EGGS AND LARVAE OF *SCOMBER SCOMBRUS* AND *SCOMBER JAPONICUS* IN CONTINENTAL SHELF WATERS BETWEEN MASSACHUSETTS AND FLORIDA

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ABSTRACT

Larval *Scomber scombrus* and *Scomber japonicus* from the western North Atlantic Ocean are compared. At 4 to 11 mm *S. japonicus* are deeper bodied, and at 3 to 15 mm have greater preanus lengths than *S. scombrus* of comparable sizes. *Scomber scombrus* larvae are more heavily pigmented than *S. japonicus*, particularly on the dorsal trunk surface and at the cleithral sympysis.

In continental shelf waters between Martha's Vineyard, Mass., and Palm Beach, Fla., 1966-68, *S. scombrus* eggs occurred north of Cape Hatteras, N.C., mostly in the shoreward half of shelf waters, during spring and summer. Surface temperatures associated with egg occurrences varied from 6.3° to 16.9°C. *Scomber japonicus* eggs were taken south of Cape Hatteras, in the outer half of shelf waters, during winter and spring cruises. Surface temperatures associated with egg occurrences ranged from 20.4° to 25.4°C.

Larval *S. scombrus* occurred north of Cape Hatteras during spring and summer with concurrent surface temperatures ranging from 12.3° to 20.7°C. With the exception of three specimens, *S. japonicus* larvae occurred south of Cape Hatteras and were taken where the surface temperature ranged from 16.0° to 29.4°C.

Despite an abundance of publications describing the young stages of Atlantic mackerel, *Scomber scombrus* Linnaeus, and their occurrences in the western North Atlantic (Dannevig 1919; Sette 1943; Bigelow and Schroeder 1953; Berrien 1975), very little information exists on young of the congeneric chub mackerel, *Scomber japonicus* Houttuyn, from the same area. There are no descriptions of *S. japonicus* eggs, larvae, or juveniles from the western North Atlantic, although there are excellent descriptions of specimens from the Pacific Ocean (Fry 1936a; Orton 1953; Uchida et al. 1958; Kramer 1960; Watanabe 1970) and some brief descriptions of this species from European waters (Ehrenbaum 1924; Padoa 1956). Ehrenbaum (1924), Padoa (1956), and Dekhnik (1959) compared larvae of the two species. Reports of young *S. japonicus* in the western North Atlantic are limited to those by Anderson and Gehringer (1958), Dooley (1972), Fahay (1975), and de Sylva.[2] Although adults of *S. japonicus* are known to range from the Gulf of St. Lawrence (Leim and Scott 1966) to Bermuda and the Gulf of Mexico (Briggs 1958) in the western Atlantic, they occur irregularly along the U.S. east coast. In various years they have been abundant, uncommon, or absent (Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953). This species apparently inhabits warmer waters than does *S. scombrus* (Bigelow and Schroeder 1953; Matsui 1967).

The purposes of this paper are: 1) to present descriptive, comparative information on two species of *Scomber* larvae, in order to facilitate their identification; and 2) to compare the spawning areas of the two species as indicated by occurrences of *Scomber* young taken between Massachusetts and Florida.

Specimens utilized in this study were taken primarily during ichthyoplankton survey cruises by the RV *Dolphin* in continental shelf waters from December 1965 to February 1968 between Martha's Vineyard, Mass., and Palm Beach, Fla. Some larvae in the descriptive section were taken on other cruises during April 1971 and June 1972, within the same area.

PROCEDURES

Sampling

Eight plankton sampling cruises were conducted between December 1965 and December

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[2]de Sylva, D. P. 1970. Ecology and distribution of postlarval fishes of southern Biscayne Bay, Florida. Prog. Rep. to Div. Water Qual. Res., Water Qual. Off., U.S. Environ. Prot. Agency Contract FWQA 18050 Div. Rosenstiel School Mar. Atmos. Sci., Univ. Miami, 198 p. (Unpubl. manuscr.)

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1966 aboard the RV *Dolphin* in continental shelf waters, between Martha's Vineyard and Cape Lookout, N.C. Four cruises were made between May 1967 and February 1968 between New River Inlet, N.C., and Palm Beach (Figure 1). Gulf V samplers, with 0.4-m mouth and 0.52-mm mesh openings, were used for plankton tows. The tows were 0.5 h long at a speed of 9.3 km/h (5 knots) in a step-oblique pattern. Normally the nets were lowered in six 3-m depth increments and towed for 5 min at each depth. One Gulf V net (net 1) sampled from 0 to 15 m, and a second net sampled from 18 to 33 m. While setting and retrieving net 2, contamination above 15 m was inevitable, since the nets were not equipped with closing devices. Plankton samples were preserved in 5% Formalin[3] buffered with borax. Sampling time, whether day or night, was essentially random, in that there was no prearranged time schedule. At each station we measured surface water temperature, made a bathythermograph cast to a maximum depth of 275 m, and measured salinity with an in situ induction salinometer at 5-m intervals down to include the plankton sampling depth. Additional details on the sampling scheme and gear used, as well as temperatures, salinities, zooplankton volumes, and midwater trawl catches, were summarized by Clark et al. (1969, 1970).

Identification of Eggs and Larvae

Scomber scombrus eggs were identifiable using criteria summarized by Berrien (1975). Briefly, distinguishing features of this species' eggs are: they are spherical and have a diameter of about 1.0 to 1.3 mm; they have a single yellowish oil globule about 0.3 mm in diameter; and after blastopore closure, melanophores occur on the head, trunk, and oil globule. Pigment is absent from the yolk except just prior to hatching when one melanophore occurs near each side of the embryo, immediately posterior to the head.

Despite a lack of information on *S. japonicus*

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

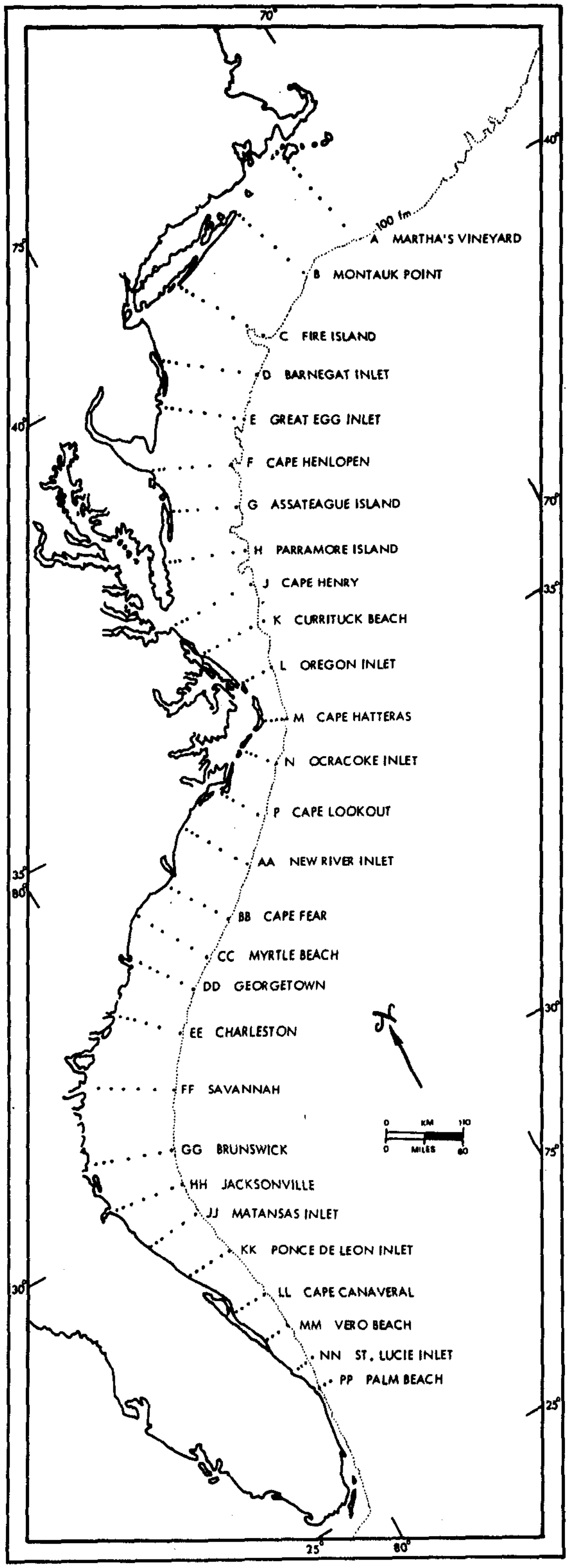

FIGURE 1.—Ichthyoplankton survey area; transects designated by single letters were sampled eight times, December 1965 to December 1966; those with two letters were sampled four times, May 1967 to February 1968. Stations starting at 1 on the inshore end of each transect were numbered consecutively, progressing oceanward.

eggs from the Atlantic Ocean, they have been well described from the Pacific Ocean, and are similar to eggs of *S. scombrus* in size and appearance (Fry 1936a; Kramer 1960; Watanabe 1970). The most obvious difference between eggs of the two species is the amount of pigment found on the yolk surface during the late or third stage in development. *Scomber japonicus* develops several melanophores on the yolk while *S. scombrus* has, at most, a pair of melanophores, as described above. Due to similarity of early-stage eggs of the two *Scomber* species, their identification must depend upon other information, such as spawning area, and the proximity of older identifiable stages.

In separating *Scomber* spp. larvae from larvae of other fishes I found the descriptions and illustrations by Bigelow and Schroeder (1953), Kramer (1960), and Watanabe (1970) to be especially helpful. *Scomber* spp. larvae are characterized by the following: 1) they have 31 myomeres and lack preopercular spines, unlike other scombrid larvae in the western North Atlantic which have more myomeres and possess strong spines; 2) melanophores are present above the forebrain, midbrain, and gut, and along the postanus ventral edge of the trunk; 3) prominent recurved teeth form in larvae by about 4 mm, and are present well into the juvenile stage although somewhat embedded and obscured at sizes above about 15 mm; and 4) a large portion of *Scomber* spp. larvae between about 7 and 15 mm have noticeably subterminal mouths.

