ABUNDANCE AND DISTRIBUTION OF YOUNG ATLANTIC MENHADEN, *Brevoortia tyrannus,* IN THE WHITE OAK RIVER ESTUARY, NORTH CAROLINA

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ABSTRACT

The effect of salinity, temperature, tide, turbidity, and illumination on the distribution of larval, prejuvenile, and juvenile menhaden in an estuary was investigated. Most menhaden larvae entered the estuary in March after the water had warmed to about 10° C, and moved upstream to the low-salinity-freshwater zone where they transformed into juveniles. More larvae were caught in the lower estuary on flood tide. After transformation to juveniles they were caught in schools throughout the estuary. Turbidity and illumination did not affect the distribution of menhaden, but illumination affected catchability, since more menhaden were collected during night tows.

In this study we investigated the effects of temperature, salinity, and light on the distribution and abundance of larval, prejuvenile, and juvenile menhaden in a single estuary, the White Oak River in North Carolina. As the strength of individual year classes of Atlantic menhaden fluctuates widely, we were interested in determining what effect these environmental factors had on menhaden during their first year in an estuary. This information could be helpful in assessing and predicting the strength of individual year classes. Estimates of the strength of individual year classes before they enter the fishery would be valuable to the commercial fishery. A single estuary was selected so that a better understanding of these variables could be achieved before being applied to a coastwise fishery.

Atlantic menhaden, found along the eastern coasts of the United States and Canada from Nova Scotia to southern Florida (Hildebrand, 1964; Reintjes, 1964), spawn in almost every month in some part of their range (Higham and Nicholson, 1964). Menhaden are spawned in the ocean and enter an estuary as larvae. Once strong enough to swim against the tidal currents, they move upstream towards fresh water (Lewis and Mann, 1971) where they transform into juveniles. They remain in the estuary for their first growing season, gradually moving downstream in the summer and reaching the lower estuary or open sea by autumn (June and Chamberlin, 1959; Massmann, Ladd, and McCutcheon, 1954).

STUDY AREA, SAMPLING LOCATIONS, PROCEDURES, AND NETS

The White Oak River estuary is a bar-built estuary (Pritchard, 1967) which drains forest lands in the upstream part and salt marshes in the downstream part (North Carolina State Board of Health, 1954). The Intracoastal Waterway crosses the mouth of the estuary near Bogue Inlet.

We selected this estuary because: (1) We knew from preliminary sampling that larval menhaden entered the lower section from the ocean in the winter and early spring and that juveniles occurred in the upper section in the summer; (2) its small size (28 sq km) permitted ample sampling coverage; and (3) its proximity to the Beaufort laboratory made frequent sampling easy.

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We assumed that few or no larvae moved from other estuaries into the White Oak River estuary.

We collected larval, prejuvenile, and juvenile menhaden at 14 sampling locations extending 34 km upstream from Bogue Inlet (Figure 1). The distance between stations varied from 2 to 5 km and averaged about 3 km. The type of gear we used, frequency of sampling, and date of sampling are listed in Table 1.

TABLE 1.—The White Oak River estuary sampling schedule.

Sampling location	Sampling frequency	Gear	Sampling period
Swansboro Bridge (Station 2)	2-3 days/week	Channel net	Nov. 1967-Apr. 1968
			Nov. 1968-Apr. 1969
Upstream stations 6-12	Monthly	Surface trawl	July-Sept. 1968
Upstream stations 6-12	Weekly	Channel net	Feb.-Apr. 1969[1]
Upstream stations 6-12	Biweekly	Channel net	May 1969
Upstream stations 6-12	Monthly	Channel net	June-Sept. 1969[2]

[1] Stations 1, 3, 4, and 5 were sampled irregularly in this period.
[2] A few samples were taken upstream with the surface trawl in this period.

