NOTES

OFFSHORE WINTER MIGRATION OF THE ATLANTIC SILVERSIDE, *MENIDIA MENIDIA*[1]

The Atlantic silverside, *Menidia menidia*, is an abundant fish in coastal waters of the western Atlantic ranging from Florida to Nova Scotia. During spring, summer, and fall, the habitat of *M. menidia* includes intertidal creeks, marshes, and the shore zone of estuaries and embayments (Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953). In such areas, ichthyofaunal surveys often cite *M. menidia* as the most numerous species encountered (Mulkana 1966; Richards and Castagna 1970; Chestmore et al. 1973; Briggs 1975; Anderson et al. 1977; Hillman et al. 1977). The entire life cycle of *M. menidia* is completed in 1 yr. Reproduction occurs in the spring, juveniles grow rapidly during the summer and reach full adult size by late fall. However, considerable uncertainty exists concerning winter ecology and habitat. In populations from Chesapeake Bay northward, Atlantic silversides are rare or absent from the shallow waters of the shore zone in midwinter (Warfel and Merriman 1944; Bayliff 1950; Hoff and Ibara 1977; Conover and Ross in press). Hildebrand and Schroeder (1928) and Richards and Castagna (1970) reported that *M. menidia* were captured in midwinter with bottom trawls in deepwater areas of Chesapeake Bay and deep estuarine channels in eastern Virginia. Catches of *M. menidia* have also been occasionally reported up to 15 km offshore (Clark et al. 1969; Fahay 1975). However, Needler (1940) noted that Atlantic silversides could be taken through the ice in Malpeque Bay, P.E.I. (although he presented no data concerning relative seasonal abundance), and investigations in South Carolina found an abundance of *M. menidia* in intertidal marsh creeks during winter (Cain and Dean 1976; Shenker and Dean 1979).

Because the Atlantic silverside is an important forage fish (Merriman 1941; Bayliff 1950; Bigelow and Schroeder 1953) and reaches a high level of biomass in the shore zone of marshes and estuaries (7.8 g/m^2 wet weight) (Conover and Ross in press), the winter movement patterns of this annual species could represent a significant pathway of energy flow from and/or within estuarine systems. This paper demonstrates that Atlantic silversides migrate offshore in winter, and we discuss aspects of their winter ecology and distribution by examining catch records of the bottom trawl survey program of the Northeast Fisheries Center (NEFC) of the National Marine Fisheries Service (NMFS).

Methods

A modern series of standardized bottom trawl surveys was begun in 1963 by the Bureau of Commercial Fisheries (BCF) Woods Hole Laboratory (Grosslein 1969). Initially, fall surveys encompassed the general range of offshore groundfish stocks of primary interest (i.e., gadoids) and thus was confined to the area between Hudson Canyon and Nova Scotia and depths from 27 to 366 m. Later, as the goals and emphasis of the survey program expanded to include a wider variety of species, both fall and spring surveys were conducted and the sampling area was extended southward to Cape Hatteras (1967). The offshore survey region was stratified into geographic zones based on depth contours and area (Grosslein 1969). A stratified random sampling design was employed to locate trawl stations within depth strata and the number of stations was allocated in proportion to stratum area. 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 of 3.5 kn; however, spring offshore surveys since 1973 have used the larger No. 41 Yankee trawl. Stations were sampled continuously 24 h/d during cruises.

Synoptic bottom trawl surveys in the nearshore environment were begun in 1972 by the NMFS Sandy Hook Laboratory. Early surveys in the inshore region (defined as depth strata of 5-27 m) assessed the technical and geographic feasibility of using offshore sampling gear in waters as shallow as 5 m. Since autumn 1972, inshore surveys have been conducted each fall and spring with summer cruises added in 1977 and a winter cruise in 1978. Of 18 inshore cruises through 1978, most (17) included the region from

[1]Contribution No. 73 of the Massachusetts Cooperative Fishery Research Unit.

