SOURCES AND DISTRIBUTION OF BLUEFISH, *POMATOMUS SALTATRIX*, LARVAE AND JUVENILES OFF THE EAST COAST OF THE UNITED STATES

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ABSTRACT

Larval bluefish are found offshore somewhere between Cape Cod, Mass., and Palm Beach, Fla., during every season of the year. However, there appear to be two main spawning concentrations—one during spring near the western edge of the Gulf Stream in the South Atlantic Bight and the other during summer over the continental shelf of the Middle Atlantic Bight. Larvae complete development near the surface; juveniles are strongly associated with the surface. Juveniles from the spring spawning remain at sea and are carried northward past Cape Hatteras, N.C., above the edge of the continental shelf. As surface shelf water warms, they move shoreward to spend the summer in estuaries of the Middle Atlantic Bight. Bluefish spawned in summer remain at sea as juveniles or enter estuaries briefly in late summer. In fall, as the water cools, the juveniles move southward out of the Middle Atlantic Bight. It is possible that these two spawnings represent different populations. A smaller fall and winter spawning which occurs offshore south of Cape Hatteras may represent a small population resident to the South Atlantic Bight.

Bluefish, *Pomatomus saltatrix* (Linnaeus), occur in most temperate coastal regions of all world oceans (Briggs 1960). Fowler (1944) erroneously reported them from the eastern Pacific where they do not occur. The earliest descriptions of eggs and larvae of bluefish by Agassiz and Whitman (1885) which have been quoted by other authors, e.g., Padoa (1956) and Salekhova (1959), are erroneous. Colton and Honey (1963), Deuel et al. (1966), and Norcross et al. (1974) correctly described them and showed that bluefish spawn pelagic eggs in the open sea and larval development takes place near the surface. Juveniles generally move from the open sea to coastal areas and estuaries. This pattern has been observed off North America, in the Black Sea, and off South Africa (Irvine 1947; Bigelow and Schroeder 1953; Oben 1957; Smith 1961).

Along the Middle Atlantic Bight, i.e., from Cape Cod, Mass., to Cape Hatteras, N.C., bluefish eggs, larvae, and juveniles have been collected during several ichthyoplankton studies (Sette 1943; Lund and Maltezos 1970; Norcross et al. 1974). Although restricted in sampling area or time, these studies have indicated that spawning and larval development take place offshore from Chesapeake Bay to southern New England in late spring and summer. Juveniles occur in estuaries along the middle Atlantic coast in summer (Clark[3]).

The sources of data for this paper are plankton collections taken by personnel of the National Marine Fisheries Service (NMFS), NOAA, Sandy Hook Laboratory, as part of a study to investigate the importance of estuaries as nursery areas of Atlantic coast fishes. The first part of this study consisted of a survey of ichthyoplankton over the continental shelf, an area thought to be the spawning grounds for many species of fishes. From information gained during this study, we hoped to trace the movement of young stages from spawning grounds and thus evaluate the importance of estuaries as nurseries. From the results of this study, several additional short cruises were conducted to study further the distribution of larval and juvenile bluefish in certain offshore areas at specific times of the year.

In this paper, information from these studies and those of previous workers is presented to help elucidate the times and places of bluefish spawn-

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[3]Clark, J. R. 1973. Bluefish. *In* A. L. Pacheco (editor), Proceedings of a workshop on egg, larval, and juvenile stages of fish in Atlantic coast estuaries, p. 250-251. Middle Atl. Coastal Fish. Cent., Tech. Publ. 1.

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ing along the east coast. Evidence to link the offshore occurrences of bluefish larvae to the estuarine occurrences of bluefish juveniles also is presented. This early life history information relates to what is known of the number and relative sizes of populations of bluefish along the east coast.

MATERIALS AND METHODS

(Table 1, Figure 1)

An ichthyoplankton study of Atlantic continental shelf waters by the Sandy Hook Laboratory began in 1965-66 with a survey from Cape Cod to

TABLE 1.—Bluefish collections from RV *Dolphin* ichthyoplankton surveys and supplemental cruises for young bluefish off the east coast of the United States.

Continental shelf area	Dates	Number of stations	Gear[1]	Bluefish		
				Number of collections	Number	Standard lengths (mm)
Cape Cod to Cape Lookout	3-15 Dec. 1965	78	Gulf V			
		35	MWT			
	25 Jan.-9 Feb. 1966	86	Gulf V	1	1	8.7
		0	MWT			
	6-22 Apr. 1966	92	Gulf V			
		3	MWT			
	12-24 May 1966	92	Gulf V	5	25	3.4-9.1
		63	MWT			
	17-29 June 1966	92	Gulf V			
		59	MWT	2	2	33-37
	5-26 Aug. 1966	92	Gulf V	25	1,621	2.4-13.2
		66	MWT	4	8	9-128
	13-18 Sept. 1966	30	Gulf V	2	2	4.0-6.7
		15	MWT			
	28 Sept.-20 Oct. 1966	92	Gulf V	1	2	3.3-4.0
		77	MWT	1	17	26-219
	9 Nov.-4 Dec. 1966	92	Gulf V			
		68	MWT	2	2	49-124
New River, N.C., to Palm Beach, Fla.	15-19 Feb. 1966	26	Gulf V	1	1	8.0
	7-15 May 1967	80	Gulf V	20	563	2.2-11.6
		80	SMN	11	14	18-34
		80	2-m ring			
	22 July-1 Aug. 1967	80	Gulf V			
		80	SMN			
		53	MWT			
	19-26 Oct. 1967	80	Gulf V	5	17	3.9-6.9
		80	SMN			
		77	3-m ring			
	27 Jan.-4 Feb. 1968	80	Gulf V	2	2	5.1-6.0
		80	SMN			
		50	MWT	2	5	63-92
New York Bight	10-16 June 1969	44	SMN			
		46	MWT	1	1	45.1
		15	Nightlight	1	1	45.9
	15-18 June 1970	44	SMN	3	3	20.8-35.0
		44	2-m ring	1	1	31.3
New Jersey to Maryland	14-18 June 1971	32	SMN	5	8	23.8-33.7
		32	Haedrich	5	7	23.6-32.1
		12	MWT	3	3	27.3-35.7
Virginia to North Carolina	27 Apr.-5 May 1971	58	SMN	19	163	12.6-31.4
		60	Haedrich	27	1,464	3.9-33.5
		19	2-m ring	3	10	4.1-11.3
Cape Hatteras, N.C.	weekly, 11 Apr.-31 May 1972	36	Haedrich	21	1,472	3.5-25.4
New Jersey to Virginia	29 Oct.-1 Nov. 1970	35	SMN	3	3	40.0-48.2
		35	Haedrich	3	4	36.4-34.9
		11	2-m ring	1	3	~200
Georgia to Florida	29-31 Jan. 1971	24	SMN			
		24	Haedrich			
		24	MWT			

[1]MWT = midwater trawl; SMN = surface meter net; see text for further details.

