Unit 1 and the combined effects of Units 1 and 2. Analyses are reported for each of 13 representative important species considered in the original 316 Demonstration report. The supplemental analyses, contained in the section of this report that follows the "II ASSESSMENT" tab, are presented in a format analogous to the July 1975 report. That is, the section and subsection numbers correspond to those used in the original report for ease of cross-referencing with Section 6 of that report.

The sources of information specific to each representative important species are noted in the respective section for the species. The information on the thermal tolerances of the representative important species, which was Appendix A in the original July 1975 report, has been supplemented and is reported as Appendix A in this report.

The assessments of isotherm areas utilized in the "316 Demonstration for Pilgrim Nuclear Power Station, Units 1 and 2," issued in July 1975, were developed from centerline profiles contained in the Pilgrim Station Environmental Report. By utilizing the distance along the centerline as the radius of a circle, areas within which the plume would be contained were determined. These were interpreted as envelope areas which would contain the plume

but not necessarily be filled by the plume. Based on the consideration of the thermal tolerances of the representative important species, relevant isotherms were used in the analysis.

This supplemental assessment utilizes the same isotherm areas as those described in the "316 Demonstration..." report. Refer to Section 2.2.3 of the "316 Demonstration..." report for a discussion of the plume characteristics.

Later models of thermal impact on the sea floor in the site vicinity indicate that, under some low tide conditions, the bottom of the plume will have a long, narrow configuration until plume detachment at around 1,000 feet from the discharge. Under infrequent conditions, plume detachment will not occur until some farther distance. This plume configuration will move about the sea floor as ambient tide and current conditions change, and the bottom area exposed to relatively constant exposure to high temperatures will be smaller than the isotherm areas used in this supplemental assessment. Isotherm areas based on this plume detachment model are too conservative to be of use in biological analysis and therefore have not been used for the following reasons: (a) the temperature tolerance data used for benthic species in this assessment are dependent on exposure time, (b) the isotherm areas already used are conservative in light of Unit 1 data which indicate detectable benthic damage in areas smaller than predicted, and (c) the plume will be mobile.

SECTION 6

IMPACT ASSESSMENT

6.1 PROCEDURES FOR ASSESSMENT OF PILGRIM STATION'S EFFECT ON SELECTED SPECIES

Impact to each of the selected species is assessed by the following strategy:

Data collected from ecological studies at the Pilgrim site are reviewed with respect to the operating history of Unit 1 (see Appendix B for listing of field and laboratory studies). The density of each of the selected species entrained, entrapped, or otherwise affected by the thermal component of the discharge or plant shutdown is then compared with available estimates of species population densities. Information on life history, geographic distribution, and thermal sensitivity is also considered to assess the sensitivity of the species population to any effect of power station operation. Predictions of the effects of Units 1 and 2 combined are made for the thermal plume, entrainment, and entrapment for all representative species based on these considerations.

Analyses of impact are also based on hydrographic information which includes: (1) estimates of the maximum size of the thermal plume contacting the bottom (for assessment of potential thermal effects for benthic species); the effects of the maximum mid-depth and surface plume are also considered for assessment of impact on pelagic species; and (2) the projected maximum intake flow for Units 1 and 2 combined (for assessment of entrainment and entrapment impacts).

A quantitative prediction of impact is presented for representative species judged to potentially sustain some mortality from plant operation. The particular model used for prediction depends upon the information available to quantify the population and the perturbation. The models presented below are used for the quantitative predictions.

Populations for which the age specific mortalities and fecundities are estimated can be simulated by a computerization of the Leslie (1945) model. This model is:

$$N_{t+1} = \underline{A}\, N_t \qquad (6.1\text{-}1)$$

where N is a 1-by-x vector corresponding to the number of organisms (n_i) in each of x life stages, and each life stage has an equal development time:

$$N_t = \begin{bmatrix} n_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ n_x \end{bmatrix}_t \qquad (6.1\text{-}2)$$

The x-by-x $\underline{A}$ matrix is the projection matrix which describes the transition of the population from time t to t+1

$$A = \begin{bmatrix} F_1 & F_2 & F_3 & \cdot & \cdot & \cdot & \cdot & F_{x-1} & F_x \\ P_1 & 0 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 \\ 0 & P_2 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 \\ 0 & 0 & P_3 & & & & & 0 & 0 \\ \cdot & \cdot & & \cdot & & & & \cdot & \cdot \\ \cdot & \cdot & & & \cdot & & & \cdot & \cdot \\ \cdot & \cdot & & & & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & & & & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & \cdot & \cdot & \cdot & P_{x-1} & 0 \end{bmatrix} \qquad (6.1\text{-}3)$$

where

F_i is the number of female offspring born to a female of age i,

P_i is the probability that an organism of age x will survive to age x+1,

and

$$P_i = e^{-d_i}, \qquad (6.1\text{-}4)$$

where

d_i is the instantaneous death rate of organisms of age i.

The finite rate of population growth (R) is calculated from the $\underline{A}$ matrix as the maximum characteristic root of the characteristic equation with the stable age distribution represented as the characteristic vector accompanying the largest root (Leslie 1945).

$$R = \text{max char root } \underline{A} \qquad (6.1\text{-}5)$$

The instantaneous population growth rate (r) is:

$$r = \log_e R \qquad (6.1\text{-}6)$$

One method of investigating impact attributable to the power station is to estimate the elements of the $\underline{A}$ matrix from field and literature values for the affected population. The value of r can then be calculated. The P_i or the probabilities of survival to the next age can then be converted to instantaneous age-specific death rates. The instantaneous mortality rate due to entrainment can be added to the age-specific death rate and the new instantaneous death rates converted to a new age-specific probability of survivorship. The maximum characteristic root and the associated characteristic vector of the second $\underline{A}$ matrix represent the instantaneous population growth rate and the stable age distribution of the impacted population.

Instantaneous rates of population growth with and without entrainment can be compared as can the stable age distributions. This represents comparison of the theoretical potential of the population under the assumptions of exponential growth and is therefore most conservative as there is no density dependence in the population. A computer program (EIGENPOP) was developed to numerically solve the characteristic roots and vector. This program is based on the EISPAC routines contained in Reinsch and Wilkinson (1971).

The analysis of the year-to-year variation in population size is made by simulating the population represented by the Leslie (1945) model. A computer program (POPI) was also developed which simulates the Leslie model. This program calculates the probability of survivorship to the next age as the combination of the instantaneous rates of natural, fishing, and power station-related mortality. Any of the elements in the $\underline{A}$ matrix can be constants or functions of the population density. The population is then simulated with and without the effect of the power station. The change in population size or any selected population parameter represents the impact associated with the power station on fish eggs and larvae.

The population methods presented thus far require a great deal of information for the affected population. Because of the nature of these parameters, it is difficult to estimate them for field studies, and many times they do not exist in the literature. A simplistic approach is to translate the number of organisms lost into the number of adults that would have resulted assuming no compensatory mechanisms (e.g., density-dependent parameters) in the population.

If the population is in equilibrium, in one generation the fecundity of a breeding pair will be reduced to two breeding adults:

$$2 = S \cdot F \qquad (6.1\text{-}7)$$

where

S is the survival from egg to adult,
F is the fecundity of a breeding pair during their life,

or

$$S = 2/F \qquad (6.1\text{-}8)$$

If the affected life stage is larval, then the survival from egg to larva (S_e) is multiplied by F to give the survivorship from larva to adult (S_1).

$$S_1 = \frac{S}{S_e} = \frac{2}{S_e F} \qquad (6.1\text{-}9)$$

The number of affected larvae (N_1) is multiplied by S_1 to give the number of adults (N_a) that would have resulted, assuming no density dependence.

$$N_a = S_1 N_1 \qquad (6.1\text{-}10)$$

The number of adults can then be compared to some reference such as catch statistics for commercial or sport species. This is a meaningful comparison when sufficient information is not available for the more extensive analysis.

In addition to the assessments made by means of the methodology described above, a number of topics have been considered in more generic way. The following paragraphs discuss items which (a) do not lend themselves to quantitative evaluations and (b) represent sources of potential impact considered remote for the Pilgrim facility.

The effects of exposing local fish populations to sublethal temperatures can include weight loss, premature spawning, larger predator populations resulting in increased exposure to predation, and possible alteration of the natural predator - prey relationship. Substantial sublethal effects will ultimately be manifested as change in mortality or reproductive rates and any measurable impact detected in data collected as part of the operational monitoring program.

Such effects are unlikely to occur since the relatively small plume size, the plume characteristics, and the behavior of fish suggest that local populations would be unlikely to reside for extended periods of time in a portion of the thermal plume with lethal or sublethal temperatures.

In some instances, the impact of thermal discharges can include alteration in the numbers of distribution of species which, for any of a variety of reasons, could be classed as nuisance species. As noted in Section 4.1.4 of the 316 Demonstration, two nuisance species have been identified at the Pilgrim site. The sea urchin (Strongylocentrotus droebachiensis) does feed on Irish moss among other macrophytes. However, it is a nonselective predator and the field studies have not indicated as direct relationship between operation of Unit 1 and the species distribution. Thus no alteration in abundance or distribution of this urchin would be anticipated after the start of operation of Unit 2. Similar evidence can be cited for the red tide organism (Gonyaulax tamarensis). Analysis of species composition and abundance of phytoplankton collected from the Pilgrim Station intake and discharge has not revealed any increase in Gonyaulax sp. In addition, other factors, such as salinity, light, and nutrients, may be more signficant than the effect of temperature and would have to be within optimal ranges before a substantial increase could occur in the local population. Finally, even if temperature were a highly signficant factor in the dynamics of the population, the volume of the thermal plume is relatively small and therefore affects only a limited portion of the species population within a limited geographic area.

It might be possible to consider the various epiphytes found on Irish moss as a nuisance form. Monitoring in the vicinity of Pilgrim has indicated changes in the degree of epiphytism over the period of the surveys. In general, the greatest degree of epiphytism appeared in 1976, but there was no indication that this was related to station operation since it occurred generally throughout the study area. There was also some indication from the Irish moss survey that Chondrus in the vicinity of the discharge was cleaner than that occurring elsewhere.

One other species which may be classed a nuisance species as a result of changes in abundance or distribution is the green crab (Carcinus maenus). Field studies at Pilgrim have shown this species to occur and to have somewhat higher numbers in the area of discharge. Because this species feeds on mussels and other bivalves, the mussel population in this area could be affected. Monitoring at Pilgrim would suggest that such an effect does not occur. Despite the somewhat higher abundance of green crabs in the discharge, 1977 mussel densities were notably greater than 1976 densities. In addition, the reproductive capacity of mussels should allow for at least partial compensation for any increased losses; seasonal recruitment from adjacent areas unaffected by any thermal plume related change would further compensate for localized density modifications.

Beyond those effects on early life stages of various species which are addressed in the following sections, it is possible that an indirect effect as a result of passive entrainment into the discharge plume could occur. This would result from small,

planktonic forms which are incapable of significant movement being carried through the thermal plume. It is improbable that such entrainment would induce detectable mortality to species affected because (1) the residence time (and thus the exposure to elevated temperatures within the plume) is very short, (2) currents and tides in the area preclude the organisms from remaining near the discharge for an extended period, (3) the maximum temperature elevation with both Units 1 and 2 operating is 23°F, (4) the volume of water at the highest temperatures is very small as a result of rapid dilution, and (5) where available, thermal tolerance data indicate that early life stages of RIS will be able to tolerate temperatures found in all but the hottest portion of the plume (see discussions of each species in Section 6.2 through 6.14). There are no aquatic or terrestrial species listed as threatened or endangered by the federal government found or known to occur at the site itself or in the marine environment in the immediate vicinity of the Pilgrim site.

Biofouling control at Pilgrim includes use of a thermal backwash. For Unit 1, the backwash is discharged through the intake and into the intake canal. The extent of the backwash plume has been monitored (Normandeau Associates, Inc., Thermal Surveys of Backwashing Operations at Pilgrim Station during July 1977, published in August 1977). This study indicated a relatively thin plume that dissipated completely within a few hours. Biologic monitoring in the intake has indicated the continued presence of macrophytes including Irish moss in the vicinity of the canal despite backwashing. In addition, no impact such as a fish kill has been reported to result from backwashing for Unit 1, and stopgates will be used in Unit 2 to limit or preclude the release of heat from the intake during backwash. Instead, the water heated by backwashing will be released through the discharge and this will be subject to the normal dilution process at that point. This should effectively eliminate backwashing from Unit 2 as a source of impact to the intake area.

In a number of instances above and in the following discussions, data obtained from surveys in or near Unit 1 have been used as evidence pertinent to impact assessment for Unit 2. This is a reasonable approach not only because it provides empirical evidence from an operating power plant, but because (1) there are numerous similarities in the intake design for the two units, (2) the units have a common intake canal and discharge, (3) the units are immediately adjacent, (4) the aquatic population affected by operation of the units is identical, and (5) source and receiving water body effects of Unit 2 will be essentially the same as those of Unit 1. Differences in impact from Unit 1 and Unit 2 will result primarily from the increased flow of two units as opposed to one and thus extrapolation of quantified impacts on the basis of the flow differential is appropriate. Overall, the approach of utilizing data for an existing intake to determine potential effects of a proposed structure is consistent

with the suggested approach contained in EPA 316 (b) guidance manual (p. 26, 1 May version).

A final general consideration is the effect that an intake approach velocity of 1 fps will have on fish impingement. As noted, the intake design of Units 1 and 2 is very similar and therefore evidence can be gained from the screenwash monitoring of Unit 1. These data have been incorporated into the impact assessments for the RIS. In addition, some data are found in the scientific literature on swim speeds of various fish species. In general, the data are limited but do indicate considerable variation due to species, condition of the fish and physical factors such as temperature. Evidence compiled in Table 2-59A of the Pilgrim ER (p. 2-304A) indicates that for those species noted, each would be capable of swim speeds above the 1-fps approach velocity and thus should be able to move away from the traveling screens. Of course, this would only occur after the fish had traversed the intake canal where velocities are well below 1 fps and entered the intake structure. The low velocity in the intake canal reduces the potential for large numbers of fish encountering the region of higher velocity in front of the screens.

To the extent that effects due to the interaction of heat with other pollutants might occur, the conclusions in this assessment are sufficiently conservative to account for them.

6.2 IRISH MOSS (Chondrus crispus)

Irish moss is a subtidal species occurring from mean low water to about 30 feet below mean low water. It is, therefore, exposed to temperature fluctuations but not to the degree of intertidal species. Primary station-related impact to Irish moss may result from the thermal plume, because the moss is a sessile organism. Entrainment of spores may occur, but should not affect a large fraction of the spores since they are not buoyant. Impact assessment for Units 1 and 2 combined can best be determined by examining the historical data from Unit 1.

6.2.1 Thermal Plume

Several studies have been conducted to determine the impact of station operation of Pilgrim Unit 1 and Units 1 and 2 combined on the local Irish moss population. These include investigations of commercial harvest and effort by Mass. Division of Marine Fisheries (MDMF), thermal tolerance of spores by Marine Research, Inc., benthic monitoring studies by Clapp Laboratories and by Drs. A. Michael and R. Wilce, and short-term surveys of relative abundance and condition by J. Ryther et al, Woods Hole Oceanographic Institution.

Generally, Chondrus crispus is found along the rocky Plymouth coastline from Warren Cove to Manomet Point, with most of the commercial harvesting being done between Rocky Point and Manomet Point. The most extensive beds occur at Rocky Point, Manomet Point, and White Horse Beach, especially around Flag Rock (see Figure 6-1).

In 1973, there was a substantial decrease in the commercial harvest of Chondrus, with a concomitant decrease in effort expended in harvesting (see Table 6-1). The harvesters reported the general condition of the moss as poor, which may account for the decreased effort and landings, though the catch per unit effort remained about the same as in previous years. By the fall of 1974, landing statistics indicated that the Chondrus population had recovered to normal or near normal conditions.

In order to assess the possible impact of Pilgrim Station on the moss, the shoreline was divided for study into eight areas. In addition, Ellisville (6 miles southeast of Manomet Point) and Gurnet Point (4 miles northwest of Pilgrim at the northern extremity of Plymouth Bay) were chosen as control locations. Ellisville eventually proved to be a poor choice for a control location, having a sandy bottom covered with eelgrass, which resulted in a moss population of poorer quality than that of the Rocky Point-Manomet Point coastline. Manomet Point also lies outside the predicted plume areas and has, therefore, been used as a basis of comparison (see Figure 6-2) for the 1971-1976 landing statistics from the Mass. Department of Marine Fisheries; landing statistics in lb-wet weight for Gurnet Point were not

available to compare to wet weight biomass values from other areas. Dry weight biomass (lb/yd^2) calculated from the relative abundance and condition survey are shown in Figure 6-3 for Manomet Point, the discharge area, the intake area, White Horse Beach, and Gurnet Point.

Examination of the 1974 survey findings failed to show power station-related effects beyond the area of exclusion. If the thermal plume adversely affects the Chondrus beds, the greatest impact would be expected nearest the discharge, dissipating as distance from the plant increases. This has not been observed to date. From the western side of Rocky Point westward to Warren Cove, the condition of Chondrus crispus increasingly deteriorated. Although restricted to a small narrow band of rocky bottom, some of the most productive beds observed were in the discharge area, just beyond the area excluded to Chondrus by the thermal plume. As usual, Manomet Point and the eastern portion of Rocky Point were good producers. Furthermore, for the remainder of the survey period (1974 to 1976), these observations held true.

Pilgrim was operative most of 1975, and the 1975 surveys show overall continued improvement in terms of weight per unit area, though the quality of the plants seemed poorer. This poorer condition was characterized by less branching, lighter pigmentation, and increased growth of epiphytes on the Chondrus. Still, as in the two previous years (1973 and 1974), the plants of best quality were found between Rocky Point and Manomet Point, especially in the discharge area of Pilgrim; the poorest were found at Warren Cove.

Pilgrim Unit 1 was non-operational from February to June in 1976, as in 1974; but, unlike 1974, which was a good year for Chondrus, 1976 saw some deterioration of the Chondrus beds. The explanation is probably not related to thermal plume effects, but more likely to natural phenomena. There was an increased incidence of epiphytes noted in 1976, such that plants everywhere (except the discharge area) were heavily overgrown. This may explain the 1976 observations.

Chondrus exhibits a large degree of natural variability in growth and condition from year-to-year and station-to-station, depending on such factors as degree of oceanic exposure, silting, local topography, predation, and other phenomena which are not totally understood. Natural fluctuations probably account for much of the year-to-year changes described above.

The areas predicted to be seasonally affected by the two-unit thermal plume are shown in Figure 6-4. Because of faster mixing (due to higher discharge velocity) of heated and ambient waters, the increased thermal load generated by two units is quickly dissipated. Thus, the near-field isotherms (15°-20°F) for Unit 1 and for Units 1 and 2 combined are very similar in size.

During summer, lethal temperatures could potentially exclude Chondrus from 2.1 acres in the immediate discharge area. Because of the similarity of the plumes for Unit 1 and Units 1 and 2 just described, it is expected that the predicted loss of 2.1 acres closely approximates the 1.8 acres presently devoid of Chondrus. In addition to the area lost to moss population, an approximately equal area will contain moss with stunted growth, as evidenced by areas of stunted growth at Unit 1.

6.2.2 Entrainment

A study of the entrainment of Irish moss spores was conducted in the fall of 1973 by Marine Research, Inc. (MRI). Thermal tolerance tests, however, indicated that mortality (30 percent) of spores on passage through the station cooling system would occur only when ambient water temperatures were greatest, in late summer, when studies have found spore density to be low (MRI 1975; Michael and Wilce 1975). Therefore, the overall effect of entrainment on the Irish moss population should be minor.

6.2.3 Entrapment

Not applicable.

6.2.4 Cumulative Impact

Most of the impact of station operation on Irish moss should result from the thermal plume. This localized effect will result in the elimination of Irish moss immediately adjacent to the discharge area (2.1 acres) and an additional area of about 2 acres having stunted growth. No impact will result from entrapment, as no life stages are susceptible to entrapment. Although entrainment may occur, thermal tolerance tests on Irish moss indicate no impact of consequence from entrainment. Station operation will result in a negligible effect on the total Irish moss population in the Warren Cove - Manomet Point area and on the commercial harvest.

TABLE 6-1

IRISH MOSS HARVEST STATISTICS: 1971*-1976
(Mass. Div. of Marine Fisheries)

Landing (lb-wet wt)

Area	1971	1972	1973	1974	1975	1976
1	92,637	133,402	57,045	105,110	79,652	72,950
2	78,060	110,246	45,310	91,290	89,614	125,140
3	10,719	17,295	4,140	11,730	16,487	25,250
4	23,252	31,402	7,695	10,795	14,317	7,010
5	82,724	78,567	18,815	28,515	72,557	56,330
6	39,925	56,881	24,995	17,230	74,417	24,280
7	14,727	17,004	30	215	10,517	2,320
8	33,429	28,368	605	25	3,252	235
Total	375,473	473,165	158,595	264,910	360,813	313,515

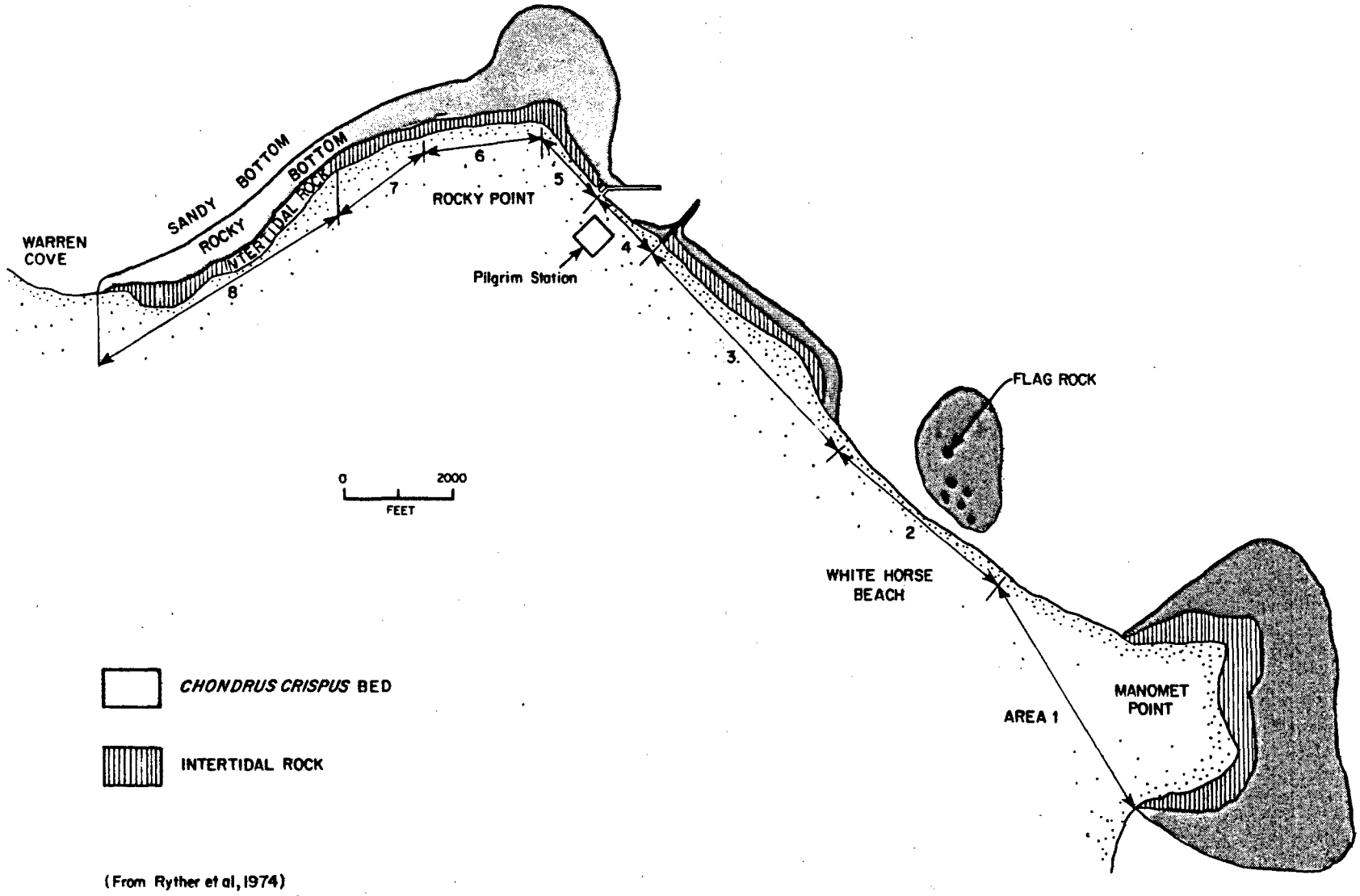
Harvest Effort (hr)

Area	1971	1972	1973	1974	1975	1976
1	411.4	573.1	343.4	446.4	339.2	373.3
2	443.7	776.3	345.8	391.9	562.8	840.8
3	55.7	90.6	22.8	77.8	83.0	159.3
4	113.6	155.9	41.3	39.7	47.9	47.8
5	406.8	374.9	102.3	139.7	290.7	284.2
6	170.7	233.9	128.8	79.0	219.5	88.7
7	87.6	80.3	0.1	1.3	27.8	11.2
8	114.9	108.1	1.4	0.3	13.9	1.2
Total	1,804.4	2,393.1	985.9	1,176.1	1,584.8	1,806.5

Harvest Rate (lb/hr)

Area	1971	1972	1973	1974	1975	1976
1	225.2	232.8	166.1	235.5	234.8	195.4
2	175.9	142.0	131.0	232.9	159.2	148.8
3	192.4	190.9	181.6	150.8	198.6	158.2
4	204.7	201.4	186.3	271.9	298.9	146.8
5	203.4	209.6	183.9	204.1	249.6	198.2
6	233.9	243.2	193.7	218.1	339.0	273.8
7	168.1	211.8	300.0	165.4	378.3	207.8
8	290.9	262.4	432.1	83.3	234.0	201.5
Total	208.1	197.7	160.9	225.2	227.7	173.5

* 1971 values do not include approximate 2-week period prior to 6/18/71.



