From: "Scheffer, Jacob" <JScheff@entergy.com>
To: <arw1@nrc.gov>
Date: 04/19/2007 8:53:49 AM
Subject: Entergy EFH Comment References

Alicia:

Attached are the following two references that you requested from our EFH comments:

* Bridges, W.L. and R.D. Anderson. 1984. A brief summary of Pilgrim Nuclear Power Plant effect upon the marine aquatic environment. In J.D. Davis and D. Merriman eds. Observations on the ecology and biology of western Cape Cod Bay, Massachusetts. P. 263-271. Lecture Notes on Coastal and Estuarine Studies 11. Springer-Veriag, NY

* MRI (Marine Research, Inc.). 1984. Assessment of finfish survival at Pilgrim Nuclear Power Station. Final Report 1980 - 1983. Submitted to Boston Edison Company

The "Lecture Notes" document is a published document.

We have asked Normandeau/MRI to supply the remaining four references you requested, and I will forward those to you upon receipt from Normandeau.

Please call me at 508-830-8323 if you have any questions about the documents.

Jay Scheffer

CC: "Bethay, Stephen" <SBethay@entergy.com>, "Ford, Bryan" <BFord@entergy.com>, "Egan, Joseph" <jegan1@entergy.com>

Mail Envelope Properties (46276645.B8A : 18 : 31626)

Subject: Entergy EFH Comment References
Creation Date 04/19/2007 8:52:21 AM
From: "Scheffer, Jacob" <JScheff@entergy.com>

Created By: JScheff@entergy.com

Recipients
nrc.gov
TWGWPO04.HQGWDO01
ARW1 (Alicia Williamson)

entergy.com
jegan1 CC (Joseph Egan)
BFord CC (Bryan Ford)
SBethay CC (Stephen Bethay)

Post Office	**Route**
TWGWPO04.HQGWDO01	nrc.gov
	entergy.com

Files	**Size**	**Date & Time**
MESSAGE	934	04/19/2007 8:52:21 AM
TEXT.htm	6398	
image001.gif	862	
PNPS Survival Final Rpt 1980-1983.pdf		1954671
PNPS effects - SpringerVerlag.pdf		1458971
Mime.822	4683907	

Options
Expiration Date: None
Priority: Standard
ReplyRequested: No
Return Notification: None

Concealed Subject: No
Security: Standard

Junk Mail Handling Evaluation Results
Message is eligible for Junk Mail handling
This message was not classified as Junk Mail

Junk Mail settings when this message was delivered

Assessment of Finfish Survival
at Pilgrim Nuclear Power Station
Final Report, 1980 - 1983

Submitted to

Boston Edison Company

Boston, Massachusetts

by

Marine Research, Inc.

Falmouth, Massachusetts

February 24, 1984

Revised

March 23, 1984

Table of Contents

Figures

Tables

Tables (continued)

I. INTRODUCTION

This report describes the results of studies conducted at the Pilgrim Nuclear Power Station (PNPS) to assess survival of finfish impinged on the plant's revolving intake screens. Data obtained between September and December 1983 appear in the report for the first time along with earlier 1983 data, all collected under Boston Edison Company Purchase Order No. 69975. This report summarizes not only the 1983 studies but the 1980-1982 work as well. All phases of the four-year study were designed to assess sources of mortality among fish collected in the PNPS screenwash system and to establish an impingement data base useful for assessment of any future fish kills.

Specific objectives were:

- To determine impingement survival rates among fish collected during routine plant operations (1980-1983).
- To examine mortality induced by a permanent sluiceway installed in 1979 to return impinged fish to Cape Cod Bay (1980, 1981).
- To obtain survival information on experimental groups of fishes released in front of the screens in continuous wash cycle simulations (1982, 1983).
- To obtain survival information on experimental groups of fishes held in front of the screens for eight-hour periods prior to impingement in simulations of typical eight-hour wash cycles (1983).
- To compare mortality rates among fish impinged before (1980, 1981) and after (1982, 1983) installation of low-pressure spray wash nozzles.

II. METHODS

A. General

To determine impingement survival rates during routine plant operations fish washed off the traveling screens were sampled at the end of the sluiceway (Figure 1). Special nets were constructed of 3/16-inch (4.8 mm) "delta" mesh so that all water passing down the sluiceway was filtered. Net-induced injury was minimized by using two nets interchanged frequently so that fish were confined to the net for only short periods before being transferred to pails containing ambient seawater.

Upon collection initial mortality was determined by immediately transferring fish to 8-liter pails containing ambient seawater. Dead fish (condition categories are defined below) were removed and set aside for identification and length-weight measurements. Live fish, whether healthy or injured, were transferred quickly to five-foot (1.5 m) diameter, circular holding pools located about 20 feet (6.1 m) from the end of the sluiceway and supplied with continuous running ambient seawater. The pools were fitted with screen and wire mesh covers to prevent fish from jumping out and to eliminate predation by shore birds and racoons.

Fish were observed in the holding pools for one hour following introduction, and any dead fish were removed following that time. All surviving fish were held in the pools until the next scheduled screenwash sampling period approximately 55 to 56 hours later. At the end of each holding period all fish were weighed ($\pm$ 0.1 gm) and measured ($\pm$ 1 mm) by condition category - alive, dead, or injured. Fish were not fed during the holding period.

The survival study was combined with the finfish impingement monitoring program so that sampling was conducted three times per week (Monday 0830, Wednesday 1630, and Saturday 0030). Studies were scheduled to be conducted during the months of March, April, August, September, November, and December 1983 as in 1980, 1981, and 1982; these months were selected because historically they have represented periods of greatest impingement. In 1983 however, sampling was delayed until April due to problems with the power supply to the holding pool pumps. To compensate for this delay sampling was extended through May; similar start-up delays occurred in other years as discussed in MRI (1981, 1982a, 1983).

Data were collected under both static and continuous wash cycles and therefore represented fish which might have spent up to eight hours on the screens (screens are routinely washed every eight hours), or only a brief time period. If the screens were static at the start of a sampling period, fish collected during the first ten minutes (the approximate time necessary for one revolution of the screens) were held in a separate pool and observed independently from any fish collected after the ten-minute period. Sampling was conducted for 0.5 hour if the screens were static prior to collection or one hour if the screens were in the continuous wash mode. Provisions were made to extend sampling beyond these time periods in any case where sampling personnel believed more fish would have been collected.

Condition categories during all phases of the study were defined as follows: alive - fish swimming and behaving in an apparently normal manner; dead - no body movement, no opercular movement, no response to gentle prodding; injured - tissue damage visible, fish swimming erratically, loss of equilibrium.

B. Sluiceway Introduction Studies 1980, 1981

To assess mortality induced by the sluiceway itself samples of fish were introduced to the sluiceway in the screenhouse just downstream of the screens while the wash system was in operation. Fish were obtained from local waters by beach seine, otter trawl, or baited lift net (for cunner, *Tautogolabrus adspersus*, and pollock, *Pollachius virens*) and transferred to PNPS in 32-50 gal (121-189 liter) plastic, aerated containers. Introduced fish were then collected at the end of the sluiceway by a second person in a manner identical to that used for fish washed off the screens. They were immediately transferred to a separate holding pool and otherwise treated as described above for naturally impinged fish. However, due to variability in collection times, introduced fish were held from 47 to 70 hours. They were not fed during the study.

Sluiceway introduction studies were conducted during September, November, and December 1980 and April, May, June, August, September, and November 1981. The beach seine, used to obtain many of the introduced fish, measured 100 by 6 feet (30.5 x 1.8 m) and was made of ¼-inch (6.4 mm) "delta" mesh. It was used at several locations along the Plymouth Harbor side of Plymouth Beach, along the town beach in Plymouth Center, and along the north side of the PNPS intake. Other fish such as winter flounder (*Pseudopleuronectes americanus*) and sculpin (*Myoxocephalus* spp.) were obtained with a small otter trawl in Plymouth Harbor-Kingston, Duxbury Bay or larger gear operated by the Massachusetts Division of Marine Fisheries off PNPS. Cunner and pollock were obtained in Sandwich, Massachusetts, along the southeast side of the Cape Cod Canal using a baited 28-inch (0.71 m), 3/16-inch (4.8 mm) mesh lift net.

C. Screen Introduction Studies 1982, 1983

Since impingement rates are frequently low at PNPS, supplemental studies were designed in 1982 and 1983 to obtain additional data based on larger sample sizes which might better define possible sources of impingement mortality. These supplemental studies also held the potential for generating information on species which have been impinged in large numbers on occasion in the past.

Samples of fish were collected from local waters by beach seine, otter trawl, or baited lift net and transferred to PNPS in large (32-50 gal; 121-189 liter), plastic, aerated containers. At PNPS these fish were handled in one of two ways: 1) To simulate continuous screenwash conditions, fish were released immediately in front of the traveling screens by lowering them in a specially designed container through the upstream access opening (Figure 2); 2) To simulate normal intermittent wash cycles where the screens remain idle for eight hours, the fish were transferred to a rigid holding pen measuring 36 in (90 cm) x 25 in (62.5 cm) x 22 in (55 cm) deep constructed of ¼-inch (6.4 mm) galvanized mesh. The pen was then held in front of the screens in the intake water flow for eight hours at which time the fish were released by opening a downstream door in the pen. The container used for the continuous wash simulation studies was fitted with a hinged lid so that it could be lowered below the inner skimmer wall (Figure 2) before the fish were released. The holding pen used for the eight-hour studies was also lowered below the skimmer wall. In all cases the screens and wash pumps were operating during the release period and for a minimum of one hour following the release period. Because of the size of the container (5 gal; 19 liter) used during continuous wash introductions to lower fish into the intake area below the inner skimmer wall, fish were released in groups rather than all at once. The size of the groups varied with species, fish size, and water temperature. In the eight-hour simulation studies all fish were held together and therefore released together. Throughout these experimental wash cycles sampling was conducted near the end of the sluiceway as described above by a second person. All fish collected this way were handled in a manner identical to that used with the naturally impinged and sluiceway-introduced fish. However, due to variations in collection times, holding periods for screen-introduced fish varied from 44 to 69 hours; they also were not fed during the study.

Fish utilized in these experiments were obtained as described for the sluiceway introductions. In 1983 special emphasis was placed on rainbow smelt (Osmerus mordax), alewife (Alosa pseudoharengus), and pollock since from 1976 through 1980 they ranked 2, 4, and 12, respectively, among all naturally impinged fish at PNPS. Rainbow smelt were collected at night in fresh water during the spawning run in the Jones River just below the Elm Street dam using the same lift net described above (no bait was used). Efforts to collect alewives were made in upper Narragansett Bay and the Taunton River using a 300 x 8-foot (91 x 2.4 m) beach seine with ½-inch (12.5 mm) mesh. Sampling for pollock was conducted with the lift net as previously described. Whenever eight-hour holding pen studies were conducted, the fish were transferred to the pen at the 0830 screenwash and then released at the 1630 screenwash. The logistics of this regime necessitated that the fish be held in a flow-through 50 gal (189 liter) tank through one night following their collection. In the case of rainbow smelt a 5 ft (1.5 m) diameter, circular holding pool containing approximately 125 gal (473 liters) was used to re-acclimate the smelt to seawater (32 $^{o}/oo$). This was accomplished by filling the pool with fresh water from the Jones River, adding the fish, and pumping seawater on a flow-through basis at approximately 200 gal (757 liters) per hour. Smelt were held for 14 hours in the pool until released in front of the screens.

Screen introduction studies were conducted from April through June and August-November 1982, and April-September 1983.

D. Controls

In early 1980 when the survival program first began, fish were collected by beach seine, otter trawl, and lift net as described above and transferred to the holding pools to confirm that those facilities did not represent a source of mortality. From late 1980 through 1983 when sluiceway and screen introduction studies were conducted, subsamples of those fish were held as controls whenever possible. In the case of uncommon species no controls were held since we chose to obtain treatment data in those instances. In 1982 and 1983 the percentage recovered among fish released in front of the screens was expected to be relatively low since we anticipated that healthy fish would avoid the 0.5 to 1.0 ft/sec (0.15 to 0.3 m/sec) current velocity at the screens and escape upstream. Because of this every effort was made to obtain large samples for the introduction studies. When collections were considered to be marginal in size, no controls were held if previous control data for that particular species indicated little or no mortality among controls.

In cases where survival among control samples was less than 90%, adjustments were made to treatment survival following Tattersfield and Morris (1923) and King et al. (1977). Adjustment simply involves dividing the observed treatment survival rate by the control survival rate.

III. RESULTS

A. Routine Screenwash Survival

Sluiceway collections, made during the routine screenwash program established at PNPS which contributed to the survival assessment program in 1983, are summarized in Table 1. A total of 260 fish were collected: 142 under 8-hour wash cycles, 118 under continuous wash cycles. Among the 260 fish 27 species were represented; however five species contributed 67% of the total number impinged during survival studies - Atlantic silversides (*Menidia menidia*, 19.6%), rainbow smelt (17.3%), Atlantic menhaden (*Brevoortia tyrannus*, 11.5%), grubby (*Myoxocephalus aenaeus*, 10.0%) and blueback herring (*Alosa aestivalis*, 8.5%). Considering months when survival was monitored, Atlantic silversides were impinged primarily during April and December, smelt during December, Atlantic menhaden during September and December, grubby during April, May, and December, and blueback herring in November and December.

