OFFSHORE DISTRIBUTION OF ALEWIFE, *ALOSA PSEUDOHARENGUS*, AND BLUEBACK HERRING, *ALOSA AESTIVALIS*, ALONG THE ATLANTIC COAST

RICHARD J. NEVES[1]

ABSTRACT

This study of the offshore distribution of alewife, *Alosa pseudoharengus*, and blueback herring, *A. aestivalis*, in the Atlantic Ocean was based on catch data collected over the 16-year period 1963-78 during bottom trawl surveys by the National Marine Fisheries Service and its predecessor agency. All catches of the two species were made where bottom water temperatures ranged from 2° to 17° C, and catches were most frequent at bottom temperatures between 4° and 7° C. Most catches of both species were made at stations where depth was less than 100 m. Chi-square analyses indicated that alewives were captured significantly more often than expected in the 56 to 110 m depth stratum and blueback herring in the 27 to 55 m stratum ($P<0.01$). During summer and autumn, all catches of the two species were confined to the region north of latitude 40° north in three general areas: Nantucket Shoals, Georges Bank, and the perimeter of the Gulf of Maine (especially in autumn along the northwestern edge of the gulf). Winter catches were between latitude 40° and 43° north, and spring catches were distributed throughout the continental shelf area between Cape Hatteras, N.C., and Nova Scotia. Previous studies on juveniles, food of adults, and differences in time of capture during National Marine Fisheries Service surveys indicated that these species are vertical migrators, apparently following the diel movements of zooplankton in the water column.

The alewife, *Alosa pseudoharengus*, and blueback herring, *A. aestivalis*, are anadromous clupeids that support substantial commercial fisheries during their spawning runs into rivers along the Atlantic coast. They are sympatric over most of their range and remarkably similar in external appearance; species separation is based primarily on eye size and the color of the abdominal peritoneum (Scott and Crossman 1973). Except for a description of some biological characteristics of these species from catches on Georges Bank (Netzel and Stanek 1966), virtually nothing has been written about the offshore biology or movements of these "river herring" (a term used by commercial fishermen for the two species combined).

The alewife, which ranges from North Carolina to the St. Lawrence River, Canada, spawns in rivers during spring. Spawning runs occur in a chronological south to north progression, from March through May. The significance of specific water temperatures for both upstream migration and spawning has been well documented for anadromous alewife populations (Cooper 1961; Dominy 1971; Saila et al. 1972; Kissil 1974; Richkus 1974; Tyus 1974). Adults migrate upstream and spawn in ponds, lakes, or slow-flowing stretches of rivers at water temperatures between 12° and 16° C (Bigelow and Schroeder 1953). Available evidence indicates that alewives home to their natal rivers to spawn (Belding 1921; Havey 1961; Thunberg 1971). The young remain in freshwater for several months, migrate downstream during summer and autumn, and generally spend 2 to 4 yr at sea, until sexually mature.

The behavioral response of alewives to changes in water temperature has received special research attention since the species invaded the Great Lakes (Colby 1973; Otto et al. 1976). Large, periodic die-offs in the Great Lakes have indicated a failure of this species to adjust completely to lake conditions. Hypotheses to explain these die-offs have alluded to differences between the lacustrine environment and the ancestral ocean, and their effect on the physiology of preadults (Smith 1968; Colby 1971; Stanley and Colby 1971); however, specific information on the marine phase of the alewife's life history is lacking.

The blueback herring ranges from northern Florida to Nova Scotia but is most abundant along the middle and south Atlantic coast. Its freshwa-

[1]Assistant Unit Leader, Virginia Cooperative Fishery Research Unit, 106 Cheatham Hall, VPI & SU, Blacksburg, VA 24061.

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ter life history is similar to that of the alewife, although its biology has not been as rigorously studied (Scherer 1972; Loesch and Lund 1977). Adults appear in rivers about 1 mo later than alewives and spawn over an extended period, at water temperatures between 21° and 24° C (Bigelow and Schroeder 1953). The young leave freshwater during their first year and remain in the ocean for 2 to 5 yr before returning to spawn.

This paper presents information on the offshore distribution and seasonal movements of these river herring, based on cruise and catch data collected during bottom-trawl surveys from 1963 to 1978 by U.S. research vessels between Cape Hatteras, N.C., and Nova Scotia, Canada.

METHODS

The National Marine Fisheries Service (NMFS) and its predecessor agency, the Bureau of Commercial Fisheries, have conducted bottom trawl surveys each autumn since 1963, using the RV *Albatross IV* and the RV *Delaware II*. The survey area, which extended from Nova Scotia to Cape Hatteras out to a depth of 366 m (Figure 1), was stratified into geographical zones based on depth and area. Coastal sampling stations were outside the 27 m depth contour. Middle Atlantic stations between New Jersey and Cape Hatteras were added during autumn 1967. A stratified, random sampling design was used in the surveys; trawl stations were allocated to strata in proportion to stratum area and randomly assigned within strata (Grosslein 1969). A standard No. 36 Yankee bottom trawl with a 1.25 cm stretched mesh cod end liner was towed at each station for 30 min at an average speed of 3.5 kn. Fall surveys were conducted 24 h/d between 3 September and 16 December 1963-78.

Bottom trawl surveys were conducted each spring during 1968-78 by U.S. vessels over the same geographical area (Figure 1). The No. 36 Yankee trawl was used from 1968 to 1972 and a larger No. 41 Yankee trawl from 1973 to 1978. Trawling procedures were the same as during autumn surveys, and stations were sampled between 4 March and 23 May. Spring and fall cruises were each conducted within an 8-wk period. A detailed description of NMFS bottom trawl surveys and survey procedures was provided by Flescher[2] and Grosslein.[3] All spring and autumn surveys and additional cruises during summer and winter are summarized in Table 1.

