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A Method to Determine Mesh-Size Selectivity in Commercial Menhaden Purse Seines

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Abstract.—A field method was developed for examining the influence of purse-seine mesh size and mesh construction on size of Atlantic menhaden (*Brevoortia tyrannus*) captured by commercial menhaden fishermen in the Virginia portion of Chesapeake Bay. A commercial purse seine of 22-mm-bar mesh was modified near the bunt by inserting 16 test panels (1 m^2) of four advertised mesh sizes (16-, 19-, 22-, 25-mm-bar) and two mesh types (knitted, knotted). During the summer and fall of 1984, the modified purse seine was used by commercial fishermen during normal fishing activity of a "snapper boat" (a small, privately owned, commercial menhaden boat). Test panels were examined for gilled fish after the net was pursed but before it was lashed to the snapper boat. "Control" fish were obtained by subsampling each set from the hold of the boat. Gilling of Atlantic menhaden was related to fish girth, mesh type, and mesh size. Fish subsampled from the hold were significantly larger than those gilled in test panels. Most of the gilled fish (79.1%) were gilled in knotted mesh panels; the largest fish were gilled in the 25-mm knotted mesh. The relationship between fish size and knitted mesh size was not statistically significant. Differences between sizes of fish gilled in knitted and knotted mesh of the same size were significant only for the 25-mm-bar mesh. Differences in the fork length–maximum girth relationship suggest that Atlantic menhaden of similar fork length, but from different stocks or locations, may be gilled at different rates. A wide size range of Atlantic menhaden was gilled in mesh of a given size and type, making it difficult to determine the size-class of fish that will be retained in the purse seine. Management of Atlantic menhaden stocks by regulation of purse-seine mesh size and type may be possible, but additional information is required on net characteristics as well as on injury to and mortality of fish that escape through the netting.

The menhaden fishery is one of the most important in the United States, ranking first in tonnage and third in finfish value (National Fishery Statistics Program 1984). The bulk of the fishery is dependent upon two species: the Atlantic menhaden (*Brevoortia tyrannus*) on the Atlantic coast and the gulf menhaden (*Brevoortia patronus*) in the Gulf of Mexico. Stocks of these two species are concentrated on the inner half of the continental shelf, including the coastal bays and sounds (Roithmayr 1963). Menhaden usually feed in large schools near the surface and are caught easily by large purse seines. Approximately 98% of all tonnage landed is by purse seine (June and Reintjes 1976).

Because of the importance of the menhaden resource and the tendency of these species to cross state and federal jurisdictional boundaries, an interjurisdictional fishery management plan was adopted for Atlantic menhaden by the Atlantic States Marine Fisheries Commission (ASMFC) in October 1981. The purpose of the plan was to manage the commercial purse-seine harvest of Atlantic menhaden on a coordinated, state-by-state basis. Several options were considered for management of the harvest, such as setting the season, specifying the mesh size, and closing certain fishing areas. Currently, seasonal restrictions are in place in many coastal states, and Delaware and Maryland do not allow purse seines to be used in the commercial harvest of Atlantic menhaden.

Mesh size was proposed by the Atlantic Menhaden Advisory Committee of the ASMFC as a potential management tool, but little information was available on the subject. Meyer and Merriner (1976) stated that maximum girth of the fish was the most important factor in determining fish escapement through mesh of specified size, assuming that the mesh would conform to the fish's body shape at maximum girth. They detemined the theoretical and experimental selectivity of knotted-mesh pound nets of various sizes on several fish species, including Atlantic menhaden, and most mesh sizes they studied (38- to 76-mm stretch mesh) were larger than those used in the menhaden purse-seine fishery.

A pilot study of mesh selectivity (Anonymous 1970) was conducted by the National Marine Fisheries Service (NMFS) at Beaufort, North Carolina, in which nets of various mesh sizes were pulled through concrete tanks. The results of the study, although limited and not directly comparable to "conditions at sea with tons of fish pressed against a purse seine" (Anonymous 1970), are presented in an appendix to this paper. The report noted that use of a large mesh would allow small Atlantic menhaden to escape, but might cause many other fish to become gilled, putting the net itself at risk. Results of the study indicated that Atlantic menhaden less than 76 mm fork length (FL) escaped through a 19-mm-bar mesh, and a 25-mm-bar mesh allowed fish less than 125 mm FL to escape. It was suggested that use of 25-mm-bar mesh would allow escapement of all young-of-year Atlantic menhaden and some yearlings, and use of 32-mm-bar mesh would allow escapement of all young-of-year fish, most yearlings off the south Atlantic states, and about one-half of the yearlings in Chesapeake Bay.

