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National Oceanic and Atmospheric Administration
National Marine Fisheries Service

Atlantic Menhaden *(Brevoortia tyrannus)* Resource and Fishery— Analysis of Decline

KENNETH A. HENRY

SEATTLE, WA.
August 1971

National Marine Fisheries Service, Special Scientific Report--Fisheries Series

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Atlantic Menhaden *(Brevoortia tyrannus)* Resource and Fishery—Analysis of Decline

By

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ABSTRACT

After record catches in 1961 and 1962 of about 2.3 billion pounds (1.043 million metric tons) of menhaden *(Brevoortia* spp.), the U.S. catch declined to about 1.2 billion pounds (0.544 million metric tons) in 1967. Most of the decrease was in the North Atlantic and Middle Atlantic. Since about 1940, catches had increased, in general, with increased fishing effort. In recent years, however, the catch per unit of effort (a standard vessel day) has declined markedly. It fell from about 148,000 pounds (67.1 metric tons) in 1962 to about 38,000 pounds (17.2 metric tons) in 1967 in the North Atlantic and from 140,000 pounds (63.5 metric tons) in 1962 to 51,000 pounds (23.1 metric tons) in 1967 in the Middle Atlantic. The catch per unit of effort in these two areas improved in 1968, but fishing effort was at such a low level that the increase is of doubtful significance.

Other possible units of effort such as catch per vessel week and catch per landing day are examined. In 1964, the catch in Chesapeake Bay exceeded the catch in the Middle Atlantic for the first time; in 1968, the Chesapeake Bay catch amounted to 63% of the total summer catch of Atlantic menhaden *(B. tyrannus)*. In recent years, over 90% of the fish in the total catch were immature. A relation is established between the estimated abundance of juvenile Atlantic menhaden, based on trawling, and the total catch from the year class. A stock-recruitment relation, based on catch per unit of effort in the Middle Atlantic and total catch from the year class, indicates that the spawning stock is below optimum size.

INTRODUCTION

Menhaden *(Brevoortia* spp.) along the Atlantic coast and the Gulf of Mexico support the largest U.S. commercial fishery in terms of pounds landed. They rank, excluding shellfish, next to salmon and tuna in dollar value. Menhaden accounted for 34% of the total domestic catch of all species in 1968. The catch is processed into (1) fish meal, used mainly as a supplement for poultry feed, and (2) fish oil, used in the manufacture of paint, lubricants, cosmetics, and a variety of other products.

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There are two separate United States menhaden fisheries, one along the Atlantic Coast and another along the Gulf of Mexico. Although both fisheries depend primarily on purse seine fishing gear, each fishery catches a different species of menhaden. Formerly the Atlantic fishery annually produced the most poundage of menhaden, but since 1962 has been overtaken by Gulf landings (Fig. 1).

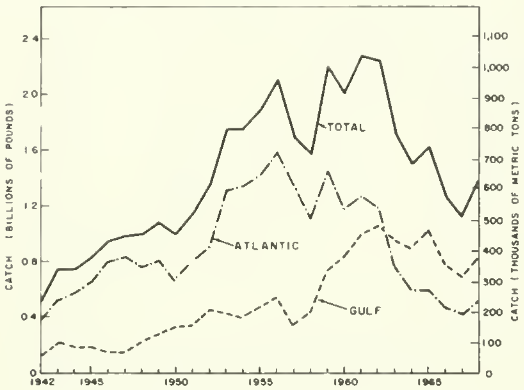

Figure 1.—Catch of menhaden, 1942-68.

In recent years the menhaden fishery has experienced a serious decline in production. After record catches in 1961 and 1962 of about 2.3 billion pounds (1.043 million metric tons) for the Atlantic and Gulf of Mexico combined, the catch declined to about 1.2 billion pounds (0.544 million metric tons) in 1967 and increased only slightly in 1968 to about 1.4 billion pounds (0.635 million metric tons).

Most of the decline in menhaden landings has been in the Atlantic coast fishery where the catch declined from 1.3 billion pounds (0.590 million metric tons) in 1962 to 0.55 billion pounds (0.249 million metric tons) in 1968, a 58% decline. The increase in the catch in 1968 must be considered relatively insignificant when compared with previous catches (Fig. 2). Thus, the 1968 Atlantic catch was not only below the average annual catch for the 5 years of continued low production (1963-67) but also less than one half the average annual catch for the 10-year period (1953-62). It also is apparent from Figure 2 that the trend of the Atlantic landings for the year is established relatively early in the fishing season.

On the Atlantic coast the fishery is in most instances a single-day operation; the boats leave

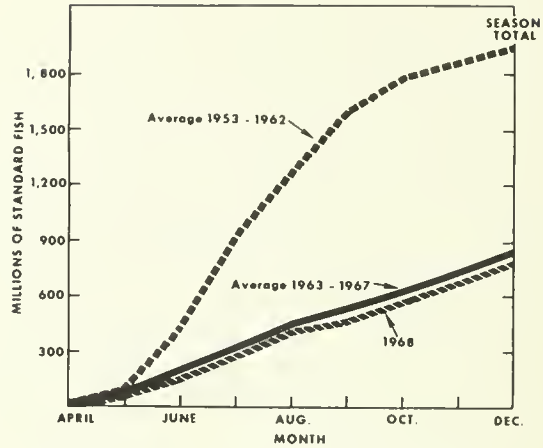

Figure 2.—Cumulative annual catch of Atlantic menhaden at end of each month of fishing season.

early in the morning and return to the plants the same day. In recent years, with reduced abundance of fish, some boats have stayed out for more than 1 day, particularly in the more northern fishing areas. For a more detailed description of the fishing operations, see Henry (1969).

When the catch of Atlantic menhaden amounted to only 0.6 billion pounds (0.272 million metric tons) in 1964, a 0.7 billion pound (0.318 million metric ton) drop in only 2 years, there was considerable concern about the resource both within the industry and the Bureau of Commercial Fisheries. At that time, I published a report (Henry, 1965), based on data through 1964, discussing some of the changes that were taking place in the fishery such as reduced catches and changes in fishing effort, fishing areas, and average age. I also discussed various methods of estimating the abundance of year classes. Also in 1964 research, which the Bureau started on this resource in 1955, was greatly expanded. After several additional years of continued low catches, it seems appropriate to continue the analysis of my previous paper for any significant changes in the expected trends and conditions of the resource. In this report I have continued, through the 1968 season, analyses and interpretations I have made of this fishery relating to the decline in abundance and the relationships between the fishing areas. Some data on migrations, age, and growth are included to emphasize that the decline would have been greater except for a compensating increase in growth of the fish and to show the interrelation between the various fishing areas. Admittedly some of the analyses contained in this report require additional study and I hope my discussions will stimulate this effort by other investigators.