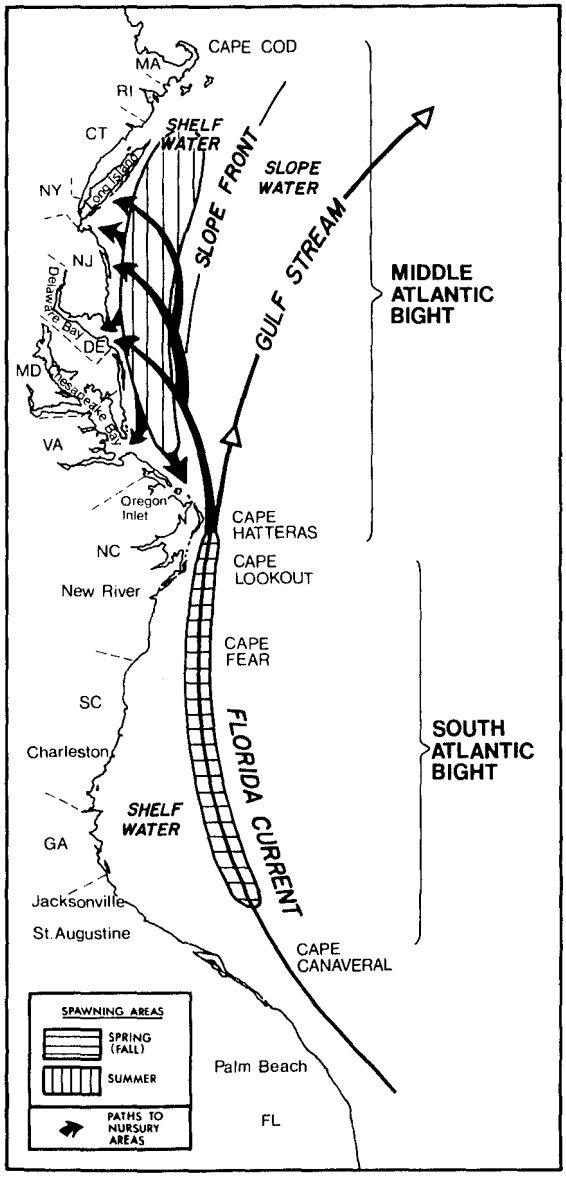


FIGURE 1.—Major features of surface waters and bluefish larval and juvenile distribution off the U.S. east coast.

Cape Lookout, N.C. Over the year, as weather permitted, 92 stations over 14 transects were sampled during 8 cruises. In 1967-68, the study continued, working from Cape Fear, N.C., to Palm Beach, Fla., sampling at 80 stations over 14 transects during each of 4 seasonal cruises. Plankton was sampled with Gulf V samplers (0.52-mm mesh). The 30-min step oblique tows were made at 2.1-2.6 m/s. Two nets were towed simultaneously; one from the surface to 15 m, the other from 18 to 33 m where water depths permitted. Details of gear, procedures, and physical, plankton volume, and juvenile fish data have been published (Clark et al. 1969, 1970).

The same procedures were followed on two additional cruises in 1966. One of these (D-66-2) sampled 26 stations on five transects between Jacksonville, Fla., and Palm Beach in February 1966. The other (D-66-11) sampled 30 stations on the four northernmost transects (Cape Cod to New Jersey) in September 1966.

Collections for pelagic juvenile fishes were made during the cruises in 1965-66 with a scaled-down Cobb midwater trawl (Clark et al. 1969). During the cruises in 1967-68, several nets were towed for juvenile fishes. At each station a surface meter net with 6-mm mesh was towed beside the ship. Subsurface samplers included the scaled-down Cobb trawl, and a 1-m and a 2-m ring net (Clark et al. 1970).

Several offshore cruises from 1969 through 1971 were designed mainly to augment the data on occurrences of bluefish juveniles. A surface meter net and a Haedrich neuston net (Bartlett and Haedrich 1968) were used in paired tows on most of these cruises. Other sampling equipment used at various times included dip nets with nightlights and several types of midwater nets.

In spring 1972, a series of eight weekly cruises near Cape Hatteras aboard a chartered sport fishing boat was conducted working from Oregon Inlet, N.C., out into the Gulf Stream. On each cruise, we made two neuston tows with a Haedrich net near Cape Hatteras. One of these was in the green coastal water, the other in the blue Gulf Stream water, and each tow was within 100 m of the interface between the two water masses. During the return to Oregon Inlet, some 60 km north of Diamond Shoals Light Tower, several additional tows sampled the full range of surface water temperatures occurring in the area. Weather and water temperature data relative to these cruises were gathered from the U.S. Naval Oceanographic Office and the U.S. National Weather Service.

Additional data on bluefish and juveniles and ancillary observations from these collections are available.[4]

[4]Kendall, A. W., Jr., and L. A. Walford. 1978. Data associated with offshore larval and juvenile bluefish collections at Sandy Hook Laboratory 1965-1972. Unpubl. manuscr., 5 p. Report No. SHL 78-9. Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, Highlands, NJ 07732.

We will generally refer to bluefish <10 mm standard length (SL) as larvae and those >10 mm SL as juveniles. Bluefish hatch at about 3 mm SL and by 10 mm SL the fin ray development is nearly complete and in living specimens the body is dark blue on the back and silvery on the sides, as in the pelagic juvenile stage of goatfish and mullet (Norcross et al. 1974).

RESULTS

Hydrographic Features of Middle and South Atlantic Bights

Shelf water characterized by salinities of <35‰, is divided into coastal water (<33.6‰) and shelf edge water (33.6-35.0‰) (Wright and Parker 1976). The Gulf Stream, characterized by salinities >36.0‰ and/or temperatures >18°C at 100 m or >15°C at 200 m, flows generally beyond the edge of the continental shelf. The water mass between the shelf water and Gulf Stream, called the slope water, is separated from the shelf water by a strong surface feature, except in midsummer, called the slope front. Surface manifestations such as lines of flotsam, differences in water color, and choppiness of the Gulf Stream are seen on moderately calm days. The shelf water is sluggish and influenced by short-term effects of wind, but generally moves south along the shore. The Gulf Stream moves northward or northeastward at velocities over 100 cm/s (Sverdrup et al. 1942).

Eggs

Bluefish eggs, which share features with pelagic eggs of many other species, were not found in any of our collections. Bluefish eggs have a smooth spherical membrane, a diameter of 0.90-1.20 mm averaging 1.00 mm, a pigmented yolk, a single oil globule about 0.2 mm in diameter, and melanophores in rows on the embryo (Deuel et al. 1966). Even though an egg has all of the above features, it can be identified with certainty as being a bluefish egg only if the oil globule is pigmented and in later development the number of myomeres has become established at 24 to 28.

Two studies have reported occurrences of bluefish eggs along the east coast. Marak and Colton (1961) listed a few of them from late May to early June 1953 in 12.8°C water south of Cape Cod. These data are suspect because: 1) identification was based on inadequate descriptions by Agassiz and Whitman (1885) and Perlmutter (1939); and 2) adult bluefish in spawning condition are not present off southern New England until later in the year when temperatures are considerably warmer. In a second study conducted from 1960 to 1962 off Virginia, Norcross et al. (1974) reported bluefish eggs during the period June through August from near shore to the continental slope. Although none occurred in our collections, from the similarity in distribution of bluefish eggs and larvae seen by Norcross et al. (1974), it seems that an accurate indication of spawning location can be derived from the capture of small larvae.