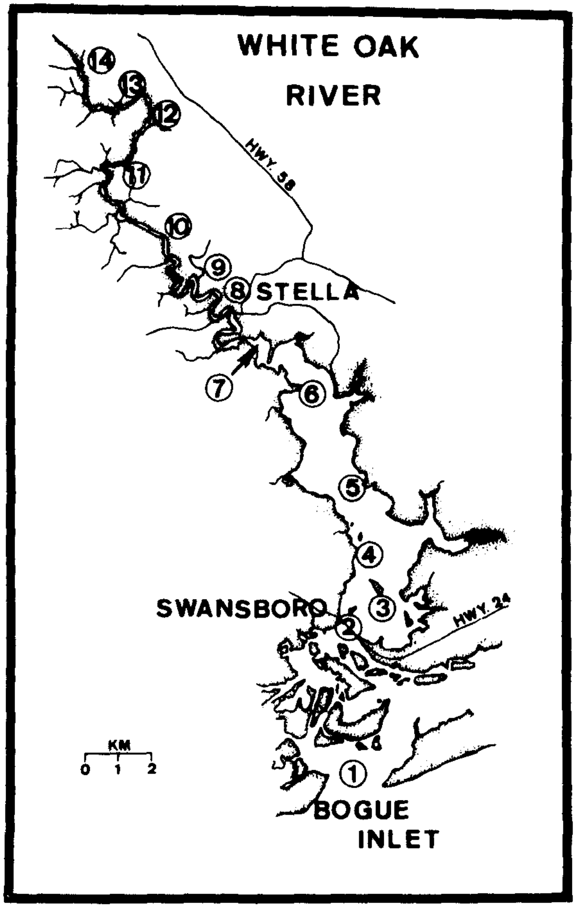

FIGURE 1.—Sampling locations for young menhaden on the White Oak River estuary, N.C.

We sampled larvae entering the estuary at the Swansboro Bridge (station 2) 2 or 3 days per week from November through April in 1967-68 and 1968-69. During July, August, and September 1968, we sampled at several of the upstream stations. Starting in February 1969 we collected menhaden throughout the river and estuary, although our efforts were concentrated on the upstream section (stations 6 through 12). In March and April we visited these stations every week; in May, every 2 weeks; and from June to September, every month.

During the 1967-68 and 1968-69 seasons, we sampled for larvae with a channel net described by Lewis, Hettler, Wilkens, and Johnson (1970). The net, with a 1 by 3 m opening, had a tail bag constructed of 0.5-mm mesh. At Swansboro we attached the net to the bridge and made four to six 30-min sets per day. At the other locations, we towed the net between two 16-ft aluminum boats and made a 15-min set when the larval and prejuvenile menhaden were scarce and a 5-min set when they were abundant.

During July, August, and September 1968, we sampled juveniles with a 6.1-m surface trawl having a 6.2-mm bar mesh. We towed it in the same manner as the channel net. During the corresponding months in 1969, most of the collections were made with the channel net.

In all the collections, the number of menhaden caught was expressed as an index (I = number of young menhaden per 100 m^3 water strained).

We recorded surface temperature and salinity at the start and end of each set at the bridge and at the end of each tow at the other sites. We measured the amount of water strained by the net during each set with a flowmeter. Dissolved oxygen and turbidity readings were taken only in July, August, and September 1968.

TEMPORAL DISTRIBUTION

Larval menhaden entered the White Oak River from November until early May. Two peaks of abundance occurred each year, one in November and December and the second and major peak in February and March (Figure 2).