GENERAL BIOLOGY AND STRUCTURE OF THE ATLANTIC MENHADEN POPULATION

Menhaden have a rather complicated life history. Although menhaden spawn in oceanic waters (Sutherland, 1963), the larvae enter estuaries and spend several months in the tributary streams reaching almost to fresh water (Fig. 3). Whether some larvae remain in the ocean is not known. During this period in the tributary streams they metamorphose from larvae into juveniles. Then, in late summer the juveniles leave the tributaries and return to the bays, sounds, and eventually the ocean.

In the ocean, Atlantic menhaden undertake rather extensive migrations—generally northward in the spring and summer and southward in the fall. Furthermore, as menhaden grow older they tend to migrate farther northward each year so during the summer fishery you generally have older fish to the north and younger fish to the south. Throughout the summer the fish generally are in water less than 20 fathoms deep and are in great concentrations in localities with extensive estuarine drainage systems, such as Chesapeake Bay. Most of the menhaden in Chesapeake Bay are reported to inhabit the bay throughout the year while they are immature 1 and 2 year old fish. When they reach maturity at the end of that third season of growth—as 2+ fish (Higham and Nicholson, 1964)—they leave the bay and enter into the migrations and fisheries along the coast.

Age of Fish

Since 1955, the Bureau of Commercial Fisheries, and now the National Marine Fisheries Service, have regularly sampled the commercial menhaden landings to obtain information on the sex, age, and size composition of the Atlantic menhaden resource. The procedures and results of the sampling were

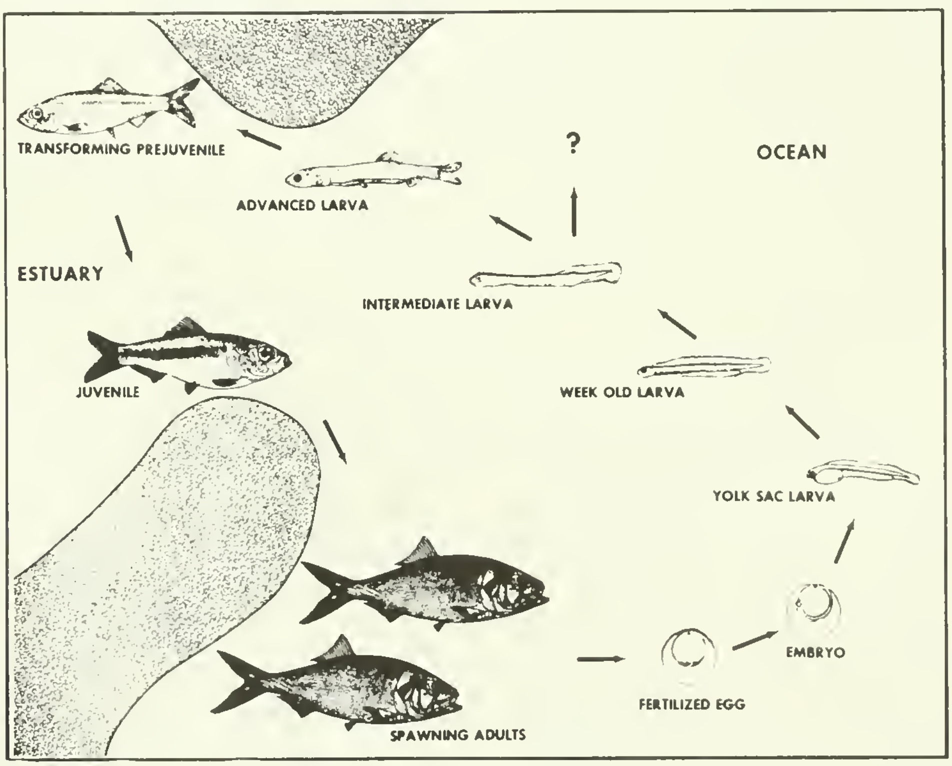

Figure 3.—Life cycle of Atlantic menhaden.

presented in a series of reports; 1962 is the latest year for which data have been published (Nicholson and Higham, 1965).

The age composition of the annual catches of Atlantic menhaden from 1955 through 1968 are shown in Figure 4. It is apparent that age-1 and -2 fish make up the bulk of the catch in most years. Larger catches persist through the older age groups only when an especially large year class, such as 1951 or 1958, is present.

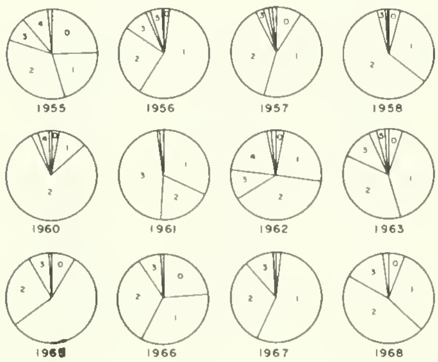

Figure 4.—Age composition (%) of Atlantic menhaden in purse seine catches, 1955-68.

Figure 5 shows the catch per standard vessel day by age group and fishing area for 1955 and 1966-68. The calculated catch by age for the various fishing areas is listed in appendix table 1.

The average age of Atlantic menhaden varies annually both between and within fishing areas. In general, the average age tends to increase from south to north through the fishery (Fig. 6).

The average age of the menhaden caught annually in all areas combined as well as the percentage of fish under 3 years of age (immatures) in the catch are shown in Figure 7. In recent years about 90% of the total catch has been immature fish. The mean age for 1955-68 was 1.67 years. Additional discussion on the average age may be found in the appendix.