Larvae

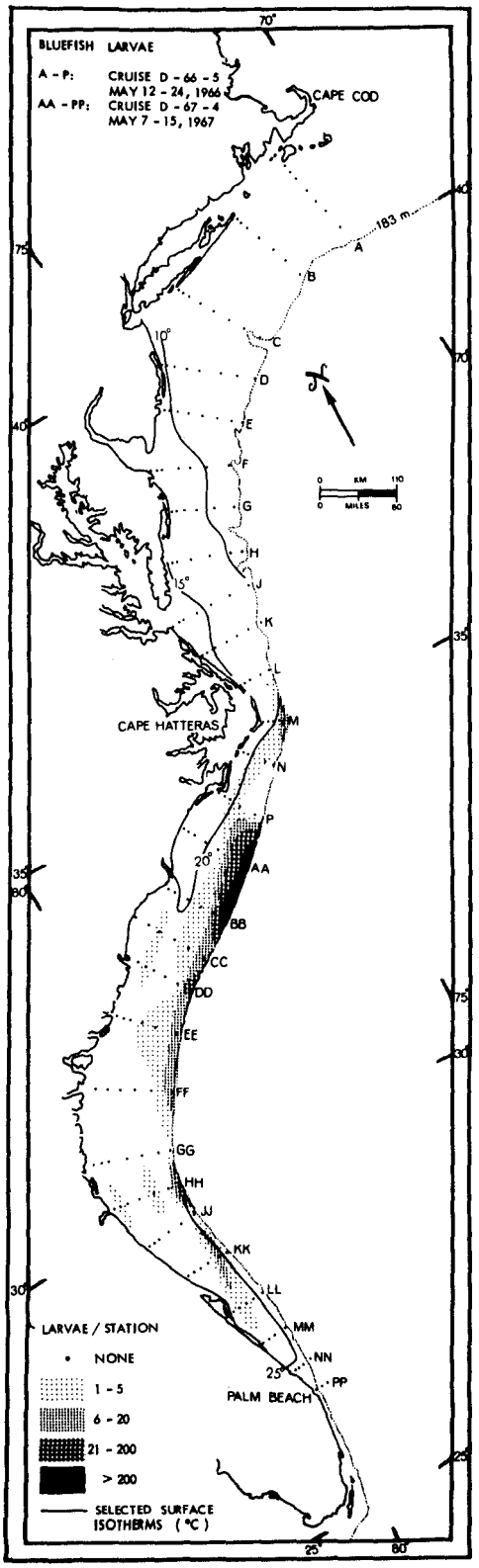
Seasonal-Geographic Distribution

Although bluefish larvae occurred between Massachusetts and Florida during every season, two major geographically distinct concentrations of larvae were found; one south of Chesapeake Bay near the Gulf Stream in spring, and the other north of Cape Hatteras over the middle of the continental shelf in summer.

During spring, bluefish larvae were taken from near Cape Hatteras to Cape Canaveral, Fla. Of the 473 larvae taken at 25 stations during the surveys of May 1966 and 1967, greatest concentrations were between the offings of New River, N.C., and Charleston, S.C., near the edge of the continental shelf (Figure 2). In April and May 1971, we also caught bluefish larvae near Cape Hatteras primarily offshore near the Gulf Stream. From these data, it appeared that bluefish spawned near the edge of the continental shelf in the South Atlantic Bight during spring.

Bluefish dominated the neuston catches near Cape Hatteras during the eight weekly cruises in spring of 1972 (Table 2). They occurred on every cruise and in every water type sampled. The variability in catches between paired tows during this series was too large to permit precise comparison among the dates or sampling areas. However, the largest catches were made in water just shoreward of the Gulf Stream. Most of the specimens taken in or near the Gulf Stream were between 5 and 12 mm SL, whereas the few taken over the shelf ranged from 11 to 21 mm SL.

The numbers of bluefish caught each week gave no indication of relative abundance during spring in this area, partially because weather-influenced



surface temperature patterns affected the catch rate. Large catches just shoreward of the Gulf Stream followed periods of northerly winds which caused a compression of surface isotherms in this area. Following southerly winds the isotherms were spread out and catches were low. It thus appears that the catch rate was related to the width of the band of suitable water, and that in turn was related to wind conditions.

No bluefish larvae were collected in the Middle Atlantic Bight in January, April, May, and June 1966, but they were abundant and widespread in August when their distribution extended from eastern Long Island, N.Y., to Virginia and more or less over the breadth of the continental shelf (Figure 3). They were most abundant off New Jersey and Delaware. Most of these larvae were small (mean, 4.0 mm SL) indicating that spawning had occurred not long before this cruise. The relative number of fish <4 mm SL was greatest at the northern end of the survey area and diminished progressively southward to Delaware Bay (Figure 4). This effect could have resulted from growth of the larvae during our sampling from north to south in this area over a 3-day period. It also might have resulted if bluefish spawning had started in the south and progressed northward. Either or both of these processes may have been involved. There was an 11-day gap in sampling between Delaware Bay (Transect F) and Maryland (Transect G). This might account for our finding so few, but larger larvae south of Delaware Bay.

Bluefish spawning in middle Atlantic waters was almost finished by the end of summer, judging from the paucity of specimens taken during September and October (Figure 5). In September, when we sampled only north of middle New Jersey, we caught two larvae; and in October, when the sampling area extended over the whole Middle Atlantic Bight, we again caught two. We have no information on the southerly extent of bluefish larvae during September, since there was no sampling south of New Jersey then.

Four bluefish larvae were taken during winter cruises, one at each of four stations near the edge of the continental shelf. One was taken off North Carolina (Transect N) and the other three between St. Augustine, Fla., and Palm Beach (Transects Y, KK, and LL).

FIGURE 2.—Distribution of surface temperatures and larval bluefish in May. Transects A-P sampled May 1966; AA-PP sampled May 1967.

TABLE 2.—Bluefish catches in paired neuston nets during eight weekly cruises off Cape Hatteras, N.C., April, May 1972.

	11 Apr.		18 Apr.		27 Apr.		4 May		11 May		16 May		23 May		31 May	
Item	Tow 1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Gulf Stream:																
Surface temperature (°C)	22.0	ND	23.3	ND	22.5	22.4	23.5	ND	24.0	ND	25.1	ND	ND	ND	25.5	ND
Bluefish catch	0	0	7	0	12	218	8	0	4	0	0	0	0	0	0	0
Mean length (mm SL)			10.9		8.9	10.0	11.6		9.8							
200 m shoreward of Gulf Stream:																
Surface temperature (°C)	16.0	ND	19.5	20.6	13.2	22.1	20.0	18.6	20.3	ND	22.6	ND	ND	ND	20.5	19.5
Bluefish catch	4	0	41	14	93	771	3	2	4	0	6	0	0	0	35	217
Mean length (mm SL)	4.8		11.1	10.0	5.5	9.9	12.3	9.1	10.6		12.0				5.9	16.3
Intermediate (shelf) water:																
Surface temperature (°C)	12.5	ND	10.6	11.7	ND	ND	15.4	17.0	18.0	16.1	19.4	ND	15.1	ND	17.3	16.3
Bluefish catch	0	0	0	0	0	0	0	1	17	0	2	0	0	0	0	0
Mean length (mm SL)								21.4	12.9		18.7					
Nearshore:																
Surface temperature (°C)	13.0	ND	10.8	ND	ND	ND	ND	ND	16.0	ND	19.5	20.0	ND	ND	19.0	ND
Bluefish catch	0	0	0	0	0	0	0	0	5	0	2	0	0	0	0	0
Mean length (mm SL)									10.7		18.8					

[1]No data.

