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FINAL REPORT

COMPILATION AND CORRELATION ANALYSIS OF PUBLISHED AND UNPUBLISHED ENVIRONMENTAL DATA WITH DISTRIBUTION, ABUNDANCE, AND MOVEMENTS OF YOUNG MENHADEN IN MID-ATLANTIC ESTUARIES

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Introduction

Atlantic menhaden is one of many species of coastal marine fishes that undertake migrations along the Atlantic coast of the United States. These migrations follow seasonal patterns that generally are northward in the spring and southward in the fall. The movements are related to the life cycle of the fish and seem correlated to water temperature.

Menhaden spawn in the ocean along the Continental Shelf and as small, slender larvae, about a month old, they leave the ocean and move into the shallow estuaries and bays. They move up the tributaries near the boundary of fresh and brackish water to metamorphose into juveniles that resemble the adults in appearance and in behavior. Spawning occurs along the middle Atlantic States during the late fall and early spring. By May and June, the young-of-the-year are occupying streams in all of the estuaries from Florida to Cape Cod. They usually remain in the tidal nurseries until August or September when they return to the ocean. Juvenile Atlantic menhaden have been observed leaving the nurseries with the first appearance of autumn. It appears that an early cold spell will cause them to move into the ocean or downstream towards higher salinity water and if the weather warms, they often return to, or remain in the estuary until the next cold spell. This movement from the estuaries, north of Chesapeake Bay, appears to be complete by late November or December. A few stragglers have been reported every year with a greater incidence of occurrence in years with late autumns and mild winters.

The exodus of young menhaden from the estuaries is more easily related to autumnal cooling of the coastal waters than it is to any other phenomonon associated with the seasons. Such changes as shorter day length, solar radiation, and angle of incidence may be the information that physiologically prepares the juveniles for fall migration. Despite the physiological mechanisms involved, temperature is the most obvious change and the one most easily measured.

The purposes of this report are to determine from published and unpublished data, the relation of temperature to the fall migration of young menhaden from the estuaries, to provide guidelines to induce young menhaden to migrate when the normal seasonal cooling of segments of the estuary is prevented by introduction of heated water, and to prevent mass mortalities from occurring if the source of heat is interrupted or discontinued.

Sources of Information

Collections of estuarine fishes have been made along the Atlantic coast for many years with some concurrent environmental observations, usually temperature and salinity. Most of these collections were infrequent, irregular and did not continue throughout the year. More significant to the present study, were the methods used to capture fishes. Menhaden are fast-swimming pelagic fish that form dense schools and are not easily nor often caught in townets, trawls, haul seines, traps, or other fishing devices customarily used to collect coastal fishes. Consequently the collections used for this study had to be regular throughout the year and include menhaden.

Regular collections of estuarine fishes, including menhaden, were made at five localities along the Atlantic coast of the United States at temperature, salinity and some other environmental observations. The number and kinds of fishes were recorded and young menhaden were one of the more commonly occurring fish in the collections. The areas and dates were as follows:

Indian River, Delaware	April 1957 - June 1958
Neuse River, N.C.	December 1965 - October 1967
Pamlico Sound, N.C.	December 1965 - October 1967
Great Egg Harbor, N.J.	September 1970 - October 1971
Newport River, N.C.	January 1970 - July 1972

Indian River, Delaware and Newport River, N.C. data were collected by the National Marine Fisheries Service, Beaufort, N.C. Neuse River and Pamlico Sound, N.C. data were provided by the University of North Carolina, Institute of Marine Sciences, Morehead City, N.C. and Great Egg Harbor, N.J. by the New Jersey Division of Fish, Game and Shellfish, Nacote Creek Research Station.

Correlation Analyses of Temperature with Menhaden Abundance

The objective of the analyses was to correlate the changes in temperature with the occurrence of young menhaden throughout the year. Each geographical locality was treated separately. Before a correlation of temperature could be made with the occurrence of menhaden, the reliability of the information had to be established. Temperature observations easily meet these requirements. Thermometers are accurate and precise enough for the temperature variations occurring in estuaries. However, the occurrence of menhaden, as determined by catching them, depends upon the effectiveness of the sampling equipment. Menhaden are

fast-swimming and elusive. Special nets are needed for their capture and the ability of the nets to catch them changes as the fish become larger and more agile. Meterological conditions, clarity of the water and time of day also influence the effectiveness of nets to catch menhaden.

Correlation analyses of temperature and menhaden abundance were made on 5 sets of observations, one of each geographical locality. These are summarized in table 1. The results show significant correlation of menhaden occurrence and temperature in all sets of data except the observations from Great Egg Harbor, N.J.

The largest amount of data was collected at eight stations in the Indian River, Delaware. A number of environmental observations were made at each station including salinity, pH, oxygen, inorganic and total phosphates and suspended solids. The Indian River study was directed towards young menhaden and had frequent observations thus providing a good basis for conclusions on menhaden occurrence as related to temperature in the middle Atlantic area. Monthly average values for salinity, temperature, pH, oxygen, inorganic and total phosphates and dissolved solids with the mean number of menhaden and other fishes are given for the eight stations in the appendix tables.

Correlation analyses of the occurrence of young menhaden with temperature were made with data from three North Carolina estuaries. The data from all three estuaries, Neuse, Pamlico and Newport Rivers show signficant correlation of menhaden occurrence with temperature. The seasonal behavior of young menhaden south of Chesapeake Bay is not as pronounced as to the northwards.

Collections of young menhaden were made by S. M. Warlen of the Beaufort Center from April 1966 to June 1968 in the Neuse River. He wanted menhaden throughout the year to follow growth and scale development. He used seines, trawls, gillnets, and pound nets and was able to catch some menhaden during each month. From these observations, it appears that some young menhaden overwinter in estuaries south of Cape Hatteras and their behavior is not a reliable guide to the movements of menhaden in New Jersey.

The analysis of Great Egg Harbor, New Jersey data did not show a significant correlation of temperature with menhaden abundance. Although statistically not significant, the seasonal occurrence as related to temperature agreed with the results of other studies in Delaware and North Carolina. Menhaden were caught at 12 stations in Great Egg Harbor. A total of 4,619 menhaden were caught; 4,617 at 11 stations in June, July and August when temperatures ranged from 70-81° F. Only 2 were caught at one station in November when the temperature was 49° F.

Table 1.--Correlation analyses of temperature and menhaden occurrence in five Atlantic coast estuaries.

Locality	Dates	Frequency of sampling	No. of observation	F value	
Indian River, Delaware	April 1957 to June 1958	3 times a week	921	70.4	Highly significant correlation of temperature to menhaden occurrence.
Neuse River, North Carolina	December 1965 to October 1967	3 to 4 times a month	210	9.7	Significant correlation
Pamlico River, North Carolina	December 1965 to October 1967	3 to 4 times a month	126	21.1	Highly significant.
Great Egg Harbor, New Jersey	September 1970 to October 1971	2 times a week	143	2.0	Not significant at 5% level.
Newport River, North Carolina	January 1970 to July 1972	3 times a month	507	6.9	Significant at 1% level.

Influence of Some Other Environmental Factors

Correlations of total phosphates, displacement volumes of suspended solids, and number of other fishes to the number of menhaden were analyzed for Indian River, Delaware and for the number of other fishes to the number of menhaden for Great Egg Harbor, N.J. and Neuse, Newport and Pamlico Rivers, N.C.

Significant correlations of total phosphates (F=32.5) and suspended solids (F=16.9) with number of menhaden were obtained for Indian River. Since much of the suspended solids are plankton, the total phosphates and suspended solids may be measures of the standing crop of plankton. As the abundance of plankton is seasonal and is related to water temperatures, the correlations are in agreement with the correlation of temperature to number of young menhaden. No measurements for phosphates or suspended solids were available from the other localities.

The correlation analyses for the number of other fishes to the number of menhaden are shown in the following table:

Locality	No. of observations	F value	Remarks
Indian River, Del.	807	13.5	Significant
Neuse River, N.C.	217	2.8	Not significant
Pamlico River, N.C.	132	18.5	Significant
Great Egg Harbor, N.J.	166	22.5	Significant
Newport River, N.C.	540	0.5	Not significant

The correlations were significant at Great Egg Harbor, N.J., Indian River, Del. and Pamlico River, N.C. but not at Neuse River and Newport River, N.C. We have no explanation for the results for the Neuse River, for the data were obtained during the same period an in the same manner as for the Pamlico River. The non-significant correlation of number of other fishes to number of menhaden in the Newport River is probably due to the highly selective method used to catch young menhaden. A surface trawl, towed between two outboard motorboats was used. This gear is designed to catch pelagic fish in the upper stratum and few other fishes, than menhaden, are in this habitat in the Newport River.

Survival of Young Menhaden in Relation to Cold Temperature and Salinity

Larval Atlantic menhaden enter estuaries from the ocean when they are 1/2 to 1 1/4 inches long. They transform into juveniles and usually spend from 6 to 9 months in these nursery areas. They normally migrate from the estuaries, bays, and sounds in the autumn to the ocean.

When they remain in the estuaries and are exposed to a rapid decrease in water temperature or the temperature approaches the freezing point, mass mortalities may occur.

The seasonal occurrences of menhaden larvae and juveniles in relation to temperature was noted at Indian River, Delaware during 1955-1958 and was reported by June and Chamberlin (1959):

> "Water temperature also is related to certain life history features and behavior patterns of the fish. There appears to be a minimum temperature associated with the occurrence of larvae at the river mouths during winter. Over the past three years, for example, water temperatures below about 3° C at the mouth of Indian River have coincided with an absence of menhaden larvae in our plankton tows. When low temperatures have prevailed over a period of several weeks, we have found a high percentage of structural abnormalities, especially among the larger larvae, once recruitment into the estuary recommenced. Thus, water temperature during the period of entry may be a source of mortality in some years. A heavy winter kill of one-year-old menhaden in the Neuse River, North Carolina in February 1958 was attributed to freezing water temperatures which persisted over a period of two weeks. Also, all young menhaden being reared in the outdoor ponds at Beaufort (ca. 500) were killed during this period.
>
> "The fall emigration of juveniles from the estuaries also appears to be directly related to water temperature. Our records from Indian River indicate that it commences when temperatures in the estuary first fall below those of the adjacent ocean. Such a drop may occur in the shallow waters on each cold night after the end of August, each occasion being accompanied by a departure of juveniles. On the other hand, during warm periods in the fall, numerous juveniles reappear in this estuary. Comparisons of size distributions and meristic characters of these late inhabitants have shown that they were not members of the endemic summer population, but probably originated in estuaries north of Long Island and presumably entered the river while migrating southward."

Experiments were performed at Beaufort, N.C. from January to April 1964 to ascertain the effect of low temperatures on Atlantic menhaden larvae. The results and discussion, including table 1, from Lewis (1965) follows:

"Behavior of larvae in test buckets followed a definite pattern. As they became chilled they lost equilibrium, floated and twitched erratically, and finally settled on the bottom. A response could be initiated by touching these larvae with a probe. Larvae that apparently were dead could be removed from the water and warmed; if still alive, heart pulsations or muscle reflexes occurred.

"Table 1 lists the number of hours that larvae survived before a 50% mortality occurred. Generally, larvae acclimated at cooler temperatures survived longer at a given test temperature than those acclimated at warmer temperatures. Due to equipment failure and subsequent repair, some of the larvae from the 15.0 C acclimation series were in holding and acclimation tanks for a month or longer. Ordinarily, larvae were kept in these tanks for 2 weeks or less. The uneven results in the 15.0 C acclimation series may be due to holding larvae an extended time or possibly are characteristic of larvae acclimated at this temperature. Only three tests could be completed in the 20.0 C acclimation series.