Mesh sizes used in the purse-seine fishery vary between states. Only two states presently regulate purse-seine mesh size: Virginia (22-mm-bar) and South Carolina (19-mm-bar). Gulf of Mexico menhaden fishermen commonly use 17-mm-bar mesh (Ed Swindell, Zapata Haynie, Hammond, Louisiana, personal communication) and most vessels in North Carolina carry 16-mm-bar mesh during the fall fishery (Robert Chapoton, NMFS, Beaufort, North Carolina, personal communication).

Two mesh types are commonly used in the purse-seine fishery. Knotted mesh is constructed of multifilament twine tied together at each twine juncture to form the mesh. Knitted mesh is constructed of several pieces of twine crocheted together to form the mesh. Construction of the mesh may alter the size (i.e., fish-girth) selectivity by the net. However, studies have not been undertaken to examine this aspect of the fishery.

The Atlantic Menhaden Management Board recommended in May 1982 that mesh-size selectivity of Atlantic menhaden be evaluated. In June 1983, a research contract was awarded to the Institute for Coastal and Marine Resources at East Carolina University by the Interstate Fishery Management Program (ISFMP) of the ASMFC to develop a method for determining mesh-size selectivity. The study was to be conducted in two phases. The objectives of phase I were to develop and demonstrate the procedure for evaluating mesh-size selectivity in purse seines used by the Atlantic menhaden fishery. Phase II would have involved the implementation of a mesh-size-selectivity study throughout the range of the fishery. Results and recommendations of the phase-I study are presented in this paper.

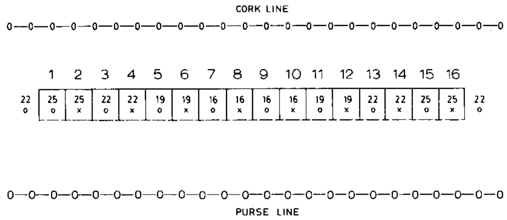

FIGURE 1.—Configuration of the 16 1-m^2 test panels used in the Atlantic menhaden mesh-selectivity study. Panels (25-, 22-, 19-, and 16-mm-bar mesh) were sewn into the purse seine (22-mm-bar mesh) approximately 150 meshes deep, starting near the bunt. Knitted mesh = o; knotted mesh = x.

Methods

A 244-m commercial purse seine of 22-mm-bar mesh was modified by replacing a portion of the existing mesh with paired, 1-m^2 panels of various advertised mesh sizes (16-, 19-, 22-, or 25-mm-bar) and mesh types (knotted or knitted) (Figure 1). Each of the 16 test panels was fitted with 13-mm-bar mesh backing to retain those fish that escaped through the test-panel mesh. The backing was removed during the latter portion of the study when it became apparent that the combination of test panel and backing produced a darkened area of the net that the fish avoided.

The test panels were sewn into the net in a 16-m-long strip at a point 150 meshes below the cork line to optimize efficiency of removing the samples while preserving the strength of the purse seine. Paired panels of each mesh size but of different types (knotted and knitted) were sewn into the net beginning with the 25-mm-bar panels, a size that closely matched the purse-seine mesh (Figure 1). The remaining panels were sewn into place in consecutive order of mesh size so that the net would hang normally in the water column. Each panel was numbered consecutively 1 through 16, with panel 16 positioned near the bunt end of the net. Polyacetal marine zippers 0.5 m long (YKK [USA]) were to be installed at the bottom of each panel to facilitate removal of the fish. However, the zippers were difficult to sew into the net (due to the various mesh sizes of the test panels) and were incompatible with a power-block net-retrieval system. Therefore, the zippers were replaced with a cotton cord woven between each test panel and backing. Fish were removed by cutting the cord and opening the backing; the backing was then reattached with new cord.