Temperature-Salinity Regimes

During the survey, bluefish larvae occurred in two distinct temperature-salinity regimes. One regime was characterized by surface temperatures of 18°-26°C and salinities of 30-32‰ (Figure 6). These conditions prevailed from late spring through the summer above the thermocline in coastal waters of the Middle Atlantic Bight. Bluefish spawning evidently did not begin there until late July or early August, judging from the small number of large larvae taken in August. Thus, spawning of bluefish in the Middle Atlantic Bight seemed to be influenced partly by features of environment other than temperature and salinity.

The other regime was associated with the inner edge of the Gulf Stream and was characterized by surface temperatures of 20°-26°C and salinities of 35-38‰. As mentioned above, few bluefish larvae occurred in this water during the fall and winter, considerable numbers during the spring, and none during the summer.

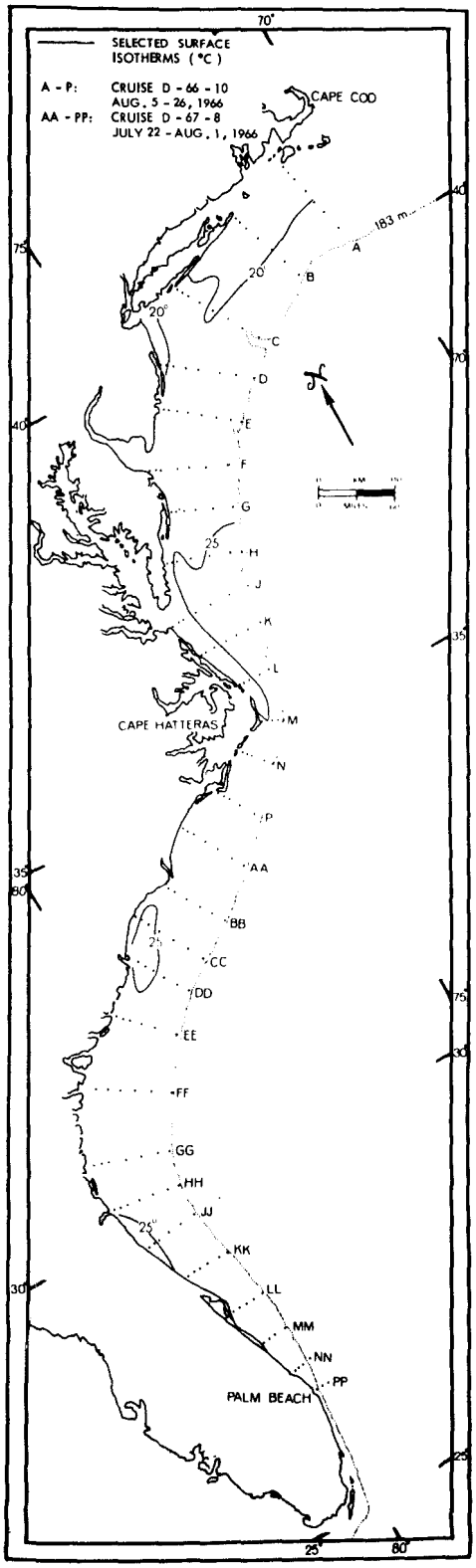
Seasonal Surface Temperature Relations

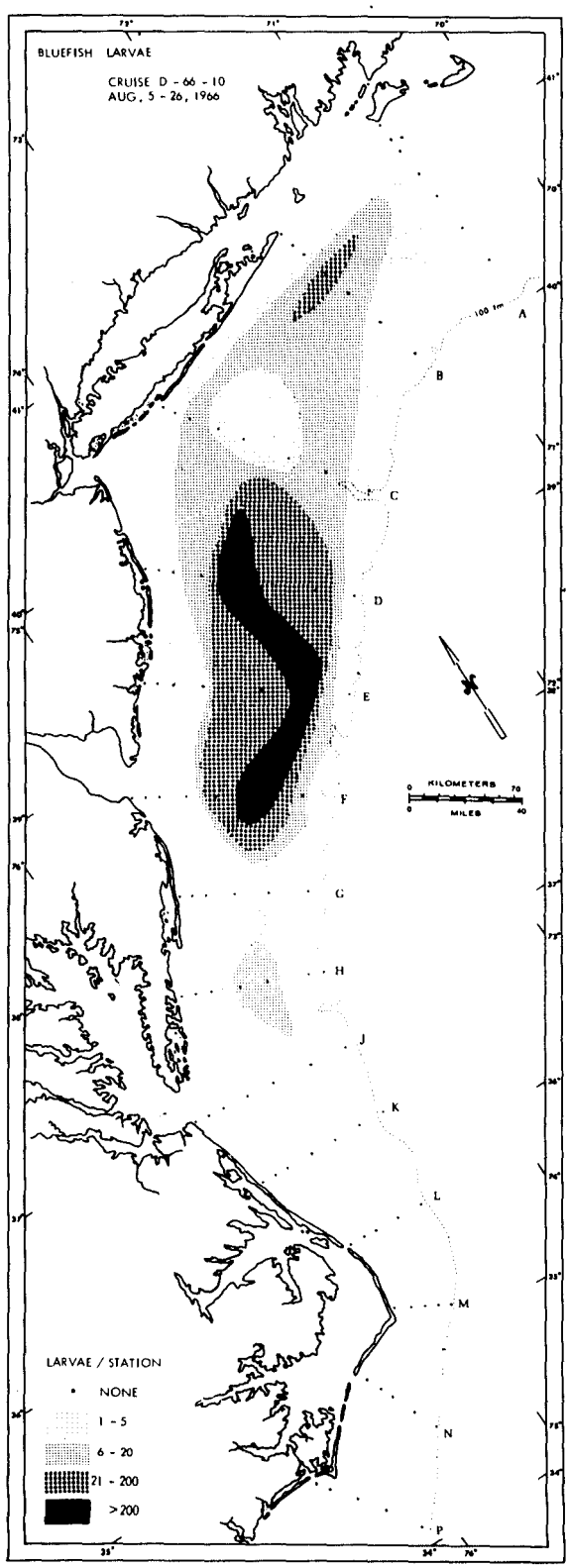
Regardless of season or area, nearly all larvae were taken in waters between 17° and 26°C. Larvae appeared on the shelf throughout the South Atlantic Bight in spring where the surface water temperatures ranged from 19° to 24.5°C. North of Cape Hatteras where we took no larvae in spring, shelf water was <15°C, but near the edge of the Gulf Stream where we did take larvae, temperatures were >15°C. At the stations where bluefish larvae were taken during August, surface temperatures ranged from 18.8° to 25.7°C. Surface water covering most of the Middle Atlantic Bight south of eastern Long Island was within this temperature range (Figure 3). However, south of Cape Hatteras no bluefish larvae were taken in July when temperatures were mostly >26°C. Surface water temperature had decreased between our September and October cruises. The 20°C surface isotherm was off Long Island in September, but had moved south to Virginia by October. The bluefish larvae were taken in 20.3°C water in September and 16.4°C water in October. The few bluefish larvae taken near the edge of the continental shelf off Florida in October were in water >25°C. In winter, all occurrences were in water >20°C, which was limited to the outer portion of the continental shelf from North Carolina to Florida at that time.