"In several cases during equipment failure, the water temperature dropped to near freezing for several hours. Approximately one-third of the larvae that were exposed to this low temperature for less than 3 hours recovered when warmed to room temperature.

"Length frequencies of larvae from those experiments in which all larvae died indicated no relation between the size of larvae and survival time.

"With few exceptions, larvae acclimated at 7.0 C survived 0.0 to 4.0 C approximately 1.5 to 3.5 times longer than those acclimated at warmer temperatures and the survival time increased with increased test temperature. There was a marked difference in the survival time of larvae acclimated at different temperatures and tested at 4.5 C. Larvae acclimated at 7.0 and 10.0 C survived over twice as long as those acclimated at 12.5 or 15.0 C. Larvae survived equally well at 5.0 C for all acclimation temperatures. Those tested at 5.5 C and above survived for approximately 6 days or more, except for larvae acclimated at 15.0 C. Larvae from the 15.0 C series showed poor survival at 6.0 and 7.0 C possibly due to holding larvae

Table 1.--Number of hours to 50% mortality of menhaden larvae exposed to different temperatures

(from Lewis, 1965)

Acclimation temperature Celsius	Test temperature C							
	-1.0	0.0	0.5	1.0	1.5	2.0	2.5	3.0
7.0	-	8.5	11.5	13.0	33.5	38.5	40.5	37.5
10.0	4.4	5.2	9.0	5.3	16.7	20.4	23.0	33.2
12.5	-	4.2	7.0	9.6	13.4	17.9	17.7	36.0
15.0	-	3.4	6.4	6.0	4.5	14.5	10.0	23.4
20.0	-	2.1	-	-	-	3.2	-	-

Acclimation temperature Celsius	Test temperature C							
	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0
7.0	77.0	96.0	>137.5	>137.5	-	-	-	-
10.0	46.0	26.8	132.7	130.0	>144.0	>144.0	-	-
12.5	39.2	45.0	60.0	132.0	216.0	>216.0	-	-
15.0	18.9	45.7	36.4	140.0	140.0	70.0	82.8	>169.0
20.0	-	11.2	-	-	-	-	-	-

"more than a month. Larvae in the control buckets did not die during any experiment. On the basis of these data, it appears that acclimation temperature is more important to the survival of larvae at test temperatures less than 5.0 C than it is at 5.0 C and above.

"The experiments conducted in the laboratory partially explain the absence of menhaden larvae in plankton collections taken when water temperatures were below 3.0 C. Whether the larvae were killed or avoided the cold water in the estuaries has not been determined."

A summary report on menhaden in estuaries with observation from Indian River, Delaware was prepared by Reintjes and Pacheco (1966). An excerpt on the effects of temperatures with table 1 and figures 1 and 2 follows:

"The collections at Indian River, Delaware, appeared to show a relation of temperature to time of entry into the estuary and, subsequently, to movements and survival within the estuary. The water temperatures, catches of larval menhaden at the inlet and catches at a nursery area nearly 12 miles above the inlet at the base of Millsboro Dam were compared from December to June, 1955-56 and from September to June, 1956-61[2] (Figs. 1 and 2). Comparison of the occurrences of the larvae at the inlet with their subsequent appearances or absences in the tributary nursery area indicate that a water temperature 3 C may be critical. This conclusion is in agreement with June and Chamberlin (1959).

"On the basis of these field observations, the effects of different low temperatures on larval Atlantic menhaden for various initial or acclimation temperatures were tested in the laboratory (Lewis, 1965). Larvae were acclimated at five temperatures from 7.0 to 20.0 C and were exposed to temperatures from 0.0 to 6.0 C at half-degree intervals. Salinities were held at 24 o/oo during the tests. The results are briefly, as follows:

'If the test temperature reached 3 C or less, 50 per cent of the larvae died within 1 1/2 days.
If the acclimation temperature was 10 C or warmer, a greater number died at 3 C and 50 per cent were killed at 4.5 C.
Cooling to 1.5 C for less than 12 hours was tolerated by most of the larvae if the acclimation temperatures were below 15 C.'

Table 1.--Mean monthly catch per plankton net tow of Atlantic menhaden larvae and range of fork lengths in mm (in parentheses) from Indian River, Delaware, 1968-16

(from Reintjes and Pacheco, 1966)

Month	Year		
	1958-59	1959-60	1960-61
October	-	4.5 (15-25)	-
November	-	2.2 (15-25)	1.9 (18-26)
December	0.8 (18-25)	156.6 (18-33)	69.3 (21-34)
January	0.5 (25)	428.8 (14-31)	66.0 (21-32)
February	1.0 (24-26)	441.1 (14-31)	-
March	153.6 (17-28)	47.9 (15-32)	0.7 (21-26)
April	34.5 (19-32)	40.8 (17-31)	2.3 (19-33)
May	1.7 (31-40)[1]	6.0 (21-43)[1]	8.6 (23-32)

[1]Menhaden more than 34 mm, fork length, are transforming into juveniles; 4 were taken in May 1959 and 14 in May 1960.

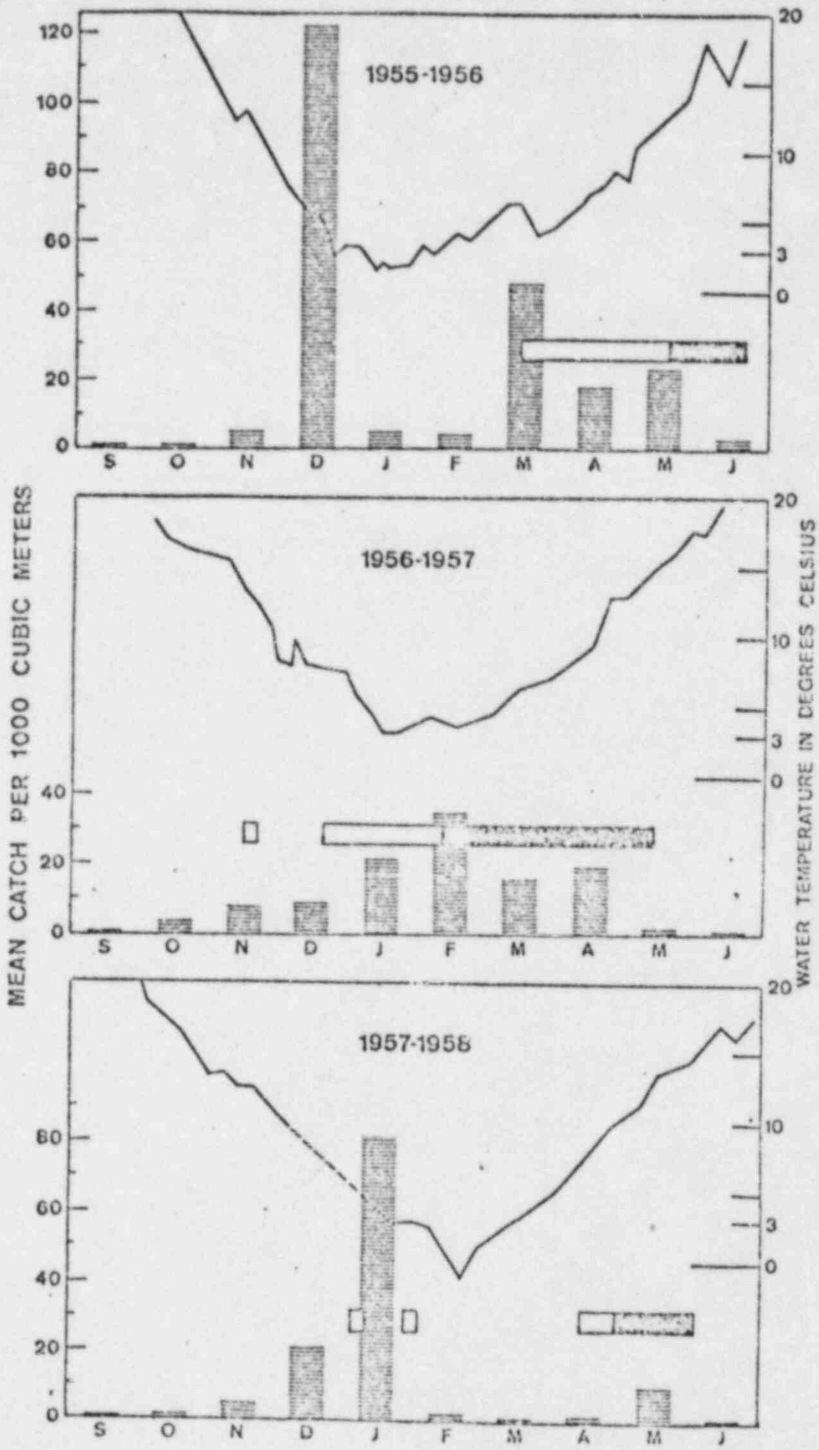

FIGURE 1.—Catches of menhaden larvae and water temperatures in the inlet compared to catches of larvae in a tributary, by month, Indian River, Delaware, 1955–58. The vertical bars represent monthly weighted geometric mean catches of larvae at the inlet during night flood tides. The horizontal bars represent weekly catches at the nursery area (open for 1 to 10 and solid for more than 10). The line graph shows the weekly mean water temperatures at the inlet during flood tides (from Pacheco MS).