The panels were tested during the normal purse-

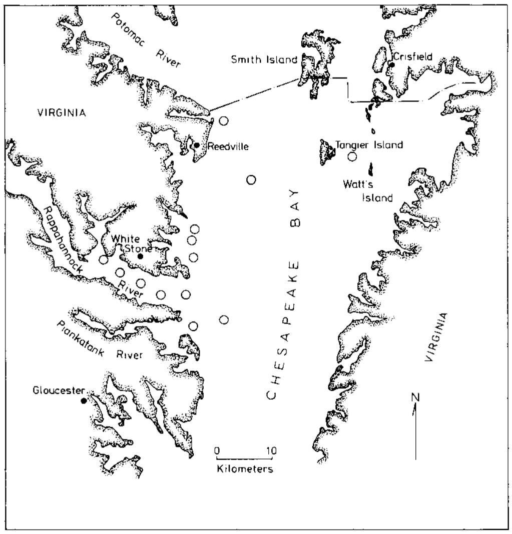

FIGURE 2.—Areas of Chesapeake Bay, Virginia, in which the Atlantic menhaden mesh-selectivity study was conducted. Open circles indicate fishing locations.

seine activity of a "snapper boat" (a small, privately owned, commercial menhaden boat) in Chesapeake Bay during the summer and fall of 1984 (Figure 2). In a typical snapper boat operation, the purse seine was deployed by one purse boat instead of the two-boat system used by the large commercial steamers. Panels were inspected from a 3-m dinghy after each set. Test panels were examined for gilled fish after the net was pursed and approximately two-thirds drawn, but before the purse boat and net were lashed to the snapper boat. Fish from each panel were placed in bags marked to indicate panel position, mesh type, and mesh size. "Control" fish (those not gilled by the net) were obtained by subsampling each set after pumping the fish into the hold of the snapper boat. Fish gilled in the panels and controls were measured for fork length and maximum girth to the nearest millimeter. Salinity (‰), temperature (°C), secchi disk visibility depth (cm), and sun bearing (degrees above horizon) were recorded for each set.

Significant differences in sizes of fish gilled in test panels were determined by a one-way analysis of variance on ranked data for all groups (SAS 1982) and the Kruskal–Wallis H-test, a nonparametric test for determining the equality of means among samples (Walpole and Myers 1979). Data from replicate panels (i.e., mesh of the same size and type) were combined because of the small numbers of fish gilled. Therefore, position effects of the test panels on numbers of fish gilled could not be tested statistically.

During December 1984, Atlantic menhaden were collected from the North Carolina fall menhaden fishery to determine average size and fork length–maximum girth relationships. Procedures for sample workup were similar to those described previously.

Results

Several problems with the modified purse seine became evident during initial testing in early May. These problems were caused by the net being new and by the reactions of Atlantic menhaden to capture in cold water (Captain D. George, White Stone, Virginia, personal communication). At that time, the net was set and retrieved "dry" (no menhaden present) or set on small schools of Atlantic menhaden. The portion of the net containing the panels bunched together on several occasions, causing the net to fish inefficiently. In cold water, Atlantic menhaden attempted to escape near the bottom of the net and submerged the corkline several meters below the water surface. This problem disappeared in late May when water temperatures increased and fish attempted to escape, or "break out," near the surface.

Thirty-one sets were made from 21 May to 24 September 1984 during 25 trips on Chesapeake Bay. Eight of 31 sets contained no fish. The number of sets per trip ranged from zero to three; the average was 1.2 sets per trip. Set locations ranged from Smith Point to Piankatank River, and from Rappahannock River to Watts Island (Figure 2). Most sets were made in the Rappahannock River. Water temperature during the study ranged from 16 to 22°C (mean ± SD: 19.9 ± 1.9; $N = 29$). Salinities ranged from 12 to 19‰ (15.0 ± 1.4), and secchi visibility depth ranged from 90 to 260 cm (169.5 ± 47.6).

The majority of Atlantic menhaden captured in each set was of similar size, but some schools were made up of mixed size classes. Fish subsampled from the hold of the ship averaged 192 mm FL (26.5 SD; $N = 2{,}083$) and 132 mm maximum girth (18.3 SD). The maximum girth (MG)–fork length (FL) relationship (Figure 3) was

$$MG = 7.04 + 0.65FL; \quad (r^2 = 0.91,\ N = 2{,}083).$$

The FL–MG relationship of Atlantic menhaden captured in the 1984 North Carolina fall fishery (Figure 4) differed from that of Chesapeake Bay fish in our study and from that reported by Meyer

