GEOGRAPHIC AND HYDROGRAPHIC DISTRIBUTION OF ATLANTIC MENHADEN EGGS AND LARVAE ALONG THE MIDDLE ATLANTIC COAST FROM RV *DOLPHIN* CRUISES, 1965-66

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ABSTRACT

Atlantic menhaden, *Brevoortia tyrannus*, eggs and larvae were collected during eight ichthyoplankton cruises of the RV *Dolphin* from December 1965 to December 1966. On each cruise tows were made with a Gulf V plankton net at 92 stations along 14 transects from the coast to the edge of the continental shelf from Martha's Vineyard, Mass., to Cape Lookout, N.C. Larvae resulting from a protracted spawning season were taken throughout the year. Eggs were taken over the middle of the shelf in fall. Seasonal shifts in geographic pattern of larvae indicated spawning started in summer off New Jersey and New York, became widespread in the Middle Atlantic Bight in fall, and continued into winter off North Carolina. Larvae were equally distributed in shallow (0-15 m) and deep (18-33 m) tows during night and day. Larvae occurred over a water temperature range from 0° to 25°C and a salinity range of 29 to 36‰. Seasonal distribution of larvae suggests some of the annual variation in year classes may be due to cold-related mortality of larvae entering middle Atlantic estuaries in late fall.

Along the Atlantic coast spawning and early development of many fishes occur in the ocean. The distribution of early stages of most coastal species is inadequately known. Personnel of the Sandy Hook Marine Laboratory designed a program to determine the spawning times and localities of migratory coastal fishes through a series of cruises off the Atlantic coast from Martha's Vineyard, Mass., to Cape Lookout, N.C. From December 1965 to December 1966 eight survey cruises were conducted to collect fish eggs, larvae, and juveniles. These cruises, together with data on juvenile and adult distribution, provided information on the oceanic life history of most of the commercial and sport fishes of the region.

Atlantic menhaden, *Brevoortia tyrannus* (Latrobe), an important commercial and forage fish, was among the species collected during this survey. The early life history of menhaden has puzzled scientists since early accounts by Baird (1873) and Goode (1879). The eggs and larvae were first described by Kuntz and Radcliffe (1917). After early development at sea, the larvae enter estuaries along the coast where they metamorphose into juveniles. June and Chamberlin (1959) concisely review the estuarine stage of menhaden.

The seasonal cycle of menhaden spawning has been inferred from ovary studies by Higham and Nicholson (1964). From Maine to eastern Long Island ovarian development starts in May and reaches a peak in October. The seasonal occurrence of sexually mature fish begins in New Jersey and Delaware in April, continues sporadically in summer, and reaches a peak in October. Around Cape Hatteras maturing fish were taken mainly in late fall; some are found as late as March.

Atlantic menhaden eggs and larvae have been collected offshore and in estuarine waters along the Atlantic coast (Table 1). These collections show a pattern similar to that found by Higham and Nicholson (1964). Spawning off New England occurs in late spring and early summer and again in early fall. Off the middle Atlantic coast eggs and larvae are found in late fall and in spring. Off North Carolina young occur in winter and spring.

Inlet and estuarine studies have collected larval menhaden as they emigrate from the ocean (Table 1). The time of entry varies considerably along the coast and from year to year in the same estuarine areas. In some years entry occurs in late fall, before lowest temperatures are reached. In other years entry occurs primarily as temperatures are warming in early spring. Larvae in the estuaries are apparently killed if winter temperatures fall below 3°C (Reintjes and Pacheco 1966). Emigration from the estuaries varies from late August in the north to January in the south, with some

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TABLE 1.—Collections of menhaden eggs and larvae, east coast of United States.

Reference	Sampling period		Sampling area	Occurrences
	Years	Months		
Open ocean				
Marak and Colton 1961	1953	Mar.-June	Georges Bank-Gulf of Maine	June—1 egg, off Martha's Vineyard
Marak, Colton, and Foster 1962	1955	Feb.-May	Georges Bank-Gulf of Maine	May—eggs, 130 km off Nantucket
Marak, Colton, Foster, and Miller 1962	1956	Feb.-June	Georges Bank-Gulf of Maine	June—larvae, off Woods Hole
Reintjes 1961	1953-54	all	Cape Hatteras-Florida	Dec.-Feb.—eggs Dec.-Mar.—larvae, off North Carolina
Massmann et al. 1962	1959-60	all	Off Chesapeake Bay	Nov.-Apr.—larvae
Reintjes 1969	1966	Dec.	Off North Carolina	Dec.—eggs, patch of several thousands
Bays and open sounds				
Bigelow and Schroeder 1953			Gulf of Maine	Oct. 1900—young fry, Casco Bay
Kuntz and Radcliffe 1917			Near Woods Hole, Mass.	Oct. 1915—eggs and larvae, Nantucket Sound Aug.—eggs, off Gay Head July—larvae, Woods Hole Harbor
Hildebrand and Schroeder 1928	1912-22		Chesapeake Bay	Jan.-May—large larvae
Pearson 1941	1929	May-Oct.	Lower Chesapeake Bay	May—larvae
	1930	Apr.-Dec.	Lower Chesapeake Bay	Apr.—larvae
	1931	Jan.-Mar.	Lower Chesapeake Bay	
Perlmutter 1939	1938	May-Oct.	Around Long Island	May-Oct.—eggs May-Sept.—larvae
Merriman and Sclar 1952	1943-46	all	Block Island Sound	Fall—larvae (see Wheatland 1956)
Wheatland 1956	1952-53	all	Long Island Sound	June-Oct.—eggs June and Sept.-Dec.—larvae
Richards 1959	1954-55	all	Long Island Sound	May-Oct.—eggs June-July and Sept.-Dec.—larvae
Deubler 1958	1955-57	Dec.-Apr.	Bogue Sound, N.C.	Winter and spring—larvae, common
Herman 1963	1957-58	all	Narragansett Bay	May-Aug. and Oct.—eggs June, July and Oct.-Feb. (most in Oct.)—larvae
Croker 1965	1960-61	all	Near Sandy Hook, N.J.	May-June—eggs Nov.-Dec.—larvae
Dovel 1971	1963-67	all	Chesapeake Bay	Spring and summer near Solomons, Md.—eggs Mar.-June and Nov.—larvae, upper Chesapeake Bay
Inlets				
Reintjes and Pacheco 1966	1955-61	Sept.-June	Indian River Inlet, Del.[1]	Oct.-May—larvae, month of peak occurrence varied with year from Dec.-Feb.
de Sylva et al. 1962	1956-58	all	Indian River Inlet, Del.[1]	Nov.-May—larvae
Tagatz and Dudley 1961	1957-60	all	Beaufort Inlet, N.C.	Jan. and Apr.-May—larvae
Lunz 1965	1964	Jan.-Mar.	Several South Carolina inlets	Feb.-Mar.—larvae
Lewis and Mann 1971	1966-68	Nov.-Apr.	Bogue and Beaufort inlets, N.C.	Nov.-Apr.—larvae
Smaller estuaries				
Warfel and Merriman 1944	1942-43	all	Morris Cove, Conn.	July-Nov.—larvae
Massmann et al. 1954	1950-52	Mar.-Oct.	Five Virginia tidal rivers	Apr.-May—larvae, brackish water
Pacheco and Grant 1965 Reintjes and Pacheco 1966	1955-61	Sept.-June	White Creek, Indian River, Del.	Nov.-June, most Feb.-June—larvae
Tagatz and Dudley 1961	1957-60	all	Neuse River, N.C.	Jan.-June and Sept.—larvae
Pearcy and Richards 1962	1959-60	all	Mystic River, Conn.	June-July—larvae
Dovel 1967	1965-66	all	Magothy River, Md.	Mar.—larvae
Wilkens and Lewis 1971	1967-69	all	White Oak River, N.C.	Jan.-Apr.—larvae

[1]Larvae emigrating from ocean.

juveniles overwintering in southern estuaries. Fish range from 50 to 160 mm when they leave the estuaries (June and Chamberlin 1959).

Recently Mansueti and Hardy (1967) amplified the descriptions of young menhaden and Reintjes (1969) reviewed the biology of the species.

This paper describes the occurrences of menhaden eggs and larvae in the *Dolphin* surveys and relates these findings to daylight, temperature, salinity, and depth, and to our understanding of menhaden early life history.

PROCEDURES

The eight ichthyoplankton cruises were made at approximately 6-wk intervals from December 1965 to December 1966 (Clark et al. 1969). On each cruise 92 stations were located along 14 transects from Martha's Vineyard to Cape Lookout (Figure 1). Stations were closely spaced inshore (9.3 km) along the transects and farther apart (27.8 km) offshore. The order that the transects were run and the time during the 24-h workday that stations were occupied varied among the cruises.

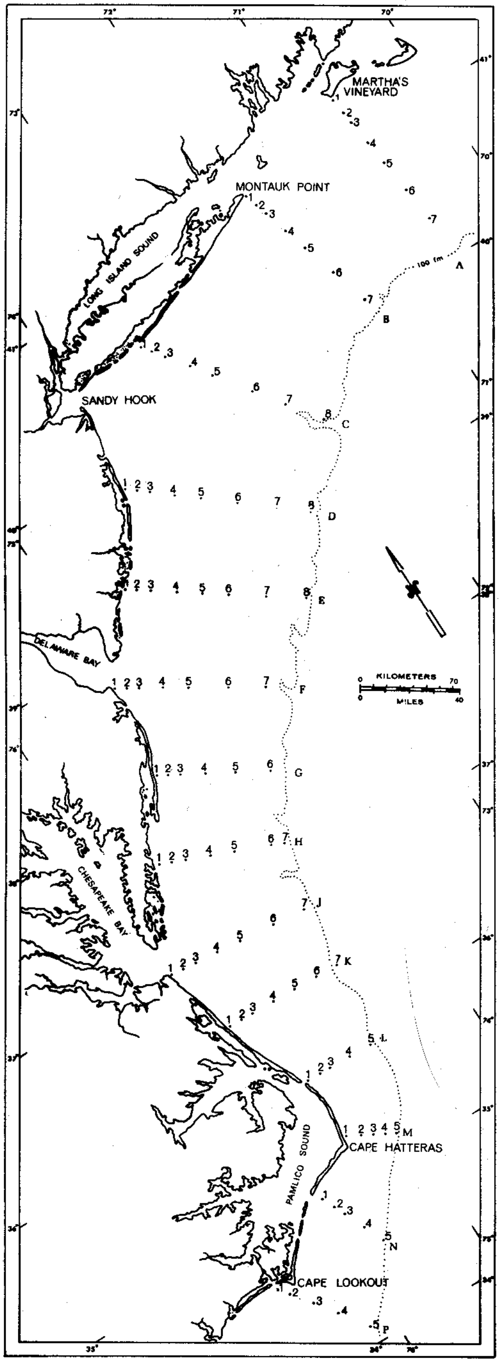

FIGURE 1.–RV *Dolphin* survey, 1965-66. Locations of transects and collecting stations.