Growth of Fish

The apparent growth rate of Atlantic menhaden varies in the different fishing areas. Atlantic menhaden are relatively fast growing, at least up to age 4 after which the growth

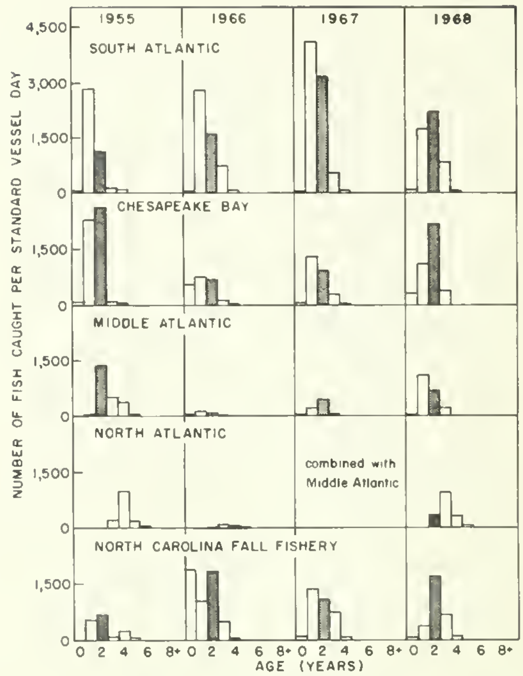

Figure 5.—Catch of Atlantic menhaden per standard vessel landing day, by age group and fishing area, 1955, 1966-68 (Shaded areas denote catch of 2-year-old fish).

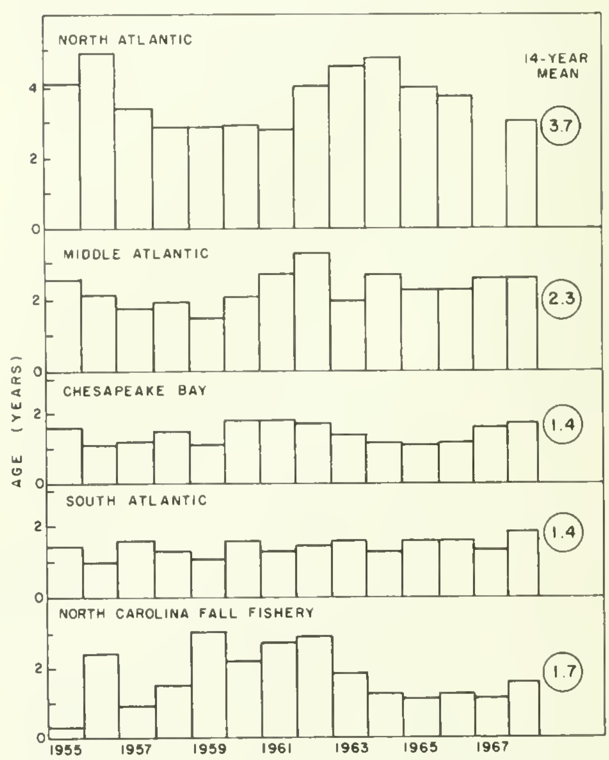

Figure 6.—Average age of Atlantic menhaden in the purse seine catch by area, 1955-68.

Figure 7.—Percentage of the total annual catch of Atlantic menhaden which were 0-, 1-, and 2-year olds (solid line) compared to the average age of fish in the catch (dashed line), 1955-68.

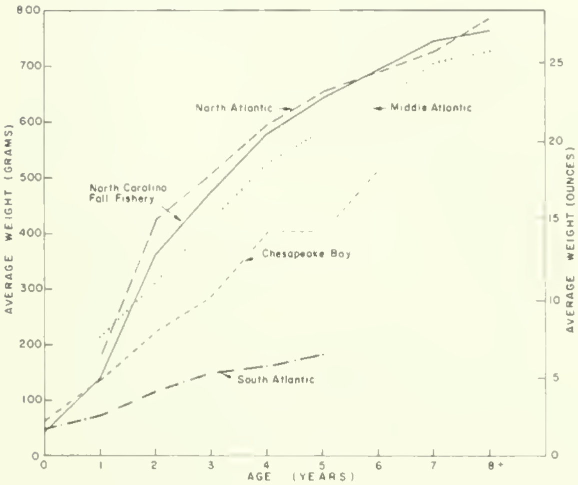

Figure 8.—Average weight of Atlantic menhaden by fishing area, both sexes combined, 1955-68.

slows down (Fig. 8). Not only are menhaden caught in the northern fishery older, but they are larger for any given age. Thus, the average weight of age-1 fish in 1955-68 was 73 g (2.35 oz) in the South Atlantic Area, 136 g (4.37 oz) in the Chesapeake Bay Area, and 214 g (6.88 oz) in the Middle Atlantic Area. Some indication of the relation between weight and length for menhaden can be obtained from Figure 9. I did not compute a similar curve for males, but they do not appear to be as large as females (Reintjes, 1969), at least for the older ages, but whether there is a consistent difference between sexes, between years, and between fishing areas has not yet been examined in detail.

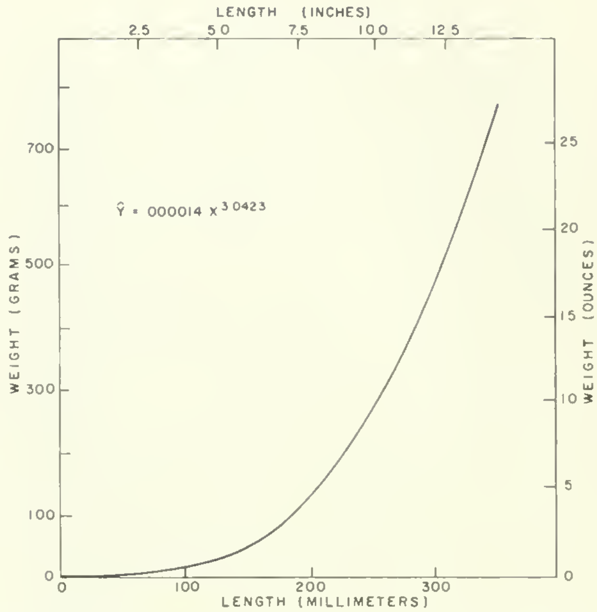

Figure 9.—Length-weight relation of female Atlantic menhaden, 1962.

Since there is such a differential distribution by age and by size throughout the Atlantic menhaden fishery, it is difficult to calculate a single growth equation that will apply to all areas. Nevertheless a plot of $(\text{weight})^{1/3}$ in year t against $(\text{weight})^{1/3}$ in year $t + 1$ gives a fairly good straight line relation for all areas combined, indicating a rather consistent rate of growth for all Atlantic menhaden. A preliminary calculation of a von Bertalanffy growth curve for all areas combined gives $Wt_{\infty} = 1193.9\text{g}$, $k = 0.20$ and $t_0 = -2.39$.