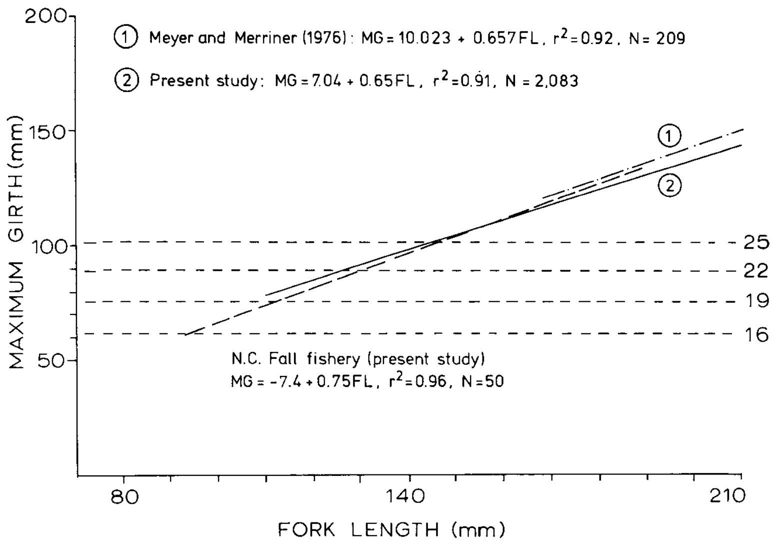

FIGURE 3.—Maximum girth (MG)–fork length (FL) relationship of Atlantic menhaden from Chesapeake Bay and the North Carolina fall fishery, and the theoretical minimum girth sizes (horizontal dashed lines) required for gilling in mesh sizes of 16-, 19-, 22-, and 25-mm-bar measure.

and Merriner (1976). These differences suggest that fish of similar lengths but from different areas or from different stocks may be gilled in purse seines at different rates.

Most Atlantic menhaden in sampled schools were too large to be gilled in the purse seine or the test panels. Fish were gilled in the purse seine in only 17% of the successful sets (four of 23 sets). The theoretical minimum girth required for gilling fish in 22-mm-bar mesh was 89 mm; i.e., Atlantic menhaden with a maximum girth smaller than 89 mm should escape through 22-mm-bar mesh (Figure 3). Heavy gilling occurred twice during the study, in 25-mm-bar mesh panels on 5 and 20 September. Controls and gilled fish from those sets were smaller in average fork length (133 mm) and maximum girth (96 mm and 97 mm, respectively) than the average sizes of fish from two other schools (193 mm FL, 133 mm MG; 152 mm FL, 110 mm MG) captured on the same day in which no gilling occurred (Figure 5).

The unique properties of mesh construction (e.g., elasticity, abrasiveness) may have modified the minimum girth size required for gilling in knitted and knotted netting (Table 1). Observed mean girths of gilled fish were greater than predicted values from panels of 16-mm- and 19-mm-bar mesh, similar from 22-mm panels, and slightly less than predicted values from the 25-mm panels.

Gilling rate in the test panels was a function of mesh type and size. Most of the gilled fish (79.1%) were caught in test panels constructed of knotted twine (Table 2). Observations during retrieval of the gilled fish suggested that knotted mesh may have less elasticity and thus hold gilled fish better than knitted mesh. Few of the gilled fish (8%) were caught from meshes smaller than 22 mm. Fish apparently were attracted to the largest openings in the seine as potential escape routes, and many avoided the 16-mm and 19-mm test panels.

Mesh size and type influenced the size of Atlantic menhaden gilled in the test panels. Statistical analyses were performed on ranked data of seven data groups (control; knotted: 16-mm, 19-mm, 22-mm, 25-mm; knitted: 22-mm, 25-mm) collected on 20 September 1984. Significant differences were observed among the fork lengths ($P < 0.001$; $F = 11.51$; df = 198) and girths ($P < 0.001$; $F = 11.61$; df = 198) of control fish and those gilled in test panels. No fish were gilled in the 19-mm knitted test panels. Nonparametric pairwise comparisons (Sidak, Bonferroni t-tests) showed that fish gilled in 25-mm knotted mesh differed significantly ($P < 0.05$; $t = 3.07$; df = 192) in fork length and girth from those gilled in 16-mm knotted mesh and in 22-mm and 25-mm knitted mesh and from control fish; that is, the 25-mm knotted mesh gilled the largest fish. Additionally,