(From Ryther et al, 1974)

FIGURE 6-1
DISTRIBUTION OF *CHONDRUS CRISPUS* ALONG THE PLYMOUTH SHORELINE

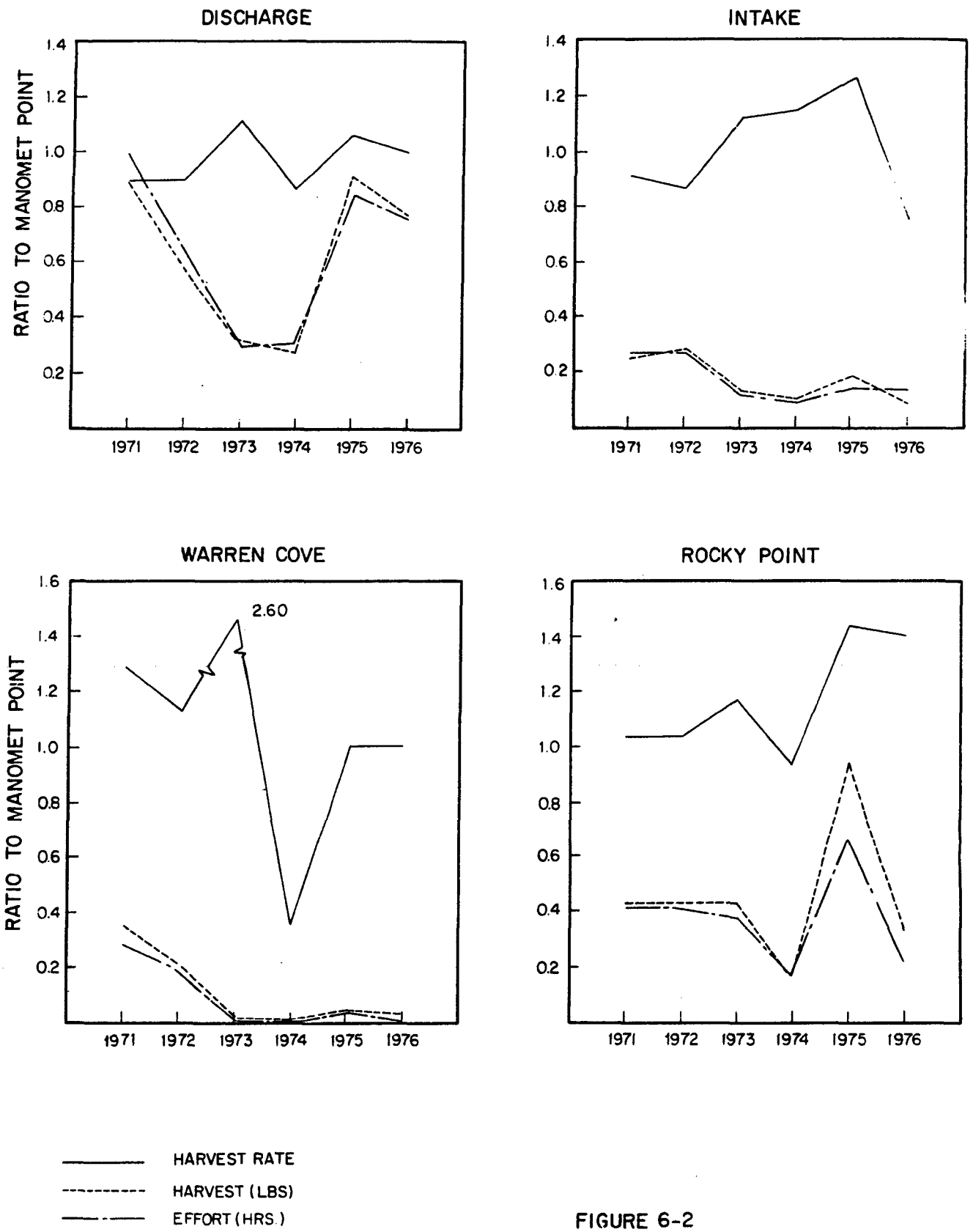
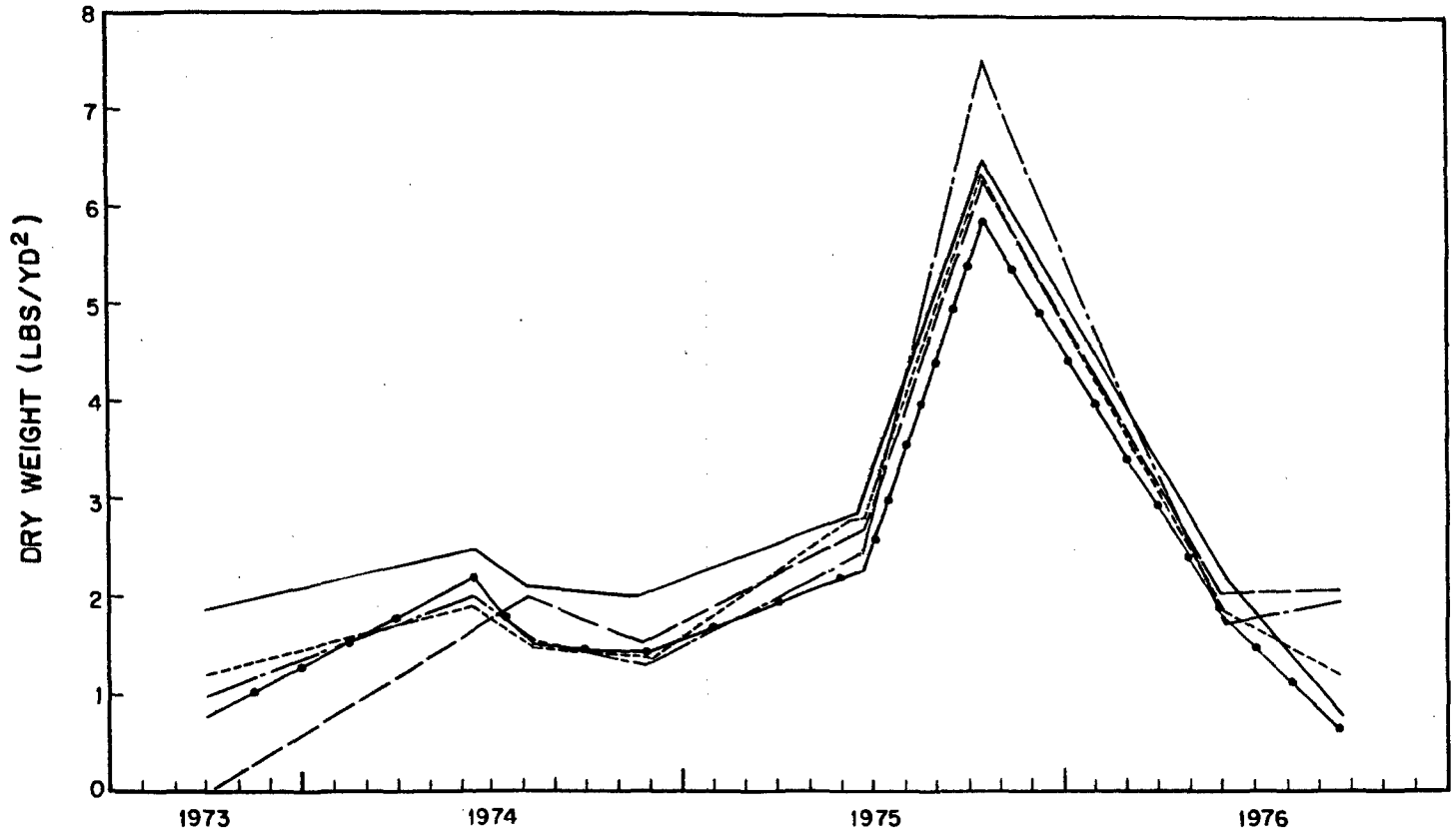


FIGURE 6-2
COMPARISON OF ANNUAL IRISH MOSS HARVEST STATISTICS AS RELATED TO MANOMET POINT



WHITE HORSE BEACH
MANOMET POINT
INTAKE
DISCHARGE
GURNET POINT

FIGURE 6-3
COMPARISON OF IRISH MOSS
DRY WEIGHT VALUES

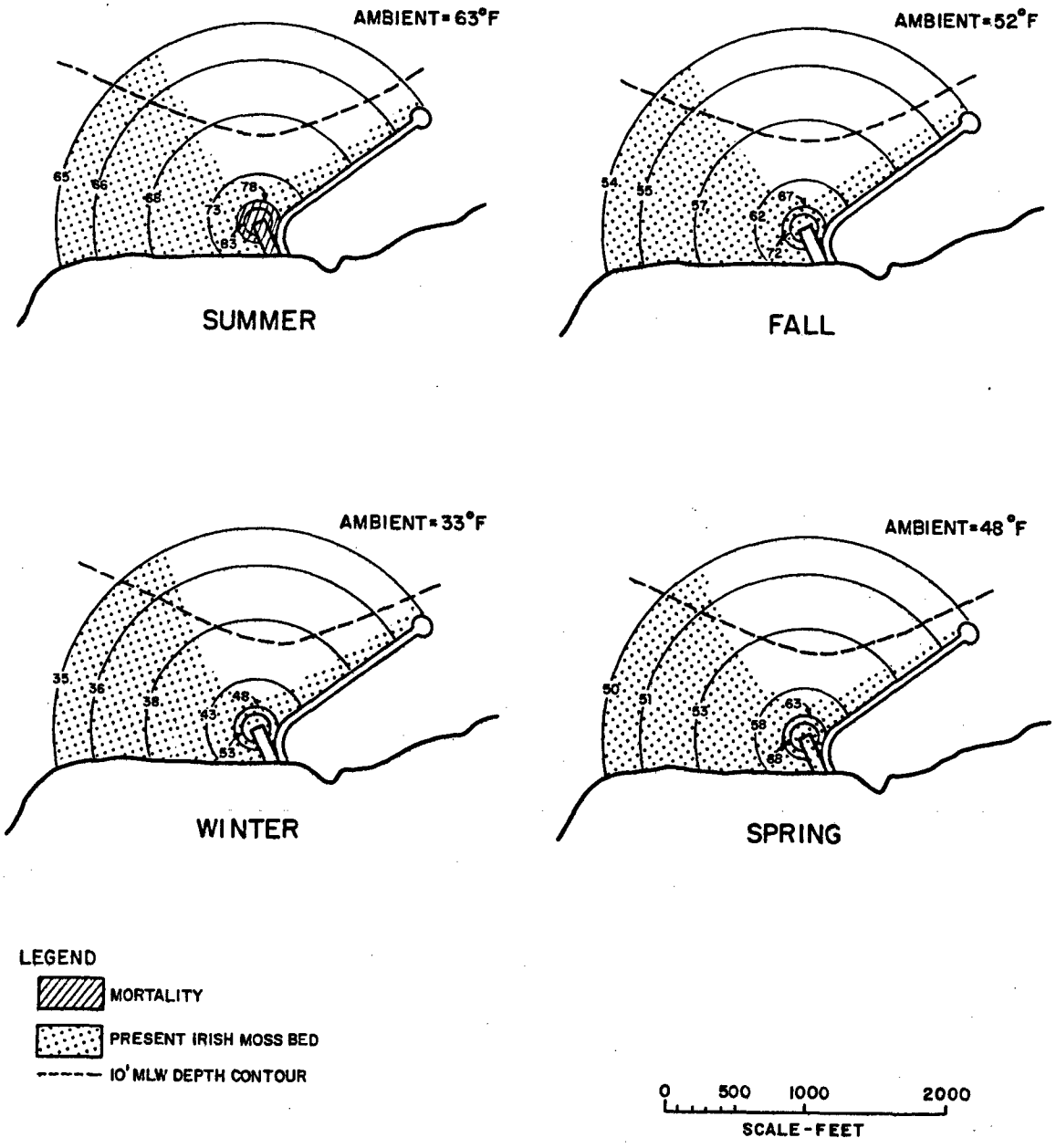


FIGURE 6-4

POTENTIAL THERMAL PLUME EFFECTS
IRISH MOSS

6.3 ROCKWEED (Ascophyllum nodosum)

Ascophyllum nodosum is an intertidal species and, therefore, is naturally exposed to large temperature fluctuations. However, as an intertidal species, it has a life history strategy which is adapted for these fluctuations. A continuous thermal stress, however, may result in stress during reproductive periods.

A. nodosum is a sessile organism. Therefore, primary station-related impact to A. nodosum should result from the thermal plume. Entrainment may occur, although the spores are nonbuoyant. Impact assessment for Units 1 and 2 combined is determined by analyzing data collected during Unit 1 operation.

6.3.1 Thermal Plume

A benthic monitoring program conducted in the vicinity of Pilgrim Station by Clapp Laboratories, and subsequently by Drs. A. Michael and R. Wilce et al, has determined seasonal biomass estimates for Ascophyllum nodosum at various transects. The two most ecologically similar stations are the intertidal stations at the Manomet Point transect and the Rocky Point transect. Rocky Point transect is the area closest to the discharge with suitable habitat for Ascophyllum nodosum and, therefore, represents the area most likely to be affected by the discharge. The Manomet Point transect is located sufficiently far away from the discharge to serve as a control location (see Figure 6-5).

Both areas represent moderately sheltered marine environments with gently sloping rocky shores that favor Ascophyllum nodosum. As such, Ascophyllum nodosum comprises 80-90 percent of the biomass at both stations (Michael and Wilce, 1975 and 1976). The mean intertidal biomasses for Rocky Point (discharge area) and Manomet Point (control area) are plotted in Figure 6-6.

Each point on Figure 6-6 represents an average value taken from samples at the same location and time. Collection techniques for each date were the same for each location. The year-to-year biomass shows a slight downward trend at both Rocky Point and Manomet Point. If the power station were having an effect on Ascophyllum nodosum, Figure 6-6 would reveal different time series of biomasses at the control and discharge stations. The more probable causes of density fluctuations are seasonal growth patterns and, possibly, subtle year-to-year variations in sampling technique since both the control and discharge stations are changing in the same manner.

As discussed in Section 5.2 for the 316 Demonstration, limited information on the thermal tolerance of Ascophyllum makes prediction of the Unit 1 and the combined effects of the Units 1 and 2 thermal plume difficult. However, operational data from Unit 1 indicate no significant impact (Michael and Wilce 1976). The average plume temperature outside of the discharge canal will

generally not reach 93°F during any season; therefore, acute mortality should not occur (refer to thermal tolerances in Appendix A). Since thermal tolerance during reproductive periods has not been studied, the possible effect of Pilgrim Station on reproduction is uncertain. However, data gathered at Unit 1 indicate minimal impact since, for the more than four years that Ascophyllum nodosum has been monitored, there has been no apparent station-related effect (see Figure 6-6).

6.3.2 Entrainment

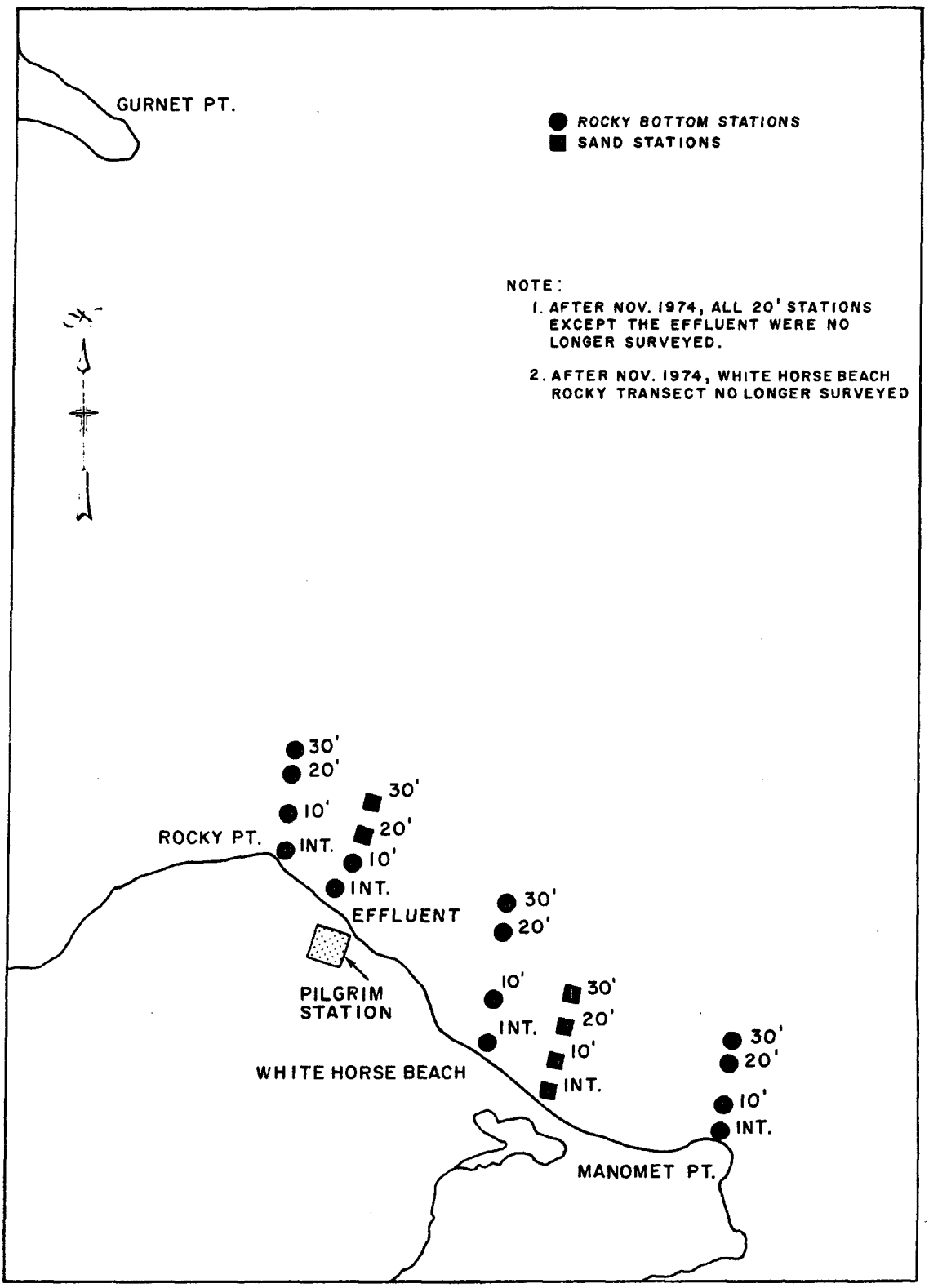
Zygotes, the only entrainable life stage of A. nodosum, are nonbuoyant and adhesive and thus are not expected to be subject to entrainment. No A. nodosum zygotes have been collected by MRI in entrainment samples.

6.3.3 Entrapment

Not applicable.

6.3.4 Cumulative Impact

No station impact on A. nodosum is expected to occur through entrapment or entrainment, since no life stage of this species is susceptible to these sources of impact. The only potential source of impact is the thermal plume. The upper lethal temperature of A. nodosum (93°F) will not be reached in the discharge plume of Units 1 and 2; therefore, little, if any, mortality is expected. Reproductive periods occur from fall through spring when discharge temperatures are low; therefore, no impact is expected during these periods. Operational data collected at Unit 1 have also not shown any station-related effect to date.



(FROM SEMI-ANNUAL REPORT NO. 4, 1974)

FIGURE 6-5

LOCATION OF FIVE TRANSECTS FOR BENTHIC SAMPLING 1971 TO 1976

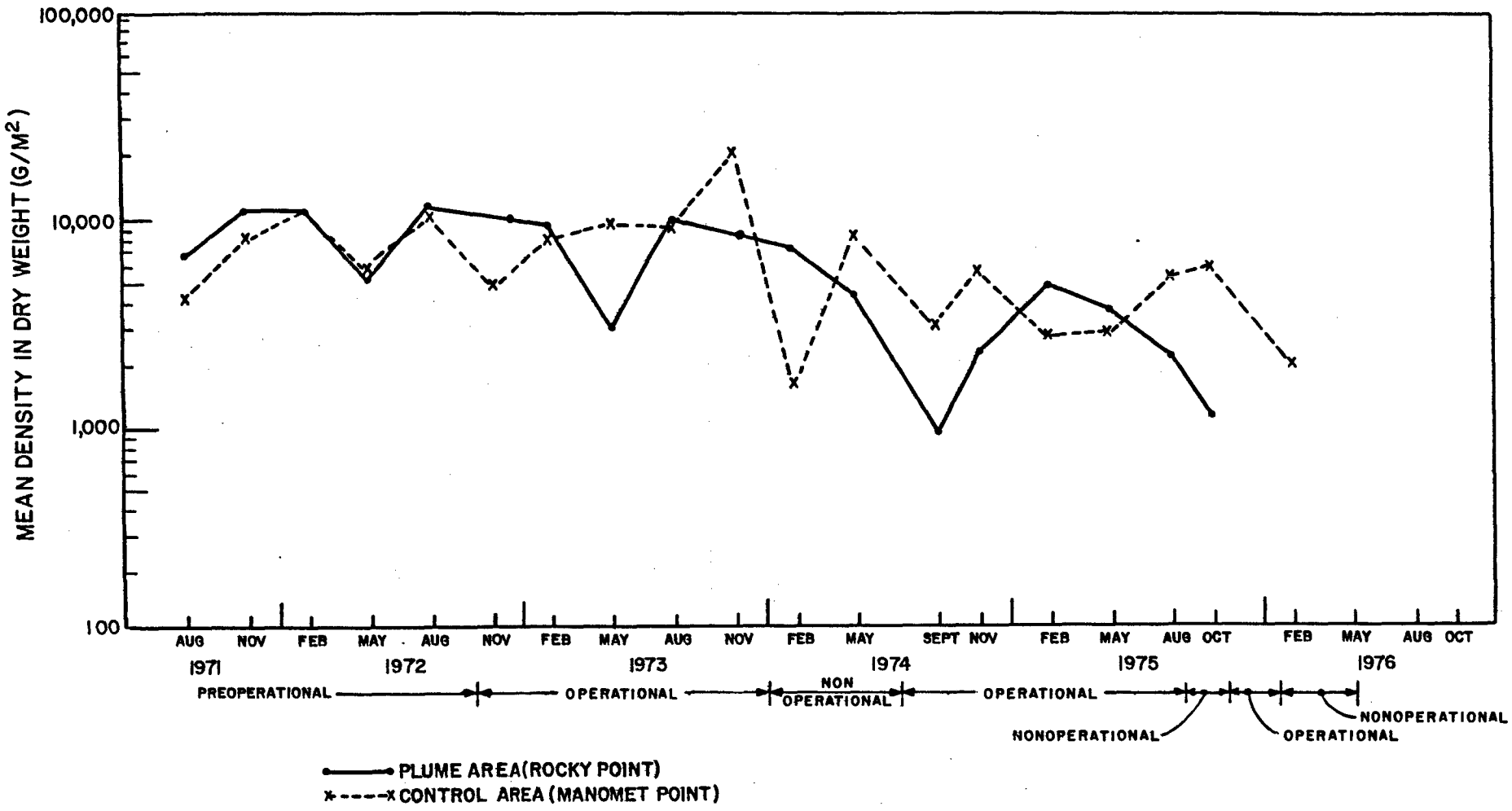


FIGURE 6-6
MEAN INTERTIDAL DENSITY
ASCOPHYLLUM NODOSUM
IN DRY WEIGHT (G/M^2)

6.4 AMPHIPOD (*Acanthohaustorius millsi*)

Acanthohaustorius millsi is a subtidal burrowing amphipod found offshore of Pilgrim Station. As an offshore species, *A. millsi* is less subject to power station effects than inshore species. The component of power station impact that will most affect *A. millsi* is the thermal plume. No *A. millsi* have been collected in entrainment samples, and the species is too small to be entrapped. Impact assessment for Units 1 and 2 combined can again be determined by using the information collected during Unit 1 operation.

6.4.1 Thermal Plume

Results of the Unit 1 benthic monitoring study have been reviewed to determine the impact of station operation on *A. millsi*. Mean densities at 20 feet below mean low water (mlw) at the discharge location and White Horse Beach (control) are compared in Figure 6-7a. A second comparison of the control and discharge for 30-foot stations is presented in Figure 6-7b, since the 20-foot stations were not sampled after 1974. Densities of *A. millsi* are highly variable at White Horse Beach and discharge locations. There are several factors which may contribute to this variability. *A. millsi* is motile and can thus avoid sampling devices. Also, the preferred habitat at the discharge sampling area is somewhat limited because of the presence of rocky areas. This would also contribute to the lower density at the effluent station, as compared to White Horse Beach. With reduced preferred substrate, collections at the discharge would be more subject to variability through clumping, and thus a nonuniform distribution of organisms. This type of variability commonly occurs in short-lived species that reproduce only once.

The thermal plume will rarely contact the bottom beyond a distance of 1,000 feet from the point of discharge (see Section 2 of the 316 Demonstration). The depth in this area is approximately 20 feet below mlw. When the plume does contact the bottom, only the 2°F and 3°F isotherms may reach this area. The habitat inshore of this area subject to higher temperature increases does not appear to be suitable for *A. millsi*, as it is primarily a rocky substrate. The thermal tolerance of *A. millsi* appears to be high, although it is a subtidal species. Temperatures as high as 97°F are necessary for complete mortality, and the temperature-mortality range appears to be small (Sameoto 1969). Therefore, no impact is expected, since temperatures will not reach 97°F in areas of *A. millsi* habitation.

6.4.2 Entrainment

Not applicable.

6.4.3 Entrapment

Not applicable.

6.4.4 Cumulative Impact

No station impact on A. millsi is expected to occur through entrapment or entrainment as no life stage of this species is susceptible to these sources of impact. The only potential source of impact is the thermal plume. Suitable habitat for A. millsi in the discharge area begins at 20 feet mlw and extends into deeper water, which is beyond the major influence of the predicted thermal plume. Therefore, there should be no impact on A. millsi as a result of the operation of Units 1 and 2.

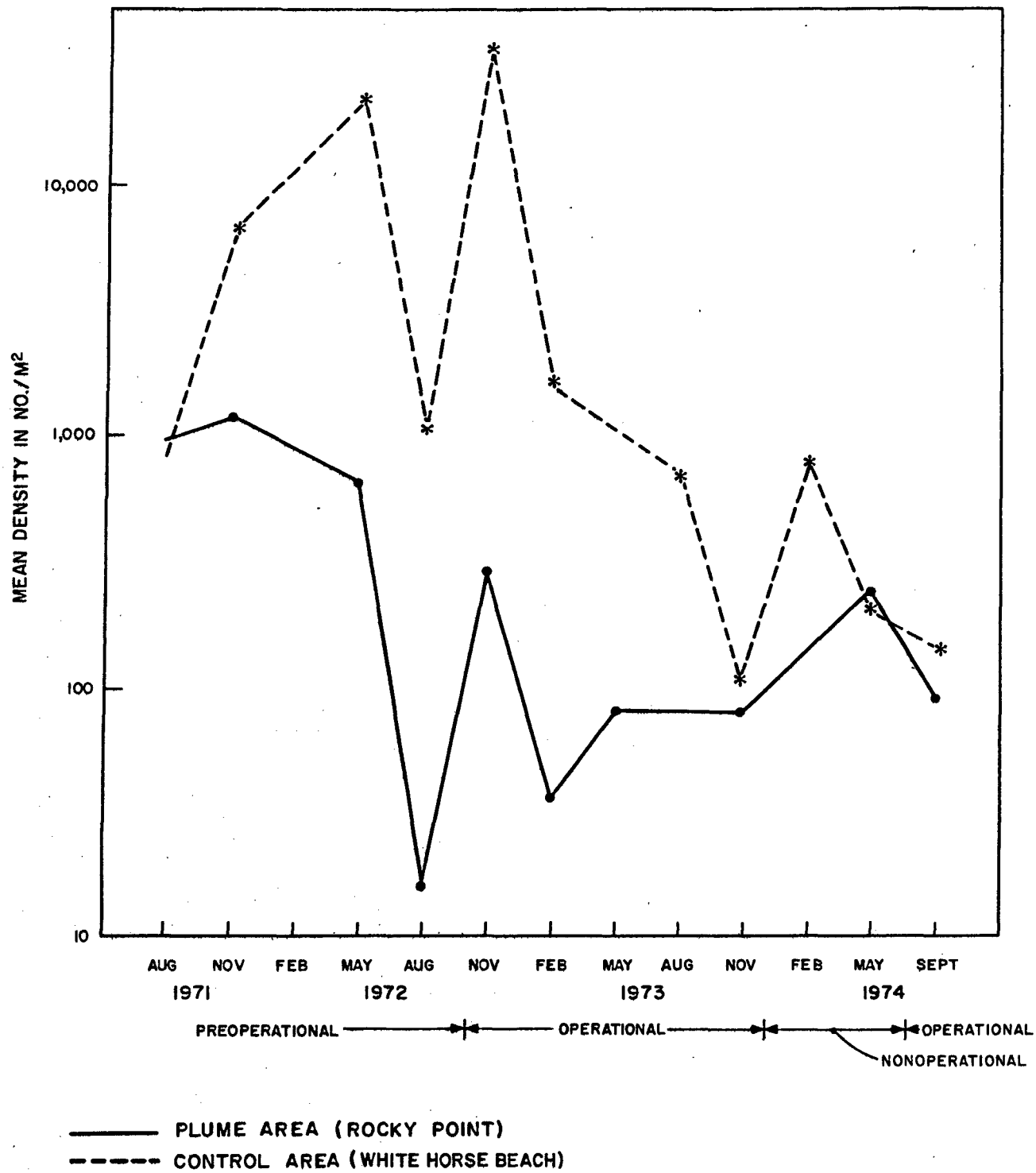


FIGURE 6-7a
MEAN DENSITY OF
ACANTHOHAUSTORIUS MILLSI
AT 20 FEET BELOW MLW

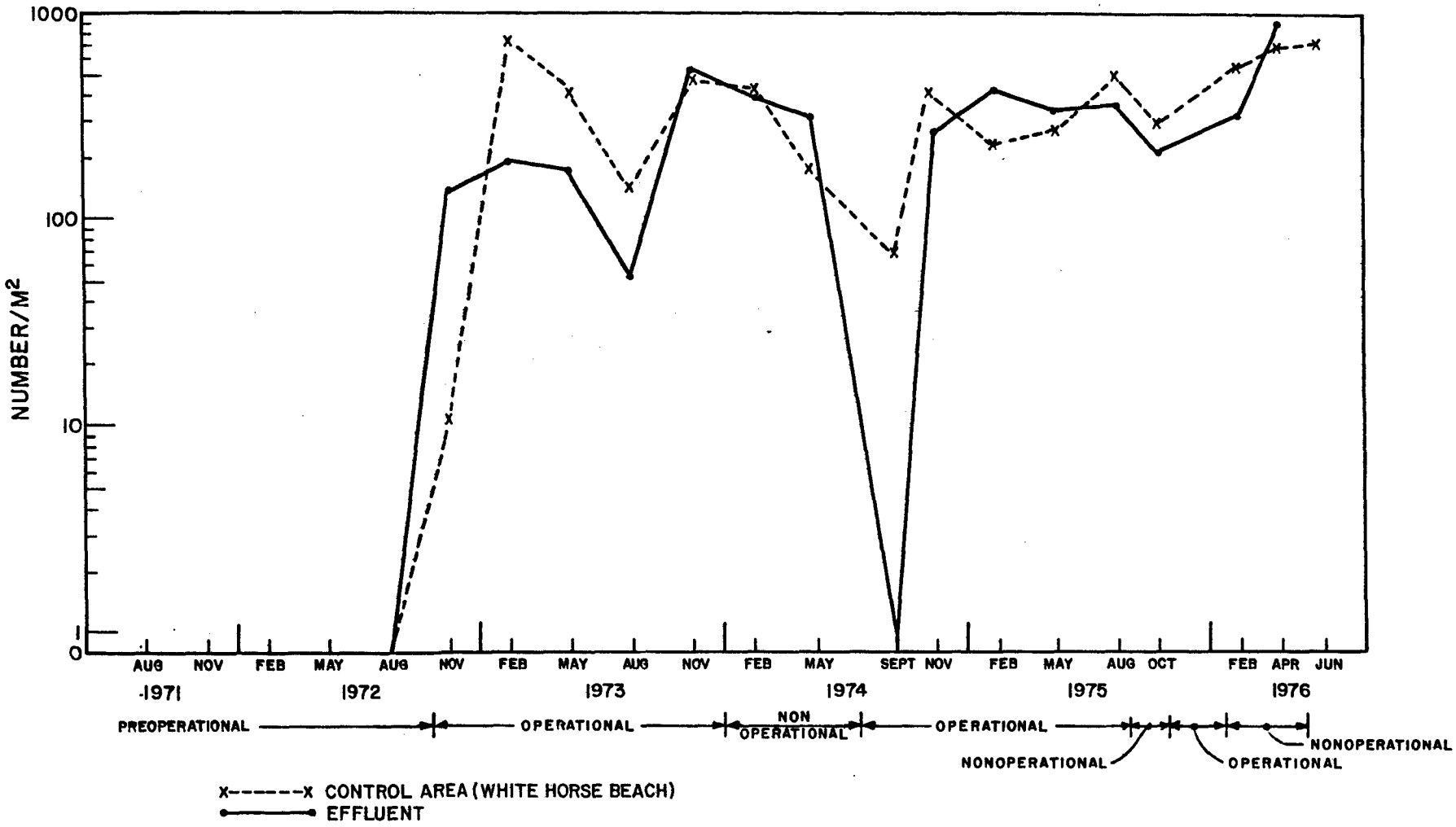


FIGURE 6-7b
MEAN DENSITY OF
ACANTHOHAUSTORIUS MILLSI
AT 30 FEET BELOW MLW

6.5 AMERICAN LOBSTER (*Homarus americanus*)

The lobster is a subtidal, mobile benthic species found offshore of the Pilgrim Station. As an offshore species, lobster are less subject to power station effects than inshore species. Monitoring studies at the site by the Mass. Div. of Marine Fisheries (MDMF), have indicated that the local population of lobster is not a self-sustaining population and relies on spawning elsewhere in Cape Cod Bay. Morrissey (1971) indicated that there was some movement of egg-bearing females from the northeastern shore of Cape Cod to this area. About 310 of 45,759 lobsters or about 7 in 1,000 handled during the 1972–1976 studies were egg-bearing females. Thus, the local population in the vicinity of Pilgrim Station is a nonsustaining population.