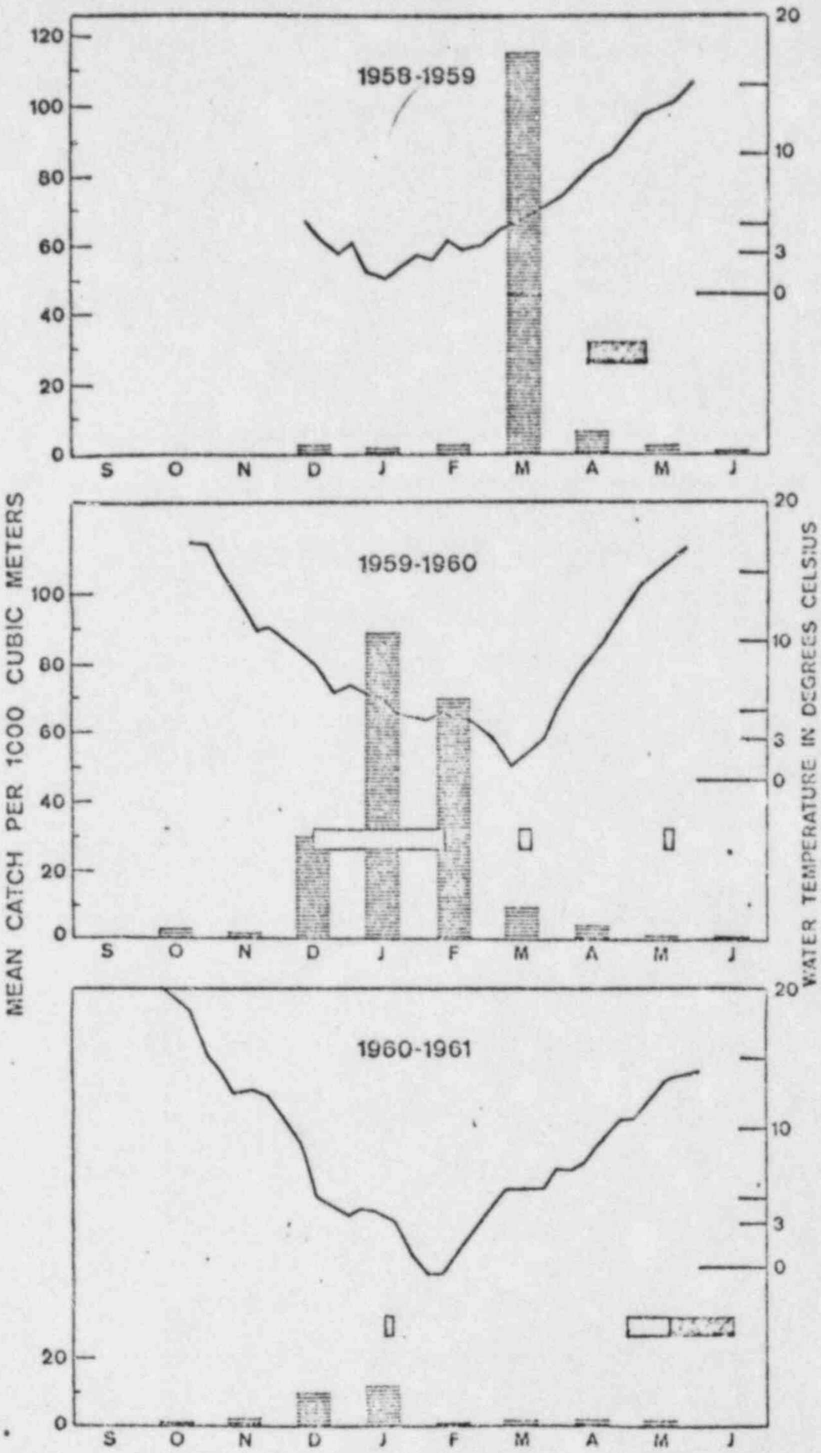

FIGURE 2.—Catches of menhaden larvae and water temperatures in the inlet compared to catches of larvae in a tributary, by month, Indian River, Delaware, 1958-61. The vertical bars represent monthly weighted geometric mean catches of larvae at the inlet during night flood tides. The horizontal bars represent weekly catches at the nursery area (open for 1 to 10 and solid for more than 10). The line graph shows the weekly mean water temperatures at the inlet during flood tides (from Pacheco MS).

These results indicated that larval menhaden can suffer mass mortalities when water temperatures fall below 3 C for several days or chill rapidly to 4.5 C."

Additional experiments on the effects of salinity and temperature on survival and development of larval Atlantic menhaden were reported by Lewis (1966):

"Results of the two acclimation series in the temperature-salinity experiment indicated that if larvae enter an estuary during the winter or early spring, when water temperatures may approach the freezing point, they will have the best chance of survival if the water temperature does not fall below 4° C and salinity remains between 10 and 20 p.p.t."

Experiments to show the effects of temperature and salinity on survival of juvenile and yearling menhaden were reported by Lewis and Hettler (1968). Their results showed that juvenile menhaden were slightly less tolerant of cold temperatures than were larvae. Also juvenile menhaden were able to survive better at lower salinities (10 p.p.t.) than at the higher (28 p.p.t.). Young-of-the-year menhaden were acclimated at 15-16° and chilled, in lots, to 3, 4, 5, and 6° C in 28 p.p.t. salinity. Others were acclimated at 18° C in 10 p.p.t. The results are shown in table 3 from that report. In general, 50% of the fish died during the first day when chilled to 3 and 4° C. Survival was better at 5° C in lower (10 p.p.t.) than in higher (28 p.p.t.) salinities.

$5°C = 5 \times \frac{9}{5} + 32 = 41°F$

The experiments show that water temperatures 3° C and below are lethal to young menhaden in all salinities and that temperatures of 5 to 7° C will kill young menhaden that are accustomed to temperatures of 15° C or above. There may be a greater tolerance to low temperatures at salinities from 10 to 20 p.p.t. than at those either lower or higher. It is reasonable to assume that the greater the rate of change the greater the mortality although there are no specific experimental results to support that assumption.

The recommendations to lessen the lethal effects of cold to young menhaden are as follows:

1. Maintain water temperatures above 3° C.

2. If temperatures are lowered to 7° C or below, the slower the rate of decrease the better the chances for survival.

3. The shorter the duration of the cold temperatures the better the chances for survival.

Table 3.--Results of tests with young-of-the-year Atlantic menhaden subjected to low temperatures at low and high salinities

(from Lewis and Hettler, 1968)

Test		Acclimation			Hours after start of experiment			
Temperature Celsius	Salinity o/oo	Number of hours	Median temperature Celsius	Median salinity o/oo	First death	50% survival	Last death	Termination
7.0	27	>500	12	28	–[1]	–	–	128
7.0	30	>500	15	28	118	–	–	160
6.0	30	>500	15	28	40	160	–	231
6.0	30	>500	15	28	141	234	–	256
5.0	26	100-500	16	29	39	61	98	98
5.0	26	100-500	16	29	40	53	98	98
4.0	26	100-500	16	29	16	28	37	37
4.0	27	100-500	16	29	3	16	–	21
3.0	27	100-500	16	29	5	10	16	16
3.0	27	100-500	16	29	3	6	11	11
7.0	10	>500	18	10	235	–	–	358
6.0	10	>500	18	10	86	149	–	334
5.0	10	>500	18	10	110	110	–	142
5.0	10	100-500	18	10	128	170	240	240
5.0	10	100-500	18	10	100	110	191	191
4.0	10	>500	18	10	24	27	63	63
4.0	10	100-500	18	10	6	6	99	99
4.0	10	100-500	18	10	23	49	98	98
3.0	10	100-500	18	10	>1	3	49	49
3.0	10	100-500	18	10	0	2	28	28

[1] Dashes indicate no deaths.

4. Cold can be tolerated more effectively at salinities from 10 to 20 p.p.t. than at those either lower or higher.

5. Larval and postlarval menhaden are more tolerant of cold than are juveniles or young-of-the-year, although neither groups will survive temperatures below 3° C.

Conclusions and Remarks

1. Juvenile menhaden usually migrate from the bays and estuaries of New Jersey commencing in late August and early September when they are about 4 inches long and 6 to 9 months old. This movement from the estuaries into the ocean appears to be complete by late November or early December. A few stragglers have been reported every year with greater incidence of occurrence in years of late autumns and mild winters.

2. The period of most marked movement from the estuaries is during October when the first autumnal cooling of the water is to 15° C (59° F) or below.

3. The correlation of young menhaden departure with the seasonal change in water temperatures indicates that the decline in temperature is the principal determinant of the fall migration. If the autumnal cooling is obscured by the addition of warm water, the young menhaden may not leave the area.

4. Experiments show that water temperatures of 3° C (37.5° F) and below are lethal to young menhaden in all salinities and that temperatures of 5° to 7° C (41° to 45° F) will kill young menhaden that are accustomed to temperatures of 15° C (59° F) and above. There may be greater tolerances to low temperatures at salinities from 10 p.p.t. to 20 p.p.t. than at those of higher or lower salinities.

5. The greater the rate of change the greater the mortality. The higher the acclimation temperatures the higher the lethal cold threshold.

6. Within the thermal toleration limits of the species, a rapidly falling temperature is in general a greater threat to survival than a rising temperature, however a marked rise in temperature will cause mortalities among fish accustomed to cold water. Although speculative, the combined effects of a rapid change in the other may increase mortalities beyond the extent of either change alone.

Recommendations

1. To induce young menhaden to leave the effluent canal, the water temperature in Oyster Creek should be allowed to approximate the temperature in Barnegat Bay during the first cold spell.

2. A second and third drop in temperature to or below 15° C (59° F) should also be approximated in Oyster Creek to flush out the remaining menhaden.

3. Water temperatures should be continuously recorded in Oyster Creek and Barnegat Bay and these should be monitored for critical changes.

4. During periods of critical changes, salinities at several locations in Oyster Creek should be taken, because in salinities below 10 or above 20 p.p.t. mortalities will be greater than in intermediate salinities.

5. After several periods that the water temperatures in Barnegat Bay and the South Branch of the Forked River have fallen to below 15° C (59° F), conduct a search for young menhaden in Oyster Creek. Gear capable of catching young menhaden should be used, such as monofilament gillnet or surface trawl.

6. To prevent a cold-kill of young menhaden that may have remained in the Creek during the rest of the winter, the Generating Station should not schedule a maintenance shut-down when the meterological forecast predicts mean daily temperatures below freezing.

7. In the event of an emergency shut-down, when water temperatures might fall below 4° C (39° F), a contingency plan, if feasible, to keep water temperatures from falling too rapidly and above a 4° C minimum should be implemented.