Gulf V plankton samplers with 0.4-m openings and 0.52-mm wire mesh were towed for 30 min at 5 knots (2.6 m/s) in step-oblique tows at each station. Two nets were fished simultaneously at six 3-m depth intervals, from separate warps, one shallow (0-15 m) and one deep (18-33 m), where water depth permitted. In shallower water fewer depth intervals were sampled for longer time periods. Plankton samples were preserved in 4% buffered formaldehyde solution and brought to shore for sorting. Supplementary data collected at each station included water temperature and salinity with depth. A scaled-down Cobb midwater trawl was towed at about half of the stations to collect juvenile fishes.

Fish eggs and larvae were separated from the plankton in the laboratory. Clupeoid larvae were distinguished by their slender body, long gut, sparse pigment, and short dorsal and anal fin bases (Table 2), and separated from other larvae.

Several other fishes whose long slender larvae resemble clupeoids occur in the area but they differ in certain features. Lizardfish larvae have a large finfold, an adipose fin later in development, and a row of 6 to 12 paired dark patches ventrally along the body (Anderson et al. 1966). Other elongate salmoniform larvae generally have an adipose fin, photophores often, and oval or stalked eyes. Sand lance larvae have little pigment, but the dorsal and anal fins extend most of the length of the body (Norcross et al. 1961). Blennioid larvae have a short gut, with the anus forward of midlength of the body, and long dorsal and anal fin bases. Other larvae are excluded by myomere counts which fall outside the range for clupeoids (38-55) or by other distinctive characters not found on clupeoid larvae.

TABLE 2.–Distinguishing features of Atlantic coast clupeoid larvae.

Character	Distinguishing features
Body shape	Body slender and elongate, the greatest body depth less than 20% of total length. Anus in posterior third of body.
Fin positions	Dorsal – single, short, about two-thirds way back along body; no adipose fin. Anal – posterior to at least part of dorsal fin, not confluent with caudal fin. Pelvics – abdominal, at about midlength on the body.
Meristic counts	Myomeres (vertebrae) – 38-55. Dorsal fin rays – 9-22. Anal fin rays – 10-30. Principal caudal fin rays – 10 + 9.
Pigmentation	Little pigment except ventrally. Ventral pigment – small spots on throat, along the gut, and at base of caudal fin.
General	Eyes round, in orbits, not stalked. Gut straight with annular folding of the intestine.

Identification of menhaden eggs and larvae among the four other clupeid genera and two engraulid genera along the North American east coast was facilitated by published illustrations and descriptions (Kuntz and Radcliffe 1917; Mansueti and Hardy 1967; Houde and Fore 1973) and reported spawning areas and times (Reintjes 1961; Higham and Nicholson 1964). Menhaden larvae collected north of Cape Lookout are presumed to be *Brevoortia tyrannus*, since *B. smithi* occurs mainly farther south and spawns inshore (Reintjes 1962). The areas of larval occurrence of menhaden overlap Atlantic herring, *Clupea harengus harengus*, in the north, and round herring, *Etrumeus teres;* Spanish sardine, *Sardinella anchovia;* and Atlantic thread herring, *Opisthonema oglinum*, in the south.

Clupeoid larvae less than 8 mm are difficult to distinguish because the median fins and other characters are not formed. However, pigmentation, body shape, and gut length are helpful in small larvae. Among clupeoid larvae the stage of development at a particular size and area of capture are helpful. For each comparable stage of larval development, menhaden are larger than anchovies, Spanish sardine, and Atlantic thread herring, and smaller than Atlantic herring. Only round herring show the same development with size as menhaden but are easily distinguished by the relative length of the snout at all sizes.

Menhaden were counted and total length measurements of larvae less than 12 mm long were made to the nearest 0.1 mm with an ocular micrometer in a dissecting microscope; those longer than 12 mm were measured with dividers and a steel rule or dial calipers to the nearest 0.5 mm. Samples containing more than 50 fish were usually randomly subsampled before measuring. To get a subsample of 25-50 larvae, the sample was floated in formaldehyde solution in a 150-mm petri dish scribed into quarters with two diameters; a random half or quarter of the dish was chosen for measuring. The process was repeated with the chosen fraction with samples of more than 200 specimens. When larvae showed slight damage, such as broken caudal rays, measurements were adjusted to approximate total length. Larvae identifiable, but too mutilated to be measured, were counted. For geographic distribution analysis, numbers of larvae at each station were adjusted to a standard tow as in Smith (1973) and Fahay (1974).

RESULTS

Geographic Distribution of Larvae

Menhaden larvae are more widely distributed than any other clupeoid in the northwest Atlantic. Larvae have been reported from Maine to Mexico in oceanic, estuarine, and fresh waters. South of Cape Hatteras Atlantic menhaden spawn in the cooler months (October to June), while along the Middle Atlantic states they spawn during the warmer months (June to November). Seasonal occurrences of larvae followed the annual north-south migration of adults. Small larvae were first collected in June near Delaware Bay. By October larvae were present from southern New England to Chesapeake Bay. In late fall they were found from New York to Cape Lookout. During the winter and spring larger larvae were present from Chesapeake Bay to Cape Lookout.

Small menhaden larvae were collected throughout the year except in late spring, indicating nearly continual spawning (Figure 2). Menhaden hatch at about 3 mm (Mansueti and Hardy 1967), but we caught few less than 5 mm. This was probably due in part to our inability to identify with certainty small larvae and in part to their fragile, slender form which caused them to be extruded from our nets. The largest larvae we collected were 30 mm, about the size at which they enter estuaries and transform into juveniles (Lewis et al. 1972).

It is not reasonable to attempt to determine a growth rate for menhaden larvae from our data. Small menhaden less than 8 mm were collected from June through February. Thus, spawning took place in our sampling area for 6 mo of the year. This protracted spawning season and probable geographic movements of larvae preclude the possibility of determining growth rate from this survey.

Data associated with collections of menhaden larvae are presented in the Appendix Table. Their occurrences are illustrated in Figures 4-11. From the irregular horizontal and vertical distributions and highly nonnormal catch frequency curve (Figure 3), it appears that the larvae are very unevenly and probably patchily distributed. The location and density of patches may be related to local currents and water conditions on a smaller scale than we sampled. This discussion follows the sequence of spawning, i.e. starting in late spring

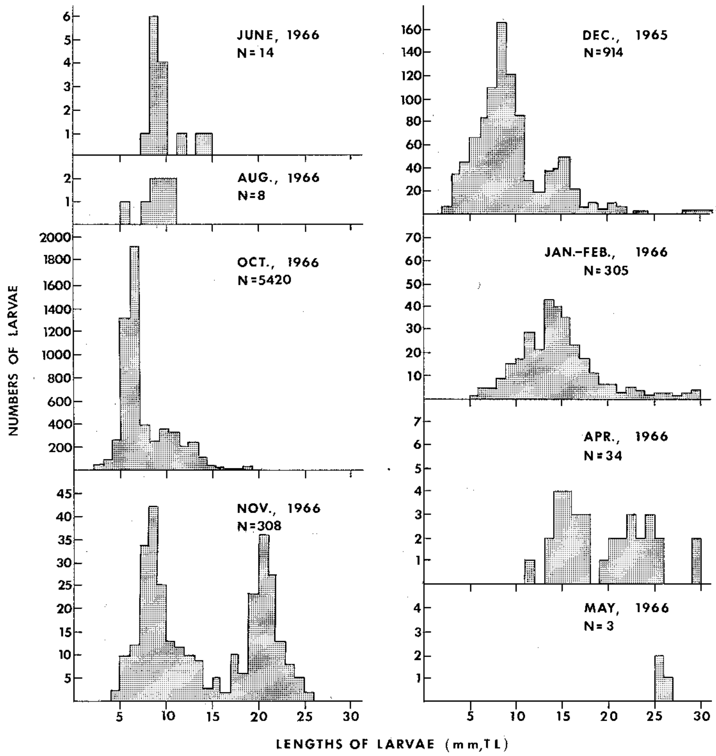

FIGURE 2.—Length-frequencies of menhaden larvae from the RV *Dolphin* survey, 1965-66.

1966. The cruises, however, began in December 1965. Thus, the cruises from December 1965 to May 1966 cover one spawning season and those from June 1966 to November-December 1966 cover the following season.

In late June a few larvae were collected nearshore off Delaware Bay (Figure 4). These larvae were small (7.8-14.4 mm), indicating they had been spawned recently. Spawning may have occurred in Delaware Bay since the larvae we

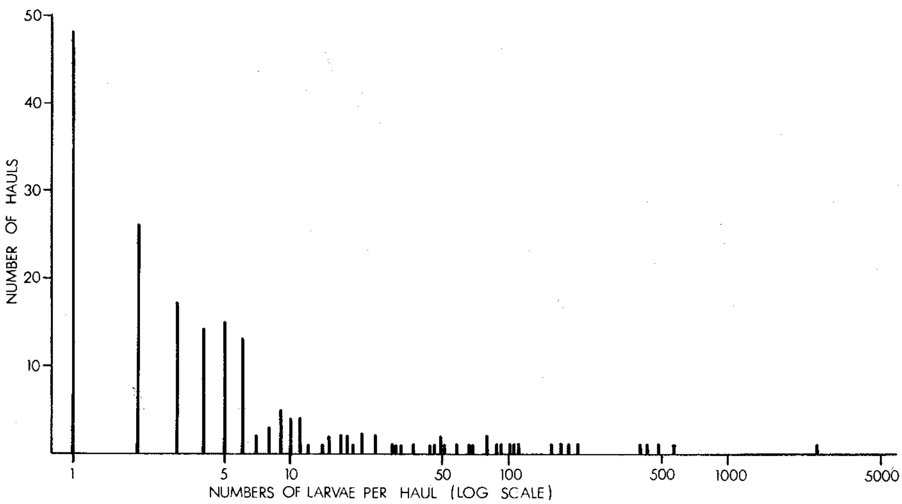

FIGURE 3.—Frequency distribution of menhaden larval catches per haul.

caught were concentrated close to its mouth. The distribution of the collections indicates spawning was not widespread. Stations north of these collections were sampled about 10 days earlier, possibly accounting for the limited distribution we observed. The absence of larvae to the north in these earlier collections would indicate spawning had recently started. Temperatures in June in the area of capture ranged from 15° to 19°C, and salinity varied from 30.3 to 32.1‰ (Figure 4). Hydrographic conditions within these ranges occurred widely along the coast during this cruise (Clark et al. 1969).

During our cruise in August there was evidence of limited spawning nearshore (Figure 5). A few small larvae, 5.6-10.5 mm, were taken off Long Island and New Jersey. Perhaps the earlier spawning in June was so limited that with dispersal during growth, insufficient larvae survived to be taken in our August sampling. Temperatures in the area of capture in August were warmer than in June, 18° to 22°C at the surface, and the seasonal thermocline was well developed about 15 m below the surface (Figure 5). Temperatures below the thermocline were less than 10°C. Larvae were collected only in the shallow net, indicating they were in the warm water above the thermocline. Salinity in the area of capture ranged from 30.1 to 31.0‰.