Table 2 summarizes all survival information obtained during routine plant operations from 1980 through 1983. Over this period 1318 fish representing 45 species were obtained under the survival program. Ten species accounted for 76.8% of the total; Atlantic silversides represented 16.1%, smelt 14.9%, cunner 14.4%, northern puffer (*Sphoeroides maculatus*) 9.3%, Atlantic menhaden 4.4%, blueback herring 4.0%, threespine stickleback (*Gasterosteus aculeatus*) 3.9%, grubby 3.8%, winter flounder 3.3%, and alewife 2.7%. These data exclude a relatively large impingement for Atlantic silversides (n = 4825, Table 2) which occurred on September 23-24, 1981, because that single incident represented an unusual monospecific occurrence which exceeded the four-year total of all other samples by a factor of nearly four.

Combining data from all 45 species obtained over four years (but again excluding the high silverside mortality in September 1981), initial finfish survival at PNPS was 8.9% under 8-hour wash cycles (n = 957) and 29.6% under continuous wash cycles (n = 361; Table 2). Among the ten dominant species initial survival under 8-hour wash cycles ranged from 1.3% among smelt (n = 151) to 37.5% among grubbies (n = 32). Under continuous wash operation initial survival among the ten dominants ranged from 0% among Atlantic menhaden (n = 7), blueback herring (n = 15), and threespine stickleback (n = 3) to 77.8% among grubbies (n = 18). Considering all remaining species besides the dominants, initial survival was 20.4% under 8-hour wash operation (n = 181) and 32.8% under continuous operation (n = 122). Initial as well as latent survival rates in both 8-hour and continuous wash categories are compared for the ten numerical dominants and all other species combined in Figure 3.

It is generally clear that initial survival rates were higher under continuous wash operation than under 8-hour wash cycles; this was true even for species with relatively small sample sizes. Among the ten dominant species initial survival rates were compared between 8-hour wash collections and continuous wash collections using Z tests for the difference between proportions (Zar 1974). Statistically significant differences were detected for silversides ($p < 0.01$, $Z = 3.069$), cunner ($p < 0.001$, $Z = 7.762$), puffer ($p < 0.01$, $Z = 2.655$), and grubby ($p < 0.02$, $Z = 2.441$). Among rainbow smelt survival was very low and about equal in both 8-hour and continuous wash categories (1.3 and 2.2%, respectively). Among Atlantic menhaden, blueback herring, threespine sticklebacks, and alewives sample sizes were too small and survival too low in both categories to permit comparisons (Table 2). Survival rates among winter flounder were considerable higher under continuous wash cycles (47.1 versus 18.5%) but sample sizes were insufficient to detect a statistically significant difference ($p > 0.05$, $Z = 1.681$). Comparisons among all species combined ($p < 0.001$, $Z = 9.439$) and among all species excluding the ten dominants ($p < 0.02$, $Z = 2.421$) indicated significantly greater survival occurred in continuous wash mode in both cases.

Survival rates declined following the 56-hour holding periods in nearly all cases. Pooling all fish from 1980-1983 latent survival was 4.8% under 8-hour cycles (n = 957) and 14.4% under continuous wash cycles (n = 361). Among the ten numerical dominants latent survival under 8-hour cycles ranged from 0% among silversides (n = 127; September 23,24, 1981 excluded), smelt (n = 151), blueback herring (n = 38), alewives (n = 30), and menhaden (n = 51) to 37.5% among grubbies (n = 32). Under continuous wash operation values ranged from 0% among silversides (n = 85; September 23,24, 1981 excluded), smelt (n = 46), blueback herring (n = 15), alewives (n = 6), and menhaden (n = 7) to 61.1% among grubbies (n = 18). As discussed above, where sufficient data were available, survival was generally found to be higher under continuous wash operation than under 8-hour wash operation (Table 2, Figure 3). Considering total fish, the numerical dominants, and all others, statistically significant differences were detected (i.e., continuous wash cycle survival was greater) for cunner ($p < 0.001$, $Z = 4.630$), northern puffer ($p < 0.05$, $Z = 2.157$), total fish ($p < 0.001$, $Z = 5.805$), and all others ($p < 0.05$, $Z = 2.128$). Among Atlantic silversides, rainbow smelt, Atlantic menhaden, blueback herring, and alewives survival was 0% in both categories. As in the case of initial survival rates, latent winter flounder survival improved under continuous wash cycles (29.4% versus 14.8%) but samples were too small to demonstrate a statistically significant difference ($p > 0.05$; $Z = 0.785$). Similar results were found for the grubby where survival increased from 37.5% under 8-hour cycles to 61.1% under continuous wash cycles, but no statistical difference was detected due to small samples ($p > 0.05$, $Z = 1.312$).

Data collected in 1980 and 1981 were compared with data collected in 1982 and 1983 to see if any increase in survival was apparent in the latter two years as a result of the low-pressure spray wash nozzles installed early in 1982. Survival rates before (1980, 1981) and after (1982, 1983) installation of the low-pressure nozzles are shown in Table 3 for all categories where sample sizes were large enough to permit some comparison. Cunner, winter flounder, and northern puffer displayed some improvement in both initial and latent survival under 8-hour wash cycles from the 1980-81 to 1982-83 data sets. The difference was statistically significant only in the case of cunner ($p < 0.05$, $Z = 2.056$ for initial survival; $p < 0.05$, $Z = 1.987$ for latent survival). Under continuous wash cycles not only were no increases in survival recorded but in each case where some survival was observed it appeared to decline from 1980-81 to 1982-83 (Table 3); none of these differences proved to be statistically significant however ($p = 0.05$).

Overall, the comparison between 1980-81 data and 1982-83 data offers little evidence that the low-pressure spray wash nozzles improved survival among impinged fish. Intuitively the low-pressure wash would appear to be valuable in reducing impingement mortality but effects may be subtle and difficult to detect with the data at hand.

B. Sluiceway Introduction Studies 1980, 1981

The numbers of fish introduced to the sluiceway in 1980 and 1981, collected at the downstream end and held for 50-90 hours, are summarized by species in Table 4. Survival in these studies was generally quite high (86-100%), indicating that little mortality occurred as a result of passage down the sluiceway. Exceptions occurred among rainbow smelt and Atlantic silversides which showed survival rates of 0 and 50%, respectively. The smelt results were based on very few fish (n = 12) while the silverside data were based on five samples introduced on five dates (one in 1980, four in 1981). The range in silverside survival over the five dates was large: 10% (April 23, 1981; n = 66) to 91.2% (June 10, 1981; n = 91). Survival among control fish was 100% on both these dates so the fish were apparently in good condition, and mean lengths were similar: 95.6 mm on April 23, 90.3 mm on June 10.

In May 1981 the program was modified slightly to determine if possible why silverside mortality was relatively high during some trials. In spite of efforts to minimize sluiceway, net-induced mortality (see Methods), water velocity at the end of the sluiceway was sufficiently high that net injury could have been significant. Flow rate measured at the downstream end of the sluiceway with a General Oceanics 2030 flowmeter (June 10, 1981) was found to be 455 cm/sec (15 ft/sec). Fish were therefore subjected to a great deal of pressure and presumably stress while in the sampling net for even a short period. Fish may also have been injured by hitting the sidewall of the sluiceway while traversing the sharp bend just above the downstream end (Figure 1). Just before the final sharp bend where the slope is low, water velocity was recorded at 204 cm/sec (7 ft/sec). Therefore to examine for mortality induced by the bend or the sampling gear, beginning in late May 1981 collections were made at both locations whenever sufficient numbers of fish were available. Results of these trials are shown in Table 5. These data indicate that, with the exception of cunner which showed 100% survival at both sampling locations, survival was higher at the upstream, low velocity point. Improvement in survival was 27% for the mummichog (Fundulus heteroclitus) and averaged about 8% for silversides. (Additional mummichogs were collected for a second trial with that species on September 1, 1981, but the sluiceway was found to be inoperable on that date.) If the sampling gear was the primary source of injury, these data suggest that for some species survival rates were somewhat under-estimated for collections made at the downstream end of the sluiceway during 1980 and 1981. Based on these results, all collections in 1982 and 1983 were made in the 7 ft/sec area.

C. Controls

Table 6 summarizes the control data obtained in 1980 and 1981 to test the effectiveness of the holding pools and the field collection and transportation methods. With the exception of the clupeids, survival among the control fish was generally high, ranging from 95% among Atlantic silversides to 100% among many other species. These data indicated that our methods introduced little or no additional mortality to the studies. Survival among clupeids ranged from 52% among menhaden to 79% among alewives. Since small clupeids are well known for being sensitive to handling stress, the relatively high mortality among these fish was not unexpected.

No adjustments were made to the 1980 and 1981 data as a result of the generally high survival rate among control fish. Adjustment among clupeids would have been warranted but only six were collected alive during the first two years of study, and none of them survived the holding periods.

D. Screen Introduction Studies - Continuous Wash, 1982

Table 7 summarizes the numbers of fish by species released in front of the screens on twelve dates during the 1982 continuous wash simulation studies. An additional 1500 fish were collected on five dates as part of the introduction studies but either could not be released due to problems at the plant or were released but were lost along with the holding pools during two severe storms. Rainbow smelt ($n = 36^{*}$) collected during April 1983, used in a continuous wash

*The sample size for smelt in 1983 was considerably smaller than planned. The first test representing n = 36 treated fish, n = 25 controls, was purposely small since we were uncertain that these fish could be successfully transferred from the Jones River to seawater in a period of time estimated at perhaps one hour. Attempts to collect larger numbers of smelt on subsequent nights failed, suggesting that the spawning run ended early in 1983.

simulation because they had not been previously tested in that regime, are included in Table 7 with two smelt introduced in 1982.

Following release and subsequent impingement, Atlantic silversides, cunner, and winter flounder provided the greatest data base. Pooled over all dates, these species showed survival rates of 19.9 (n = 564), 100 (n = 59), and 99.5% (n = 195), respectively, following one-hour holding periods. After 44 to 70-hour holding periods survival dropped to 68.7% among flounder and 4.3% among silversides. Survival among cunner remained at 100%. No adjustment for survival among controls was necessary for winter flounder or cunner since both showed latent control survival rates of 100%. However, since Atlantic silversides showed a pooled control survival rate of 88.5% following 44 to 70-hour holding periods (Table 7), the latent, test survival rate for that species was adjusted to 4.9%.

Results for winter flounder, cunner, and silversides are shown in more detail in Tables 8 and 9 where data are presented by replicate. The 317 winter flounder introduced in front of the screens were collected and released on eight sampling dates. Over those eight dates latent survival ranged from 2.2 to 100%. Relative to the other dates where survival was fairly consistent, ranging from 72.2 to 100%, the value of 2.2% obtained on September 24, 1982 was unusually low; control survival on that date was 100%. On September 24 we experienced a two-hour delay at the screenhouse due to chlorination operations. During the delay the fish were aerated continuously and water was exchanged periodically with fresh ambient seawater. Control fish were subsampled at the end of the day from those transported into the plant so they were actually held in the barrels for an additional 0.5 hour. Nevertheless the exceptionally low survival rate among introduced fish on that date suggests that the long holding period followed by impingement and screenwash exceeded the tolerance of those fish.

Cunner were introduced on three dates (Table 8). Survival was 100% in all cases including controls.

Silverside latent survival rates observed on seven dates were relatively low ranging from 0 to 34.8% (Table 9). Although silversides were subjected to the same problem on September 24, 1982 described above for winter flounder, 100% mortality was also realized on two additional dates. This species generally appears to be sensitive to impingement. In some of the introduced samples a portion of the fish (e.g., 21.2%, October 27) were dead when collected at the end of the sluiceway which rarely occurred among other species. Tissue damage was also frequently noticed on these fish. For example, on September 24, 1982, 67.3% of the fish showed hematomas around the brain and eyes; this type of injury may occur among other species as well but be particularly noticeable on silversides because their dorsal tissue is relatively clear. Also because of their generally small size and attenuated shape, silversides are susceptible to penetration of the 3/8-inch screen mesh which may explain the more severe injuries.

E. Screen Introduction Studies - 8-Hour Wash, 1983

Table 10 presents numbers of fish by species released in front of the operating traveling screens following 8-hour holding periods in a pen suspended in front of the screens.

Following release and recovery Atlantic silversides, winter flounder, and mummichogs provided the greatest amount of information. Pooled over all sampling dates one-hour survival rates among these species were 13.7, 48.1, and 94.5%, respectively. Following 49 to 69-hour holding periods survival declined to 0% among silversides, 9.6% among winter flounder, and 40.0% among mummichogs. Latent survival among controls was 74.2% among silversides, 96.7% among flounder, and 100% among mummichogs. Based on these data, no adjustment was necessary for the flounder or mummichog data due to their high control survival rates, and an adjustment to the silverside data was not possible with zero survival.

Table 11 presents individual observations for Atlantic silversides and winter flounder, the data in Table 10 having been pooled from three replicates in both cases. These data further indicate that silversides are sensitive to impingement stress with fish surviving the first post-impingement hour of observation in only one of the three replicates (17.8% survival, n = 118) and no survival occurring after 44+ hour holding periods. Data were obtained from only two replicates with winter flounder since recovery was 0% in the third trial. Survival varied from 38.6% (n = 44) to 100% (n = 8) at one hour declining to 0 and 62.5%, respectively, at 44+ hours.

As mentioned above under the 1982 continuous wash simulation results, silversides subjected to impingement and subsequently collected at the end of the sluiceway following 8-hour holding periods were frequently dead or very nearly so when collected. For example, on September 30, 1983 all 24 silversides recovered were dead when collected; whether these fish died in the holding pen or following impingement is unknown. Hematomas were frequently observed in the 1983 studies; e.g., on May 11, 35 of the 118 recovered silversides (29.7%) showed this sign of tissue damage.