Other larval fishes found along the U.S. east coast which grossly resemble one or the other of the two *Scomber* spp. include *Sebastes marinus, Pomatomus saltatrix, Centropristis striata,* and *Stenotomus chrysops*. Despite pigmentation similarities myomere counts alone will separate *Scomber* larvae (with 31 myomeres) from *P. saltatrix* (with 26) and *C. striata* and *Stenotomus chrysops* (each with 24 myomeres). *Sebastes marinus* can have the same number of myomeres (with 30 to 32) as *Scomber* and is pigmented in most of the same body areas as both species of *Scomber*. However, at lengths less than about 9 mm *Sebastes marinus* lack teeth and have dorsal and ventral trunk melanophores which are close enough together to appear as dorsal and ventral lines of pigment. Comparably sized *Scomber* larvae have prominent teeth and discrete dorsal and ventral trunk melanophores. Also *Sebastes marinus* larvae are more slender and have shorter snout-to-anus lengths than *Scomber* larvae. The presence of temporal and preopercular spines on *Sebastes marinus* and their absence on *Scomber* larvae separate the two species at lengths >9 mm, before fin-ray counts are distinguishable.

Treatment of Specimens and Data

Measurements, as defined by Kramer (1960), made in this study include: standard length (SL = anterior tip of snout to tip of notochord, or to posterior edge of the hypurals after notochord flexure); preanus length (PAL = anterior tip of snout to the most posterior edge of the anus); and body depth (BD = the vertical distance from the dorsal surface of the body directly above the dorsal point of the cleithrum to the ventral point of the cleithrum). Length measurements in this paper are standard lengths, unless otherwise stated.

Osteological characters in developing *Scomber* larvae were investigated by examination of bone-stained specimens (Hollister's method in Clothier 1950) and radiographs.

All *Scomber* eggs in samples containing <400 eggs were identified and tabulated. In larger samples, the numbers of *S. scombrus* eggs were estimated from a random subsample of 200. To test the validity of this procedure *S. scombrus* eggs were identified from seven aliquots of 200 eggs from one sample. No significant differences were found between aliquots (chi-square = 5.415, $P = 0.5$).

Lengths for length-frequency diagrams were measured to the nearest 0.1 mm in fish <15 mm and to the nearest 0.5 mm in those >15 mm. Measurements were taken of all specimens from samples of 100 or fewer fish and of 50 to 75 randomly selected specimens from larger samples.

The numbers of *Scomber* spp. eggs and larvae taken during survey cruises are presented on charts. For these charts the catches from net 1 (0-15 m) and net 2 (18-33 m) were combined at stations where both were towed. Before these numbers were plotted some were adjusted in an attempt to standardize the catches. Because net 2 spent an estimated 3 min of the ½-h tow being set and retrieved through the upper 15 m, the catch by net 2 was reduced by 10% of the net 1 catch to correct for contamination. In cases where there was insufficient water depth to allow lowering the plankton net for the standard of six 3-m depth increments, the towing scheme was altered. During these tows we sampled for 15 min at each of two levels, or for 10 min at each of three levels. The resulting catch was reduced to one-third when two levels were sampled or to one-half when three levels were sampled. Fahay (1974) explained this procedure in more detail.

COMPARISON OF TWO SPECIES OF *SCOMBER* LARVAE

Scomber larvae occurred in samples from our northernmost transect, off Martha's Vineyard to our southernmost transect off Palm Beach. The larvae were of two types, the distinction between the two being more obvious in larvae smaller than 15 mm. One type, collected north of Cape Hatteras, predominantly over the inshore and central portions of the continental shelf, during May, June, and August 1966, was tentatively identified as Atlantic mackerel, *S. scombrus*. A second type collected south of Cape Hatteras was tentatively identified as chub mackerel, *S. japonicus*. It occurred predominantly in samples taken near the offshore edge of the continental shelf, during May and July 1967 and January and February 1968. The identities of the two types were confirmed by examination of some meristic characters of the large larvae and juveniles.

Because of the similarity and possible confusion of these two species, the following descriptions and comparisons were compiled to facilitate future identifications. Three study areas were considered in larval development: meristic characters, morphology, and pigmentation.

Meristic Characters

Of the 12 characters listed by Matsui (1967, table 5) as distinguishing between the species of *Scomber*, four were found to be useful in identifying young stages dealt with here. These were: 1) first-dorsal-fin spine counts; 2) counts of precaudal and caudal vertebrae; 3) counts of first-dorsal-fin ptergiophores and the arrangements in relation to neural spines; and 4) the relative position of the first haemal spine and the first anal pterygiophore.

Scomber japonicus has 9 or 10 first-dorsal-fin spines and *S. scombrus* has 11 to 14 (Matsui 1967). Examination of Formalin-preserved specimens under a dissecting microscope revealed that counts of 9 or 10 were attained by a length of 18.5 mm in *S. japonicus* and counts of 11 to 15 by 21.0 mm in *S. scombrus*. However, bone-stained specimens of both species had higher counts and earlier formation of spines than indicated in the above. Apparently some of the minute, posterior spines in the first dorsal fin, observed in bone-stained specimens, were obscured in nonstained specimens by surrounding muscle and epithelial tissue and by their position in the longitudinal groove. I observed a complement of 10 or 11 spines in *S. japonicus* as small as 11.9 mm long and 12 to 17 spines in *S. scombrus* 18.2 mm and greater (Table 1).

Counts of vertebrae were made to help identify the two species of *Scomber* larvae. *Scomber japonicus* is reported to have 14 precaudal and 17 caudal vertebrae and *S. scombrus* to have 13 precaudal and 18 caudal vertebrae (Matsui 1967). The first caudal vertebra is the most anterior vertebra which has an elongate pointed haemal spine and lacks ribs. In *Scomber* larvae the haemal spine on the first caudal vertebra is noticeably longer than the haemal arch on the last precaudal vertebra. Also, rib articulation surfaces on haemal arches of posterior precaudal vertebrae are distinctly flattened or truncated, rather than pointed as are haemal spines on caudal vertebrae. In my work counts of precaudal vertebrae were distinguishable in bone-stained *S. japonicus* as small as 7.6 mm (indeterminate at 6.7 mm) and on radiographs by 9.3 mm. Precaudal counts characteristic of *S. scombrus* were observable in bone-stained larvae at 8.6 mm (indeterminate at 7.6 mm) and on radiographs by 11.2 mm (Table 1). A few of the *S. scombrus* specimens had precaudal and caudal vertebral counts different from those reported by Matsui (1967). Six of the 136 *S. scombrus* specimens bone-stained or X-rayed large enough for determination had 12 precaudal and 19 caudal vertebrae. In two other specimens the 28th and 29th vertebrae were fused together, as evinced by a total count of 30 and by the presence of two neural and two haemal spines on the 28th vertebra. One additional larva was observed with partial fusion of the same two vertebrae.

The numbers of first-dorsal-fin pterygiophores separate the two species of *Scomber*. Matsui (1967) reported *S. japonicus* has 12 to 15 first-dorsal-fin pterygiophores and *S. scombrus* has 21 to 28. Full complements of pterygiophores, 13 or 14 in *S. japonicus* and 22 to 25 in *S. scombrus*, were found in bone-stained *S. japonicus* as small as 20.2 mm and on radiographs by 33.3 mm; they were found in bone-stained *S. scombrus* at 32.0 mm and on radiographs at 38.8 mm (Table 1). Because anterior pterygiophores ossify before posterior ones and because there is a difference

TABLE 1.—Some meristic characters in *Scomber japonicus* and *S. scombrus* young as determined in bone-stained (and two X-rayed) specimens. D_1 refers to the first dorsal fin; pterygiophore counts were made between successive neural spines, starting in the second interneural space. (— = count was indeterminate. X = X-rayed specimen. * = pterygiophore series completed. M = mutilated, spine(s) lost in handling.)

Scomber japonicus				*Scomber scombrus*			
SL (mm)	Vertebrae	D_1 spines	D_1 pterygiophores	SL (mm)	Vertebrae	D_1 spines	D_1 pterygiophores
6.7	—	—	—				
7.6	14 + —	—	—	7.6	—	—	—
7.7	14 + 17	1	—				
8.4	14 + —	6	—				
8.5	14 + 17	7	—	8.6	13 + —	—	—
9.0	14 + 17	4	—				
9.1	14 + 17	6	—	9.3	13 + —	—	—
10.2	14 + 17	8	—				
10.5	14 + 17	9	—	10.5	13 + 18	—	—
				10.7	13 + 18	—	—
				11.4	13 + —	—	—
11.7	14 + 17	8	11121	11.6	13 + 18	—	—
11.9	14 + 17	11	1121				
12.4	14 + 17	11	11121	12.3	13 + 18	2	—
13.8	14 + 17	11	112111	13.4	13 + 18	5	—
14.0	14 + 17	10	11121	14.8	13 + 18	6	—
16.5	14 + 17	10	11121111	16.0	13 + 18	10	—
17.7	14 + 17	10	1112111	18.2	13 + 18	17	1122
20.2	14 + 17	11	11211111121*	19.8	12 + 19	15	1123
22.1	14 + 17	10	111211120211*	22.1	13 + 18	16	112221
24.7	14 + 17	11	11121111	24.3	13 + 18	13	11222
26.3	14 + 17	11	11121111112*	26.0	13 + 18	14	1122221
				28.2	13 + 18	14	11222222
28.6X	14 + 17	10	111211	29.9	12 + 19	15	1123221
				32.0	13 + 18	12M	1132212212221*
33.3X	14 + 17	11	11121111121*	34.2	13 + 18	13	112222223222*
				36.6	13 + 18	13	1122322133221*
				38.6	13 + 18	13	112322122222*

between the two species in counts of pterygiophores in anterior, successive interneural spaces, the two species can be separated well before the total complement is attained. A count of six pterygiophores in the 2d through 6th interneural spaces, characteristic of *S. japonicus*, was observed in bone-stained larvae as small as 11.7 mm and on radiographs at 20.2 mm; a count of six or seven pterygiophores in the 2d through 50th interneural spaces, characteristic of *S. scombrus*, was observed in bone-stained larvae as small as 18.2 mm and on radiographs at 20.1 mm.

In *S. japonicus* the first anal pterygiophore is anterior to the first haemal spine while in *S. scombrus* the first anal pterygiophore is posterior to the first haemal spine (Matsui 1967). This was observable in bone-stained *S. japonicus* at 11.7 mm and in *S. scombrus* at 32.0 mm, and on radiographs at 17.0 mm in *S. japonicus* and 32.0 mm in *S. scombrus*.