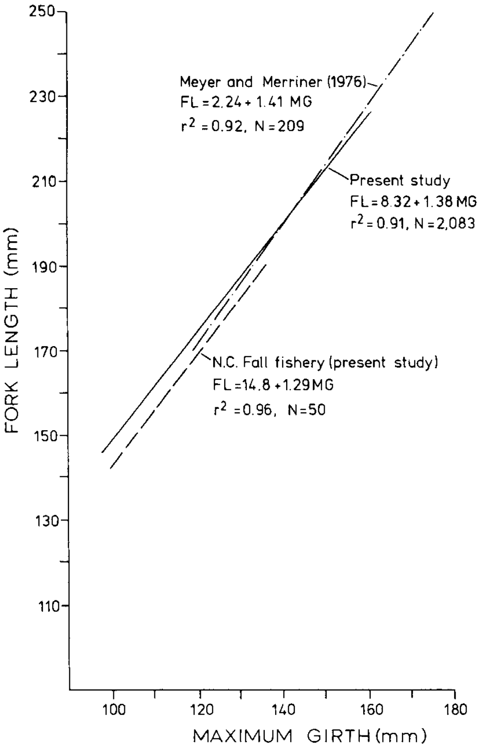

FIGURE 4.—Fork length (FL)–maximum girth (MG) relationship of Atlantic menhaden from Chesapeake Bay and the North Carolina fall fishery.

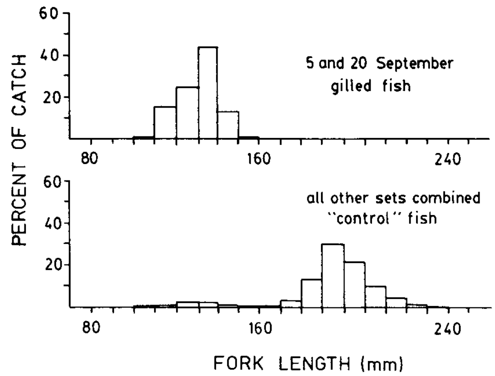

FIGURE 5.—Size-class distributions (percent) of Atlantic menhaden subsampled from the hold of the snapper boat ("control" fish) and those gilled in the purse seine on 5 and 20 September 1984.

Discussion

The demonstration of a method for determining mesh-size selectivity of purse seines for Atlantic menhaden was accomplished during normal commercial fishing activities. Problems that occurred during the study were the result of weather conditions and the operating procedures of the commercial fishery, neither of which could be controlled or modified by the research team.

Commercial menhaden fishermen in Chesapeake Bay avoid the sizes of fish that may cause gilling in purse seines and thus are reluctant to set

the 22-mm knotted mesh gilled larger fish ($P < 0.05$; $t = 3.07$; df = 192) than the 25-mm knitted mesh panels.

Atlantic menhaden gilled in knotted mesh panels differed significantly ($P < 0.001$) in fork length among the four mesh sizes tested (Table 3); the largest fish were gilled in 25-mm-bar-mesh panels. No significant difference was found between the lengths of fish gilled in the three sizes of knitted mesh panels. Statistical comparisons of knitted and knotted mesh of the same size indicated that differences in length of gilled fish were significant ($P < 0.001$; df = 1; $N = 83$) only for panels of 25-mm-bar mesh (Table 3).

Atlantic menhaden attempted to escape through the net in the direction of the sun, which often did not coincide with location of the test panels. Forty-one percent of the "breakout" attempts were oriented within 15° of the sun bearing and 82% were within 45° of the sun bearing (Figure 6).

TABLE 1.—Theoretical minimum girth sizes required for gilling, and observed girths of Altantic menhaden gilled in purse seine test panels of four mesh sizes and two mesh types. Theoretical size does not consider the stretch or abrasive characteristics of each mesh type. Numbers of fish gilled are shown in parentheses.

Bar-mesh size (mm)	Mesh type	Panel positions[a]	Theoretical minimum girth for gilling (mm)	Observed mean girth (mm)	Observed range of girths (mm)
25	Knitted	1, 15	101.6	89.7 (13)	74–97
	Knotted	2, 16	101.6	98.4 (70)	75–116
22	Knitted	3, 13	88.9	84.5 (2)	82–87
	Knotted	4, 14	88.9	90.7 (33)	75–103
19	Knitted	5, 11	76.2	(0)	
	Knotted	6, 12	76.2	88.8 (5)	75–102
16	Knitted	7, 9	63.5	87.0 (3)	83–93
	Knotted	8, 10	63.5	89.6 (5)	86–94

[a] See Figure 1.