Not only has the abundance of Atlantic menhaden declined markedly in recent years, but there also have been conspicuous changes in the apparent growth of fish from the different year classes. Since about 1961 almost all ages of menhaden caught have been considerably larger than average, and the fish were particularly small during 1957-61. Whether the increased growth is due to a smaller number of fish, improved growing conditions, or both, is not known. It is obvious, however, that the decline in the catch of Atlantic menhaden would have been even more drastic if this significant increase in the growth of the fish had not occurred. Additional details on changes in growth can be found in the Appendix.

THE FISHERY

The Atlantic menhaden fishery extends from New England to Florida and for convenience of discussion has been divided into four geographic areas: North Atlantic, Middle Atlantic, Chesapeake Bay, and South Atlantic (Fig. 10). In addition to a summer fishery that generally extends from about May to October in the four areas, there is a fall fishery which depends primarily on maturing fish migrating from the north to spawn off the North Carolina and South Atlantic coast. Furthermore, there is some biological basis for this division. Although there is considerable interchange of fish between those areas throughout the fishing season, the Chesapeake Bay and South Atlantic catches consist principally of 1 and 2 year old, immature fish, whereas the Middle and North Atlantic catches are of the older fish which migrate northward in the spring and summer.

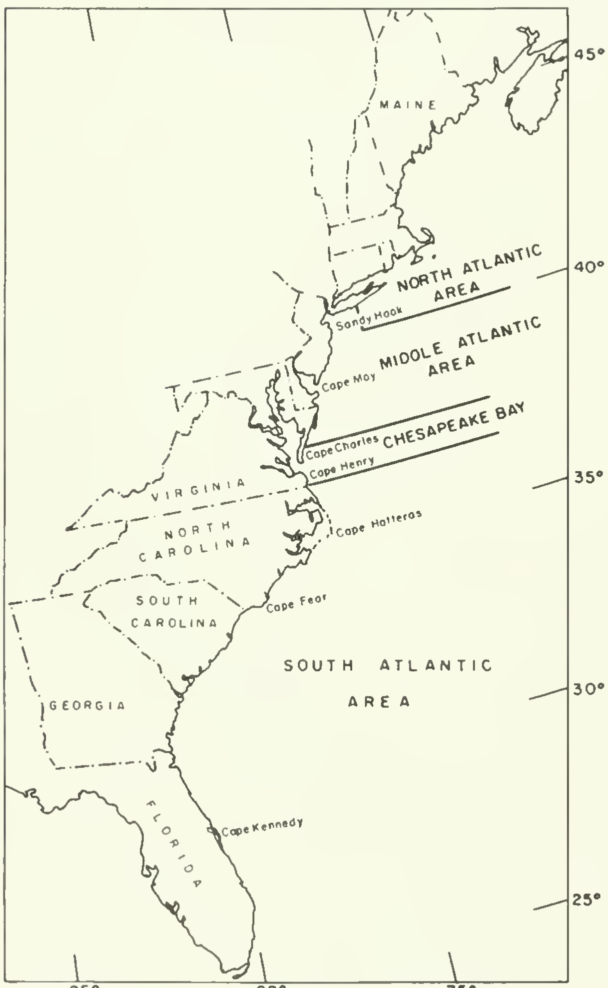

Figure 10.—Fishing areas for Atlantic menhaden.

The Chesapeake Bay segment of the menhaden industry has expressed the view that the menhaden stock in the Bay essentially is independent of the stocks outside the Bay. This view appears contrary to all the data available; in fact, results from our tagging studies have shown very clearly the close interrelations of the menhaden along the entire coast.

Development of a Unit of Fishing Effort

In the analysis of a fishery it is important to develop a meaningful unit of fishing effort. In the earlier years of the Atlantic menhaden studies (June and Reintjes, 1957), a boat-week unit of effort was developed in an analysis of the fishery off Delaware Bay. In subsequent analyses for the entire Atlantic coast, the unit of fishing effort mentioned was the purse seine set.

The number of sets and catch per set were recorded annually through the 1962 fishing season (Nicholson and Higham, 1965). However, it was realized that the catch per set was more a measure of school size than a relative measure of fishing effort on the stocks. It did not seem realistic to assume that 10 sets on 10 small schools would have the same effect on the stocks that 10 sets on 10 large schools would have. Consequently, a new unit of effort was developed[2] called the "standard vessel day."

Each menhaden fishing vessel was given a relative weighting factor, based on catches made by the vessels over a comparable period of years. Vessels added to the fleet since 1962 have been given a weighting factor which appears most reasonable based on the size of the new vessel relative to the sizes of the vessels for which the catches were compared. Since the newer vessels are generally larger, they usually have received relatively large weighting

[2] Changes in catch and effort in the Atlantic menhaden fishery, 1940-62, by W.R. Nichols. Unpublished manuscript, National Marine Fisheries Service, Center for Estuarine and Menhaden Research, Beaufort, N.C.

factors. The number of days each vessel landed menhaden was then multiplied annually by the appropriate weighting factor to give the number of standard vessel days. The relation of a vessel's weighting factor to other features of the vessel such as weight and length is examined later in the paper.

Figure 11 shows the relation between the calculated standard vessel days and the actual landing days for the Chesapeake Bay fishery. Of the total standard vessel days calculated for the 1968 Atlantic menhaden fishery, 58% were from the Chesapeake Bay fishery. It is obvious from Figure 11 that the trends for the two lines are similar and that the standard vessel day is a fairly constant percentage of the actual landing days.

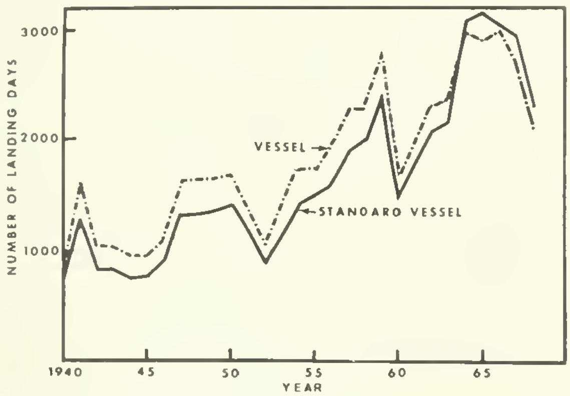

Figure 11.—Number of vessel and standard vessel landing days in Chesapeake Bay menhaden purse seine fishery, 1940-68.