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Appendix Tables and Figures

Table 3 - Conversion of Fahrenheit to Centigrade

°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
25.0	-3.9	35.0	1.7	45.0	7.2	55.0	12.8	65.0	18.3	75.0	23.9	85.0	29.4
25.2	-3.8	35.2	1.8	45.2	7.3	55.2	12.9	65.2	18.4	75.2	24.0	85.2	29.6
25.4	-3.7	35.4	1.9	45.4	7.4	55.4	13.0	65.4	18.6	75.4	24.1	85.4	29.7
25.6	-3.6	35.6	2.0	45.6	7.6	55.6	13.1	65.6	18.7	75.6	24.2	85.6	29.8
25.8	-3.4	35.8	2.1	45.8	7.7	55.8	13.2	65.8	18.8	75.8	24.3	85.8	29.9
26.0	-3.3	36.0	2.2	46.0	7.8	56.0	13.3	66.0	18.9	76.0	24.4	86.0	30.0
26.2	-3.2	36.2	2.3	46.2	7.9	56.2	13.4	66.2	19.0	76.2	24.6	86.2	30.1
26.4	-3.1	36.4	2.4	46.4	8.0	56.4	13.6	66.4	19.1	76.4	24.7	86.4	30.2
26.6	-3.0	36.6	2.6	46.6	8.1	56.6	13.7	66.6	19.2	76.6	24.8	86.6	30.3
26.8	-2.9	36.8	2.7	46.8	8.2	56.8	13.8	66.8	19.3	76.8	24.9	86.8	30.4
27.0	-2.8	37.0	2.8	47.0	8.3	57.0	13.9	67.0	19.4	77.0	25.0	87.0	30.6
27.2	-2.7	37.2	2.9	47.2	8.4	57.2	14.0	67.2	19.6	77.2	25.1	87.2	30.7
27.4	-2.6	37.4	3.0	47.4	8.6	57.4	14.1	67.4	19.7	77.4	25.2	87.4	30.8
27.6	-2.4	37.6	3.1	47.6	8.7	57.6	14.2	67.6	19.8	77.6	25.3	87.6	30.9
27.8	-2.3	37.8	3.2	47.8	8.8	57.8	14.3	67.8	19.9	77.8	25.4	87.8	31.0
28.0	-2.2	38.0	3.3	48.0	8.9	58.0	14.4	68.0	20.0	78.0	25.6	88.0	31.1
28.2	-2.1	38.2	3.4	48.2	9.0	58.2	14.6	68.2	20.1	78.2	25.7	88.2	31.2
28.4	-2.0	38.4	3.6	48.4	9.1	58.4	14.7	68.4	20.2	78.4	25.8	88.4	31.3
28.6	-1.9	38.6	3.7	48.6	9.2	58.6	14.8	68.6	20.3	78.6	25.9	88.6	31.4
28.8	-1.8	38.8	3.8	48.8	9.3	58.8	14.9	68.8	20.4	78.8	26.0	88.8	31.6
29.0	-1.7	39.0	3.9	49.0	9.4	59.0	15.0	69.0	20.6	79.0	26.1	89.0	31.7
29.2	-1.6	39.2	4.0	49.2	9.6	59.2	15.1	69.2	20.7	79.2	26.2	89.2	31.8
29.4	-1.4	39.4	4.1	49.4	9.7	59.4	15.2	69.4	20.8	79.4	26.3	89.4	31.9
29.6	-1.3	39.6	4.2	49.6	9.8	59.6	15.3	69.6	20.9	79.6	26.4	89.6	32.0
29.8	-1.2	39.8	4.3	49.8	9.9	59.8	15.4	69.8	21.0	79.8	26.6	89.8	32.1
30.0	-1.1	40.0	4.4	50.0	10.0	60.0	15.6	70.0	21.1	80.0	26.7	90.0	32.2
30.2	-1.0	40.2	4.6	50.2	10.1	60.2	15.7	70.2	21.2	80.2	26.8	90.2	32.3
30.4	-0.9	40.4	4.7	50.4	10.2	60.4	15.8	70.4	21.3	80.4	26.9	90.4	32.4
30.6	-0.8	40.6	4.8	50.6	10.3	60.6	15.9	70.6	21.4	80.6	27.0	90.6	32.6
30.8	-0.7	40.8	4.9	50.8	10.4	60.8	16.0	70.8	21.6	80.8	27.1	90.8	32.7
31.0	-0.6	41.0	5.0	51.0	10.6	61.0	16.1	71.0	21.7	81.0	27.2	91.0	32.8
31.2	-0.4	41.2	5.1	51.2	10.7	61.2	16.2	71.2	21.8	81.2	27.3	91.2	32.9
31.4	-0.3	41.4	5.2	51.4	10.8	61.4	16.3	71.4	21.9	81.4	27.4	91.4	33.0
31.6	-0.2	41.6	5.3	51.6	10.9	61.6	16.4	71.6	22.0	81.6	27.6	91.6	33.1
31.8	-0.1	41.8	5.4	51.8	11.0	61.8	16.6	71.8	22.1	81.8	27.7	91.8	33.2
32.0	0.0	42.0	5.6	52.0	11.1	62.0	16.7	72.0	22.2	82.0	27.8	92.0	33.3
32.2	0.1	42.2	5.7	52.2	11.2	62.2	16.8	72.2	22.3	82.2	27.9	92.2	33.4
32.4	0.2	42.4	5.8	52.4	11.3	62.4	16.9	72.4	22.4	82.4	28.0	92.4	33.6
32.6	0.3	42.6	5.9	52.6	11.4	62.6	17.0	72.6	22.6	82.6	28.1	92.6	33.7
32.8	0.4	42.8	6.0	52.8	11.6	62.8	17.1	72.8	22.7	82.8	28.2	92.8	33.8
33.0	0.6	43.0	6.1	53.0	11.7	63.0	17.2	73.0	22.8	83.0	28.3	93.0	33.9
33.2	0.7	43.2	6.2	53.2	11.8	63.2	17.3	73.2	22.9	83.2	28.4	93.2	34.0
33.4	0.8	43.4	6.3	53.4	11.9	63.4	17.4	73.4	23.0	83.4	28.6	93.4	34.1
33.6	0.9	43.6	6.4	53.6	12.0	63.6	17.6	73.6	23.1	83.6	28.7	93.6	34.2
33.8	1.0	43.8	6.6	53.8	12.1	63.8	17.7	73.8	23.2	83.8	28.8	93.8	34.3
34.0	1.1	44.0	6.7	54.0	12.2	64.0	17.8	74.0	23.3	84.0	28.9	94.0	34.4
34.2	1.2	44.2	6.8	54.2	12.3	64.2	17.9	74.2	23.4	84.2	29.0	94.2	34.6
34.4	1.3	44.4	6.9	54.4	12.4	64.4	18.0	74.4	23.6	84.4	29.1	94.4	34.7
34.6	1.4	44.6	7.0	54.6	12.6	64.6	18.1	74.6	23.7	84.6	29.2	94.6	34.8
34.8	1.6	44.8	7.1	54.8	12.7	64.8	18.2	74.8	23.8	84.8	29.3	94.8	34.9

$$°C = \frac{°F - 32}{1.8}$$

From: Special Publication No. 278
U.S. Department of Commerce
Coast and Geodetic Survey
Washington, D.C. 1951

Appendix table 2

155/1

Indian River, Delaware

Station 1 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	27.1	15.5	8.2	--	--	--	--	0	11.4
May	28.2	19.6	8.2	--	0.3	2.1	0.04	0	34.8
June	28.7	23.8	8.1	4.8	0.4	2.5	0.08	5.5	98.3
July	30.8	25.0	8.0	3.3	0.5	3.5	0.08	163.5	71.3
Aug.	31.9	24.9	7.9	3.3	0.9	4.6	0.09	9.5	110.5
Sept.	31.4	23.0	7.9	3.7	1.0	5.3	0.07	0	269.8
Oct.	30.7	14.7	8.0	5.5	0.6	3.1	0.05	0	199.8
Nov.	29.3	10.3	8.3	8.0	0.3	1.0	0.03	1.0	139.5
Dec.	27.0	5.7	8.1	7.5	0.2	1.2	0.05	29.0	3.4
Jan.	23.8	3.1	7.9	8.1	0.2	1.5	0.06	0	2.5
Feb.	22.0	2.3	7.8	8.6	0.1	1.2	0.05	0	0
March	22.5	6.1	7.9	7.7	0.1	2.0	0.07	0	9.0
April	21.2	12.9	8.0	7.0	0.1	1.4	0.05	0	33.5
May	23.3	16.5	8.1	--	0.2	2.6	0.05	0	135.2
June	25.3	22.7	8.4	--	0.4	1.8	0.08	1.0	248.3

Appendix table 3

155/2

Indian River, Delaware

Station 2 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/1	Inorg. PO_4 µg-at/1	Total PO_4 µg-at/1	Solids ml/1	No. of menhaden	No. of other fishes
April	25.8	15.9	8.0	--	--	--	0.02	0	126.6
May	27.1	19.7	8.0	--	0.4	1.9	0.05	1	110.2
June	27.4	24.6	8.1	3.7	0.3	2.6	0.10	69.0	115.2
July	30.3	25.3	8.0	3.4	0.4	4.0	0.09	113.3	99.1
Aug.	32.0	25.3	7.9	3.2	0.5	4.6	0.08	222.5	278.0
Sept.	31.2	23.1	7.8	3.3	0.7	4.8	0.07	607.0	117.5
Oct.	30.4	14.9	8.0	5.3	0.4	2.6	0.04	0	228.3
Nov.	27.6	10.6	8.1	7.4	0.2	1.0	0.32	1.0	331.5
Dec.	24.7	5.7	8.0	8.2	0.2	1.4	0.05	0	46.0
Jan.	20.7	3.8	7.6	8.1	0.1	1.5	0.05	3.0	5.3
Feb.	17.2	2.4	7.4	8.9	0.3	1.6	0.04	0	2.0
March	21.7	6.5	7.9	7.7	0.1	2.5	0.06	0	7.5
April	19.7	13.4	7.8	6.7	0.2	1.6	0.06	0	132.2
May	20.8	16.8	7.8	--	0.2	1.5	0.04	1.0	153.7
June	22.0	23.4	8.0	--	0.1	1.5	0.11	59.6	431.7

Appendix table 4

155/3

Indian River, Delaware

Station 3 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/1	Inorg. PO_4 µg-at/1	Total PO_4 µg-at/1	Solids ml/1	No. of menhaden	No. of other fishes
April	24.6	17.1	7.8	--	--	--	0.02	0	70.6
May	26.5	20.5	7.9	--	0.3	1.9	0.04	55.0	83.4
June	26.5	25.1	8.1	4.3	0.3	2.8	0.11	4.4	103.5
July	29.8	26.1	8.1	3.6	0.4	4.5	0.11	298.0	51.5
Aug.	31.8	25.9	7.9	3.4	0.4	4.1	0.12	188.0	130.6
Sept.	30.8	23.5	7.8	3.5	0.8	7.9	0.10	407.0	252.5
Oct.	30.2	15.2	7.9	5.3	0.4	2.9	0.05	0	135.4
Nov.	27.2	10.7	8.1	7.2	0.2	1.7	0.08	1.0	95.5
Dec.	23.3	5.6	8.0	7.3	0.2	1.6	0.06	0	42.5
Jan.	15.9	3.3	7.5	8.0	0.2	1.5	0.04	14.0	5.5
Feb.	14.0	2.4	7.3	8.6	0.2	1.8	0.04	0	1.0
March	18.3	6.6	7.6	7.6	0.2	2.1	0.06	0	1.5
April	17.7	13.4	7.6	6.3	0.2	2.1	0.05	0	138.7
May	19.7	17.2	7.7	--	0.2	2.2	0.05	0	164.0
June	20.7	23.8	7.9	--	0.2	1.3	0.10	26.0	202.8

Appendix table 5

155/4

Indian River, Delaware

Station 4 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	21.0	17.6	7.4	--	--	--	0.03	0	140.8
May	24.9	21.2	7.8	--	0.2	2.4	0.05	49.4	94.9
June	24.9	25.7	8.1	4.3	0.2	3.1	0.13	14.0	79.5
July	28.8	26.6	8.3	4.1	0.3	4.8	0.16	220.7	48.5
Aug.	31.2	26.2	7.9	3.6	0.3	4.9	0.16	102.8	144.9
Sept.	30.0	23.7	7.9	4.0	0.5	8.1	0.14	74.3	202.8
Oct.	29.4	15.4	7.8	4.8	0.2	3.1	0.06	490.0	125.3
Nov.	26.0	10.8	8.0	6.9	0.2	1.6	0.09	1.0	397.0
Dec.	19.6	6.3	7.6	6.8	0.1	1.9	0.07	1.0	256.3
Jan.	11.4	3.5	7.1	7.6	0.3	1.7	0.04	0	25.5
Feb.	11.2	2.8	7.1	8.5	0.3	2.1	0.05	0	0
March	14.2	6.4	7.3	7.5	0.2	2.0	0.05	0	14.5
April	13.9	13.7	7.3	6.1	0.3	1.7	0.06	2.0	142.7
May	16.1	17.6	7.4	--	0.2	1.7	0.07	1.0	139.6
June	19.7	24.0	7.6	--	0.1	1.7	0.12	114.6	239.6

CHARLES B. WURTZ, Ph.D., *Consulting Biologist*

3220 PENN STREET
PHILADELPHIA, PA. 19129
215-844-7461

11 January 1973

Mr. H. J. Williams
GPU Service Corporation
260 Cherry Hill Road
Parsippany, New Jersey 07054

Dear Mr. Williams:

On January 9th Mr. Roy Younger, of Resource Management, Inc., and I visited Oyster Creek as requested to investigate the reported fish kill. This letter is a report on the results of our investigation.

At the Route 9 bridge downstream to the end of the parking lot the stream was open with stretches of rim ice along the shore. Water temperature (at 1325) was 34°F at both the surface and the bottom. At 0900 three men were fishing, but they left before noon. No dead fish were seen.