In October 5,420 larvae were collected that ranged from 3.5 to 18.5 mm (Figure 2). The length-frequency distribution was skewed to the left (mean 7.3 mm; mode 6.5 mm). Larvae were more widespread and in greater concentrations than during any other cruise (Figure 6). They occurred from Martha's Vineyard to Currituck Beach, N.C., and were abundant from Long Island to Maryland, near the middle of the shelf. They occurred nearshore from southern New England to New Jersey and near Chesapeake Bay. The fish

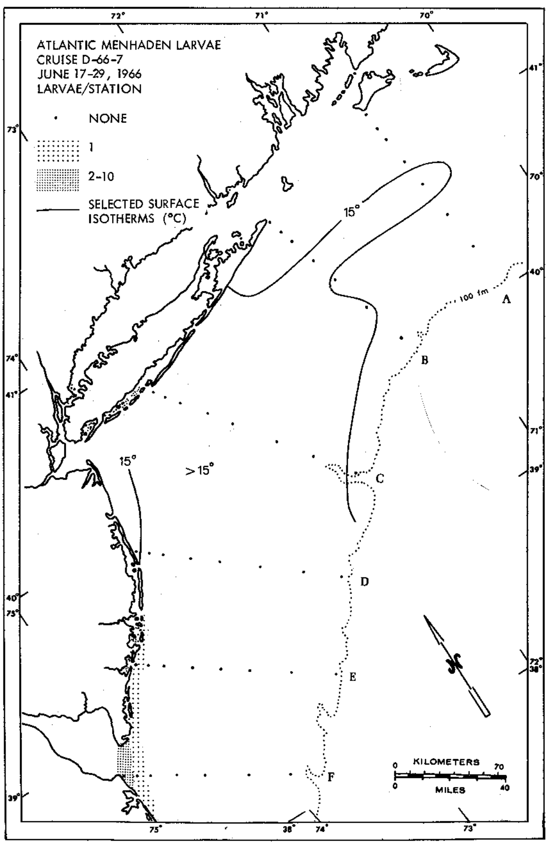

FIGURE 4.—Distribution and abundance of menhaden larvae in the June cruise.

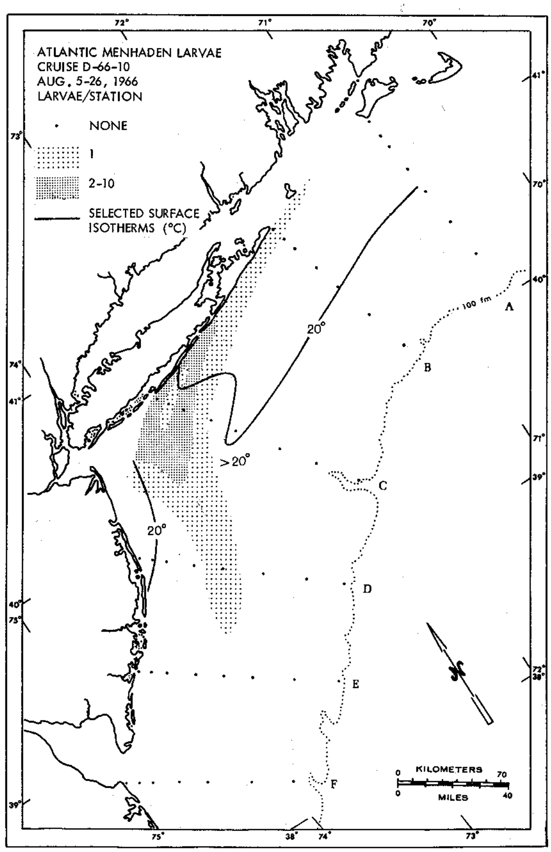

FIGURE 5.—Distribution and abundance of menhaden larvae in the August cruise.

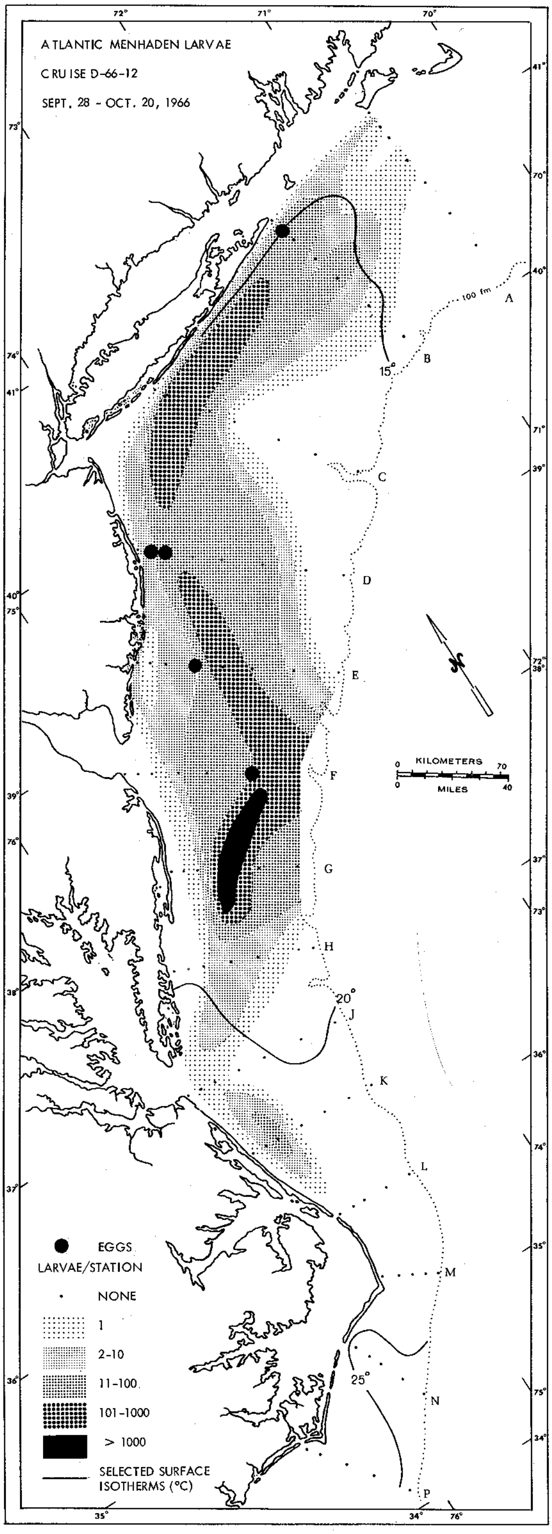

FIGURE 6.–Distribution and abundance of menhaden larvae and distribution of menhaden eggs in the October cruise.

were 8-12 mm in the northern part of the sampling range, from New York north. Fish in a broader size range, 4-12 mm, were present off New Jersey. Nearly all fish south of New Jersey were smaller, 4-8 mm.

In October the thermocline was breaking down but still present over much of the area, and surface temperatures were about 3°C cooler than in August (Figure 6). Salinity values were about the same as in August, mostly between 30.5 and 32.0‰, except near the mouth of Chesapeake Bay where they dropped to 28.0‰.

The cruise in late fall 1966 (Figure 7) shows a distribution pattern quite similar to the cruise in December 1965 (Figure 8). During both cruises, larvae occurred mostly nearshore from Long Island to North Carolina. They were most abundant near Cape Hatteras, where they were taken to the edge of the shelf.

In November 1966 there was a bimodal size distribution with one peak at 8 mm and the other at 20 mm (Figure 2). There were few larvae between 14 and 18 mm. In December 1965 the peak at 8 mm is similar to that in late fall 1966, but the second peak at 20 mm is not seen (Figure 2). Possibly this difference is due to year-to-year variation in spawning pattern in the area studied.

In the November and December cruises, small fish were found south of Delaware Bay and tended to occur at least 12 km offshore. Larger fish occurred mainly north of Chesapeake Bay and mostly within 15 km of shore. In transition areas between north and south and inshore and offshore areas, fish in a wide length range occurred at the same station and bimodal length-frequency curves were seen. This may indicate that spawning occurs in waves, and as the larvae grow they disperse from the area where they were spawned.

By late fall the thermocline was gone and surface isotherms roughly paralleled the coastline (Figures 7, 8). Larvae were taken over a wide range of temperature, from 7° to 25°C. Most collections were in water between 10° and 20°C. Salinity varied considerably between the two late fall cruises. In 1965, several patches of low saline water, less than 30‰, were found mostly near the shore (Clark et al. 1969). However, in 1966 salinity throughout the area was greater than 31‰, except immediately outside Chesapeake Bay. The distribution of larvae is quite similar between these two cruises in spite of these differences in salinity.

In February menhaden larvae were taken from Virginia to Cape Lookout (Figure 9). They probably occurred farther south than we sampled since they were most abundant on our southernmost transect. Most larvae were taken between Cape Hatteras and Cape Lookout. Lengths presented a fairly symmetrical distribution with a peak at 13 mm (Figure 2). There is indication again that the larger fish were taken nearer to shore and farther north than the smaller fish. Few fish shorter than 8 mm were seen at this time, and the maximum length was 29 mm. Apparently, at about this size menhaden have either entered estuaries or can avoid our nets. In winter the temperature was 4°C at 11 of the 23 stations where menhaden were taken; it was less than 3°C at 4 stations (Figure 9). Water at these stations was practically isothermal with depth (Clark et al. 1969).

During April larvae occurred in approximately the same areas as in February (Figure 10). Fewer, larger larvae were taken between Chesapeake Bay and Ocracoke Inlet, N.C., than earlier. Larvae north of Cape Hatteras ranged from 21 to 29 mm. Off Ocracoke Inlet larvae were 11-19 mm. The larger larvae north of Cape Hatteras were taken nearshore; those farther south extended 37 km offshore. A bimodal length-frequency curve had peaks centered at 15 and 24 mm, although insufficient numbers of fish were collected to determine the statistical significance (Figure 2). By April, temperatures in the areas of capture were warmer than winter temperatures, above 8°C, and mostly between 10° and 12° (Figure 10). Salinity ranged from 30.3 to 35.6‰.

In May a few large (25-26 mm) larvae were taken off Virginia, inshore near Chesapeake Bay (Figure 11). These were apparently remnants of the early winter spawning, the rest of the larvae having already entered estuaries. Water in the areas of capture had warmed to 13° to 17°C (Figure 11). Salinity was generally lower, from 28.4 to 31.2‰, due to spring freshening nearshore (Clark et al. 1969).