Body Proportions

Larvae of the two species differ noticeably in several body proportions. *Scomber japonicus* is deeper bodied and has a greater preanus length than *S. scombrus*. Measurements of body depth (BD) and preanus length (PAL) were converted to percentages of standard length (SL) and the results were graphed (Figure 2). Although the separation of the two species by these characters is not total, more than two-thirds of the larvae are separable by BD measurements at lengths of 4 to 11 mm and by PAL measurements at 3 to 15 mm long. Of these two characters the PAL difference is more useful, as it is present over a greater size range.

Other morphological differences between the two species have been reported by previous workers. These contrasts were not considered strong enough in the larvae from this study to warrant elaboration. Padoa (1956) noted a larger eye, shorter lower jaw, and shorter snout relative to eye diameter in *S. japonicus* than in *S. scombrus*. Dekhnik (1959) presented a brief and generalized comparison of larvae of the two species. She reported *S. japonicus* larvae are more advanced than *S. scombrus* of the same length. Thus *S. japonicus* are smaller than *S. scombrus* at hatching, at yolk and oil globule absorption, and at the initial formation of caudal fin rays. These differences were not as striking in my specimens. In our survey both species apparently hatched at about 3 mm long, and yolk and oil globules were absorbed in both by a length of 4 mm. Caudal ray development varied between species; in *S. japonicus* the

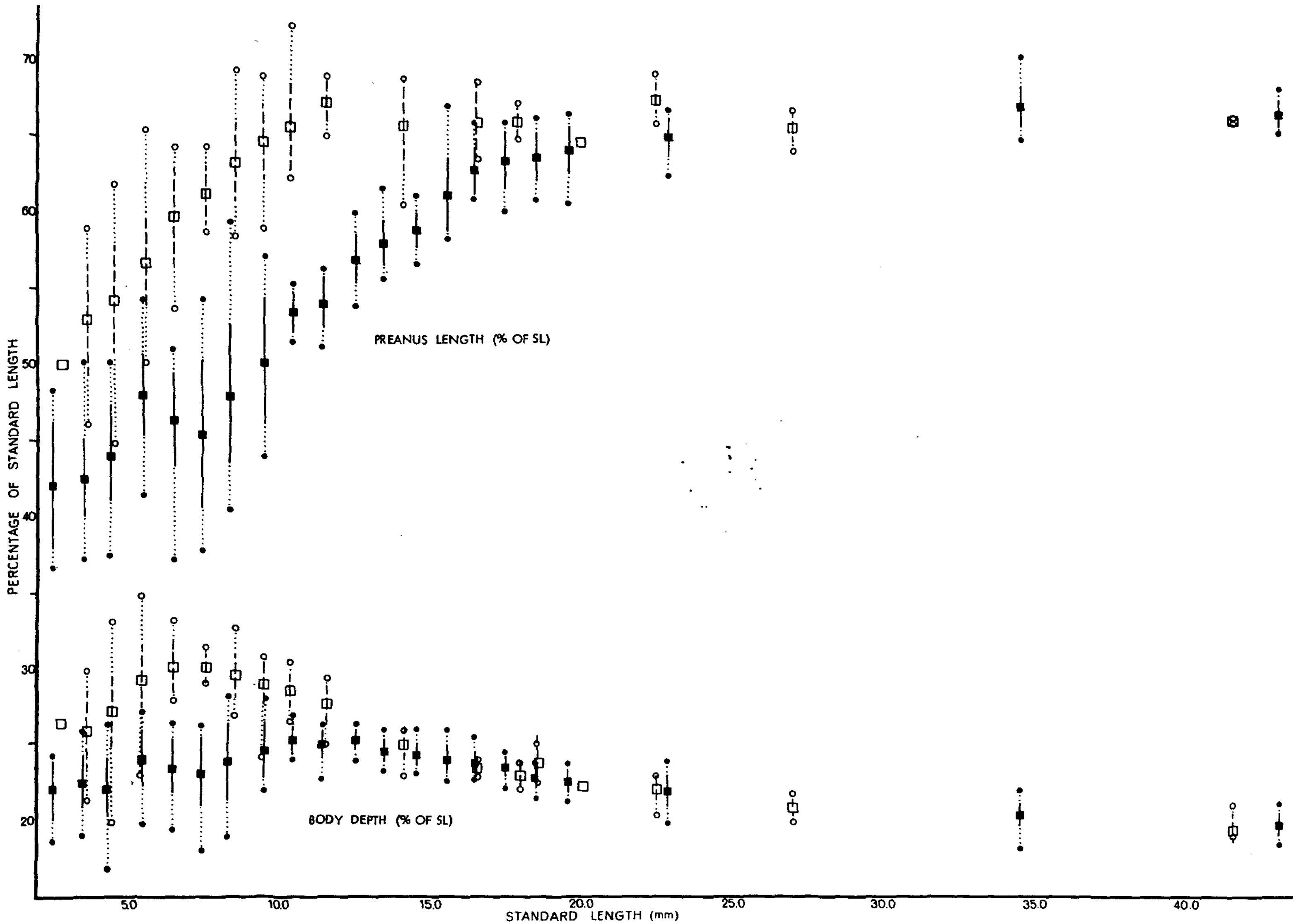

FIGURE 2.—Body proportions of two species of *Scomber* larvae; open symbols (squares, dashes, and circles) denote *S. japonicus*; solid symbols denote *S. scombrus*; squares denote means; bars denote $\pm\sigma$, dots and circles denote total range of observations.

rays were forming at a length of 5 mm and in *S. scombrus* at 7 mm.

Pigmentation

Differences in pigmentation were found between larvae of the two species. Pigmentation over the gut and midbrain and on the caudal region is not described in detail because it does not differ between the two species. A series of 210 *S. japonicus* specimens ranging from 2.8 to 49.0 mm long and 187 *S. scombrus*, 2.6 to 21.6 mm long, were used in the pigmentation comparison. Figure 3 illustrates the development of pigmentation and various body features.

Forebrain

Scomber scombrus larvae usually acquire melanophores on the forebrain at smaller sizes than *S. japonicus*. They were present on *S. scombrus* as small as 3.7 mm and were present on all larvae larger than 5.5 mm. The smallest *S. japonicus* with such pigment was 5.2 mm, and not until 8.7 mm was attained did all larvae have this pigment. Forebrain pigment should not be confused with that on the midbrain which larvae of both species possess at all sizes.

Hindbrain

Pigmentation on the hindbrain begins as a single melanophore then increases to three to five melanophores on the posterior and middle portion of the hindbrain. This pigmentation is increasingly obscured by overlying tissue after about 5 mm. All *S. scombrus* larvae examined had this pigment, but *S. japonicus* <3.5 mm did not.

Snout

Pigmentation on the snout refers to melanophores on, or within, epidermal tissue, not subsurface as on the forebrain. Melanophores appear first near the tip of the snout. *Scomber scombrus* generally develop snout pigmentation at smaller sizes than *S. japonicus*. The smallest *S. scombrus* with such pigmentation was 4.3 mm long and it was present in all that were 6.3 mm and greater. It was first observed in *S. japonicus* at 5.2 mm and was present in all specimens 10.5 mm and longer.

Cleithral Symphysis

Pigmentation at the symphysis of the cleithra, and on the isthmus immediately anterior to the symphysis, was lacking in all specimens of *S. japonicus*. However, in *S. scombrus* prominent melanophores were noted at this location in larvae as small as 3.7 mm and occurred in all larvae >8.0 mm (Figures 3, 4). Melanophores occurred on the isthmus of *S. scombrus* in: 13% of those 4.0 to 4.9 mm long; 41% of those 5.0 to 5.9 mm; 67% of those 6.0 to 6.9 mm; 95% of those 7.0 to 7.9 mm; and in all specimens 8.1 mm and longer. In larvae <8 mm the presence of melanophores at the cleithral symphysis indicates *S. scombrus*; however, the absence of this pigment at this size does not indicate either of the two species. At sizes >8 mm the presence of this pigment indicates *S. scombrus* and its absence indicates *S. japonicus*.

Lower Jaw

Melanophores on the lower jaw first appear at the mandibular symphysis, then spread laterally and posteriorly. *Scomber scombrus* acquire this pigment at a smaller size than *S. japonicus*. The smallest larval *S. scombrus* observed with lower jaw pigmentation was 4.6 mm long and it occurred in all specimens 6.2 mm and greater. The smallest *S. japonicus* with such pigment was 8.3 mm long and it occurred in all larvae of this species 11.7 mm and greater.

Ventrum of Gut

In his paper on the development of *S. japonicus*, Kramer (1960) referred to two or three characteristic, minute melanophores on the ventral surface of the gut, found after yolk absorption. During my study pigment in this location was observed in both *S. japonicus* and *S. scombrus*. The percent occurrence of melanophores on the ventrum of the gut in *S. japonicus* <12 mm long varied from 70% to 92% for each 1-mm size group, with an average of 88% occurrence. The occurrence for the same sizes of *S. scombrus* varied from 10% to 41%, with an average of 28%.