Cape Cod to Cape Hatteras, 4 included the Gulf of Maine, and 7 included the region from Cape Hatteras to Cape Fear. During 1972-75, all inshore surveys used either a ¾ modified Yankee trawl or the No. 36 Yankee trawl. Since 1976, a No. 41 Yankee trawl has been used. Towing procedures were the same as described for offshore surveys. The seasonal and geographic variation in the extent of inshore surveys reflects their evolution as a monitoring tool.

Capture data employed in this study included date, location, time, depth, surface and bottom temperatures, and number collected. Catch locations from all surveys were plotted to the nearest 10′ of latitude and longitude on depth contour maps by season. Surface and bottom temperatures and depth frequencies were plotted for each occasion that *M. menidia* were captured.

Results

Standard bottom trawl tows at 2,057 stations from inshore surveys collected 979 *M. menidia* at 107 sites (5.2% occurrence), while offshore tows at 10,209 stations captured 464 *M. menidia* at 72 sites (0.7% occurrence). Because sampling effort by season was not uniform with respect to inshore and offshore surveys or geographic zones, analysis of catch per effort data (catch frequency) was compiled by month for inshore and offshore surveys in three geographic regions (i.e., Gulf of Maine-Georges Bank, Cape Cod-Cape Hatteras, Cape Hatteras-Cape Fear). In the inshore surveys, effort was primarily concentrated in the Cape Cod-Cape Hatteras region, where the percent frequency of capture of *M. menidia* was negligible in summer, increased in November (4.9%), peaked in January (34.3%), and declined through the spring (Table 1). Number of stations sampled in the inshore surveys of the Gulf of Maine-Georges Bank and Cape Hatteras-Cape Fear regions was inadequate for monthly or regional comparisons. In offshore surveys, the monthly pattern of occurrence of *M. menidia* was similar to that of inshore surveys; catch frequency was zero in summer and autumn, peaked in January (3.8%) in the Gulf of Maine-Georges Bank and in February (11.2%) in the Cape Cod-Cape Hatteras regions, and declined thereafter (Table 2). These data support the hypothesis of an offshore winter migration.

The geographic distribution of catches by season (Fig. 1) indicates that most collections are confined to a zone within roughly 50 km of the shoreline and within the 40 m depth contour. One collection occurred 170 km from the mainland. Although most catches appear to occur between Cape Cod and Cape Hatteras and especially in the New York Bight, sampling effort among inshore surveys was much greater in this region as previously noted (Table 1). Although only four collections of *M. menidia* were observed south of Cape Hatteras (two off Cape Fear, S.C., and two off Cape Romain, S.C.; not appearing in Figure 1), no offshore or inshore surveys were conducted south of Cape Hatteras in winter when catches might be expected.

Surface temperatures recorded at 141 of the inshore and offshore stations where Atlantic silversides were captured ranged from 1° to 22°C, but 86% of these were within a range of 2°-6°C ($\bar{x}$ = 4.9°C; Fig. 2A). Bottom temperatures recorded at 135 collecting sites revealed a similar

TABLE 1.—Percent frequency of occurrence of *Menidia menidia* at stations sampled in the inshore survey region (depth strata of 5-27 m) of the NMFS bottom trawl survey program over the continental shelf of eastern North America. Catch statistics are from cruises conducted from 1972 to 1979 and are pooled by month and area of capture. The number in parentheses is the total number of stations sampled.