Diel Cycles of Vertical Distribution

The number of larvae caught in shallow tows (0-15 m) when compared with deep tows (18-33 m) during day and night provided limited information about diel cycles of vertical distribution. The catch rate was highly dependent on net depth. At the 46 stations where both nets were towed and either caught bluefish larvae, more occurred in the shallow net at 37 stations indicating that the larvae were more abundant in the shallow layer (sign test, $P<0.001$). Nearly all of the catch of the deeper net may have occurred as it passed through the surface layer during setting and retrieving.

FIGURE 3.—Distribution of surface temperatures (left) and larval bluefish (right) in July-August. Transects A-P sampled August 1966; AA-PP sampled July-August 1967.


SELECTED SURFACE ISOTHERMS (°C)
A - P: CRUISE D - 66 - 10 AUG. 5 - 26, 1966
AA - PP: CRUISE D - 67 - 8 JULY 22 - AUG. 1, 1966
CAPE COD
CAPE HATTERAS
PALM BEACH
183 m
20
25


BLUEFISH LARVAE
CRUISE D - 66 - 10
AUG. 5 - 26, 1966
100 fm
KILOMETERS
MILES
LARVAE / STATION
NONE
1 - 5
6 - 20
21 - 200
>200

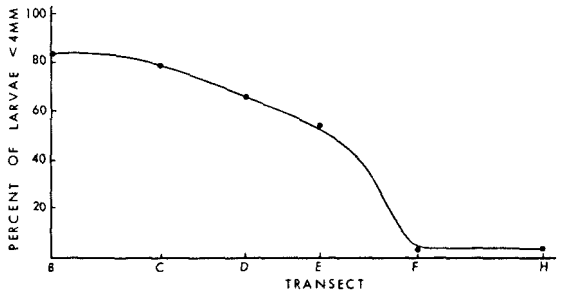


FIGURE 4.—Percent of bluefish larvae <4 mm SL captured on transects B-H (Figure 2) in the Middle Atlantic Bight in August 1966.

Indeed, later studies (Kendall and Naplin[5]) have shown that bluefish larvae occur primarily within 6 m of the surface. The distribution of catches was similar during day and night (Table 3).

Larval Lengths

The length distribution of larvae taken in the shallow tows was not significantly different from that taken in deeper tows (χ^2 $P>0.05$) (Table 4). This result is to be expected if, as indicated above, the catches in the deeper tows can be accounted for by contamination in the surface layer. Fish taken during the day, however, were generally smaller (2.5-4.5 mm) than those taken at night (5.5 mm and larger) (χ^2 $P<0.001$). This effect could result from net avoidance by larger larvae during daytime. The cruises were too infrequent to estimate larval growth.

Juveniles

During the survey cruises we tried to collect pelagic juvenile fishes and during later cruises tried to clarify results from the surveys by sampling in areas and during seasons in which juveniles had occurred earlier. We took bluefish juveniles in several kinds of midwater and surface nets. It is difficult to compare the catches of these several nets or the catches made in different years; nevertheless, this limited information about

[5]Kendall, A. W., Jr., and N. A. Naplin. Diel-vertical distribution of bluefish (*Pomatomus saltatrix*) larvae and that of associated fish eggs and larvae. *Manuscr. in prep.* Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, Highlands, NJ 07732.

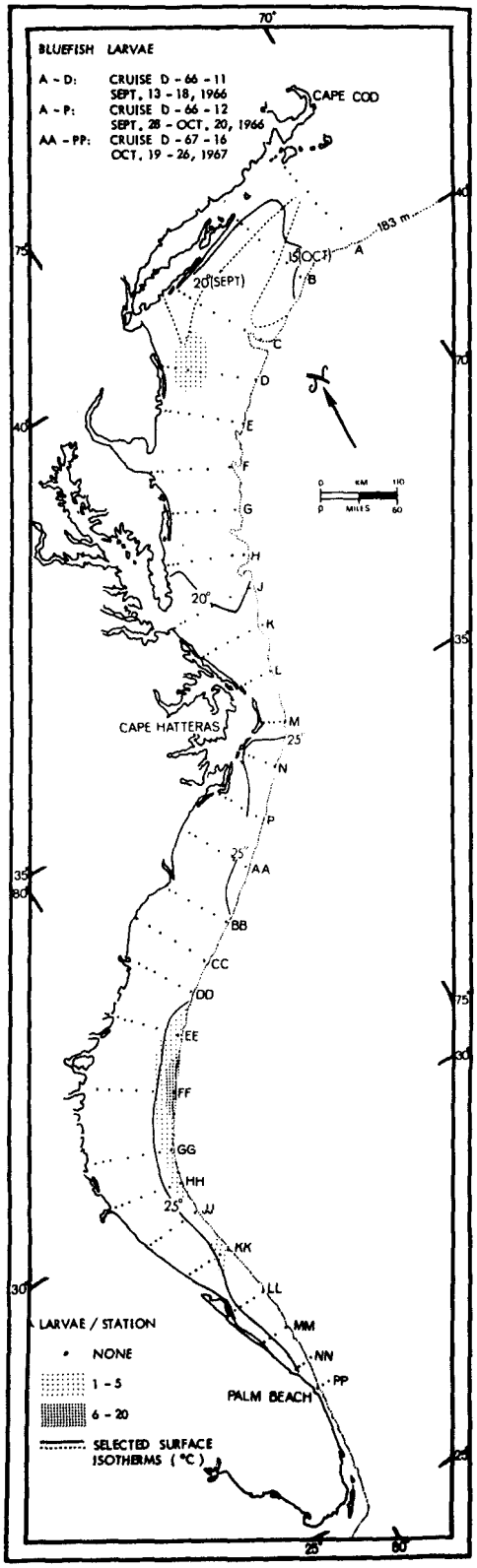


FIGURE 5.—Distribution of surface temperatures and larval bluefish in September-October.

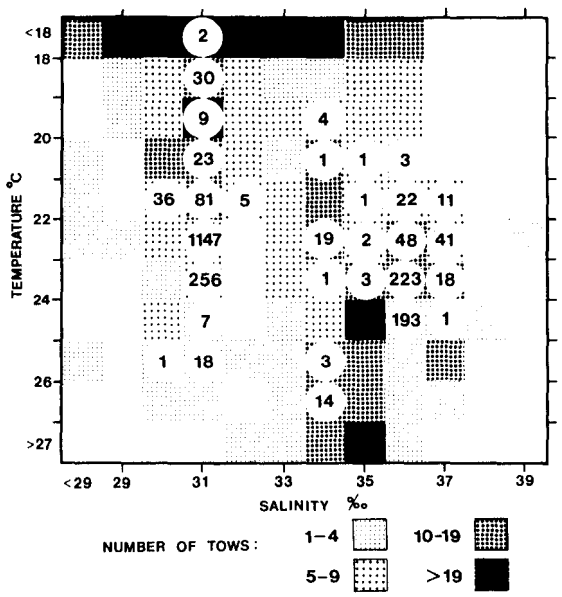


FIGURE 6.—Clustering of catches of larval bluefish by temperature-salinity combination during RV *Dolphin* surveys, 1965-68. Numbers of bluefish larvae superimposed on temperature-salinity combinations where they were caught.