6.5.1 Thermal Plume

Two monitoring studies by the MDMF have been conducted to determine the impact of station operation on lobster. A harvest-per-pot study monitored lobster catch within grid areas (Figure 6–8) in the vicinity of the station. Figure 6–9 shows the catch per pot for grids in the discharge area and catch per pot at Manomet Point (control area). There are no apparent station-related effects since such stresses would appear as non-parallel time paths of the control and affected areas.

A second study monitored lobster migration in control and affected areas. The discharge area did not seem to present an unmanageable stress on lobster because the patterns of migration were similar for Rocky Point (discharge area) and Manomet Point (control area).

The seasonal effects from the predicted thermal plume (Appendix A) of Units 1 and 2 are shown in Figure 6–10. Based on thermal tolerance data for lobster (Appendix A), permanent residence of adult and juveniles will be excluded from the area (2.1 acres) immediately adjacent to the discharge canal during the summer months. The area beyond will maintain temperatures promoting (68°–77°F) maximum growth for adults and juveniles during the summer months. During other seasons, the temperature will stimulate growth in the summer exclusion area (15°F isotherm). Growth of lobster to harvestable size has been reduced from 7 to 2 years in some heated waters (Hughes et al 1972). Lobster are mobile and can thus migrate to the thermal plume when temperatures are suitable, and migrate out of the thermal plume if temperatures are less than optimal.

6.5.2 Entrainment

Prior to 1975, no lobster larvae were collected in the entrainment study by MRI at Pilgrim Unit 1. Therefore, the original 316 Demonstration utilized a very conservative approach,

assuming that the density of lobster larvae entrained was the same as the density of lobster larvae in the Bay near Pilgrim.

In 1975, a modified entrainment sampling program by MRI was initiated. As a result of this modified program, one larva was collected in the entrainment studies at Pilgrim during 1975 and two were found in the 1976 studies. The analysis in this supplemental report is, therefore, based on these recent entrainment figures. Based on an extrapolation of the two lobster larvae collected in the 1976 Unit 1 entrainment study, an estimate of the total number of larvae which would have been entrained during operation of Units 1 and 2 was developed by integrating through the sampling dates before and after each of the lobster larvae were collected. A linear extrapolation between sampling points was utilized. This projection was about 24,000 lobster larvae entrained for full time operation of Units 1 and 2.

The number of adults that could have been recruited into the adult population from 24,000 larvae is calculated as follows. After determining the number of larvae potentially entrained, the equivalent number of eggs from which 24,000 larvae would have survived is computed. Assuming a survivorhsip of 0.01 from eggs to stage IV larvae, the equivalent of 2,400,000 eggs would have been entrained. An estimate of loss of harvestable adults (see Section 6.1) assuming 100 percent entrainment mortality can be made based on average harvest size (1.2 lb) and fecundity (10^4 eggs/female) for this year class (Saila et al 1969)

N_a (no. of adults) =

$$\frac{2.4 \times 10^6 \text{ eggs}}{\text{yr}} \times \frac{10^{-4} \text{ females}}{\text{egg}} \times \frac{2 \text{ adults}}{\text{female}} \approx 490 \text{ adults}$$

This estimate, although based on conservative assumptions, is the most reasonable estimate of the effects of entrainment on the lobster. The number of harvestable lobster potentially lost represents about 0.07 percent of the average yearly harvest for Plymouth County (Beals et al 1970).

6.5.3 Entrapment

Prior to 1976, lobsters were not collected in the impingement monitoring study. In 1976 four lobsters were collected from the intake screens during 2,022 hours of monitoring. Assuming the number impinged is proportional to the volume of water withdrawn, 23 lobsters could have been entrapped in 1976 by Unit 1 and 98 entrapped by Units 1 and 2 if Units 1 and 2 were operating continuously. Impingement monitoring study data (particularly from other marine organisms) suggest that a linear prediction is highly conservative. Therefore, entrapment of lobsters will be negligible when Units 1 and 2 are operating.

6.5.4 Cumulative Impact

Minimal impact on lobster is expected due to entrapment because very few (4) have been collected during 4 years of Unit 1 operation.

Based on thermal tolerances during the summer months, adult and juvenile lobsters will be excluded from 2.1 acres immediately adjacent to the discharge canal. During the spring and fall of the year, growth should be stimulated within this area. Since lobsters could avoid less than optimal temperatures, no mortality as a result of the predicted thermal plume is expected.

Entrainment figures indicate about 24,000 lobster larvae, or about 490 adults, per year potentially entrained by Units 1 and 2. This number of adults represents only about 0.07 percent of the Plymouth County harvest. Considering these predictions and the conservative assumptions used, the effect of the operation of Units 1 and 2 in the Cape Cod Bay lobster population should be negligible.

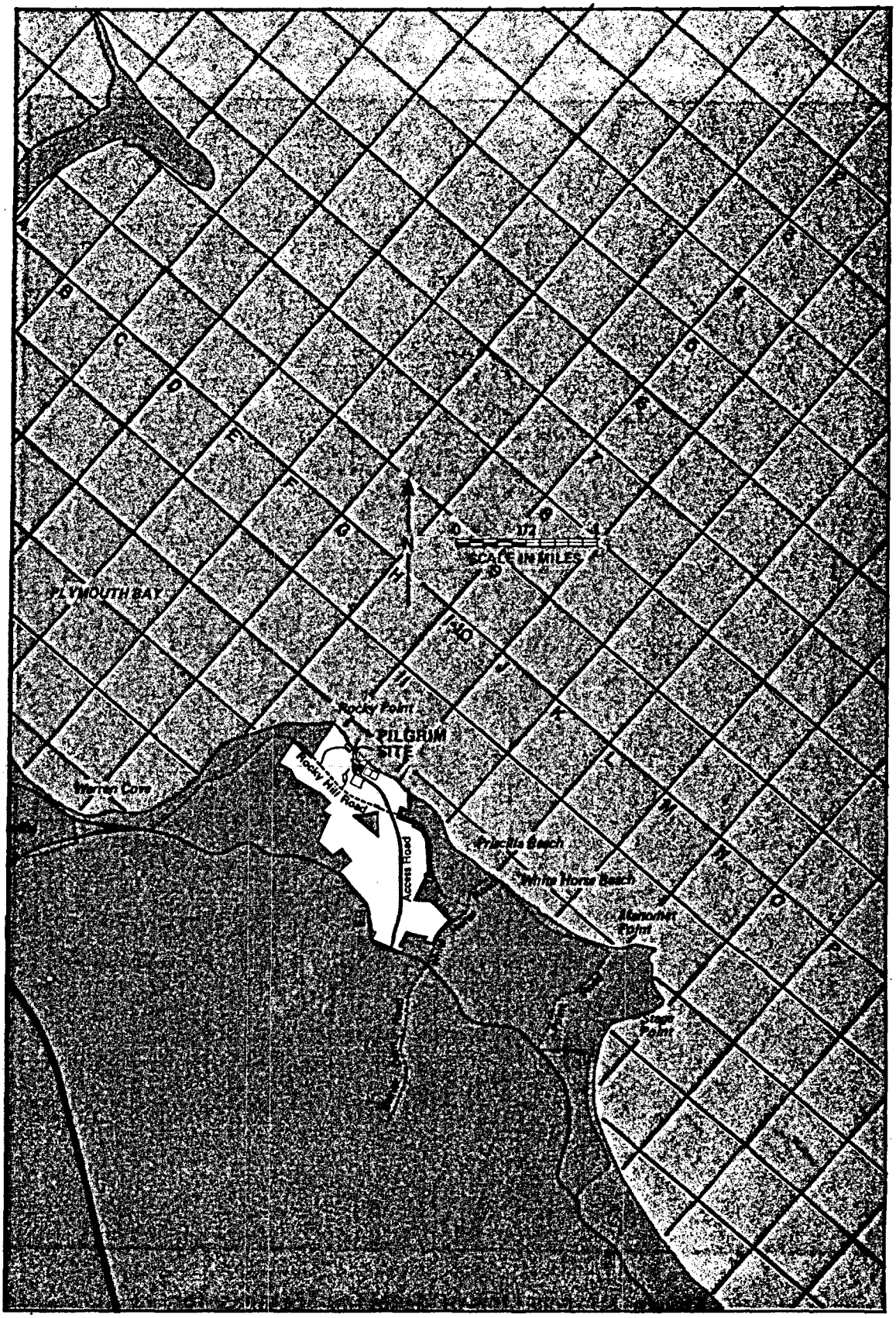


FIGURE 6-8
LOBSTER POT SAMPLING GRID

(FROM SEMI-ANNUAL REPORT
No. 9, 1977)

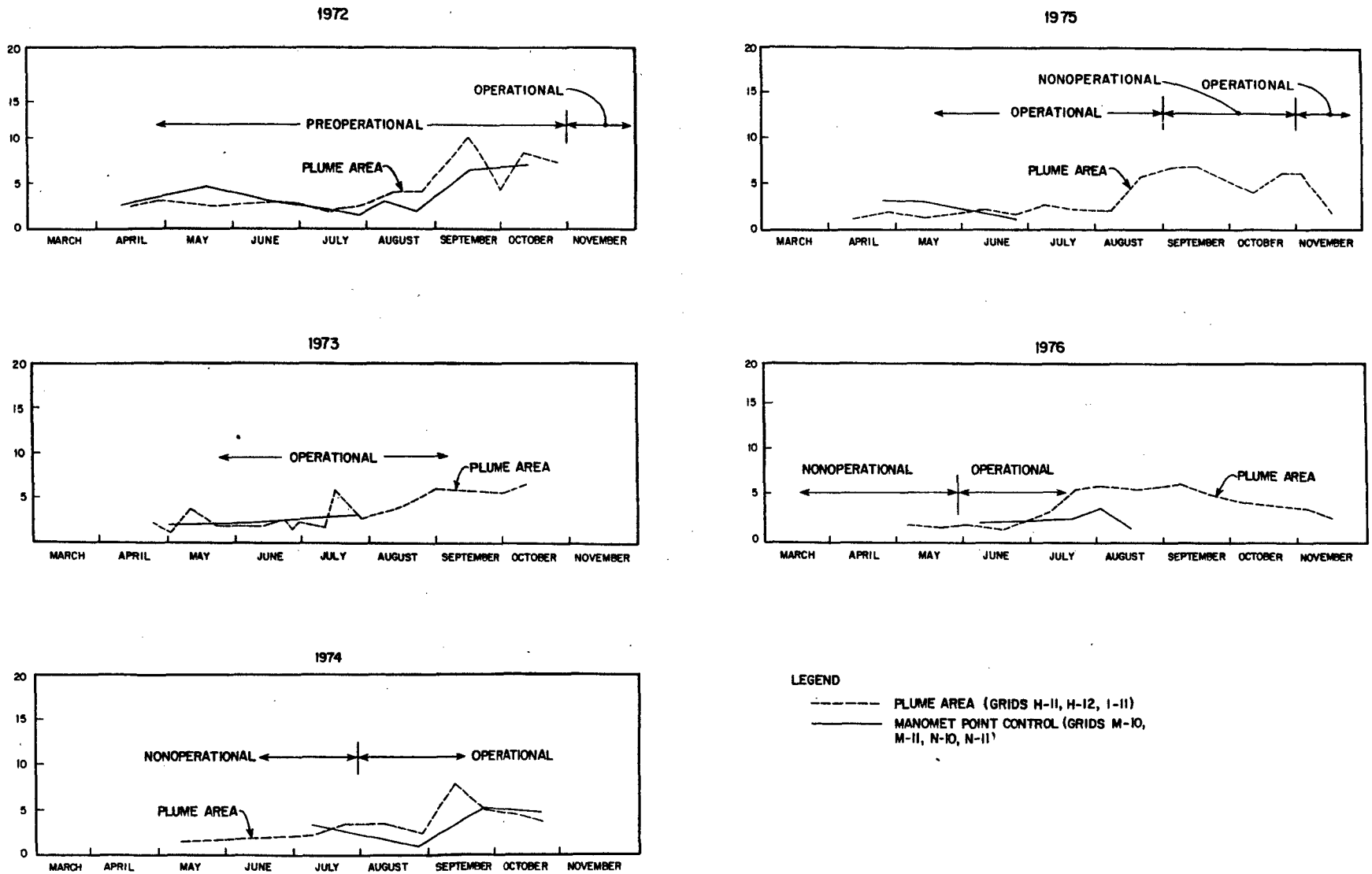


FIGURE 6-9
MEAN LOBSTER CATCH PER POT

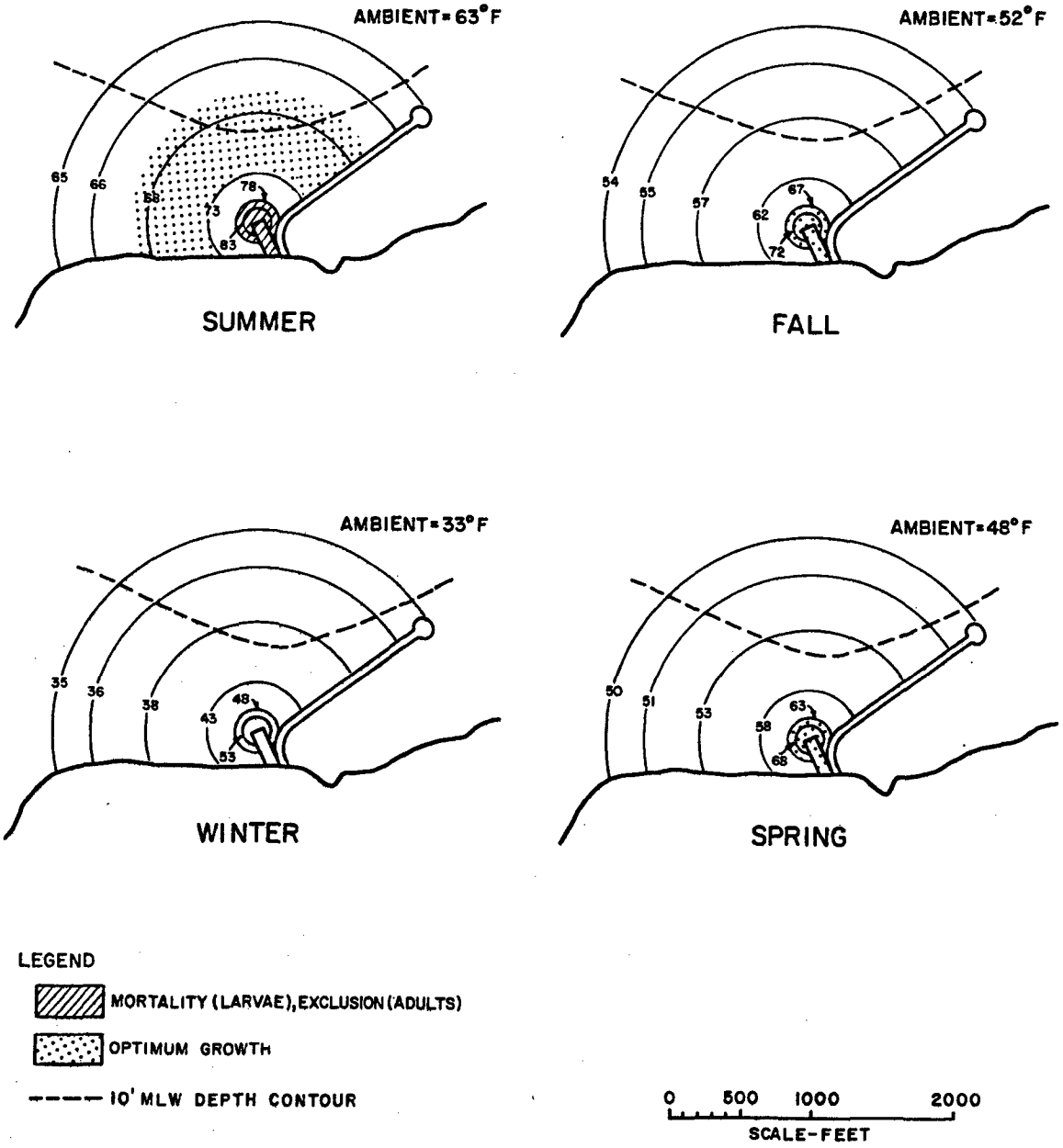


FIGURE 6-10

POTENTIAL THERMAL PLUME EFFECTS
LOBSTER

6.6 BLUE MUSSEL (*Mytilus edulis*)

Mytilus edulis, due to its life history and distribution, is adapted to extreme environmental conditions, including a broad range of temperatures and exposure to partial drying. Station impact would result from the thermal plume on adult organisms and entrainment of planktonic larvae. Potential impact of Units 1 and 2 is assessed using the information obtained during Unit 1 operation.

6.6.1 Thermal Plume

The benthic monitoring program that surveyed *Ascophyllum nodosum* and other species of the algal community considered in the 316 Demonstration also encompassed a faunal survey including quarterly monitoring of *Mytilus*. Because most of the mussels collected for sampling were very small (1-3 mm), positive identification of species was not possible. Since adult *Mytilus edulis* is usually found in intertidal zones, while *Modiolus modiolus* is found subtidally, it was assumed that all intertidal specimens were *Mytilus edulis*. *Mytilus* densities for 1971-1976 are shown in Figure 6-11. Although there are large fluctuations, this is common in intertidal communities. No station-related effects are apparent, since such stresses would appear as non-parallel time paths of the control and affected areas.

The seasonal effects of the predicted thermal plume compared to thermal tolerances (based on Appendix A) from Units 1 and 2 are shown in Figure 6-12. The greatest density of *Mytilus* occurs within the 10-foot mlw contour. A higher ambient temperature (maximum seasonal surface temperature) is used for the discussion of *Mytilus* than for the previous sub-tidal species since an elevated temperature is more representative of the intertidal environment.

During maximum ambient temperatures reached in summer, the thermal plume will have two primary effects on the mussel population (see Figure 6-12): lethal temperatures within the 10°F isotherm will affect approximately 4.9 acres; also, critical thermal maximum (CTM) may be reached in an additional 7 acres as evidenced by anticipated aberrant behavior of the mussels. In this area of CTM, the mussels may cease feeding for brief periods, though no mortality is expected. Furthermore, Pearce (1969) reports that at 75°F normal attachment, movement and aggregation of *Mytilus* is inhibited. The byssal fibers by which mussels attach to the substratum fail to tightly hold the mussels, even when disturbed. Although this water temperature also impedes feeding activities of such mussel predators as the seastar, green crab, and the whelk, the population may remain vulnerable to foraging finfishes. In the fall, the area of mortality will be about 1 acre, and the area of CTM about 1.2 acres.

6.6.2 Entrainment

Data have been gathered by MRI during 1974, 1975, and part of 1976 to determine the number of Mytilus larvae entrained at Pilgrim. However, it was not always possible to identify species of mollusks during early stages of development. Therefore, for this analysis, all bivalves were assumed to be Mytilus edulis. Thus, the evaluation is conservative.

The data gathered for 1974 through 1976 are plotted in Figure 6-13. By integrating over the period of occurrence formed by the data sets of 1974 and 1975, the number of larvae entrained per year can be calculated. The estimates were calculated by trapezoidal integration for Unit 1 alone and are 6.68×10^{11} entrained for 1974, and 5.78×10^{12} entrained for 1975. For both Units 1 and 2, estimated entrainment is 2.21×10^{12} for 1974 and 1.91×10^{13} for 1975.

According to Purchon (1968), natural mortality of bivalve larvae to adults is 99.9 percent. Applying this mortality to Mytilus, the larvae entrained by Units 1 and 2 might have produced 2.21×10^{9} adults in 1974, and 1.91×10^{10} adults in 1975.

The average number of adult Mytilus for Rocky Point and Manomet Point intertidal stations combined is 8,537 per square meter. Using the above entrainment figures, this would be equivalent to 2.6×10^{5} and 2.2×10^{6} square meters or 64 and 544 acres of Mytilus edulis for 1974 and 1975, respectively.

Assuming 100 percent entrainment mortality and that all bivalves are Mytilus edulis makes these estimated losses highly conservative. Theoretically, 19.3 and 167 acres of Mytilus (for 1974 and 1975, respectively) should have been lost as a result of Unit 1 entrainment. In general, no detectable change in Mytilus density has occurred as a result of Unit 1 operation (pers. comm., Dr. A. Michael, 8-15-77).

6.6.3 Entrapment

Mussels are commonly collected from intake screens; however, they are not considered entrapped species since they actively colonize the screens rather than being passively swept onto them.

6.6.4 Cumulative Impact

No detrimental station impact on M. edulis is expected to occur through entrapment, as this species readily colonizes intake screens. However, the reason for biofouling control which includes chlorination and thermal backwashing is control of mussels in the circulating water system. Therefore, potential station-related effects on M. edulis can result from the thermal plume and entrainment.

Based on thermal tolerances, some mortality may occur in summer within the 10°F isotherm (4.9 acres) and within the 20°F isotherm (0.9 acre) in fall. In addition, approximately 6.8 acres of Mytilus in summer and 0.9 acre in fall may sustain increased predation and temporary cessation of feeding as a result of thermal effects.

Entrainment of M. edulis larvae will occur during operation of Units 1 and 2. The predicted entrainment numbers are 2.2×10^{12} for 1974 and 1.9×10^{13} for 1975, based on Unit 1 sample data. Conservative estimates of equivalent acreage lost through entrainment (assuming 100 percent mortality) are 64 and 544 acres for 1974 and 1975, respectively. More realistic but still conservative estimates based on entrainment mortality studies by MRI (1975) (assuming 10 percent mortality) are 6.4 acres for 1974 and 54.4 acres of Mytilus edulis lost for 1975.

Based on the above estimates, the large size of Cape Cod Bay, and rapid colonization of M. edulis, the cumulative impact of Units 1 and 2 operation on the population of M. edulis will be negligible.