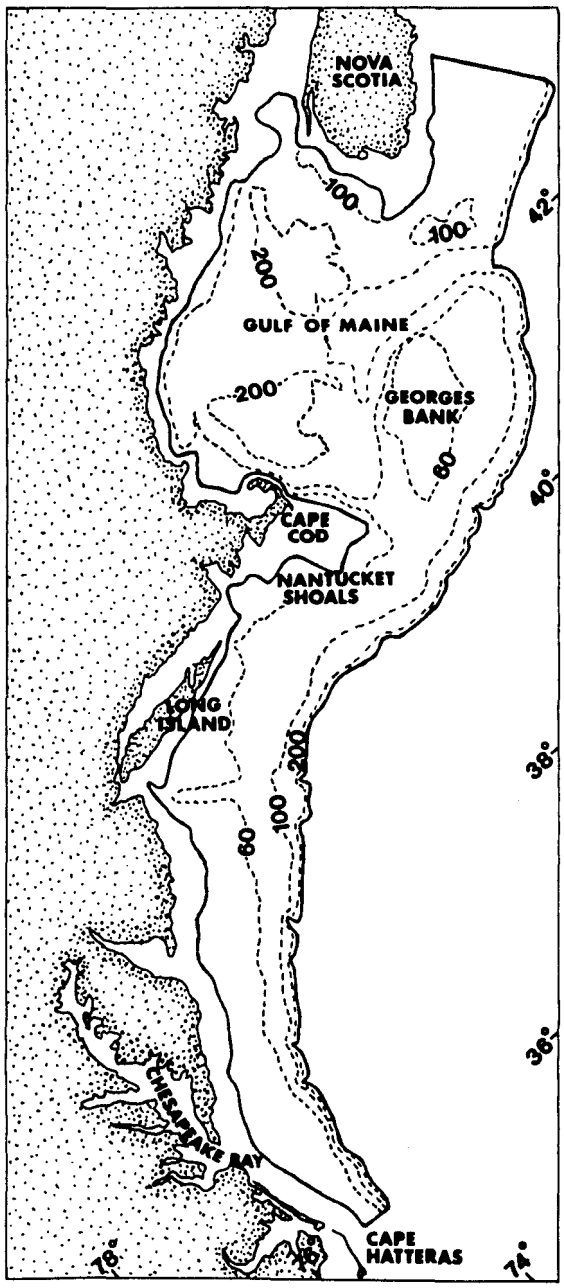

FIGURE 1.—National Marine Fisheries Service bottom trawl survey area, between depths of 27 and 366 m, Cape Hatteras, N.C., to Nova Scotia, western North Atlantic. Contour intervals are in meters (from Neves and Despres 1979).

[2]Flescher, D. 1976. Research vessel cruises, 1963-1975 National Marine Fisheries Service, Woods Hole, Massachusetts. NMFS, Woods Hole, Mass., Lab. Ref. No. 76-14, 30 p.
[3]Grosslein, M. D. 1969. Groundfish survey methods. NMFS, Woods Hole, Mass., Lab. Ref. No. 69-2, 34 p.

TABLE 1.—Summary of seasonal bottom trawl surveys conducted by U.S. research vessels between Cape Hatteras, N.C., and Nova Scotia, 1963-78.

Season	No. of surveys	No. of stations	Inclusive dates
Spring	11	3,097	4 Mar.-23 May
Summer	6	1,137	7 July-31 Aug.
Autumn	16	4,397	3 Sept.-16 Dec.
Winter	3	563	16 Jan.- 8 Apr.
Totals	36	9,194	

Pertinent survey station and catch data included date, location, time, depth, bottom and surface water temperatures, and number and length frequencies of river herring captured. Only catches of 10 or more alewives or blueback herring/trawl tow were used in this study. I plotted catch locations from all surveys (Table 1) by 10′ rectangles of latitude and longitude on depth contour maps according to month or season. Locations of catches during spring (March-May) and autumn (September-November) were plotted by month, although cruise direction and time schedules influenced date of sampling within the survey area. Surveys in summer (June-August) and winter (December-February) were grouped by season because sampling effort and catch frequency were lower during these seasons. Commercial catches reported to the International Commission for the Northwest Atlantic Fisheries (ICNAF[4]) by member nations from 1970 to 1978 were provided by Hodder.[5] These catch data were used to locate U.S. and foreign catches of river herring within each ICNAF division and were correlated with distribution patterns based on survey data. Surface and bottom temperatures (to the nearest 1° C) and depths were plotted for each trawl tow that collected 10 or more alewives or blueback herring.

RESULTS

Bottom trawling at 9,194 stations during the 36 survey cruises yielded 37,313 alewives at 512 stations and 3,058 blueback herring at 96 stations within the survey area. The fish ranged from 6 to 35 cm fork length. Water temperatures recorded at approximately 95% of these collecting stations were used to plot catch frequency at 1° C intervals. Water temperatures at stations where alewives were collected ranged from 2° to 23° C at the surface (Figure 2) and from 3° to 17° C at the bottom (Figure 3). Surface temperatures at stations with blueback herring ranged from 2° to 20° C and

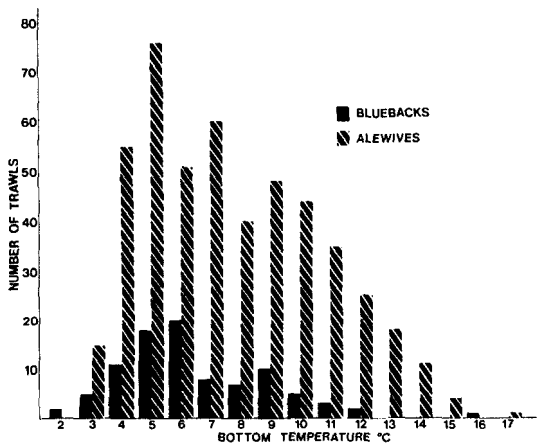

FIGURE 3.—Bottom temperatures at stations where alewives and blueback herring were collected during bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