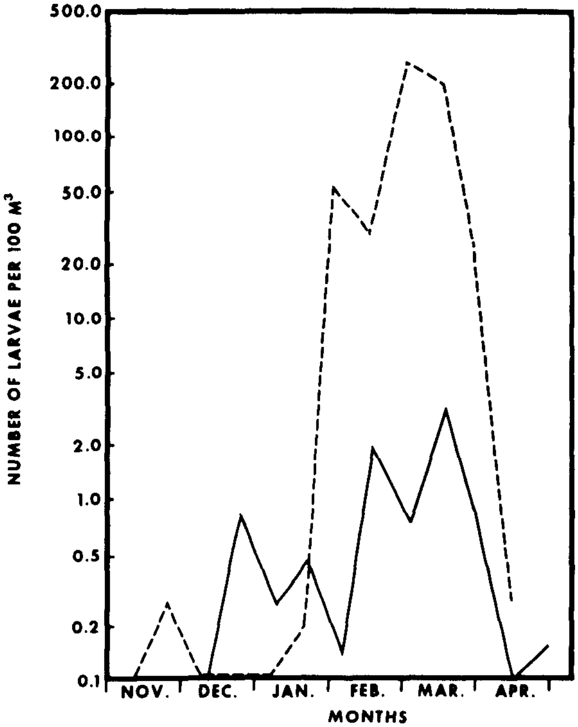

FIGURE 2.—The mean biweekly abundance indexes at Swansboro Bridge in 1967-68 (solid line) and 1968-69 (dashed line).

The entrance of large numbers of larvae in February and March probably resulted from the migratory schools of menhaden that spawned off the North Carolina coast during the winter. Higham and Nicholson (1964) found that during November and December most of the females in the landings were nearly ripe. Reintjes (1969) reported finding hundreds of thousands of developing menhaden eggs off the North Carolina coast in December 1966.

Those larvae that entered the estuary during November and December were probably the

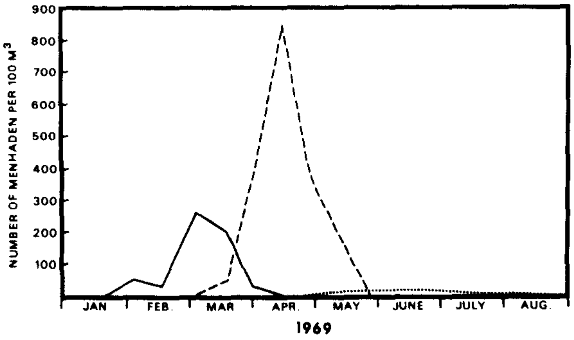

FIGURE 3.—The relative abundance of larval (solid line), prejuvenile (dashed line), and juvenile menhaden (dotted line) in the White Oak River estuary. (The larval indexes are from the bridge, and the prejuvenile and juvenile indexes are from the upstream zone where the fresh and salt water mix. Larval and prejuvenile indexes are biweekly means, but the juvenile index is a monthly mean plotted on the day the sample was obtained.)

progeny of fish that either had inhabited North Carolina waters in the summer or had moved into North Carolina waters from other areas in early autumn.

Prejuvenile menhaden were first caught in March and became abundant in late March and April (Figure 3). After the peak in April the number of prejuveniles decreased, and by the beginning of May most had transformed into juveniles.

Juvenile menhaden, collected in relatively low numbers from May until September, occurred with maximum abundance in late May and June. As young menhaden got above 45 mm fork length during the summer of 1968, we caught fewer fish during the day. To determine if illumination was a factor that resulted in greater net avoidance by juvenile menhaden, we scheduled a series of day-night sampling trips. We collected larger samples of menhaden during nighttime tows, which indicated that some fish were able to avoid our net during the day. Fish from day and night tows were similar in length. In addition, we caught more menhaden on overcast or moonless nights than on clear, moonlight nights. As a result of our findings in 1968, we sampled for juveniles in 1969 only at night in order to increase our sampling efficiency.

EFFECT OF SALINITY, TEMPERATURE, AND TIDE ON THE DISTRIBUTION OF YOUNG MENHADEN

SALINITY

Larval menhaden, after entering the lower estuary, move upstream into lower salinities to metamorphose. They seek the zone of the river from 1 ‰ salinity to fresh water. This zone extends a short distance upstream from the interface between fresh and salt water. Larval and prejuvenile menhaden were most abundant in this zone where metamorphosis occurs (Figure 4). They apparently range into fresh water for only a short distance since they were absent or present only in small numbers in our samples farther upstream.