One goal of the 1983 program was to collect and introduce large numbers of alewives and pollock, species which rank high on the PNPS impingement list. Sampling for alewives was concentrated in Narragansett Bay where they have been readily collected by beach seine in past years. Between late May and late September 1983 seven sampling trips were made resulting in the collection of only seven alewives. Young pollock have been noted in large numbers along the bulkheads lining the Cape Cod Canal in past years although they are difficult to collect in large numbers due to their speed. In 1983 we surveyed the canal for pollock on eight occasions between early September and late November but they apparently did not congregate there since none were observed.

F. Introduction Study Recovery Rates 1982, 1983

The recovery rate data presented in Tables 7-11 are interesting because they indicate that initially healthy-appearing fish can avoid impingement when released suddenly in front of the screens (1982) or when held for eight hours prior to release (1983). Recovery rates among species with sample sizes of at least 25 ranged from 0% among pollock (n = 25) to 61.5% among winter flounder (n = 317) in the continuous wash simulations and 0.9% among cunner (n = 570) to 69.6% among mummichogs (n = 158) in the 8-hour simulation studies. Recovery rates were also found to be quite variable within species between replicate samples (Tables 8, 9, 11). Based on the replicates for continuous wash simulations (1982), recovery rates ranged from 55.1 to 82.1% for flounder (excluding August 18, 1982 when n = 1), 4.9 to 21.2% for cunner, and 2.8 to 75.6% for silversides. In the 8-hour simulation studies recovery rates ranged from 34.3 to 100% for silversides and 0 to 64.7% for winter flounder.

Recovery rates were examined between continuous and 8-hour wash simulation data sets to see if fish were more or less likely to be impinged following the long holding period in the intake current. Pooled recovery rates were compared among silversides, winter flounder, cunner, and mummichogs, species with large samples in both screenwash categories, using Z tests for differences between proportions. In all four cases statistically significant differences were apparent. Interestingly recovery rates were higher under 8-hour wash simulations for silversides ($p < 0.01$, $Z = 3.201$) and mummichogs ($p < 0.001$, $Z = 11.245$) but higher under continuous wash simulations for winter flounder ($p < 0.001$, $Z = 6.462$) and cunner ($p < 0.001$, $Z = 8.601$). These data suggest that winter flounder and cunner acclimated to the current in the intake bay during the holding period and were better able to escape impingement once released. Under continuous wash simulation sudden release from the introduction container probably led to a brief period of disorientation during which impingement was more likely to occur. The reverse results for silversides and mummichogs suggest that these fish were stressed by eight hours in the intake bay and were therefore more susceptible to impingement.

Table 12 summarizes some observations which were made regarding elapsed time between the release of samples of fish and their appearance at the end of the sluiceway and also the time between the last release and the last collection at the end of the sluiceway. For example, if on day X of a continuous wash simulation study the first subsample of 20 silversides was released in front of the PNPS screens at 1200 and the first silverside appeared in the sluiceway collections at 1208, eight minutes elapsed before that fish was impinged, washed from the screens, and traveled down the sluiceway. If on day X the last subsample of 20 silversides was released at 1300 and the last silverside appeared in the collections at 1405, 65 minutes elapsed during which time that fish must have avoided impingement for most of that period; if that fish had been introduced in an earlier subsample, considerably more time than 65 minutes would have elapsed. Under the 8-hour simulation studies all fish were released from the pen at the same time so elapsed time between release and the last fish taken was more accurately determined.

These data indicate that a minimum of about six minutes elapses before an impinged fish is returned to Cape Cod Bay. The shortest observed time was three minutes presumably because those particular fish were impinged immediately after release and were probably near the surface where screen travel time is shortest. The longer time interval between release and last collection indicates that fish avoid impingement for periods of one hour or more presumably by swimming in front of the screens. For example, on September 17, 1982 most of the silversides recovered at the end of the sluiceway were collected one hour after the last subsample was introduced. These fish were in poor condition and died in less than one hour. Presumable they swam in front of the screens until exhausted and then became impinged.

It is also interesting to note that some members of several species held for eight hours in the intake bay, once released, still appeared to avoid impingement for periods of about 30 minutes to over one hour in the case of silversides.

Additional observations were made in 1982 and 1983 which suggested that most fish, which were not recovered within approximately an hour of release, escaped from the intake structure entirely. Six sampling dates in 1982 (April, August, September) and three dates in 1983 (June, August, September) were scheduled on Friday afternoons so that a screenwash collection would again be made during the regularly scheduled 0030 wash period Saturday morning. In several of these cases all introduced fish received shallow fin clips so they could be easily identified and separated from naturally impinged fish. On two of the six dates in 1982 the screens were inoperative during the scheduled 0030 wash - in no instance during the remaining four dates were fish introduced Friday afternoon (approximately eight hours prior to the 0030 wash) found in the subsequent 0030 wash collection. In 1983 none of the introduced fish was collected in the Saturday morning impingement sample. Interestingly however, two fin-clipped cunner were obtained in a screenwash collection on September 3, 1983, 15 days following their introduction in an 8-hour simulation study. Since aggregations of cunner are commonly seen swimming through and around the PNPS trash racks, it seems probable that the introduced fish joined the local population until they died.

G. Continuous Wash Versus 8-Hour Wash Simulation Survival Comparison

Comparison of survival rates between the 1982 continuous wash simulations and the 1983 8-hour simulations showed reduced survival following the 8-hour holding periods in both one-hour and latent survival categories (Tables 7 and 10). Statistical comparisons were possible among silversides, winter flounder, and cunner although in the later case only five fish were recovered during the 8-hour simulation studies. Among Atlantic silversides one-hour survival declined from 19.9% under continuous wash simulations (n = 564) to 13.7% under 8-hour simulations (n = 153) which did not prove to be a statistically significant decrease ($p > 0.05$, $Z = 1.614$). However, latent survival declined from 4.3% (n = 564) to 0% (n = 153) which was statistically significant ($p < 0.02$, $Z = 2.342$). Among winter flounder significant differences were apparent in both categories - one-hour values declined from 99.5% (n = 195) to 48.1% (n = 52; $p < 0.001$, $Z = 10.144$) and latent values from 68.7% (n = 195) to 9.6% (n = 52; $p < 0.001$, $Z = 7.477$). Among cunner one-hour survival dropped from 100% under continuous wash introductions (n = 59) to 60.0% under 8-hour wash introductions (n = 5) and latent survival dropped from 68.7% (n = 59) to 40.0% (n = 5), respectively. Both these changes were statistically significant ($p < 0.001$, $Z = 3.597$ and 4.993, respectively). Finally comparisons were also included for all species combined. One-hour survival rates were not significantly different (46.8 versus 50.6% for continuous and 8-hour simulations, respectively). However, latent survival declined from 27.9% under continuous wash introductions (n = 871) to 16.9% under 8-hour introductions (n = 344) which was a statistically significant decrease ($p < 0.001$, $Z = 3.942$).

H. Introduction Survival Versus Natural Impingement Survival

Survival rates were compared between samples of naturally impinged fish and samples of fish introduced to the screenwash system in the continuous and 8-hour wash simulation studies (Table 13). Comparisons were possible under 8-hour wash cycles for silversides, winter flounder, and cunner (Tables 2 and 10) although as mentioned above only five cunner were recovered from those particular introduction studies. Total fish, i.e., all species combined, were also included. In all four categories one-hour survival rates were significantly higher among the introduced fish than among those naturally impinged. Latent survival rates were significantly different only among cunner and total fish. A latent survival rate of zero was obtained among both introduced and naturally impinged silversides while flounder showed comparable rates in both classes (introduced = 9.6%, natural = 14.8%). Survival was also higher among introduced fish under continuous wash cycles. Sufficient numbers were available for statistical comparisons among silversides, cunner, flounder, windowpane (*Scophthalmus aquosus*), and all fish combined (Table 13). Statistically significant differences were found in each category for both one-hour survival rates and latent survival rates with the exception of silversides in the one-hour and latent subclasses and windowpane in the latent subclass.

I. One-hour Survival

Throughout the routine screenwash phase of the survival study, survival at one hour into the holding periods amounted to 84.4% of the 192 fish collected alive. Considered another way 31.9% of all live fish dying during the holding periods from 1980 through 1983 did so during the first hour.

Among the 1980-1981 control and sluiceway-introduced fish, lowest survival at one hour occurred among the clupeids. Among alewives and menhaden 87.5 and 100%, respectively, of the fish which did not survive either the control or introduction studies died during the first hour of the holding period. One-hour survival was also relatively low among rainbow smelt; 33% of those which died during the experiments did so in the first hour.

Among the fish introduced directly in front of the screens in 1982, one-hour survival was relatively low among Atlantic silversides (see Table 9); of 540 fish that died following introduction, 452 (83.7%) did so during the first hour. Threespine sticklebacks and bluefish (Pomatomus saltatrix) also showed low one-hour survival although sample sizes were small in both cases. Among sticklebacks 87.5% (n = 11) of those dying following release and impingement did so during the first hour, and among bluefish 100% (n = 2) did so.

In 1983 when 8-hour simulations were completed, one-hour survival was again very low among silversides (Tables 10 and 11); of 153 fish which died following eight hours in front of the screens with subsequent impingement, 132 (86.3%) did so within the first hour. As mentioned earlier, it was not uncommon for silversides to be dead when recovered at the end of the sluiceway. One-hour survival was also relatively low in one of the two winter flounder trials where fish were recovered (Table 11, June 27). A total of 44 fish died during the holding periods, 61.4% of those during the first hour.

IV. DISCUSSION

Comparisons of screenwash survival rates between the Pilgrim Station and other power plants is complicated by the fact that there are probably as many different intake velocities and screenwash systems as there are power plants. Nevertheless, to the extent that data were available, general comparisons with other plants were considered useful in assessing data obtained at PNPS.

For example, at the Manchester Street Station in Providence, Rhode Island, survival studies were conducted under continuous, 2, 4, 8, and 12 to 18-hour wash cycles (MRI 1980). A total of 26 species were taken, but collections were dominated by mummichogs, striped killifish (Fundulus majalis), winter flounder, and windowpane. Over all species of fish (sample sizes for individual species were low), survival following a 24-hour holding period ranged from 55.7% under continuous wash to 31.3% under 8-hour cycles, these two cycles being most comparable to the PNPS schedule. Under 2, 4, and 12 to 18-hour wash cycles, survival was 37.0, 46.9, and 26.5%, respectively, following 24-hour holding periods. Not included with these data were the alewife, blueback herring, and bluegill (Lepomis macrochirus), which did not survive impingement under any circumstance.

The same sampling regime was utilized at the Brayton Point Station in Somerset, Massachusetts (MRI 1982b). Winter flounder and Atlantic silversides contributed most to the Brayton Point data base. Among flounder, survival following 24-hour holding periods ranged from 90.2 to 94.4% under continuous, 2, 4, and 8-hour wash cycles; a decline to 83.0% occurred under 12-hour cycles. Latent survival among Atlantic silversides was low at 2, 4, 8, and 12-hour cycles (9.5-1.3%) but increased to 47.3% under continuous wash cycles. Other species taken during the Brayton Point studies which were also taken at PNPS included alewives, blueback herring, Atlantic menhaden, Atlantic herring

(Clupea harengus harengus)--all grouped as clupeids because of small sample sizes, silver hake (Merluccius bilinearis), Atlantic tomcod (Microgadus tomcod), and windowpane. Survival among these taxa under continuous and 8-hour cycles, those most comparable to PNPS, was 11.1 (n = 9) and 0% (n = 18), respectively, for tomcod, 83.3 (n = 18) and 65.5% (n = 87), respectively, for windowpane. Clupeids showed 0% survival under both wash cycles with sample sizes of only n = 5 and n = 18, respectively. A survival rate of 12.5% was recorded under 4-hour wash cycles (n = 8). Silver hake did not survive under any wash cycles where data were available (continuous, n = 12; 4-hour, n = 5; 12-hour, n = 43).

Continuous wash studies at several screen rotation periods conducted at Mystic Station in Boston, Massachusetts, provided comparative survival data with 96-hour holding periods for rainbow smelt, alewife-blueback herring, and winter flounder (Stone and Webster 1981). Among small smelt (probably age II) survival ranged from 22.5% at low screen speeds to 66.7% at high screen speeds. Survival was lower among larger smelt (probably age III); 11.0% at low speed, 40.0% at high speed. Alewives were also taken in two size classes; survival among young-of-the-year fish ranged from 6.7% at low speed to 48.1% at high speed, while among larger fish it ranged from 0.8% at low speed to 0.5% at high speed. Winter flounder survival was high among all sizes, ranging from 96.8% at low screen speed to 98.6% at high screen speed.

King et al. (1977) summarized fish survival studies at three Hudson River power plants under continuous, 2, and 4-hour wash cycles. For juvenile white perch (Morone americana) at the Bowline Point Plant, latent survival (96-hour) was 56% in a continuous wash mode and 19% in a 4-hour wash mode. These data were not adjusted for control survival which, based on the limited data presented, appeared to be relatively low. At the Roseton Plant latent (84-hour) white perch survival in a continuous wash mode was 29 and 60% in two separate studies compared with 23 and 36% for 4-hour wash modes. These data were adjusted for control survival and were collected with a wash water pressure of 50 psi. Data were collected on the Atlantic tomcod at the Roseton Plant; however, screen wash pressure data were unavailable. Survival under a continuous wash mode was 81% compared with 72% under a 2-hour wash mode after adjustment for controls. Similar data were collected at the Danskammer Point Plant for juvenile white perch and tomcod. Adjusted survival (84-hour latent) for white perch in two studies was 40 and 61% under continuous wash, and based on one study (April-May), 9% under a 4-hour wash cycle. Adjusted survival among tomcod was 83% under continuous wash and 87% under a 2-hour cycle.