Month	Gulf of Maine and Georges Bank		Cape Cod-Cape Hatteras		Cape Hatteras-Cape Fear	
Jan.	—	(0)	34.3	(70)	0.0	(2)
Feb.	—	(0)	—	(0)	—	(0)
Mar.	—	(0)	21.4	(206)	0.0	(18)
Apr.	0.0	(7)	9.6	(240)	0.0	(25)
May	—	(0)	0.7	(141)	—	(0)
June	—	(0)	0.0	(33)	—	(0)
July	0.0	(3)	0.0	(41)	0.0	(47)
Aug.	0.0	(80)	0.5	(216)	0.0	(31)
Sept.	—	(0)	0.0	(150)	0.0	(82)
Oct.	—	(0)	0.2	(398)	0.0	(40)
Nov.	0.0	(10)	4.9	(183)	9.1	(22)
Dec.	—	(0)	0.0	(6)	33.3	(6)

TABLE 2.—Percent frequency of occurrence of *Menidia menidia* at stations sampled in the offshore survey region (depth strata 27-366 m) of the NMFS bottom trawl survey program over the continental shelf of eastern North America. Catch statistics are from cruises conducted from 1963 to 1979 and are pooled by month and area of capture. The number in parentheses is the total number of stations sampled.

Month	Gulf of Maine and Georges Bank		Cape Cod-Cape Hatteras		Cape Hatteras-Cape Fear	
Jan.	3.8	(159)	—	(0)	—	(0)
Feb.	0.4	(221)	11.2	(98)	—	(0)
Mar.	0.0	(386)	4.3	(925)	0.0	(18)
Apr.	0.2	(1,270)	1.5	(518)	—	(0)
May	0.0	(456)	0.0	(2)	—	(0)
June	—	(0)	—	(0)	—	(0)
July	0.0	(310)	0.0	(114)	0.0	(41)
Aug.	0.0	(522)	0.0	(336)	—	(0)
Sept.	—	(0)	0.0	(344)	0.0	(9)
Oct.	0.0	(1,265)	0.0	(1,219)	—	(0)
Nov.	0.0	(1,628)	0.0	(154)	—	(0)
Dec.	0.0	(155)	0.0	(55)	—	(0)

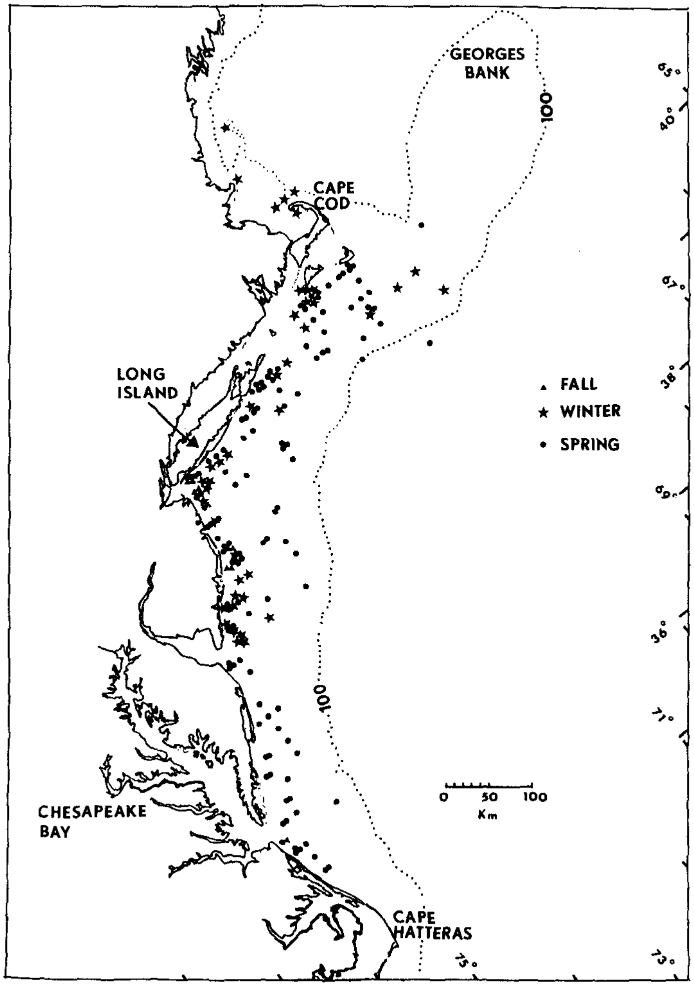

FIGURE 1.—Location of Atlantic silverside catches by season during inshore and offshore bottom trawl surveys of the National Marine Fisheries Service, Cape Hatteras to Nova Scotia, 1963-79 (fall = Sept.-Nov.; winter = Dec.-Feb.; spring = Mar.-May). Seven catch locations do not appear: Two off the northern coast of Maine, one off the outer coast of southern Nova Scotia, two off Cape Fear, S.C., and two off Cape Romain, S.C.