TABLE 3.—RV *Dolphin* 1965-68 ichthyoplankton survey. A comparison of bluefish larval catches during day and night.

Larvae/tow	Number of tows		χ^2	
	Day	Night		
1	12	8	0.309	
2-10	6	7	0.303	
11-100	7	7	0.080	
>100	3	2	0.078	
Totals	28	24	0.770	(3 df; P >0.80)

offshore seasonal geographic distribution of bluefish juveniles indicates a complex pattern of movements from offshore spawning areas to coastal and estuarine nursery areas.

In summary we found bluefish juveniles, presumably from the spring spawning, at the surface near the slope front from south of Cape Hatteras to off the Middle Atlantic Bight in April to June (Figure 1). We hypothesize that they move northward along the slope front, then cross the shelf, enter estuaries of the Middle Atlantic Bight and after spending the summer in the estuaries, return to the sea and move southward along the coast and out of the Middle Atlantic Bight. Some juveniles from the summer spawning in the Middle Atlantic Bight remain in coastal waters while some enter estuaries briefly. They too leave the Middle Atlantic Bight in early fall. The following is our evidence for these conclusions.

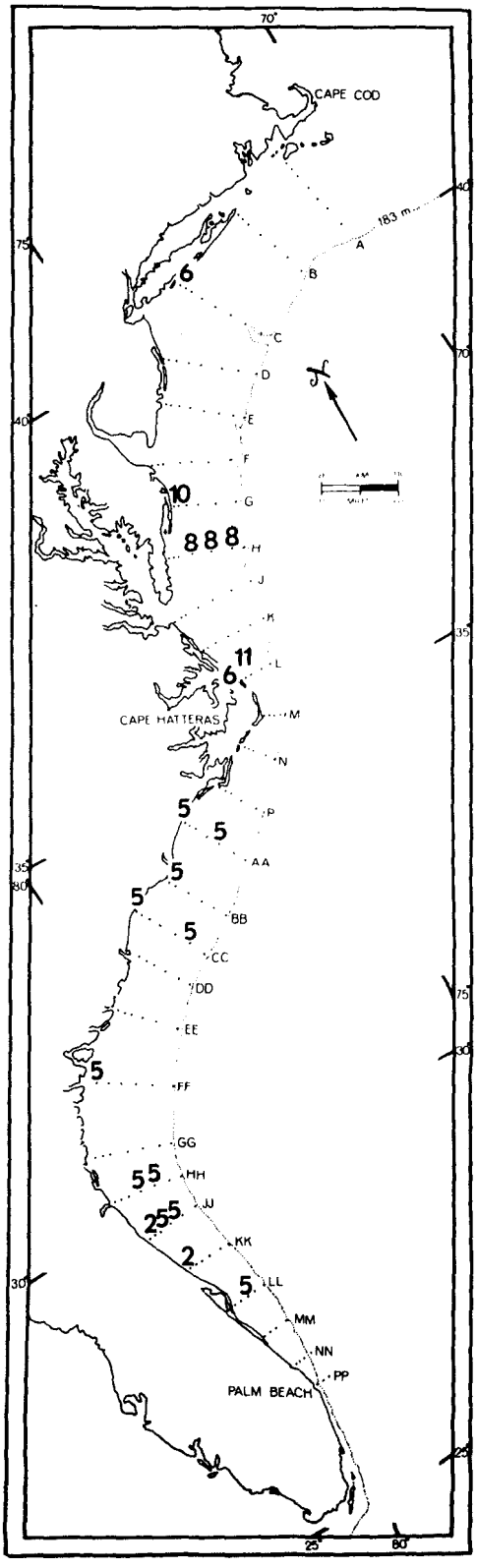
In May 1967, juvenile bluefish were scattered over the continental shelf in the South Atlantic Bight and north to Cape Hatteras (Figure 7). The largest specimens were from stations near shore.

In April and May 1971, we sampled the offshore area intensively around Cape Hatteras to find any trace of young bluefish which could be attributed to larvae and juveniles such as had appeared previously to the south. During this cruise neuston tows took bluefish juveniles near the edge of the continental shelf (100-fm (183-m) isobath) (Figure 8a). All of the specimens taken were in water >15°C, which occurred all across the shelf south of Cape Hatteras, but only near the edge of the shelf north of there.

In the June 1966 survey, when 59 stations were sampled, bluefish appeared at each of two widely

TABLE 4.—RV *Dolphin* ichthyoplankton surveys 1966-68. Length distributions of larval bluefish collected in Gulf V samples.

Interval midpoint (mm SL)	South Atlantic Bight						Middle Atlantic Bight			Shallow tows	Deep tows	Day	Night	All data
	Winter			Spring		Fall	Summer							
	D-66-1	D-66-2	D-68-1	D-66-5	D-67-4	D-67-16	D-66-10	D-66-11	D-66-12					
2.5					97		231			301	27	266	62	328
3.5				4	205	8	610		2	739	89	689	139	828
4.5					128	6	515	1		602	49	371	280	651
5.5			1	4	15	1	136			145	12	72	85	157
6.5			1	2		2	21	1		22	5	11	16	27
7.5				5			11			14	2	7	9	16
8.5	1	1		8			5			13	2	10	5	15
9.5				2	1		5			7	1	2	6	8
10.5							10			10			10	10
11.5					1		1			2		1	1	2
12.5							1			1			1	1
13.5							1			1			1	1
23.5					1					1			1	1
Total	1	1	2	25	448	17	1,547	2	2	1,858	187	1,429	616	2,045
Mean				6.88	3.63	4.31	4.00			3.98	3.88	3.73	4.51	3.97
Variance				3.55	1.61	0.96	1.31			1.58	1.26	0.84	2.78	1.55



separated nearshore stations (Figure 7). The regular presence of bluefish juveniles in offshore waters of the Middle Atlantic Bight in June was observed in three subsequent years. They occurred during 1969 only near shore; during 1970 only near the edge of the continental shelf; and during 1971 they were scattered over the shelf and slope (Figure 8b, c, d). The origin of these juveniles was puzzling, because there was no evidence of bluefish larvae in the Middle Atlantic Bight until midsummer. We had taken larvae and juveniles in April and May from Cape Hatteras south to Florida mainly offshore near the slope front. Apparently these fish become distributed along the slope front off the Middle Atlantic Bight in May and June and then cross the continental shelf in June as surface waters become suitably warm. Surface temperatures on the shelf are generally 15° to 20°C at this time, and most of the juveniles were taken in water >18°C.