Dorsum of Trunk

There are substantial differences between the two species in pigmentation on the dorsum of the

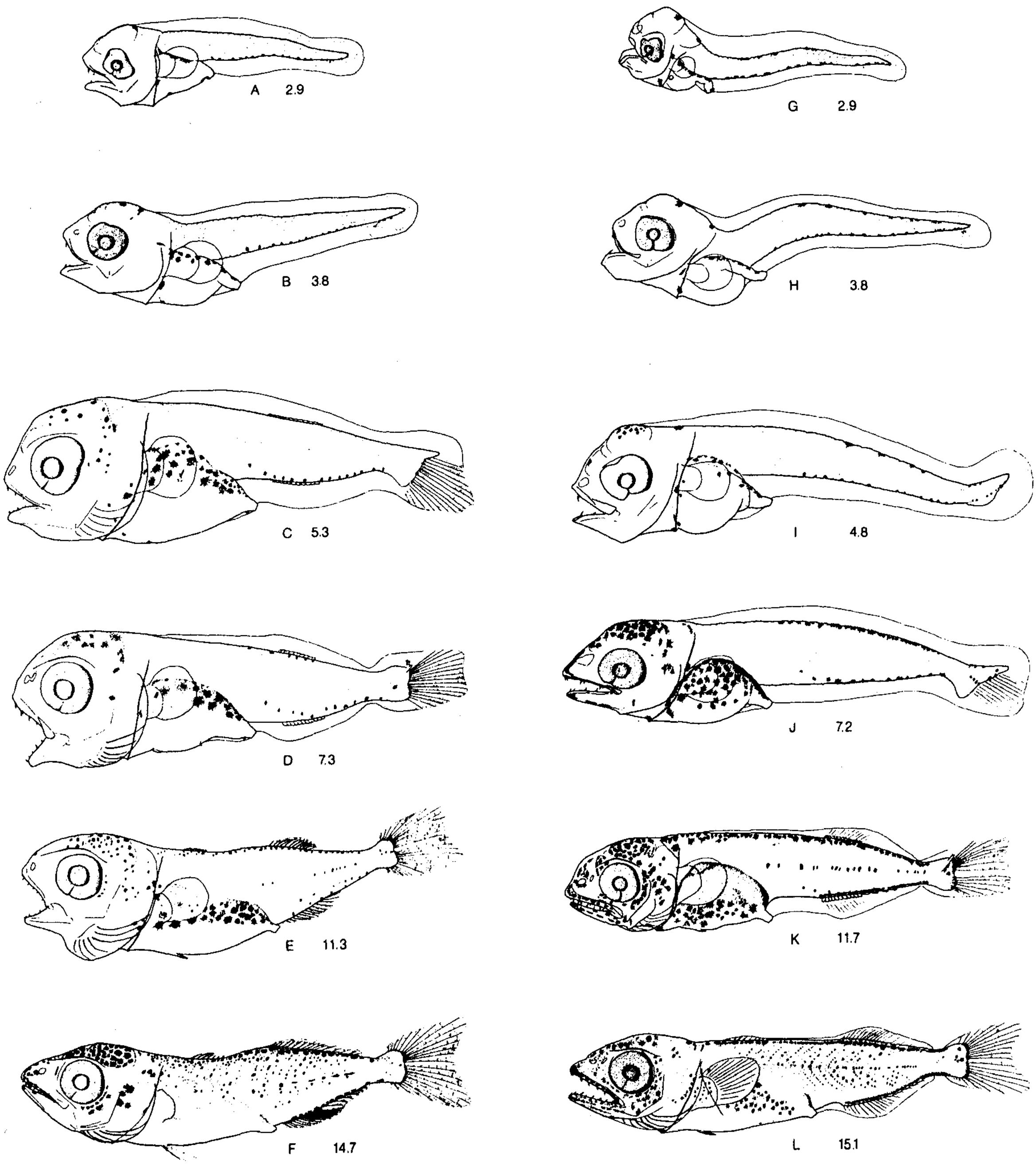

FIGURE 3.—*Scomber japonicus*, A to F; *S. scombrus*, G to L; lengths (SL) are given in millimeters.

trunk, posterior to the nape, particularly at lengths less than about 8 mm (Figures 3, 4). All *S. scombrus* specimens examined, 2.6 mm and larger, possessed dorsal melanophores. At lengths less than about 5 mm this pigmentation consists of a single median series of dendritic melanophores, initially 3 to 6 in number, increasing to 4 to 13, located between myomeres 13 and 28. In larvae greater than about 5 mm the median series becomes double, one row on each side of the developing dorsal fin base, and increases in number of melanophores and extent so that by a length of 9.5

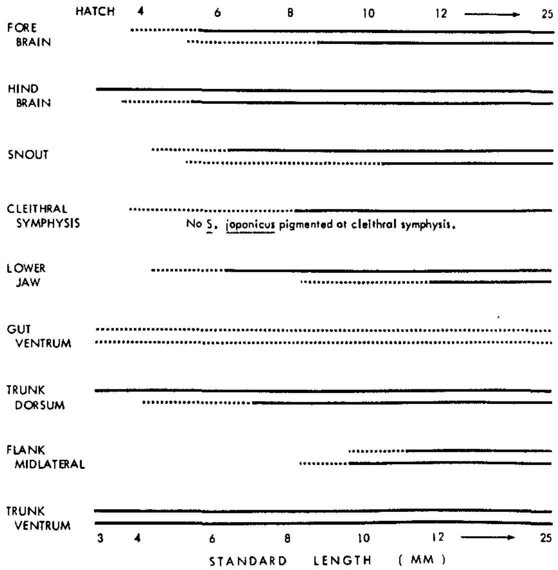

FIGURE 4.—Acquisition of pigmentation of larval *Scomber scombrus* and *S. japonicus*. Dashed lines indicate some specimens have pigmentation; solid lines indicate all specimens have pigmentation. The upper of each pair of lines refers to *S. scombrus*, the lower to *S. japonicus*.

mm the dorsal edge of the trunk is pigmented from nape to caudal fin. With further growth melanophores form on the flanks, and spread downward from the dorsal row; this happens first in the abdominal area, then posteriorly.

Scomber japonicus larvae develop this pigmentation at larger sizes than *S. scombrus*. Only one *S. japonicus* (4.1 mm) <5.2 mm long possessed dorsal melanophores. Subsequent percent occurrences of *S. japonicus* larvae possessing this pigmentation were: 24% at 5.0 to 5.9 mm, 59% at 6.0 to 6.9 mm, and 100% at 7.0 mm and greater. The largest *S. japonicus* lacking dorsal melanophores was 6.9 mm long. As in *S. scombrus* this pigmentation develops from a single median series into a double row and increases to extend from the nape to the caudal fin by a length of about 11.0 mm.

Thus at sizes smaller than about 11 or 12 mm there is a difference in dorsal pigmentation between the two species. While *S. scombrus* possess dorsal pigmentation many *S. japonicus* either lack melanophores in this location or have considerably less than comparably sized *S. scombrus*. This conclusion is in general agreement with earlier published statements. Padoa (1956) mentioned that postanal pigmentation of *S. japonicus* is less intense than that of *S. scombrus*, but he did not specify whether he was referring to dorsal or ventral postanal pigment. Dekhnik (1959) reported that, between yolk absorption and a length of 6.18 mm TL, larval *S. japonicus* lack melanophores on the dorsal edge of the trunk while larval *S. scombrus* have melanophores in this area.

Fry (1936a, figure 12G) illustrated a late yolk-sac stage *S. japonicus* with a small dorsal patch of melanophores near the 23d myomere, but did not comment in the text on the occurrence of this pigmentation. Uchida et al. (1958) and Kramer (1960) referred to a similar dorsal patch of melanophores in some of their late yolk-sac stage *S. japonicus*. Watanabe (1970) did not illustrate such dorsal pigment in his paper on this species. None of the *S. japonicus* larvae in my study had this dorsal patch; however, I identified only two larvae <3.0 mm long.

Flank

A longitudinal row of melanophores develops along the midline of the lateral trunk surface in *Scomber* larvae. This row begins forming in *S. japonicus* at 8.3 to 9.6 mm long and in *S. scombrus* at 9.6 to 11.1 mm long. The pigment in this row, first observable as a few distinct melanophores in the postanal region, increases to form a line flanked by scattered melanophores. These scattered melanophores tend to occur along the myosepta; this tendency is more pronounced in *S. scombrus* than in *S. japonicus*.

Postanus Ventral Pigmentation

Both species possess postanus ventral pigmentation, at all sizes examined. This pigmentation occurs in the smallest larvae as a median row of 15 to 20 melanophores. This series occurs first near the dermal surface and becomes internally situated along the median ventral septum as the anal fin develops. A second, double series of melanophores forms on the dermal surface, on either side of the developing anal fin base. This second series appears first at lengths of 7.0 to 7.9 mm in both species and increases in number of melanophores, so that by a length of about 15 mm there is a line of melanophores along either side of the anal fin, continuous with a median group of melanophores between the anal and caudal fin.

The initial median series of melanophores gradually becomes obscured by overlying tissue and pigmentation, so that by a length of 15 mm only one to four melanophores of that series are still visible, and these only under favorable lighting conditions.

Summary of Contrasting Characters

The precaudal and caudal vertebral counts, 14 + 17 in *S. japonicus* and 13 + 18 (or 12 + 19) in *S. scombrus*, are distinguishable in *S. japonicus* as small as 7.6 mm and in *S. scombrus* at 8.6 mm. First dorsal fins, with 10 or 11 spines in *S. japonicus* and 12 to 17 spines in *S. scombrus*, attain their full complement by 13.0 and 17.0 mm in the two species, respectively. In *S. japonicus* a total complement of 13 or 14 first-dorsal-fin pterygiophores is attained by 20.2 mm while in *S. scombrus* a total complement of 22 to 25 is attained by 32.0 mm. Because anterior pterygiophores ossify before posterior ones, and the counts differ between the two species, counts of pterygiophores in the second through fifth or sixth interneural spaces serve to identify *S. japonicus* by 11.7 mm and in *S. scombrus* by 18.2 mm (Table 1).

The relative position of the first anal pterygiophore and the first haemal spine is first observable in *S. japonicus* at 11.7 mm and in *S. scombrus* at 32.0 mm. In *S. japonicus* the first anal pterygiophore is anterior to the first haemal spine while in *S. scombrus* it is posterior.

Scomber japonicus larvae are deeper bodied at 4 to 11 mm and have greater preanus lengths at 3 to 15 mm than comparably sized *S. scombrus* larvae.

Scomber scombrus larvae are more heavily pigmented and acquire pigmentation earlier than *S. japonicus* at lengths less than about 15 mm (Figure 4). Of the two species *S. scombrus* is earlier in developing melanophores on the snout and lower jaw. Some specimens of both species possess a few minute melanophores on the ventrum of the abdomen, but their occurrence is more frequent in *S. japonicus* larvae <4.2 mm. At given sizes up to 12 mm, where additional dorsal trunk pigmentation is developing in both species, the melanophores are more numerous and larger in *S. scombrus* than in *S. japonicus*. At lengths greater than about 12 mm this character is equally developed in both species. Melanophores are not found at the symphysis of the cleithra in any *S. japonicus* larvae, but are present in *S. scombrus* larvae as small as 3.7 mm, then in increasing frequency of occurrence so that all *S. scombrus* larvae >8 mm possess this pigmentation

DISTRIBUTIONS OF EGGS AND LARVAE

Scomber scombrus, Egg Distributions

During the May cruise, *S. scombrus* eggs were taken from Martha's Vineyard to below the mouth of Chesapeake Bay and were concentrated from Fire Island, N.Y., to Cape Henry, Va. (Figure 5). Spawning apparently extended northward in the inshore portion of shelf water in an area whose northeastern boundary roughly paralleled the surface isotherms. The egg distribution extended out to at least the edge of the continental shelf off Maryland to North Carolina on transects F, G, J, and K.