Survival studies at the Oyster Creek Station in New Jersey were summarized by Tatham et al. (1977). Long-term survival (48-hour) with 2-hour wash cycles ranged from 5% for Atlantic menhaden to 98% for striped searobin (*Prionotus evolans*). Other values included 79% for northern pipefish (*Syngnathus fuscus*), 67% for winter flounder, 35% for Atlantic silversides, and 9% for bay anchovy (*Anchoa mitchilli*). Initial survival improved under continuous wash cycles (no delayed mortality data were presented). For example, initial survival among menhaden increased from 9% with intermittent screen rotation to 25% under continuous rotation.

Species-specific comparisons between PNPS results and the work reviewed above are limited because either species were not comparable or PNPS sample sizes were insufficient. Comparisons can be made for winter flounder between PNPS, Manchester Street, and Brayton Point Stations, keeping in mind that few fish were taken at PNPS. For this species latent percent survival was lowest at PNPS under both continuous and 8-hour wash cycles:

Wash cycle	PNPS Initial	PNPS Latent	Manchester St. Latent	Brayton Point Latent
Continuous	47.1	29.4 (n=17)	48.4 (n=31)	90.2 (n=123)
8-hour	18.5	14.8 (n=27)	39.5 (n=38)	94.4 (n=447)

Since latent survival was determined following 56 hours at PNPS versus 24 hours at the other two stations, both initial and latent values are shown for PNPS. As indicated, even initial values at PNPS were lower than latent values at either Manchester Street or Brayton Point.

Survival data among Atlantic silversides can be compared for PNPS and Brayton Point although, as mentioned above, holding periods were longer at PNPS. For this species survival rates (%) compare as follows:

Wash cycle	PNPS Initial	PNPS Latent	Brayton Point Latent
Continuous	18.8	0 (n=85)	47.3 (n=203)
8-hour	4.7	0 (n=127)	2.3 (n=262)

Some comparison can be made among rainbow smelt impinged at PNPS and Mystic Station. Latent survival under continuous wash modes was higher at Mystic Station (48.3% at 96 hours among small smelt, n = 60, intermediate screen speed) than at PNPS (0% at 56 hours, n = 46) for fish of similar size and similar screen speeds. The higher survival at Mystic Station may be attributable to modifications to the fish and debris trays and troughs which helped protect fish during the wash regime.

Several points which arose from the survival monitoring and introduction studies may be of particular interest in considering future impingement mortality at PNPS.

Species such as the Atlantic silversides, rainbow smelt, and the clupeids appear to be highly susceptible to impingement mortality. The data for natural impingement and, in the case of silversides, the introduction studies suggest that for these species little or no improvement in survival can be expected in switching from 8-hour wash cycles to continuous wash cycles. Among hardier species such as cunner, winter flounder, and grubby, survival rates improved considerably under continuous wash operation (Figure 3; Tables 7 and 10).

The frequently low percent-recovery data among fish introduced to the screens in both continuous wash and 8-hour simulation studies suggests that most species of fish can not only avoid PNPS intake velocities but apparently can leave the intake structure. It therefore appears logical to question why naturally-occurring fish are impinged at all. The comparison of introduction survival rates and natural survival rates (Table 13) showing the latter to be lower suggests that naturally impinged fish may generally be in poorer condition than those used in the introduction work. If naturally impinged fish are on the average in poor physiological condition, that might explain why they enter the intake area and become impinged. It also suggests that the traveling screens selectively remove weak fish.

V. SUMMARY

Initial finfish impingement survival determined at the end of the PNPS sluiceway during routine plant operations using continuous and 8-hour wash cycles was 14.6% (n = 1318) during studies conducted from 1980 through 1983. Considered separately initial survival was 8.9% (n = 957) under 8-hour wash cycles and 29.6% (n = 361) under continuous wash cycles. Following 56-hour holding periods overall survival declined to 7.4%; 4.8% under 8-hour cycles, 14.4% under continuous wash cycles. Among Atlantic silversides (n = 127), rainbow smelt (n = 151), cunner (n = 164), northern puffer (n = 107), Atlantic menhaden (n = 51), blueback herring (n = 38), threespine sticklebacks (n = 49), grubby (n = 32), winter flounder (n = 27), and alewives (n = 30), the ten most abundant species, latent survival amounted to 1.2, 5.6, 2.0, 37.5, and 14.8% for cunner, puffer, sticklebacks, grubby, and flounder, respectively, under 8-hour wash cycles. No latent survival was observed among silversides, smelt, menhaden, blueback herring, or alewives. Under continuous wash cycles latent survival was 23.1% among cunner, 25.0% among puffer, 61.1% among grubby, 29.4% among flounder, and 0% among silversides, smelt, menhaden, blueback herring, threespine sticklebacks, and alewives. These values do not include 4825 Atlantic silversides lost to impingement during a single 27-hour period in September 1981.

Survival rates were generally found to be higher under continuous wash operation than under 8-hour wash cycle operation. Latent survival was significantly greater under continuous wash cycles among cunner, northern puffer, total fish, and "all others" defined as all species excluding the dominants. Among silversides, smelt, menhaden, blueback herring, and alewives, survival was 0% in both categories as mentioned above. Although winter flounder and grubby survival did improve also, sample sizes were too small to demonstrate statistical differences.

Samples of fish collected near PNPS by beach seine and otter trawl in 1980 and 1981 were introduced to the sluiceway and collected at the downstream end to assess mortality induced by passage down the system. Survival based on these studies was 100% in many cases. Exceptions occurred among rainbow smelt (0%, n = 12), Atlantic silversides (50%, n = 282), and mummichogs (86%, n = 49). Based on paired samples survival improved by 4 to 27% when silversides and mummichogs were collected further up the sluiceway where the flow rate was about half that at the downstream end.

In 1982 samples of fish were collected as in 1980-1981, released in front of the screens while the wash system was in operation, and collected at the downstream end of the sluiceway in simulations of continuous wash operation. Latent survival among Atlantic silversides, cunner, and winter flounder in those studies was 4.9, 100, and 68.7%, respectively; silverside data were adjusted for control survival which was 88.5%.

Similar introduction work was conducted in 1983 but the fish were held in front of the screens in the intake water flow for eight hours prior to release to simulate 8-hour wash cycle operation. Latent survival rates in these studies was 0% among silversides, 9.6% among winter flounder, and 40.0% among mummichogs.

Recovery rates among fish introduced in front of the screens in 1982 and 1983 were examined because they suggested that fish in good condition can avoid impingement when released in front of the screens. Under continuous wash simulations recovery rates ranged from 0% among pollock to 61.5% among winter flounder, and under 8-hour simulations they ranged from 0.9% among cunner to 69.6% among mummichogs. Recovery rates were found to be quite variable within species in cases where replicate introductions were made. Comparisons of recovery rates between continuous wash introductions and 8-hour wash introductions indicated that silversides and mummichogs were recovered at a significantly higher rate under 8-hour studies while winter flounder and cunner were recovered at a significantly higher rate under continuous wash studies. These results suggested that flounder and cunner acclimated to the current during the 8-hour holding periods and were better able to escape impingement once released. Silversides and mummichogs on the other hand were probably stressed to a greater extent by the holding period and were therefore more susceptible to impingement upon release.

Comparison of survival rates between the 1982 continuous wash simulations and the 1983 8-hour simulations showed reduced survival following the 8-hour holding periods in both one-hour and latent survival observation periods. Statistically significant declines in latent survival were observed among silversides, winter flounder, cunner, and all species combined, taxa where sample sizes were sufficiently large to permit analyses.

Survival rates were compared between samples of naturally impinged fish and samples of fish introduced to the screenwash system in the continuous and 8-hour wash simulation studies. Latent survival was found to be significantly higher among introduced fishes for cunner, winter flounder, and total fish. These results along with the generally low recovery rates among introduced fish suggests that the traveling screens may selectively remove fish in poor physiological condition.

Table 14 summarizes survival data from all phases of the 1980-1983 studies for the ten numerically dominant species among those impinged during survival assessment studies; data for all other species combined are also shown. Included are survival values for the sluiceway introduction studies, the continuous and 8-hour wash simulation studies, as well as the natural continuous and 8-hour wash cycle results.

VI. LITERATURE CITED

King, L.F., J.B. Hutchinson, Jr., and T.G. Huggins. 1977. Impingement survival studies on white perch, striped bass, and Atlantic tomcod at three Hudson River power plants. p217-233. In L.D. Jensen, Ed. Fourth National Workshop on Entrainment and Impingement. E. A. Communications, Melville, N.Y.

MRI (Marine Research, Inc.). 1980. Manchester Street Station revolving screen survival study, March-June 1980. Submitted to New England Power Co., August 4, 1980. 37p.

———. 1981. Final report - assessment of finfish survival at the Pilgrim Nuclear Power Station screen wash sluiceway, 1980. In Marine Ecology Studies Related to the Operation of Pilgrim Station. Semi-annual Report No. 17. January 1980-December 1980. 13p.

———. 1982a. Assessment of finfish survival at Pilgrim Nuclear Power Station screenwash sluiceway - 1981. In Marine Ecology Studies Related to the Operation of Pilgrim Station. Semi-annual Report No. 19. January 1981-December 1981. 19p.

———. 1982b. Brayton Point Station impingement survival study 1981, 1982. Submitted to New England Power Co. July 29, 1982. 15p + appendix.

———. 1983. Assessment of finfish survival at Pilgrim Nuclear Power Station, 1982. In Marine Ecology Studies Related to the Operation of Pilgrim Station. Semi-annual Report No. 21. January 1982-December 1982. 38p.

Stone and Webster Engineering Corp. 1981. Final report - biological evaluation of a modified traveling screen, Mystic Station - Unit No. 7. 15p.

Tatham, T.R., D.L. Thomas, and G.J. Miller. 1977. Survival of fishes and macroinvertebrates impinged at Oyster Creek Generating Station. p235-243. In L.D. Jensen, Ed. Fourth National Workshop on Entrainment and Impingement. E. A. Communications, Melville, N.Y.

Tattersfield, F. and H.M. Morris. 1923. An apparatus for testing the toxic values of contact insecticides under controlled conditions. Bull. Entom. Research 14:223-233.

Zar, J.H. 1974. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J. 620p.

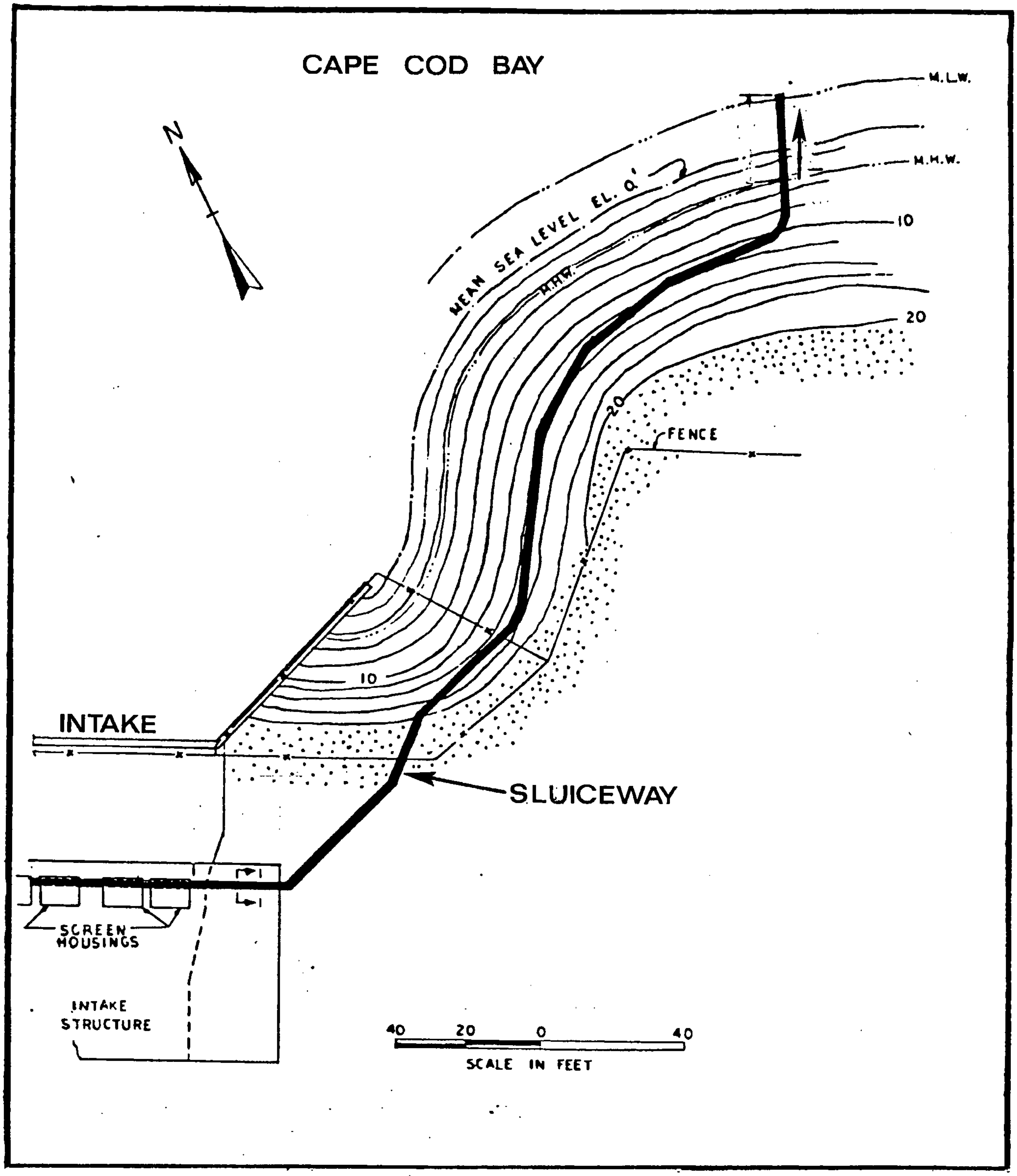

Figure 1: The PNPS sluiceway designed to return impinged fish to ambient temperature water in Cape Cod Bay.