Temperature-Salinity Relations

The catches of menhaden larvae during all cruises in the shallow net were compared

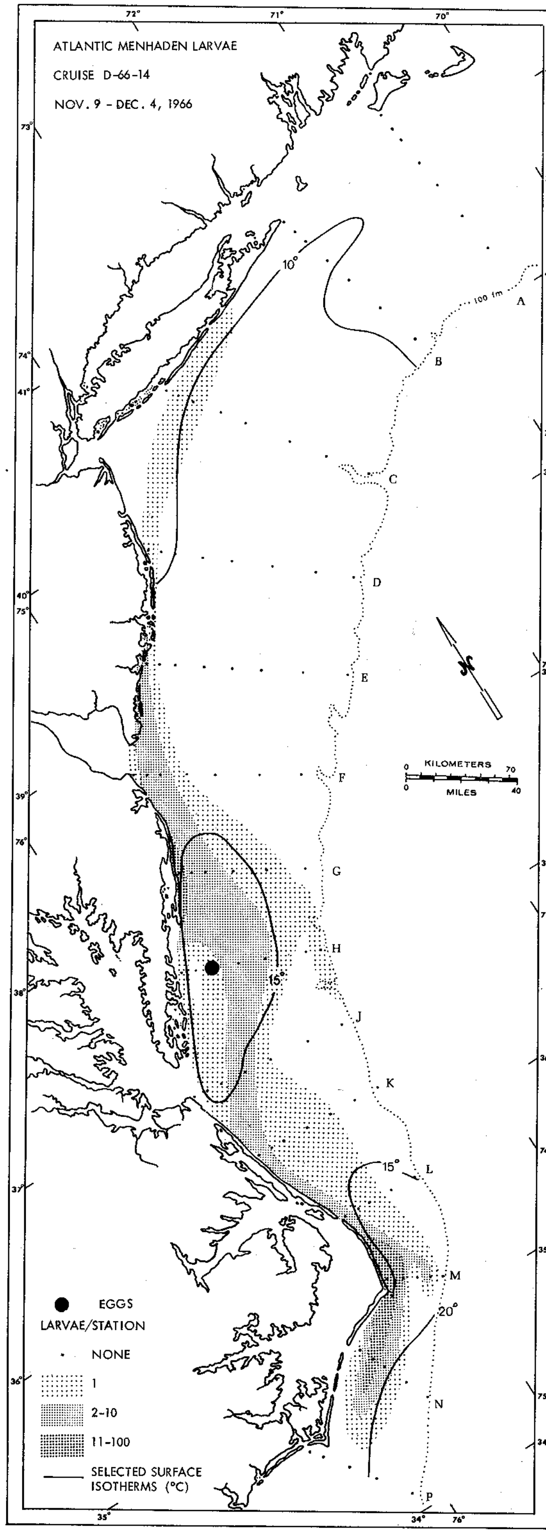

FIGURE 7.–Distribution and abundance of menhaden larvae and distribution of menhaden eggs in the November-December 1966 cruise.

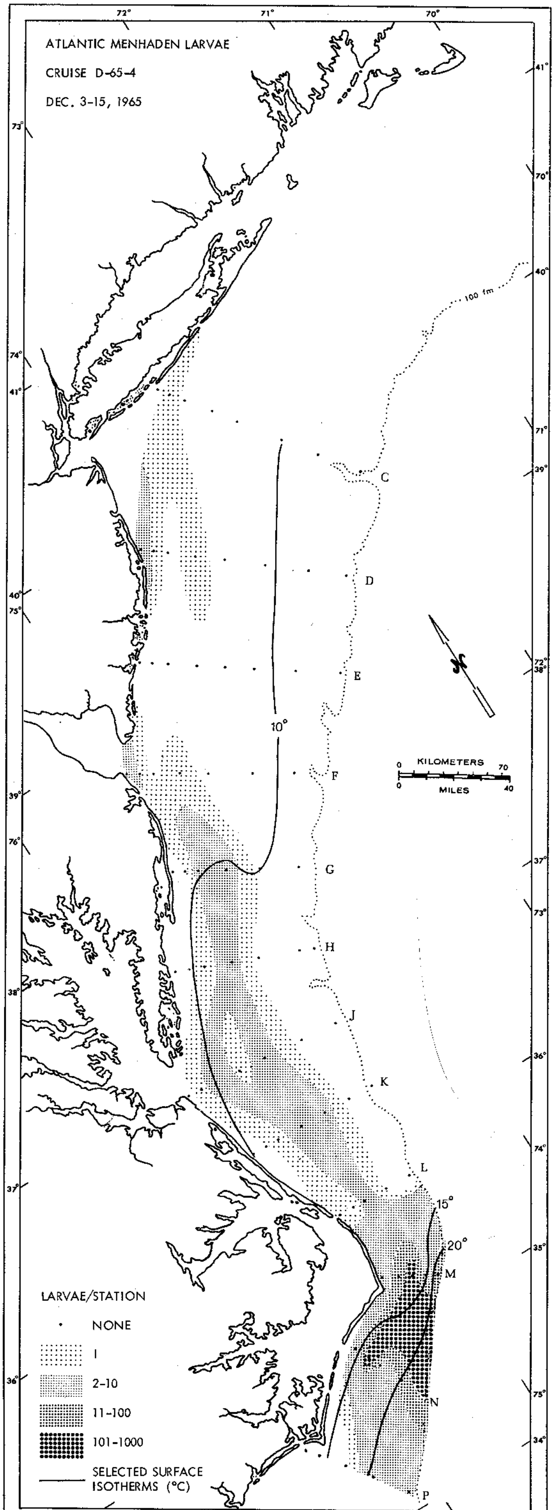

FIGURE 8.—Distribution and abundance of menhaden larvae in the December 1965 cruise.

graphically with observed surface temperatures and salinities. Surface observations were thought adequate since most larvae were collected when hydrographic conditions were nearly uniform with depth and menhaden larvae were scarce below the thermocline. Mean temperatures and salinities within the sampling depth range were also compared with catches and showed patterns similar to those discussed here.

Observed surface temperatures varied from -1° to 28°C (Figure 12). At each of nine whole-degree intervals between 6° and 19°C, more than 30 stations were occupied. More than 40 stations were occupied at 10° and 14°C. Menhaden occurred at stations when temperatures were between 0° and 25°C. The curve of positive stations (those where menhaden were taken) was similar in shape and range to that of total stations. The numbers of larvae taken at each temperature were plotted on a log scale. This plot was slightly skewed to the right, with modal catch at 18°C. Catches of over 100 larvae were made at temperatures from 9.3° to 20.5°C, with most between 15.8° and 18.5°C.

Surface salinity varied from 23 to 38‰, with a mode at 31‰ (Figure 13). Positive stations occurred over the entire range of salinities, with a mode at 30‰. The larval catch curve, on a log scale, is similar in shape to the total station curve, with a mode at 31‰. At stations with salinities between 30 and 36‰, a total of at least 200 larvae were taken within each part-per-thousand interval.

Diel-Vertical Comparisons of Larval Catches

Comparisons were made of the catches of larvae in shallow and deep tows made during night and day. These comparisons are on the basis of the volume of water sampled, which was assumed to be constant among the tows. The use of parametric statistics was precluded by the highly nonnormal catch frequency curve (Figure 3). Of the 172 tows with menhaden larvae, 48 contained only 1 larva, and 11 tows contained more than 100 larvae. Of the 11 tows with more than 100 larvae, 7 were taken in shallow tows during daylight. Altogether menhaden occurred in 85 daylight tows and 87 nighttime tows (Table 3). The distribution of catches was not significantly different with time of day (chi-square test; $P > 0.50$). Day and night

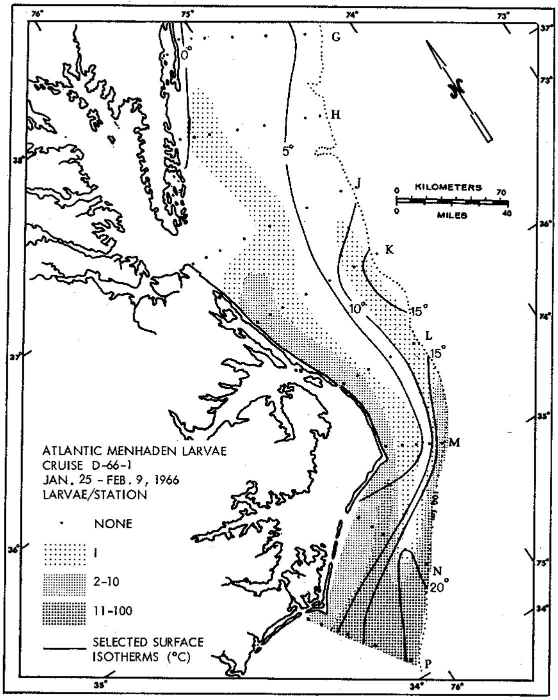

FIGURE 9.—Distribution and abundance of menhaden larvae in the February cruise.

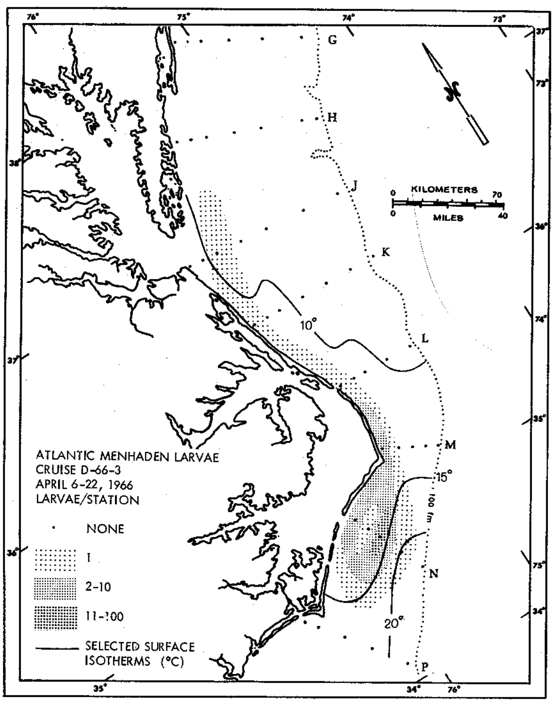

FIGURE 10.—Distribution and abundance of menhaden larvae in the April cruise.

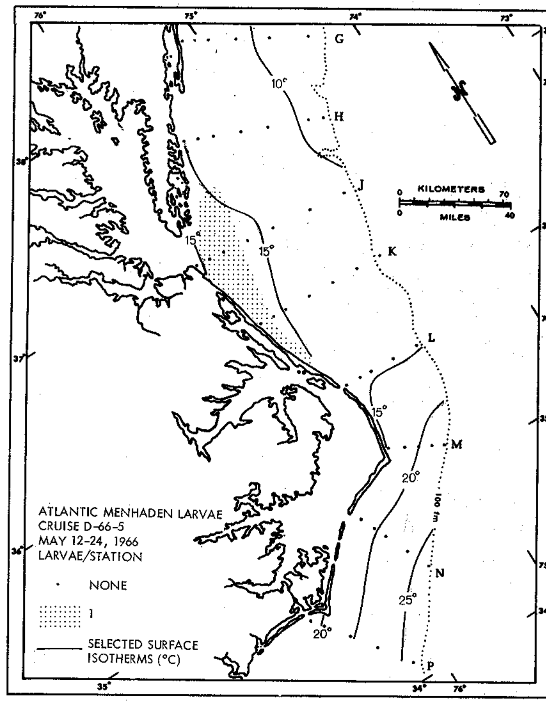

FIGURE 11.—Distribution and abundance of menhaden larvae in the May cruise.

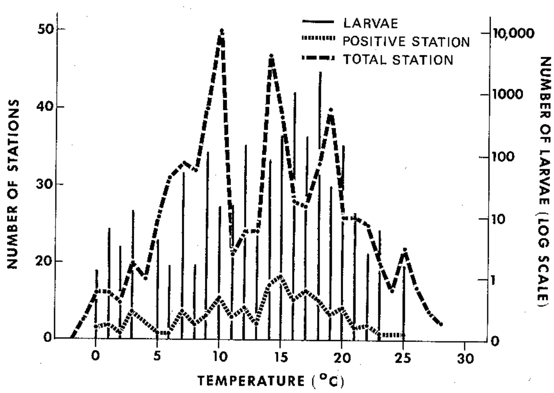

FIGURE 12.—Relation between surface temperature to menhaden larval catch and sampling effort.

tows were combined to compare the distribution of catches by the shallow and deep nets. By the shallow net, menhaden were taken in 138 tows and by the deep net in 34 tows (Table 3). The distribution of catches was not significantly different in the two nets ($P > 0.50$). Comparisons of size of larvae between day and night tows with the shallow and deep nets showed no significant differences.