By the time of the June cruise, spawning of *S. scombrus* had shifted to the northeast. Eggs were taken only on the three northernmost transects, the majority occurring in the inner half of shelf waters (Figure 6).

Scomber scombrus, Larva Distributions

During May, *S. scombrus* larvae were caught between Chespeake Bay and Oregon Inlet, N.C., across the breadth of the continental shelf and south of the area where eggs were taken during this cruise (Figure 7). These larvae were small, ranging from 2.5 to 8.1 mm long with a mode of 3.0 to 3.9 mm.

During the June cruise we took *S. scombrus* young over a greater area than in May. Larvae occurred from the offing of Martha's Vineyard, which was probably not the northern limit of their distribution, south to the offing of Currituck Beach, N.C. (Figure 8). The distribution of larvae overlapped that of eggs on the three northernmost transects and extended across the entire breadth of the continental shelf between Martha's Vineyard and New Jersey. The largest numbers occurred off Montauk Point, N.Y. Most larvae taken in June were north of the area of larva occurrence in May.

A marked increase in lengths of young, progressing from north to south, is shown in length-frequency data for this cruise (Figure 9). This increase may be due to earlier spawning or higher temperatures to the south which may enable the larvae to grow faster.

The inordinately large increase in lengths between transects D and E and decrease in lengths south of transect E may have been caused by the

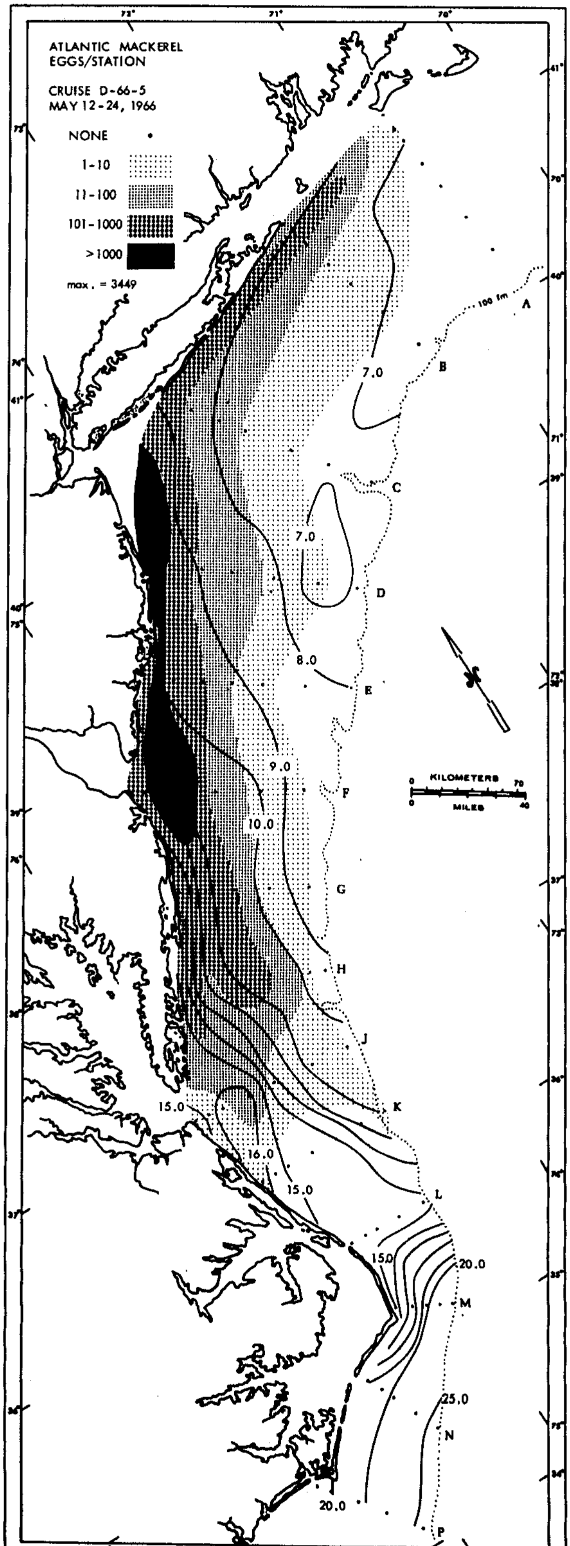

FIGURE 5.—Distribution of *Scomber scombrus* eggs and selected surface isotherms (°C) during May 1966.

time sequence of sampling. We sampled transect E as much as 4 days after transects G, H, and K, and 8 or 9 days after transect D. If we had progressed southward over the whole cruise, the young taken on transect E probably would have been smaller by 8 or 9 mm and intermediate between the lengths of those found on transects D and G, assuming Sette's (1943) calculated growth rate of about 1.0 mm/day in 20- to 30-mm *S. scombrus* is correct.

During August we took *S. scombrus* larvae only on the two northernmost transects, off Martha's Vineyard and Montauk Point between about 10 and 90 km offshore. Relatively few larvae were caught, 76 in all. They were small, ranging from 2.6 to 7.7 mm with a mode of 3.0 to 3.9 mm long.

Because 1) no *S. scombrus* eggs were taken on the August cruise and 2) larvae occurred only near the northeastern extreme of sampling at a time when the adults are known to be migrating toward the north and east, it follows that these larvae may have resulted from the last spawning within our survey area for 1966. In fact, they may have been spawned northeast of the survey area, for Bumpus and Lauzier (1965) report a southwesterly drift in continental shelf waters off Rhode Island and Long Island, N.Y., in August.

Scomber scombrus, Catch Characteristics

Statistical tests were run on catch characteristics, in order to summarize the data. These tests included: 1) comparison of catch sizes by net 1 (0 to 15 m) versus those by net 2 (18 to 33 m) for eggs; 2) the same comparison for larvae; 3) comparison of larva lengths taken by net 1 versus net 2 during day; 4) the same comparison during night; and 5) comparison of larva lengths taken during day versus those taken during night. Because the samples were collected by open nets, net 2 catches were corrected for contamination.

Results of tests 1 and 2 showed significant differences in the catch between nets 1 and 2. Net 1 caught 2.3 times as many eggs (chi-square = 1,533.956, $P<0.005$, with 19 df) and 6.1 times as many larvae (chi-square = 1,360.618, $P<0.005$, with 26 df) as net 2. The larger catch in the 0- to 15-m (net 1) tow is probably related to the occurrence of most eggs and larvae of *S. scombrus*

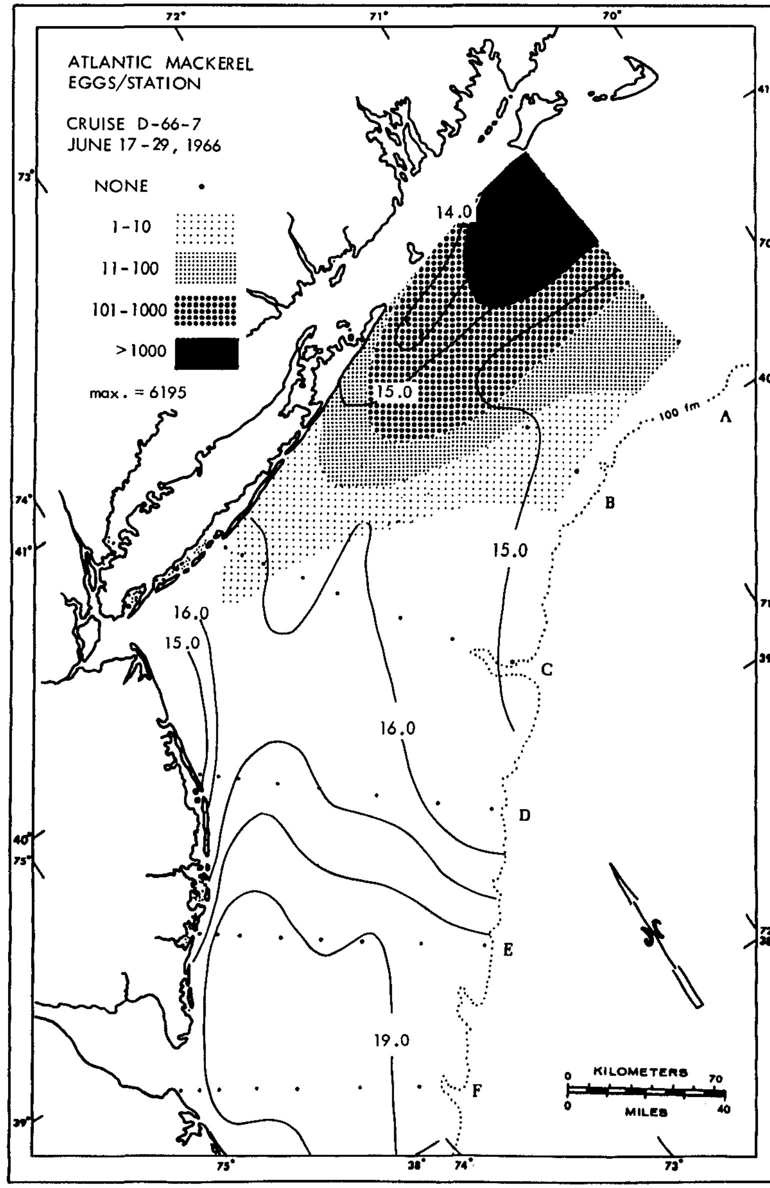

FIGURE 6.—Distribution of *Scomber scombrus* eggs and selected surface isotherms (°C) during June 1966.

above the thermocline as reported by Sette (1943). During Sette's study the thermocline occurred between 17 and 19 m. During this survey, at stations where *S. scombrus* eggs or larvae were caught, the thermocline was situated so that the surface mixed layer was sampled by net 1 and was rarely deep enough for the surface layer to be sampled by net 2.