The conclusions based on either set of data would have to be the same—a significant increase in fishing effort in the Chesapeake Bay area in recent years. One change occurred about 1964; prior to that time the number of standard vessel days was always less than the actual landing days, but after 1963 the annual number of standard vessel days was greater. This change coincided with a major change in the composition of the fleet in 1964 as can be seen from Figure 12. Note in particular the dramatic and continuing increase in average horsepower and the decline in the average age of the vessels. In other words, the newer, bigger vessels in recent years have increased the average weighting factor used to calculate the number of standard vessel days based on the number of actual landing days.

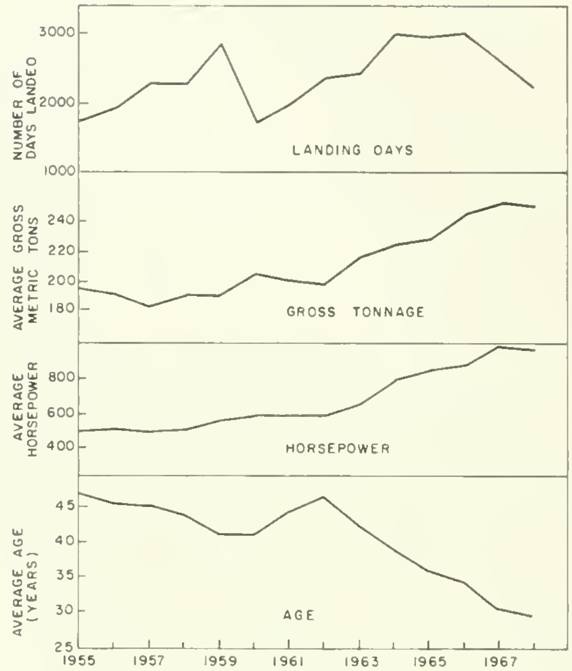

Figure 12.—Average age, horsepower, gross tonnage, and landing days of Chesapeake Bay purse seine vessels, 1955-68.

At the time the standard vessel day unit of effort was developed, it was assumed that there were few zero catches. Nevertheless, the unit of effort developed was in reality a "standard vessel landing day," which may or may not be a true reflection of the actual fishing days. Data have become available from some of the fishing companies which permit a closer examination of the relation between the landing day and fishing day for some of the fishing areas. Unfortunately, these data are available only since 1963 or 1964 through 1967, depending on area.

In Figure 13 is shown the relation between the total days fished, the total days fish landed, and the calculated total standard vessel days for a portion of the boats in the Chesapeake Bay fishery. The relation between the three sets of data is remarkably consistent, and the trends are almost identical. One important feature of these data is the fact that no fish were caught on 30 to 40% of the days fished, so that the landing days are a gross underestimation of the actual fishing effort, at least during this period.

Several comparisons for other areas between total days fished, total days fish landed, and

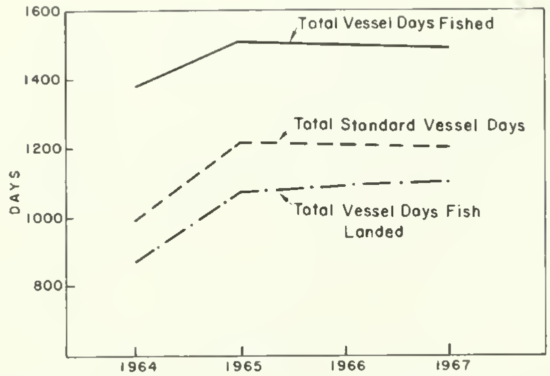

Figure 13.—Total vessel days fished, total vessel days fish landed, and total standard vessel days in Chesapeake Bay, 1964-67.

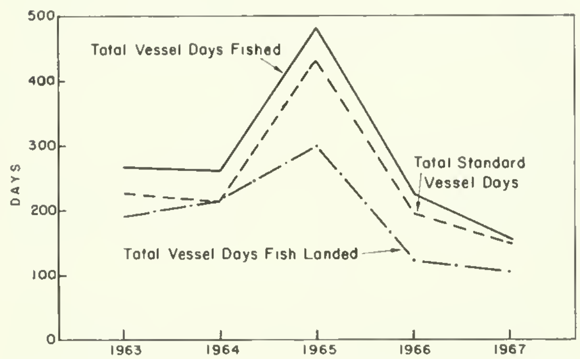

Figure 14.—Total vessel days fished, total vessel days fish landed, and total standard vessel days, Southport N.C., 1963-67.

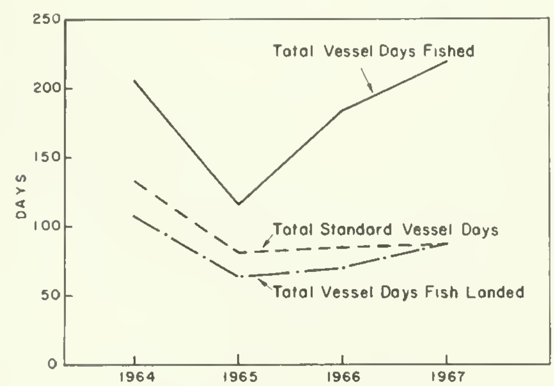

Figure 15.—Total vessel days fished, total vessel days fish landed, and total standard vessel days at Wildwood, N.J., 1964-67.

total standard days are shown in Figures 14 and 15. Data from one company for North Carolina are shown in Figure 14. All three curves fluctuate in a somewhat similar manner. The percentage of unsuccessful fishing days varied from around 35 to 45%. For certain boats at Wildwood, N.J., for which data were available (Fig. 15), the number of days fished without catching anything increased markedly in 1966 and 1967, causing the increased discrepancy between the curves for total vessel days fished and the total vessel days fish landed. This increased difference obviously reflects the poorer fishing on the reduced stocks of fish in recent years. The curve for total standard vessel days closely follows that for total vessel days fish landed. It appears that total days fished might be a better measure of fishing effort. Unfortunately, these data are not available from most companies and would have to be estimated from log book data. Such a course certainly should be considered in future analyses.