After the menhaden have transformed from prejuveniles to juveniles, they appear to seek higher salinity water. In late May when most of the prejuveniles had metamorphosed, we found juveniles in low-salinity water. As the season progressed the juveniles were present in the low-salinity water upstream, but they tended to be more abundant in water downstream. Schools of juvenile menhaden generally moved out of the estuary in the fall.

Both the position and length of the upstream zone where young menhaden concentrated are influenced by tidal excursion, rainfall, and wind direction and strength. A northeast wind causes unusually high tides and pushes salt water farther upstream than during normal flooding and ebbing tides.

We do not understand why low-salinity water is important to young menhaden, but one explanation is that they cannot metamorphose properly in either fresh or high-salinity water. When larvae were held in salinities ranging from 15 to 40 ‰, about one-third of the fish in each salinity group developed abnormalities of the spine (Lewis, 1966). Juveniles may also congregate in low-salinity areas at times because food may be more abundant.

In some estuaries turbidity may vary with salinity. We measured the turbidity at the Swansboro site in March, April, and May 1968 and at our upstream sites during the summer of 1968 to determine if it affected the number of young menhaden caught by our net, and to see if there was any relation between salinity and turbidity. At Swansboro, where the water remained relatively clear (light transmittance ranged from 89 to 96%), no correlation existed between turbidity and the catch of larvae. At our upstream tow areas, where the water also was clear, light transmittance ranged from 68 to 95%. We also found no relation between turbidity and catch of young menhaden. We concluded therefore that turbidity was too low to affect catchability in the White Oak River. As there were no marked differences between up- and downstream turbidities, we concluded also that there was no relation between salinity and turbidity.

TEMPERATURE

Larval menhaden are sensitive to low temperatures, particularly if the salinities are high or low. They have the best chance for survival in an estuary if the temperature remains above 4° C and the salinity ranges between 10 and 20 ‰ (Lewis, 1966). Below 4° C they survive for only a short time. Lewis (1965) determined that the number of hours to 50% mortality at 2.0° C varied from 3.2 to 38.5 hr depending on the acclimation temperature.

We compared the temperatures in the estuary during the 2-year study with temperature tolerances of larval menhaden determined in the laboratory by Lewis (1965, 1966). The water temperature in the White Oak River went below 4° C for several days in January and December 1968 and January 1969. Except for two sampling days in 1968 and one in 1969, the water temperature did not get over 10° C from the beginning of January to mid-March; it stayed at 2° C for 2 days during this period in 1968, and 1 day in 1969. We caught few menhaden larvae during the periods of low water temperature.

Most larvae that enter the estuary before the lethal cold water temperatures in the winter probably do not survive, while those that enter during the late winter and early spring probably remain in the downstream area because of the colder water upstream. As the water warms in the spring to above 10° C they move towards