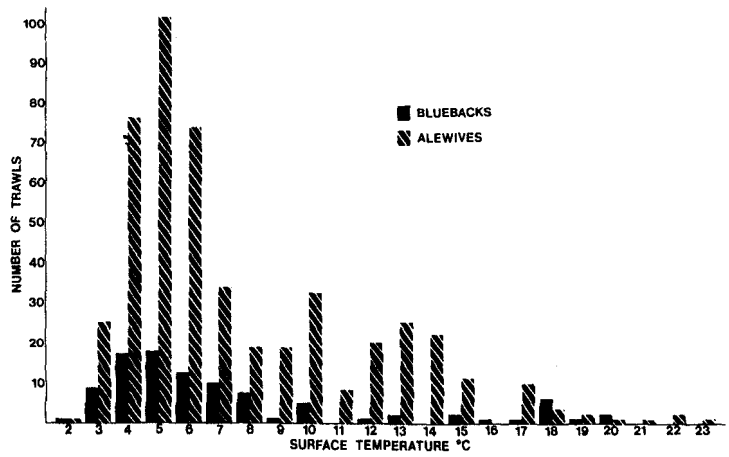

FIGURE 2.—Surface temperatures at stations where alewives and blueback herring were collected during bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

[4]ICNAF was replaced by the Northwest Atlantic Fisheries Organization (NAFO) in January 1980.

[5]V. M. Hodder, ICNAF Office, Dartmouth, N.S., Canada B2Y 3Y9, pers. commun. July 1977, June 1980.

bottom temperatures from 2° to 16° C. Catches of each species were more frequent at stations where both surface and bottom temperatures were 4° to 10° C (Figures 2, 3).

Most stations with bottom temperatures <4° C occurred in the Gulf of Maine during early spring. Stations with bottom temperatures >15° C were mainly off the mid-Atlantic coast during late summer and early autumn. The apparent decline in occurrence of alewives and blueback herring as bottom temperatures increased was examined further by comparing catches with total sampling effort for each bottom temperature (range, 1°-23° C) at which trawls were fished (Table 2). Nearly all blueback herring were taken at water temperatures <13° C. Alewives were caught at temperatures from 3° to 17° C, and frequency of capture was highest at 4° C (Table 2).

Ocean depths at stations where river herring were caught ranged from 20 to 293 m, but most catches of alewives (77%) and blueback herring (83%) were made at stations <100 m deep (Figure 4). Since trawling effort during surveys was proportional to the area of each depth interval, the number of catches within these depth strata was amenable to chi-square analysis with correction for continuity (Zar 1974). A comparison between alewife and blueback herring catches at each depth interval and catches at all other depths combined indicated that both species were collected significantly more often than expected at depths <110 m (Table 3). Based on expected values, blueback herring were captured significantly more often in the 27-55 m depth stratum and alewives in the 56-110 m stratum ($P<0.01$).

TABLE 2.—Total sampling effort and percent of trawl tows with alewives or blueback herring at different bottom temperatures during bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

Bottom temp (° C)	Total trawl tows (no.)	Alewives (%)	Blueback herring (%)
1	9	0	0
2	87	0	2.3
3	243	6.2	2.1
4	589	9.3	1.9
5	1,064	7.1	1.7
6	1,040	4.9	1.9
7	1,018	5.9	.8
8	896	4.5	.8
9	806	6.0	1.2
10	699	6.3	.7
11	653	5.4	.5
12	523	4.8	.4
13	424	4.2	0
14	250	4.4	0
15	153	2.6	0
16	69	0	1.4
17	43	2.3	0
18	31	0	0
19	21	0	0
20	22	0	0
21	21	0	0
22	6	0	0
23	4	0	0

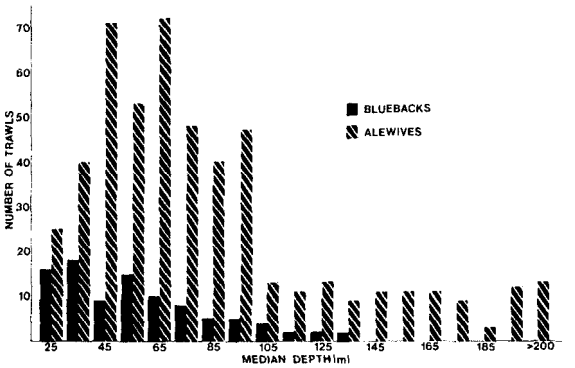

FIGURE 4.—Frequency of catches of alewives and blueback herring in relation to depth at trawling stations, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

Seasonal Distribution

Spring surveys were conducted primarily in March and April, accounting in part for the more frequent collections of alewives and blueback herring during these 2 mo (Figures 5, 6). During the spring, both species were widely distributed along the Middle Atlantic Bight, and mixed catches were common in this region. Alewife catches were also frequent between Cape Cod, Mass., and the western perimeter of Georges Bank (Figure 5). No spring catches of blueback herring were recorded for Georges Bank (Figure 6).

During the summer surveys of July and August, neither species was captured south of lat. 40° N; stations in the central Gulf of Maine were also unproductive (Figure 7). Alewives were collected most frequently on Georges Bank and south of

TABLE 3.—Depth intervals within the survey area and associated catches of alewives (A) and blueback herring (B) during complete bottom trawl surveys, 1967-78, Cape Hatteras, N.C., to Nova Scotia.