Eggs

We found menhaden eggs at only six stations, five from the October cruise and one from the late fall cruise in 1966 (Figures 6, 7). All but one sample contained less than 100 developing eggs. The exceptional sample was from 85 km off Delaware Bay in October where about 2,000 eggs were taken. Precise counts were not possible due to the poor state of preservation of the samples when they were examined. Eggs were collected in areas where small larvae were taken. Apparently menhaden spawn as large schools producing dense patches of eggs (Reintjes 1969). During the short incubation time (48 h), these patches do not become dispersed. Thus the distribution of menhaden eggs at sea is probably more uneven than that of larvae. Chance was a dominant factor in catching menhaden eggs so distributed in our survey.

Mid-Water Trawl Catches

Sampling by mid-water trawl during the cruises collected a few larval and adult menhaden. Sampling effort was good in areas where the catches were made, so they probably reflect the actual geographic distribution of menhaden subject to capture by this type of sampling (Clark et al. 1969). A few large larvae, 21-37 mm, were taken in August off the Chesapeake Bay area. Age-0 fish, 89-177 mm FL (fork length) (Reintjes 1969), occurred close to shore from southern New England to Chesapeake Bay in late fall 1966. These probably represent young fish migrating south after spending the summer in estuaries (June and Chamberlin 1959). Other catches included two large fish, 305 and 361 mm FL, close to shore off southern New Jersey in May, and several age-0 fish off Oregon Inlet, N.C., in June.

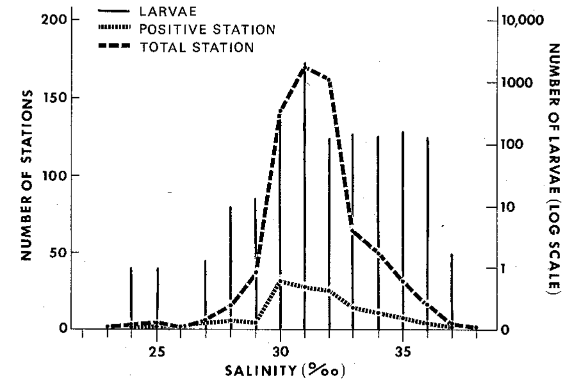

FIGURE 13.—Relation between surface salinity to menhaden larval catch and sampling effort.

DISCUSSION

Much speculation has surrounded the distribution of early stages of menhaden. Spawning times and places have been inferred from examination of gonads of adults (McHugh et al. 1959; Higham and Nicholson 1964) and nearshore and estuarine samples of larvae and juveniles (e.g. Richards 1959; Sutherland 1963; Pacheco and Grant 1965). Few studies have actually taken menhaden eggs and larvae to determine more directly the area of spawning (Reintjes 1961; Massmann et al. 1962). Controversy has concerned whether menhaden spawn in Chesapeake Bay (Hildebrand and Schroeder 1928) and whether there are two separate populations along the east coast, one spawning in spring and one in fall (Nicholson 1972). Annual variation in time of spawning and entry of larvae into estuaries may account for some of the confusion, since most studies have been short-termed and in a relatively small portion of the range of menhaden.

Caution needs to be exercised in analyzing the present data since they were collected during a single year and do not encompass the entire range of spawning of menhaden (Reintjes 1969). During summer larvae were taken from our inshore stations to our farthest offshore station and at our most northerly station. The possibility of spawning within estuaries is indicated by the presence of

TABLE 3.—Diel and depth distribution of menhaden larval catches and mean lengths.

	Day			Night			Day and Night		
Larvae/tow	Shallow	Deep	Both	Shallow	Deep	Both	Shallow	Deep	All
				Number of tows					
1-2	29	9	38	34	2	36	63	11	74
3-4	7	3	10	7	4	11	14	7	21
5-20	18	3	21	18	6	24	36	9	45
>21	15	1	16	10	6	16	25	7	32
Total tows	69	16	85	69	18	87	138	34	172
Mean larvae/tow	68.2	6.4	56.0	19.1	48.2	25.6	43.0	27.2	39.8
Mean larval length (mm)	8.3	8.8	8.3	9.0	6.9	8.2	8.5	7.1	8.3

small larvae near their mouths. In winter they were found at our southernmost stations. Therefore, spawning could have taken place inshore and offshore of our stations and farther north and south of our sampling.

Our results on area of spawning confirm the conclusions of Higham and Nicholson (1964) and Nicholson (1972) that menhaden spawn during both their northward spring migration and their southward fall migration. We conclude that spawning apparently continues in winter in the south, based on our catches around Cape Lookout. Midsummer spawning may have occurred north of our sampling area, or may have been inhibited in 1966 by water cooler than usual.

Harrison et al. (1967) postulated that bottom drift of waters off Chesapeake Bay influence the success of year classes of menhaden. During years when bottom drift was weak and southwesterly, poor year classes occurred. However, our data and that of Massmann et al. (1962) do not indicate a preference for bottom waters by larger menhaden larvae. Larvae entering the estuaries are found throughout the water column (Lewis and Mann 1971), and later, in the estuaries, they are found primarily in surface waters (Massmann et al. 1954). Possibly the factors affecting bottom drift also affect the success of year classes, but in an indirect way.

Reintjes and Pacheco (1966) reported on inlet and nursery area collections in Indian River, Del., made over a 6-yr period (1955-61). Among the years studied, the peak in larval abundance at the inlet occurred in all months from December through March. Larvae were taken at the inlet from September through June in most years. It appeared that when temperatures at the inlet dropped to 3°C, larvae in the area were killed. In four seasons, when large catches of larvae were made at the inlet between December and February and temperature later dropped below 3°C, larvae were scarce or absent in upstream nursery areas. However, larvae taken in years when temperature remained above 3°C and those taken after the critical low temperature period were later represented in collections upstream.

Due to the extreme year-to-year variability in time of entry at the inlet at Indian River, it is difficult to relate our catches to these data. The few small larvae taken near Delaware Bay in June would probably have entered the estuary in July, a month when Reintjes and Pacheco (1966) reported none. We made large catches in this area in October. Larvae were also present offshore in November and December. In February, larvae were not taken north of Virginia and water temperature close to shore between Chesapeake and Delaware bays was less than 0°C. From these data, it would appear that 1965-66 was dissimilar to any year studied by Reintjes and Pacheco (1966) with regard to menhaden larvae near Delaware Bay. Presumably during 1965-66 larvae could have been taken in abundance in late fall but would have been killed by cold water in February. Subsequently no larvae would have entered in winter or spring, but some might have appeared in early summer.

Menhaden larvae were taken off Chesapeake Bay in waters 1° to 15°C by Massmann et al. (1962). Herman (1963) reported them in Narragansett Bay from 1° to 22°C. The larvae we collected at temperatures below 3°C did not appear decomposed as would be expected had they been dead when captured. Lewis (1965, 1966) has studied the effects of subjecting menhaden larvae to low temperatures and a range of salinities in the laboratory. He has shown that moderate salinities (10-20‰) enhance survival at low temperature as do lowered acclimation temperatures. At 7°C acclimation temperature, the lowest he used, and 2° to 4°C test temperatures, 50% mortality occurred in about 40 h at 24‰. Salinities in our areas of capture were 31 to 35‰—higher than those tested by Lewis (1966). If temperatures below 3°C in estuarine waters kill many menhaden (Reintjes and Pacheco 1966), it may be advantageous for larvae to remain in the ocean where temperature changes are more gradual. Menhaden entering estuaries are usually larvae less than 30 mm long, and in the estuary they rapidly transform by 38 mm (Lewis et al. 1972). Reintjes and Pacheco (1966) reported a few transforming specimens (greater than 34 mm) entering Indian River in May. That they are dependent on estuarine conditions for transformation is supported by the absence of transforming specimens and juveniles in our collections.

SUMMARY AND CONCLUSIONS

A total of 7,006 menhaden larvae were collected in 172, 0.5-h Gulf V plankton tows. The larvae were taken on eight cruises along the middle Atlantic coast throughout the year. Eggs were taken in a few tows in the fall. The catch distribution was nonnormal, with 48 tows catching only 1 fish and 1 tow catching 2,553 fish. No differences in larval catches or size were found in shallow and deep tows or during day or night. Small larvae, less than 8 mm, were taken from June through February, indicating a protracted spawning period. However, there was a seasonal shift in area of spawning. In late spring and summer limited spawning was occurring off New Jersey and New York. By early fall spawning was widespread from southern New England to Virginia. By late fall and early winter spawning was limited to areas between Delaware and North Carolina. Larger larvae were taken in the north in late fall and south of Delaware Bay in winter and spring.

Larvae occurred over a wide range of temperature, from 0° to 25°C. Several were taken in waters cooler than the 3°C limit found lethal in laboratory tests and inferred to be limiting in inlet sampling studies. Most larvae were collected at temperatures between 15° and 20°C. There was an inverse relationship between temperature and size of larvae.

Salinity seemed to have little influence on the distribution of larvae. They occurred at practically every salinity encountered and the frequency of salinities closely resembled the frequency of positive tows.

Our findings are similar to recent investigations of early life history of Atlantic menhaden based on inlet sampling of larvae, gonad studies, and scale annulus formation. It appears that spawning and early development at sea take place over a long period in a given coastal area, and the larvae resulting from this spawning may reach the inlets over a long seasonal time. In years with mild winters, successful immigration to estuarine areas may occur before the winter temperature minimum. However, under more severe conditions, when winter temperatures in the estuaries fall below 3°C, successful immigration may occur only as temperatures are increasing in spring because larvae entering estuaries during the fall may not survive the winter. This could account for some of the annual variation in year-class strength of Atlantic menhaden.

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APPENDIX TABLE—RV *Dolphin* 1965-66 ichthyoplankton survey. Data associated with Gulf V catches of Atlantic menhaden larvae.