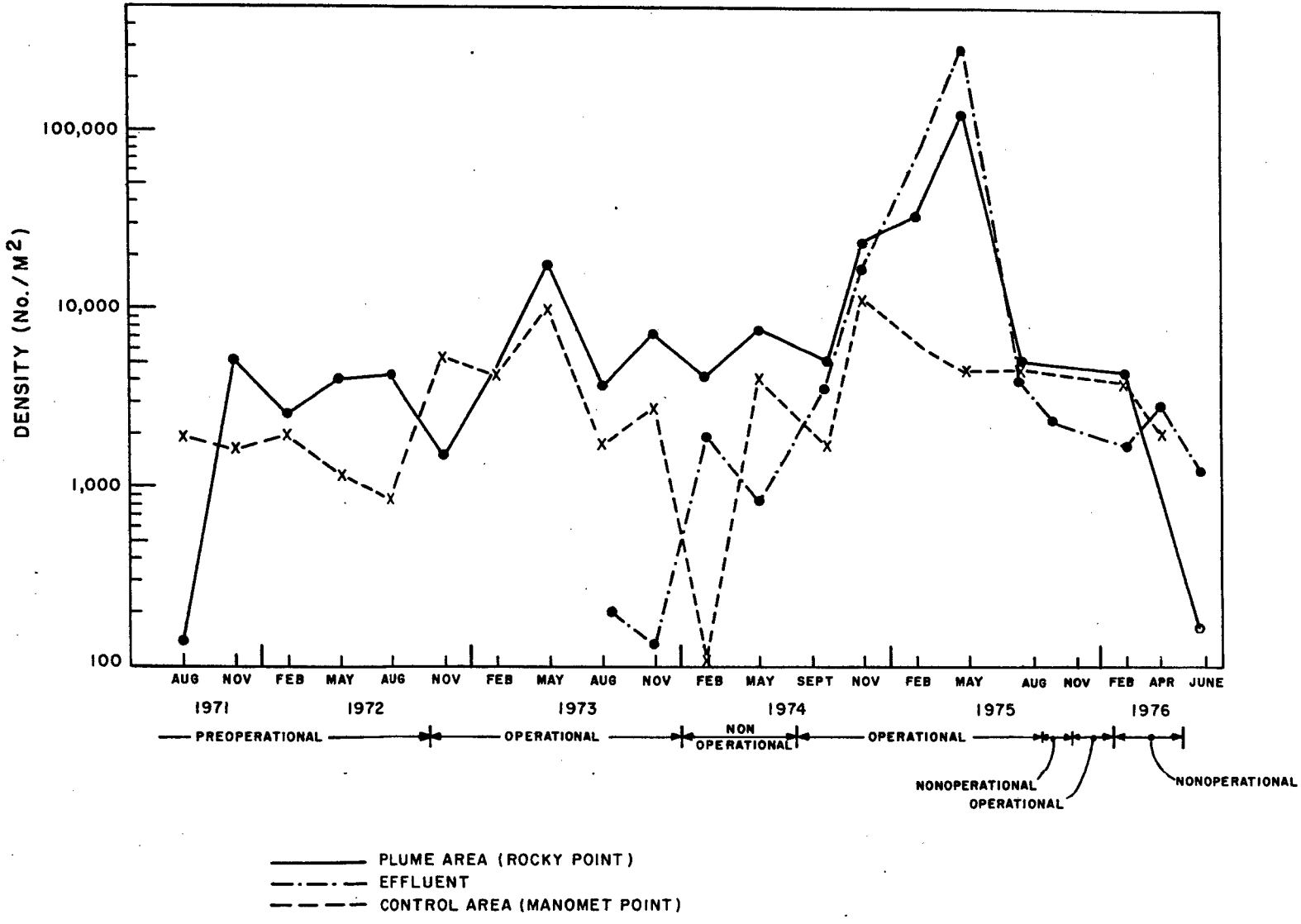


FIGURE 6-11
MEAN INTERTIDAL *MYTILUS* DENSITY

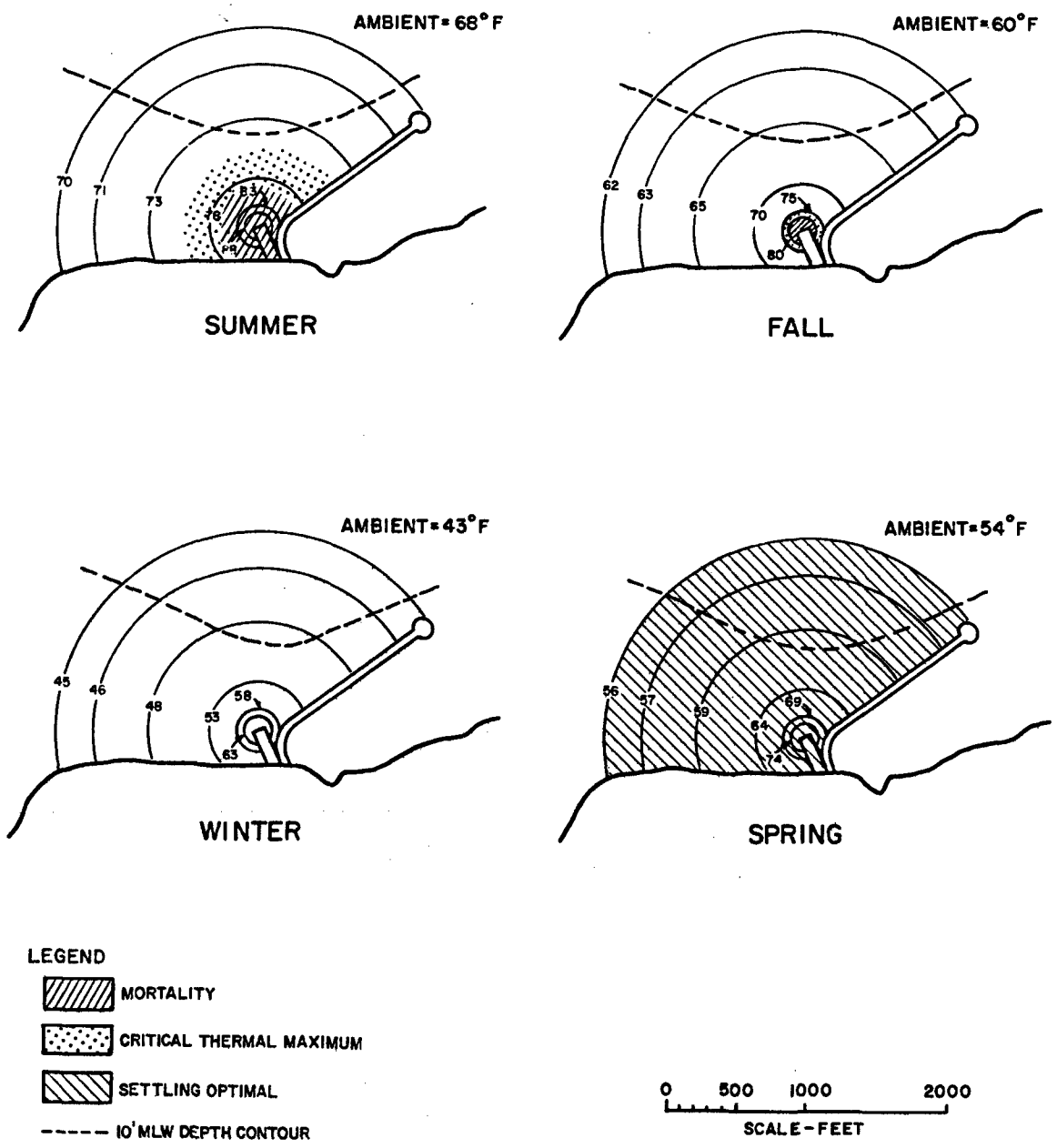
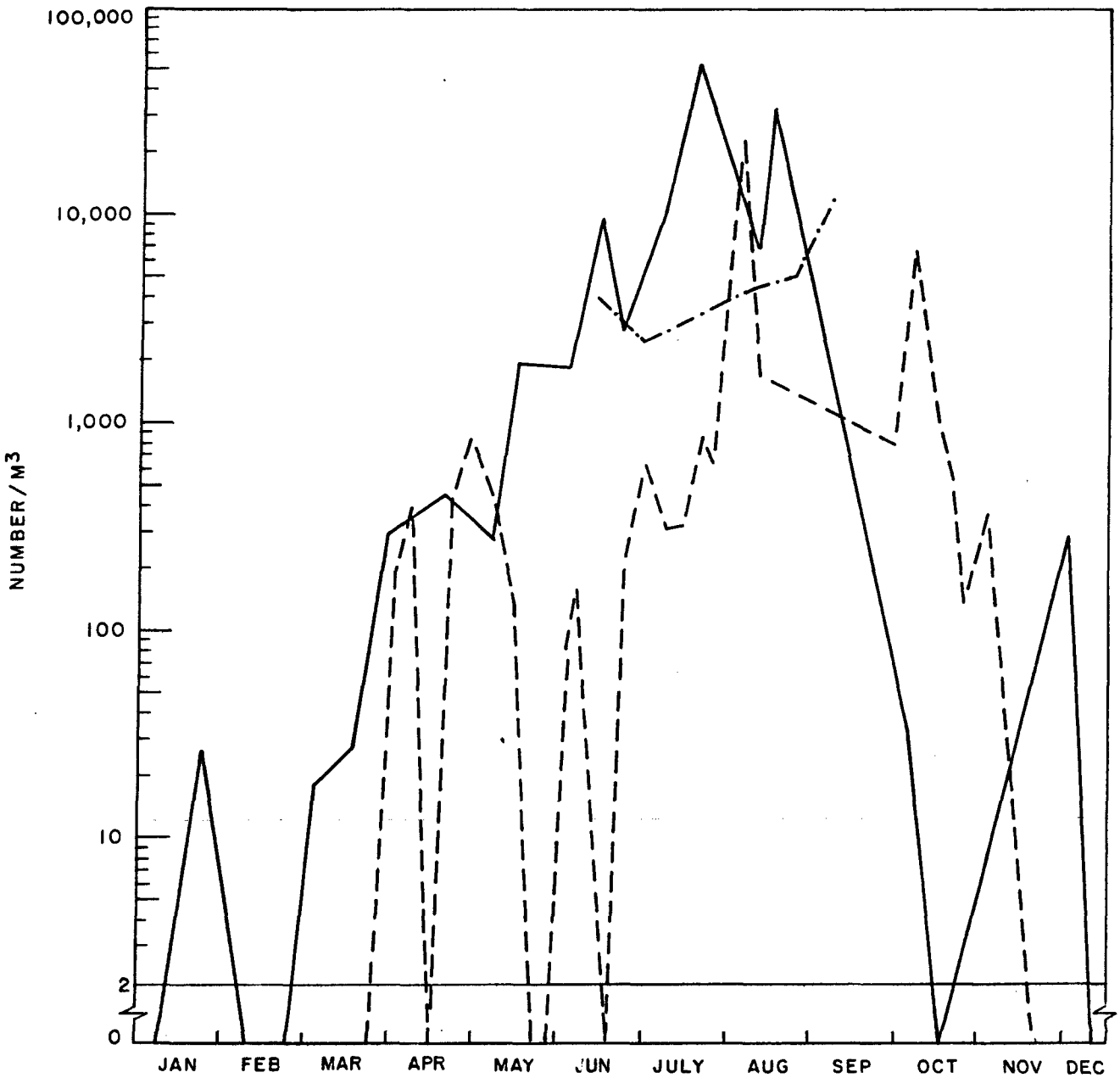


FIGURE 6-12

POTENTIAL THERMAL PLUME EFFECTS
BLUE MUSSEL



—·—·—1976
———1975
– – – –1974

FIGURE 6-13

DENSITY OF *MYTILUS* (BIVALVE) LARVAE OBSERVED AT UNIT I 1974 THROUGH 1976

6.7 COMMON PERIWINKLE (*Littorina littorea*)

Common periwinkle is a dominant intertidal gastropod at Pilgrim Station. It is a tolerant organism adapted to varying temperatures and partial drying. Power station-related impact could result from the effect of the thermal plume on adults and entrainment of planktonic eggs and larvae. As in previous discussions, the potential impacts of the combined Units 1 and 2 discharge are described by relating results of monitoring studies at Unit 1 to the predicted Units 1 and 2 discharge data.

6.7.1 Thermal Plume

As for *Mytilus edulis*, intertidal densities of *Littorina littorea* have been measured quarterly as part of the benthic monitoring study. Data collected between 1971 and 1976 are plotted in Figure 6-14. No station-related effects are apparent since station-related stresses would appear as non-parallel time paths of the control and affected areas. Due to the high thermal tolerance of *Littorina littorea* (see Appendix A), no thermal impact is expected.

6.7.2 Entrainment

Due to difficulty in species identification, all gastropod eggs and larvae are assumed to be *Littorina littorea*. Egg and larval samples have been collected by MRI for 1974, 1975, and part of 1976 (see Figure 6-15). By integrating over the period of occurrence (formed by the data sets of 1974 and 1975), the number of larvae entrained per year can be estimated. The estimates were calculated for Unit 1 alone, and for Units 1 and 2 combined. The estimates are:

	1974		1975	
	Unit 1	Units 1 & 2	Unit 1	Units 1 & 2
No. eggs entrained:	8.7×10^{10}	2.9×10^{11}	8.1×10^{10}	2.7×10^{11}
No. larvae entrained:	4.3×10^{10}	1.4×10^{11}	3.2×10^{11}	1.0×10^{12}

The projected larval entrainment is high relative to egg entrainment. This is because larvae are planktonic for about a 6-week period but eggs are in the water column only 6 days. Thus, there would be a greater opportunity for larvae originating outside the station area to be entrained by Pilgrim Station than for eggs to be entrained.

As a conservative estimate of localized impact, the number of larvae entrained will be included with the number of larvae normally expected to survive from the entrained eggs. Assuming

0.1 survivorship of eggs to larvae, this totals 1.69×10^{11} entrained for 1974 ($2.9 \times 10^{10} + 1.4 \times 10^{11}$) and 1.0×10^{12} larvae entrained for 1975 ($2.7 \times 10^{10} + 1.0 \times 10^{12}$) for Units 1 and 2.

Applying 99.9 percent mortality of larvae to adults (Purchon 1968), the above eggs and larvae would have produced 1.69×10^{8} and 1.0×10^{9} adults in 1974 and 1975, respectively. The average number of adults at Manomet Point, the station farthest from the discharge, is about 380 per square meter. Using the estimated number of adults lost due to entrainment, an equivalent area lost would be 110 acres in 1974 and 668 acres in 1975.

This estimate is very conservative since all gastropod larvae were assumed to be Littorina littorea, and larval entrainment mortality was assumed to be 100 percent. In fact, larval entrainment mortality is probably less than 10 percent (MRI 1975). Using 10 percent mortality, a more reasonable estimate would be 11 acres lost in 1974 and 68 acres lost in 1975 as a result of Units 1 and 2 operation. Theoretically, 33.6 and 213 acres would be expected lost in 1974 and 1975 from Unit 1 operation. To date, no detectable change in Littorina density has occurred as a result of Unit 1 operation (pers. comm., Dr. A. Michael, 8-15-77).

6.7.3 Entrapment

Not applicable.

6.7.4 Cumulative Impact

No entrapment of L. littorea is expected because no life stage is susceptible to this source of impact. Potential station-related effects on L. littorea may result from the thermal plume and entrainment.

Based on thermal tolerances, no thermal impact on Littorina littorea is anticipated. Entrainment of both periwinkle eggs and larvae will occur; based on entrainment monitoring at Unit 1, 1.69×10^{11} and 1.0×10^{12} larvae would have been entrained in 1974 and 1975, respectively, as a result of two-unit operation. If all larvae entrained are assumed lost, a conservative estimate of equivalent adult acreage lost is 110 acres for 1974 and 668 acres for 1975. Based on entrainment mortality studies, a more realistic estimate using 10 percent entrainment mortality would be 11 and 68 acres lost for 1974 and 1975, respectively.

Based on the above conservative estimates, the large area of Cape Cod Bay, and rapid colonization of L. littorea, the cumulative impact of Units 1 and 2 operation on the Cape Cod Bay population of L. littorea (the equivalent of approximately 25 acres) will be negligible.

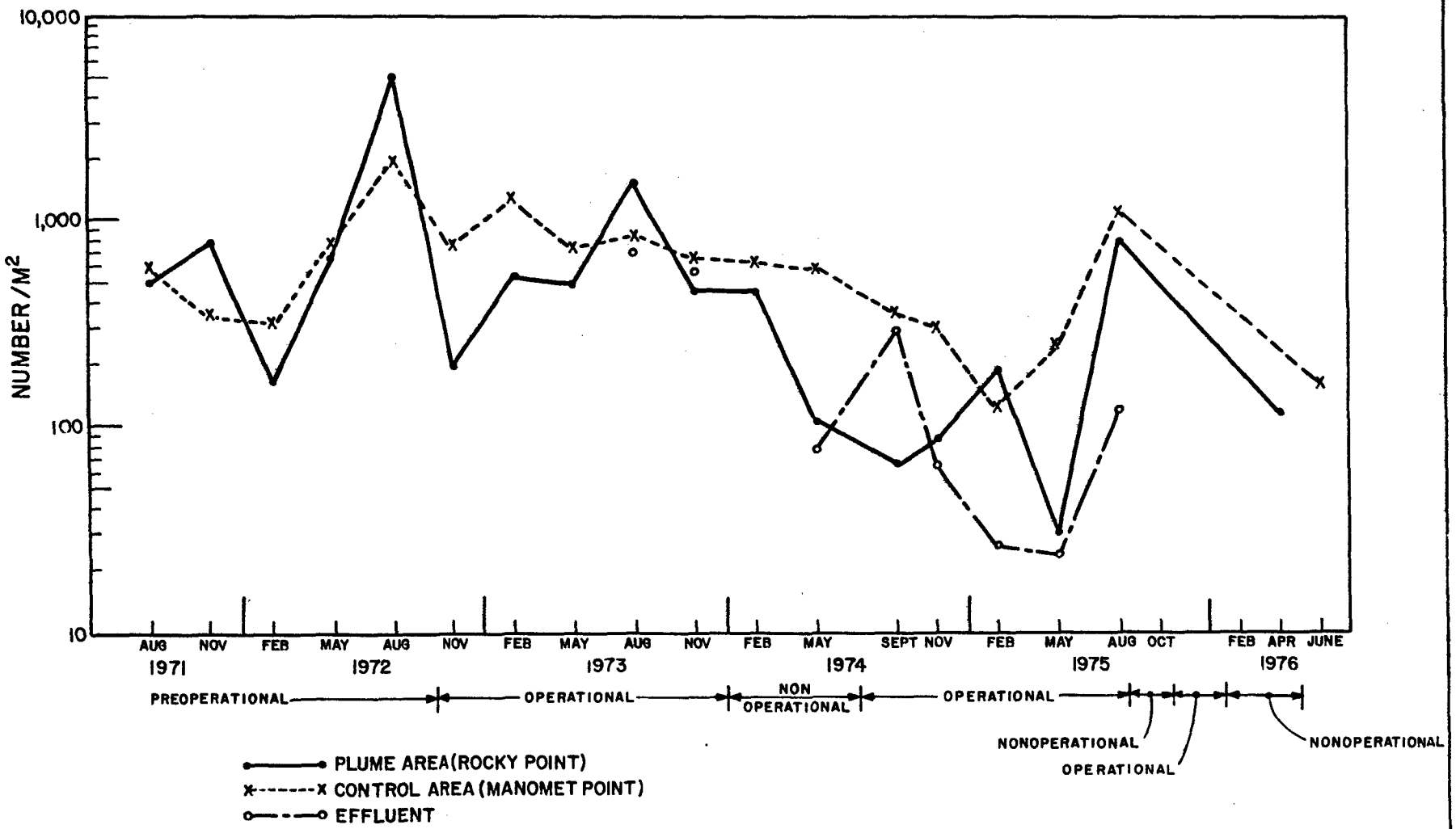
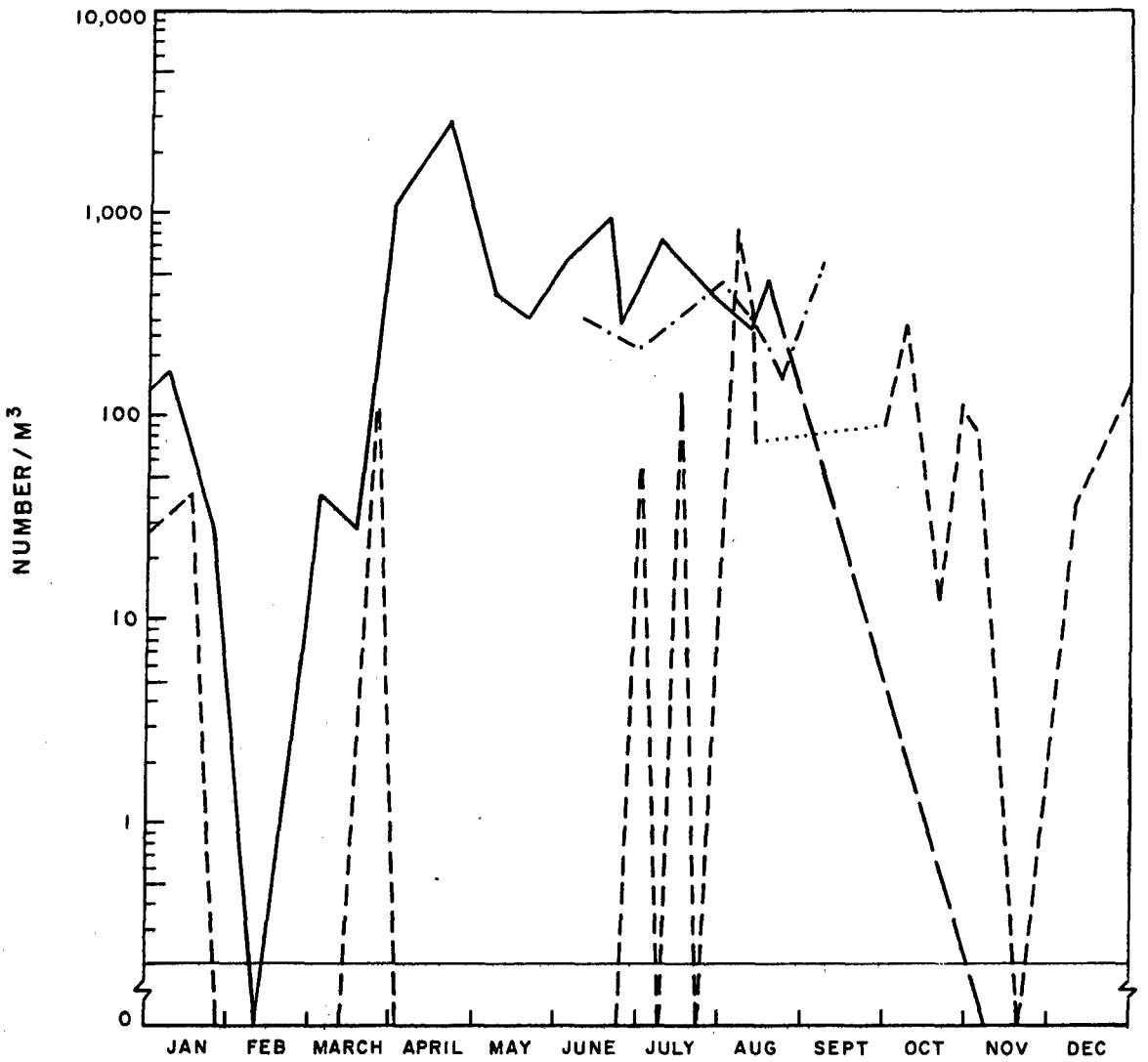


FIGURE 6-14
MEAN INTERTIDAL DENSITY OF *LITTORINA LITTOREA*



1976
1975
1974

FIGURE 6-15
DENSITY OF *LITTORINA* (GASTROPOD) LARVAE OBSERVED AT UNIT I 1974 THROUGH 1976

6.8 ATLANTIC MENHADEN (*Brevoortia tyrannus*)

The effect of the operation of Units 1 and 2 on the Atlantic menhaden (*Brevoortia tyrannus*) population is predicted by a population simulation model. Sources of impact to this population include entrainment of larvae, impingement of yearlings, and the effects of the thermal plume, such as gas bubble disease to adults. The basis for the analysis of impact is a population dynamics simulation model initially developed by Schaaf and Huntsman (1972). The model was used to simulate menhaden populations for a 50-year period. The analysis also included additional sources of mortality representing the power station operation effects. Results of both simulations were compared with respect to population size and the projected yield to the commercial fishery.

6.8.1 The Model

The menhaden life cycle model used for this analysis allows prediction of future population structure. A Ricker (1958) stock and recruitment function from Schaaf and Huntsman (1972) was used to predict the number of fish in age-class 1 (R) from the total number of spawners (S) the previous year:

$$R = S \exp (1626 - S/10^6)/654 \qquad (6.8\text{-}1)$$

The stock and recruitment function is the density-dependent component in this population dynamics model. A graph of the function is depicted in Figure 6-16. For spawning densities below 6.54×10^8, an increase in the spawning stock results in an increased number of recruits. For spawning densities above 6.54×10^8, an increase in the spawning stock results in a decreased number of recruits.

The instantaneous natural mortality and fishing mortality were assumed to be constant for all 10 age-classes. The instantaneous fishing mortality of age-class 1 was calculated as 66 percent of the fishing mortality of the other ages (Table 6-2). The simulations were run with a natural mortality rate of 0.37, as developed by Schaaf and Huntsman (1972). The instantaneous fishing mortality rate of 0.8 was used. Schaaf and Huntsman (1972) determined that this fishing mortality rate results in annual commercial catches of 400,000 to 500,000 metric tons.

Yield to the commercial fishery was calculated using the exploitation formula:

$$U = F(1-e^{-Z})/Z, \qquad (6.8\text{-}2)$$

where

U is the exploitation rate,
F is the instantaneous fishing mortality, and
Z is the total mortality rate from all sources.

The yield is calculated in metric tons by using average weight at each age-class from the data of Reintjes (1969) and is presented in Table 6-3. The number of fish which incur mortality from the power station is also calculated using the formula (Eq. 6.8-2) by substituting the instantaneous mortality rate due to the power station for F.

The effect of the power plant was simulated by first calculating a mortality rate due to power plant-related events (e.g., entrainment, entrapment, and plume effects). Entrainment data were collected for 1974, 1975, and 1976. The number of larvae entrained in any one year at Unit 1 was calculated by integrating the curve formed by density values determined during the period of entrainment for that year. To predict the effects of two-unit operation, the estimate was then multiplied by the ratio of flow of Units 1 and 2 to the flow of Unit 1. (See Table 6-4 for numbers of larvae entrained.)

To estimate the mortality rate which would result if all entrained larvae were lost, the number of larvae produced by the simulated population was calculated.

The age-specific fecundity for menhaden was estimated from the weight-fecundity relationship of Higham and Nickolson (1964). The age-specific mean weight from Reintjes (1969) was then used to obtain the age-specific fecundity (Table 6-2). The equilibrium population (see Table 6-4) was multiplied by the fecundity to obtain an estimate of the number of eggs produced. It was assumed that 1 in 10 eggs hatch. This results in an estimated 1.45×10^{13} larvae. The estimate of entrainment mortality is:

$$Me = -\ln (1-(\text{no. of eggs} \div 10 \cdot \text{no. of larvae entrained in a year}/1.45 \times 10^{13})) \qquad (6.8\text{-}3)$$

The effect of impingement of menhaden on the traveling screens was estimated from the screenwashing data collected from 1973 to 1976. Menhaden impinged were not distinguishable from other clupeid species for 1974-1975, therefore, it is conservatively assumed for this analysis that all clupeids are menhaden. It is also assumed these fish are age-class 1, since they are unidentifiable as menhaden.

Numbers of fish entrapped per year have been estimated for 1974 to 1976 (see Table 6-5) for one-unit operation, assuming that the power station runs continuously throughout the year. The prediction for two-unit operation assumes that the number of fish entrapped is proportional to the rate of flow (a conservative assumption). The estimated additional mortality to the population would be:

$$MI = -\ln (1 - \text{no. impinged in a year}/2.82 \times 10^{9} \text{ (no. of age 1 fish)}) \qquad (6.8\text{-}4)$$

The effect of gas bubble disease-related mortality is conservatively predicted by calculating the additional mortality that would have resulted from a kill of the size which occurred at Pilgrim Unit 1 in April 1973, and imposing this additional mortality each year. Since this mortality does not occur every year, as evidenced by 1974, 1975, and 1976 data, this estimate is most likely an overestimate.

The 1973 fish kill has been estimated to be about 43,000 age-3 fish. In 1975, a smaller fish kill estimated at about 5,000 menhaden took place. The additional mortality to the equilibrium-simulated population based on the higher 1973 kill would be:

$$Mg = -\ln (1 - 4.3\times10^{4}/3.5\times10^{8} \text{ (no. age 3 fish)}) = 1.23\times10^{-4}$$

The mortalities attributed to the power station are added singularly and in combination to the total mortality rate and the population re-simulated. The number of fish which suffer mortality due to the power station and the percentage of the equilibrium population affected were also calculated from the simulation.

The initial population structure and size for the simulation analysis was calculated based on the data from Schaaf and Huntsman (1972) for the year 1955. This estimate of population size was calculated from the number of fish in the commercial catch and the 1955 age-specific exploitation rates (Table 6-2). The exploitation rate for age-class 1 was two-thirds the average exploitation rate for fish ages 2 to 5. For fish 6 years and older, the average exploitation rate was used.

6.8.2 Results of Thermal Plume, Entrainment, and Impingement

The population simulation of menhaden with the parameters listed in Table 6-2 revealed a population which reached an equilibrium size of 4.48×10^{9} individuals and a stable age distribution (Table 6-3). At equilibrium and an annual fishing mortality rate of 36 percent, the yield to the commercial fishery is 3.94×10^{5} metric tons.

The results of imposing additional mortality to the population to simulate the effect of entrainment, entrapment, and the thermal discharge are presented in Table 6-6. The result of imposing an additional mortality due to entrainment is a population which comes to an equilibrium and is reduced in size by 0.00003 to 0.0003 percent from the non-impacted population.

The simulation of entrapment and the thermal effect reveal similar levels of reduction in population size. These simulations also produced populations which reached an equilibrium.

The combined effects of all three sources of power plant mortality were simulated for all three years. The resulting population had stable equilibrium and population sizes 0.0007 to 0.001 percent below the non-impacted population.

6.8.3 Cumulative Impact

The simulation performed using the population dynamics model of Schaaf and Huntsman (1972) reveals a population which is regulated only by the stock and recruitment function. The other population parameters which include age specific individual weight, natural and fishing mortalities are constants regardless of population density.

Any perturbation to the population within several orders of magnitude of that estimated for the Pilgrim Nuclear Power Station, Units 1 and 2, results in a change in the equilibrium population density, but not the stability of the equilibrium. It is difficult to predict the reduction in the Massachusetts menhaden catch as a result of the operation of Pilgrim Units 1 and 2, since Massachusetts does not represent a biological sub-unit of the North Atlantic menhaden population. An estimate in the reduction in Massachusetts catch could be made for the fish which were killed by entrainment, entrapment, and the effects of the thermal plume if these were assumed to all be translated into reductions in the Massachusetts catch.

These losses due to power station events may be compared to the yield to commercial fisheries. The landings of menhaden in all Massachusetts ports and the dollar value of the landings are presented in Figure 6-17. A loss of 43,000 age-3 fish which was estimated for the 1973 fish kill would have represented 0.11 percent of the 1973 Massachusetts catch, or an approximate dollar value of $944.

An estimate of the reduction in the commercial fishery catch as a result of power station operation (due to all three sources of mortality) was made for a constant rate of fishing mortality. The worst-case reduction in the North Atlantic catch in the impacted population vs. the non-affected population is about 53,000 fish per year, a 0.001 percent reduction.

If it is further assumed that the reduction in Atlantic menhaden population size of 0.001 percent is represented by fish weighing about one pound each, the weight of this loss is then 24 metric tons. This corresponds to about 0.13 percent of the 1973 Massachusetts catch, or a dollar value of about $1,119.