Depth interval (m)	Study area		Number of trawl tows with alewives or blueback herring					
			Observed		Expected		χ^2	
	km²	%	A	B	A	B	A	B
27-55	47,412	25.4	120	50	102	22	4.02	46.00**
56-110	55,009	29.5	194	33	118	26	68.45**	2.31
111-185	53,789	28.9	63	4	116	25	33.43**	23.59**
186-366	30,181	16.2	24	0	65	14	30.11**	15.52**
Totals	186,391	100.0	401	87	401	87		

**$P<0.01$.

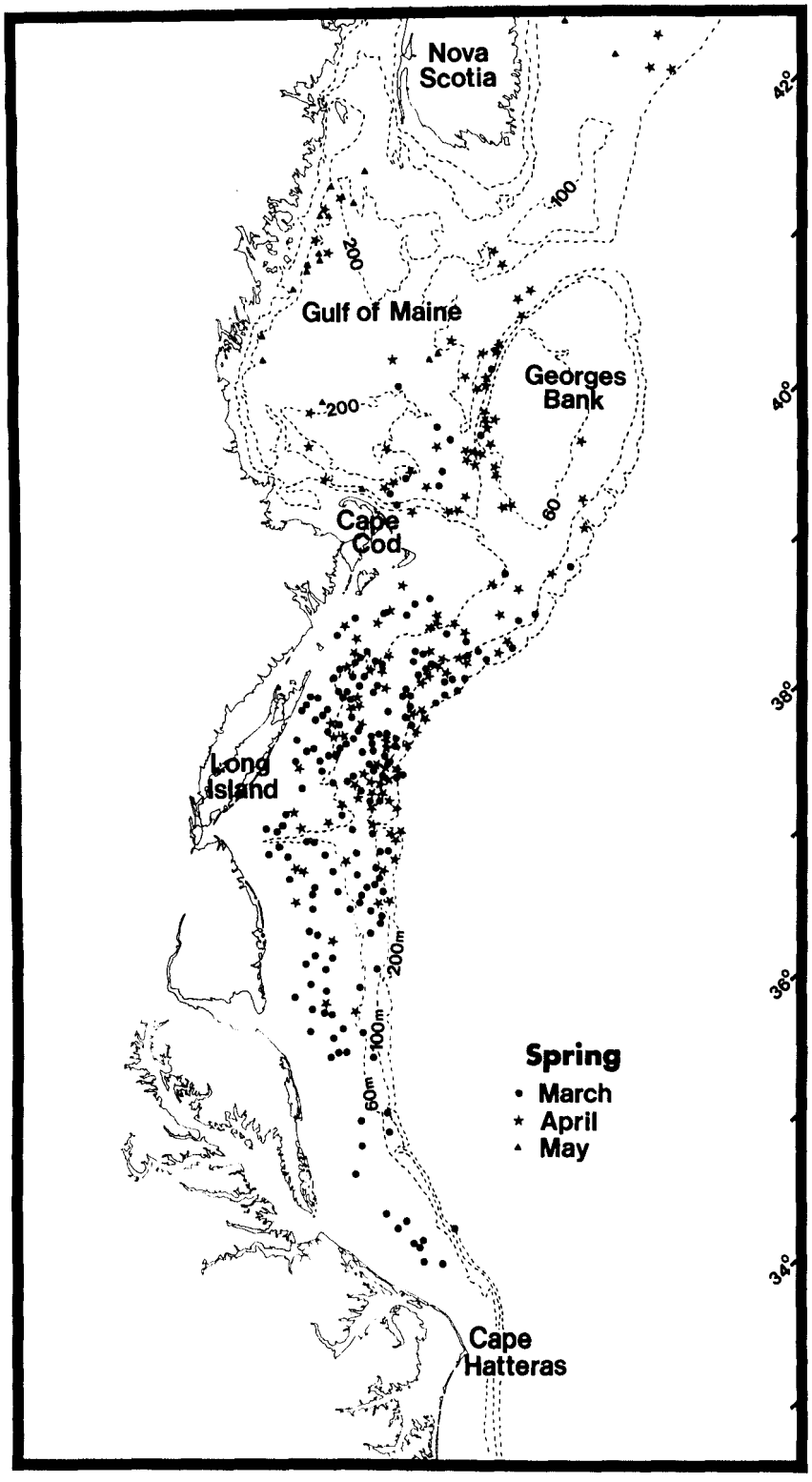

FIGURE 5.—Location of alewife catches during spring bottom trawl surveys, 1968-78, Cape Hatteras, N.C., to Nova Scotia.