In an attempt to avoid the problem of recording no effort for days when fishing effort was expended but no fish were caught, as well as to reduce the amount of work required to compute fishing effort, a vessel-week unit of effort was developed. Under this procedure if a vessel fished anytime during a week it was considered as fishing for that week. Thus, a vessel that fished only 1, 2, or 3 days would be given as much weight as a vessel that fished 5 or 6 days of the week. This might be most important in the North Carolina fall fishery where the weather greatly affects the number of days fished. The vessel week unit of effort tends to reduce the accuracy of the estimated number of units of effort and the amount of data available as well as to reduce the differences between years. For the period 1955 through 1968 on Chesapeake Bay, there were only about 25% as many vessel weeks as standard vessel days. There is no evidence that the vessel week is any better or any worse a measure of fishing effort than the standard vessel landing day. In fact, there is a rather constant relation between the catch per vessel week and the catch per standard vessel day, as demonstrated by data for the Chesapeake Bay fishery in Figure 16. Furthermore, there is a very close correlation between the number of vessel weeks and the number of standard vessel days. For the 1955 through 1968 data, from Chesapeake Bay, these two units of effort had a highly significant correlation coefficient of $r = 0.981$ ($P < .01$, 12 df). Thus, whether standard vessel days or vessel weeks were used, the conclusions would be similar.

On the basis of these analyses it appears that the standard vessel landing day probably well represents the trend of the fishing effort for Atlantic menhaden but underestimates the actual amount of fishing. Even the landing days themselves are a fairly reliable index of the changes in fishing effort over a number of years, although landing days make no allowance for differences between vessels. As pointed out previously, there even is a good correlation between standard vessel days and vessel weeks. With reduced stocks, however, the amount of unsuccessful fishing has increased and the standard vessel landing days and the landing days are underestimating fishing effort even more in recent years. However, this can and should be corrected through the use of logbook data.

The standard vessel day as originally calculated makes no allowance for changes that have increased the efficiency of the fishing fleet, particularly since the early 1950's. Besides the introduction of newer and larger boats, innovations such as power blocks, fish pumps, nylon nets, and airplanes have been added (Henry, 1968). The airplanes, in particular, have greatly increased the searching ability of the menhaden fleet. These factors have not been considered in calculating the standard vessel days; however, most of these improvements occurred rather rapidly in the mid-1950's so effort since that time would be comparable. A comparison between effort before and after the mid-1950's would be of more doubtful validity.

Another undesirable feature of the standard vessel day is that since catch comparisons were made only in certain years for specific vessels there was no consistent and precise method to assign a weighting factor to new vessels that subsequently entered the fishery. Consequently, it is important if some physical feature of a menhaden vessel can be related to the catching ability of the vessel. A number of features, including horsepower, gross tonnage, net tonnage, and age of vessel were examined. In other fisheries, including the Gulf menhaden and Peruvian anchovy (Schaefer, 1967), gross tonnage of the fishing vessel has been related to

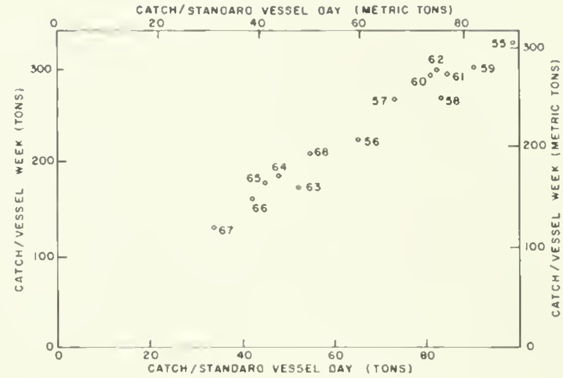

Figure 16.—Relation between catch of Atlantic menhaden per standard vessel day and per vessel week in Chesapeake Bay, 1955-68.

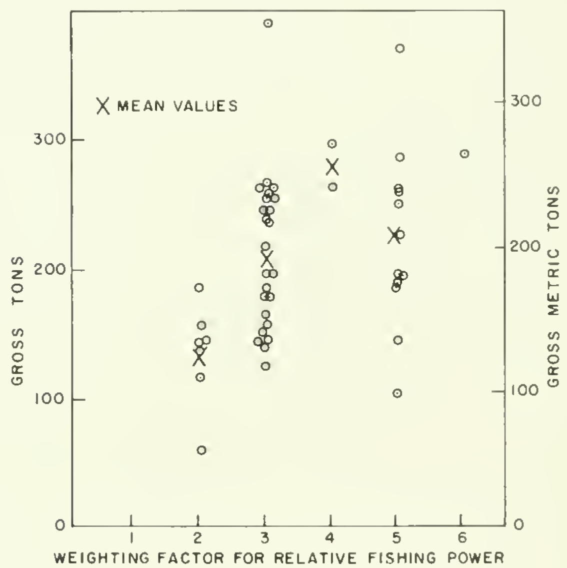

Figure 17.—Relation between weighting factor for relative fishing power and gross tonnage of purse seine vessels in Chesapeake Bay.

the catches by the vessel. This relation is not advantageous to the Atlantic menhaden fishery, however (Fig. 17). Chesapeake Bay data are used in these analyses since the major amount of fishing in recent years has occurred in that area. Although the mean values indicate increased catches with increased gross tonnage, at least for the smaller weighting factors (the method of calculating these weighting factors was discussed previously), the amount of overlap masks any possible significant relation. One reason for this may be that the Atlantic fishery includes many converted vessels not specifically built for menhaden fishing, leading to a variety of vessel types in the fishing fleet. Although there is a relation between gross tonnage and net tonnage, at least for the larger vessels, there also is tremendous variability for the smaller vessels (Fig. 18). This variability clearly emphasizes the diverse nature of the fleet menhaden vessels. On the other hand, a significant relation between length of vessel and catch does exist (Fig. 19), although one group of vessels in the 30- to 50-m range is much more effective (weighting factor of 5 vs. 3).

It might be appropriate at this point to summarize briefly the results of my analyses on a suitable unit of fishing effort for Atlantic menhaden. A number of possible units of effort were examined including: (1) vessel fishing days, (2) vessel landing days, (3) vessel weeks, and (4) standard vessel landing days. In addition, vessel tonnage and length were related to the relative fishing power of the vessel. In this report I have used the standard vessel landing day as a measure of fishing effort. However, all these units were rather similar and any one of them could have been used without altering the results and conclusions I reached in this report.