The juveniles we caught in August (Figure 7) were presumably products of recent spawning in nearby waters, for only slightly smaller larvae appeared in the plankton tows in the same area. One specimen 128 mm SL taken just outside Chesapeake Bay had probably been spawned in the spring off the South Atlantic Bight.

We collected a few juveniles of widely differing sizes during two surveys in fall 1966. In a cruise conducted in 1970, we confirmed the regular presence of juvenile bluefish in the Middle Atlantic Bight in fall. We then collected juveniles between Delaware and Chesapeake Bays within 13 km of the shore (Figure 8e); and several specimens about 200 mm SL in the same area. The juveniles from these cruises can be attributed to the summer spawning of bluefish in continental shelf waters of the Middle Atlantic Bight; and the fish about 200 mm SL to the southern spring spawning. The latter fish had presumably spent the summer in middle Atlantic estuaries (Wilk[6]) and had returned to the ocean. A 124-mm SL specimen taken in November may have originated from either spawning.

No bluefish juveniles were taken in fall in the South Atlantic Bight and neither larvae nor

[6]Wilk, S. J. 1977. Biological and fisheries data on bluefish, *Pomatomus saltatrix* (Linnaeus). Sandy Hook Lab. Tech. Ser. Rep. 11, 56 p.

FIGURE 7.—Months of capture (indicated by numerals) of juvenile bluefish at stations sampled by surface meter net and midwater trawl during RV *Dolphin* surveys, 1965-68.

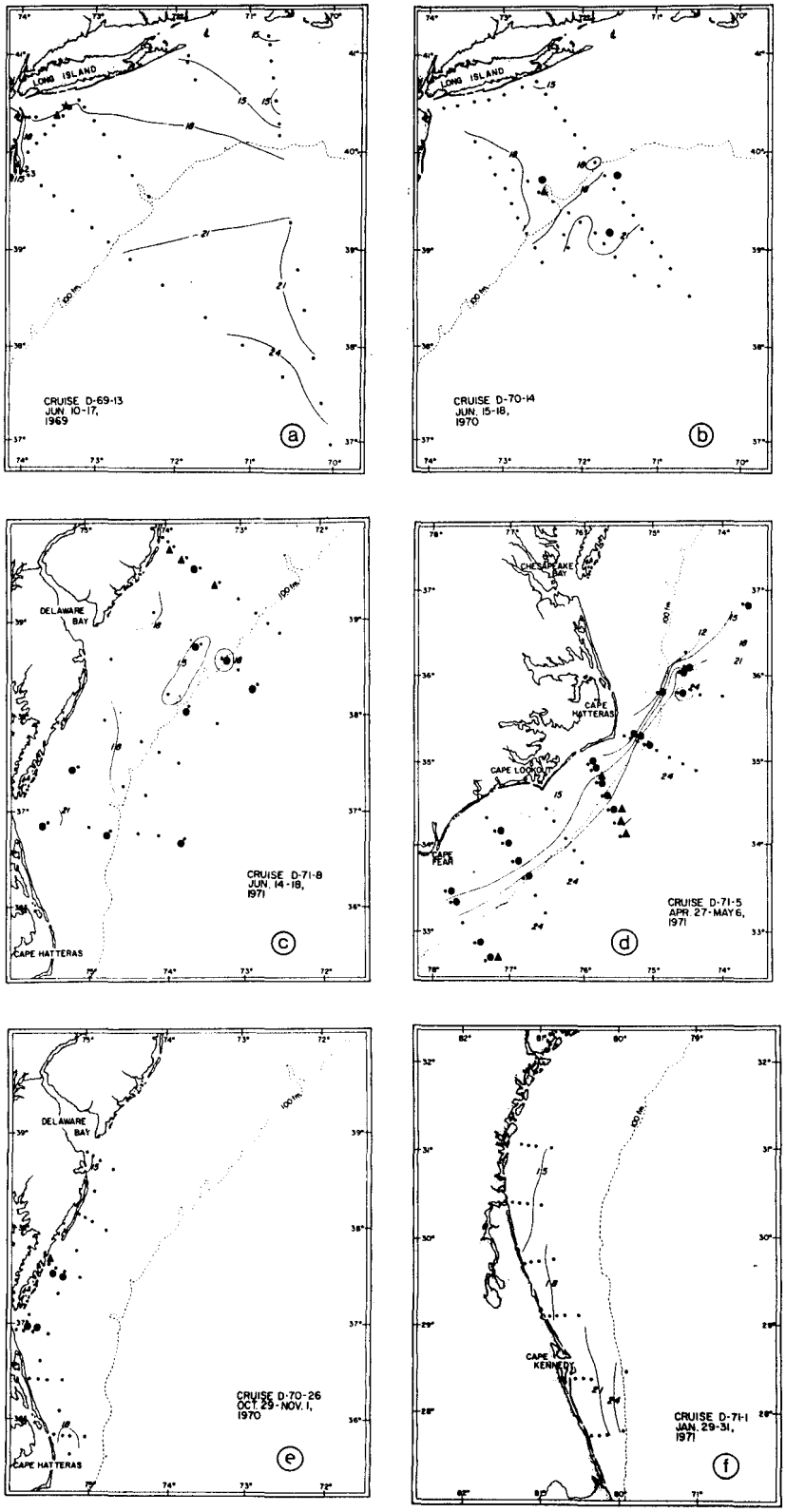


FIGURE 8.—Distribution of juvenile bluefish and surface temperatures during six cruises over portions of the Middle Atlantic Bight. Sampling stations indicated by dots. Presence of juvenile bluefish in surface meter net or Haedrich net indicated by circles, in midwater trawls by triangles, and under nightlight by a star.

juveniles were taken in the Middle Atlantic Bight from late fall to June.

In the winter survey, a few juveniles were taken off Florida (Figure 7), but during a follow-up cruise, none were caught (Figure 8f).

DISCUSSION

The patterns of distribution of young stages of bluefish off the east coast can be summarized based on our collections and those of others (Table 5).

From our collections of small larvae, bluefish appear to spawn in two quite different areas—in water just shoreward of the Gulf Stream (Florida Current) from Florida to Cape Hatteras, i.e., the South Atlantic Bight, and in shelf water from Cape Hatteras to Cape Cod, i.e., the Middle Atlantic Bight.

In the South Atlantic Bight, spawning occurs primarily during spring and apparently also to a lesser extent in fall and winter. Most of the larvae we caught were well offshore just shoreward of the Gulf Stream in water which was 20°-26°C and had a salinity of 35-38‰.

Larvae from the spring spawning in the southern area are evidently carried northward past Cape Hatteras in April and May and become spread out along the continental slope off the Middle Atlantic Bight. As shelf waters become suitably warm, generally in mid-June, the young bluefish appear to cross the shelf and enter estuaries, where they spend the summer. There they grow from 25-50 mm SL to 175-200 mm SL (Wilk see footnote 6) and in early fall migrate south along the coast.

Larvae from the fall and winter spawning in southern waters may find their way inshore south of Cape Hatteras as indicated by a few juveniles which we found in Florida in winter.

The spawning in the Middle Atlantic Bight in continental shelf waters occurs in summer. The water in which larvae were found here was 3°C cooler and 5‰ less saline than that in the south-

TABLE 5.—Collections of bluefish eggs, larvae, and juveniles, east coast of United States.