For the lowermost 200 yards at the mouth of Oyster Creek, and along the bay shore for about one-half mile south from the mouth, no dead fish were seen. Rim ice was present along the shorelines.

In the short lagoon at the curve in Dock Ave. (where the newspaper photographs were taken last year) the surface was mostly ice covered. No dead fish were seen.

Four lagoons extend southerly from Oyster Creek and terminate at Bay Ave. These lagoons are bulkheaded and about 100 feet wide. At the butt end they were fully ice covered with the ice about three inches thick. We did see dead fish under (or in) the ice of these lagoons and made counts in the last 50 feet of each lagoon. Estimated numbers, based on our field counts, for each of these four lagoons from west to east follow.

Venice lagoon. An estimated 50 dead menhaden from four to eight inches long were seen in the terminal 5,000 square feet of the lagoon. In addition, a cluster of 20 to 30 one-inch bay anchovy were found dead and frozen into the ice.

Sanabelle lagoon. An estimated 400 dead menhaden were seen in the terminal 5,000 square feet of this lagoon. The size range was two to ten inches.

Buccaneer lagoon. An estimated 50 dead menhaden were found in the terminal 5,000 square feet of this lagoon. These fish were all small, ranging in size from two to four inches.

Privateer lagoon. An estimated 400 dead menhaden were found in the terminal 5,000 square feet of this lagoon. These fish ranged in size from two to ten inches.

Although some gulls were seen on these laggons standing on the ice, the population was apparently the normal resident population. The many hundreds observed last year at the time of the fish kill were not seen this year.

The fish kill appeared quite small compared to that of January 1972. Only 900 menhaden were seen in 20,000 square feet of those areas where dead menhaden were found.

On January 8th, at 1400, Oyster Creek Plant personnel collected a sample of nine dead menhaden from Privateer lagoon. The size and weight of these fish follows.

10.25	inches	7	oz.
9.75	"	4	"
8.5	"	3	"
7.75	"	3	"
7.75*	"	3	"
7.25*	"	3	"
2.75	"	-	
2.0	"	-	

* Pecked by gulls.

These fish showed no scale loss, no cutaneous hemorrhages, no excessive accumulations of mucus, and no distension of the mouth, opercula or gills. Death can be assumed to be the result of a cold kill rather than mechanical damage or the effect of some toxicant.

A further field observation was made at the Beach Blvd. bridge over South Branch Forked River. Some shore ice was present. No dead fish were seen.

We also sampled in the mouth of the discharge pipe that carries water from the trash flume of the travelling screens. A work crew was performing maintenance on the screens and some discharge was coming through. A 15-minute sample produced one living Atlantic silversides, two dead Atlantic herring 2.5 and 3.25 inches long, and ten dead menhaden. Sizes of the latter were: 2.75, 2.75, 2.75, 3 , 3, 3, 3 , 3.25, 3.25, and 3.5 inches. Of

particular interest is the fact that these menhaden were from the intake canal. We presume death was due to mechanical damage by impingement on the travelling screens. In the intake canal any resident menhaden would be expected to have been acclimated to the natural ambient temperature.

Dr. John Reintjes telephoned me this morning from Beaufort. He had been asked to prepare comments on the fish kill by a director of the NMFS in Newark. I summarized the above information for him over the telephone.

I would, of course, appreciate being kept advised of developments in this matter.

Sincerely yours,

Charles B. Wurtz

Charles B. Wurtz

cc7 R. R. Younger
Resource Management, Inc.

CHARLES B. WURTZ, Ph.D., *Consulting Biologist*

3220 PENN STREET
PHILADELPHIA, PA. 19129
215-844-7461

17 January 1973

Mr. H. J. Williams
GPU Service Corporation
260 Cherry Hill Road
Parsippany, New Jersey 07054

Dear Mr. Williams:

This letter represents a follow-up report on the recent fish kill at Oyster Creek. My original letter on this subject was sent under date of January 11th.

The Oyster Creek Plant went down at 6:00 AM on the morning of December 29th. Following this, the water temperatures in Oyster Creek fell to 45°F (surface) and 44°F (bottom), which was the ambient temperature of the water. A severe cold wave began January 6th and dead fish were first reported January 8th. We visited Oyster Creek January 9th, at which time the water temperature of Oyster Creek was 34°F (top to bottom). The results of that visit were presented in my letter of January 11th.

The plant came back on line the night of January 10th, but is apparently not operating at the efficiency level desired. A request to take the plant down again has been made (for the night of January 26th). We felt we needed to know what menhaden population was present in Oyster Creek after the earlier kill and before the plant went down a second time. With this in mind, Mr. Younger and I sampled in Oyster C reek yesterday at our Station 1 (below the Route 9 bridge). In a half-hour setting of 400 feet of gill netting we did not take a single fish. In a comparable setting on December 29th we collected 210 fish, of which 205 were menhaden. At the time of sampling yesterday the water temperature was 53°F (surface) and 55°F (bottom).

Please note, our failure to take fish in the gill nets does not mean fish are not present. Anglers were making good catches of winter flounder from the canal's banks and the bridge. In addition, many small fish were seen in shoal waters. Only one was identified. This was a specimen of fourspine sticleback. Pelagic fish, such as the menhaden, however, were apparently absent.

There are two possible explanations for the absence of menhaden from Oyster Creek at this time.

First, it is possible that a total kill of menhaden occurred as a result of the chilling of the water after the plant shut down. The kill was not immediate because the plant shut down only lowered the water temperature to an ambient of about 44°F, but when natural temperatures lowered to 34°F a kill occurred.

Second, it is possible that after the plant shut down the menhaden in colder, ambient temperatures of 44°F migrated out of Oyster Creek, and those killed were simply residual fragments of the population that were caught in the lagoons and could not escape.

Mr. Younger and I favor the latter thesis for the following reasons:

a. The number of fish killed was much smaller than the number of those killed last year.

b. The only place dead fish were found was at the dead end of each of the four lagoons that project southerly off Oyster Creek.

c. As the water cooled the water of the lagoons would lag behind by virtue of being out of the flow of the stream, and fish would tend to remain pocketed in the lagoons rather than venture into the colder water of the stream.

Those menhaden acclimated to ambient temperatures (i.e., those menhaden resident in South Branch Forked River intake canal) were neither killed by the colder water, nor did they migrate from the area. We sampled yesterday at the mouth of the discharge pipe draining the trash flume from the travelling screens. A five-minute sample produced one 18-inch eel, eight Atlantic herring, five Atlantic silversides, and 87 Atlantic menhaden. The silversides were alive and had survived transport by the screens. Some of the menhaden were alive, but dying. The menhaden ranged in size from 1 1/2 to 4 inches. (It is possible that larger menhaden may be present in the intake canal, but that they resist impingement on the screens.) These fish were killed mechanically by impingement and physical damage; they were not cold-killed. One northern pipefish was also seen alive and uninjured by Mr. Younger, but it escaped the sampling net. (The herring were dead.) (The eel was dead, and had been for some time. Death must have occurred at the intake screens.)

Our regular sampling program is scheduled to be concluded next week. You will recall, the proposal was made for six monthly samples (August through January). We expect to be in the field next Thursday, Friday and Saturday (January 25-27). We would be happy to have you join us if you are able to get away from your other duties.

A few days ago I gave you information on the dollar value of menhaden as y ou had requested over the telephone. The sources of this information were Commercial Fisheries Review, U.S.Dept. Commerc e, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Vol. 33, No's. 11-12. An article in that journal gave values as $186/ton in January 1971, $150/ton in June 1971 and $160/ton in September 1971. In addition, Mr. Younger had a telephone conversation with the Belford Fisheries Coop (N.J.) and was advised that last summer they were selling menhaden at $5/100 lbs.

I enclose my invoice for services and costs associated with the fish kill investigation. Although I have posted this against Purchase Order No. 64608, as r equested, I am not sure this is appropriate. It would appear that the purchase order was issued only for our regular program.

If you have any questions about any of the above I would be most happy to respond to them.

Sincerely yours,

Charles B. Wurtz

Charles B. Wurtz

Enclosures
cc/ Mr. R. R. Younger
Resource Management, Inc.

Appendix table 6

155/5

Indian River, Delaware

Station 5 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	16.3	17.9	7.2	--	--	--	0.05	44.5	167.0
May	21.6	21.7	7.8	—	0.3	3.8	0.08	193.3	112.0
June	21.3	26.2	8.0	5.1	0.2	3.8	0.16	19.8	140.3
July	27.1	27.3	8.4	5.1	0.2	5.8	0.21	4.3	62.0
Aug.	29.9	26.5	8.1	4.3	0.5	6.8	0.18	84.5	142.1
Sept.	28.4	23.9	8.0	4.4	0.3	10.5	0.16	215.4	189.6
Oct.	28.1	15.8	7.8	5.1	0.2	3.1	0.08	0	144.4
Nov.	24.3	10.8	7.9	7.1	0.1	1.8	0.10	1.5	661.3
Dec.	11.7	6.2	7.2	7.2	0.3	2.0	0.05	2.0	54.0
Jan.	7.8	4.0	6.9	7.5	0.3	1.7	0.04	0	62.0
Feb.	8.7	3.3	7.0	8.0	0.5	5.6	0.08	0	4.0
March	10.9	6.8	7.1	7.1	0.3	1.3	0.06	0	6.3
April	9.9	14.1	7.0	5.6	0.4	2.6	0.07	93.0	392.5
May	8.8	17.3	7.0	—	0.5	3.3	0.10	365.2	79.0
June	16.9	25.0	7.4	--	0.2	3.1	0.32	91.3	280.6

Appendix table 7

155/6

Indian River, Delaware

Station 6 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	14.3	18.6	7.1	--	--	--	0.09	78.0	198.5
May	19.6	22.6	7.9	--	0.2	4.4	0.10	313.1	116.6
June	18.3	26.7	7.9	5.8	0.2	4.3	0.20	37.0	85.5
July	25.5	27.8	8.4	6.0	0.2	7.8	0.21	4.2	73.8
Aug.	29.2	27.2	8.1	4.8	0.4	7.8	0.23	11.4	118.6
Sept.	27.1	24.2	7.9	4.7	0.3	10.8	0.18	141.7	172.7
Oct.	27.0	16.0	7.6	5.1	0.2	3.5	0.10	141.7	104.8
Nov.	22.3	11.2	7.8	7.2	0.1	2.3	0.14	1.0	476.0
Dec.	9.1	6.4	6.9	6.9	0.4	5.1	0.09	2.0	111.3
Jan.	5.6	3.9	6.7	7.2	0.4	1.9	0.04	3.0	21.7
Feb.	7.6	3.6	6.8	8.0	0.6	3.7	0.12	0	4.0
March	8.6	6.9	7.0	7.1	0.4	2.1	0.05	0	139.3
April	7.6	14.0	6.9	5.3	0.5	2.6	0.07	58.2	301.3
May	6.1	17.1	6.6	--	0.7	2.7	0.09	425.0	143.2
June	13.2	25.3	7.2	--	0.2	2.5	0.36	113.6	219.0