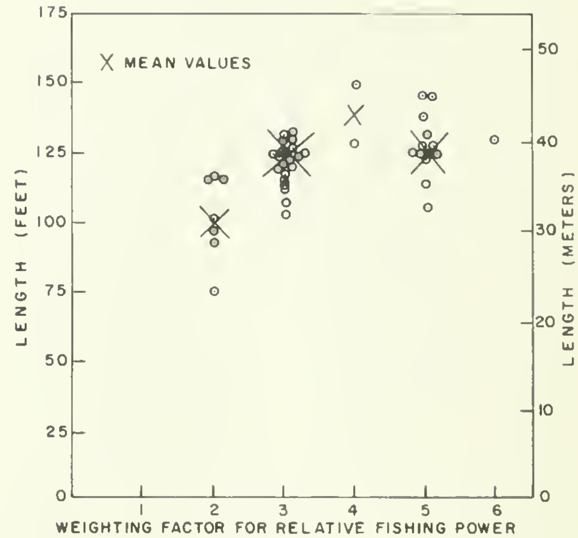

Figure 19.—Relation between weighting factor for relative fishing power and length of purse seine vessels in Chesapeake Bay.

The major drawbacks for the units of effort other than standard vessel day were as follows: (1) for vessel fishing days—data not readily available, needs to be estimated from logbooks; (2) for vessel landing days—makes no allowance for differences in fishing power of the various vessels or for days of zero catches, and (3) for

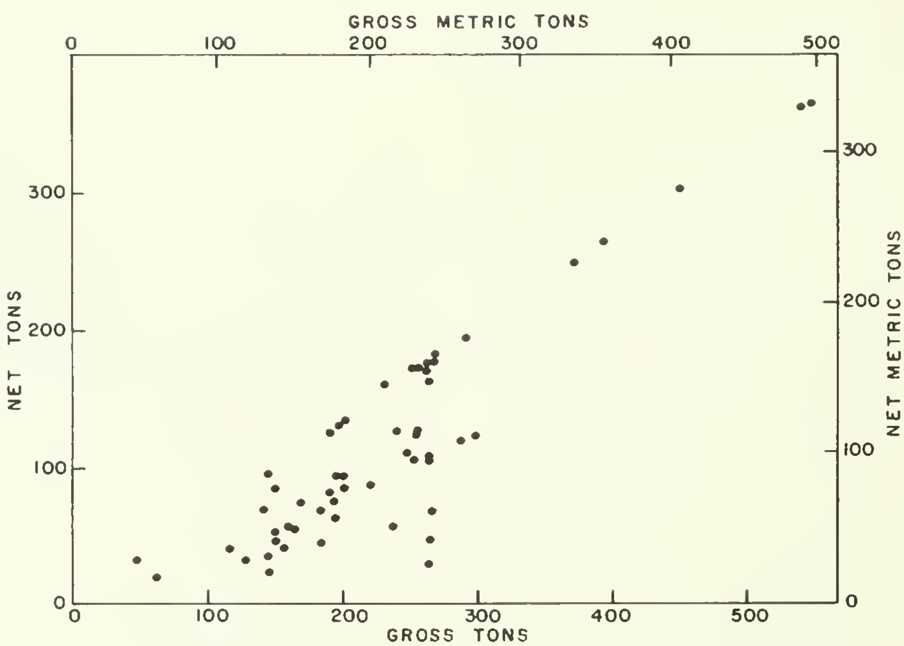

Figure 18.—Relation between gross tons and net tons on Chesapeake Bay menhaden vessels.

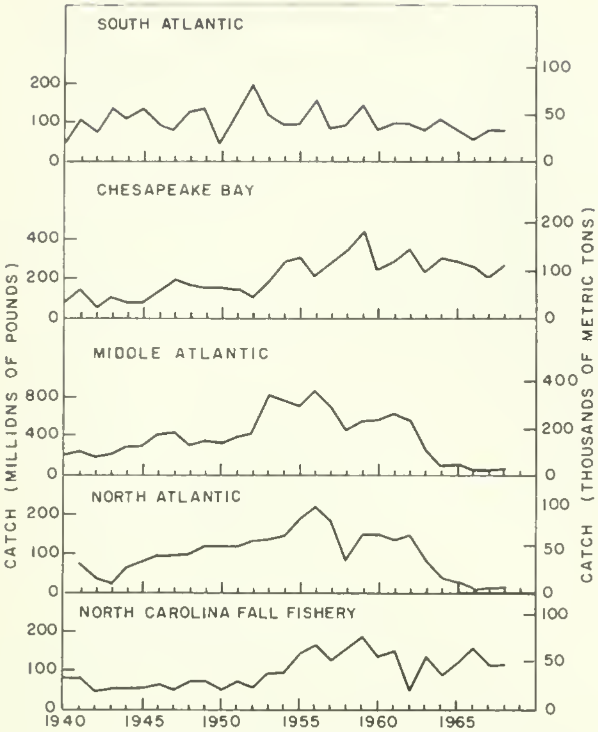

Figure 20.—Annual catch of Atlantic menhaden by area, 1940-68.

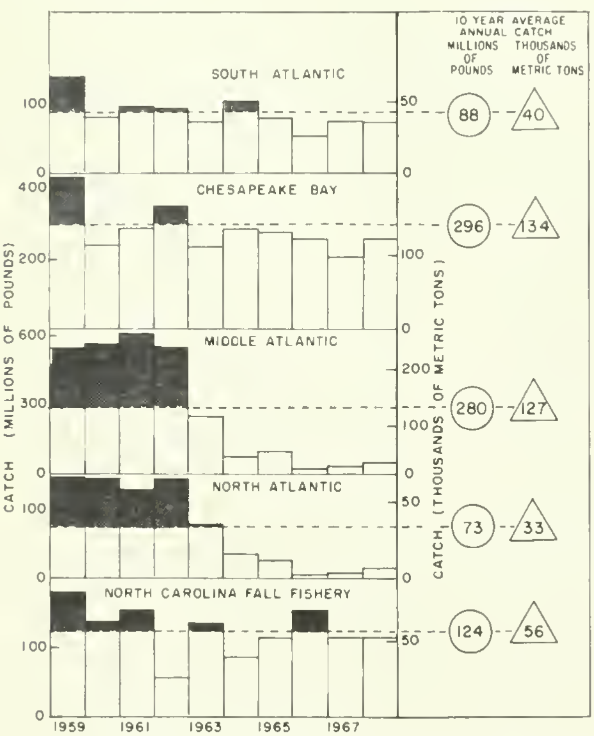

Figure 21.—Annual catch of Atlantic menhaden by area, 1959-68. (The shaded area indicates the portion of the annual catch that exceeds the 10 year average.)

vessel weeks—reduces the amount of data and the accuracy of the estimates. Although there have been changes in the efficiency of the vessels, these would be most important in comparisons of effort before and after the mid-1950's. For future studies of this resource, I believe the best unit of effort would be a standard vessel fishing day (includes days of zero landings and allowances for differing fishing power) possibly related to the length of the vessel. Studies also should be undertaken to estimate the increased efficiency of the gear in recent years.