pattern: the majority (86%) of all Atlantic silverside collections occurred within a range of 2°-6° C ($\bar{x}$ = 5.1°C; Fig. 2B). These data indicate that *M. menidia* occur over the continental shelf primarily under winter temperature conditions after fall overturn when temperatures are isothermal.

The distribution of Atlantic silversides with respect to depth was examined by comparing catch frequency to depth of capture in 5 m intervals. The majority of catches occurred in waters <50 m deep (86%), and 42% of all catches were in depths of 10-20 m (Fig. 3). Maximum depth of capture was 126 m.

Some aspects of the winter ecology of Atlantic silversides while at sea can be revealed by examining their vertical distribution in the water column. Vertical distribution was inferred from diel variations in capture times partitioned into six 4-h intervals. Chi-square analysis comparing catch frequency in each time interval to all others combined showed that catch frequencies during night intervals (2000-0359 h) were significantly less than expected ($P<0.01$; Table 3), while catch frequencies during midday intervals (0800-1559 h) were significantly greater than expected ($P<0.01$). Apparently, *M. menidia* occurred nearer the bottom during daylight hours and hence were more susceptible to bottom trawl tows conducted during the day. These observations indicate that while at sea, Atlantic silversides are vertical migrators like other planktivores such as Atlantic herring, *Clupea harengus*, (Blaxter 1975) and American shad, *Alosa sapidissima*, (Neves and Depres 1979).

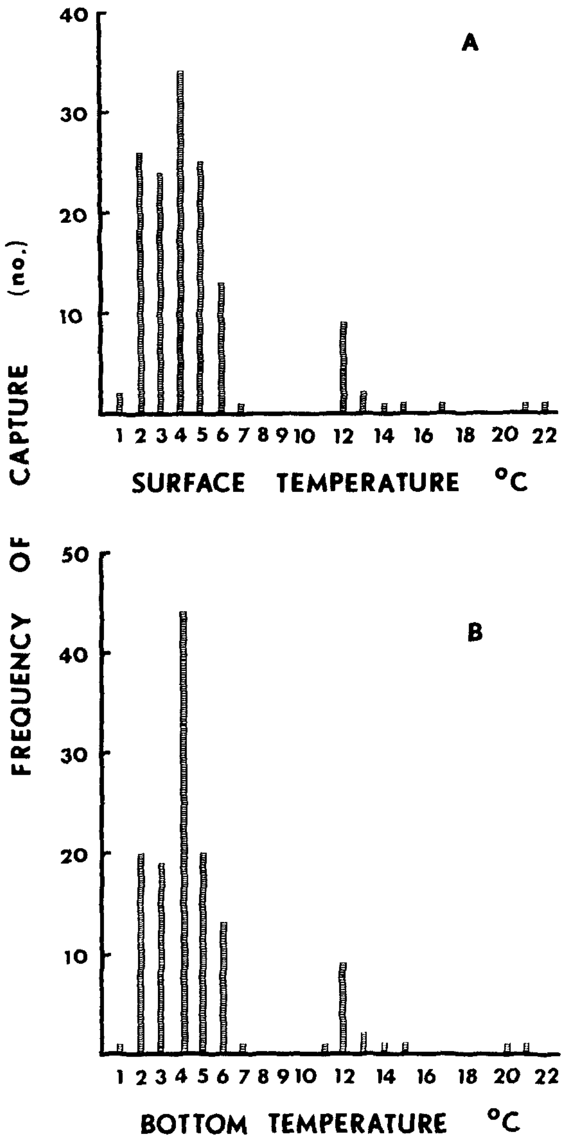

FIGURE 2.—Water temperatures at stations where Atlantic silversides were captured during inshore and offshore bottom trawl surveys conducted by the National Marine Fisheries Service during 1963-79 over the eastern North American continental shelf. A. Surface temperatures (n = 141). B. Bottom temperatures (n = 135).