TABLE 6-2

PARAMETERS OF MENHADEN POPULATION SIMULATION MODEL

Age-Class	Instantaneous Natural Mortality	Instantaneous Fishing Mortality	Average Weight (grams)	Fecundity
1	0.37	0.53	127.3	-
2	0.37	0.80	270.5	-
3	0.37	0.80	488.2	239,845
4	0.37	0.80	600.0	345,976
5	0.37	0.80	689.1	408,269
6	0.37	0.80	762.0	459,237
7	0.37	0.80	793.6	481,330
8	0.37	0.80	839.5	513,420
9	0.37	0.80	839.5	513,420
10	0.37	0.80	839.5	513,420

TABLE 6-3

SIMULATED EQUILIBRIUM OF MENHADEN POPULATION

Age-Class	Population Size ($x10^6$)	Age Distribution	Yield (Metric Tons)
1	2,815.9	0.629112	125,270
2	1,144.8	0.255780	146,030
3	355.32	0.079386	75,096
4	110.28	0.024639	31,201
5	34.227	0.007647	11,122
6	10.623	0.002373	3,812
7	3.2970	0.000737	1,234
8	1.0233	0.000229	405
9	0.3176	0.000071	125
10	0.0986	0.000022	39
Total	4,475.9	1.000000	394,334

TABLE 6-4

PREDICTED NUMBERS OF EGGS AND LARVAE ENTRAINED

Species No./m³		1974 Unit 1	1974 Units 1 & 2	1975 Unit 1	1975 Units 1 & 2	1976 Unit 1	1976 Units 1 & 2
Pollock							
	Eggs	2.9041×10^{7}	9.6066×10^{7}	3.3233×10	1.0986×10^{2}	6.3174×10^{4}*	2.0885×10^{7}*
	Larvae	2.6940×10^{6}	8.9060×10^{6}	6.4872×10^{5}	2.1446×10^{6}	7.6442×10^{4}	2.5271×10^{5}
Winter flounder							
	Larvae	6.8059×10^{7}	2.2500×10^{8}	1.5814×10^{7}	5.2280×10^{7}	1.0201×10^{7}*	3.3725×10^{7}*
Menhaden							
	Eggs	3.9159×10^{5}	1.2945×10^{6}	3.5473×10^{5}	1.1727×10^{6}	2.1777×10^{6}	7.1993×10^{6}
	Larvae	2.2730×10^{7}	7.5142×10^{7}	1.8475×10^{6}	6.1078×10^{6}	4.3852×10^{6}	1.4497×10^{7}
Rainbow smelt							
	Larvae	9.1065×10^{4}	3.0105×10^{7}	4.3982×10^{4}	1.4540×10^{5}	2.6390×10^{4}	8.7242×10^{4}
Silverside							
	Eggs	-	-	2.4247×10^{5}	8.0158×10^{5}	2.9848×10^{4}	9.8675×10^{4}
	Larvae	9.7949×10^{4}	3.2381×10^{5}	2.2537×10^{5}	7.4504×10^{5}	7.0718×10^{5}	2.3379×10^{6}
Alewife							
	Larvae	2.8958×10^{5}	9.5733×10^{5}	0	0	3.9252×10^{3}	1.2976×10^{4}
Blue mussel							
	Larvae	6.6811×10^{11}	2.2087×10^{12}	5.7844×10^{12}	1.9122×10^{13}	8.7455×10^{11}*	2.8912×10^{12}*
Periwinkle							
	Eggs	8.7454×10^{10}	2.8911×10^{11}	8.1231×10^{10}	2.6854×10^{11}	4.9113×10^{10}*	1.6236×10^{11}*
	Larvae	4.3949×10^{10}	1.4529×10^{11}	3.1841×10^{11}	1.0526×10^{12}	5.9363×10^{10}*	1.9625×10^{11}*

*Incomplete data; entrainment values for partial year.

TABLE 6-5

PREDICTED NUMBERS OF FISH IMPINGED

	1973		1974[1]		1975		1976[2]	
	Unit 1	Units 1 & 2	Unit 1	Units 1 & 2	Unit 1	Units 1 & 2	Unit 1	Units 1 & 2
Atlantic menhaden[3]	14,698	47,084	6,373	19,172	2,402	14,450	300	905
Winter flounder	413	1,358	10	51	55	172	128	642
Pollock	96	334	17	61	0	0	302	1,520
Cunner	824	2,927	87	256	466	1,813	2,299	7,337
Rainbow smelt	2,181	7,832	198	724	91	335	602	2,746
Atlantic silverside	765	2,472	7	59	884	2,820	491	2,392
Alewife[3]	14,537	46,491	6,373	19,172	2,402	14,450	16,266	48,557

NOTES:

(1) Unit 1 did not operate from January through July; collection was discontinued in March, resumed in August.

(2) Unit 1 did not operate from February through May; collection was not discontinued because one of the two circulating pumps was operating at all times.

(3) Clupeids from 1974-1975 have been used twice. For menhaden analysis, all clupeids were assumed to be menhaden; for alewife analysis, all clupeids were assumed to be alewife.

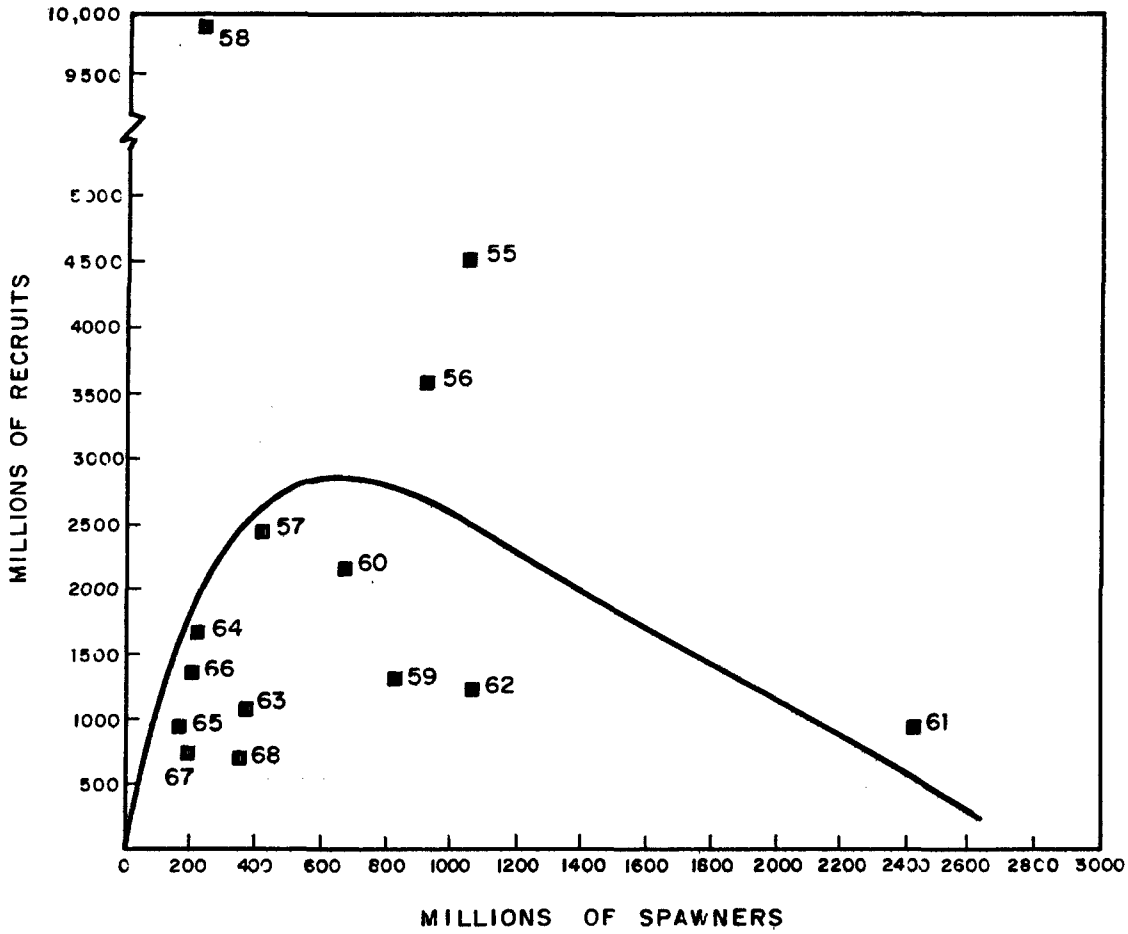
TABLE 6-6

RESULTS OF SIMULATION OF MENHADEN POPULATION

Condition	Year	Additional Mortality Unit 1	Additional Mortality Units 1 & 2	% Reduction in Population Unit 1	% Reduction in Population Units 1 & 2
Without Power Plant	All Years	0	0	0	0
Entrainment (larvae)	1974	1.5703×10^{-6}	5.19×10^{-6}	0.000097	0.000326
	1975	1.30×10^{-7}	4.29×10^{-7}	0.000007	0.000026
	1976	3.175×10^{-7}	1.0495×10^{-6}	0.000019	0.000067
Impingement (age-class 1)	1974	2.2633×10^{-6}	6.81×10^{-6}	0.000094	0.000282
	1975	8.531×10^{-7}	5.1316×10^{-6}	0.000035	0.000212
	1976	1.066×10^{-7}	3.213×10^{-7}	0.000004	0.000013
Thermal Plume (age-class 3)	All Years	1.23×10^{-4}	1.23×10^{-4}	0.000576	0.000576 — (0.00156% - 1975 Demo.)
Total	1974	all of the above	all of the above	0.000767	0.001184 } — (0.00485% - 1975 Demo.)
	1975			0.000618	0.000813
	1976			0.000599	0.000656

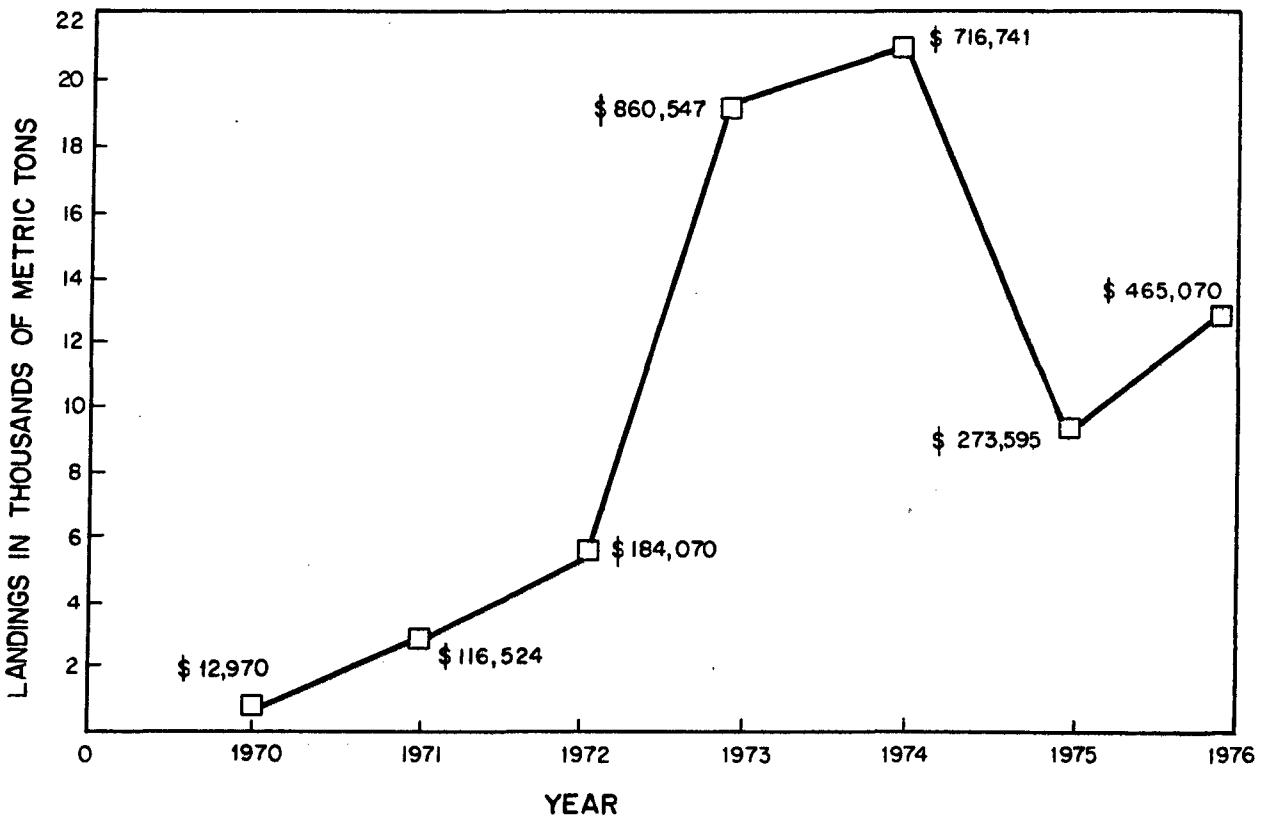
NOTE:

No entrainment data available for 1973 simulation



FROM SCHAAF AND HUNTSMAN (1972)
(DATA POINTS REPRESENT YEARLY
ESTIMATES OF FISH ABUNDANCE)

FIGURE 6-16
THE RICKER STOCK AND
RECRUITMENT FUNCTION



(FROM U.S. DEPARTMENT OF COMMERCE CURRENT FISHERIES STATISTICS; TOTAL LANDINGS AND DOLLAR VALUE OF EACH YEAR'S CATCH)

FIGURE 6-17
MENHADEN LANDINGS FOR ALL MASSACHUSETTS PORTS

6.9 WINTER FLOUNDER (*Pseudopleuronectes americanus*)

The effects of the operation of Pilgrim station Unit 1 and Units 1 and 2 combined have been assessed for winter flounder. The winter flounder is a species of interest since it is a commercially valuable resource and supports a recreational fishery.

Winter flounder in the area of Cape Cod Bay exist in relatively localized populations. Howe et al (1976) summarize Perlmutter (1947) as follows, "Following an early migration study, it was postulated that each resident breeding population could be managed since young fish were the product of local spawning and adult movements were highly localized." The tagging study of Howe and Coates (1975) in Cape Cod Bay, as well as other areas, indicates that 90 percent of the winter flounder tagged within an area were recaptured within the same area.

The Plymouth Harbor-Kingston Duxbury Bay (PHKDB) area is the area closest to the Pilgrim station where intensive breeding takes place for winter flounder. Initially, a conservative decision was made to consider the impact of Pilgrim station on the local population. Localized populations are more sensitive to stresses of the type which arise from power station operation than widely distributed populations.

A further conservative assumption was made that the local population is closed to migration from other populations. The result of this assumption was to concentrate the effects of power station operation on the local populations and not permit exchange with adjoining populations. Thus, winter flounder entrained or impinged were assumed to be members of the local population.

Winter flounder populations exhibit a seasonal inshore-offshore migration within localized areas. The adults move inshore to breed. The size of the breeding population can be estimated at this time. An initial estimate of the size of the local population breeding in the PHKDB was based on the size of the area and the breeding densities observed by Saila (1961). This initial population size and distribution with age is presented in Table 6-7.

The adults disperse to deeper water after the breeding season. Winter flounder eggs are demersal or tend to be associated with the bottom. Thus, the eggs do not tend to be entrained. The larvae are more planktonic and more apt to be suspended in the water column; therefore, they are transported by currents and dispersion. Since the population is localized, the larvae that survive remain in the area in sufficient numbers to repopulate succeeding generations of flounder. Therefore, we have measured the effect of entrainment as being the reduction in larvae

6.9.2 Entrainment

The effect of entrainment of winter founder larvae on the PHKDB population was characterized as an increase in mortality to the larvae. An estimate of entrainment mortality was derived from a mathematical modeling study conducted by the staff of the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics at MIT.

The MIT study investigated entrainment by employing mathematical models to simulate circulation and dispersion of suspended particles in the water. These models include the phenomena of tides, currents, and winds to simulate the transport of larvae during this planktonic life stage. A description of the circulation model CAFE can be found in Wang and Conner (1975) and a description of the dispersion model DISPER can be found in Leimkuhler (1974).

As an example of the simulation of larval transport, Figures 6-18 and 6-19 depict the center of mass for groups of larvae at various points of origin in the area of Pilgrim station. These figures represent the direction in which the concentration of larvae would be transported without regard to the dispersion of larvae from the center of the mass.

The MIT study of larval entrainment has been carried out in two phases. The first phase was conducted in 1975 and the results are reported in Pagenkopf et al (1976). In this study, 2×10^9 larvae were loaded into the PHKDB in two tidal cycles. The larval production of 2×10^9 was determined from breeding densities of winter flounder determined by Saila (1961), the area of the PHKDB, the fecundity of winter flounder (Hess et al 1976), and the survivorship of eggs. The decision to compress the period of larval production into two tidal cycles was based on the extensive computer time required to perform a real time simulation and the linear nature of the problem.

Two sets of simulations were performed for this first phase. The first set estimated the transport of larvae without the effect of the Pilgrim station. This simulation provided an idea of the number of larvae surviving and remaining in the PHKDB area and consequently available for recruitment into the population as juvenile winter flounder. Larvae are lost from the area due to death and transport out of the area by physical phenomena.

The second set of simulations included the effects of Pilgrim station, Units 1 and 2. By comparison of the number of larvae remaining in the population with and without the effect of the intake, an estimate of the increase in larval mortality beyond that normally experienced was made. This mortality was estimated to be about 0.1 percent (0.001).

believed to be a reasonable agreement for the degree of uncertainty associated with the input parameters of the study.

The second phase of the MIT modeling study utilized a single set of simulations which included the effects of the Pilgrim intake. Based on this set of simulations, the percentage of the larvae produced in the PHKDB which pass through the intake of Unit 1 was projected to be 0.8 percent and for Units 1 and 2 was projected to be 2.9 percent.

The 2.9 percent agrees well with the comparable estimate (2.7 percent) derived from the first phase of the MIT study for the northwest wind condition. Thus, the second phase does support the reasonableness of the estimates from the first phase. For the assessment of entrainment effects on winter flounder, the 316 Demonstration utilized the Southwest wind condition. This choice of southwest wind maximizes the estimate of reduction in larval recruitment (Table 1, Pagenkopf et al 1976).

The first phase of the MIT study concluded that, under the southwest wind condition, 1 in 10 of the larvae which pass through the intake would have been recruited into the PHKDB population. The results of the southwest wind condition yielded the largest estimate of reduction in recruitment of all the wind conditions. Therefore, this relationship was selected for application to the results of the 1977 study, and a reduction in recruitment of 0.08 percent was obtained for Unit 1 and 0.29 percent for Units 1 and 2.

6.9.3 Impingement

In addition to entrainment of larvae, the winter flounder population is also subject to impingement of adults, assumed to be age-class 2. The original estimate of mortality contained in the 316 Demonstration was made by extrapolation from Unit 1 screenwashing data for 1974. For two-unit operation, an estimated 769 flounder would be impinged per year. The expression for impingement mortality rate is:

$$MI = -\ln\left(1 - \frac{\text{No. impinged}}{\text{No. of age 2 fish}}\right) \qquad (6.9\text{-}2)$$

This analysis assumes that all winter flounder impinged die and that all the impinged represent an increase in mortality to the local population. Results of imposing this additional impingement mortality are presented in Table 6-8. Subsequent to the original estimate, more recent impingement data were collected. Impingement data for 1973, 1974, 1975, and 1976 (Table 6-5) have been incorporated to give an average number of winter flounder impinged. The impingement mortality figures and the results of imposing this additional mortality are given in Table 6-8.

TABLE 6-7

PARAMETERS OF THE WINTER FLOUNDER SIMULATION MODELS

Age-Class	Initial Population Size	Instantaneous Natural Mortality	Instantaneous Fishing Mortality	Average Weight (Grams)	Fecundity
1	507,506	1.928	0.0	25.7	0
2	73,791	0.66	0.45	105.2	0
3	24,351	0.66	0.45	222.3	182,000
4	8,035	0.66	0.45	356.1	310,100
5	2,650	0.66	0.45	489.2	445,900
6	874	0.66	0.45	607.3	569,100
7	288	0.66	0.45	707.9	679,000
8	95	0.66	0.45	793.7	774,900
9	32	0.66	0.45	861.4	851,900
10	11	0.66	0.45	913.9	910,700
11	3	0.66	0.45	954.2	956,900
12	1	0.66	0.45	988.3	996,800
	617,637				

TABLE 6-8

RESULTS OF WINTER FLOUNDER SIMULATION OVER A 40-YEAR PERIOD

(Based on the model of Hess, Sissenwine, and Saila 1975)

	Additional Mortality	Population Size	% Reduction
1976 (Units 1 & 2)			
Non-affected population	0	610,830	0
Entrainment (Phase I, MIT study)	0.001	606,890	0.65
Impingement (Data from 1973-1974)	0.0104	575,330	5.81
Entrainment and Impingement (Phase I, MIT study, data from 1975)	both	574,950	5.87
1977			
Non-affected population	0	617,640	0
Entrainment (Phase II, MIT study)			
Unit 1	0.0008	606,190	1.8
Units 1 & 2	0.00294	597,890	3.2
Impingement (Data avg. 1973-1976)			
Unit 1	0.0026	600,610	2.8
Units 1 & 2	0.0076	583,710	5.5
Entrainment (Phase II, MIT study) and Impingement (Data avg.)			
Unit 1	both	599,200	3.0
Units 1 & 2	both	572,580	7.3

TABLE 6-9

SUMMARY OF ENTRAINMENT STUDY
PILGRIM STATION - UNITS 1 AND 2

PHASE I - MIT 1976

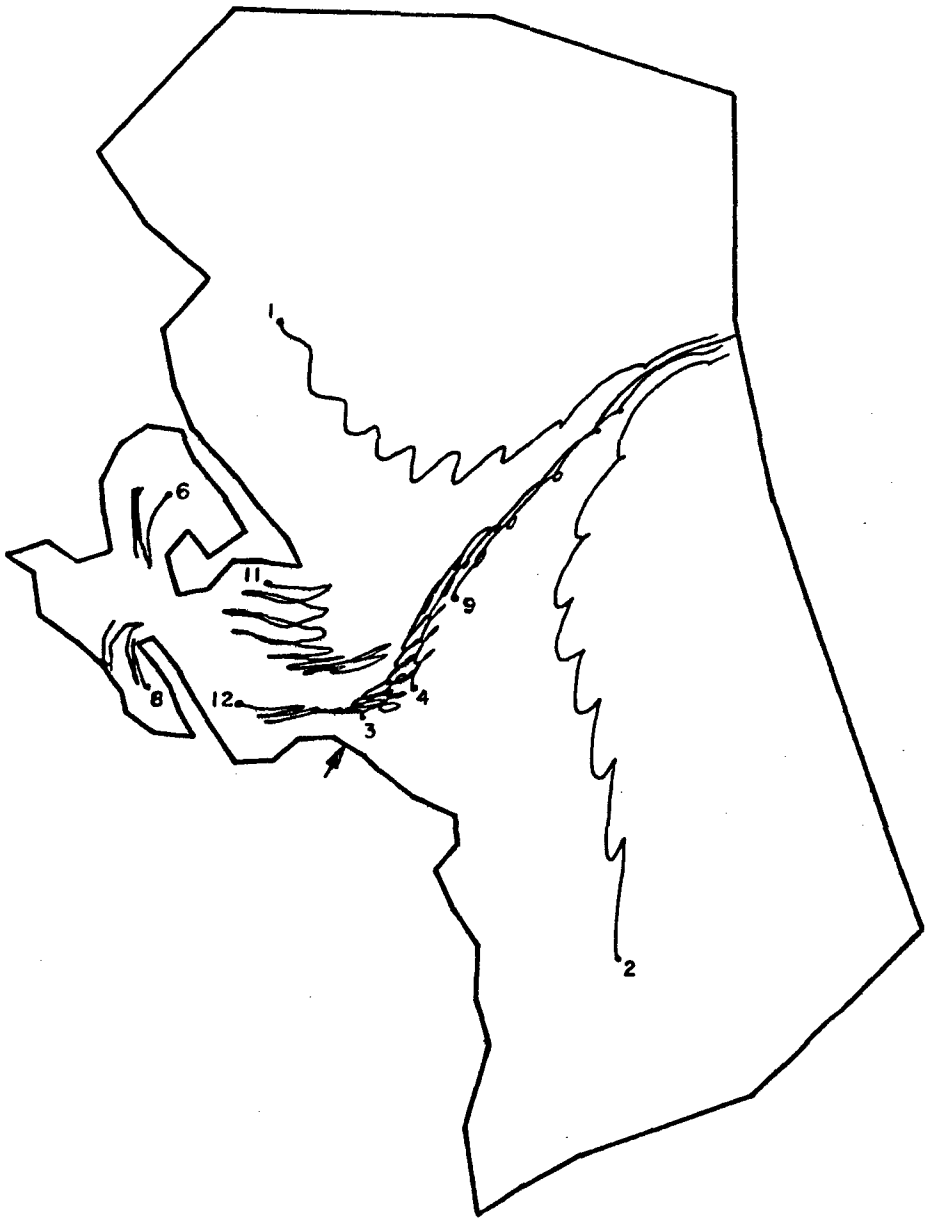
1. Percent reduction in larval recruitment into the Plymouth Harbor - Kingston Duxbury Bay population due to power station entrainment only: 0.1 percent.

2. Percentage of larvae produced in Plymouth Harbor-Kingston Duxbury Bay which pass through the intake, including larvae which would have died from causes other than entrainment: 1 percent

PHASE II - MIT 1977

1. Percent reduction in larval recruitment into the Plymouth Harbor - Kingston Duxbury Bay population due to power station entrainment only: 0.29 percent

2. Percentage of larvae produced in Plymouth Harbor - Kingston Duxbury Bay which pass through the intake, including larvae which would have died from causes other than entrainment: 2.9 percent



(FROM PAGENKOPF ET AL., 1975, FIG. 8)

FIGURE 6-18
DEPTH-AVERAGED PARTICLE PATHS;
VELOCITIES TAKEN FROM "CAFE"
USING TIDE AND 10-KNOT SOUTHWEST WIND

(FROM PAGENKOPF ET AL., 1975, FIG. 14)

FIGURE 6-19
DEPTH-AVERAGED PARTICLE PATHS;
VELOCITIES TAKEN FROM "CAFE"
USING TIDE AND 20-KNOT NORTHEAST WIND

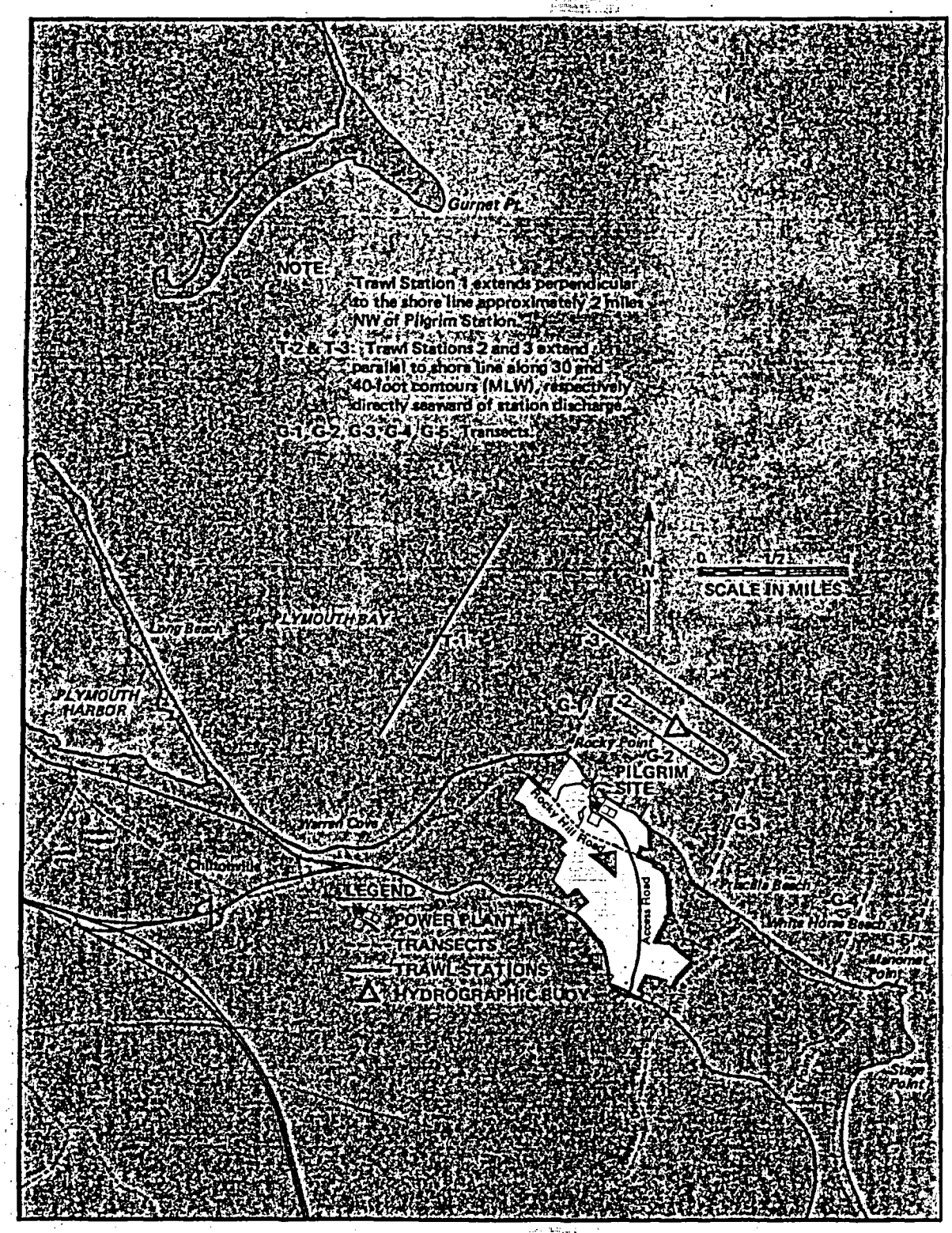


FIGURE 6-20

LOCATION OF TRAWL STATIONS

(FROM SEMI-ANNUAL REPORT No. 9, 1977)

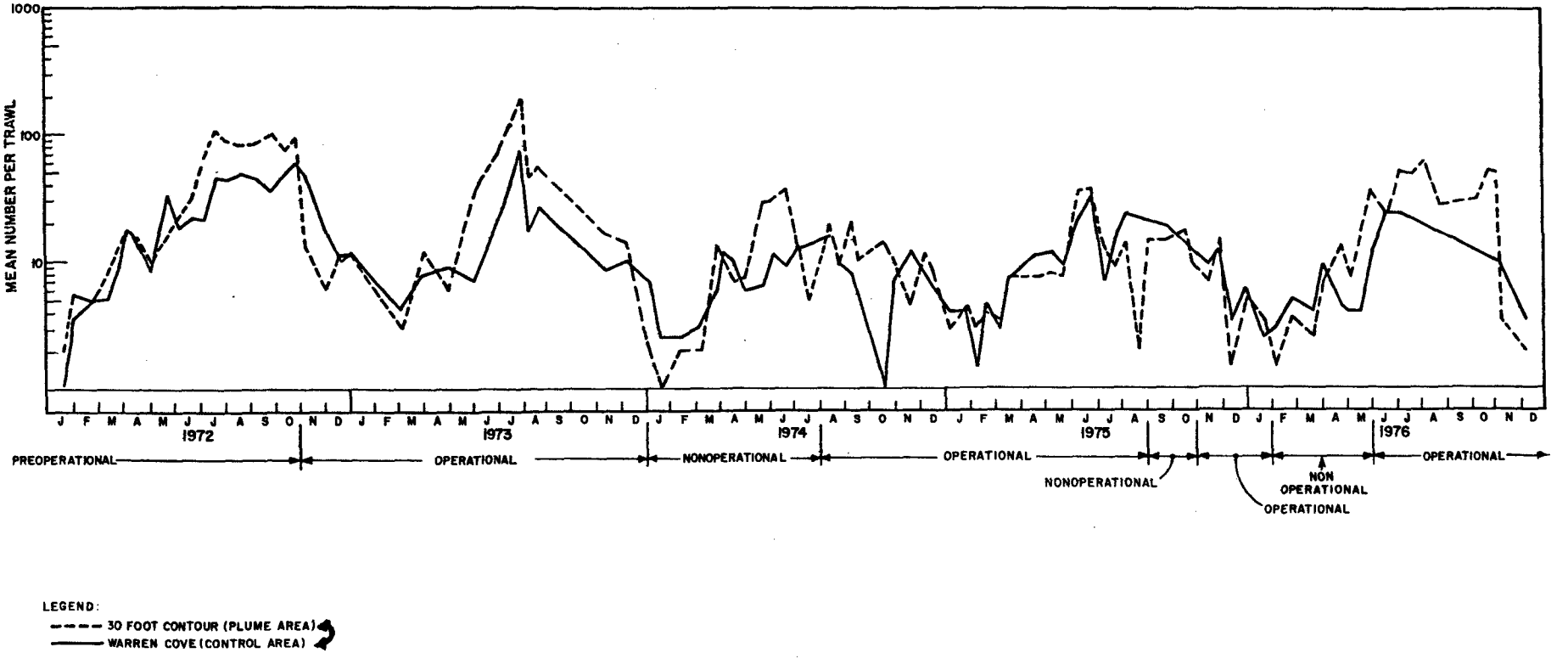


FIGURE 6-21
WINTER FLOUNDER TRAWL CATCH

6.10 POLLOCK (*Pollachius virens*)

Pollock is a predatory schooling fish species which is present at Pilgrim station during certain seasons of the year. Pollock could be subject to station impact through the thermal plume, entrainment of eggs and larvae, and impingement.