CRUISE STAT. D65 4	TOW DEPTH (M)	LARVAE NUMBER TOTAL	LARVAE NUMBER MEAS.	LARVAE LENGTHS MEAN (MM TL)	LARVAE LENGTHS RANGE (MM TL)	DATE 1965 D M	TOW START TIME (EST)	LIGHT COND.	WATER DEPTH (M)	TEMPERATURE (°C) RANGE	TEMPERATURE (°C) MEAN	TEMPERATURE (°C) SURF.	TEMPERATURE (°C) BOT.	THERMOCLINE DEGREE	THERMOCLINE DEPTH (M)	SALINITY (0/00) RANGE	SALINITY (0/00) MEAN
C 2	0-15	1	1	18.7		312	2353	NIGHT	27	8.2 8.2	8.2	8.2	8.3	NONE	-	30.0 30.4	30.2
D 1	0- 6	6	6	18.7	15.4 23.8	512	1458	DAY	11	7.7 7.7	7.7	7.7	7.8	NONE	-	29.0 29.1	29.1
D 2	0- 9	1	1	20.2		512	1557	DAY	18	7.9 8.0	7.9	8.0	7.9	NONE	-	29.0 29.6	29.3
D 4	18-24	1	1	16.9		512	1905	NIGHT	33	8.5 8.5	8.5	8.5	8.5	NONE	-	29.4 29.7	29.5
F 1	0- 9	2	2	30.0	29.4 30.6	912	1707	NIGHT	17	7.2 7.3	7.3	7.3	7.0	NONE	-	28.4 28.6	28.5
F 2	0- 9	1	1	23.3		912	1803	NIGHT	17	7.3 7.4	7.3	7.3	7.4	NONE	-	24.3 24.6	24.5
F 4	0-15	1	1	21.0		1012	0119	NIGHT	20	9.1 9.2	9.2	9.2	9.1	NONE	-	30.1 30.2	30.1
G 3	0- 6	6	6	11.8	10.6 13.7	1012	2302	NIGHT	18	9.8 10.0	9.9	10.0	9.5	NONE	-	30.1 30.4	30.3
G 4	0-15	2	2	12.3	10.2 14.4	1012	2126	NIGHT	29	10.1 10.2	10.2	10.1	10.2	NONE	-	31.8 32.2	32.0
H 3	0- 6	2	2	12.1	10.2 14.0	1112	0812	DAY	23	10.8 10.9	10.9	10.8	10.9	NONE	-	28.3 28.4	28.3
H 4	0-15	2	2	11.8	10.9 12.8	1112	1237	DAY	25	10.7 10.7	10.7	10.7	10.7	NONE	-	28.1 30.0	29.2
J 2	0- 3	1	1	17.4		1212	1900	NIGHT	9	9.8 10.3	10.0	9.8	10.8	NONE	-	30.3 30.8	30.6
J 3	0- 6	5	5	16.5	13.7 18.9	1212	1030	DAY	16	10.0 10.9	10.5	10.0	10.9	NONE	-	30.5 32.1	31.4
J 4	0- 6	1	1	10.1		1212	0902	DAY	17	10.9 11.0	11.0	10.9	11.0	NONE	-	32.8 32.8	32.8
J 5	0-15	2	2	15.7	15.6 15.8	1212	0537	NIGHT	26	10.8 10.9	10.8	10.9	10.8	NONE	-	32.5 34.0	33.1
K 3	0-15	1	1	15.1		1312	0038	NIGHT	25	10.2 10.8	10.3	10.2	10.8	NONE	-	33.3 34.0	33.7
K 4	0-15	7	7	15.3	13.7 19.5	1312	0410	NIGHT	31	11.9 12.0	11.9	12.0	11.9	NONE	-	33.9 34.2	34.0
K 4	18-24	3	3	13.6	11.4 15.0	1312	0410	NIGHT	31	11.9 11.9	11.9	12.0	11.9	NONE	-	34.3 34.5	34.5
K 5	0-15	3	3	14.1	13.4 15.1	1312	0607	NIGHT	35	11.3 11.5	11.3	11.5	11.3	NONE	-	32.5 32.9	32.6
L 1	0- 6	1	1	15.2		1312	1939	NIGHT	18	11.3 11.5	11.4	11.3	11.7	NONE	-	33.8 34.6	34.2
L 3	0-15	1	1	18.3		1312	2152	NIGHT	35	12.1 12.4	12.3	12.4	12.2	NONE	-	34.1 34.2	34.2
L 3	18-24	7	7	12.5	9.1 15.9	1312	2152	NIGHT	35	12.2 12.2	12.2	12.4	12.2	NONE	-	33.9 34.1	34.0
M 1	0- 3	18	18	18.4	12.3 21.3	1412	1838	NIGHT	13	12.4 12.4	12.4	12.4	12.5	NONE	-	34.1 34.4	34.2
M 2	0- 9	79	36	14.2	10.1 18.4	1412	1730	NIGHT	18	12.6 12.7	12.6	12.7	12.6	NONE	-		
M 3	0-15	181	77	10.6	5.1 16.3	1412	1553	DAY	20	12.7 12.8	12.7	12.8	12.7	NONE	-	33.2 34.5	33.6
M 4	0-15	5	5	12.8	9.5 14.2	1412	1445	DAY	26	13.0 13.1	13.1	13.1	12.8	NONE	-	34.1 34.5	34.2
M 4	18-24	1	1	11.9		1412	1445	DAY	26	12.8 13.0	12.9	13.1	12.8	NONE	-	34.2 34.2	34.2
M 5	0-15	57	32	7.5	3.5 10.3	1412	1235	DAY	90	23.1 23.1	23.1	23.1	20.1	NONE	-		
M 5	18-33	4	4	9.7	7.8 11.5	1412	1235	DAY	90	22.5 23.1	22.8	23.1	20.1	NONE	-		
N 1	0- 6	5	5	15.3	12.5 19.0	1512	0005	NIGHT	19	14.3 14.4	14.3	14.4	14.3	NONE	-	34.6 34.8	34.7
N 2	0-15	206	81	6.2	2.9 15.2	1512	0058	NIGHT	24	18.4 18.8	18.5	18.4	19.4	NONE	-	35.1 35.8	35.5
N 3	0-15	10	10	8.2	4.9 11.2	1512	0341	NIGHT	25	17.5 17.5	17.5	17.5	17.8	NONE	-	35.3 36.5	35.8
N 4	0-15	36	32	7.5	4.1 12.7	1512	0520	NIGHT	45	19.1 20.6	20.1	20.6	17.6	NONE	-	36.3 36.8	36.6
N 4	18-33	21	21	9.1	5.0 11.7	1512	0520	NIGHT	45	17.6 18.9	18.2	20.6	17.6	NONE	-	36.1 36.2	36.1
N 5	0-15	172	49	8.2	3.9 11.2	1512	0900	DAY	128	20.5 20.5	20.5	20.5	17.0	NONE	-	36.3 36.3	36.3
N 5	18-33	49	45	8.6	5.3 12.7	1512	0900	DAY	128	19.9 20.4	20.2	20.5	17.0	NONE	-	36.3 36.3	36.3
P 4	0-15	8	8	9.2	7.7 12.0	1512	1630	DUSK	34	22.4 23.2	23.0	23.2	19.3	NONE	-	36.9 37.5	37.1
P 4	18-33	2	2	9.2	8.3 10.1	1512	1630	DUSK	34	19.3 22.3	21.5	23.2	19.3	NONE	-		
P 5	0-15	3	3	9.5	8.7 10.7	1512	1335	DAY	82	25.4 25.4	25.4	25.4	23.5	NONE	-	37.4 37.8	37.6

APPENDIX TABLE—Continued.

CRUISE STAT. D66 1	TOW DEPTH (M)	********* LARVAE ********* NUMBER TOTAL	MEAS.	LENGTHS MEAN (MM TL)	RANGE (MM TL)	DATE 1966 D M	TOW START TIME (EST)	LIGHT COND.	WATER DEPTH (M)	*** TEMPERATURE (°C) *** RANGE	MEAN	SURF.	BOT.	THERMOCLINE DEGREE	DEPTH (M)	SALINITY (0/00) RANGE	MEAN
H 2	0- 6	2	2	21.1	19.4 22.9	7 2	0200	NIGHT	16	0.5 0.7	0.6	0.5	0.7	NONE	–	31.6 32.0	31.8
H 3	0- 6	1	1	15.5		7 2	0059	NIGHT	22	1.5 1.6	1.6	1.5	1.6	NONE	–	32.2 32.4	32.3
J 5	0-15	1	1	23.5		7 2	1143	DAY	26	3.5 3.6	3.5	3.6	3.5	NONE	–	32.9 33.0	33.0
K 1	0- 6	3	3	16.8	9.5 29.4	8 2	0138	NIGHT	15	1.5 1.6	1.5	1.6	1.5	NONE	–	30.9 31.2	31.1
K 2	0-15	4	4	17.3	13.8 24.3	8 2	0038	NIGHT	25	1.5 1.9	1.6	1.8	2.1	NONE	–	31.2 32.1	31.6
K 3	0-15	1	1	17.0		7 2	2332	NIGHT	22	3.4 3.8	3.5	3.8	3.4	NONE	–	32.6 32.6	32.6
K 6	0-15	1	1	17.9		7 2	1938	NIGHT	50	14.4 14.8	14.7	14.4	13.2	NONE	–	34.9 35.1	35.0
L 1	0- 6	6	6	22.3	17.0 29.1	8 2	0711	DAY	19	2.0 2.4	2.2	2.4	2.0	NONE	–	31.9 31.9	31.9
L 2	0- 6	4	4	19.6	15.9 28.0	8 2	0824	DAY	23	3.3 3.4	3.4	3.3	3.4	NONE	–	32.4 32.4	32.4
L 5	18-33	1	1	17.0		8 2	1225	DAY	145	12.2 13.2	12.7	14.5	11.1	NONE	–	34.6 34.9	34.7
M 1	0- 6	3	3	23.6	17.4 27.4	8 2	1633	DAY	13	3.3 3.4	3.3	3.4	3.3	NONE	–	31.6 31.6	31.6
M 2	0- 6	2	2	18.8	17.7 20.0	8 2	1726	DUSK	20	3.7 3.8	3.8	3.7	3.9	NONE	–	31.7 31.7	31.7
M 3	0- 6	2	2	16.6	15.8 17.4	8 2	1822	NIGHT	20	3.9 3.9	3.9	3.9	4.0	NONE	–	32.3 32.3	32.3
M 5	0-15	2	2	17.2	14.5 19.9	8 2	2018	NIGHT	139	12.2 17.0	16.0	17.0	10.0	STRONG	9-16	34.0 35.1	34.7
N 1	0- 6	6	6	20.3	17.5 23.0	9 2	0034	NIGHT	19	5.5 5.8	5.6	5.5	6.4	NONE	–	31.3 31.5	31.4
N 2	0-15	5	5	13.9	11.5 18.0	9 2	0126	NIGHT	24	7.9 8.6	8.1	7.9	8.6	NONE	–	32.7 33.1	33.0
N 3	0-15	49	49	13.7	7.1 29.8	9 2	0218	NIGHT	30	7.7 9.0	8.3	7.7	10.6	NONE	–	32.6 32.9	32.8
N 5	0-15	15	15	11.9	5.7 17.5	9 2	0509	NIGHT	82	19.2 19.4	19.3	19.4	16.6	NONE	–	35.3 35.5	35.5
N 5	18-33	6	6	11.5	8.6 13.4	9 2	0509	NIGHT	82	18.5 18.8	18.6	19.4	16.6	NONE	–	35.3 35.4	35.4
P 1	0- 6	3	3	14.9	13.6 17.3	9 2	1337	DAY	16	6.5 6.5	6.5	6.5	7.1	NONE	–	33.5 33.5	33.5
P 2	0- 6	9	9	21.1	14.6 26.6	9 2	1244	DAY	17	7.2 7.6	7.4	7.6	6.5	NONE	–	33.2 33.3	33.3
P 3	0- 6	108	108	14.8	6.5 23.9	9 2	1154	DAY	17	9.1 9.6	9.3	9.6	9.1	NONE	–	33.8 33.9	33.8
P 4	0-15	45	44	12.6	7.1 17.9	9 2	1033	DAY	31	14.1 17.0	15.8	17.0	13.1	WEAK	7-10	34.9 35.4	35.2
P 5	0-15	21	21	10.1	7.0 16.0	9 2	0848	DAY	60	20.0 20.0	20.0	20.0	17.8	NONE	–	35.5 35.6	35.5
P 5	18-33	5	5	10.5	6.5 15.4	9 2	0848	DAY	60	19.6 19.9	19.8	20.0	17.8	NONE	–	35.4 35.5	35.5
D66 3	(M)			(MM TL)		1966 D M	(EST)		(M)						(M)		
J 3	0- 6	1	1	29.4		16 4	0825	DAY	19	8.9 8.9	8.9	8.9	8.5	NONE	–	31.8 31.8	31.8
K 1	0- 6	2	2	27.3	25.3 29.3	19 4	1528	DAY	17	10.3 10.4	10.4	10.3	10.4	NONE	–	31.0 31.4	31.2
L 1	0- 6	1	1	25.0		20 4	0635	DAY	17	9.6 10.7	10.1	10.7	9.2	NONE	–	30.3 30.7	30.4
M 1	0- 6	12	12	22.7	20.6 24.7	20 4	1001	DAY	16	11.3 11.6	11.5	11.6	11.0	NONE	–	30.1 30.6	30.3
N 1	0-15	3	3	15.2	14.1 17.0	20 4	1753	DAY	21	10.7 12.2	10.9	12.2	10.7	WEAK	0- 4	32.2 32.6	32.4
N 2	0- 6	1	1	14.0		20 4	1851	NIGHT	22	11.7 11.8	11.8	11.8	11.9	NONE	–	32.1 32.1	32.1
N 3	0-15	9	9	15.0	11.0 17.4	20 4	1948	NIGHT	29	9.9 12.5	11.3	12.2	9.9	STRONG	6-10	31.7 32.2	32.0
N 3	18-24	4	4	15.3	14.4 16.0	20 4	1948	NIGHT	29	9.9 10.0	10.0	12.2	9.9	STRONG	6-10	32.1 33.9	32.7
N 4	0-15	1	1	19.0		20 4	2125	NIGHT	49	20.9 21.0	21.0	21.0	18.5	NONE	–	35.5 35.6	35.6