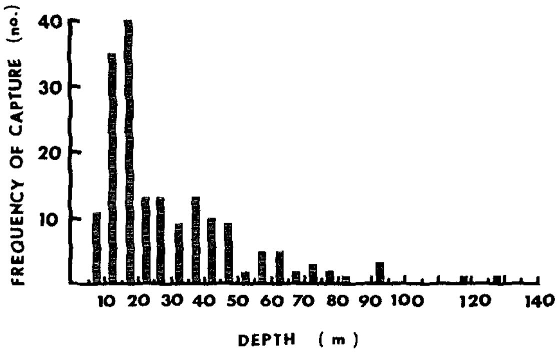

FIGURE 3.—Water depths at which Atlantic silversides were captured during inshore and offshore bottom trawl surveys of the National Marine Fisheries Service over the eastern North American continental shelf, 1963-79.

TABLE 3.—Chi-square analysis of diel variations in catch frequencies of Atlantic silversides in combined inshore (5-27 m) and offshore (27-366 m) trawl surveys conducted by NMFS, 1963-79, over the continental shelf of eastern North America.

Time of capture (e.s.t.)	Tows capturing *Menidia* (no.) Observed	Expected	χ^2
0000-0359	11	29.8	14.3***
0400-0759	28	29.8	0.1
0800-1159	46	29.8	10.5***
1200-1559	43	29.8	7.0**
1600-1959	35	29.8	1.1
2000-2359	16	29.8	7.7**
Totals	179	179	

** $P<0.01$.
***$P<0.005$.

Discussion

The results of this study demonstrate that populations of *M. menidia* north of Cape Hatteras undergo an offshore winter migration from inland to inner continental shelf waters. Atlantic silverside winter habitat probably also includes deep inland waters not sampled by NMFS surveys, as Hildebrand and Schroeder (1928) and Richards and Castagna (1970) have noted. Since the lower lethal temperature for *M. menidia* in short-term experiments was 1°-2°C (Hoff and Westman 1966; Conover unpubl. data), the offshore migration may be promoted by potentially stressful or lethal low water temperatures in shallow inland waters during midwinter. Conover and Ross (in press) and Warfel and Merriman (1944) found that Atlantic silversides leave the New England shore zone in November as water temperatures drop to about 6°-8°C. The timing of Atlantic silverside disappearance from shallow inland waters corresponds closely with their appearance in deeper offshore waters.

If the offshore migration of Atlantic silversides is primarily motivated by low temperature stress, than offshore movements in warmer waters, such as south of Cape Hatteras, would not be expected. Even though our data cannot address this question directly, evidence from ichthyofaunal surveys in South Carolina indicate that *M. menidia* abundance remains high in intertidal creeks (Cain and Dean 1976; Shenker and Dean 1979) and in the surf zone of barrier beaches (Anderson et al. 1977) throughout winter.

The relative abundance of Atlantic silversides over the continental shelf is difficult to judge from this study, since bottom trawling is a relatively ineffective method for catching small pelagic fish such as *M. menidia* (see Conover and Ross in press). In addition, the low overall catch frequency for *M. menidia* reported herein is primarily due to the relatively small number of stations sampled in midwinter when maximum catches might be expected. Neves and Depres (1979) used similar NMFS offshore survey data on a larger pelagic species, the American shad, and reported catches at 527 of the 10,435 stations sampled (5.05%). Considering the methods used, the percent occurrences of *M. menidia* in the inshore and offshore surveys of the mid-Atlantic during midwinter (34 and 11%, respectively) may indicate considerable abundance.