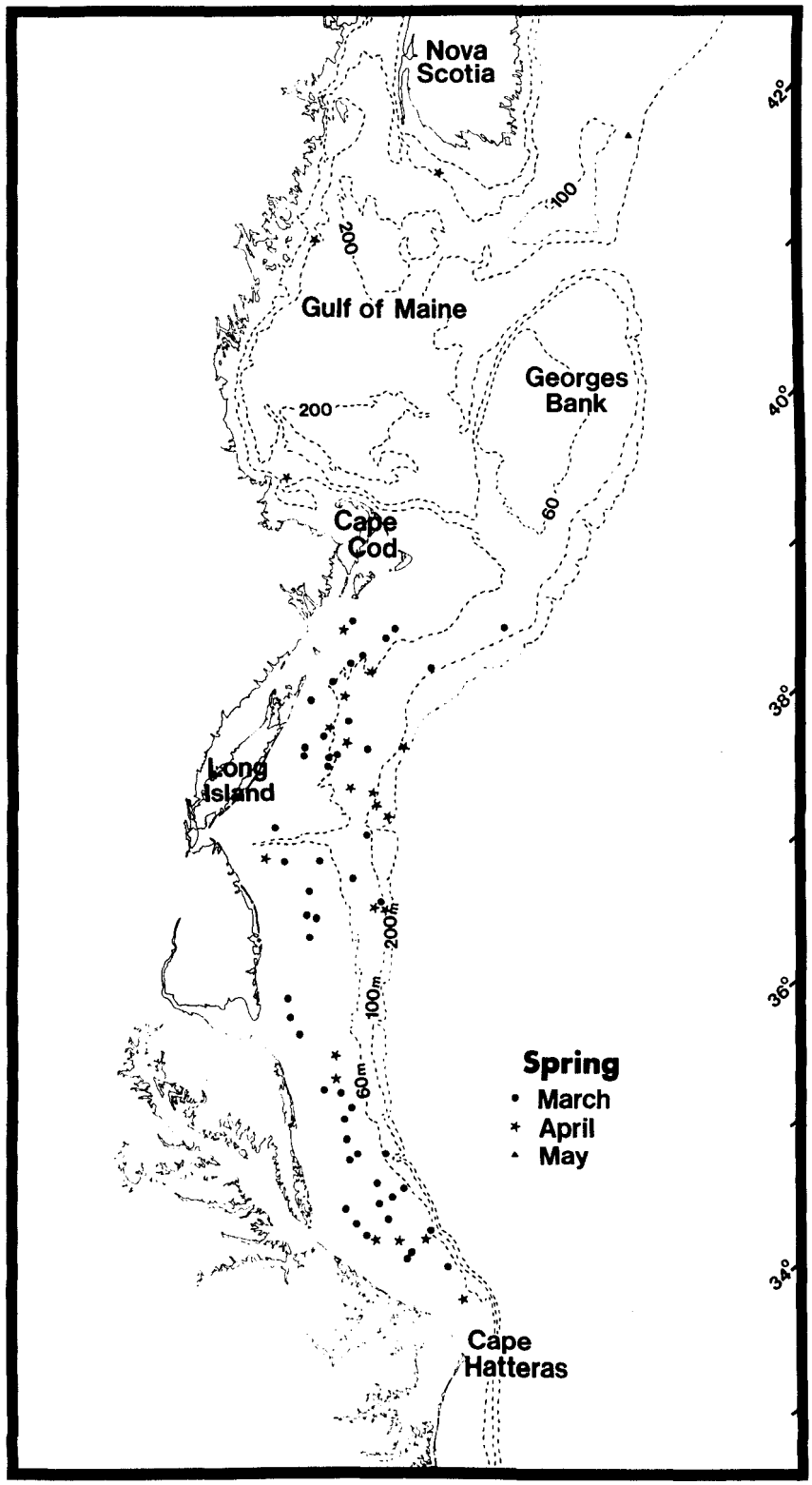

FIGURE 6.—Location of blueback herring catches during spring bottom trawl surveys, 1968-78, Cape Hatteras, N.C., to Nova Scotia.

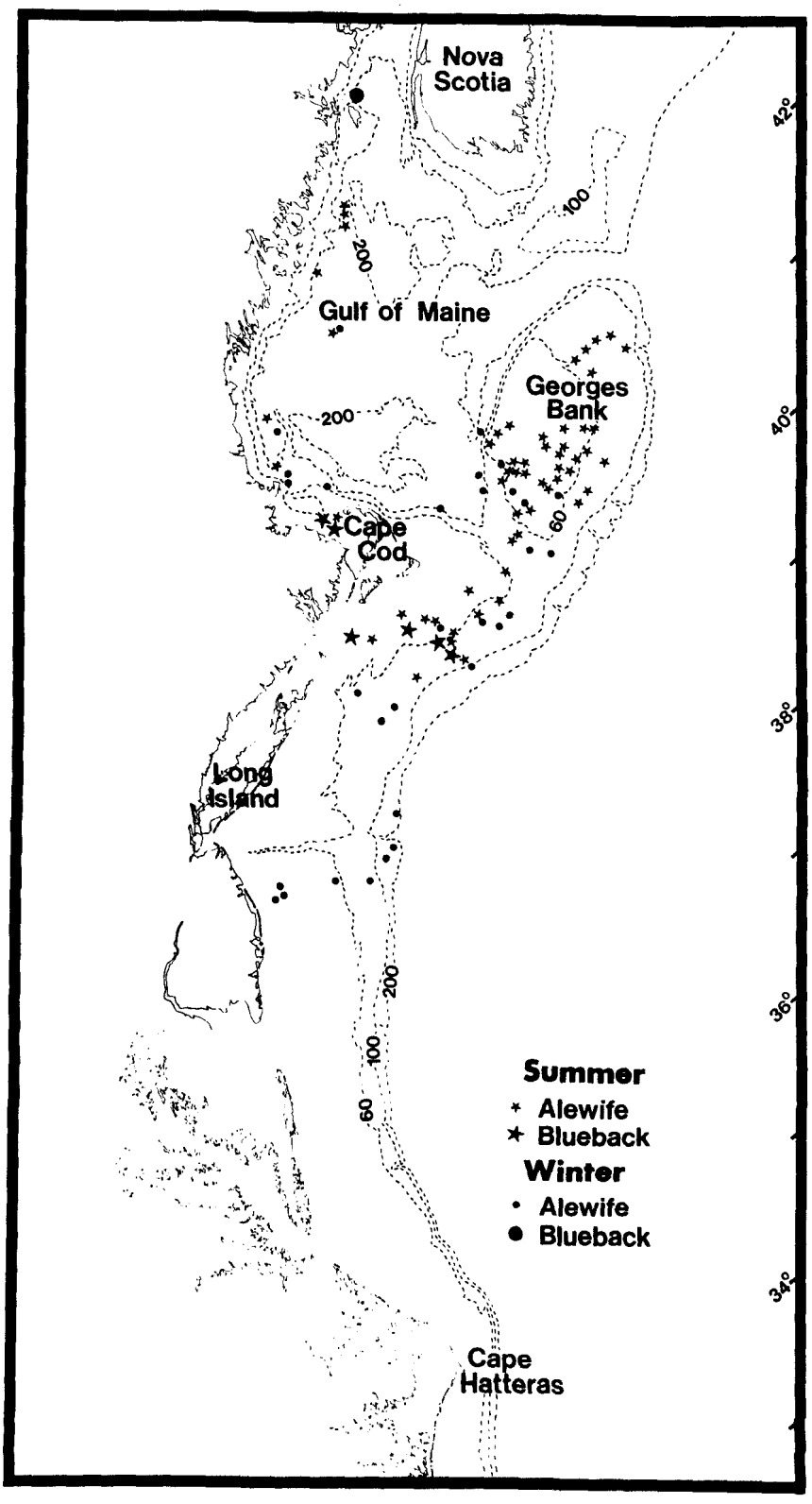

FIGURE 7.—Location of catches of alewives and blueback herring during summer and winter bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