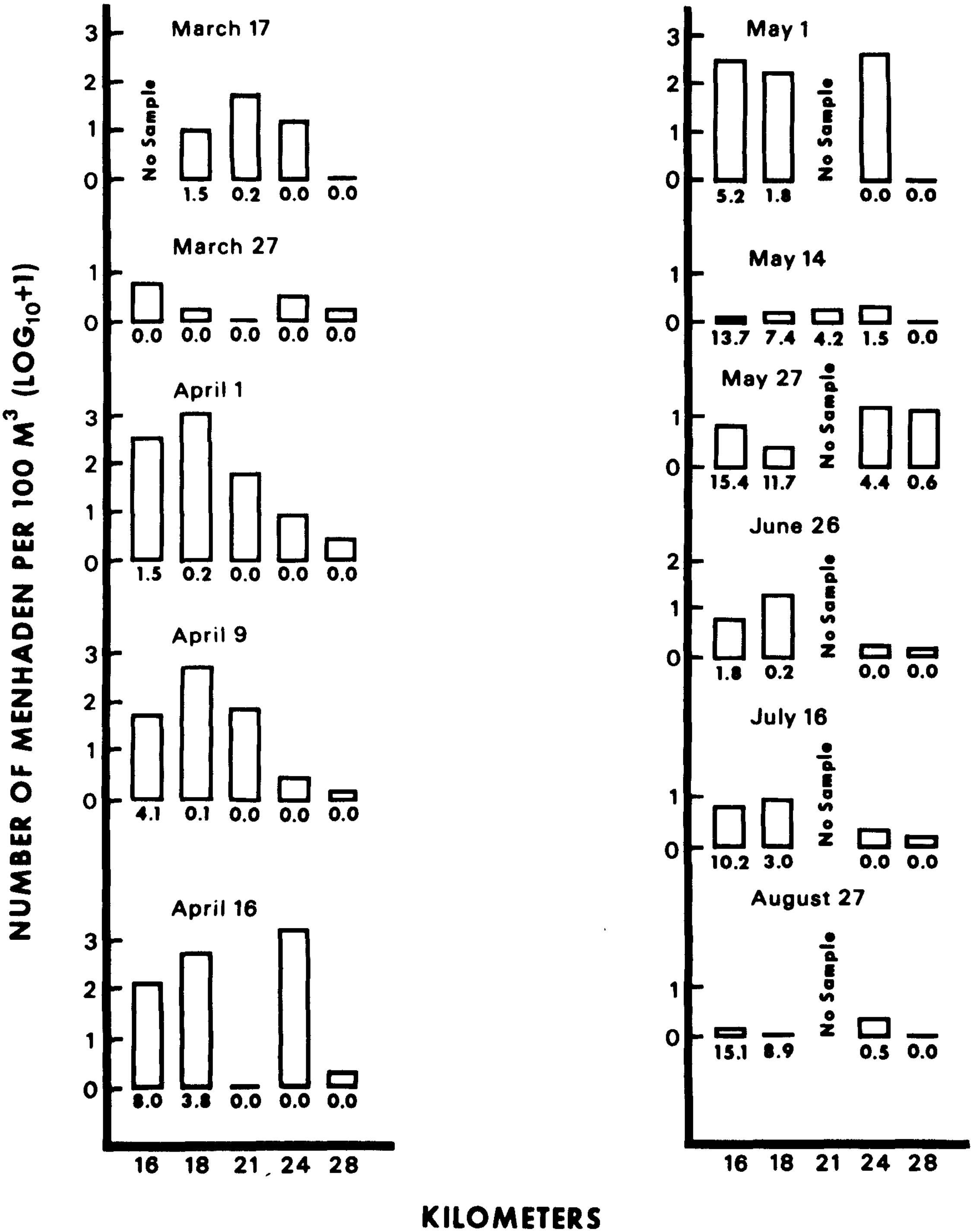

FIGURE 4.—The distribution of menhaden by date, kilometer, and salinity in the White Oak River, March-August 1969. (Number below each bar is salinity at station.)

the low-salinity freshwater zone. Those that enter later in the season, after the water has warmed, move upstream in a shorter time. Once menhaden had moved upstream, salinity and food supply probably affected their distribution more than temperature.

Since dead menhaden larvae do not float, we probably would not notice if kills occurred when the temperature dropped below 4° C. However, we did observe many dead young and adult bay anchovy (*Anchoa mitchilli*) and pinfish (*Lagodon rhomboides*) floating on the surface on January 10 and 12, 1968, when the water temperature was 2° C. Some of the floating fish revived when placed in warmer water, but most did not. We assume that many of the species present in the estuary either died from or were subject to cold stress. Thus any cold weather that occurs during the time larval fish are present in the estuary can have an important effect on the number of individuals surviving in the population.

Although high water temperature does kill juvenile menhaden, it did not appear to cause any mortality in the White Oak River estuary. In laboratory tests, juvenile menhaden died in water temperatures above 33° C (Lewis and Hettler, 1968). In the White Oak River the temperature remained below 33° C except for a short period when it rose to 34.1° C.