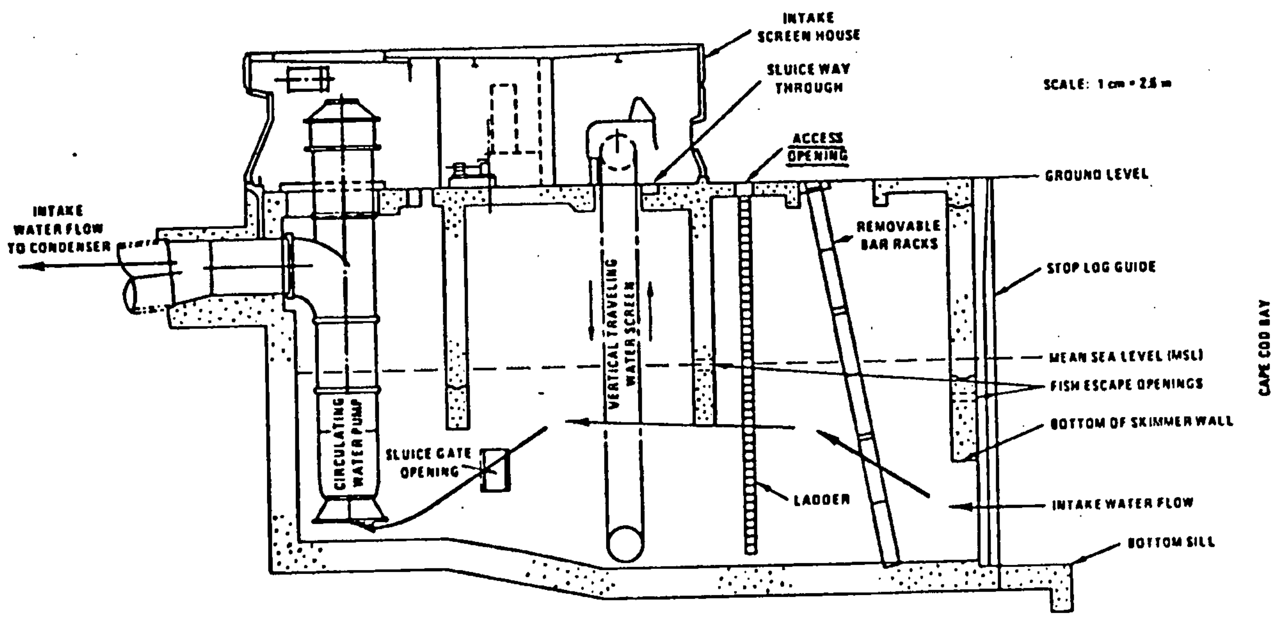

Figure 2. Diagram of the PNPS seawater intake system (illustration provided by Boston Edison Company).

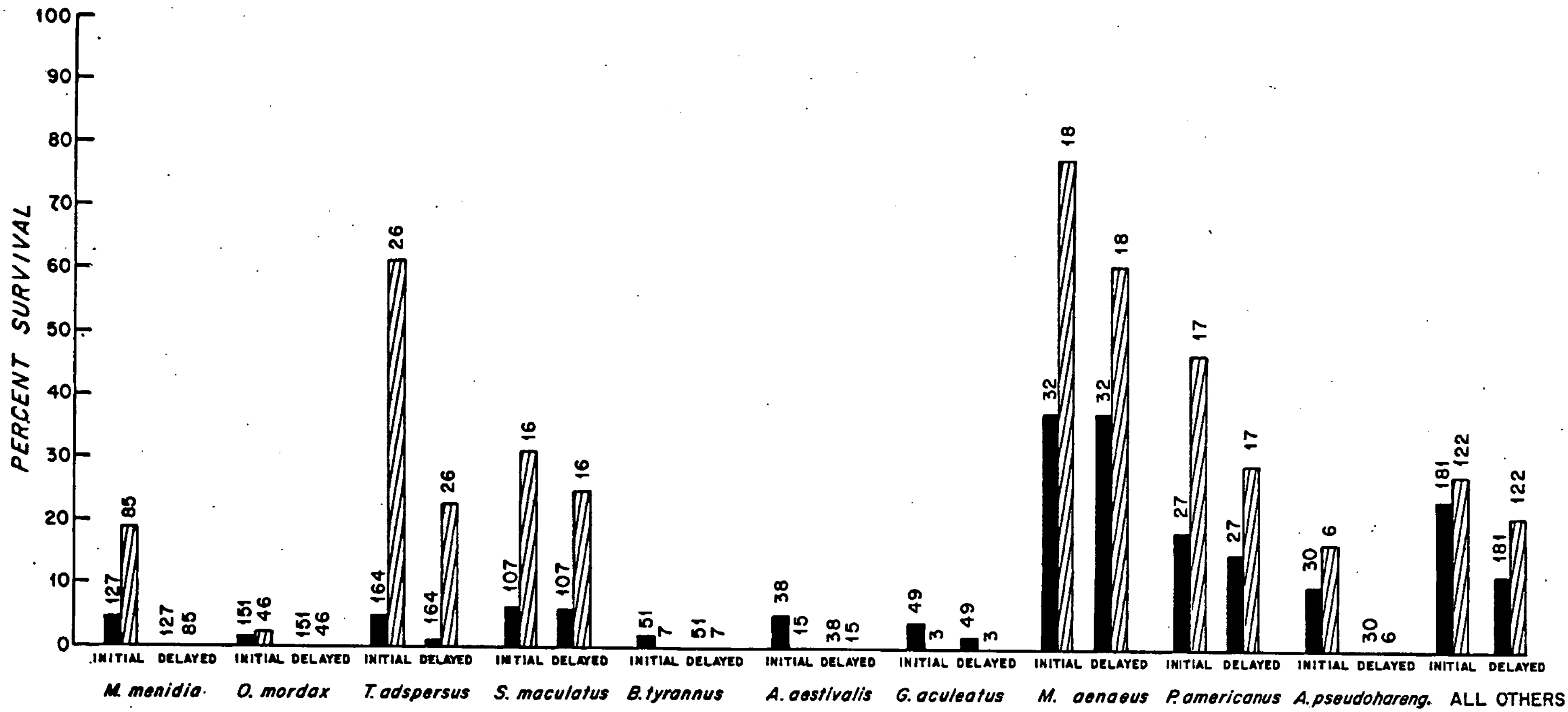

Figure 3. Percent survival for the ten most abundant species of finfish plus all other fish combined collected on the PNPS traveling screens 1980-1983. Solid bars represent 8-hour wash cycles; striped bars, continuous wash cycles. Sample size is indicated above each bar.

Table 1. Total length, mean and range (mm), total number of fish collected, number and percentage alive, and number and percentage surviving a 56-hour holding period by species in the PNPS sluiceway, 1983.

Species	Total length (mm)		Number collected		Number (%) collected alive		Number (%) surviving 56 hours	
	Mean	Range	Static Washes	Contin. Washes	Static Washes	Contin. Washes	Static Washes	Contin. Washes
Spiny dogfish (Squalus acanthias)	1014	978-1050	2	0	0	-	-	-
Little skate (Raja erinacea)	485	460-510	0	2	0	2(100)	-	1(50.0)
Blueback herring (Alosa aestivalis)	117	80-159	14	8	0	0	-	-
Alewife (A. pseudoharengus)	93	70-115	5	0	1(20.0)	0	0	-
Atlantic menhaden (Brevoortia tyrannus)	84	38-271	23	7	0	0	-	-
Atlantic herring (Clupea h. harengus)	32	26-37	0	2	0	0	-	-
Rainbow smelt (Osmerus mordax)	115	74-185	39	6	0	0	-	-
Silver hake (Merluccius bilinearis)	250	-	1	0	0	-	-	-
Atlantic tomcod (Microgadus tomcod)	162	125-220	4	5	3(75.0)	3(60.0)	2(50.0)	3(60.0)
Pollock (Pollachius virens)	182	163-225	0	4	0	3(75.0)	-	0
Atlantic silverside (Menidia menidia)	106	84-135	11	40	0	1(2.5)	-	0
Threespine stickleback (Gasterosteus aculeatus)	63	-	1	0	0	0	-	-
Northern pipefish (Syngnathus fuscus)	125	78-200	2	5	1(50.0)	2(40.0)	1(50.0)	2(40.0)
Scup (Stenotomus chrysops)	60	-	0	1	0	0	-	-
Tautog (Tautoga onitis)	78	76-78	1	1	0	1(100)	-	1(100)
Cunner (Tautogolabrus adspersus)	100	54-175	6	6	0	2(33.3)	-	2(33.3)
Rock gunnel (Pholis gunnellus)	82	65-110	2	1	0	1(100)	-	1(100)
Sand lance (Ammodytes sp.)	125	64-165	1	5	0	1(20.0)	-	0
Butterfish (Peprilus triacanthus)	16	-	0	1	0	0	-	-
Northern searobin (Prionotus carolinus)	263	225-284	0	3	0	0	-	-

Table 1 (continued).

Species	Total length (mm)		Number collected		Number (%) collected alive		Number (%) surviving 56 hours	
	Mean	Range	Static Washes	Contin. Washes	Static Washes	Contin. Washes	Static Washes	Contin. Washes
Grubby (Myoxocephalus aenaeus)	72	34-102	17	9	5(29.4)	7(77.8)	5(29.4)	5(55.6)
Longhorn sculpin (M. octodecemspinosus)	310	-	1	0	1(100)	0	1(100)	-
Lumpfish (Cyclopterus lumpus)	59	42-67	2	1	2(100)	1(100)	2)100)	1(100)
Fourspot flounder (Paralichthys oblongus)	296	-	0	1	0	1(100)	-	1(100)
Windowpane (Scophthalmus aquosus)	78	52-126	3	3	3(100)	2(66.7)	3(100)	2(66.7)
Winter flounder (Pseudopleuronectes americanus)	76	51-91	5	1	2(40.0)	1(100)	2(40.0)	1(100)
Northern puffer (Sphoeroides maculatus)	105	64-199	2	6	0	3(50.0)	-	3(50.0)
Total			142	118	18(12.7)	31(26.3)	16(11.3)	23(19.5)

Table 2. Total number of fish collected, number and percentage alive, and number and percentage surviving a 56-hour holding period by species in the PNPS sluiceway under static (8-hour) and continuous wash cycles, 1980-1983.

Species	Number collected		Number (%) collected alive		Number (%) surviving 56 hours		Total length (mm)	
	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	Mean	Range
Atlantic silverside (Menidia menidia)	127	85	6(4.7)	16(18.8)	0	0	100	50-140
	4825	0	0	-	-	-	89	75-136
Rainbow smelt (Osmerus mordax)	151	46	2(1.3)	1(2.2)	0	0	103	64-220
Cunner (Tautogolabrus adspersus)	164	26	8(4.9)	16(61.5)	2(1.2)	6(23.1)	106	47-209
Northern puffer (Sphoeroides maculatus)	107	16	7(6.5)	5(31.3)	6(5.6)	4(25.0)	79	37-199
Atlantic menhaden (Brevoortia tyrannus)	51	7	1(2.0)	0	0	-	89	38-271
Blueback herring (Alosa aestivalis)	38	15	2(5.3)	0	0	-	121	66-180
Threespine stickleback (Gasterosteus aculeatus)	49	3	2(4.1)	0	1(2.0)	-	59	50-73
Grubby (Myoxocephalus aenaeus)	32	18	12(37.5)	14(77.8)	12(37.5)	11(61.1)	81	34-155
Winter flounder (Pseudopleuronectes americanus)	27	17	5(18.5)	8(47.1)	4(14.8)	5(29.4)	178	50-384
Alewife (Alosa pseudoharengus)	30	6	3(10.0)	1(16.7)	0	0	131	64-306
Bay anchovy (Anchoa mitchilli)	20	15	0	1(6.7)	-	0	62	36-90
Pollock (Pollachius virens)	17	16	0	5(31.3)	0	0	186	102-350
Atlantic tomcod (Microgadus tomcod)	13	17	5(38.5)	9(52.9)	4(30.8)	9(52.9)	152	98-260
Windowpane (Scophthalmus aquosus)	8	14	5(62.5)	7(50.0)	5(62.5)	7(50.0)	100	35-310
Northern pipefish (Syngnathus fuscus)	9	9	1(11.1)	5(55.6)	1(11.1)	4(44.4)	148	58-245
Northern searobin (Prionotus carolinus)	13	4	2(15.4)	0	1(7.7)	-	239	58-315
Atlantic herring (Clupea harengus harengus)	9	7	2(22.2)	2(28.6)	0	0	153	26-284
White hake (Urophycis tenuis)	15	1	0	1(100)	-	0	132	58-229
Scup (Stenotomus chrysops)	11	5	1(9.1)	2(40.0)	0	0	62	43-138

Table 2 (continued).