TABLE 2.—Observed fork lengths of Atlantic menhaden gilled, and predicted minimum fork length required for gilling, in purse seine test panels of four mesh sizes and two mesh types. Predicted values were calculated from maximum girth–fork length relationships shown in Figure 4. Numbers of fish measured are in parentheses.

Bar-mesh size (mm)	Mesh type	Panel positions	Estimated percentage of fish gilled in panels[a]	Observed mean length (mm)	Observed range of lengths (mm)	Predicted minimum length for gilling (mm)	
						Chesapeake Bay	North Carolina[b]
25	Knitted	1, 15	3.5	124.0 (13)	112–133	145.8	145.9
	Knotted	2, 16	34.6	135.3 (70)	115–150	145.8	145.9
22	Knitted	3, 13	15.4	118.5 (2)	117–120	126.3	129.5
	Knotted	4, 14	38.4	126.6 (33)	110–138	126.3	129.5
19	Knitted	5, 11	1.3	(0)		106.7	113.1
	Knotted	6, 12	4.5	125.4 (5)	105–144	106.7	113.1
16	Knitted	7, 9	0.6	121.7 (3)	115–130	87.2	96.7
	Knotted	8, 10	1.6	126.2 (5)	121–131	87.2	96.7

[a] Estimates include fish that were not measured.
[b] Fall fishery.

on any schools that contain fish of small or mixed size-classes for fear of losing their nets. On two occasions, the crew intentionally set on small fish for our benefit in collecting data. Therefore, we believe that little additional information could be obtained by repeating the experiment using 22-mm-bar-mesh purse seines with the experimental mesh sizes used in this study.

Noting that the escape behavior of Atlantic menhaden was influenced by sun direction, we asked the crew to set the net so that the test panel area would be positioned toward the sun. Thus, the "breakout" attempts of the fish would be in the direction of the test panels. However, the method of setting the net was difficult to modify because the pilot in the spotter plane must always position the purse boat so that the net will be set to the wind and tide. The few attempts at changing this procedure resulted in collapse of the net, due either to tide or wind, and subsequent loss of the catch.

TABLE 3.—Chi-square differences in fork lengths (mm) of Atlantic menhaden gilled in purse seine test panels of four mesh sizes and two mesh types determined by the Kruskal–Wallis H-test.[a]

Net type and mesh size compared	N	df	χ^2	P
Knotted: 16, 19, 22, 25 mm	113	3	19.709	0.001
Knitted: 16, 22, 25 mm	18	2	3.008	NS
25 mm knitted, 25 mm knotted	83	1	23.624	0.001
22 mm knitted, 22 mm knotted	35	1	1.729	NS
16 mm knitted, 16 mm knotted	8	1	1.094	NS

[a] The Dunn method was used to compute for a type-I error at a critical P_α of 0.05; no subtest exceeded a P_α of 0.005.

Sample retrieval with a small boat was possible only in calm water. Seas frequently were too rough to approach the net in the dinghy, even in the protected waters of the Rappahannock River. Attempts were made to retrieve gilled fish from the panels as the purse seine was pulled through the power block, but some fish that were gilled in knitted mesh panels fell out before they could be collected, causing bias in the data. The 13-mm-bar-mesh backing, which would have retained those fish, was removed midway through the study when it was apparent that fish actively avoided the darkened areas of the purse seine created by the backing.

The range in size of fish gilled in mesh of a given size and type makes it difficult to state precisely

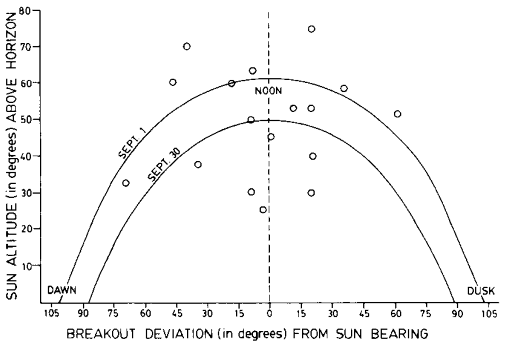

FIGURE 6.—Relationship of attempted escapes of Atlantic menhaden through a purse seine to position of the sun above the horizon. Curved lines depict the range of change in sun altitude during the month of September. Highest altitude of the sun in Chesapeake Bay is 77° in June.