TIDE

Velocity of water current affects the abundance and distribution of fish larvae in an estuary. Bishai (1959) found that herring larvae (6-8 mm total length) maintained themselves in a current of 0.58 to 1.03 cm/sec and that at higher velocities they drifted with the current but at a rate less than the current.

During our sampling in the field we noticed that larval menhaden also held their positions only in weak currents. The menhaden larvae collected at the Swansboro bridge were larger (10-30 mm total length) than the herring tested by Bishai and seemed able to maintain their position at velocities less than 10 cm/sec. Above this velocity they were carried by the current. One would expect, therefore, to obtain large larval indexes during peak tidal flows at midflood and at early ebb. Larval indexes during these periods varied considerably, but in general were larger than indexes during late ebb and early flood tide stages (Table 2). The variability in abundance indexes arises, in part, from day-to-day changes in menhaden distribution in the lower estuary during the 2-month period. A 24-hr study in March 1968 at Beaufort, N.C., showed that larval abundance varied with the tide, current, and time of day (Lewis and Wilkens, 1971).

TABLE 2.—Number of menhaden larvae per 100 m^3 of water at hourly flood and ebb-tide stages, Swansboro, N.C., February-March 1969.

Stage	Hour	Mean velocity	Abundance index	Range	Number of collections
		m/sec			
Flood	1	0.10	33.6	17.2- 45.2	3
	2	0.17	216.0	16.0- 591.4	4
	3	0.15	94.9	0.8- 578.4	8
	4	0.18	74.0	4.0- 338.8	7
	5	0.15	894.9	1.5-3,582.0	7
Ebb[1]	1	0.22	65.6	20.6- 110.6	2
	2	0.27	168.0	25.6- 365.4	3
	3	0.23	43.1	7.2- 121.1	5
	4	0.21	26.4	0.4- 90.5	6
	5	0.19	17.8	2.2- 82.9	7
	6	0.16	6.5	1.9- 13.0	8
	7	0.11	8.7	1.4- 14.4	7

[1] The ebb-tide stage generally lasted about 2 hr longer than flood.

Tides affect the movement of larvae in and out of an estuary as well as within an estuary. Flooding currents carry larval menhaden into the estuary where, before heading upstream, they move back and forth with the changing tides. At the Swansboro bridge station more larvae were caught on flood tide than on ebb. During February and March 1969, larval indexes greater than 10 occurred in 81% of the sets made on flood tide but only in 51% of the sets on ebb tide. June and Chamberlin (1959) reported similar results at Indian River, Del. Some of the larger catches of the season occurred on late flood. The early hours of ebb tide had higher larval indexes than late ebb. As more larvae enter than leave, the number of larvae in the estuary reaches a maximum by midspring.

Tidal stage and current velocity affected the catchability of larvae. In the lower estuary these forces either concentrated the larvae in one location or spread them over a large area. In the upper estuary the location and width of the low-salinity-freshwater zone, which was influenced by the tide, affected the distribution of larvae and prejuveniles.

SUMMARY

Larval menhaden were present in the White Oak River estuary from November to May but were most abundant in February and March. Prejuveniles were abundant in late March and April, and by the beginning of May most had transformed into juveniles. Our largest catches of juveniles occurred in May.

Larvae progress upstream to the zone where the salt and fresh water mix (0-1 ‰ salinity). Large catches of prejuvenile and larval menhaden occurred within this zone. We did not find juvenile menhaden in the zone until the end of May when most prejuveniles had transformed to juveniles.

Laboratory tests from other studies showed that menhaden died when the water temperature fell below 4° C and rose above 33° C. Even though young menhaden encountered both extremes of water temperature in the White Oak River, we saw no evidence of any deaths.

Catches of larval menhaden at the Swansboro bridge were more abundant on flood tide than ebb. The early hours of ebb tide had higher larval indexes than late ebb.

Illumination affected the catches of juvenile menhaden at our upstream stations as we caught more menhaden on overcast or moonless nights than on clear, moonlight nights or during the daylight hours.

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