Species	Number collected		Number (%) collected alive		Number (%) surviving 56 hours		Total length (mm)	
	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	Mean	Range
Sand lance (*Ammodytes* sp.)	9	6	7(77.8)	2(33.3)	1(11.1)	0	138	64-210
Lumpfish (*Cyclopterus lumpus*)	6	7	3(50.0)	5(71.4)	2(33.3)	1(14.3)	41	27-67
Fourspot flounder (*Paralichthys oblongus*)	10	1	5(50.0)	1(100)	3(30.0)	1(100)	294	190-382
Silver hake (*Merluccius bilinearis*)	8	1	0	0	-	-	214	81-326
Pearlside (*Maurolicus muelleri*)	0	7	-	0	-	-	50	46-56
Spiny dogfish (*Squalus acanthias*)	4	0	0	-	-	-	801	234-1050
American eel (*Anguilla rostrata*)	2	2	0	2(100)	-	1(50)	365	101-510
Tautog (*Tautoga onitis*)	3	1	0	1(100)	-	1(100)	152	76-320
Radiated shanny (*Ulvaria subbifurcata*)	3	1	2(6. . .)	0	1(33.3)	-	120	115-125
Rock gunnel (*Pholis gunnellus*)	3	1	1(33.3)	1(100)	1(33.3)	1)100)	109	65-190
Little skate (*Raja erinacea*)	0	2	0	2(100)	-	1(50.0)	485	460-510
Winter skate (*Raja ocellata*)	2	0	1(50.0)	-	1(50.0)	-	293	95-490
Atlantic cod (*Gadus morhua*)	1	1	0	0	-	-	148	80-215
Red hake (*Urophycis chuss*)	1	1	0	0	-	-	243	90-395
Hake (*Urophycis* sp.)	2	0	0	-	-	-	96	-
Mummichog (*Fundulus heteroclitus*)	2	0	1(50.0)	-	0	-	88	80-95
Northern kingfish (*Menticirrhus saxatilis*)	2	0	0	-	-	-	169	156-182
Butterfish (*Peprilus triacanthus*)	1	1	0	0	-	-	46	16-76
Longhorn sculpin (*Myoxocephalus octodecemspinosus*)	2	0	1(50.0)	-	1(50.0)	-	295	280-310
Fourspine stickleback (*Apeltes quadracus*)	0	1	-	0	-	-	59	-

Table 2 (continued).

Species	Number collected		Number (%) collected alive		Number (%) surviving 56 hours		Total length (mm)	
	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	8-hour cycles	Contin. cycles	Mean	Range
Bluefish (*Pomatomus saltatrix*)	1	0	0	-	-	-	90	-
Atlantic mackerel (*Scomber scombrus*)	1	0	0	-	-	-	82	-
Silver-rag (*Arioma bondi*)	1	0	0	-	-	-	135	-
Shorthorn sculpin (*Myoxocephalus scorpius*)	0	1	-	0	-	-	290	-
Summer flounder (*Paralichthys dentatus*)	1	0	0	-	-	-	295	-
Orange filefish (*Aluterus schoepfi*)	1	0	0	-	-	-	191	-
Total*	957	361	85(8.9)	107(29.6)	46(4.8)	52(14.4)		

*Total does not include the silverside data from the high mortality period of September 23-24, 1981 (see text).

Table 3. Comparison of impinged finfish survival rates at PNPS before (1980-81) and after (1982-83) installation of low-pressure spray wash nozzles.

Species	Initial Survival (%) 1982-1983	Initial Survival (%) 1980-1981	Latent Survival (%) 1982-1983	Latent Survival (%) 1980-1981
8-hour Static Cycles				
A. aestivalis	5.0 n = 20	5.6 n = 18	0 n = 20	0 n = 18
A. pseudoharengus	7.1 n = 14	12.5 n = 16	0 n = 14	0 n = 16
B. tyrannus	0 n = 32	5.3 n = 19	0 n = 32	0 n = 19
O. mordax	0 n = 66	2.4 n = 85	0 n = 66	0 n = 85
M. menidia	1.7 n = 59	7.4 n = 68	0 n = 59	0 n = 68
G. aculeatus	2.4 n = 42	14.3 n = 7	0 n = 42	14.3 n = 7
T. adspersus	14.3 n = 28	2.9 n = 136	10.7 n = 28	1.5 n = 136
M. aenaeus	35.0 n = 20	41.7 n = 12	35.0 n = 20	41.7 n = 12
P. americanus	23.1 n = 13	14.3 n = 14	23.1 n = 13	7.1 n = 14
S. maculatus	20.0 n = 15	4.3 n = 92	13.3 n = 15	4.3 n = 92
All Others	14.1 n = 92	20.8 n = 168	10.9 n = 92	10.1 n = 168
All Fish	8.5 n = 401	9.2 n = 556	6.2 n = 401	4.3 n = 556
Continuous Cycles				
O. mordax	0 n = 33	7.7 n = 13	0 n = 33	0 n = 13
M. menidia	17.1 n = 76	33.3 n = 9	0 n = 76	0 n = 9
T. adspersus	60.9 n = 23	66.7 n = 3	17.4 n = 23	66.7 n = 3
M. aenaeus	69.2 n = 13	100 n = 5	46.2 n = 13	100 n = 5
All Others	28.7 n = 164	45.5 n = 22	18.3 n = 164	22.7 n = 22
All Fish	26.9 n = 309	40.4 n = 52	12.9 n = 309	23.1 n = 52

Table 4. Sample size, percent survival, and total length data (mm) for fish introduced at the head of the PNPS sluiceway, collected at the downstream end, and held for 50 to 90 hours, 1980 and 1981.

Species	Number Introduced	Number (%) Surviving	Total Length (mm) Mean	Total Length (mm) Range	Number of Trials
Little skate (*Raja erinacea*)	1	1(100)	230	-	1
Atlantic menhaden (*Brevoortia tyrannus*)	1	0	55	-	1
Rainbow smelt (*Osmerus mordax*)	12	0	99	86 - 116	2
Mummichog (*Fundulus heteroclitus*)	49	42(86)	86	52 - 131	2
Atlantic silverside (*Menidia menidia*)	282	141(50)	99	50 - 139	5
Threespine stickleback (*Gasterosteus aculeatus*)	4	3(75)	59	56 - 73	1
White perch (*Morone americana*)	5	5(100)	226	126 - 302	1
Cunner (*Tautogolabrus adspersus*)	74	73 (99)	142	76 - 206	2
Sea raven (*Hemitripterus americanus*)	2	2(100)	300	266 - 303	1
Longhorn sculpin (*Myoxocephalus octodecemspinosus*)	19	19(100)	297	260 - 326	2
Windowpane (*Scophthalmus aquosus*)	6	6(100)	242	189 - 270	1
Yellowtail flounder (*Limanda ferruginea*)	25	25(100)	255	190 - 340	2
Winter flounder (*Pseudopleuronectes americanus*)	70	70(100)	104	64 - 396	4

Table 5. Results of sluiceway introduction trials conducted in 1981 in which fish were collected in relatively low and high velocity areas of the sluiceway and held for approximately 56 hours (see text for clarification).

Species	Short Sluice n	Short Sluice Number (%) Surviving	Short Sluice Mean TL	Long Sluice n	Long Sluice Number (%) Surviving	Long Sluice Mean TL	Difference (±%) Short vs. Long Sluice	Date (1981)
Alewife (*Alosa pseudoharengus*)	20	0	57	-	-	-	-	August 14
Mummichog (*Fundulus heteroclitus*)	24	24(100)	70	11	8(73)	70	+27	June 10
Atlantic silverside (*Menidia menidia*)	33	33(100)	98	20	17(85)	101	+15	May 22
	31	30(97)	93	91	83(91)	90	+6	June 10
	37	13(35)	110	48	15(31)	107	+4	August 14
Cunner (*Tautogolabrus adspersus*)	37	37(100)	152	32	32(100)	153	0	September 16

Table 6. Number, percent survival after 55 to 100-hour holding periods, and total length data (mm) for control fish used in survival studies at the PNPS sluiceway, 1980-1981.

Species	Number Held	Number (%) Surviving	Total Length (mm) Mean	Total Length (mm) Range	Number of Trials
Little skate (Raja erinacea)	8	8(100)	283	230 - 329	1
Blueback herring (Alosa aestivalis)	4	3(75)	83	56 - 145	2
Alewife (A. pseudoharengus)	19	15(79)	58	49 - 71	2
Atlantic menhaden (Brevoortia tyrannus)	23	12(52)	65	46 - 71	3
Rainbow smelt (Osmerus mordax)	1	1(100)	158	-	1
Pollock (Pollachius virens)	10	10(100)	43	38 - 47	2
Mummichog (Fundulus heteroclitus)	313	312(99)	82	46 - 132	7
Striped killifish (F. majalis)	9	9(100)	76	70 - 94	2
Atlantic silverside (Menidia menidia)	684	650(95)	96	56 - 150	11
Threespine stickleback (Gasterosteus aculeatus)	2	1(50)	57	53 - 60	2
White perch (Morone americana)	1	0(0)	67	-	1
Bluefish (Pomatomus saltatrix)	2	2(100)	93	86 - 99	1
Cunner (Tautogolabrus adspersus)	125	125(100)	131	91 - 171	3
Longhorn sculpin (Myoxocephalus octodecemspinosus)	23	23(100)	300	272 - 330	3
Windowpane (Scophthalmus aquosus)	9	9(100)	275	240 - 301	2
Yellowtail flounder (Limanda ferruginea)	25	24(96)	280	154 - 349	3
Winter flounder (Pseudopleuronectes americanus)	118	117(99)	189	36 - 435	6

Table 7. Species of fish released in front of the PNPS traveling screens without a holding period during continuous wash simulations, number recovered, survival rates, including control samples, and total length data, 1982.

						Total Lengths (mm)			
						Recovered		Controls	
Species	Number Introduced	Number (%) Recovered	Number (%) Alive 1 hr	Number (%) Alive 44+ hrs	% Control Survival (n)	Mean	Range	Mean	Range
Atlantic silverside (*Menidia menidia*)	1360	564(41.5)	112(19.9)	24(4.3)	88.0(n=408)	103	68 - 133	96	70 - 142
Cunner (*Tautogolabrus adspersus*)	387	59(15.2)	59(100)	59(100)	100 (n=14)	123	71 - 157	126	100 - 155
Winter flounder (*Pseudopleuronectes americanus*)	317	195(61.5)	194(99.5)	134(68.7)	100 (n=60)	121	52 - 356	110	54 - 360
Mummichog (*Fundulus heteroclitus*)	118	2(1.7)	2(100)	2(100)	100 (n=73)	*	*	97	83 - 107
Sand lance (*Ammodytes* sp.)	55	1(1.8)	0	-	100 (n=35)	106	-	110	100 - 123
Rainbow smelt** (*Osmerus mordax*)	38	1(2.6)	1(100)	1(100)	100 (n=25)	135	-	171	123 - 231
Pollock (*Pollachius virens*)	25	0	-	-	-	-	-	-	-
Windowpane (*Scophthalmus aquosus*)	17	12(70.6)	12(100)	10(83.3)	-	137	82 - 285	-	-
Little skate (*Raja erinacea*)	14	10(71.4)	10(100)	+	-	+	+	-	-
Threespine stickleback (*Gasterosteus aculeatus*)	11	11(100)	4(36.4)	3(27.3)	-	54	40 - 61	-	-
Northern pipefish (*Syngnathus fuscus*)	8	3(37.5)	3(100)	3(100)	-	160	155 - 165	-	-
Grubby (*Myoxocephalus aenaeus*)	8	6(75.0)	6(100)	4(66.7)	100 (n=1)	102	63 - 130	128	-
Bluefish (*Pomatomus saltatrix*)	6	2(33.3)	0	-	-	69	62 - 76	-	-
Atlantic tomcod (*Microgadus tomcod*)	5	3(60.0)	3(100)	1(33.3)	-	172	-	-	-
Red hake (*Urophycis chuss*)	3	2(66.7)	2(100)	2(100)	-	81	71 - 90	-	-
Sea raven (*Hemitripterus americanus*)	1	0	-	-	-	-	-	-	-
Longhorn sculpin (*Myoxocephalus octodecemspinosus*)	1	0	-	-	-	-	-	-	-
Total	2374	871(36.7)	408(46.8)	243(27.9)	92.0(n=616)				

*Fish decomposed due to insufficient formalin.

**Thirty-six rainbow smelt actually introduced in 1983.

+All skates were missing, apparently removed by someone since screen covers were in place.

Table 8. Numbers of winter flounder and cunner released in front of the PNPS traveling screens, number recovered, and survival rates, by date 1982.

Date (1982)	Number Introduced	Number (%) Recovered	Number (%) Alive 1 hr	Number (%) Alive 44+ hrs	Control Survival 44+ hrs
Winter flounder					
April 16	28	23 (82.1)	23 (100)	23 (100)	-
April 30	67	38 (56.7)	38 (100)	32 (84.2)	-
May 14	69	38 (55.1)	36 (94.7)	31 (81.6)	100% (n = 21)
Aug 13	25	18 (72.0)	18 (100)	13 (72.2)	-
Aug 18	1	1 (100)	1 (100)	1 (100)	-
Sept 24	68	45 (66.2)	45 (100)	1 (2.2)	100% (n = 20)
Oct 27	2	0	-	-	-
Nov 8	57	33 (57.9)	33 (100)	33 (100)	100% (n = 19)
Cunner					
June 21	236	50 (21.2)	50 (100)	50 (100)	100% (n = 14)
Sept 10	82	4 (4.9)	4 (100)	4 (100)	-
Oct 27	69	5 (7.2)	5 (100)	5 (100)	-

Table 9. Numbers of Atlantic silversides released in front of the PNPS traveling screens, number recovered, and survival rates, by date 1982.

Date (1982)	Number Introduced	Number (%) Recovered	Number (%) Alive 1 hr	Number (%) Alive 44+ hrs	Control Survival 44+ hrs	Adjusted % Latent Survival
April 30	67	18 (26.9)	10 (55.6)	2 (11.1)	100% (n = 30)	11.1
May 5	264	203 (76.9)	12 (5.9)	0	95.1 (n = 41)	0
May 14	37	23 (62.2)	14 (60.9)	8 (34.8)	-	34.8
June 2	*	-	-	-	99.3 (n = 149)	-
Aug 18	71	2 (2.8)	0	0	76.0 (n = 25)	0
Sept 17	287	217 (75.6)	42 (19.4)	14 (6.5)	80.0 (n = 30)	8.1
Sept 24	463	49 (10.6)	2 (4.1)	0	65.6 (n = 93)	0
Oct 27	171	52 (30.4)	32 (61.5)	0	100 (n = 40)	0

*Screens inoperative, therefore all fish held as controls.