Appendix table 8

155/7

Indian River, Delaware

Station 7 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	8.9	22.7	6.8	--	--	--	0.10	2.3	132.0
May	17.3	23.3	7.9	--	0.3	5.4	0.12	439.9	94.1
June	16.3	27.5	8.0	6.9	0.3	4.7	0.23	82.8	53.2
July	23.0	28.5	8.5	6.5	0.3	9.0	0.27	3.0	45.0
Aug.	27.3	26.1	7.9	4.4	0.4	5.1	0.21	4.0	244.3
Sept.	25.6	24.7	7.8	5.0	0.3	8.5	0.20	27.3	202.5
Oct.	25.8	16.4	7.5	5.3	0.2	3.3	0.12	428.3	291.1
Nov.	19.9	11.3	7.6	7.6	0.1	2.2	0.19	1.0	617.8
Dec.	8.1	6.1	6.9	6.4	0.3	2.1	0.05	2.0	592.0
Jan.	5.0	4.7	6.6	7.1	0.4	2.0	0.06	1.0	122.8
Feb.	5.5	4.0	6.6	7.6	1.1	5.4	0.13	0	0
March	7.6	7.0	6.8	7.0	0.4	2.3	0.05	0	77.7
April	5.7	14.1	6.7	5.3	0.5	2.5	0.09	5.0	248.7
May	3.9	17.1	6.5	--	0.6	2.9	0.11	83.0	197.0
June	10.9	25.6	7.1	--	0.3	3.4	0.49	92.6	200.6

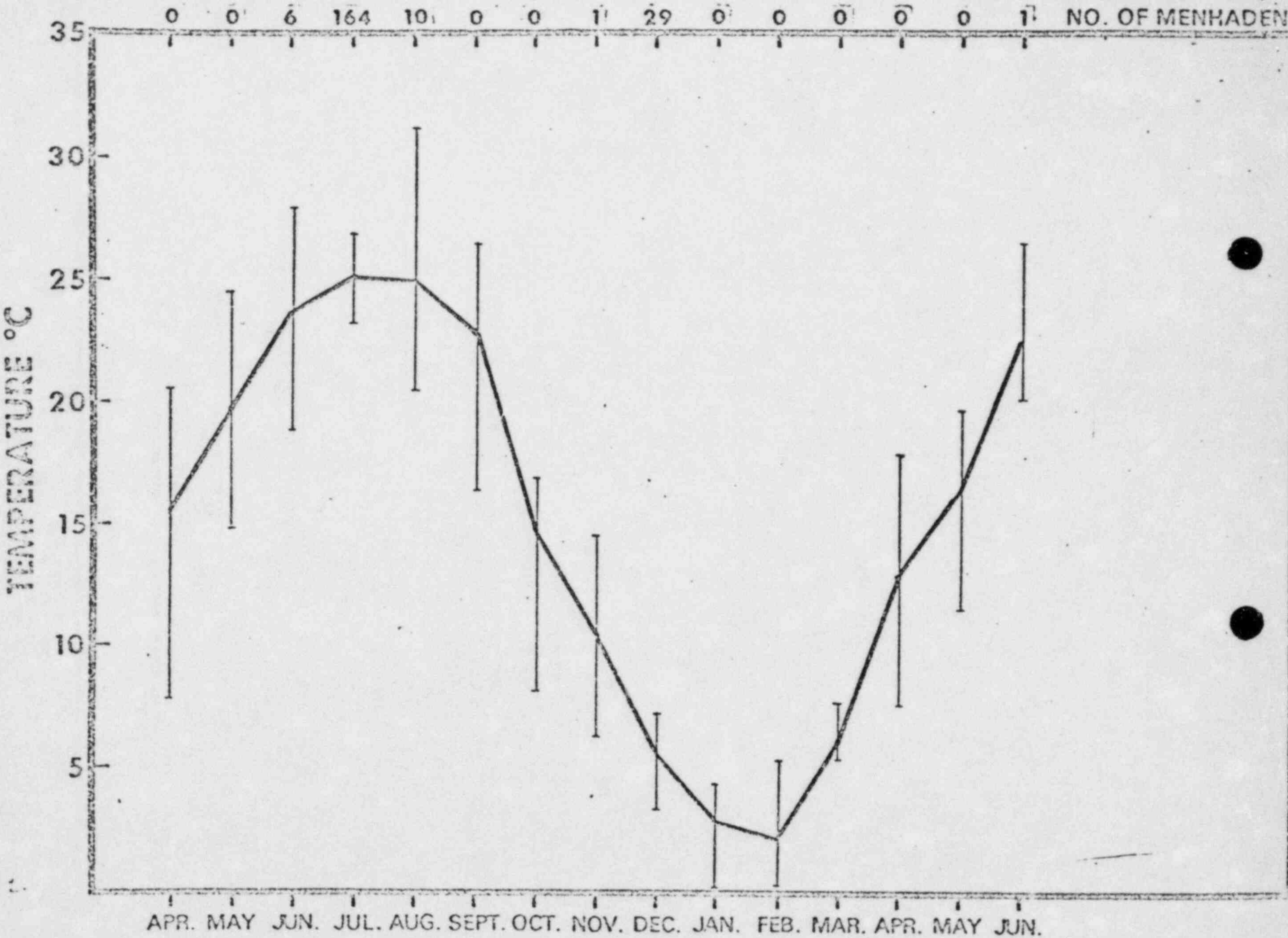
Appendix table 9

155/8

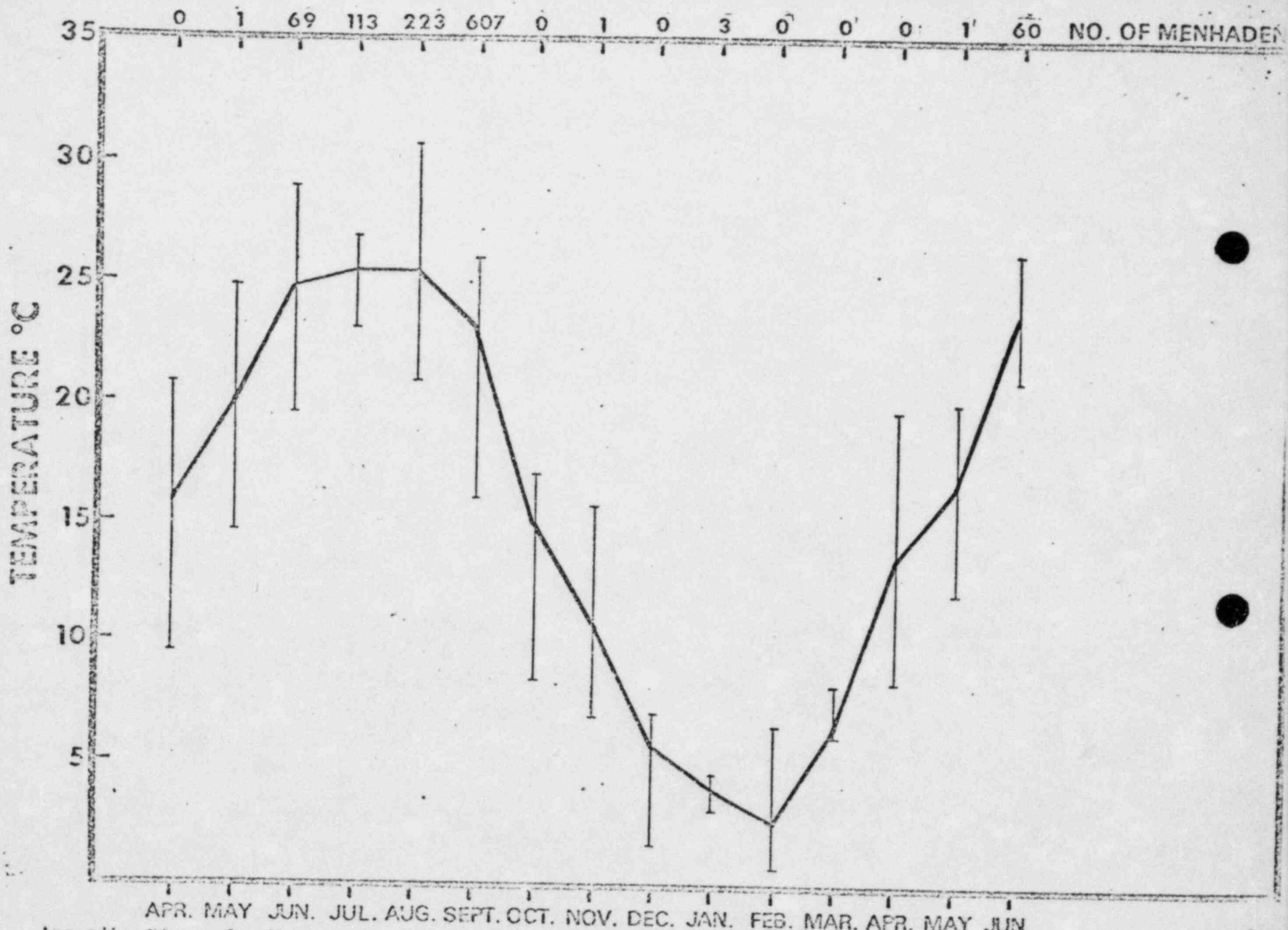
Indian River, Delaware

Station 8 - Monthly mean salinity, temperature, pH, oxygen, phosphates and suspended solids with mean number of menhaden and other fishes, 1957-1958.