I tested the two hypotheses that the mean lengths (SL) were equal in catches from net 1 and net 2 during both day and night tows, and found in both cases that the mean lengths were not significantly different between the paired catches. In another analysis I tested for differences in mean lengths between day and night tows. In this case the pairs tested were adjacent stations either on the same or adjacent transects. The result of the test was not significant, i.e., there was no significant difference between the means. I used analysis of variance in these tests for differences in mean lengths between the two nets and between light regimes because this procedure segregates the known differences in lengths observed over the geographical distribution.

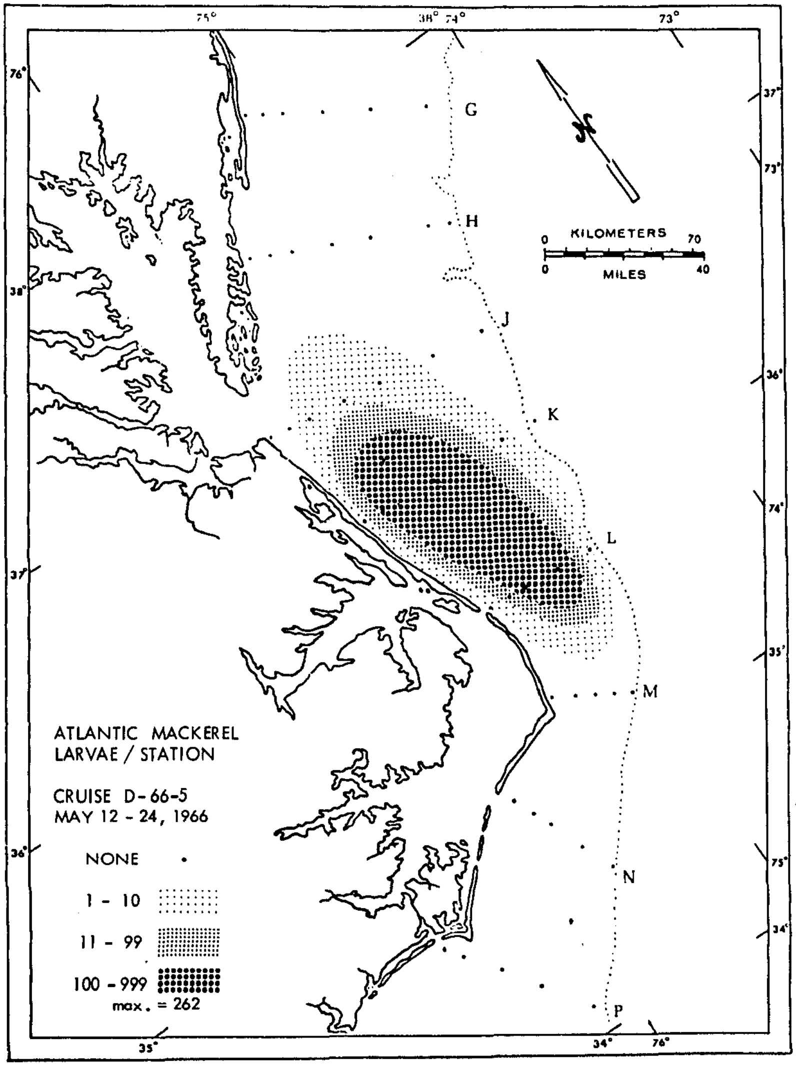

FIGURE 7.—Distribution of *Scomber scombrus* larvae during May 1966.

Scomber scombrus, Relationship of Temperature to Egg and Larva Occurrences

Temperature dependence of spawning is suggested by the parallel relationship of the surface isotherms and the northeastward edge of the egg abundance contours in May (Figure 5). This temperature dependence is also implied by the June cruise results, i.e., while shelf waters warmed, with consequent northward and eastward displacement of surface isotherms, the distribution of eggs moved accordingly (Figure 6). While the northern extent of the egg distribution was defined only during the May cruise, the southern extent was defined during both the May and June cruises, falling within the 16.0°- to 16.9°C-temperature interval despite the northerly displacement of temperatures between the two cruises. Along with even higher water temperatures prevailing during the August cruise, spawning had ceased entirely within the survey area by that time.

Sette (1943) related his egg catches to surface temperature and reported a weighted mean of 10.9°C for all eggs taken in 1932, with 98% occurring at 9.0°C to 13.5°C. During the May cruise of our survey, similar surface temperatures were associated with the eggs. The weighted mean surface temperatures for all eggs taken during May was 11.0°C, with 97% at 8.7° to 13.8°C and the temperature associated with all eggs in May ranged from 6.3° to 16.9°C.

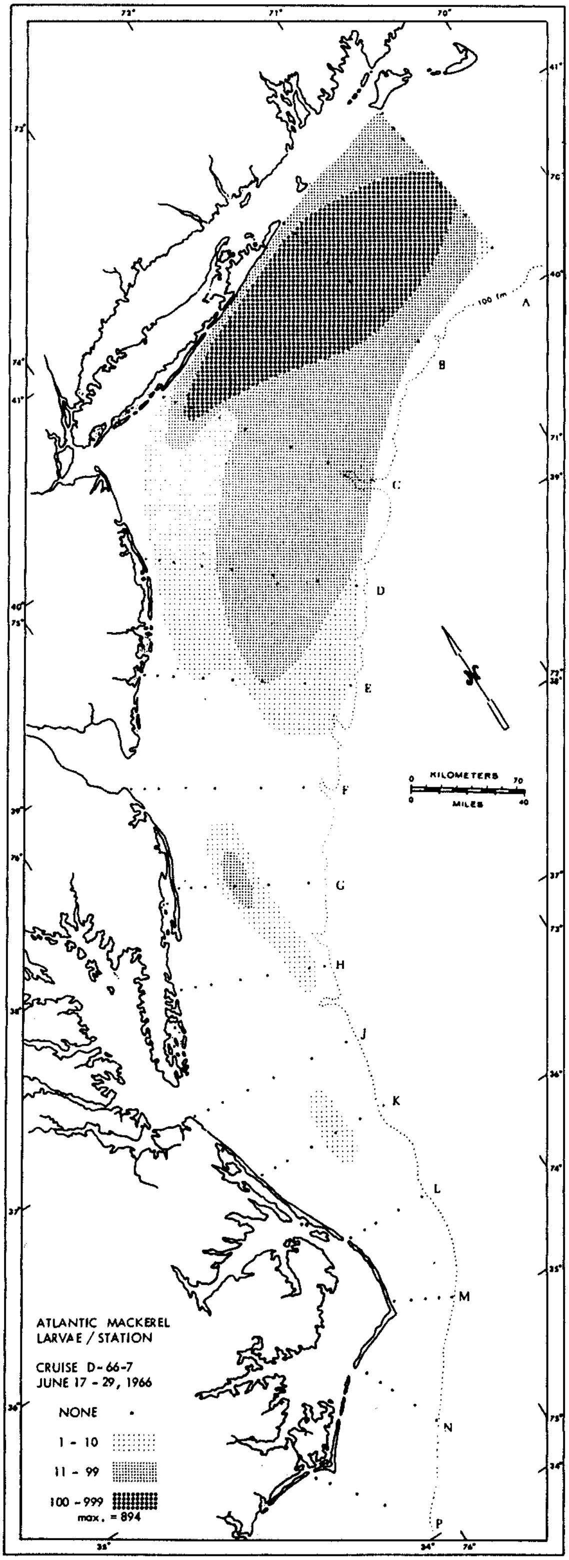

FIGURE 8.—Distribution of *Scomber scombrus* larvae during June 1966.

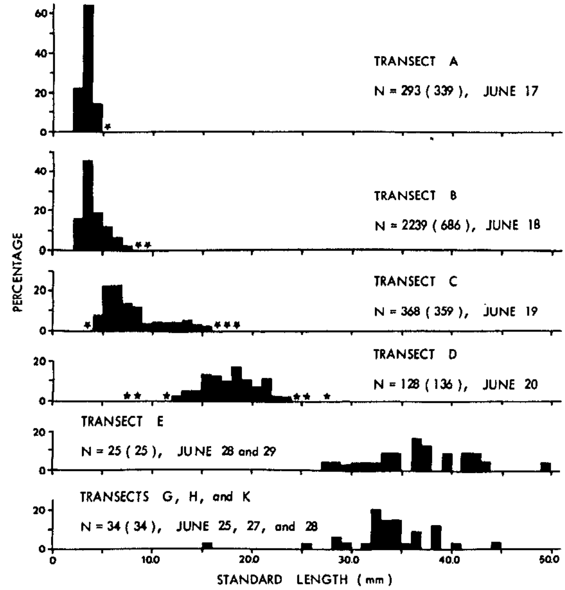

FIGURE 9.—Length-frequency distributions of *Scomber scombrus* larvae taken during June 1966. N indicates the adjusted total catch and, in parentheses, the number measured; a star indicates less than 1%.

Because larvae were inhabiting waters undergoing warming they were associated with slightly higher temperatures than were eggs. Surface temperatures associated with larvae caught during May, June, and August ranged from 12.3° to 20.7°C, with 96% occurring at 13.7° to 16.8°C.

Scomber japonicus, Egg Distributions

Eggs of *S. japonicus* were taken on two survey cruises conducted south of Cape Lookout. During the January-February 1968 cruise eggs occurred on seven transects, between Charleston, S.C. and St. Lucie Inlet, Fla. (Figure 10). During the May 1967 cruise they occurred more northerly, from New River, N.C., to Cape Canaveral, Fla. (Figure 11).