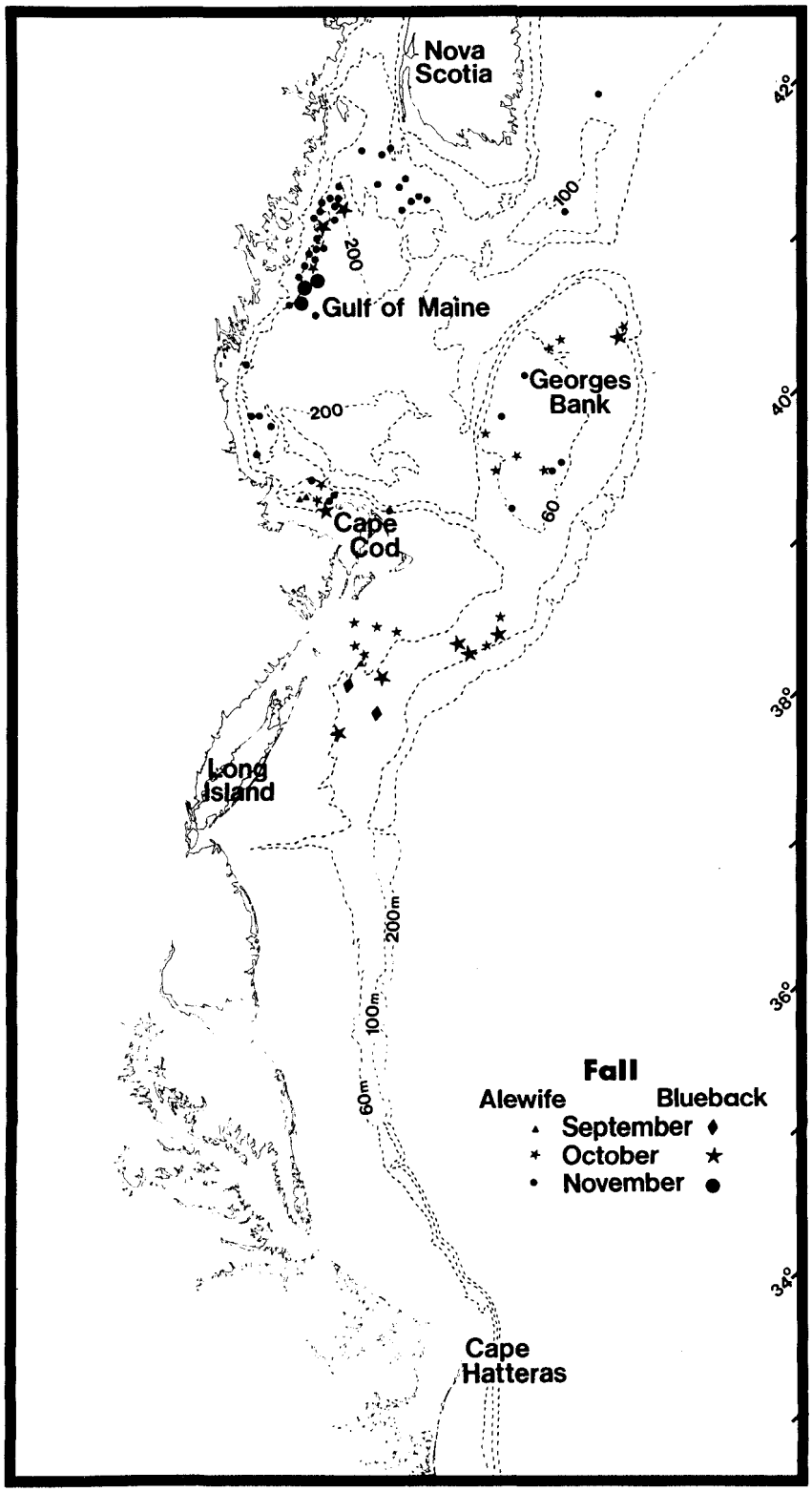

FIGURE 8.—Location of catches of alewives and blueback herring during fall bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

Nantucket Shoals; catch records of blueback herring were too infrequent to determine summer occurrence. Both species were rarely captured in water deeper than 100 m in summer.

During fall surveys, catches of river herring were less frequent than during the spring, even though more stations were sampled (Table 1). Distribution of catches was similar to that in summer, except that a concentration of both species was evident along the northwest perimeter of the Gulf of Maine (Figure 8). Catches of river herring were recorded at most stations in this region. In 12 yr of autumn bottom trawl surveys along the Atlantic coast, river herring were never collected offshore south of lat. 40° N.

The relatively small number of winter sampling stations was inadequate to define the wintering area for either species (Figure 7). The few winter catches were widely distributed, primarily from lat. 40° N (south of Long Island) to lat. 43° N (north of Cape Cod).

Commercial Catches

The time periods for major catches of river herring in ICNAF divisions by domestic (primarily inshore) and foreign (offshore) fisheries are summarized in Figure 9. Domestic catches in Subarea 5 resulted from both inshore and offshore fishing operations. The south to north progression in spawning runs is reflected in the time and location of commercial catches by the United States (Subareas 6 and 5) and Canada (Subarea 4), since most domestic catches occur during the upstream migration of anadromous stocks in each subdivision. The periods of principal foreign catches preceded or overlapped those of domestic catches in coastal waters. The year-round occurrence of river herring between Long Island and Georges Bank, as indicated by NMFS survey data, was corroborated by commercial catches in ICNAF divisions 5Zw and 5Ze (Figure 9).