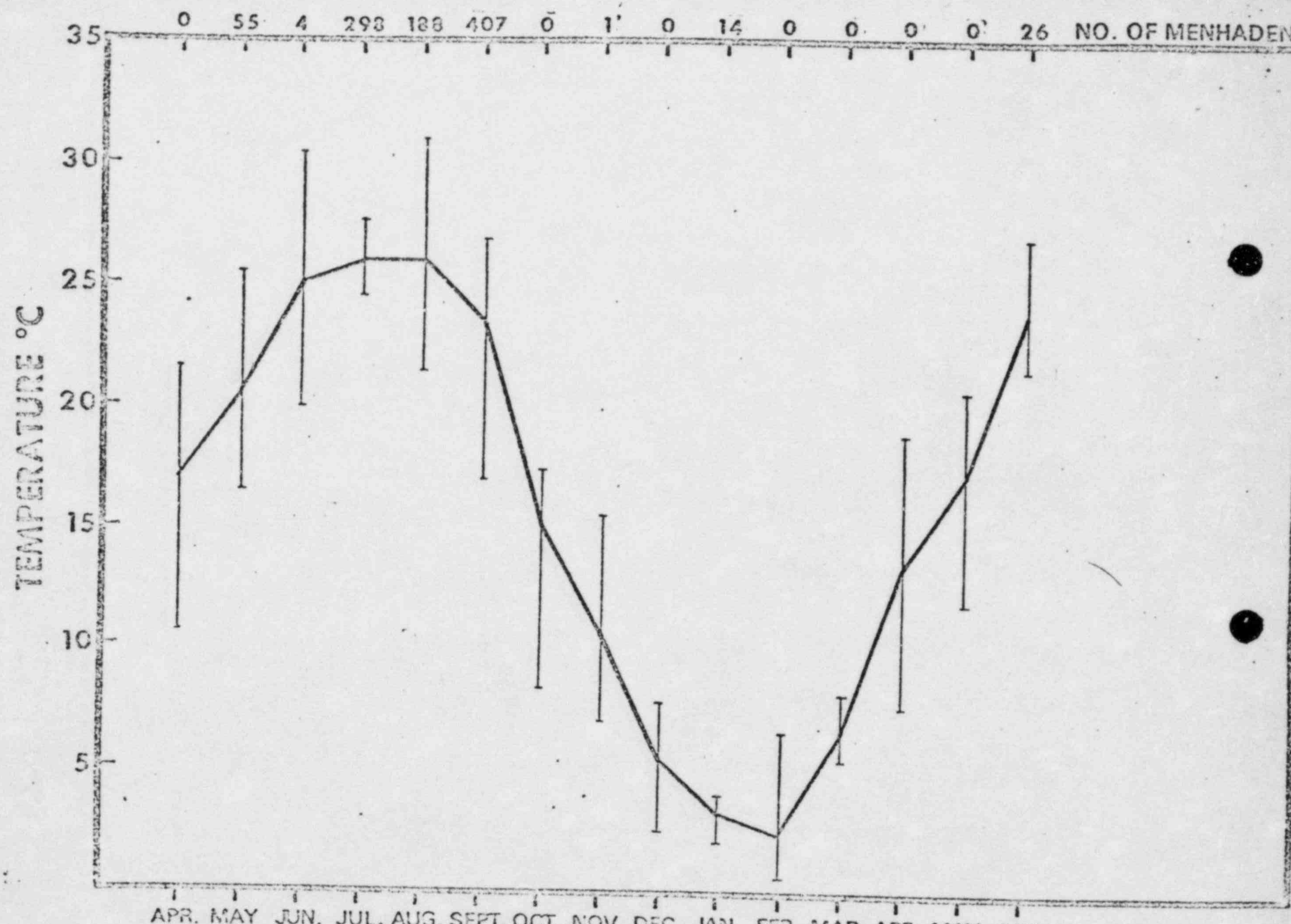
Month	Salinity p.p.t.	Temp. °C	pH	O_2 ml/l	Inorg. PO_4 µg-at/l	Total PO_4 µg-at/l	Solids ml/l	No. of menhaden	No. of other fishes
April	--	--	--	--	--	--	--	--	--
May	16.2	21.4	7.4	--	0.3	3.2	0.20	230.3	60.8
June	12.9	27.0	7.6	7.0	0.3	4.1	0.20	54.2	90.7
July	20.4	28.0	8.2	7.1	0.3	7.3	0.22	9.0	58.8
Aug.	27.0	23.3	7.4	3.5	0.3	7.0	0.16	21.0	22.0
Sept.	24.7	24.0	7.7	4.6	0.4	11.0	0.16	119.7	134.1
Oct.	23.8	16.0	7.3	5.3	0.2	2.4	0.09	31.8	143.3
Nov.	18.0	11.4	7.4	7.7	0.5	2.1	0.16	1.0	669.8
Dec.	5.5	6.2	6.7	6.3	0.3	1.5	0.06	0	267.0
Jan.	1.4	4.7	6.7	6.6	0.6	2.0	0.05	1.0	1450.0
Feb.	4.5	3.9	6.4	7.0	1.2	6.0	0.14	0	1.0
March	5.9	7.1	6.6	6.5	0.4	2.4	0.05	0	190.0
April	2.9	13.7	6.5	5.2	0.7	4.6	0.06	0	514.1
May	1.6	16.5	6.3	--	1.0	5.2	0.11	0	392.8
June	10.0	24.3	7.0	--	0.2	3.9	0.28	189.0	411.8



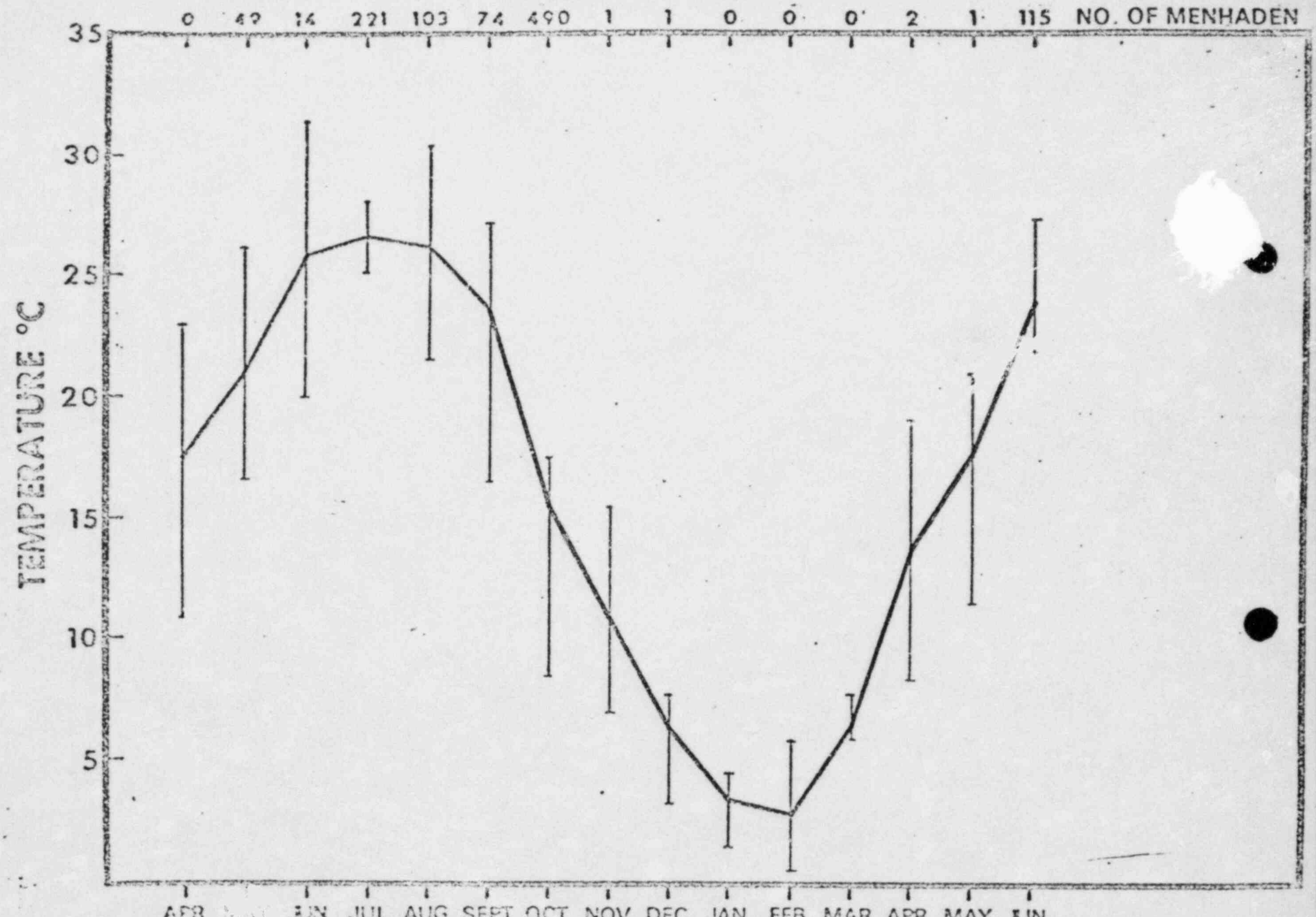
Appendix Figure 1. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 1 White Creek, a tributary of Indian River, Delaware.



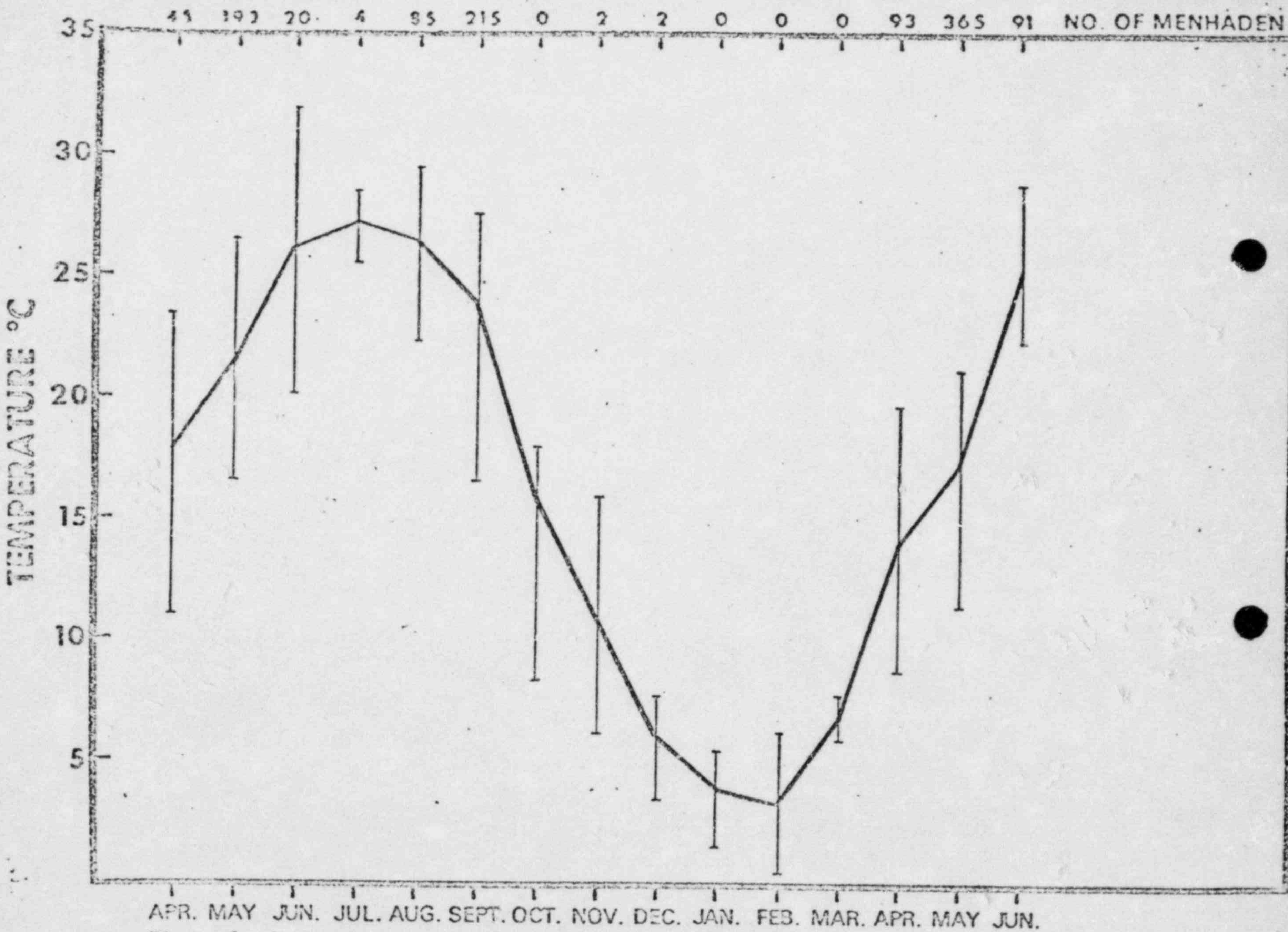
Appendix Figure 2. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 2 White Creek, a tributary of Indian River, Delaware.