Most *S. japonicus* eggs were found over the outer half of the continental shelf. All were taken where the water was at least 32 m deep; the six largest catches (more than 10 eggs/station) were at locations where the water was at least 60 m deep. The fact that these eggs occurred at the offshore extremes of two-thirds of the transects

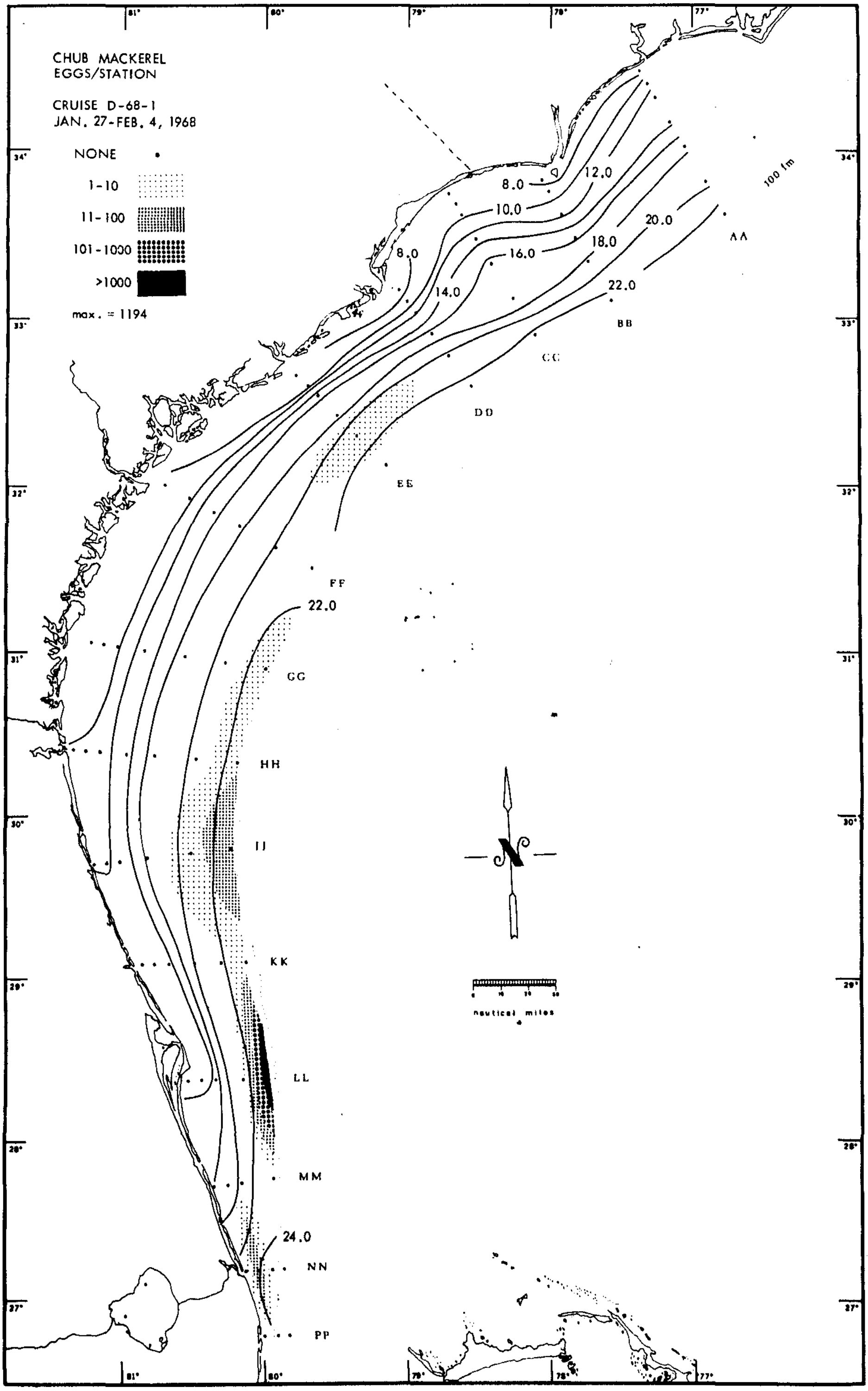

FIGURE 10.—Distribution of *Scomber japonicus* eggs and selected surface isotherms (°C) during January-February 1968.

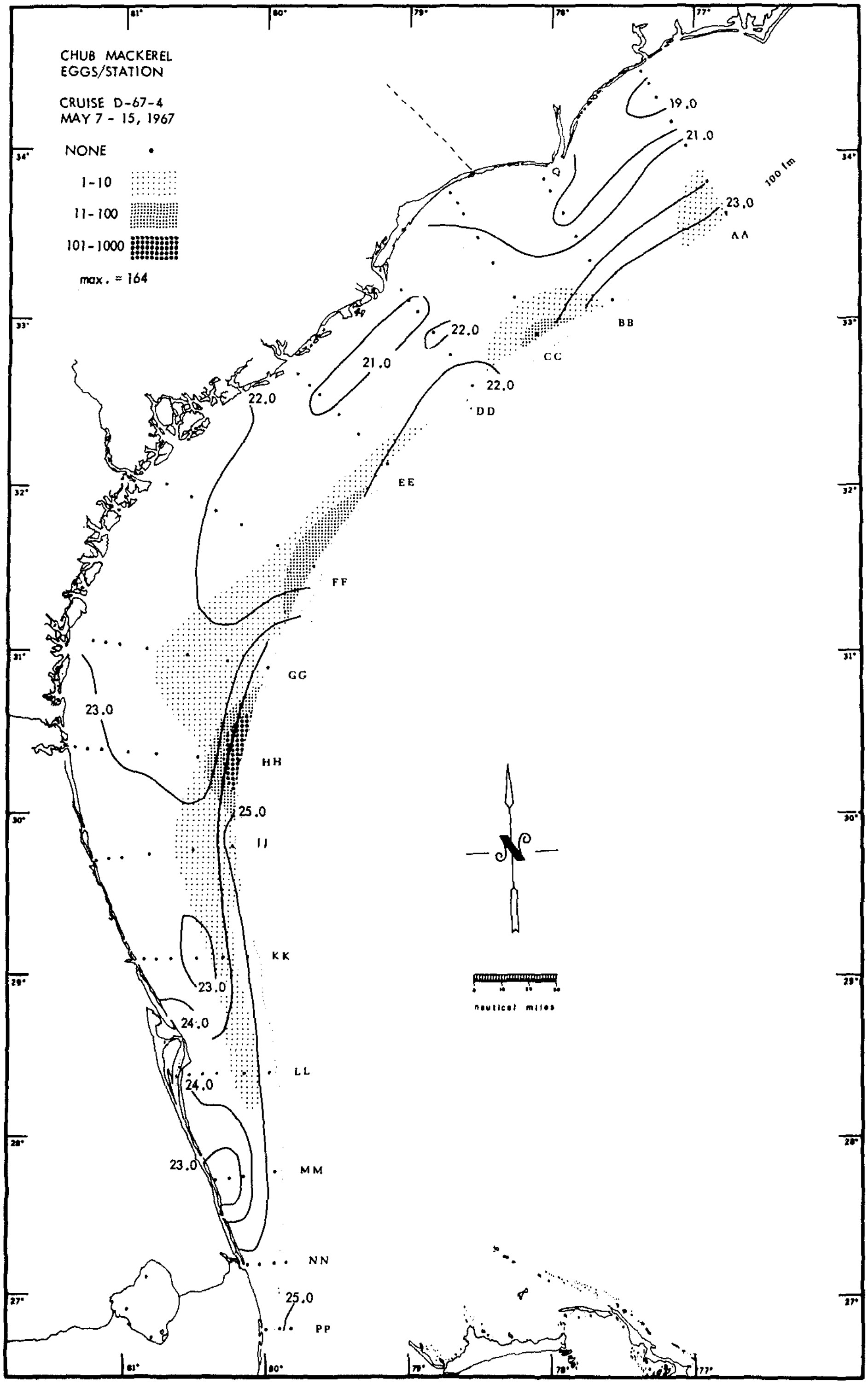

FIGURE 11.—Distribution of *Scomber japonicus* eggs and selected surface isotherms (°C) during May 1967.

where they were taken suggests that their distribution extended beyond the continental shelf.

Scomber japonicus, Larva Distributions

Larval *S. japonicus* were caught on five cruises, during January, February, April, May, and July. They were most abundant during the same two cruises on which eggs were taken (January-February 1968 and May 1967). During January-February 1968, larvae were caught from off New River to off Palm Beach (Figure 12). During May 1967, larvae were found from off New River to Ponce de Leon Inlet, Fla. (Figure 13). In addition to those plotted, there were single occurrences of *S. japonicus* larvae on three other crusies during: April 1966, off Currituck Beach; May 1966, off Cape Hatteras, N.C.; and July 1967, off St. Lucie Inlet.

Larvae were found slightly farther inshore than were the eggs, in waters as shallow as 25 m, but were generally over the outer half of the continental shelf. Larvae apparently occurred beyond shelf waters, for they were caught at the edge of the shelf on almost two-thirds of all the transects on which they were taken.

Scomber japonicus larvae taken during the January-February 1968 cruise ranged from 2.5 to 11.5 mm long. The modal length, 4.0 to 4.9 mm, for this cruise was made up of larvae from both areas of concentration, on the Brunswick, Ga., and Cape Canaveral transects. Larvae caught during May 1967 ranged from 2.8 to 20.5 mm long. There were two modal length intervals during this cruise; larvae composing the first, at 4.0 to 5.9 mm, were largely from the Cape Lookout transect while those of the second, at 8.0 to 8.9 mm, were from both the Cape Romaine, N.C., and Brunswick transects. No latitudinal size progression was observed in the data, as seen in *S. scombrus* data from June. Spawning appears to occur simultaneously from North Carolina to Florida, and to extend over at least 7 mo (January to July).

Scomber japonicus, Temperature vs. Egg and Larva Occurrences

During January-February the surface isotherms roughly paralleled the shoreline south of Cape Hatteras, with higher temperatures found offshore (Figure 10). Therefore, the generally offshore distributions of *S. japonicus* eggs and larvae mentioned previously were also correlated with the upper temperatures sampled on this cruise. Larvae were found over a greater range of surface temperature (18.5° to 24.7°C) Than were the eggs (20.4° to 23.2°C) in January-February.

Surface temperature conditions during May were different from those of the January-February cruise. During May many surface isotherms extended across the shelf (Figure 11), especially within the temperature range at which most eggs and larvae of this species were found (approximately 21° to 24°C). However, the distributions of eggs and larvae were similar on this cruise to those from the January-February cruise, i.e., restricted to the outer half of the shelf waters. Eggs were found within approximately the same surface temperature range as larvae during this cruise, 21.3° to 25.4°C for eggs and 21.3° to 24.2°C for larvae. Including all occurrences of *S. japonicus* eggs and larvae, on five cruises, the ranges of surface temperatures encountered were 20.4° to 25.4°C for eggs and 16.0° to 29.4°C for larvae.