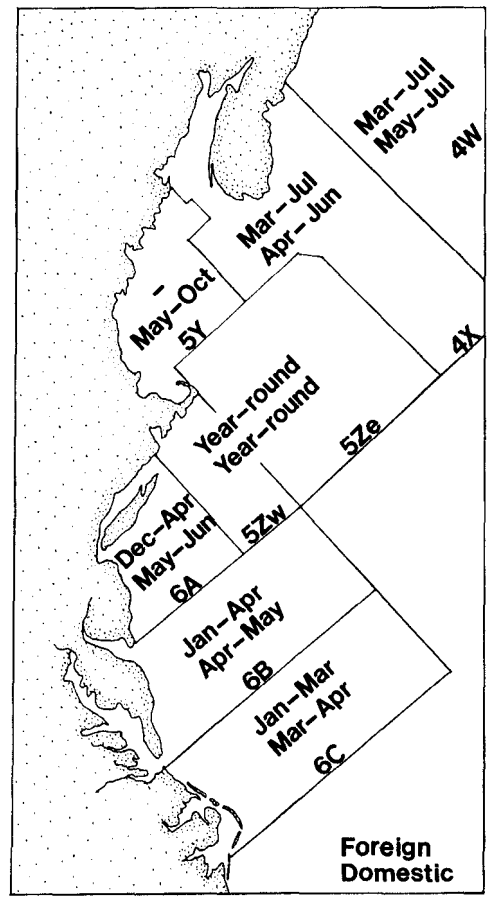

FIGURE 9.—Seasonal distribution of major catches of alewives and blueback herring in divisions of the International Commission for the Northwest Atlantic Fisheries, 1970-78, Cape Hatteras, N.C., to Nova Scotia. Within each division, the months for major catches are shown separately for foreign vessels (upper entry) and the domestic fishery (lower entry).

DISCUSSION

Offshore Distribution

Fish sampling during NMFS bottom trawl surveys covers a large area in a relatively short period and provides the most detailed, available records on offshore distribution of fishes and concurrent environmental conditions. As judged by the accumulated survey data, the seasonal offshore distribution of alewives and blueback herring resembles that of American shad, *Alosa sapidissima* (Neves and Despres 1979). River herring are widely distributed along the Middle Atlantic Bight during spring, appear to move north in the Nantucket Shoals, Georges Bank, and coastal Gulf of Maine areas during summer and early autumn, and then return south to the mid-Atlantic coast in winter and early spring. The extent of overwintering in deep water off the continental shelf is unknown. The similarities in seasonal distribution between American shad and river herring may be indicative of similar inshore and offshore migratory patterns. However, a determination of stock mixing and migratory routes is not possible, because no tagging studies have been conducted

comparable with those on other anadromous species (Merriman 1941; Raney et al. 1954; Talbot and Sykes 1958; Chapoton and Sykes 1961; Leggett and Whitney 1972).

If the water temperature regime recorded for oceanic occurrence of alewives and blueback herring (Figure 3) applies to all stocks of these species at sea, the migratory route of blueback herring populations returning to South Atlantic rivers would be similar to that proposed for American shad by Neves and Despres (1979). Prespawning adults returning to coastal waters from the ocean would encounter a thermal barrier south of Cape Hatteras, where offshore temperatures remain above 17.5° C throughout the year. Migration toward shore north of Cape Hatteras and then south along the coast would appear to be essential for successful homing to South Atlantic rivers.

A determination of oceanic location and migratory routes of river herring stocks has particular relevance to the commercial fishery, centered primarily in Virginia and North Carolina. Large catches of river herring were taken offshore by foreign fishing vessels in ICNAF Subarea 6 during the mid-1960's, and by 1969 foreign catches exceeded domestic catches (McHugh and Ginter 1978). The increase in high-seas catches, consisting of juveniles and adults, was accompanied by a marked decrease in inshore landings. This foreign fishing pressure, added to that of the domestic fishery, resulted in a drastic reduction of total annual catches (Table 4). Street and Davis[6] postulated that this decline reflected a reduction in stock size due to excessive harvest. The United States obtained certain limitations on foreign catches of river herring through bilateral negotiations during the mid-1970's, and after the implementation of the Fishery Conservation and Management Act of 1976 (PL 94-265), offshore catches of river herring by foreign vessels were virtually eliminated. Johnson et al.[7] reported that Virginia landings of river herring in 1978 increased 53% compared with those in 1977, but did not attribute this increase to good recruitment. River herring catches in North Carolina have continued to decline, and water quality degradation in several spawning areas may be creating additional problems (Street[8]). Future monitoring of stock abundance by coastal states should help resolve the question of whether stocks were seriously reduced by offshore fishing.

[6]Street, M. W., and J. Davis. 1976. Notes on the river herring fishery of SA6. Int. Comm. Northwest Atl. Fish. Annu. Meet. 1976, Res. Doc. 76/VI/61, Serial No. 3848, 7 p.

TABLE 4.—Annual catches (metric tons round, fresh) of alewives and blueback herring (species combined) by domestic and foreign fisheries in three ICNAF subareas, 1966-78.

Year	ICNAF subarea 4	5	6	Total
1966	3,703	4,344	21,178	29,225
1967	2,978	9,285	23,182	35,445
1968	3,028	22,598	24,724	50,350
1969	1,655	26,185	34,732	62,572
1970	3,288	14,598	20,842	38,728
1971	10,938	14,618	21,213	46,769
1972	7,948	8,656	5,146	21,750
1973	8,859	5,865	11,202	25,926
1974	17,954	3,771	12,583	34,308
1975	5,683	5,019	9,553	20,255
1976	7,954	1,812	6,444	16,210
1977	7,744	1,765	4,586	14,095
1978	7,626	1,640	4,122	13,388

Depth Distribution

Frequency of alewife and blueback herring catches within the four depth strata indicated that these species occur primarily at water depths <110 m at sea. Both species are size-selective zooplankton feeders (Bigelow and Schroeder 1953; Hildebrand 1963; Brooks and Dodson 1965). My examination of the stomachs of 100 alewives and 75 blueback herring, collected in April 1978 during the spring survey, revealed calanoid copepods, mysids, and other zooplankters in that order of frequency and abundance in both species. The occurrence of major zooplankton concentrations in the Gulf of Maine at depths <100 m (Bigelow 1926; Whiteley 1948) may therefore influence the depth distribution of river herring.