Table 10. Species of fish held in front of the PNPS traveling screens for eight hours and subsequently released, number recovered, survival rates, including control samples, and total length data, 1983.

Species	Number Introduced	Number (%) Recovered	Number (%) Alive 1 hr	Number (%) Alive 49+ hrs	% Control Survival (n)	Total Lengths (mm) Recovered Mean	Total Lengths (mm) Recovered Range	Total Lengths (mm) Controls Mean	Total Lengths (mm) Controls Range
Cunner (*Tautogolabrus adspersus*)	570	5(0.9)	3(60.0)	2(40.0)	100 (n=44)	133	85 - 185	125	78 - 210
Atlantic silverside (*Menidia menidia*)	295	153(51.9)	21(13.7)	0	74.2(n=31)	90	70 - 134	89	67 - 124
Winter flounder (*Pseudopleuronectes americanus*)	171	52(30.4)	25(48.1)	5(9.6)	96.7(n=30)	156	83 - 280	173	74 - 345
Mummichog (*Fundulus heteroclitus*)	158	110(69.6)	104(94.5)	44(40.0)	100 (n=37)	72	61 - 95	76	65 - 98
Striped killifish (*Fundulus majalis*)	54	7(13.0)	5(71.4)	4(57.1)	100 (n=15)	79	62 - 110	76	66 - 106
Grubby (*Myoxocephalus aenaeus*)	12	1(8.3)	1(100)	1(100)	-	60	-	-	-
Threespine stickleback (*Gasterosteus aculeatus*)	9	9(100)	9(100)	0	100 (n=3)	61	55 - 65	55	40 - 62
Windowpane (*Scophthalmus aquosus*)	4	4(100)	4(100)	2(50.0)	-	134	125 - 144	-	-
Sand lance (*Ammodytes* sp.)	3	2(66.7)	2(100)	0	-	140	-	-	-
Atlantic tomcod (*Microgadus tomcod*)	1	0	-	-	-	-	-	-	-
Northern puffer (*Sphoeroides maculatus*)	1	1(100)	0	-	-	50	-	-	-
Total	1278	344(26.9)	174(50.6)	58(16.9)	94.4(n=160)				

Table 11. Numbers of Atlantic silversides and winter flounder released in front of the PNPS traveling screens following 8-hour holding periods, number recovered, and survival rates by date, 1983.

Species	Date	Number Introduced	Number (%) Recovered	Number (%) Alive 1 hr	Number (%) Alive 44+ hrs	Control Survival 49+ hours
Atlantic silversides	May 4	11	11(100)	0	-	-
	May 11	214	118(55.1)	21(17.8)	0	90.0% (n=20)
	Sept 30	70	24(34.3)	0	-	45.5% (n=11)
Winter flounder	June 3	73	8(11.0)	8(100)	5(62.5)	95.5% (n=22)
	June 27	68	44(64.7)	17(38.6)	0	-
	Sept 30	30	0	-	-	100% (n=8)

Table 12. Mean elapsed time between release of fish and first appearance at the end of the sluiceway and last release and last appearance at the end of the sluiceway, 1982-1983 (see text for details).

Species	Mean Elapsed Time (min)	
	First release to collection	Last release to collection
Continuous Wash Simulations		
Winter skate	8*	41*
Atlantic silverside	6	66
Bluefish	25*	-
Cunner	10	10
Windowpane	29	11
Winter flounder	6	46
8-hour Wash Simulations		
Rainbow smelt	24*	24*
Mummichog	9*	43*
Atlantic silverside	8	75
Cunner	7*	-
Windowpane	-	27*
Winter flounder	6*	-

*One observation only.

Table 13. Comparison of survival rates between introduced and naturally impinged fish. One-hour and latent survival rates are shown for 8-hour and continuous wash cycles. Z values for difference between proportion tests are also shown.

	Percent Survival Introduced	Percent Survival Naturally impinged	Z
	8-HOUR CYCLES		
One-hour Survival			
M. menidia	13.7 (n = 153)	3.9 (n = 127)	2.603 ($p < 0.01$)
T. adspersus	60.0 (n = 5)	3.0 (n = 164)	4.838 ($p < 0.001$)
P. americanus	48.1 (n = 52)	18.5 (n = 27)	2.323 ($p < 0.05$)
Total*	50.6 (n = 344)	7.8 (n = 957)	17.204 ($p < 0.001$)
Latent Survival**			
M. menidia	0	0	-
T. adspersus	40.0 (n = 5)	1.2 (n = 164)	4.126 ($p < 0.001$)
P. americanus	9.6 (n = 52)	14.8 (n = 27)	0.317 ($p > 0.05$)
Total*	16.9 (n = 344)	4.8 (n = 957)	6.954 ($p < 0.001$)
	CONTINUOUS CYCLES		
One-hour Survival			
M. menidia	19.9 (n = 564)	17.6 (n = 85)	0.332 ($p > 0.05$)
T. adspersus	100 (n = 59)	30.8 (n = 26)	6.911 ($p < 0.001$)
P. americanus	99.5 (n = 195)	47.1 (n = 17)	9.183 ($p < 0.001$)
S. aquosus	100 (n = 12)	50.0 (n = 14)	2.422 ($p < 0.05$)
Total*	46.8 (n = 871)	24.1 (n = 361)	7.347 ($p < 0.001$)
Latent Survival**			
M. menidia	4.3 (n = 564)	0 (n = 85)	1.630 ($p > 0.05$)
T. adspersus	100 (n = 59)	23.1 (n = 26)	7.426 ($p < 0.001$)
P. americanus	68.7 (n = 195)	29.4 (n = 17)	3.005 ($p < 0.01$)
S. aquosus	83.3 (n = 12)	50.0 (n = 14)	1.368 ($p > 0.05$)
Total*	27.9 (n = 871)	14.4 (n = 361)	4.978 ($p < 0.001$)

*Total = All species combined.

**Latent Survival = Following 44+-hour holding periods.

Table 14. Survival summary for the ten numerically dominant species obtained during the PNPS sluiceway survival studies, 1980-1983. One-hour and latent percent survival is shown for sluiceway introductions, continuous wash and 8-hour simulation introductions and those naturally impinged on the screens.

	Sluiceway Introductions		Continuous Wash Cycles				8-hour Wash Cycles			
			Simulations		Natural		Simulations		Natural	
Species	One-hour	Latent	One-hour	Latent	One-hour	Latent	One-hour	Latent	One-hour	Latent
Atlantic silverside	96.5	50.0	19.9	4.9*	17.6	0	13.7	0	3.9	0
Rainbow smelt	66.7	0	-	-	2.2	0	-	-	0.7	0
Cunner	100	98.6	100	100	30.8	23.1	60.0	40.0	3.0	1.2
Northern puffer	-	-	-	-	31.3	25.0	-	-	5.6	5.6
Atlantic menhaden	-	-	-	-	0	0	-	-	2.0	0
Blueback herring	-	-	-	-	0	0	-	-	2.6	0
Threespine stickleback	75.0	75.0	36.4	27.3	0	0	100	0	4.1	2.0
Grubby	-	-	100	66.7	72.2	61.1	-	-	37.5	37.5
Winter flounder	100	100	99.5	68.7	47.1	29.4	48.1	9.6	18.5	14.8
Alewife	-	-	-	-	16.7	0	-	-	10.0	0
All others	100	93.5	91.4	54.3	32.8	21.3	92.7	40.3	20.4	11.6

*Adjustment made for control survival.

Lecture Notes on Coastal and Estuarine Studies

Managing Editors:
Richard T. Barber Christopher N. K. Mooers
Malcolm J. Bowman Bernt Zeitzschel

11

Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts

Edited by John D. Davis and Daniel Merriman

Springer-Verlag
Berlin Heidelberg New York Tokyo 1984

A BRIEF SURVEY OF PILGRIM NUCLEAR POWER PLANT EFFECTS UPON THE MARINE AQUATIC ENVIRONMENT

W. Leigh Bridges

and

Robert D. Anderson

ABSTRACT

A broad range of enviromental studies, begun in 1969, were designed to detect environmental disturbances attributable to release of heated cooling water into Cape Cod Bay from the Pilgrim Nuclear Power Station. Investigations extending over more than a decade revealed no major damaging effects to the marine environment.

On a scale encompassing the more immediate vicinity of the power station certain site specific or occasionally occurring effects were documented. Most notable were several significant mortalities due to "gas bubble disease", periodic incidences of finfish impingement on the cooling water intake traveling screens, near-field alterations of the benthic and epibenthic communities in the vicinity of the cooling water discharge, and entrainment of phytoplankton, zooplankton, and ichthyoplankton in the cooling water flow.

INTRODUCTION

In 1967, when Boston Edison Company announced plans to build Pilgrim Nuclear Power Station on Cape Cod Bay, both the public and regulatory agencies raised concerns about possible major environmental damage. Early attention focused on the release of large quantities of warmed water into Cape Cod Bay while later investigations centered on the broad scale possible effects arising from passage of plankton through the cooling water system, but transformation of general concerns into specific studies produced investigations designed to reveal the presence of environmental impacts over a broad range of Cape Cod Bay habitats. Nevertheless, there was concentration on commercially important finfish, the lobster, and Irish moss resources.

In most cases, studies compared control areas with sampling sites potentially within the influence of the power station (that is, habitats likely to receive warmed cooling waters from the discharge flow) or studied ecological community components having either immature stages or adults drawn into the cooling water system and either impinged on traveling screens or forced through the heat exchanger condenser cooling system. Aside from observed results near the power station and readily attributable to its operation, the examination of long term relative abundance indices for fish and lobster provided the best means of discerning impacts. Nevertheless, because the amplitude of natural population variation was unknown for many species, it was impossible to wholly separate natural variation from possible plant effects in most cases. On balance, however, the term of most studies was long enough to show general natural variation separate from disruptive perturbations attributable to plant operation.

Pilgrim Station, unlike other East Coast power stations, is located on an open coast. Although Cape Cod Bay is enclosed on three sides, its connection with Massachusetts Bay and the Gulf of Maine to the north is sufficiently broad to allow maximum exchange with ocean waters and justify the open coast characterization.

In general, there have been no major disruptions of western Cape Cod Bay ecology as a result of construction and operation of Pilgrim Nuclear Power Station. However, on a smaller scale adjacent to the plant there have been documented local biotic changes and environmental disruptions. Most of these have been either site specific or occasional in occurrence.

DETECTABLE IMPACTS

Gas Saturation Mortalities

Water supersaturated with dissolved gases can adversely affect finfish and other aquatic organisms as a result of "gas bubble disease (GBD), a pathological condition analogous to caisson disease in man. While fish appear to tolerate moderate GBD levels, extreme situations with very high supersaturation often result in substantial mortalities.

Supersaturated conditions have resulted from solar and geothermal heating (Harvey 1967; Boyer 1974; Bouck 1975), high photosynthetic activity (Woodbury 1941; Ruckavina and Varenika 1956; Renfro 1963), waterfalls (Harvey and Cooper 1962), and high stream velocities (Lindroth 1957; Boyer 1974). GBD-causing gas supersaturation has also been observed below spillways of dams and hydro-electric facilities (Harvey and Cooper 1962; Ebel 1969; Beiningen and Ebel 1970; Merrill et al. 1971); and in fish hatcheries and other facilities where there is infusion of air at water pump intakes, leaking pipelines, etc. (Marsh and Gorham 1905; Harvey and Smith 1961; Dennison and Marchyshyn 1973; Wold 1973; Penrose and Squires 1976); and more recently in thermal cooling water discharges from power stations on lakes (DeMont and Miller 1971; Miller and DeMont 1974), estuaries (Marcello and Strawn 1972), and coastal waters (Marcello and Fairbanks 1976; and Fairbanks and Lawton 1977).

Three events involving gas bubble disease have occurred at Pilgrim Station. In April 1973, 43,000 adult menhaden (*Brevoortia tyrannus*) died of gas bubble disease in the discharge canal and thermal plume. Two years later, in April 1975, approximately 5,000 adult Atlantic menhaden died from a similar cause in the same locations. An incident involving approximately 500 striped mullet (*Mugil cephalus*) with symptoms of gas bubble disease was also recorded from the discharge canal in late fall and early winter of 1975, but there were no detectable mortalities. No substantial mortalities attributable to supersaturated water have occurred at Pilgrim Station since 1975.

Fish Impingement on Intake Screens

Impingement of fishes on intake water screens at electric generating stations has been described from various northeast Atlantic coastal regions (Fairbanks et al. 1971; Clark and Brownell 1973; Anderson et al. 1975; Grimes 1975; Thomas and Miller 1977). Stupka and Sharma (1977) surveyed fish impingement at coastal and estuarine sites throughout the United States. Many impingement studies appear in the literature of electric utility industry environmental reports. These, as well as those in the open literature, are annotated in bibliographies prepared by the ESIC and IEIS (1979) and AIF and ORNL (1981).

Impingement can occur whenever cooling water pumps draw water through the traveling screens. Fishes, other marine life, and debris collected on the screens are routinely washed from the screens and returned to the adjacent ocean waters via a sluiceway. Sampling of impinged animals has provided considerable information regarding species collected, their abundance, and seasonal or other periodic occurrence.