The abundance of pollock in the vicinity of the station, measured by gill net collections, is presented in Figure 6-22. The data were corrected for catch per unit effort. No decline in abundance is apparent.

6.10.1 Thermal Plume

There is little quantifiable evidence concerning the effect of the thermal plume on pollock. Visual observations indicate that pollock stay on the edge of the plume, feeding, and do not appear to be affected by the plume (R.B. Fairbanks, personal communication). Thermal tolerance data (Appendix A) indicate that pollock mortality could occur within the 20° isotherm (less than 1 acre) during the summer months. Pollock avoid the immediate plume areas; thus, no mortality is expected.

6.10.2 Entrainment

Pollock eggs and larvae are planktonic and therefore are subject to entrainment. Eggs and larvae were collected during the entrainment monitoring study in 1974, 1975, and 1976. Because it was difficult to distinguish pollock from other gadid and glyptocephalus eggs, all these eggs were assumed to be pollock. There was no such problem with larvae. These data were used to predict the impact of Units 1 and 2 on pollock.

Assuming the number entrained is proportional to the volume of water withdrawn, the numbers of eggs and larvae entrained were predicted as though Unit 1 alone, and Units 1 and 2, had been operating in 1974, 1975, and 1976 (see Table 6-4).

The fecundity of pollock has been reported as high as 4 million eggs per year per female (Bigelow and Schroeder 1953) with an average of 225,000 eggs per year per female. Age of first reproduction is 3 years and the life span rarely exceeds 10 years. Assuming 90 percent natural mortality from egg to larvae, and using the equivalent adult model (described in Section 6.1) for entrainment due to Unit 1 alone, 498 adults may be lost because of 1974 operation, 353 due to 1975, and 63 due to 1976 operation. If Units 1 and 2 had been operating during the same period, 1,645 adults may have been lost due to operation in 1974, 1,168 due to operation in 1975, and 208 due to 1976 operation.

6.10.3 Entrapment

Pollock have been entrapped on the intake screens at Unit 1. Assuming the number entrapped is proportional to the volume of water withdrawn, the numbers of fish entrapped were predicted for Unit 1 alone, and as though Units 1 and 2 had been operating full time during 1973 through 1976. The results are presented in Table 6-5.

6.10.4 Cumulative Impact

No station impact on pollock from heat or cold shock is expected to occur through the thermal plume because behavioral observations indicate that pollock position themselves outside the plume. Based on equivalent adult model estimates from entrainment and impingement predictions, between 208 and 3,165 adults could be lost to the population per year due to operation of Units 1 and 2. The predictions are based on data collected from 1973 to 1976.

An assessment of the impact on the total pollock population was made based on commercial harvest. Commercial fishing records give harvest estimates based only on eviscerated fish. The average annual harvest for Massachusetts (1970-1976) is 11.7 million pounds. Adult pollock potentially affected by the station were assumed to be equivalent to a 5-pound eviscerated fish. Therefore, the potential station-related loss would represent from 0.009 to 0.135 percent of the Massachusetts commercial landings of pollock, and would therefore be negligible.

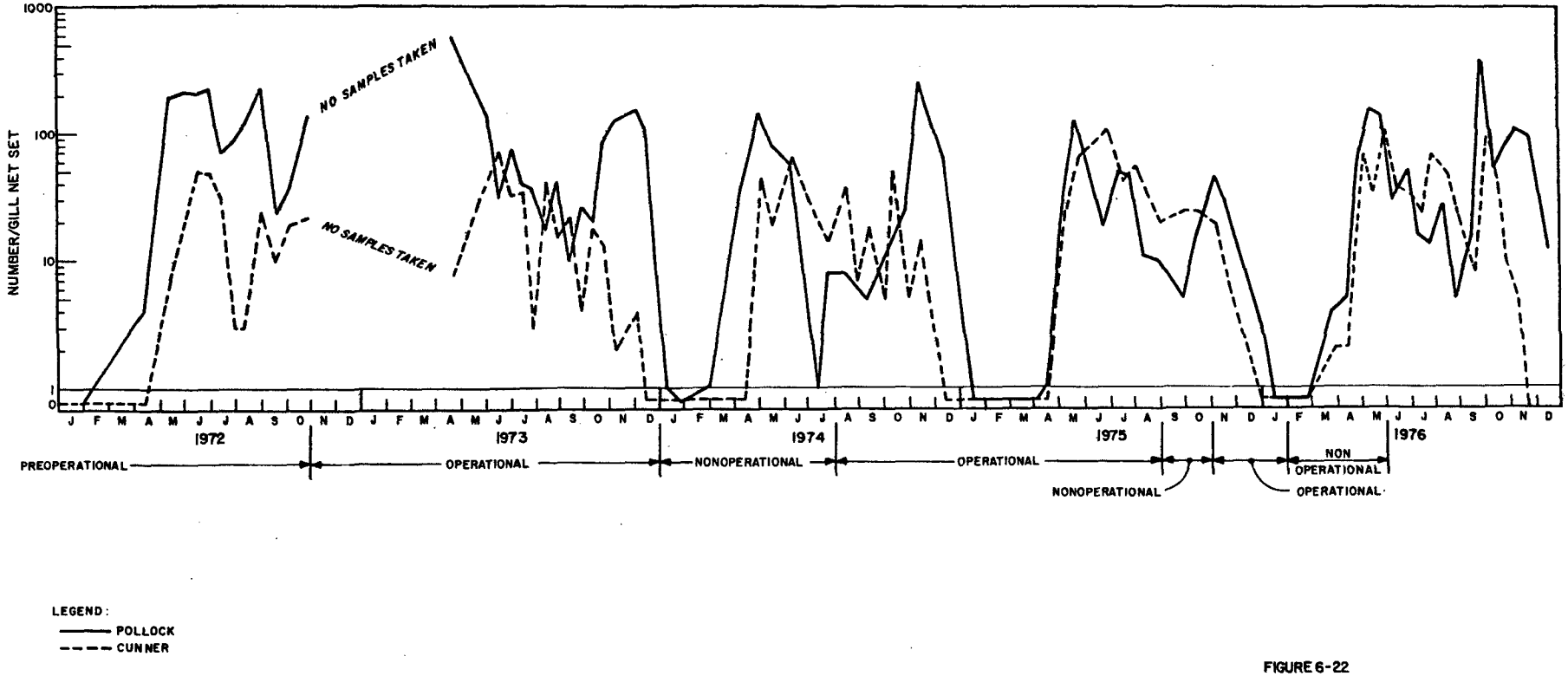


FIGURE 6-22
NUMBERS OF POLLOCK AND CUNNER COLLECTED IN GILL NETS IN VICINITY OF PILGRIM STATION

6.11 CUNNER (*Tautogolabrus adspersus*)

Cunner is an abundant local fish species found in the vicinity of Pilgrim station. The relative abundance of cunner has been increasing (Table 6-10) in the gill net catch, although there was some population variability from month to month (Figure 6-22) due to variability in catch and movement offshore in winter. The sport fishing catch (Table 6-11) indicates the same trend as the gill net catch with cunner predominating in summer and fall. Therefore, cunner could expect to be most affected by station operation in summer and fall. Cunner could be affected by the thermal plume, entrainment of eggs and larvae, and entrapment.

6.11.1 Thermal Plume

Since the cunner population has been increasing both preoperationally and postoperationally, it appears that Unit 1 has had little effect on the cunner population. Based on temperature tolerance data in Appendix A, the thermal plume for Units 1 and 2 should not result in overt mortality of cunner beyond the discharge canal. During periods of maximum ambient temperature (summer), cunner will probably not reside within the 15° isotherm. Optimum spawning and adult growth should take place outside this area during the summer months. In the fall, temperatures immediately outside the discharge canal will be optimal for growth. In spring, temperatures immediately outside the discharge canal will be optimal for spawning and for the incubation and hatching of eggs.

6.11.2 Entrainment

Techniques used for assessing the impact of entrainment on the cunner population have been amended since the 1974 data were first evaluated. Due to the identification problems, all labrid and some early-stage limanda eggs were again assumed to be cunner. A quantitative estimate of impact was determined from the percentage of the population potentially lost as a result of station operation; these percentages were taken from isocontours of larval loss as defined by a Massachusetts Institute of Technology study by Pagenkopf et al (1976).

The first step in analyzing impact is to estimate the number of larvae and the number of eggs in the impacted population. Since cunner eggs are buoyant and the larvae are planktonic, both are subject to entrainment by Pilgrim Station.

As shown in Figure 6-23, an area of Cape Cod Bay around the plant was chosen for the evaluations. This area includes all shoreline nearest to Pilgrim suitable for cunner spawning. The seaward boundary was arbitrarily chosen such that it includes only a part of the population. Assuming that the affected population is that of Cape Cod Bay, the area defined above includes a subset of the whole population; looking at this subset as being the entire

impacted population is both practical and conservative since impact is being imposed on a population smaller than that present in the bay (thus impact is overestimated).

Density samples were obtained during periods of egg and larval occurence at stations located in the study area. An approximation of the numbers of eggs (1.15×10^{11}) and larvae (9.23×10^{9}) present was determined by multiplying the average density per cubic meter by the number of cubic meters in the area (dependent on the varying depth of Cape Cod Bay).

The percentage of eggs and larvae entrained is predicted by knowing the manner in which Pilgrim Station acts as sink on the egg and larval densities of Cape Cod Bay. From circulation and dispersion studies conducted by MIT, isocontours of percent decrease in winter flounder larval concentrations resulting from station operation have been determined. These isocontours (see Figure 6-23) were then applied to both the egg and larval populations of cunner since they represent a reasonable approximation of impact for species such as cunner, which spawn along the shore. Thus, by calculating the equivalent number of eggs (1.09×10^{9}) and larvae (8.76×10^{7}) lost to entrainment, the percentage of eggs and larvae entrained is determined:

$$\frac{8.76 \times 10^{7}}{9.23 \times 10^{9}} \times 100 \cong 1 \text{ percent of larvae entrained}$$

$$\frac{1.09 \times 10^{9}}{1.15 \times 10^{11}} \times 100 \cong 1 \text{ percent of eggs entrained}$$

The effect of this additional 1 percent mortality sustained each year is best understood by use of the Leslie (1945) model as described by Horst (1977) (also see Section 6-1). This matrix model predicts the finite population growth rate and stable age distribution which would develop under a schedule of age-specific fertility and survivorship. The finite growth rate, R, is represented mathematically by the maximum, positive real eigenvalue of the matrix. Parameters for the cunner matrix are given in Table 6-12.

Changes in any of the elements in the matrix, such as survivorship, necessarily result in change of the eigenvalue. Comparison of the original eigenvalue to that from the altered matrix, therefore, can indicate the significance of environmental impact on growth rate or age distribution.

An increased mortality of about 1 percent for both eggs and larvae is equivalent to an overall increase in mortality of about 1 percent to age class 0. Mortality (0.01) is easily converted to survivorship by subtraction from 1 (=0.99). The new survivorshop of age 0 reflecting entrainment mortality is

0.199×10^3. Comparison of this eigenvalue to that of a non-impacted population shows that for every 1,000 individuals produced originally, two will be lost to entrainment, an overall reduction of 0.2 percent per year.

6.11.3 Entrapment

Numbers of adult cunner entrapped (see Table 6-5) on the intake screens at Unit 1 have ranged from a low of 87 in 1974 to a high of 2,299 in 1976; predicted entrapment for two-unit operation similarly ranges from 256 to 7,337, assuming the number impinged is proportional to flow.

Assuming the worst - case entrapment of 7,337 fish for two-unit operation, this impact was evaluated in a manner similar to that for entrainment. Eigenvalues from the cunner matrices with and without adjustment in survivorship for entrapment were compared.

Since no data were available to describe the age class or classes subject to impingement, that age class was chosen where impact to the overall population would be greatest, age class 4. The additional mortality due to entrapment, 1.3435×10^{-2}, was determined by dividing the number of fish impinged (7,337) by the number of fish in age class 4 (extrapolated from the number of larvae and the survivorships of the previous age classes). The adjusted survivorship was calculated as:

$$(1 - \text{mortality}) \times 0.6652 = 0.65627$$

(where 0.6652 is the survivorshop of age class 4).

Comparison of the eigenvalues shows that for every 1,000 individuals originally produced, two will be lost to entrapment, an overall reduction of 0.2 percent per year.

6.11.4 Cumulative Impact

No mortality is anticipated due to thermal effects, although during maximum ambient temperatures, cunner will probably not reside within the 15°F isotherm. Mortality from Units 1 and 2 is expected only as a result of entrainment and entrapment.

The combined effects of entrainment and entrapment were assessed by eigenvalue analysis as previously described. Both sources of impact were simultaneously allowed for in the matrix and compared to the non-impacted population; for every 1,000 individuals produced originally, 997 would be produced by the impacted population, an overall reduction of 0.3 percent per year.

By way of comparison, the mortality rate from sport fishing at Pilgrim is about 0.3 fish per hour during the six months of the year that cunner were caught in 1974 and 1975; the average entrapment rate in 1976 is about 0.84 fish per hour. Considering

the relative abundance of cunner in this area the station impact on the population is predicted to be negligible.

TABLE 6-10

SPECIES COMPOSITION OF GILL NET COLLECTIONS

Species	1971 No.	1971 No./Set	1971 %	1972 No.	1972 No./Set	1972 %	1973 No.	1973 No./Set	1973 %	1974 No.	1974 No./Set	1974 %
Pollock	950	73.1	37.5	1,558	119.85	68.7	1,707	106.69	58.9	750	41.66	29.8
Cunner	265	20.38	10.4	242	18.6	12.7	337	21.06	11.6	340	18.89	29.8
Sea herring	199	15.31	7.8	20	1.54	0.9	74	4.62	2.6	267	14.83	10.6
Alewife	620	47.69	24.4	141	10.85	6.2	244	15.25	8.4	522	29	20.7
Blueback herring	30	2.31	1.2	2	.15	0.1	90	5.62	3.1	15	0.83	0.6
Atlantic mackerel	195	15	7.7	65	5.0	2.9	100	6.25	3.5	44	2.44	1.7
Striped bass	7	0.54	0.3	18	1.38	0.8	105	6.56	3.6	11	0.61	0.4
Atlantic cod	199	15.31	7.8	184	14.15	8.1	154	9.62	5.3	142	7.89	5.6
Tautog	10	0.77	0.4	8	0.61	0.3	20	1.25	0.7	18	1.0	0.7
Atlantic menhaden	25	1.92	1.0	9	0.69	0.4	31	1.94	1.1	88	4.89	3.5
Northern kingfish	2	0.16	0.1	1	0.08	<0.1	0	0	0.0	0	0	0.0
Four-spotted flounder	1	0.08	<0.1	0	0	0.0	0	0	0.0	0	0	0.0
Hickory shad	1	0.08	<0.1	0	0	0.0	0	0	0.0	0	0	0.0
Bluefish	1	0.08	<0.1	2	0.16	0.1	6	.37	0.2	119	6.61	4.7
Butterfish	12	0.92	0.5	0	0	0.0	1	.06	<0.1	7	0.39	0.3
Winter flounder	5	0.38	0.2	5	0.38	0.2	6	.37	0.2	3	0.17	<0.1
Atlantic tomcod	7	0.54	0.3	3	0.23	0.1	1	.06	<0.1	0	0	0.0
Silver hake	4	0.31	0.1	1	0.08	<0.1	7	.44	0.2	151	8.39	6.0
Scup	0	0	0.0	3	0.23	0.1	3	.19	0.1	4	0.22	0.2
Rainbow smelt	1	0.08	<0.1	1	0.08	<0.1	4	.25	0.1	35	1.94	1.4
Hake	2	0.16	0.1	3	0.23	0.1	7	.43	0.2	1	0.06	<0.1
Hardtail	0	0	0.0	0	0	0.0	0	0	0.0	2	0.11	0.1
Black sea bass	0	0	0.0	0	0	0.0	0	0	0.0	1	0.06	<0.1
Banded rudderfish	0	0	0.0	0	0	0.0	0	0	0.0	1	0.06	<0.1
White perch	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
TOTAL	2,536	13		2,266	13		2,897	16		2,521	18	

TABLE 6-10 (CONT'D)

Species	1975 No.	1975 No./Set	1975 %	1976 No.	1976 No./Set	1976 %
Pollock	397	21.84	24.5	1,258	57.18	24.3
Cunner	423	26.44	26.1	607	27.59	11.7
Sea herring	279	17.44	17.2	2,115	96.14	40.8
Alewife	66	4.12	4.1	268	12.18	5.2
Blueback herring	10	0.62	0.6	46	2.09	0.9
Atlantic mackerel	91	5.69	5.6	35	1.59	0.7
Striped bass	2	0.12	0.1	3	0.14	0.1
Atlantic cod	98	6.12	6.1	96	4.36	1.9
Tautog	7	0.44	0.4	27	1.23	0.5
Atlantic menhaden	66	4.12	4.1	140	6.36	2.7
Northern kingfish	0	0	0.0	7	0.32	0.1
Four-spotted flounder	0	0	0.0	0	0	0.0
Hickory shad	1	0.06	0.1	0	0	0.0
Bluefish	70	4.38	4.3	13	0.59	0.3
Butterfish	1	0.06	0.1	21	0.95	0.4
Winter flounder	6	0.38	0.4	10	0.45	0.2
Atlantic tomcod	2	0.12	0.1	10	0.45	0.4
Silver hake	82	5.12	5.1	480	21.81	9.3
Scup	2	0.12	0.1	1	0.04	<0.1
Rainbow smelt	8	0.50	0.5	19	0.86	0.4
Hake	6	0.38	0.4	9	0.41	0.2
Hardtail	0	0	0.0	1	0.04	<0.1
Black sea bass	0	0	0.0	3	0.14	0.1
Banded rudderfish	0	0	0.0	0	0	0.0
White perch	0	0	0.0	1	0.04	<0.1
Total	1,618	16		5,179	22	

TABLE 6-11

SPORT FISHING CATCH AT PILGRIM STATION, 1973-1975

	April		May		June		July			Aug		
	1974	1975	1974	1975	1974	1975	1973*	1974	1975	1973	1974	1975
Cod	17	7	24	34	15	35	39	6	10	5	1	-
Mackerel	-	-	2	-	-	-	46	-	42	5	-	18
Striped Bass	-	-	-	21	-	5	5	4	3	3	3	-
Tautog	-	-	2	5	2	6	23	12	12	8	4	-
Pollock	208	-	90	25	95	122	461	25	24	41	8	11
Winter Flounder	60	-	70	23	70	30	35	26	45	2	6	17
Cunner	-	-	9	78	178	542	82	240	989	-	157	310
Tomcod	-	-	-	3	2	-	11	-	-	-	-	-
American Eel	-	-	-	-	4	-	-	-	3	-	-	-
Bluefish	-	-	-	-	-	2	4	8	15	62	68	92
"Snapper" Bluefish	-	-	-	-	-	-	-	-	-	-	1,086	97

	Sept			Oct			Nov			Totals*		
	1973	1974	1975	1973	1974	1975	1973	1974	1975	1973	1974	1975
Cod	-	-	-	15	72	-	-	4	-	59	139	86
Mackerel	-	-	-	-	-	-	-	-	-	51	2	60
Striped Bass	127	-	6	511	32	-	2	-	-	648	39	35
Tautog	14	4	5	24	4	3	-	-	-	69	28	31
Pollock	11	4	4	75	10	-	-	-	-	588	440	186
Winter Flounder	-	-	-	-	-	-	-	-	-	37	232	115
Cunner	-	466	128	-	244	40	-	-	-	82	1,294	1,087
Tomcod	-	4	-	2	1	-	-	-	-	13	7	3
American Eel	-	-	-	-	-	-	-	-	-	-	4	3
Bluefish	441	615	14	127	69	-	-	-	-	634	760	123
"Snapper" Bluefish	-	140	180	-	-	-	-	-	-	-	1,176	277

* 1973 survey commenced in July

TABLE 6-12

ESTIMATION OF AGE-SPECIFIC FERTILITY AND SURVIVAL FOR CUNNER

Age-i (years)	Length[1] (mm)	Weight[2] (grams)	Fertility[3] (eggs/female)	Sex ratio[4]	Eggs/Adult[5] f_i	Number[6] of fish Collected	Number[7] of fish Predicted	S_i
0					0			0.0002101[8]
1	46	1.34	268	0.317	85	71	73.1	0.6252
2	89	11.00	2,201	0.317	698	26	45.7	0.6252
3	124	32.01	6,402	0.317	2,029	35	28.6	0.6252
4	153	65.58	12,515	0.317	3,967	31	17.9	0.6252
5	177	99.28	19,856	0.317	6,294	22	11.2	0.6252
6	196	138.74	27,748	0.317	8,796	3	7.0	0.6252
7	212	178.27	35,655	0.317	11,303	0	4.4	0

(1) $L = 284.77\ (1-\mathrm{Exp}[-0.1979(i-0.1044)])$ from Serchuk (1972, Table 7)

(2) $\mathrm{Log}\ W_i = -5.2216 + 3.21214\ (\log L_i)$, from Serchuk (1972, Table 8)

(3) Assumed linear relationship between weight and fertility (Bagenal 1967) 200 eggs/gram body weight from Williams et al (1973, p. 189)

(4) Proportion of the population which is female from Dew (1970, p. 21)

(5) Eggs/adult is eggs/female times the proportion of the population which is female

(6) From Serchuk (1972, Table 3)

(7) Based on regression of number of fish collected (N) against age (i), $\ln(N) = 4.76 - 0.4698i$, $r = -0.82$ $S_{yx} = 0.55$

(8) From formula of Vaughan and Saila (1976) $S_o = \left[f_1 + \sum_{i=3}^{7} f_{i-1} \left(\prod_{j=1}^{i-2} s_j \right) \right]^{-1}$

6.12 RAINBOW SMELT (*Osmerus mordax*)

The effect of the operation of Pilgrim Units 1 and 2 on the smelt population in the area is predicted from published life history information and plant monitoring data. The sources of impact to the population include entrainment of larvae and impingement of adults. The maximum temperature predicted in the immediate area of the discharge during the summer is near the upper maximum temperature tolerance presented in Appendix A for smelt. It is therefore assumed that adult smelt will be excluded from the immediate area of discharge. From the combination of the area of exclusion and the mobility of the adults, this source of impact is judged to be negligible and will not be quantified in the present analysis.

Marine populations of this species generally spawn upstream of the tidal influence and the eggs are adhesive. While there is a net downstream movement of larvae, McKenzie (1964) reports that larvae are carried back and forth under the influence of the tide. After a few days, the larvae become negatively phototropic which results in higher densities near the bottom during the day. It may be concluded from this strategy that larvae are retained in the brackish estuary and those which are washed out of the estuary have a lower probability of being recruited into the adult population.

Refer to Section 6.9 for a discussion of the effect of the Pilgrim Station on populations in the Plymouth-Duxbury Harbor. The analysis presented in Section 6.9 is for winter flounder; however, the effect on the larval smelt population would be similar, since both populations breed in the Plymouth-Duxbury area. Smelt breed in the rivers while flounder breed closer to the mouth of the estuary; therefore, the predictions for winter flounder larvae entrainment will be overestimates for smelt.

6.12.1 The Model

Presently, there is no published population dynamics life cycle model for smelt. A paper by McKenzie (1964) was used to obtain statistics for the development of a life table for use in the present analysis. While the statistics were gathered for the smelt population of the Miramichi River in New Brunswick, comparison with the work of Warfel, Frost, and Jones (1943) in Great Bay, New Hampshire, and Rothschild (1961) in Dean Brook, Maine suggests that the values are applicable to other populations. It is therefore assumed that this life table is applicable to the population which could be affected by Pilgrim Station.

The life table for smelt is presented in Table 6-13. The survivorship for ages 2 through 5 and the estimates for fecundity were taken from Mckenzie (1964). The survivorship for age 1 was assumed to be the same as for larvae to age 1 and the

survivorship for age 6 was assumed to be the same as age 5. The number of eggs produced by fish from ages 2 to 5 was calculated using the McKenzie (1964) estimates of fecundity. A function for egg survivorship was developed from McKenzie's data by polynomial regression.

$$L = -3588 + 1191(E) - 124(E)^2 + 4.2(E)^3$$
$$[F = 7.789, \ \alpha \leq 0.05]$$

where

L is larval density per ft^2 of surface area, and
E is the natural log egg density per ft^2 of surface area.

The estimate of fishing mortality was taken from the Miramichi smelt fishery since no other estimate was available. This fishery uses trap nets. McKenzie (1964) estimated a 4 percent annual harvest for ages 2 through 4. Therefore, a fishing mortality of 0.04 per year was used in the simulation.

An estimate of the density of smelt in the Plymouth-Duxbury Harbor was made from data collected by the Massachusetts Division of Marine Fisheries in 1971. Smelt were collected in a 30-foot shrimp trawl in 5-minute tows at 1 to 2 knots. The area swept by this trawl was estimated to be approximately 1,411 m^2. Smelt were most consistently collected during November when an average of 10.33 individuals (standard error of 2.84) was collected per trawl.

It was assumed that this trawl had an efficiency of 50 percent and, on the average, it sampled no more than one-half of the water column. It is also assumed that the adult smelt have a uniform distribution with depth. This yields an estimated density of adults in the harbor of 0.0027 per ft^2 of surface area.

The density of eggs in the Jones River, where the Massachusetts Department of Marine Fisheries collects smelt eggs, has been estimated as high as 230,400 per square foot during each period of collection (pers. comm., B. DiCarlo). It was assumed for conservatism that the average density of eggs was about 1,000 eggs per square foot over the area in which spawning takes place.