the size-class of fish that should be retained in a net of given mesh size. Meyer and Merriner (1976) presented their data as a 50% retention rate. Results of the 1970 NMFS study indicated that fish shorter than 127 mm FL (young-of-year and some yearling Atlantic menhaden) escaped through 25-mm-bar mesh, and fish shorter than 76 mm FL escaped through 19-mm-bar mesh (see Appendix). The latter size could escape through the 22-mm-bar mesh currently in use. Our study suggests that all fish shorter than 112 mm FL can escape through 25-mm-bar mesh, and those less than 105 mm FL would escape through 19-mm mesh (Table 2).

Factors other than mesh size and type may influence size selectivity of purse seines. Meyer and Merriner (1976) listed several factors contributing to mesh-size selectivity of pound nets. Factors that are applicable to purse seines include (1) variability in fish girth and mesh size; (2) alteration of mesh perimeter dimensions due to stress and pressure; (3) blockage of meshes by gilled fish, fouling organisms, or large catch; (4) behavioral and physical differences of each species that affect ability to escape; and (5) hanging coefficients of the net webbing. These factors may account for some of the overlap in girths of gilled Atlantic menhaden collected from the test panels and the apparent differences between theoretical and observed values (Table 2).

Results of our study indicated that size of fish gilled in purse seines is controlled by mesh size only in seines constructed of knotted mesh. Purse seines constructed of 25-mm knotted mesh should catch larger fish than 25-mm knitted mesh nets can, but the larger fish gilled in the knotted webbing may be more numerous and more difficult to remove. The 25-mm knotted mesh panels gilled considerably more fish (34.6% of the total gilled) than the 25-mm knitted mesh panels (3.5%), and fish gilled in knotted mesh panels were the larger. Overall, gilled fish may be removed more easily from knitted-mesh purse seines.

Management of Atlantic menhaden stocks by purse-seine mesh size and mesh type may be possible, but additional information is required before management decisions can be reached. Results of our study were limited due to the small number and size of data sets. Also, little information was available concerning injury and mortality of Atlantic menhaden after escaping through purse-net webbing. These areas should be addressed in future research.

Acknowledgments

We sincerely appreciate the help, cooperation, and tireless efforts made by David and Roland George and the crew of the *Seven Brothers* in conducting the study. David Bronson of the Institute for Coastal and Marine Resources assisted in sample collection. Thomas J. Lawson of the Institute designed the original study and was initially awarded the contract. We thank Robert Chapoton, John Merriner, Paul Perra, Mike Street, and members of the ASMFC Atlantic Menhaden Advisory Committee for their support and advice. The project was conducted under the auspices of the ASMFC's Interstate Fisheries Management Program, Atlantic Menhaden Advisory Committee. Funds for the study were provided by Northeast Region of the National Marine Fisheries Service under cooperative agreement NA-80-FA-H-00017.

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Appendix

The following assessment was taken verbatim from Anonymous (1970).

Preliminary tests of menhaden escapement through meshes of sizes ranging from 16 mm to 41 mm bar measure were conducted in concrete tanks in July 1970. Although these tests are not directly comparable to conditions at sea with tons of menhaden in a purse seine, they represent the first information on escapement. Sections of netting with No. 6 twine were used. The nets were constructed of knotless knitted and knotted twisted twines and were tarred or treated with copper naphthenate. The net surrounded the fish in the tank and was pursed. The fish were either held in the net, were gilled, or escaped out into the tank. The results showed the following:

a) 32-mm bar mesh caught or gilled fish over 190 mm long (fork length);

b) 25-mm bar mesh caught or gilled fish over 127 mm long (fork length);

c) 19-mm bar mesh caught or gilled fish over 76 mm long (fork length).

From these limited results, the following mesh sizes were suggested:

1. 25-mm bar measure nets will allow escapement of all young-of-the-year fish and some yearlings;
2. 32-mm bar measure nets will allow escapement of all young-of-the-year fish and most of the yearlings in the South Atlantic states and about half of the yearlings in Chesapeake Bay.

Selection by mesh size is a hazardous fishing operation because of fish gilling. The successful use of larger meshes that permit escapement is practical only when used in areas where small fish are scarce or can be avoided by use of spotter planes.