The numerous catches of river herring in the northwestern Gulf of Maine during autumn were centered at about lat. 44° N, long. 68° W. Mean depth at these stations was 112 m (range, 64-179 m), and mean bottom temperature was 9.5° C (range, 8.0°-13.4° C). This apparent concentration of river herring is noteworthy, particularly since studies on zooplankton availability in this region are contradictory. From late summer to December, zooplankton is most abundant in the northern Gulf of Maine (Cohen[9]); however, Sherman (1970)

[7]Johnson, H. B., D. W. Crocker, B. F. Holland, Jr., J. W. Gilliken, D. L. Taylor, and M. W. Street. 1978. Biology and management of mid-Atlantic anadromous fishes under extended jurisdiction. Annu. Rep. Anadromous Fish Proj. 1978, N.C.-Va. AFCS 9-2, 175 p.

[8]M. W. Street, N.C. Div. Mar. Fish. Morehead City, N.C. 28556, pers. commun. June 1980.

[9]Cohen, E. B. 1975. An overview of the plankton communities of the Gulf of Maine. Int. Comm. Northwest Atl. Fish. Annu. Meet. 1975, Res. Doc. No. 106, Ser. No. 3599, 16 p.

recorded low volumes of zooplankton along the northern coast of Maine. Confirmation of river herring abundance in this region requires more extensive investigation.

The apparent difference in preferred depth distribution between the alewife and blueback herring (Table 3) may be related to the diagnostic character differences between these two species. The alewife has a slightly larger eye, an adaptation usually associated with an existence at greater depths (Marshall 1966). In addition, green wavelengths (ca. 500 mμ) penetrate waters of the continental shelf most effectively (Wald et al. 1957). Could the color of the dorsum, green in the alewife and blue in the blueback, be a countershading mechanism for reduced predation within the depth ranges most frequently occupied by each species? No direct evidence is available to support either the eye size or dorsal coloration postulates; however, the vertical segregation evidenced at sea has also been reported for juveniles in rivers (Loesch and Kriete[10]). Juvenile blueback herring occur in the upper levels of the river water column, and juvenile alewives frequent midwater depths.

Diel differences in catchability of river herring were examined by partitioning capture time (eastern standard time) during survey cruises (24 h/d) into day (0600-1800 h) and night (1800-0600 h). Chi-square analysis with correction for continuity on time of capture revealed that catches were made significantly more often ($P < 0.01$) during the day than at night (Table 5). Alewives and blueback herring were apparently closer to the bottom during daylight, and thus more susceptible to bottom trawling gear. This diel difference in depth distribution has also been reported for juvenile river herring in estuaries (Warriner et al. 1969; Loesch et al.[11]) and adult alewives in the Great Lakes (Janssen and Brandt 1980).

I deduce from the above observations that river herring are vertical migrators like other schooling clupeids such as American shad and sea herring, *Clupea harengus* (Blaxter 1975; Neves and Despres 1979), which follow the diel movements of zooplankton in the water column. This reliance on zooplankton for food may partly account for the disjunct distribution of river herring in offshore waters during most seasons. Zooplankton distribution in the Gulf of Maine during summer and autumn is closely related to local and regional hydrography (Redfield 1941; Sherman 1970; Cohen footnote 9), and concentrations generally are along areas of current convergence and divergence (Zinkevich 1967). The waters around Georges Bank during the winter are nearly devoid of zooplankton, whereas sizeable neritic populations occur from Nantucket Shoals to southern Long Island (Clarke 1940; Grice and Hart 1962; Zinkevich 1967). Sette (1950) concluded that water temperature had a limiting rather than causal influence on the seasonal movements of the planktivorous Atlantic mackerel, *Scomber scombrus*. Similarly, Neves and Despres (1979) related American shad distribution to bottom temperatures and possibly seasonal shifts in zooplankton concentrations. Catches of river herring in specific areas along Georges Bank, the perimeter of the Gulf of Maine, and south of Nantucket Shoals may therefore be related to zooplankton abundance in these regions, although direct evidence is lacking.

TABLE 5.—Chi-square test comparing the number of day and night catches of alewives (A) and blueback herring (B) during U.S. bottom trawl surveys, 1963-78, Cape Hatteras, N.C., to Nova Scotia.

	Observed		Expected		χ^2	
Time	A	B	A	B	A	B
Day, 0600-1800 h	317	68	250	48		
Night, 1800-0600 h	183	28	250	48		
Total	500	96	500	96	35.4**	15.8**

**$P < 0.01$.

Critical data on the oceanic life history of most anadromous fishes are lacking, and my synthesis of NMFS survey data and previous studies on the alewife and blueback herring should be considered tentative. Unanswered questions such as stock identification and mixing, and time and direction of migrations at sea during the year must await prescribed oceanic research.

ACKNOWLEDGMENTS

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[10]Loesch, J. G., and W. H. Kriete, Jr. 1976. Biology and management of river herring and shad. Completion Rep. Anadromous Fish Proj. 1974-1976, Va. AFC 8-1 to 8-3, 226 p.

[11]Loesch, J. G., W. H. Kriete, Jr., H. B. Johnson, B. F. Holland, and M. W. Street. 1977. Biology and management of mid-Atlantic anadromous fishes under extended jurisdiction. Annu. Rep. Anadromous Fish Proj. 1977, N.C.-Va. AFCS 9-1, 183 p.

analysis, and reviewing the manuscript. The Virginia Cooperative Fishery Research Unit provided financial support.

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