The number of eggs produced each season (E) can be estimated:

$$E = X \cdot R \cdot T \qquad (6.12\text{-}1)$$

where

X is the standing crop of eggs per square foot,

R is the area of the river which eggs are deposited, and

T is the turnover rate for eggs.

The adult population (A) which resides in the harbor during the fall is:

$$A = Y \cdot H \qquad (6.12\text{-}2)$$

where

Y is the standing crop of adults per square foot, and

H is the area of the harbor.

The turnover rate for adults is assumed to be one. The relationship between the number of eggs (E) and adults (A) in the population is:

$$E = A \cdot F \cdot S \qquad (6.12\text{-}3)$$

where

F is the fecundity, and

S is the sex ratio.

Substituting Equation 6.12-2 into 6.12-3, and setting this equal to Equation 6.12-1:

$$F \cdot Y \cdot H \cdot S = X \cdot R \cdot T. \qquad (6.12\text{-}4)$$

Equation 6.12-4 can be solved for the turnover rate T:

$$T = \frac{H}{R} \cdot \frac{F \cdot Y \cdot S}{X} \qquad (6.12\text{-}5)$$

Estimates of the adult density Y and the egg density have been made. The average fecundity from Table 6-13 is 15,560; the adult density is 2×10^{-3}; and the egg density is 10^3 per square foot. The turnover rate becomes:

$$T = \frac{H}{R} \cdot \frac{1.5 \times 10^4 \times 2 \times 10^{-3} \cdot \cancel{7}\ .23}{10^3} = \frac{H}{R} \cdot 2.1 \times 10^{-2} \simeq \frac{H}{R} \cdot 10^{-2}$$

The estimate of the number of eggs in the population becomes:

$$E = X \cdot R \cdot T = X \cdot R \cdot \frac{H}{R} \cdot 10^{-2} = X \cdot H \cdot 10^{-2} \qquad (6.12\text{-}6)$$

Bangalia catchpole area of Harbor

The area of the harbor (H) has been estimated as 1.95×10^7 square meters at mean low water. Therefore, the number of eggs is estimated as:

$$E = X \cdot H \cdot 10^{-2} = 10^3 \cdot 1.95 \times 10^7 \cdot 10.764 \cdot 10^{-2} = 2 \times 10^9$$

(actually 3.62) .03 survival conser.
(actually 60000) $10^3/ft^2$ density conser.
(actually .1) .7 sex ratio Ethel

The initial population structure and the equilibrium population structure for the simulation are presented in Table 6-14. The estimate of the number of larvae entrained results from an extrapolation from the densities of smelt entrained at Unit 1. Based on these densities and the combined flows of both units, an average value of 3.1×10^6 larvae for Unit 1 alone and 1.0×10^7 larvae for Units 1 and 2 would be entrained per year. It is conservatively [redacted] that the number of adults potentially recruited from this number of larvae were lost to the population.

The number of smelt impinged each year was estimated from the Unit 1 screenwashing data from 1973 to 1976. The extrapolation for two-unit operation assumes the fish are impinged in proportion to the flow. It was estimated that an average of 768 smelt for Unit 1 alone and 2,909 smelt for Units 1 and 2 would be impinged per year. It is assumed that all these fish are of age 2.

6.12.2 Cumulative Impact

The effect of this loss of young fish on the adult population was investigated by adding the mortality attributable to entrainment and impingement to the simulated population. The effect of the thermal plume was not considered in this analysis due to the negligible nature of the effect.

The population was resimulated, including the mortalities associated with power station operation. The population size was depressed by 1.15 percent for Unit 1 alone, and 3.74 percent for Units 1 and 2, when compared to the non-impacted population after 40 years. The impacted population came to equilibrium as did the non-impacted population.

TABLE 6-13

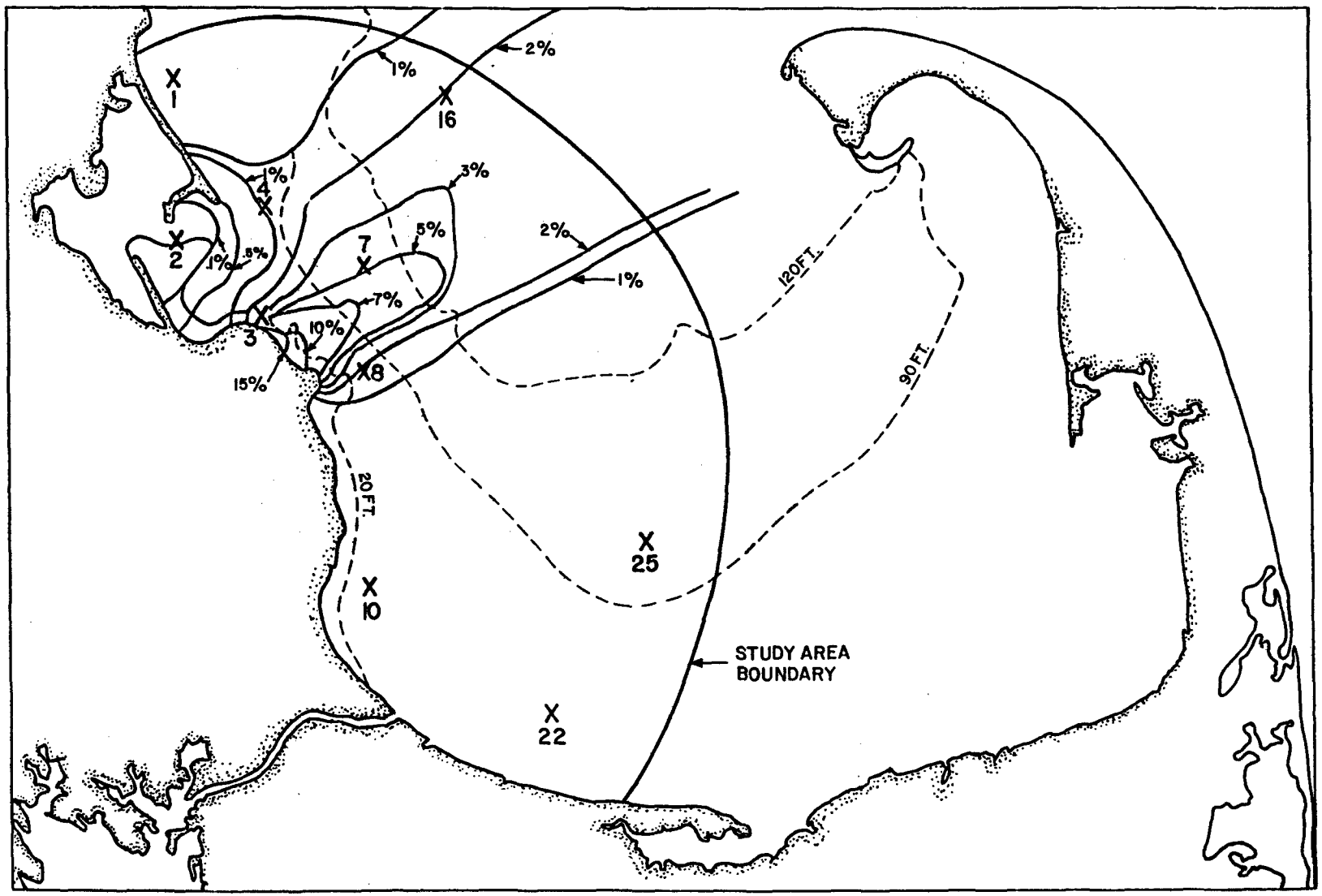
LIFE TABLE FOR SMELT

Age	Survivorship	Fecundity	Sex Ratio (Female/Male)	Weight (grams)
Eggs	0.036	0		
Larvae	0.070	0		
1	0.070	0		8
2	0.454	11,488	0.23	14
3	0.133	22,847	0.23	17
4	0.094	33,120	0.25	22
5	0.072	45,555	0.24	32
6	0.072	59,980	0.50	

TABLE 6-14

INITIAL AND EQUILIBRIUM POPULATION STRUCTURES FOR SMELT SIMULATION

Age	Initial Number	Equilibrium Number
Eggs	2×10^9	7.355×10^9
Larvae	7.196×10^7	2.647×10^8
1	5.066×10^6	1.863×10^7
2	3.567×10^5	1.312×10^6
3	1.621×10^5	5.962×10^5
4	2.161×10^4	7.947×10^4
5	2.034×10^3	7.479×10^3
6	1.47×10^2	5.41×10^2



X – DENOTES M.R.I. SAMPLING STATIONS.

FIGURE 6-23
ISOCONTOURS OF LARVAL DEPLETION

6.13 ATLANTIC SILVERSIDE (*Menidia menidia*)

The impact of operation of Pilgrim Units 1 and 2 on silversides is predicted from temperature tolerance data, entrainment data, and screenwashing data. Published life history data on silversides were researched to obtain fecundity, sex ratio, and life span.

6.13.1 Results of Thermal Plume, Entrainment, and Impingement

Temperature tolerance and acclimation information is presented in Appendix A. Based on these data, silversides can be anticipated to be excluded from about 7.4 acres inside the 10°F isotherm area during the summer. It is expected that many of the fish will simply move to other areas to avoid the thermal plume. The effect of this impact will not be quantified in the present analysis.

Larval silversides were collected in entrainment studies from 1974 to 1976 (see Figure 6-24); eggs were found entrained in 1975 and 1976. Integrating over the density curve of eggs and larvae collected (see Table 6-4) provides an estimate of entrainment for two-unit operation. The equivalent number of adults was estimated by assuming the fecundity is 300 eggs per female, and that 1 in 10 eggs hatch (Bayliff 1950).

Using the formulas:

No. adults lost = no. larvae entrained x 2/F.E and
No. adults lost = (no. larvae entrained x 2/F.E) + (no. eggs entrained x 2/F)

where F = fecundity and E = survivorship of eggs to larvae;

between 21, 587 and 187,267 adults per year are predicted lost as a result of two-unit operation.

Assuming an adult silverside weighs about 10 grams (Austin et al 1973), the loss of this many adults would be equivalent to a loss of between 476 and 4,128 pounds per year.

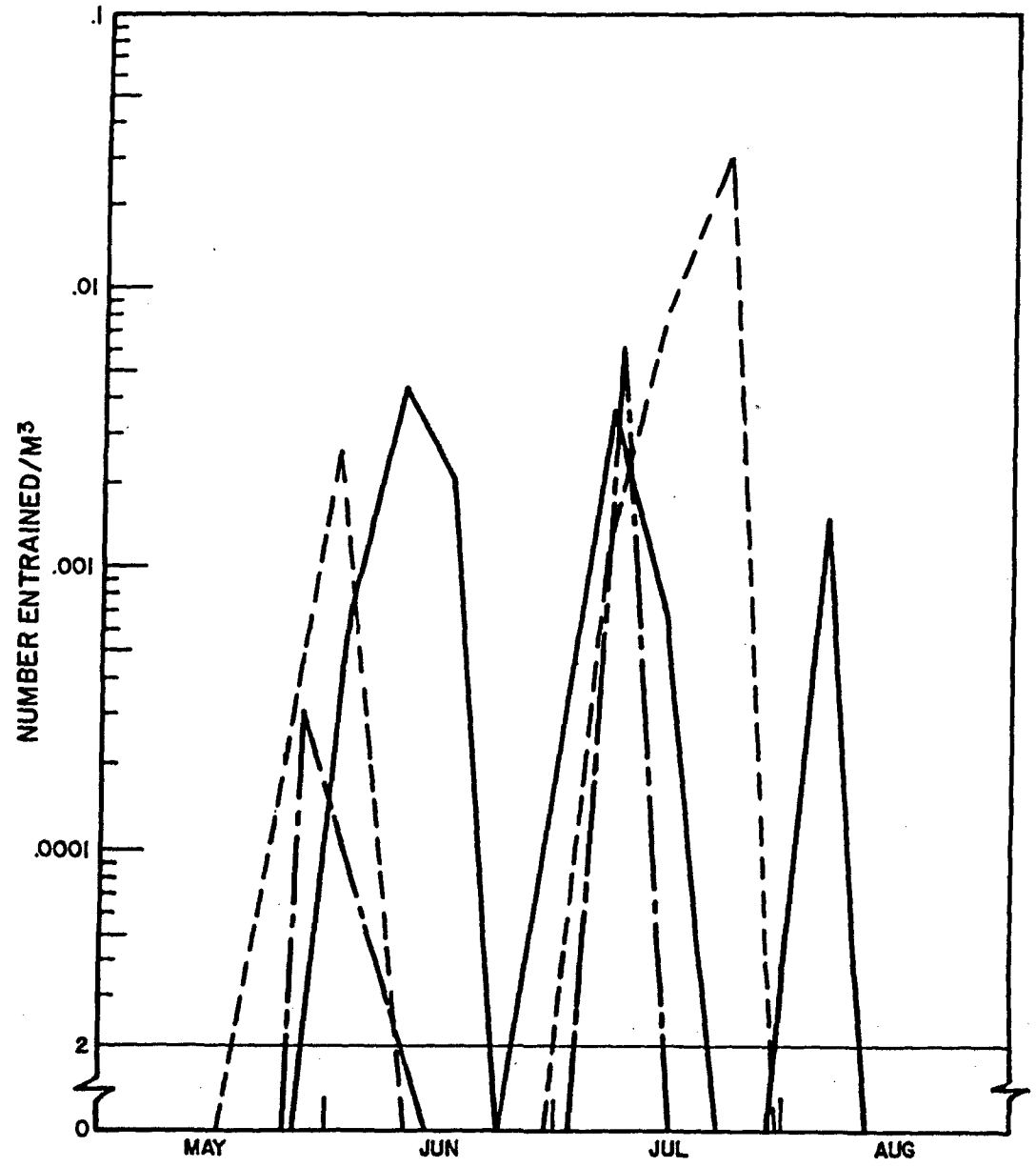
The loss due to impingement has been estimated from data collected in impingement monitoring programs from 1973-1976 (see Table 6-5). The predicted loss for both Units 1 and 2 is between approximately 2,392 and 2,820 fish per year. Assuming again that these fish weigh 10 grams each, this results in a loss of 53 to 62 pounds per year.

The combined effect of entrainment and impingement is predicted to be 23,980 to 190,000 fish per year, or about 529 to 4,191 pounds per year. Since this species is not of commercial value in Massachusetts, no comparisons with commercial catch in Massachusetts can be made. Anderson and Power (1950) reported

that 126,300 pounds of silversides were commercially caught in New York State in 1946. The availability of silversides may also be indexed by the number caught in seines. Bigelow and Schroeder (1953) reported that up to 3,500 were caught in a single seine haul from the southern side of the Gulf of St. Lawrence. Warfel and Merriman (1944) reported as many as 1,938 in a 30-foot seine which was fished for about 100 feet parallel to shore in water less than 4 feet deep.

6.13.2 Cumulative Impact

The effect of the thermal plume is expected to be minimal to silversides based on the abundant nature of the species and the area from which they could potentially be excluded (7.4 acres). No observation of thermal impact to silversides has occurred. An estimated 23,980 to 190,000 adults could be lost from entrainment and impingement combined. These losses assume no compensatory mechanism in the population and are therefore an overestimate of the impact to this species. The abundant nature of this species would suggest a minimal impact to the population from this additional source of mortality.



——— 1974
——— 1975
------ 1976

FIGURE 6-24
DENSITY OF *MENIDIA* SPP. LARVAE OBSERVED AT UNIT I 1974 THROUGH 1976

6.14 ALEWIFE (*Alosa pseudoharengus*)

The impact of the operation of Pilgrim Nuclear Power Station, Units 1 and 2, is predicted from published life history information and station operation data. The sources of possible impact from station operation include the thermal plume, entrainment of larvae, and mortality of adults on the traveling screens.

6.14.1 Results of Thermal Plume, Entrainment, and Impingement

Based on the studies presented in Appendix A, and the predicted areas of various isotherms in Section 2 of the July 1975 report, it is predicted that alewives will be excluded from about 2 acres in the immediate area of the discharge. The studies of Stanley and Colby (1971) indicate that alewives are able to tolerate temperatures up to 87.8°F, which is near the predicted summer maximum surface temperature at the discharge area.

Based on avoidance temperatures (see Appendix A), it is anticipated that most alewives will avoid the thermal plume. Since this should not constitute a problem, it will not be quantitatively considered in the present analysis.

Calculation of entrainment impact was made by assuming the average fecundity is 229,000, the sex ratio is 1 to 1 (Kissil 1974), alewives reproduce three times in their life (Marcy 1969), and the survival of eggs is no less than 1 in 10 (Edsall 1970). For further details on life history information, see Section 5.13 of the original report.

The number of larvae predicted to be entrained with two units operating at the Pilgrim site was based on Unit 1 entrainment studies conducted from 1974 to 1976. During this 3-year period, very few alewife larvae were entrained; the largest entrainment predicted for two-unit operation of 9.57×10^5 larvae occurred in 1974, and the low of no larvae entrained occurred in 1975 (see Table 6-4). Intermediate numbers of larvae were entrained during 1976. The number of adults expected to survive from this number of larvae had they not been entrained varied from zero to about 28 adults for 1975 and 1974 respectively (see Figure 6-25).

Extrapolation of larvae lost through entrainment to adults lost is made using the method outlined in Section 6.1. Using the greatest entrainment value, the largest number of adults predicted lost is:

$$N_a = S_1 N_1 = 9.57 \times 10^5 \times 2/(3 \times 229{,}000 \times 0.1) = 28 \text{ adults/yr.}$$

The losses due to impingement are predicted from data collected in the Unit 1 impingement monitoring programs of 1973 to 1976. Since the fish collected in these programs are small, they are identified only as clupeids. As with other clupeids considered

in this report, it is conservatively assumed that all clupeids impinged are alewives. The predicted number impinged each year is between 14,450 and 48,557.

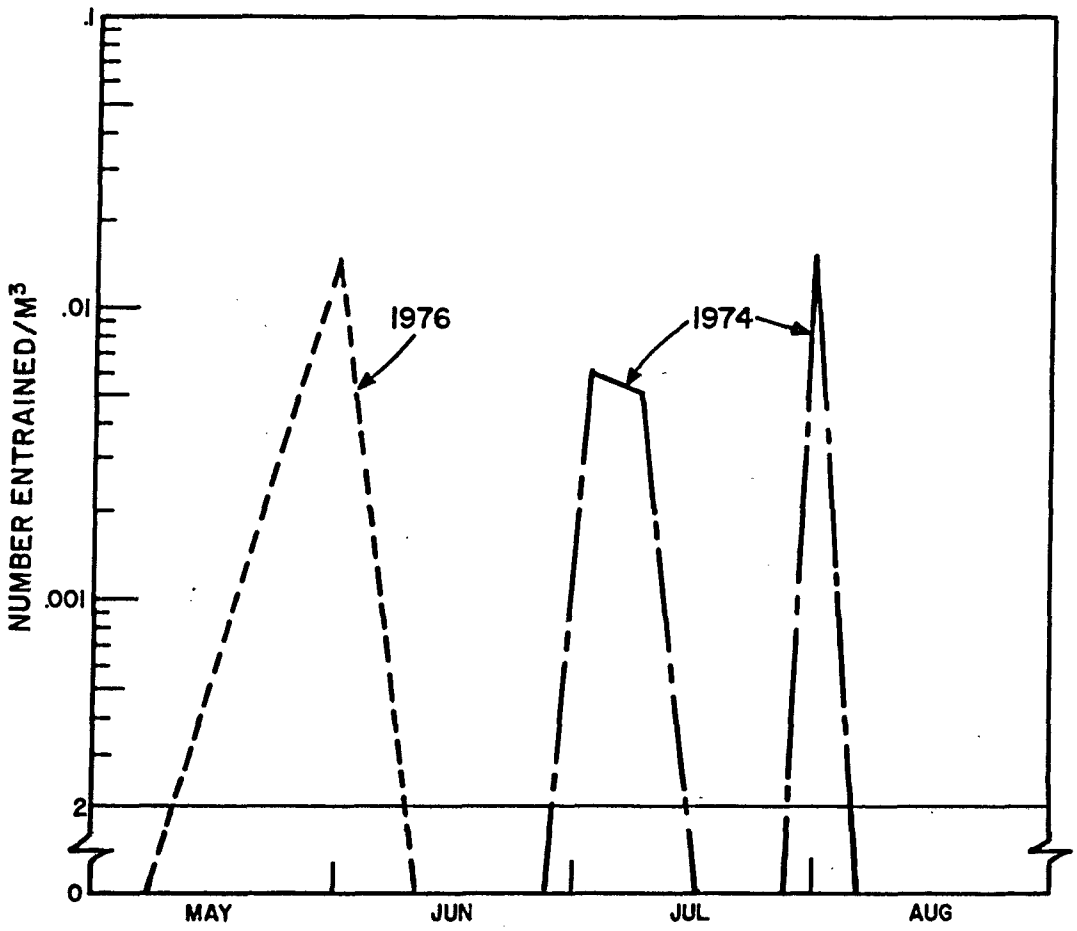
The combined effects of impingement and entrainment should be less than 50,000 fish per year for two-unit operation. This analysis assumes no compensatory mechanisms in the population which would be reduced by this number. The analysis also does not consider species other than alewives collected in the clupeid category in the screenwashing programs.

To give some perspective to this number of fish, Kissil (1974) reported 184,151 and 140,203 (162,177 average) alewives in Bride Lake, Connecticut, which has an area of 18.2 hectares. If the same breeding density were to occur in the areas near the Pilgrim station, this would be equivalent to removing spawning adults from 5.61 hectares, or 13.86 acres.

The weight of adult alewives can be roughly calculated at about one-half pound. Bigelow and Schroeder (1953) reported that 526,500 fish were caught in Cape Cod Bay and the Merrimack River in 1896, having a total weight of 293,671 pounds. This is about 0.56 pound per fish. Using this average weight, the 50,000 fish would weigh 29,000 pounds. This would have been 9 percent of the 1896 catch. Unfortunately, no recent catch statistics for the local alewife fishery are known to exist.

6.14.2 Cumulative Impact

The effect of the thermal plume is expected to be minimal. Allowing for no compensation by the population, no more than approximately 28 and 50,000 adults are expected lost due to entrainment and impingement, respectively. The effect of this additional mortality on the population is expected to be minimal.



NOTE:
NONE ENTRAINED IN 1975

FIGURE 6-25
DENSITY OF *ALOSA* SPP. LARVAE OBSERVED AT UNIT I 1974 THROUGH 1976

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III CONCLUSION

The supplemental analyses considered in this report have expanded the data base upon which the conclusions of the 316 Demonstration Pilgrim Nuclear Power Station Units 1 and 2, Boston Edison Company, July 1975, were based. These analyses demonstrate the basic validity of the conclusions of the 316 Demonstration by considering the most recent data collected at the Pilgrim site subsequent to the 316 Demonstration.

The types of analyses presented in the supplemental analyses are similar to those utilized in the 316 Demonstration. Conservative assumptions are used in the analyses. Thus, the analyses tend to overestimate the effects of the operation of Pilgrim station Unit 1 and the operation of Units 1 and 2. These conservative assumptions are discussed in Section I, Introduction, of this report as well as in conjunction with the individual species analysis in Section II of this report. Examples of the conservative assumptions are the 100 percent mortality assumed for all organisms entrained, and the failure to use the concept of biological compensation in many of the analyses.

The results of the analysis for each of the 13 representative important species are similar to those reported in the July 1975 316 Demonstration. The differences for individual species predictions can in large measure be attributed to annual variability in the abundances of the organisms. For summary purposes, predicted power plant effect for all the species, for which exploitation or cumulative effect has been predicted, is below 10 percent.

The purpose of this summarization is for comparison with the conclusions of the extensive review conducted by J.T. McFadden (1977) on the ability of fish populations to compensate for man-inducted exploitation. In summarizing his review, McFadden states on page 172, "...it becomes clear that cases in which >25 percent of the exploitable age classes in a population have been removed annually are common." With specific reference to power station exploitation (page 178), McFadden concludes "...the addition of an exploitation rate greater than 25 percent [due to the power station] to a pre-existing fishery exploitation of 25 percent would not endanger the stock of many species." The levels of exploitation predicted for the Pilgrim Station fall far below the levels suggested as acceptable by McFadden.

Therefore, this supplemental analysis indicates that the conclusion of the 316 Demonstration is correct. Based on an analysis of impact on 13 representative important species, Pilgrim station Unit 1 and Pilgrim station Units 1 and 2 with the proposed open cycle cooling system will not adversely affect the "balanced indigenous population of fish, shellfish, and wildlife."

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APPENDIX A

THERMAL TOLERANCE DATA

316 DEMONSTRATION

PILGRIM NUCLEAR POWER STATION - UNITS 1 AND 2

BOSTON EDISON COMPANY

EXPLANATION OF TERMS
THERMAL TOLERANCE DATA

Tolerance Limit (LT50)

A measure of resistance to temperature. The upper or lower median tolerance limit (LT50) is defined as the temperature at which 50 percent of the test animals under consideration are able to survive a designated period of time (Doudoroff, 1942).

Critical Thermal Maximum (CTM)

The temperature at which the locomotory activity becomes disorganized and the animal loses its ability to escape from conditions that will soon cause its death (Mihursky & Kennedy, 1967).

Acclimation

The thermal level to which an individual is physiologically adjusted (Mihursky & Kennedy, 1967).

Avoidance Temperature

At the upper avoidance temperature, a fish's ability to discriminate slight temperature differences becomes a meaningful activity, i.e., the fish will avoid temperatures that create sufficient stress (Gift & Westman, 1971).

Preferred Temperature

The temperature of maximum frequency of occurrence in the experimental gradient is the preferred temperature determined by noting the response of fish to particular portions of an experimental thermal gradient. However, fish are not always found at their preferred temperature in the field. The physiological state of a fish (season of the year, diet) or additional behavioral activities (feeding) may override a purely behavioral response to temperature (Gift & Westman, 1971). The range of temperatures occupied by a fish in its natural environment are also reported here.

Lethal Temperature

One hundred percent mortality of the test animals. This may be determined in a bioassay where the test animals are held at a constant temperature until death, or exposed to heating or cooling at a standard rate until death.

Optimum Growth Temperature

Maximum rate of growth occurs at this temperature.