Reference	Sampling period: Years	Sampling period: Months	Sampling area	Occurrences of bluefish	Numbers	Lengths (mm)
Eggs:						
Marak and Colton (1961); Marak, . . . , Foster (1962); Marak, . . . , Miller (1962)	1951-56	Feb.-June	Ocean off New England	Late May-early June 1953 *south of Martha's Vineyard*	few	
Norcross et al. (1974)	1959-60	all except Oct.	Ocean off Chesapeake Bay	*June, July, August 1960 and 1961*		
	1961-62	all	Ocean off Chesapeake Bay	July 1962, nearshore to slope waters	many	
	1962	seasonally	Ocean off Chesapeake Bay			
	1963	July, Aug.	Ocean off Chesapeake Bay			
Larvae:						
Sette (quoted by Perlmutter 1939)	1929	Apr.-July	Ocean from Cape Cod-Chesapeake Bay	40°N-Chesapeake Bay; waters near 21°C; mostly outer half of shelf	many	3-21
Herman (1963)	1957-58	all	Narragansett Bay	July, 20.7°C	1	3
Lund[1]	1965	May, July-Sept.	Ocean off eastern Long Island	July-Sept. (most in Aug.)	73	5-30
	1966	June-Sept.	Ocean off eastern Long Island		981	5-20
de Sylva et al. (1962)	1956-58	all	Indian River Inlet, Del.	Aug.-Sept.	2	4-28
Pearson (1941)	1929-30	all	Lower Chesapeake Bay	24 July, at mouth of bay	4	4-7
Norcross et al. (1974)	1959-60	all except Oct.	Ocean off Chesapeake Bay	May-Aug.	34	3-7
	1961-62	all	Ocean off Chesapeake Bay	July-Sept.	441	3-11
	1962	seasonally	Ocean off Chesapeake Bay	July	34	5-14
	1963	July, Aug.	Ocean off Chesapeake Bay	July-Aug.	93	4-22
Juveniles (<100 mm):						
Pearcy and Richards (1962)	1959-60	all	Mystic River, Conn.	Seined, July-Aug. lower estuary	2	75-94
Perlmutter (1939)	1938	all	Waters around Long Island	Throughout summer—small fish trawl	6	78-96
Lund[1]	1968	July-Sept.	Shinnecock Bay, N.Y.	Throughout summer—seined small (40 mm) fish in July and Aug.	200	40-100
de Sylva et al. (1962)	1958	every other	Delaware River, Del.	Seined, June-Sept. lower estuary	130	30-100
Pacheco and Grant (1965)	1957-58	all	White Creek, Del.	Seined, May-June, Sept.	45	39-104
Richards and Castagna (1970)	1965-66	all	Eastern shore of Virginia	Trawled, at inlets, July, Sept.	5	31-85
Tagatz and Dudley (1961)	1957-60	all	Shoal waters near Beaufort, N.C.	Seined, May-July; Oct.-Nov.	37	40-100
Turner and Johnson (1973)	1970	all	Newport River, N.C.	Surface, trawled, upper river May, July, Oct.	few	45-72

[1]Lund, W. A., Jr. Early life history of the bluefish, *Pomatomus saltatrix* (Linnaeus), off the coast of New York and southern New England. Contrib. 64 Mar. Res. Lab., Noank, Conn., 23 p.

ern area (18°-26°C and 30-32‰). Bluefish larvae have been reported by other authors in this area from May through September, but mostly in July and August (Table 5). Larvae have also been reported in the more saline areas of several estuaries of the Middle Atlantic Bight (Table 5). Although some juveniles from the Middle Atlantic Bight spawning inhabit estuaries in late summer, more seem to remain along the shore. Nevertheless, all appear to move southward and out of the bight in midfall. Their distribution in late fall and winter is still unknown.

From the scarcity of juveniles (i.e., fish 50-150 mm SL) in our samples at sea, and the abundance of these fish in estuarine collections, it appears that bluefish depend chiefly on estuaries for habitat during this stage. Their dependence is determined by the time and place of their spawning. Those from the spring spawning spend most of their first summer in estuaries, while those from the summer spawning spend at most about a month there. Both changes in temperature and seasonal photoperiod influenced the activity and distribution of adult bluefish at least under laboratory conditions (Olla and Studholme 1971, 1972). Thermal edges may act as barriers affecting the distribution of juvenile bluefish, as shown in recent laboratory work (Olla[7]). These factors, and possibly others, probably trigger movements of juveniles from the open ocean to estuaries and back to the open ocean.

In order to assess the relative proportions of the two major spawning areas to the total recruitment of bluefish on the Atlantic coast in any given year, it would be necessary to sample repeatedly during the spring south of Cape Hatteras and during the summer in the Middle Atlantic Bight.

Our present limited understanding of early life history contributes to several other facets of bluefish biology. Population differences of bluefish on the U.S. Atlantic coast have been studied using meristic characters (Lund 1961), migratory patterns, morphometrics, and scale morphology (Wilk see footnote 6). All of these studies indicate that more than one population exists. Scale studies defined two groups of bluefish by the size of fish when the first annual ring forms in May. One group, which reaches about 260 mm by the end of its first winter, evidently represents fish spawned in spring south of Cape Hatteras. The other group, which reaches only about 120 mm by the end of its first winter, represents fish spawned in the summer in the Middle Atlantic Bight. Body proportions of these two groups of fishes are statistically different (Wilk see footnote 6).

Precise information on adult bluefish migration is not available, but general patterns are known (Wilk see footnote 6). Some mature bluefish spawn near the inner edge of the Gulf Stream as they migrate northward from their wintering grounds off Florida. To a lesser extent some bluefish also spawn in the same area in fall and winter, presumably on their return migration. Adult bluefish migrate to coastal waters off the Middle Atlantic Bight in spring and feed there until they migrate south coincident with fall cooling. During their stay in the Middle Atlantic Bight, bluefish spawn on the shelf, and to some extent in mouths of the larger estuaries (Norcross et al. 1974). Although spawning can take place as soon as the adults arrive in the area in May, most seems to occur in July and August, while some continues into September. From the apparent annual variations in timing and amount of this spawning, it is dependent on a combination of several features of the environment including temperature, salinity, photoperiod, and food for the adults.

If each mature fish spawns in both areas and in all seasons, this would indicate that there is a single stock of bluefish on the east coast of the United States. If each fish spawns in only one area, separate populations must exist. Our early life history information is consistent with other information that indicates that there are separate populations. Southern and northern spawnings take place under quite different hydrographic conditions and in quite different current regimens to assist the young fish in movements to nursery grounds. In time these conditions could allow genetically distinct populations to become established. Tagging and fecundity studies would show to what extent this has happened.

Since year-class strength of fishes is determined mainly during their young stages, it is important to understand the factors influencing survival of these stages. In bluefish, the eggs and larvae occur at the surface of the ocean and the juveniles occur in estuaries, areas affected by annual variations in weather-related phenomena and, to an increasing extent, affected by man's activities. It is thus important to monitor these influences and

[7]B. L. Olla, Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, Highlands, NJ 07732, pers. commun. August 1978.

develop models to relate them to year-class strength of the various spawnings of bluefish.

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