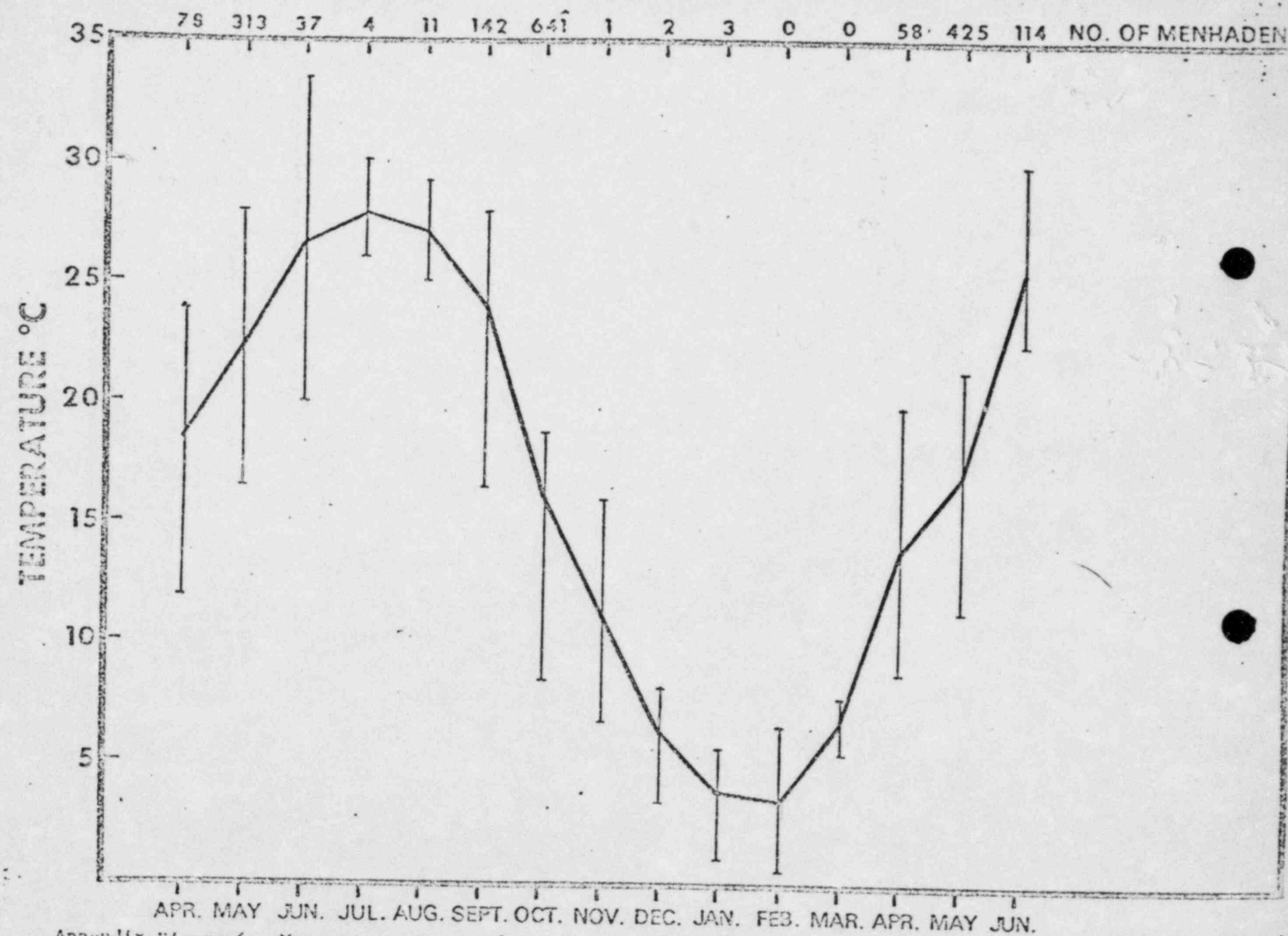
Appendix Figure 3. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 3 White Creek, a tributary of Indian River, Delaware.



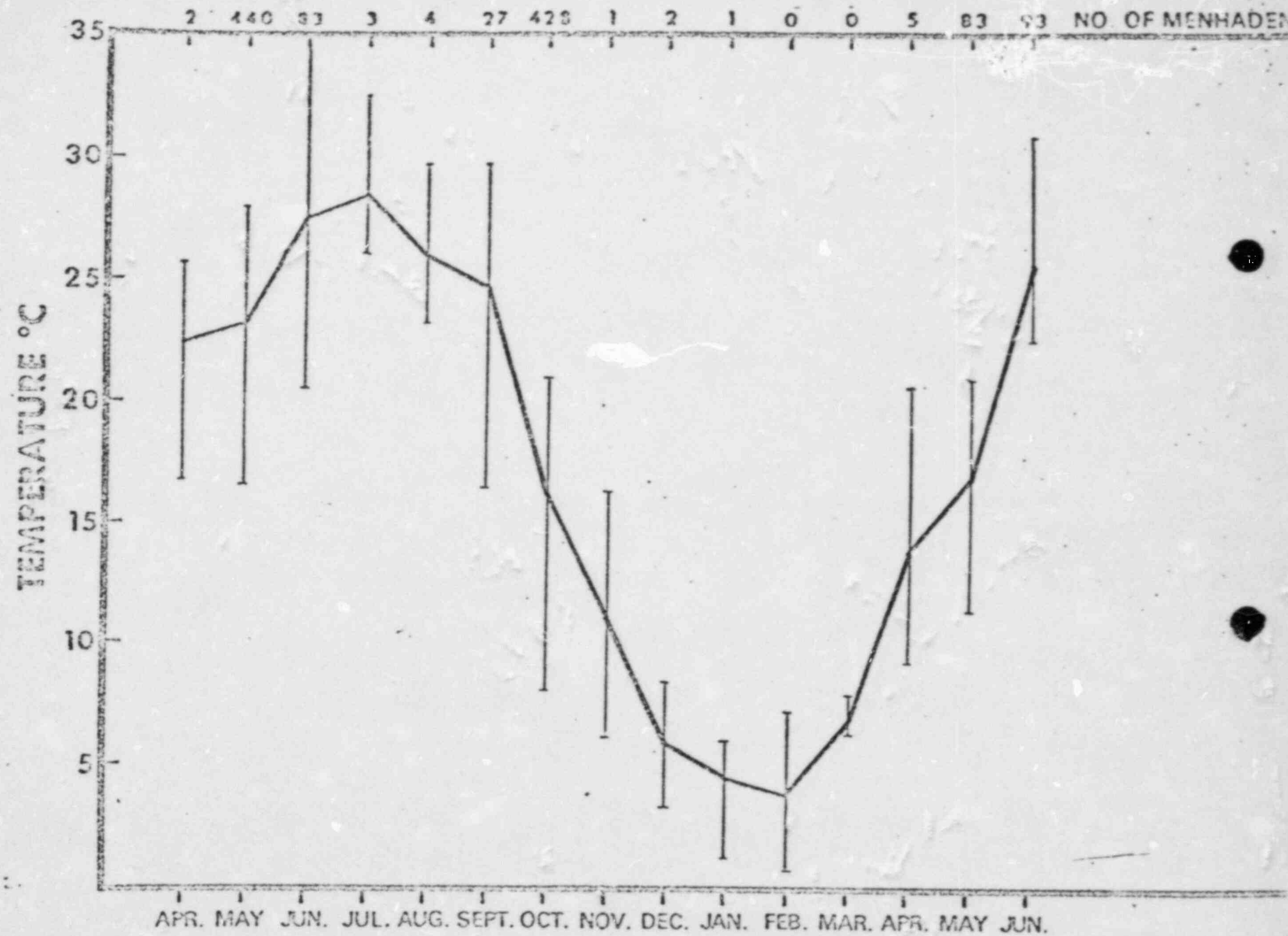
Appendix Figure 4. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 4 White Creek, a tributary of Indian River, Delaware.



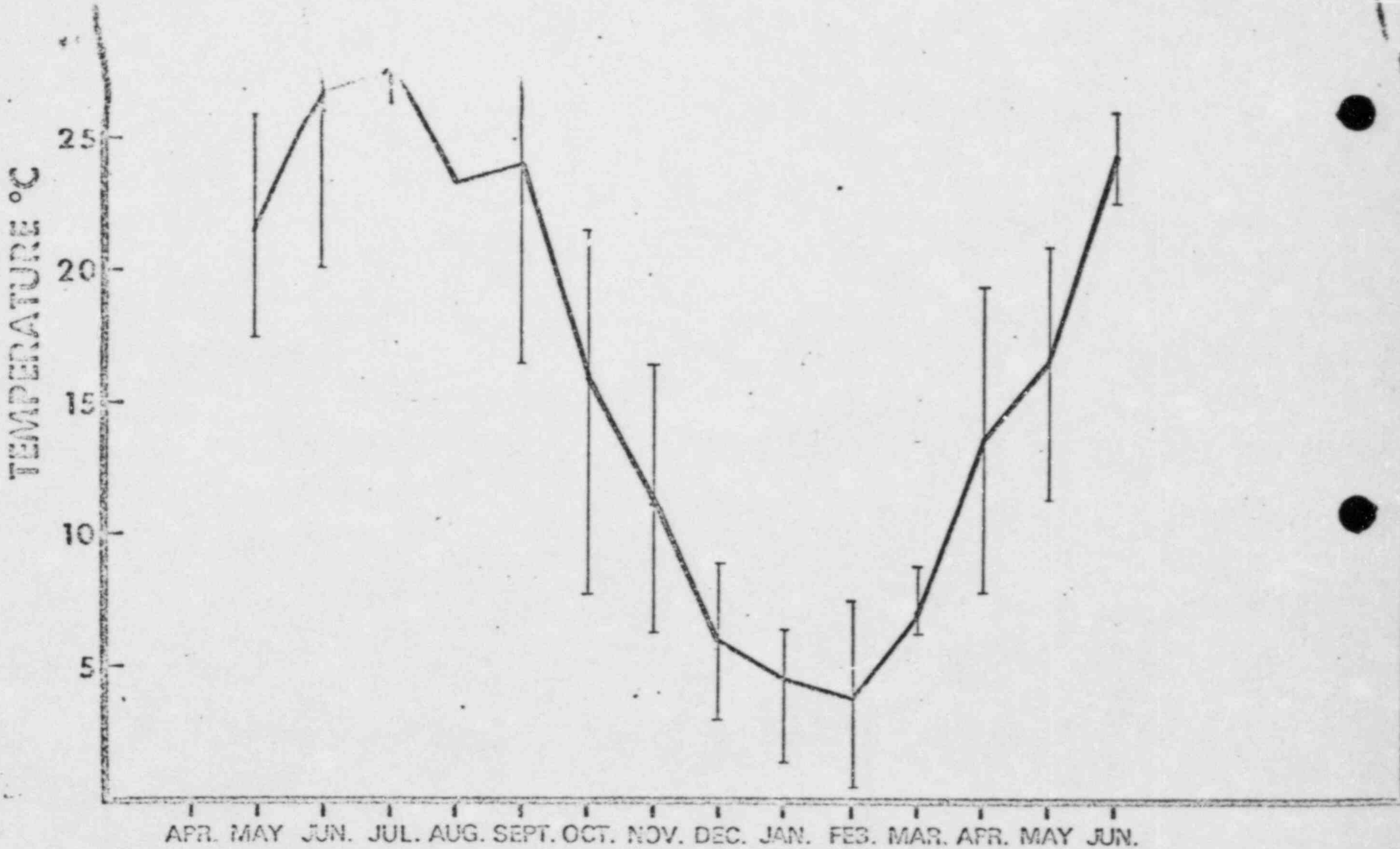
Appendix Figure 5. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 5 White Creek, a tributary of Indian River, Delaware.



Appendix Figure 6. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 6 White Creek, a tributary of Indian River, Delaware.



Appendix Figure 7. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 7 White Creek, a tributary of Indian River, Delaware.



Appendix Figure 8. Mean temperature and range by month, 1957-1958, with mean number of menhaden at Station 8 White Creek, a tributary of Indian River, Delaware.