Impinged biota were sampled at Pilgrim Station at specific intervals for predetermined lengths of time totalling 48 hours per week from 1973 to 1978 (three 8-hour periods, and one 24-hour period with collections at 8-hour intervals). The collections were distributed as four nighttime and two day-time samplings. From 1979 to 1980, weekly collection time was 24 hours (three 8-hour periods). These collections consisted of two nighttime and one daytime samplings. Because of variable Pilgrim Station operating regimes, the mean sample collecting time was 7.70 hours. Traveling screens were washed at the beginning and end of each sampling period (minimum of 10 minutes for each wash, i.e., one rotation) and all marine organisms collected.

In 10,629 collecting hours between January 1973 and December 1980, 25,339 fishes of 56 species were impinged on the station's intake screens. By comparison, the number of species identified in impingement collections at several power stations on estuaries north of Cape Cod (Massachusetts Bay/Gulf of Maine) include 31 at Maine Yankee (Westport, Maine), 33 at Salem Harbor (Salem, Massachusetts), and 25 at Mystic Station (Everett, Massachusetts).

The Pilgrim Station impingement rate for all fishes for 1973 to 1980 was 2.39 fish/hour; the total weight of all fishes collected was 660 kg. Five species, Atlantic herring (*Clupea harengus harengus*), rainbow smelt (*Osmerus mordax*), Atlantic silverside (*Menidia menidia*), alewife (*Alosa pseudoharengus*), and cunner (*Tautogolabrus adspersus*), accounted for about 90% of the total impinged from 1976 to 1980, the period when all fish were identified to species.

Five large (more than 1000 specimens) and several small (more than 100 specimens) impingement mortalities occurred during the period 1973-1980 (Table 1). Both large and small mortalities involved the same species with the exception of cunner, which was involved only in small mortality events. The first large mortality (1973) involved 1,597 clupeids, probably alewives (at that time fish were not identified to species) and occurred in August and September when the species was usually most abundant. Other large mortalities were alewife (August 1976), Atlantic herring (November 1976), rainbow smelt (December 1978) and Atlantic silverside (March and April 1979).

Night/day, tide, wind speed and direction had no apparent effect on fish impingement except for two species, alewife and rainbow smelt, which showed definite relationships to wind directions. Alewife experienced higher impingement during easterly winds and rainbow smelt during westerly winds. The Pilgrim Station intake is a shoreline structure partially enclosed by breakwaters. It appeared to encourage to some extent impingement of juveniles of larger fishes and both juveniles and adults of smaller species.

Near-Field Benthic Effects of Cooling Water Discharge

The release of large volumes of warmed cooling water at considerable velocity was expected to alter the condition and nature of benthic and epibenthic communities on the bottom near the Pilgrim Station discharge canal. These effects were realized but on a somewhat lesser scale than anticipated.

Table 1. Conditions during large impingement fish mortalities at Pilgrim Nuclear Power Station, 1973 - 1980[a].

Date	Time	Tide stage	Mean Dissolved Oxygen (mg/l)	Intake Temp. (C)	Species (with mean total length mm)	Number	#/Hour
13 Aug. -27 Sept. 1973	Variable	Variable	8.15	15.4	Clupeids (not identified to species but probably primarily alewife)	1,597	---
5 Aug. 1976	Variable	Variable	9.2	16.2	Alewife (80.3)	1,864	6-227
23-28 Nov. 1976	Variable	Variable	9.5	5.5	Atlantic herring (261)	10,193[b]	1-240
11-12 Dec. 1978	Variable	Variable	10.4	5.2	Rainbow smelt (100)	6,200[b]	0-77
3 Mar. -30 Apr. 1979	Variable	Variable	11.0	3.2	Atlantic silverside (110)	1,167	0-42

a. Months when 100 or more representatives of a species were collected:

Atlantic herring, 11/76

Alewife, 8/73, 9/73, 8/74, 7/76, 8/76

Atlantic silverside, 2/73, 3/77, 3/78, 4/78, 3/79, 4/79

Rainbow smelt, 6/73, 12/77, 12/78

Cunner, 8/76

b. Estimated

In January and August 1980 a special study delineated the extent and nature of the discharge flow effect. A series of radial (radiating from the mid-point of the outer end of the discharge canal) and parallel (extending seaward parallel to the discharge plume centerline) transects were established and surveyed by SCUBA divers. Condition of the benthic community was noted and the approximate percent cover by *Chondrus* and *Phyllophora* was determined.

Results revealed a 1100 m^2 to 1400 m^2 "denuded" zone and a more peripheral area of "stunted" algal growth approximately 1900 m^2 to 2900 m^2. Configuration and extent of the "denuded" zone varied seasonally and appeared attributable to scour in the immediate path of the discharge plume, while the more distal "stunted" area appeared due primarily to thermal effects of the plume.

Entrainment in the Cooling Water Flow

Concern had been expressed regarding the potential for destruction of planktonic forms in the passage of ocean waters through the cooling water system. Far reaching effects could result from loss of planktonic food stocks on one hand and larval or juvenile stages of commercially important species on the other.

Comparison of intake and discharge phytoplankton samples indicated that survival ranged from 48% to 98% after passage through the cooling water system. At discharge temperatures below 17 C, the combined effects of heat and chlorine (chlorine is used to control biofouling) had no effect on survival rates. The percentage of mortality increased at temperatures above 17 C when phytoplankton was subjected to both heat and chlorination.

Entrained zooplankton generally had high survival rates ranging from 95% to 100% under most operating conditions. However, exposure to heat combined with chlorination resulted in mortality rates of 100% when discharge temperatures exceeded 29 C. No attempt was made to identify separately the effects of mechanical damage.

Unlike many of the more common zooplankton components, ichthyoplankton composition varies considerably across time as various species reproduce, grow, and then abandon planktonic life. Because of the lack of continuous replication or multiple spawning seasons, power plant "predation" via entrainment has the potential for significantly depleting important finfish populations. For example, at Pilgrim Station entrainment mortality of labrid eggs averaged 55% and ranged from 48% to 71%. However, mathematical modeling, which interrelated fish larval production estimates, natural mortality, and water volumes derived from Plymouth-Kingston-Duxbury Bays nearby and traveling past the plant, showed overall entrainment mortalities of less than 1% for larval forms of 16 species--when entire local populations were considered. Entrainment mortalities for winter flounder larvae were slightly higher, i.e., 2% to 3%.

Entrainment of larval lobsters at Pilgrim Station was a major concern. However, larval lobster densities in the vicinity were low, ranging from 1.2 to 4.5 per 1000 m^3 water, and larval lobster distribution and abundance studies revealed little hatching near Pilgrim Station. Special sampling for lobster larvae in the discharge canal in 1976 recovered only two larvae in 26,000 m^3 of water sampled. Only six additional lobster larvae were taken in 691 entrainment samples at Pilgrim Station from 1977 to 1979.

Effects of Plant Operation on Adult Finfish and Lobster Populations

A series of specially-designed studies failed to detect any influence on lobster growth, movement, and harvest rates. There has been a general decline in total catch as well as catch rates in the study area over a number of years--a phenomenon observed throughout the lobster's natural range. These trends were reported occurring elsewhere within the species natural range by Dow (1967) and Flowers and Saila (1972). Concurrently, lobster fishing effort increased in western Cape Cod Bay by 59% from 1970 to 1979.

Comparative sampling with gill nets and trawls produced little information one way or the other regarding plant impacts on either adult or juvenile fishes. Factors such as gear bias, seasonal migrations and natural variability in population densities allowed only the general conclusion that there appeared to be a detectable decline in relative abundance over large areas for most species during the study period.

LITERATURE CITED

AIF, (Atomic Industrial Forum, Inc.) and ORNL (Oak Ridge National Laboratory). 1981. Impingement and entrainment: An updated annotated bibliography. Electric Power Research Institute. EA-1855: 317 pp.

Anderson, C.O., Jr., D. J. Brown, B. A. Ketschke, E. M. Elliott and P. L. Rule. 1975. The effects of the addition of a fourth generating unit at the Salem Harbor Electric Generating Station on the marine ecosystem of Salem Harbor. Massachusetts Division of Marine Fisheries, Boston: 47 pp.

Beiningen, K. T., and W. J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society 99(4):664-671.

Bouck, G. R. 1975. Supersaturations and fishery observations in selected alpine Oregon streams. Proceedings of the Gas Bubble Disease Workshop, Battelle Northwest, Richland, Washington.

Boyer, P. B. 1974. Lower Columbia and lower Snake Rivers, nitrogen (gas) supersaturation and related data analysis and interpretation, March, 1974. North Pacific Division, Corps of Engineers. Portland, Oregon 20 + 87 p.

Clark, J. and W. Brownell. 1973. Electric power plants in the coastal zone: Environmental issues. American Littoral Society Special Publication Number 7. Highlands, N. J.

DeMont, D. J. and R. W. Miller. 1971. First reported incidence of gas bubble disease in the heated effluent of a steam generating station. Proceedings of the 25th Annual Conference of the Southeastern Game and Fish Commission 25:392-398.

Dennison, B. A., and M. J. Marchyshyn. 1973. A device for alleviating supersaturation of gases in hatching water supplies. Progressive Fish Culturist 35(1):55-56.

Dow, R. L. 1967. The influence of temperature on Maine lobster supply. Marine Sea and Shore Fisheries Department Publication: 2 pp.

Ebel, W. J. 1969. Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. United States Fish and Wildlife Service, Fisheries Bulletin 68:1-11.

ESIC (Ecological Sciences Information Center) and IEIS (Inforum Environmental Information Service). 1979. Impingement: An annotated bibliography. Electric Power Research Institute. EA-1050: 193 pp.

Fairbanks, R. B., and R. P. Lawton. 1977. Occurrence of large striped mullet, *Mugil cephalus*, in Cape Cod Bay, Massachusetts. Chesapeake Science 18(3):309-310.

Fairbanks, R. B., W. S. Collings, and W. T. Sides. 1971. An assessment of the effects of electrical power generation on marine resources in the Cape Cod Canal. Massachusetts Department of Natural Resources, Division of Marine Fisheries, Boston, Massachusetts.

Flowers, J. M. and S. B. Saila. 1972. An analysis of temperature effects on the inshore lobster fishery. Journal of the Fisheries Research Board of Canada 29:1221-1225.

Grimes, C. G. 1975. Entrapment of fishes on intake water screens at a steam electric generation station. Chesapeake Science 16(3):172-177.

Harvey, H. H. 1967. Supersaturation of lake water with a precaution to hatchery usage. Transactions of the American Fisheries Society 96:194-201.

Harvey, H. H., and A. C. Cooper. 1962. Origin and treatment of a supersaturation rated river water. International Proceedings on Salmon. Fisheries Commission Progress Report Number 9. Cultus Lake, British Columbia. 19 pp.

Harvey, H. H., and S. B. Smith. 1961. Supersaturation of the water supply and occurrence of gas bubble disease at Cultus Lake Trout Hatchery. Canadian Fisheries Culturist 30:39-46.

Lindroth, A. 1957. Abiogenic gas supersaturation of river water. Archive of Hydrobiology 53(4):589-597.

Marcello, R. A., Jr., and R. B. Fairbanks. 1976. Gas bubble disease mortality of Atlantic menhaden, *Brevoortia tyrannus*, at a coastal nuclear power plant. p. 75-80. *In*: Fickeisen, D. H., and M. J. Schneider, editors, Gas Bubble Disease proceedings of a workshop held at Richland, Washington. Oct. 8-9, 1974. Conference-741033 (Technical Information Center, U.S. ERDA, Oak Ridge, Tennessee).

Marcello, R.A., Jr., and K. Strawn. 1972. The cage culture of some marine fishes in the intake and discharge canals of a steam-electric generating station, Galveston Bay, Texas. Sea Grant Report TAMU-SG-72-206. 267 pp.

Marsh, M. C., and F. P. Gorham. 1905. The gas disease in fishes. Report of the United Statues Bureau of Fisheries 1904:345-376.

Merrill, T. R., M. D. Collins, and J. W. Greenough. 1971. An estimate of mortality of chinook salmon in the Columbia River near Bonneville Dam during the summer of 1955. Fishery Bulletin 68:461-492.

Miller, R. W., and D. J. DeMont. 1974. Fisheries research. pp. 187-216. *In*: Environmental Responses to Thermal Discharge from Marshall Steam Station, Lake Norman, North Carolina. Report Number 11. John Hopkins University, Department of Geography and Environmental Engineering.

Penrose, W. R., and W. R. Squires. 1976. Two devices for removing supersaturated gases in aquarium systems. Transactions of the American Fisheries Society 105(1):116-118.

Renfro, W. C. 1963. Gas bubble mortality of fishes in Galveston Bay, Texas. Transactions of the American Fisheries Society 92:320-322.

Rukavina, J., and D. Varẽnika. 1956. Air bubble disease of trout at the source of the River Bosna. Acta Ichthyologica Bosniae et Hercegovinae. Editium 1, X, Number 7:5-12.

Stupka, R. C. and R. K. Sharma. 1977. Survey of fish impingement at power plants in the United States. Vol. III. Estuaries and coastal waters. Argonne National Lab: 310 pp.

Thomas, D. L. and G. J. Miller. 1977. Impingement studies at the Oyster Creek Generating Station, Forked River, New Jersey, from September to December 1975. Pages 317-342 *In*: L. D. Jensen, editor: Third national workshop on entrainment and impingement. Ecological Analysts, Melville, N.Y.

Wold, E. 1973. Surface agitators as a means to reduce nitrogen gas in a hatchery water supply. Progressive Fish-Culturist 35(3):143-145.

Woodbury, L.A. 1941. A sudden mortality of fishes accompanying a supersaturation of oxygen in Lake Waubesa, Wisconsin. Transactions of the American Fisheries Society 71:112-117.