APPENDIX TABLE—Continued.

CRUISE STAT.	TOW DEPTH (M)	********* LARVAE ********* NUMBER TOTAL	MEAS.	LENGTHS MEAN (MM TL)	RANGE	DATE 1966 D M	TOW START TIME (EST)	LIGHT COND.	WATER DEPTH (M)	*** TEMPERATURE (°C) *** RANGE	MEAN	SURF.	BOT.	THERMOCLINE DEGREE	DEPTH (M)	SALINITY (0/00) RANGE	MEAN
D66 5																	
J 2	0- 6	1	1	25.0		21 5	0505	DAY	14	13.7 15.2	14.3	15.2	13.5	WEAK	3- 4	28.4 31.2	30.0
J 3	0- 6	1	1	25.0		21 5	0547	DAY	19	13.9 16.9	15.3	16.9	13.0	STRONG	1- 5	25.9 30.7	28.6
K 1	0- 6	1	1	26.0		21 5	2119	NIGHT	18	12.8 16.3	14.4	16.3	11.8	STRONG	1- 6	29.7 30.4	30.1
D66 7	(M)			(MM TL)		1966 D M	(EST)		(M)						(M)		
E 1	0- 3	1	1	13.7		29 6	0705	DAY	14	15.8 17.1	16.4	17.1	14.7	NONE	-	32.0 32.1	32.0
F 1	0- 6	11	11	9.5	7.8 14.4	28 6	0833	DAY	17	18.5 18.5	18.5	18.5	18.5	NONE	-	30.8 30.9	30.8
F 2	0- 6	2	2	8.0	8.0 8.1	28 6	0917	DAY	24	18.5 18.7	18.6	18.7	14.9	NONE	-	30.3 30.6	30.5
D6610	(M)			(MM TL)		1966 D M	(EST)		(M)						(M)		
B 1	0-15	1	1	5.6		6 8	1249	DAY	20	17.5 18.5	17.7	18.5	17.5	NONE	-	30.1 30.3	30.2
C 1	0- 6	3	3	8.6	8.1 9.1	6 8	2343	NIGHT	19	19.8 20.6	20.5	20.6	12.3	STRONG	5-13	30.6 30.8	30.7
C 2	0-15	1	1	7.7		7 8	0037	NIGHT	28	13.3 20.2	18.2	20.2	9.6	WEAK	5-19	30.6 30.8	30.7
C 3	0-15	2	2	9.8	9.3 10.3	7 8	0139	NIGHT	32	14.5 20.3	18.8	20.3	7.9	STRONG	11-22	30.6 30.7	30.7
D 5	0-15	1	1	10.6		8 8	1515	DAY	37	20.1 22.2	21.5	22.2	8.6	STRONG	14-19	30.9 31.0	30.9
D6612	(M)			(MM TL)		1966 D M	(EST)		(M)						(M)		
A 2	0-15	1	1	8.0		1510	0209	NIGHT	30	14.0 14.3	14.2	14.3	12.9	NONE	-	31.2 31.3	31.2
A 2	18-24	4	4	4.4	4.1 4.7	1510	0209	NIGHT	30	13.2 13.9	13.6	14.3	12.9	NONE	-	31.3 31.5	31.4
A 4	0-15	1	1	9.3		1510	0615	DAY	49	14.2 14.3	14.2	14.3	10.1	STRONG	30-35	31.0 31.3	31.2
B 2	0-15	15	15	13.7	6.9 18.7	1410	1937	NIGHT	35	13.5 15.1	14.2	15.1	12.7	NONE	-	30.9 31.3	31.1
B 2	18-24	9	7	5.3	3.6 8.2	1410	1937	NIGHT	35	12.7 13.4	13.2	15.1	12.7	NONE	-	31.3 31.3	31.3
B 3	0-15	24	22	11.7	4.4 18.7	1410	2034	NIGHT	45	15.7 16.1	16.0	15.7	9.8	WEAK	25-39	31.3 31.5	31.4
B 3	18-33	31	27	5.9	4.0 11.1	1410	2034	NIGHT	45	12.9 15.9	14.8	15.7	9.8	WEAK	25-39	31.4 31.6	31.5
B 4	0-15	8	8	9.7	7.1 11.3	1410	1306	DAY	60	15.4 15.6	15.4	15.6	8.0	STRONG	29-42	30.7 31.0	30.9
B 4	18-33	2	2	9.8	9.7 10.0	1410	1306	DAY	60	13.8 15.5	15.3	15.6	8.0	STRONG	29-42	30.9 31.6	31.3
B 5	0-15	9	9	13.1	9.3 16.2	1410	1138	DAY	71	14.9 15.2	15.0	15.2	7.4	STRONG	26-42	30.7 31.0	30.8
B 5	18-33	4	3	8.8	6.9 9.7	1410	1138	DAY	71	12.9 14.9	14.5	15.2	7.4	STRONG	26-42	31.0 31.5	31.2
B 6	0-15	1	1	9.6		1410	0750	DAY	81	15.1 15.2	15.1	15.2	9.1	STRONG	33-46	31.5 31.7	31.6
C 2	0-15	155	65	11.6	5.0 18.2	1310	0912	DAY	25	15.7 15.9	15.8	15.9	11.9	STRONG	19-23	30.9 31.0	31.0
C 3	0-15	398	153	11.5	7.7 16.2	1310	1007	DAY	31	16.2 16.4	16.3	16.3	10.5	STRONG	24-30	31.0 31.2	31.1
C 3	18-24	4	4	10.8	9.3 12.2	1310	1007	DAY	31	16.1 16.2	16.2	16.3	10.5	STRONG	24-30	31.0 31.3	31.2
C 4	0-15	19	18	11.3	5.4 17.4	1310	1133	DAY	38	15.7 16.0	15.8	16.0	9.1	STRONG	25-32	30.9 31.0	30.9
C 4	18-33	1	0			1310	1133	DAY	38	9.7 15.6	13.6	16.0	9.1	STRONG	25-32	31.0 31.6	31.4

APPENDIX TABLE—Continued.