DISCUSSION

Scomber scombrus spawns from Cape Hatteras to the Gulf of St. Lawrence. Spawning progresses northeastward along the coast as the adults migrate during spring and early summer. Within the survey area, most spawning takes place over the shoreward half of the continental shelf, with small numbers of eggs occurring out to and possibly beyond, the edge of the continental shelf. Surface temperatures associated with spawning (egg occurrences) range from about 7° to 16°C. In comparison, the majority of *S. japonicus* spawn south of Cape Hatteras; the southern extent of spawning is unknown, but it extends at least as far south as Key Biscayne, Fla. Spawning by this species may occur north of Cape Hatteras but farther offshore than sampling was conducted, possibly in Slope Water or the shoreward edge of the Gulf Stream. The spawning season extends at least from mid-winter to early summer south of Cape Hatteras. Unlike *S. scombrus*, if *S. japonicus* undertakes a spawning migration it has not been described. Spawning occurs predominantly over the outer half of the continental shelf, and probably beyond. Surface temperatures associated with *S. japonicus* spawning in the western North Atlantic Ocean vary from about 20° to 25°C.

Scomber japonicus eggs were associated with generally higher temperatures (20° to 25°C)

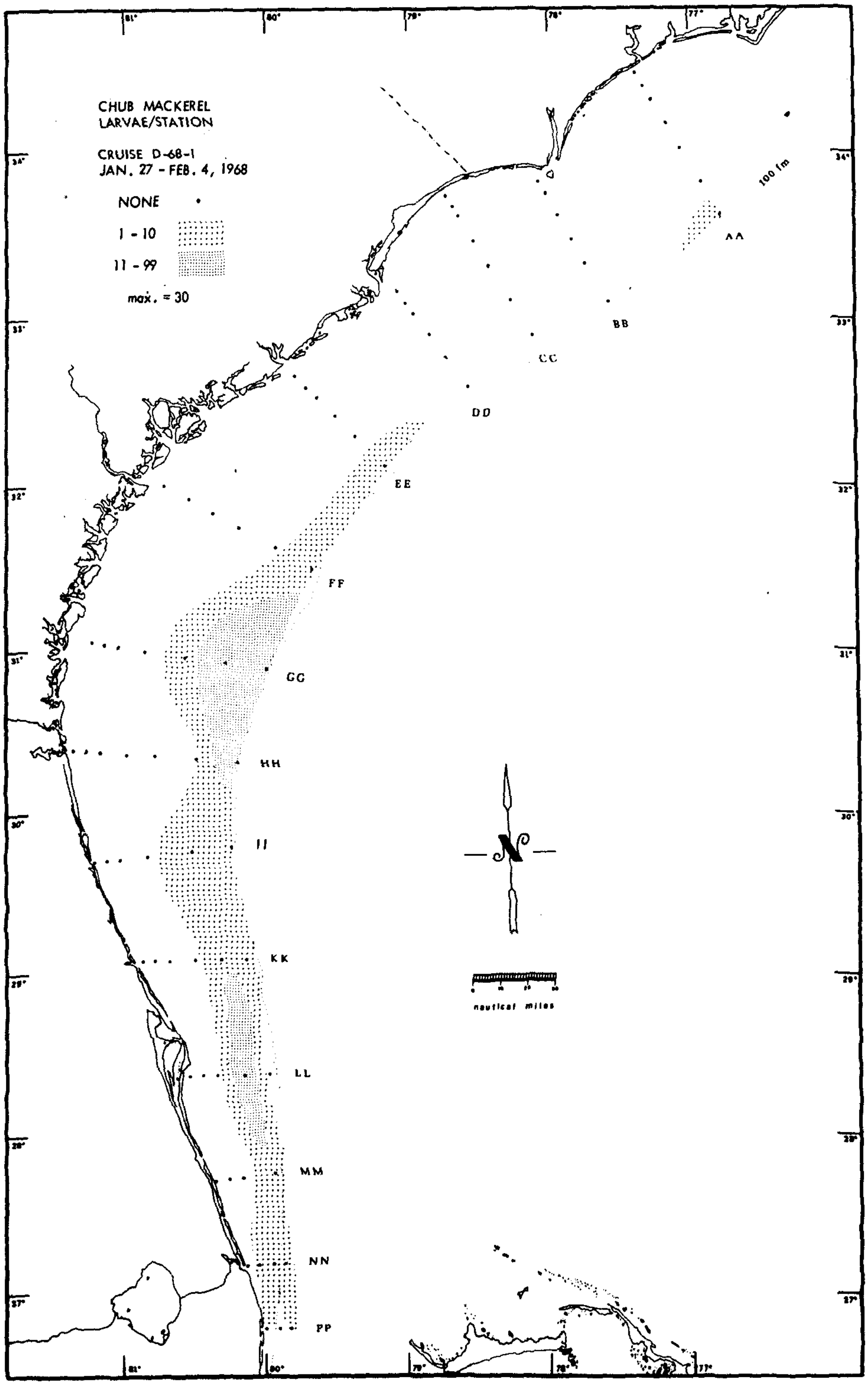

FIGURE 12.—Distribution of *Scomber japonicus* larvae during January-February 1968.

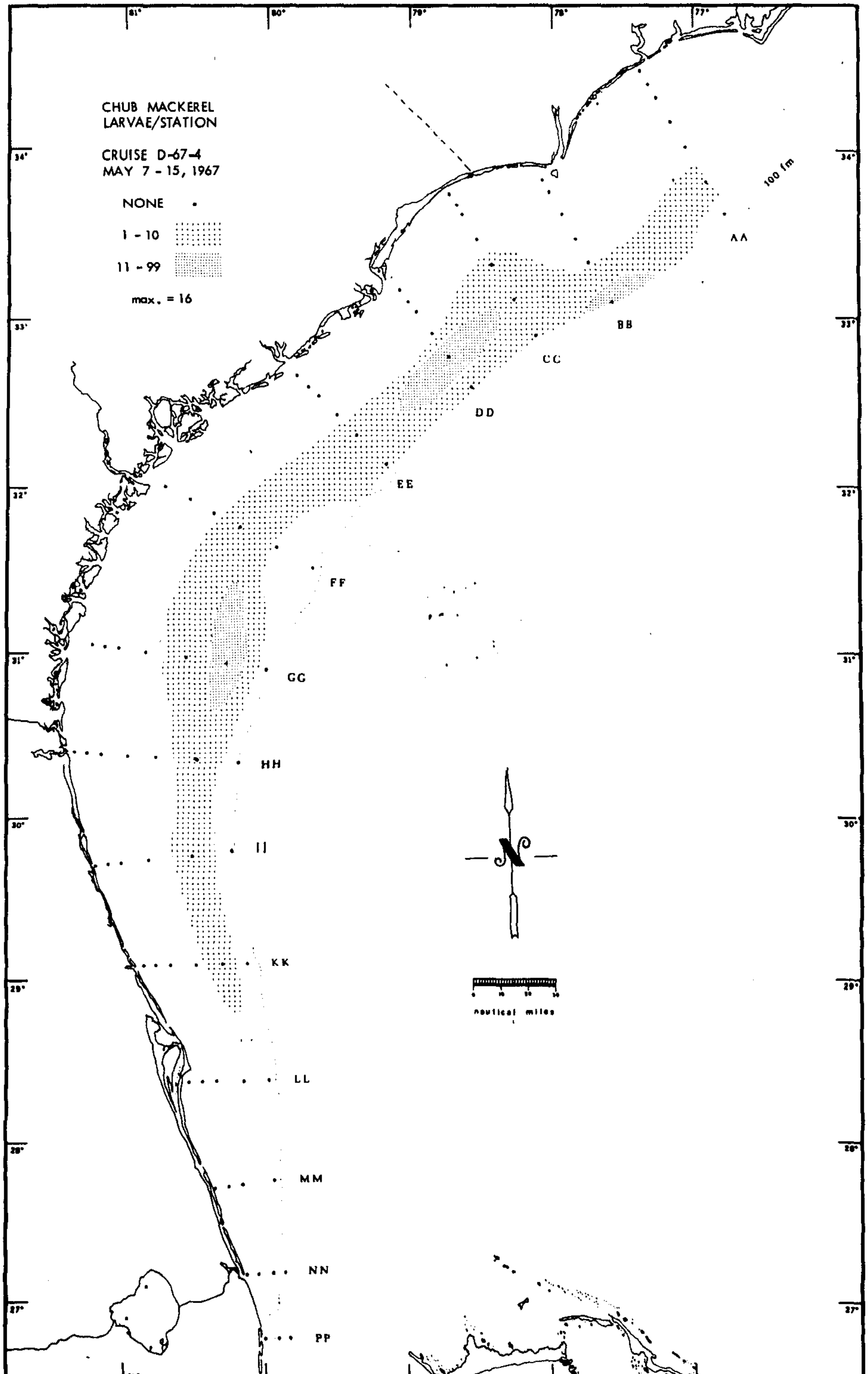

FIGURE 13.—Distribution of *Scomber japonicus* larvae during May 1967.

during this survey than in other studies on this species in the western North Pacific Ocean by Uchida et al. (1958), Dekhnik (1959), and Watanabe (1970) and in the eastern North Pacific Ocean by Fry (1936b). Although there was some variation between these studies, all reported surface temperatures within the range of 15° to 21°C associated with spawning or with the majority of eggs caught.

Scomber scombrus population estimates of 18 and 17 million spawners, based on our May and June 1966 cruises, respectively, were reported by Berrien and Anderson.[4] As discussed by the authors, these point estimates, calculated from egg catches, probably understated the true population size due to cruise timing and the area sampled. Apparently the May cruise occurred prior to peak spawning intensity resulting in many spawners being unaccounted for in the point estimate. During June, although the egg density was greater than in May, only a portion of the egg population was surveyed; therefore, the population was incompletely sampled.

Other plankton survey efforts within the Mid-Atlantic Bight have resulted in higher and probably more accurate, *S. scombrus* spawning population estimates. Sette (1943) reported a season-long, Mid-Atlantic Bight spawning population of 320 million spawners in 1932. Berrien and Anderson (see footnote 4) reported a point estimate of 392 million spawners within the New York Bight during May 1975.

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[4]Berrien, P. L., and E. D. Anderson. 1976. *Scomber scombrus* spawning stock estimates in ICNAF Subarea 5 and Statistical Area 6, based on egg catches during 1966, 1975 and 1976. ICNAF (Int. Comm. Northwest Atl. Fish.) Res. Doc. 76/XII/140, 10 p.

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