Acanthohaustorius millsi - Amphipod

I. Mortality

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
97		(1)	77	Sameoto, 1969b, p. 2287

III. Reproduction

Optimum Temp. (F)	Temp. Range (F)	Season	Data Source
	41.9+	April-August peak June	Sameoto, 1969a, p. 1337

NOTE:

(1) Rise in temperature of 1.8 F per minute beginning at acclimation temperature until death

Alosa pseudoharengus - Alewife

I. Mortality

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
37.4 (L)	adult	(1)	60.8	Stanley & Colby, 1971, p. 629
87.8	adult	(1)	60.8	Stanley & Colby, 1971, p. 629

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Season	Location	Data Source
Migration		39.6-62.0		Chesapeake Bay	Mansueti & Hardy, 1967, p. 57
Spawning		60-82	May	Kalamazoo River	Edsall, 1970, p. 378
		55-60		Gulf of Maine	Bigelow & Schroeder, 1953, p. 103
		39.6-62.0	Mar.-Apr.	Chesapeake Bay	Mansueti & Hardy, 1967, p. 57
Incubation/ Hatch	45		15 days		Edsall, 1970, p. 379
		68-70	3.9 days		Edsall, 1970, p. 379
	84		2.1 days		Edsall, 1970, p. 379
	60		6 days		Bigelow & Schroeder, 1953, p. 103
	63	44.4-84.9			Edsall, 1970, p. 378

Alosa pseudoharengus - Alewife p. 2

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Time	Location	Data Source
Incubation/ Hatch	68		3-5 days	Chesapeake Bay	Mansueti & Hardy, 1967, p. 58
	72		2-4 days	Massachusetts Bay	Belding, 1921, p. 13

IV. Preferred Temperature

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Acclimation Temp. (F)	Season	Data Source
	68	adults	64		Meldrim & Gift, 1971, p. 27
	71	adults	70		Meldrim & Gift, 1971, p. 27
79		adults	63	Nov.	Meldrim & Gift, 1971, p. 34
76		adults	64	Oct.	Meldrim & Gift, 1971, p. 34
86		adults	77	Aug.	Meldrim & Gift, 1971, p. 34

NOTE:

(1) Change in temperature of 4.5 F per day beginning at acclimation temperature

Ascophyllum nodosum - Rockweed

I. Mortality

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
93.2-96.8	Thallus			Fritsch, 1945, p. 382

• *Brevoortia tyrannus* - Atlantic menhaden

I. Mortality

Tolerance Limit (LT_{50})	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
84	larvae	(2)	50	Hoss et al., 1973, p. 360
85.4	larvae	(2)	59	Hoss et al., 1973, p. 360
91.4	juveniles			Lewis & Hettler, 1968, p. 349
93.2	juveniles	161 hr	69.8	Lewis & Hettler, 1968, p. 347
96	juveniles	2 hr	75.2	Lewis & Hettler, 1968, p. 347
95	juveniles	22 hr	80.6	Lewis & Hettler, 1968, p. 347
94.6	juveniles	77 hr	84.2	Lewis & Hettler, 1968, p. 347
86	adult	24 hr		Engstrom & Kirkwood, 1974, p. 14
38.2(L)	larvae	72 hr	44.6	Lewis, 1965, p. 411(1)
39.4(L)	larvae	72 hr	50	Lewis, 1965, p. 411(1)
40.0(L)	larvae	72 hr	54.5	Lewis, 1965, p. 411(1)
41.4(L)	larvae	72 hr	59.0	Lewis, 1965, p. 411(1)

Brevoortia tyrannus - Atlantic menhaden, p. 2

I. Mortality

Tolerance Limit (LT_{50})(F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
41(L)	juveniles	98 hr	60.8	Lewis & Hettler, 1968, p. 348
41(L)	juveniles	191 hr	64.4	Lewis & Hettler, 1968, p. 348

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
37.4(L)	larvae			June & Chamberlin, 1959, p. 43
90	adults			Fairbanks, et al., 1971, p. 42

II. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Location	Season	Data Source
Spawning		55-80	Long Island	May-Oct.	Perlmutter, 1939, p. 17
		56-74	Long Island	June-Oct.	Wheatland, 1956, p. 248
				Time	
Incubation/ Hatch		72		48 hr	Kuntz & Radcliffe, 1917, p. 122

• Brevoortia tyrannus - Atlantic menhaden, p. 3

IV. Preferred Temperature

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Season	Location	Acclimation Temp. (F)	Data Source
	34.2-72.0	larvae	June-July	Narragansett Bay		Herman, 1963, p. 107
	>50	adults				Bigelow & Schroeder, 1953, p. 117
	46.6-75.0	adults	July-Nov.	New Haven, Ct.		Warfel & Merriman, 1944, p. 35, 65
	70	adults	June	Delaware R.	79	Meldrim & Gift, 1971, p. 27
78		adults	June	Delaware R.	69	Meldrim & Gift, 1971, p. 34
83		adults	June	Delaware R.	72	Meldrim & Gift, 1971, p. 34
86		adults	July	Delaware R.	70	Meldrim & Gift, 1971, p. 34
85		adults	Aug.	Delaware R.	77	Meldrim & Gift, 1971, p. 34
90		adults	Aug.	Delaware R.	81	Meldrim & Gift, 1971, p. 34

Note:

(1) Brett (1970, p. 525) figured these temperatures by graphical interpolation of Lewis' work

(L) Lower thermal tolerance limit or lethal temperature

(2) Transfer of larvae directly from acclimation temperature to increased temperature. Held at increased temperature until death.

Chondrus crispus - Irish Moss

I. Mortality

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
80	tetraspores	4-10 days		Prince, 1971, p. 117
80	carpospores	4 days		Prince, 1971, p. 117
95-104	carpospores and tetraspores	6 min	53	Prince, 1971, p. 143, 160
104	carpospores and tetraspores	1 min	53	Prince, 1971, p. 143
80	mature plants from tetraspores	35 days	53	Prince, 1971, p. 151
100.4	spores	0.5-6 min	71.6	Marine Research, 1974, p. 8

II. Growth

Optimum Temp. (F)	Temp. Range (F)	Life Stage	Data Source
70	53-75	carpospores and tetraspores	Prince, 1971, p. 107-8

Spore Attachment

	40-80		Prince, 1971, p. 108

Homarus americanus - American lobster

I. Mortality

Tolerance Limit (LT_{50}) (F)		Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
78.2		adult	48 hr	41	McLeese, 1956, p. 259
83.2		adult	48 hr	59	McLeese, 1956, p. 259
86.9		adult	48 hr	77	McLeese, 1956, p. 259
84.5		larvae			Engstrom & Kirkwood 1974, p. 14
79.7		adult		48.2	McLeese, 1956, p. 255
35.2 (L)		adult	48 hr	62.6	McLeese, 1956, p. 263
41 (L)		adult	48 hr	81.5	McLeese, 1956, p. 263
Lethal Temp (F)					
75.2		larvae			Templeman, 1936, p. 494-495
77					Chaisson, 1932, p. 5
34 (L)		adult	24 hr	69-70	Wood, 1885, p. 32
	CTM (F)				
89.6-95.8	84.2-93.2	larvae		59-77	Huntsman & Sparks, 1924 p. 100
89.6	78.8	larvae		50-59	Huntsman & Sparks, 1924, p. 100

Homarus americanus - American lobster, p. 2

II. Growth

Optimum Temp. (F)	Data Source
71.6-75.2	Hughes et al., 1972, p. 1110
64.4-72.2	Hughes & Matthiessen, 1962, p. 416

III. Reproduction

Hatching	Optimum Temp. (F)	Temp. Range (F)	Season	Data Source
	68	54.5-83.3	June-August	Lund & Stewart, 1970, p. 48
	68	59+	Beginning in May	Hughes & Matthiessen 1962, p. 415
		50.8-57.4	June to August	Templeman, 1936, p. 495
		46.6	50 weeks	Perkins, 1971, p. 98

IV. Preferred Temperature (F)	Life Stage	Acclimation Temp. (F)	Data Source
29-75			McLeese & Wilder, 1964, p. 5

Note:

(L) Lower thermal tolerance limit or lethal temperature

Littorina littorea - Common periwinkle

I. Mortality

Tolerance Limit (LT_{50}) (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
99.6-102.2	adult	6-10 hr	59	Newell et al., 1971, p. 529-530
102.2	adult	5.5 hr		Fraenkel, 1960, p. 177
103.8	adult	90-120 min		Fraenkel, 1960, p. 177
106	adult	1 hr		Fraenkel, 1960, p. 177
114.8	adult		68	Evans, 1948, p. 167
Lethal Temp. (F)				
104	adult	11.5-12 hr		Evans, 1948, p. 171
105.8-110.6	adult	(1)		Gowanloch & Hayes, 1926, p. 152
113	adult	(1)		Fraenkel, 1960, p. 177
114.8	adult	129 hr (1)	68	Hayes, 1929, p. 428
115.9	adult	(1)		Gowanloch & Hayes, 1926, p. 152

IV. Preferred Temp. (F)	Life Stage	Locality	Data Source
64.4	adult	New Brunswick	Hayes, 1929, p. 424
<70	adult	Southern limit	Wells, 1965, p. 40

Note:

(1) Rise in temperature of 1.8 F per 5 minutes beginning at acclimation temperature until death

Menidia menidia - Atlantic silverside

I. Mortality

Tolerance Limit (LT50) (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
73.4-77	"small fish"	5-13 min	57.2	AEC, 1972, p. 5-7
83.1-86.7	"small fish"	5-13 min	69.8	AEC, 1972, p. 5-7
71.6	juvenile	72 hr	44.6	Hoff & Westman, 1966, p. 134
77	juvenile	72 hr	57.2	Hoff & Westman, 1966, p. 134
86.8	juvenile	72 hr	69.8	Hoff & Westman, 1966, p. 134
90.5	juvenile	72 hr	82.4	Hoff & Westman, 1966, p. 134
88	adult	3 hr		Engstrom & Kirkwood, 1974, p. 14
47.6 (L)	juvenile	72 hr	82.4	Hoff & Westman, 1966, p. 134
39.8 (L)	juvenile	72 hr	69.8	Hoff & Westman, 1966, p. 134
35.6 (L)	juvenile	72 hr	57.2	Hoff & Westman, 1966, p. 134
34.7 (L)	juvenile	72 hr	44.6	Hoff & Westman, 1966, p. 134
	CTM (F)	Life Stage		
98.4	94	age I	72.5	Gift & Westman, 1971, p. 32
98.9	93.5	age I	77.0	Gift & Westman, 1971, p. 32

Menidia menidia - Atlantic silverside, p. 2

Lethal Temp(F)	CTM(F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
90	87	adults			Fairbanks et al., 1971, p. 42
	80	adults		64.4	Pearce et al., 1968, cited in AEC, 1972, p. 5-59
89.6			24 hr	59	Pearce, 1969, p. 229
90.5		adults	2 hr	62.2	Pearce et al., 1968, cited in Fairbanks et al., 1971, p. 42

III. Reproduction

Spawning	Optimum Temp.(F)	Temp. Range(F)	Season	Location	Data Source
		68+	May-July	Southern New England Coast	Bigelow & Schroeder, 1953, p. 303
		<59	May-July	Long Island	Wheatland, 1956, p. 263
		59-73	May	Long Island	Perlmutter, 1939, p. 23

Incubation/ Hatch	Optimum Temp.(F)	Temp. Range(F)	Time		
	72 F		8-9 days		Kuntz & Radcliffe, 1917, p. 127

Menidia menidia - Atlantic silverside, p. 3

IV. Preferred Temperature

Avoidance Temp.(F)	Temp. Range(F)	Life Stage	Season	Location	Acclimation Temp.(F)	Data Source
	34 +	young fry & adults				Bigelow & Schroeder, 1953, p. 303
	58.6-73.4	larvae				Herman, 1963, p. 107
	52.8-74.8	larvae	May-August			Perlmutter, 1939, p. 55
	39.6-80.2	adult	April-Dec.	New Haven, CT		Warfel & Merriman, 1944, p. 10, 65
	59	young-of-the year	Nov.-Dec.	Delaware R.	43-46	Meldrim & Gift, 1971, p. 28
	70	young-of-the year	Nov.	Delaware R.	57	Meldrim & Gift, 1971, p. 28
	74	young-of-the year	May or Oct.	Delaware R.	61-63	Meldrim & Gift, 1971, p. 28
	76	young-of-the year	June	Delaware R.	68	Meldrim & Gift, 1971, p. 28
	75	young-of-the-year	Oct.	Delaware R.	70	Meldrim & Gift, 1971, p. 28
	74	young-of-the-year	Aug.	Delaware R.	77	Meldrim & Gift, 1971, p. 28
68		young-of-the-year	Dec.	Delaware R.	48	Meldrim & Gift, 1971, p. 35

Menidia menidia - Atlantic silverside, p. 4

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Season	Location	Acclimation Temp. (F)	Data Source
75		young-of-the-year	Dec.	Delaware R.	48	Meldrim & Gift, 1971, p. 35
84		young-of-the-year	Oct.	Delaware R.	54	Meldrim & Gift, 1971, p. 35
81		young-of-the-year	Nov.	Delaware R.	57	Meldrim & Gift, 1971, p. 35
84		young-of-the-year	Nov.	Delaware R.	57-9	Meldrim & Gift, 1971, p. 35
82		young-of-the-year	Oct.	Delaware R.	60	Meldrim & Gift, 1971, p. 35
84		young-of-the-year	Oct.	Delaware R.	63	Meldrim & Gift, 1971, p. 35
90		young-of-the-year	Sept.	Delaware R.	65	Meldrim & Gift, 1971, p. 35
85-88		young-of-the-year	Oct.	Delaware R.	67-68	Meldrim & Gift, 1971, p. 35
87-92		young-of-the year	June-July	Delaware R.	68	Meldrim & Gift, 1971, p. 35
85		young-of-the-year	Aug.-Sept.	Delaware R.	74-75	Meldrim & Gift, 1971, p. 35
91-92		young-of-the-year	Aug.	Delaware R.	77	Meldrim & Gift, 1971, p. 35

Menidia menidia - Atlantic silverside, p. 5

Avoidance Temp.(F)	Temp. Range(F)	Life Stage	Season	Location	Acclimation Temp.(F)	Data Source
97		young-of-the-year	July	Delaware R.	79	Meldrim & Gift, 1971, p. 35
94		young-of-the-year	July	Delaware R.	80	Meldrim & Gift, 1971, p. 35
85		age I	Aug.	Great Bay or Barnegat Bay, N.J.	77	Gift & Westman, 1971, p. 32
86.5		age I	Sept.	Great Bay or Barnegat Bay, N.J.	72.5	Gift & Westman, 1971, p. 32
68-77		young-of-the-year	Jan.	Delaware R.	41	Meldrim et al., 1974, p. 33
73		young-of-the-year	Nov.	Delaware R.	46	Meldrim et al., 1974, p. 34
74		young-of-the-year	April	Delaware R.	54	Meldrim et al., 1974, p. 33
75		young-of-the-year	Oct.	Delaware R.	55	Meldrim et al., 1974, p. 33
77		young-of-the-year	Oct.	Delaware R.	59	Meldrim et al., 1974, p. 34

Menidia menidia - Atlantic silverside, p. 6

Avoidance Temp.(F)	Temp. Range(F)	Life Stage	Season	Location	Acclimation Temp.(F)	Data Source
81		young-of-the-year	Oct.	Delaware R.	61	Meldrim et al., 1974, p. 34
84-87		young-of-the-year	May	Delaware R.	63	Meldrim et al., 1974, p. 34
90		young-of-the-year	Sept.	Delaware R.	73	Meldrim et al., 1974, p. 33
94		young-of-the-year	Aug.	Delaware R.	75	Meldrim et al., 1974, p. 34
93		young-of-the-year	Aug.	Delaware R.	77	Meldrim et al., 1974, p. 34
93-95		young-of-the-year	July-Aug.	Delaware R.	79	Meldrim et al., 1974, p. 33
86		young-of-the-year	Aug.	Delaware R.	81	Meldrim et al., 1974, p. 34
89		young-of-the-year	Aug.	Delaware R.	82	Meldrim et al., 1977, p. 34

Note:

(L) Lower thermal tolerance limit

Mytilus edulis - Blue mussel

I. Mortality

Tolerance Limit (LT_{50})(F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
78.8		∿14 days	29.6	Read & Cumming, 1967, p. 151
80.6		∿ 4 days	34.6	Read & Cumming, 1967, p. 151
82.4		∿ 2 days	39	Read & Cumming, 1967, p. 151
Lethal Temp. (F)				
105.4		(1)	59	Henderson, 1929, p. 407
77	larvae	16-17 days		Brenko & Calabrese, 1969, p. 225
84	adult	14 hours		Ritchie, 1927, p. 14
80.6		645 hours		Pearce, 1969, p. 230
82.4		41 hours		Pearce, 1969, p. 230
86		(2)	45.5	Read & Cumming, 1967, p. 151-2
80				Wells & Gray, 1960 cited in Read & Cumming, 1967, p. 149

Mytilus edulis - Blue mussel, p. 2

II. Growth

Optimum Temp. (F)	Temp. Range (F)	Life Stage	Data Source
68	59-68	larvae	Brenko & Calabrese, 1969, p. 225
60.8	50-69.8	larvae	Bayne, 1965, p. 7, 22
51.8-57.2	58.1-68.9	larvae	Lough, 1974, p. 76

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Season	Data Source
Spawning		60.8-64.4		Bayne, 1965, p. 5
		60	April-June	Loosanoff, 1943, p. 26
Settling	54.5-66.2	54.5-71.6	June-August	Allen, 1955, p. 107-8
		57-74	June-August	Engle & Loosanoff, 1944 p. 438, Fig. 3; p. 435, Fig. 1
		<75.2		Pearce, 1969, p. 231

IV. Preferred Temperature

Optimum Temp. (F)	Temp. Range (F)	Data Source
	50-80	Hutchins, 1947, p. 330
	41-68	Brenko & Calabrese, 1969, p. 225

Mytilus edulis - Blue mussel, p. 3

IV. Preferred Temperature

Optimum Temp. (F)	Temp. Range (F)	Data Source
38.3-66.2		Lough, 1974, p. 75-76
	50-77	Widdows, 1973, p. 275

Note:

(1) Rise in temperature of 1.8 F per 5 minutes beginning at acclimation temperature until death

(2) Rise in temperature of 1.8 F per 3 to 5 days beginning at acclimation temperature until death

Osmerus mordax - Rainbow Smelt

I. Mortality

Lethal Temp.(F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
70.7-83.3	adult		50-59	Huntsman & Sparks, 1924, p. 103

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Season	Location	Data Source
Migration		40-60	March-May	Hingham, MA	Kendall, 1927, p. 233
Spawning		50-57	by May	Massachusetts Bay	Bigelow & Schroeder, 1953, p. 137
Incubation/ Hatch	47.3		22 days	Massachusetts Bay	Crestin, 1973, p. 42
	42.5		19 days	Green Lake, ME	Kendall, 1927, p. 341
	57		13 days	Massachusetts	Kendall, 1927, p. 340
	40-42		42 days	Long Island	Kendall, 1927, p. 333-334
	40-65		3 days	Long Island	Kendall, 1927, p. 335
	37-58		30 days	Long Island	Kendall, 1927, p. 334

Pseudopleuronectes americanus - Winter flounder

I. Mortality

Tolerance Limit (LT_{50}) (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
66.2	adult	24 hr	39.2	McCracken, 1963, p. 575
71.6	adult	24 hr	50	McCracken, 1963, p. 575
75.2	adult	24 hr	59	McCracken, 1963, p. 575
79.7	adult	24 hr	68	McCracken, 1963, p. 575
71.6	juvenile	72 hr	44.6	Hoff & Westman, 1966, p. 135
74.6	juvenile	72 hr	57.2	Hoff & Westman, 1966, p. 135
80.6	juvenile	72 hr	69.8	Hoff & Westman, 1966, p. 135
84.4	juvenile	72 hr	82.4	Hoff & Westman, 1966, p. 135
71.1-74.7	small fish	5-13 min	57.2	AEC, 1972, p. 5-7
77.0-80.6	small fish	5-13 min	69.8	AEC, 1972, p. 5-7

	CTM(F)	Life Stage	Acclimation Temp. (F)	Data Source
89.2-89.7	87.3-88.0	young-of-the-year	68.9	Gift & Westman, 1971, p. 43
88.9	87	age I	71.6	Gift & Westman, 1971, p. 43
89.4	87.3	young-of-the-year	74.3	Gift & Westman, 1971, p. 43
89.8	88.5	young-of-the-year	76.6	Gift & Westman, 1971, p. 43

Pseudopleuronectes americanus - Winter flounder, p. 2

Tolerance Limit (LT_{50}) (F)	CTM	Avoidance	Life Stage	Acclimation Temp. (F)	Data Source
		88	Adult		Pearce, et al., 1968 (cited in Fairbanks, et al., 1971, p. 29)

	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
34.6 (L)	juvenile	72 hr	69.8	Hoff & Westman, 1966, p. 135
42.8 (L)	juvenile	72 hr	82.4	Hoff & Westman, 1966, p. 135

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp. (F)	Data Source
75.2	age I		41	Frame, 1973, p. 616
77		48 hr		Pearce, 1969, p. 228
82.2-87	juvenile	(1)	50-59	Huntsman & Sparks, 1924, p. 107-8
81.5-85	adult	(1)	50-59	Huntsman & Sparks, 1924, p. 107-8
83.0-88.6	adult		53.6-61	Britton, 1924, p. 417
28.6 (L)	adult	1.25 hr	50-61	Britton, 1924, p. 417
35.6 (L)	larvae			Laurence, 1975, p. 225

Pseudopleuronectes americanus - Winter flounder, p. 3

II. Growth

Optimum Temp. (F)	Temp. Range (F)	Life Stage	Data Source
	53.6-60.8	age I	Frame, 1973, p. 615-616
46.4	35.6-46.4	larvae	Laurence, 1975, p. 224

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Season	Location	Data Source
Spawning		<39-40.2	Before April	Georges Bank	Lux et al., 1970, p. 487
		32-42	Jan.-May	New England	Bigelow & Schroeder, 1953, p. 280
	35.6-41	34-50	Feb.-Apr.		Pearcy, 1962, p. 17
		32-35		Woods Hole	Lux et al., 1970, p. 486
		32-37		Gloucester	Lux et al., 1970, p. 486
Incubation/ Hatch		37-38	15-18 days		Bigelow & Schroeder, 1953, p. 280
		69	15 days		Breder, 1921-1922, p. 313-314

IV. Preferred Temperature

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Season	Location	Acclimation Temp. (F)	Data Source
	∿29-70	adult				Bigelow & Schroeder, 1953, p. 279
	[illegible]-63[illegible]	[illegible]lar[illegible]	[illegible]eb.[illegible]e	[illegible]Narragansett Bay		Herman, 1963, p. 107

Pseudopleuronectes americanus - Winter flounder, p. 4

IV. Preferred Temperature

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Season	Location	Acclimation Temp. (F)	Data Source
	53-60	adult		Connecticut		Thompson et al., 1971, p. 148
	42.0-56.0	larvae	March-June	Long Island Sound		Wheatland, 1956, p. 295
	54-72	larvae	May-June	Long Island		Pearlmutter, 1939, p. 52
	39.6-80.2	adult	April-Dec.	New Haven, CT.		Warfel & Merriman, 1944, p. 17, 65
	53.6-59	adult		Atlantic Coast		McCracken, 1963, p. 579
	63-72	adult		Long Island		Olla et al., 1969, p. 720
76	67	adult	Nov.	Delaware R.	57	Meldrim & Gift, 1971, p. 29, 36
73.4		adult		Long Island		Olla et al., 1969, p. 720
80		young-of-the-year			68.9	Gift & Westman, 1971, p. 43
75.5		age I			71.6	Gift & Westman, 1971, p. 43
80		young-of-the-year			74.3	Gift & Westman, 1971, p. 43

Pseudopleuronectes americanus - Winter flounder, p. 5

IV. Preferred Temperature

Avoidance Temp. (F)	Temp. Range (F)	Life Stage	Season	Location	Acclimation Temp. (F)	Data Source
80		young-of-the-year			76.6	Gift & Westman, 1971, p. 43

Note:

(1) Rise in temperature of 1.8 F per 5 minutes beginning at acclimation temperature until death

(L) Lower thermal tolerance limit or lethal temperature

Pollachius virens - Pollock

I. Mortality

Tolerance Limit (LT_{50})(F)	Life Stage	Exposure Time	Acclimation Temp.(F)	Data Source
82.2(U)	adult			Britton, 1924, p. 417
28.6(L)	adult	3 min		Britton, 1924, p. 417

III. Reproduction

	Optimum Temp. (F)	Temp. Range (F)	Season	Location	Data Source
Spawning	40-43	35-49	late Autumn-early Winter	Massachusetts Bay	Bigelow & Schroeder, 1953, p. 215-216

	Temp. Range (F)	Time		
Incubation/ Hatch	43-49	6-9 days		Bigelow & Schroeder, 1953, p. 216
	38-48			Bigelow & Schroeder, 1953, p. 216

IV. Preferred Temperature

Temp. Range (F)	Location	Data Source
42.8-55.4	Nova Scotia	Steele, 1963, p. 1272
34.0+	Scotian Shelf & Gulf of St. Lawrence	Steele, 1963, p. 1272
32-52	Gulf of Maine	Bigelow & Schroeder, 1953, p. 215

Note:

(U) Upper thermal tolerance limit
(L) Lower thermal tolerance limit

Tautogolabrus adspersus - Cunner

I. Mortality

Lethal Temp. (F)	Life Stage	Exposure Time	Acclimation Temp.(F)	Data Source
>82.4-84.2	juvenile		64.4-71.6	Haugaard & Irving, 1943, p. 24
>77-78.8	juvenile		33.8-37.4	Haugaard & Irving 1943, p. 24
<41	juvenile		64.4-71.6	Haugaard & Irving 1943, p. 24
<33	juvenile		33.8-37.4	Haugaard & Irving 1943, p. 24

III. Reproduction

	Optimum Temp.(F)	Temp. Range(F)	Season	Location	Data Source
Spawning		55+	late spring - early summer		Bigelow & Schroeder, 1953, p. 475
		51.8-85.4	April-August	Weweantic R., Mass.	Serchuk, 1972, p. 69
Incubation/ Hatch		55-65	3 days	Gulf of Maine	Bigelow & Schroeder, 1953, p. 476
	70-72		40 hr		Bigelow & Schroeder, 1953, p. 476
Spawning		50+	May-October	Long Island	Wheatland, 1956, p. 273
		52.7-76.0	May-September	Narragansett Bay	Herman, 1963, p. 107
		46.2-79.9	May-September	Long Island Sound	Perlmutter, 1939, p. 63-64
		50.0-78.8	May-October	Long Island Sound	Williams, 1967, p. 452

Tautogolabrus adspersus - Cunner, p. 2

IV. Preferred Temperature

Temp. Range(F)	Life Stage	Location	Data Source
68.2-76.0	larvae	Narragansett Bay	Herman, 1963, p. 107
66.4-73	larvae	Long Island Sound	Wheatland, 1956, p. 276
50.9-71	larvae	Long Island	Perlmutter, 1939, p. 63-64
32-72	adult		Bigelow & Schroeder, 1953, p. 475-476

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APPENDIX B

LIST OF MARINE ECOLOGICAL AND HYDRAULIC STUDIES ASSOCIATED WITH PILGRIM STATION

APPENDIX B

LIST OF MARINE ECOLOGICAL AND HYDRAULIC STUDIES
ASSOCIATED WITH PILGRIM STATION

Project[1]	Contractor-Consultant-Agency	Study Period[2]
A. Marine Ecology		
1. Marine Ecology Surveys (finfish, lobster, sport fishery, dissolved gases, water temp., and Irish moss)	Mass. Department of Fisheries, Wildlife and Recreational Vehicles, Division of Marine Fisheries (MDMF)	1968-1977
2. Benthic Studies	a. Raytheon Marine Lab.	1969-1970
	b. Clapp Laboratories, Battelle Memorial Inst.	1971-1974
	c. Dr. A. Michael (Marine Biological Lab., (MBL) and Yale U.), Dr. R.D. Wilce (U. Mass.)	1974-1977
3. Ichthyoplankton Survey of Cape Cod Bay	Marine Research, Inc. (M.R.I.)	1974-1976
4. Entrainment Studies	M.R.I.	1973-1977
5. Screenwash Monitoring for Impingement	MDMF	1973-1975
6. Impingement Study	Marine Research Institute (Dr. B.L. Marshall)	1976-1977
7. Winter Flounder Larvae Studies	M.R.I.	1976-1977
8. Lobster Larvae Studies	M.R.I.	1974-1976
9. Water Quality Measurements	Dr. D. Carritt (U. Mass.)	1973
10. Temperature and Chlorine Tolerance Measurements	Clapp Laboratories, Battelle Memorial Institute	1972-1974
11. Life History Study of *Chondrus crispus*	Cornell Univ. (J. Prince)	1969-1971
12. Menhaden Gas-Bubble Tolerance Studies	New England Aquarium	1974-1976
13. Irish Moss Quality Surveys	Woods Hole Oceanographic Institution (Dr. J.H. Ryther et al)	1974-1976

APPENDIX B (CONT'D)

Project	Contractor-Consultant-Agency	Study Period
14. Pilgrim Unit 1 Intake Monitoring	Mass. DMF/BECO/Marine Research Institute	1973-1977
15. Study of Alternative Solutions to Menhaden Attraction Problem	Yankee Atomic Service Company/EG&G	1975-1977
16. Fish Barrier Study	U.R.I. (Dr. G. Mott)	1973-1977
B. Thermal Plume and Oceanographic Studies		
1. Model Development and Predictions of Thermal Plume Behavior.	a. MIT (Dr. D.R.F. Harleman et al)	1972-1977
	b. Dr. D.W. Pritchard (Johns Hopkins Univ.)	1970-1974
	c. EG&G, Environmental Equipment Division	1974-1975
2. Winter Flounder Larvae Model Development	MIT (Dr. B. F. Pearce)	1975-1977
3. Field Measurements of Unit 1 Thermal Plume		
3a. Boat Surveys	a. MIT	1972-1973
	b. VAST, Inc.	Dec. 1972
	c. EG&G	Oct. 1974
3b. Aerial Infrared Surveys	a. Coastal Research Corp.	Dec. 1974
	b. Aero-Marine Surveys, Inc.	Aug. 1973
	c. Environmental Protection Agency	Sept. 1974 Oct. 1975
3c. Dye Release Studies	a. Westinghouse-Zone Research	1971
	b. Vast, Inc.	Dec. 1972
	c. EG&G	Oct. 1974
4. Oceanographic Measurements (ambient temperature and currents)	a. MDMF	1968-1977
	b. Endeco-Mr. R. O'Hagan	1973-1975
	c. EG&G	1974-1975
5. Analyses Related to Physical Oceanography and Thermal Plume (in addition to above)	a. Dames & Moore	1967
	b. Dr. D.W. Pritchard (Johns Hopkins Univ.)	1970-1974
	c. Stone & Webster Environmental Engineering Division	1974
	d. Yankee Atomic Service Co.	1975
C. Alternate Cooling	Bechtel Corp.	1971-1975

Project	Contractor-Consultant-Agency	Study Period
System Studies		
D. Impact Analysis for Selected Marine Species	Stone & Webster Environmental Engineering Division	1975-1977

(1) Refer to Pilgrim Unit 1 and 2 ER and Pilgrim Station Semi-Annual Marine Ecology Series for scope description and individual study results.

(2) Inclusive periods including extensions into the future wherever contractual arrangements have been made.