In a previous study, Conover and Ross (in press) showed that Atlantic silversides reach a high level of biomass during late fall in marsh areas and also suffer a high rate of winter mortality (90-99%). Their hypothesis that winter movement and mortality patterns of *M. menidia* represent a one-way export of biomass from the shore zone of bays, marshes, and estuaries to offshore communities is strengthened by this study. The causes of high winter mortality experienced by Atlantic silversides at northern latitudes are unknown but conceivably could include predation and perhaps physiological stress imposed by the migration itself and prolonged exposure to cold temperatures. Atlantic silversides could be an important forage fish over the inner continental shelf, but it will require an analysis of the food habits of offshore fishes in midwinter to address this question.

Acknowledgments

The authors wish to thank the staff of the Resource Surveys Investigation Section and other members of the staff at NMFS, Woods Hole, who have participated in the cruises, and B. E. Brown and M. R. Ross for reviewing the manuscript. The senior author also received support from the Graduate School of the University of Massachusetts and the Massachusetts Cooperative Fishery Research Unit, which is jointly sponsored by the Massachusetts Division of Marine Fisheries, the Massachusetts Division of Fish and Wildlife, the University of Massachusetts, and the U.S. Fish and Wildlife Service.

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DAVID O. CONOVER

Massachusetts Cooperative Fishery Research Unit
Department of Forestry and Wildlife Management
University of Massachusetts, Amherst, MA 01003
Present address: *Marine Sciences Research Center*
State University of New York at Stony Brook
Stony Brook, NY 11794

STEVEN A. MURAWSKI

Northeast Fisheries Center Woods Hole Laboratory
National Marine Fisheries Service, NOAA
Woods Hole, MA 02543

GROWTH DURING METAMORPHOSIS OF ENGLISH SOLE, *PAROPHRYS VETULUS*

Among fishes, the period of transformation from the larval to adult form is marked not only by changes in morphology, behavior and in some species, habitat (Jakóbczyk 1965; Sale 1969; Hoar 1976; Marliave 1977), but in growth rate as well. Ontogenetic changes in growth have not been well documented principally because a method for determining age of larvae and juveniles has not, until recently, been available. The discovery of daily growth rings on otoliths has made possible the precise determination of age, in days, of larval and juvenile fishes (Brothers et al. 1976). Changes in growth rates during different life history stages which could be correlated with behavioral and habitat changes were observed in the French grunt, *Haemulon flavolineatum* (Brothers and MacFarland in press). Struhsaker and Uchiyama (1976) observed an inflection point in the age-length plot of larval and juvenile nehu, *Stolephorus purpureus*, indicating a change in growth rate. This inflection point corresponded with the size when body depth began to increase in proportion to the length of the fish, but not with changes in diet or habitat that occur over the course of development.

Age estimates based on counts of otolith growth increments have now allowed us to determine growth during metamorphosis of the pleuronectid *Parophrys vetulus* Girard.

Methods

The results of this study are based on the standard length (SL) in millimeters and age in days of 127 pelagic larvae and transforming individuals of *P. vetulus* ranging 10-20 mm SL, and 106 benthic 0-age individuals from 18 to 35 mm SL. Pelagic specimens were collected off Newport, Oreg. (approximately lat. 44°37′N, long. 124°06′W), from November 1977 through June 1978 with a 70 cm bongo net with 0.505 mm Nitex[1] mesh (see Laroche et al. 1982 for sampling details). Benthic *P. vetulus* were collected off Moolach Beach, Oreg., 10 km north of Newport, during September 1978 through September 1979 with a 1.5 m wide beam trawl (7 mm stretch mesh).

The removal and mounting of saccular otoliths from larvae followed the methods outlined in Methot and Kramer (1979) except that otoliths were mounted on rectangular glass cover slips to improve the optical properties of the preparation. Otolith growth increments were counted at 800 or 1250 × under bright-field illumination. A complete description of the counting technique and validation of the daily periodicity of the rings can be found in Laroche et al. (1982).

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