CRUISE STAT.	TOW DEPTH (M)	LARVAE NUMBER TOTAL	LARVAE NUMBER MEAS.	LARVAE LENGTHS MEAN (MM TL)	LARVAE LENGTHS RANGE (MM TL)		DATE 1965 D M	TOW START TIME (EST)	LIGHT COND.	WATER DEPTH (M)	TEMPERATURE (°C) RANGE		TEMPERATURE (°C) MEAN	TEMPERATURE (°C) SURF.	TEMPERATURE (°C) BOT.	THERMOCLINE DEGREE	THERMOCLINE DEPTH (M)	SALINITY (0/00) RANGE		SALINITY (0/00) MEAN
D6612(CON'D)																				
D 1	0- 6	2	2	7.6	5.1	10.2	610	0124	NIGHT	18	17.2	17.3	17.3	17.2	17.5	NONE	-	30.4	30.5	30.5
D 2	0- 6	5	5	6.9	4.4	8.7	610	0213	NIGHT	23	17.0	17.1	17.0	17.1	17.0	NONE	-	30.5	30.7	30.6
D 3	0-15	89	33	6.9	4.1	10.1	510	0308	NIGHT	24	16.8	17.0	16.9	17.0	16.8	NONE	-	30.8	30.9	30.8
D 4	0-15	24	17	8.1	4.7	12.8	1210	2336	NIGHT	27	16.3	16.4	16.4	16.4	15.4	NONE	-	30.8	31.2	31.0
D 4	18-24	105	41	6.8	4.7	12.8	1210	2336	NIGHT	27	15.4	16.2	15.9	16.4	15.4	NONE	-	31.0	31.3	31.2
D 5	0-15	11	10	7.8	5.0	10.0	1210	2204	NIGHT	36	16.5	16.6	16.6	16.6	11.0	WEAK	23-37	31.2	31.3	31.2
D 5	18-24	50	50	6.5	3.1	12.5	1210	2204	NIGHT	36	15.5	16.4	16.1	16.6	11.0	WEAK	23-37	31.2	31.4	31.3
D 6	0-15	17	17	12.0	9.3	13.7	1210	1801	NIGHT	54	16.4	16.4	16.4	16.4	7.4	STRONG	19-24	31.5	31.8	31.7
D 6	18-33	11	11	11.4	9.5	13.0	1210	1801	NIGHT	54	8.3	15.5	10.8	16.4	7.4	STRONG	19-24	31.1	31.7	31.3
E 1	0- 6	10	9	7.2	5.6	8.7	510	1501	DAY	16	17.7	17.9	17.8	17.7	17.9	NONE	-	30.3	30.6	30.4
E 3	0- 6	6	6	5.9	4.0	10.3	510	1323	DAY	22	17.4	17.4	17.4	17.4	16.9	NONE	-	30.8	30.9	30.8
E 4	0-15	3	2	11.5	10.0	13.0	1110	2034	NIGHT	29	16.4	17.2	17.0	17.2	13.0	STRONG	21-28	30.8	31.3	31.0
E 5	0-15	476	111	7.2	3.7	12.5	1110	2210	NIGHT	35	16.4	16.6	16.5	16.6	9.0	STRONG	22-31	31.2	31.4	31.3
E 5	18-24	563	89	6.6	2.9	13.7	1110	2210	NIGHT	35	15.3	16.4	16.0	16.6	9.0	STRONG	22-31	31.4	31.4	31.4
E 6	0-15	66	36	10.4	7.7	13.0	1210	0150	NIGHT	43	15.8	16.2	16.1	16.2	7.9	STRONG	19-24	31.2	31.5	31.4
E 6	18-33	9	9	9.6	4.9	12.2	1210	0150	NIGHT	43	7.9	15.4	10.4	16.2	7.9	STRONG	19-24	30.9	31.9	31.4
E 7	18-33	4	4	10.3	10.0	10.5	1210	0352	NIGHT	65	11.0	17.1	15.7	17.2	6.2	STRONG	26-39	31.7	32.3	32.1
F 4	0-15	4	4	6.2	4.7	6.9	510	0227	NIGHT	22	17.7	18.0	17.8	18.0	17.7	NONE	-	30.8	30.9	30.8
F 5	0-15	18	16	6.9	5.0	11.4	410	2151	NIGHT	35	17.4	17.9	17.7	17.9	14.2	WEAK	18-24	30.7	30.9	30.8
F 5	18-24	30	29	7.1	5.0	12.5	410	2151	NIGHT	35	14.9	17.0	16.1	17.9	14.2	WEAK	18-24	30.9	30.9	30.9
F 6	0-15	92	43	7.0	5.8	10.2	410	1953	NIGHT	54	16.4	17.3	17.0	17.3	6.8	STRONG	15-23	30.9	31.2	31.1
F 6	18-33	8	6	7.2	6.9	7.6	410	1953	NIGHT	54	7.5	14.4	9.9	17.3	6.8	STRONG	15-23	30.8	31.3	31.0
F 7	0-15	426	38	6.6	3.1	8.5	410	1552	DAY	91	17.8	18.2	18.1	18.2	10.2	WEAK	14-42	31.6	31.9	31.8
F 7	18-33	2	2	6.7	5.8	7.6	410	1552	DAY	91	10.6	16.8	14.3	18.2	10.2	WEAK	14-42	31.4	31.7	31.5
G 3	0-15	1	1	11.6			310	2231	NIGHT	22	18.2	18.3	18.3	18.2	18.3	NONE	-	31.0	31.0	31.0
G 4	0-15	2553	116	6.4	2.7	10.5	410	0627	DAY	31	18.1	18.2	18.2	18.2	15.8	NONE	-	31.0	31.1	31.0
G 5	0-15	79	37	7.1	2.7	10.3	410	0816	DAY	51	17.4	18.0	17.8	18.0	9.4	STRONG	19-26	30.9	31.0	30.9
G 5	18-33	2	2	7.3	7.2	7.4	410	0816	DAY	51	10.9	16.9	12.9	18.0	9.4	STRONG	19-26	31.0	31.2	31.1
G 6	0-15	29	24	7.0	3.9	9.7	410	1209	DAY	85	19.1	19.4	19.2	19.1	11.7	STRONG	26-40	31.5	31.9	31.7
G 6	18-33	6	5	7.4	6.3	10.3	410	1209	DAY	85	15.9	19.5	18.7	19.1	11.7	STRONG	26-40	31.8	32.3	32.1
H 4	0-15	10	10	10.3	8.0	11.3	310	1114	DAY	28	19.3	19.4	19.3	19.3	19.4	NONE	-	30.0	30.9	30.7
H 5	0-15	1	1	7.3			310	0950	DAY	39	19.6	19.7	19.7	19.7	14.0	NONE	-	30.8	30.9	30.9
H 5	18-33	5	5	7.4	6.9	8.0	310	0950	DAY	39	16.1	18.6	17.2	19.7	14.0	NONE	-	30.9	31.1	31.0
J 2	0- 3	2	2	5.9	5.5	6.4	110	1351	DAY	11	21.6	21.6	21.6	21.6	21.2	NONE	-	27.8	29.1	28.5
J 3	0- 6	2	2	3.9	3.5	4.4	110	1257	DAY	17	21.9	22.0	21.9	22.0	21.8	NONE	-	28.4	28.8	28.5
K 2	0-15	2	2	3.6	3.5	3.7	110	0825	DAY	22	21.4	22.0	21.9	22.0	18.9	WEAK	15-21	30.0	30.7	30.2
K 3	0-15	11	10	6.4	4.5	7.7	110	0924	DAY	25	19.9	21.9	21.5	21.9	16.3	WEAK	12-22	29.9	30.9	30.3

APPENDIX TABLE—Continued.

CRUISE STAT. D6614	TOW DEPTH (M)	LARVAE NUMBER TOTAL	LARVAE NUMBER MEAS.	LARVAE LENGTHS MEAN (MM TL)	LARVAE LENGTHS RANGE (MM TL)		DATE 1966 D M	TOW START TIME (EST)	LIGHT COND.	WATER DEPTH (M)	TEMPERATURE (°C) RANGE		TEMPERATURE (°C) MEAN	TEMPERATURE (°C) SURF.	TEMPERATURE (°C) BOT.	THERMOCLINE DEGREE	THERMOCLINE DEPTH (M)	SALINITY (0/00) RANGE		SALINITY (0/00) MEAN
C 2	0- 6	1	1	22.0			312	0645	DAWN	28	9.8	9.9	9.9	9.8	9.9	NONE	-	32.9	33.0	33.0
C 3	0-15	1	1	21.5			312	0537	NIGHT	34	10.1	10.3	10.1	10.3	10.1	NONE	-	33.0	33.1	33.1
D 1	0- 6	2	2	21.7	20.0	23.5	112	1854	NIGHT	14	9.4	9.4	9.4	9.4	9.3	NONE	-	32.1	32.3	32.2
E 1	0- 6	5	5	19.9	18.5	20.5	911	2248	NIGHT	11	12.5	12.6	12.6	12.5	12.8	NONE	-	31.1	31.3	31.2
F 1	0- 6	1	1	21.0			1111	0602	NIGHT	18	13.5	13.5	13.5	13.5	13.5	NONE	-	31.4	31.8	31.6
F 2	0- 6	3	3	20.7	19.5	21.5	1111	0515	NIGHT	20	13.6	14.3	14.0	13.6	13.9	NONE	-	31.8	31.9	31.8
F 3	0-15	2	2	15.2	15.0	15.5	1111	0432	NIGHT	26	14.5	14.7	14.6	14.7	14.2	NONE	-	32.5	32.8	32.6
G 1	0- 6	100	55	20.7	17.0	25.0	1111	1604	DAY	10	14.5	15.0	14.7	15.0	14.3	NONE	-	32.4	32.4	32.4
G 2	0- 6	5	5	16.5	14.5	18.0	1111	1657	NIGHT	17	14.4	15.0	14.6	15.0	14.0	NONE	-	32.6	32.6	32.6
G 3	0-15	5	5	18.6	15.0	24.0	1111	1753	NIGHT	16	15.2	15.7	15.5	15.6	15.5	NONE	-	32.6	32.9	32.8
G 4	0-15	1	1	5.0			1111	1919	NIGHT	29	15.0	15.5	15.4	15.4	13.0	NONE	-	32.9	33.1	33.1
G 5	0-15	1	1	9.3			1111	2234	NIGHT	49	14.3	14.8	14.6	14.8	10.5	STRONG	26-28	33.3	33.5	33.4
H 1	0- 6	1	1	15.0			1211	1312	DAY	10	14.7	14.9	14.8	14.9	14.7	NONE	-	32.0	32.2	32.1
H 3	0- 6	1	1	5.7			1211	1041	DAY	25	15.8	15.9	15.9	15.8	15.3	NONE	-	32.6	32.8	32.7
H 4	0-15	2	2	13.7	13.5	14.0	1211	0918	DAY	29	14.9	15.6	15.2	15.6	14.7	NONE	-	32.8	33.4	33.1
H 5	18-33	2	2	5.3	5.0	5.7	1211	0754	DAY	42	14.0	14.3	14.2	15.3	14.0	NONE	-	33.8	33.9	33.9
H 7	0-15	1	1	19.0			1211	0503	NIGHT	134	14.5	15.1	14.7	14.5	11.2	STRONG	43-52	33.8	34.6	34.0
J 2	0- 6	1	1	20.5			1311	0036	NIGHT	10	15.1	15.3	15.2	15.1	15.2	NONE	-	31.7	32.0	31.8
J 3	0- 6	1	1	10.6			1311	0202	NIGHT	16	15.0	15.2	15.1	15.2	15.3	NONE	-	32.3	32.4	32.4
J 4	0-15	6	6	9.3	7.4	12.5	1411	1348	DAY	22	14.9	15.0	14.9	14.9	15.0	NONE	-	33.2	33.3	33.2
K 1	0- 6	17	17	15.1	4.4	22.0	1811	0842	DAY	15	14.5	14.5	14.5	14.5	14.6	NONE	-	33.2	33.3	33.2
K 2	0-15	1	1	12.5			1811	0929	DAY	20	14.1	14.7	14.4	14.2	14.7	NONE	-	32.3	33.8	33.2
K 3	0-15	1	1	6.0			1811	1022	DAY	24	14.7	14.7	14.7	14.7	14.9	NONE	-	33.6	34.0	33.8
K 4	18-24	2	2	11.5	10.6	12.5	1811	0325	NIGHT	33	14.4	14.6	14.5	14.7	14.5	NONE	-	34.1	34.1	34.1
K 5	0-15	1	1	13.1			1811	0155	NIGHT	37	14.5	14.8	14.7	14.8	13.9	NONE	-	34.2	34.4	34.3
L 1	0- 6	3	3	10.9	10.2	11.9	1711	0838	DAY	21	14.2	14.4	14.3	14.2	15.1	NONE	-	31.0	31.6	31.2
L 2	0- 6	2	2	13.7	10.5	17.0	1711	0754	DAY	21	15.0	15.2	15.1	15.2	15.0	NONE	-	33.3	33.5	33.4
L 3	18-24	1	1	11.9			1711	0707	DAY	32	14.8	15.0	14.9	15.1	15.0	NONE	-	33.3	33.8	33.5
M 1	0- 6	43	43	9.7	6.6	14.0	1611	1530	DAY	26	14.8	14.9	14.8	14.9	14.7	NONE	-	33.4	33.5	33.5
M 2	0- 6	67	37	8.0	5.0	11.4	1611	1440	DAY	20	14.9	15.1	15.0	15.1	15.0	NONE	-	33.7	33.8	33.7
M 4	0- 6	10	10	9.8	6.5	11.4	1611	2339	NIGHT	41	17.5	17.6	17.5	17.6	17.9	NONE	-	35.0	35.1	35.1
N 1	0- 6	1	1	10.7			1611	1034	DAY	25	16.4	16.4	16.4	16.4	16.4	NONE	-	34.0	34.0	34.0
N 2	0-15	14	14	9.0	4.3	11.4	1611	0937	DAY	26	18.6	18.8	18.7	18.8	18.9	NONE	-	35.5	35.6	35.6
N 3	0-15	3	3	7.2	5.1	11.1	1611	0833	DAY	30	19.3	19.5	19.4	19.3	19.4	NONE	-	35.6	35.8	35.8