Changes in the Distribution of Landing and Fishing Effort

The annual catches of Atlantic menhaden from 1940 through 1968, for the four summer fishing areas, as well as for the North Carolina fall fishery, are shown in Figure 20. In my earlier publication (Henry, 1965), which listed catches through 1964, I stated "The decline in the catches in the Middle Atlantic and North Atlantic Areas in 1963 and 1964 is of deep concern to the fishing industry." It is apparent that the production in these two areas has declined even more in the 4 years since 1964, causing increased concern. The extent of change in the various fishing areas can be seen somewhat better if the annual catches are compared with the mean catch over the past 10 years (Fig. 21). It is obvious from these data that production has been down in recent years in all areas. In only two instances since 1963 (South Atlantic—1964; North Carolina fall fishery—1966) have any of the annual area catches exceeded the 10-year average annual catch.

The summer fishery in the South Atlantic area actually encompasses two separate fishing areas: (1) off North Carolina, and (2) off Florida-Georgia. Some fish were landed in South Carolina through 1959—these have been included with the annual Florida catches. In Figure 22, the catches for North Carolina and Florida-South Carolina are plotted separately as annual deviations from the average catch in each area for the 10-year period 1959-68. The annual landings in these two areas do not fluctuate in the same manner. These differen-

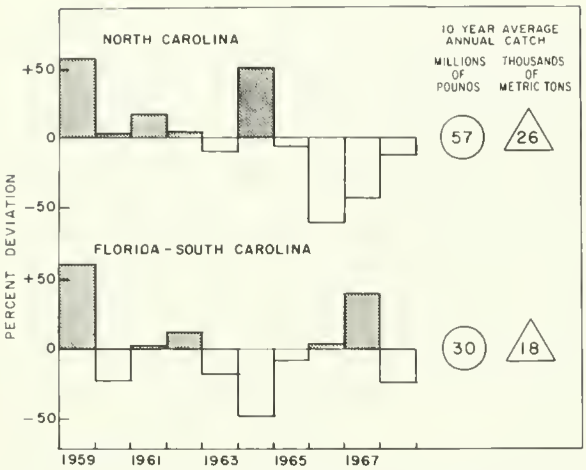

Figure 22.—Yearly deviations (%) from the average annual catch of North Carolina and Florida-South Carolina Areas, 1959-68.

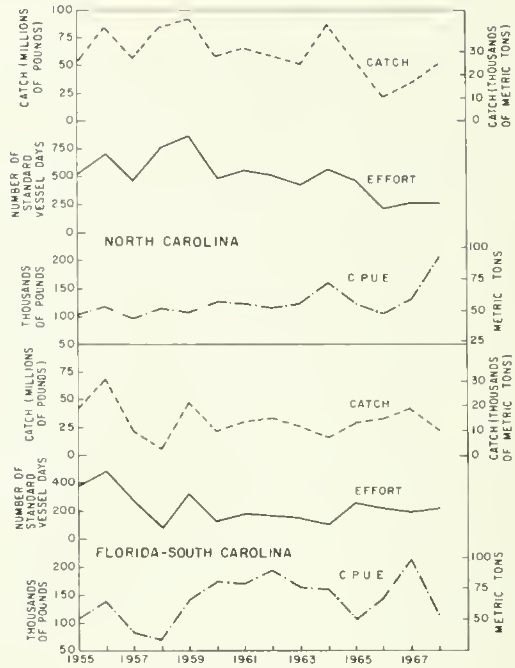

Figure 23.—Catch, fishing effort, and catch per unit of effort (C.P.U.E.) for the North Carolina and Florida-South Carolina summer fisheries, 1955-68.

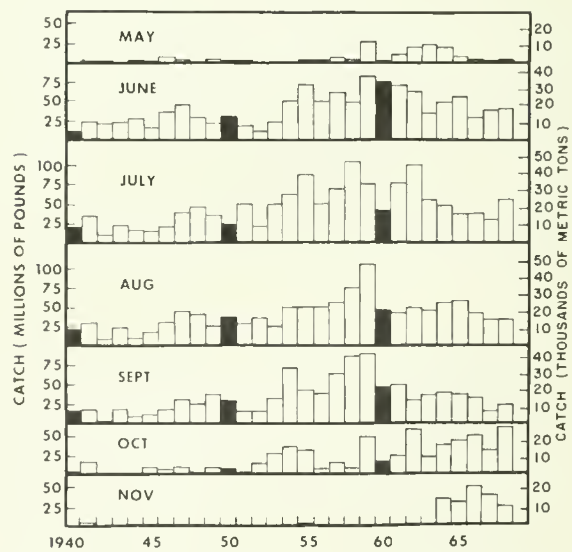

Figure 24.—Catch of Atlantic menhaden in Chesapeake Bay by month, 1940-68. (Dark bars emphasize 10-year periods.)

ces in catches between the two areas are not due merely to differences in fishing effort, as can be readily seen from Figure 23. Not only is the pattern of the catches different, but the catch per unit of fishing effort (i.e., catch per standard vessel landing day) also is different. The method of computing this particular unit of fishing effort is given in detail in my earlier paper (Henry, 1965). These data as well as other information on migrations from tagging (Henry and Kutkuhn, 1970) lead me to believe that for proper analyses, the South Atlantic area should be separated into the two areas mentioned above.

Although the total catch of menhaden in Chesapeake Bay has not decreased to the same extent as in the Middle and North Atlantic Areas, it has been maintained by significantly increasing fishing effort, including a major extension of the fishing season. The monthly catches for Chesapeake Bay since 1940 are shown in Figure 24. Historically, most of the fish were caught during June through September; there were few landings of importance in October, prior to 1952, and no landings of importance in November, prior to 1964. Since 1964, however, November landings have contributed up to 20% of the total annual catch in Chesapeake Bay, not to mention the increased October catches. In other words, if the season had not been extended in recent years, the total annual catches from Chesapeake Bay would have been down 20% or more from those actually recorded.

Since 1955, there has been a considerable shift in the percentage of the total catch of Atlantic menhaden made in each of the fishing

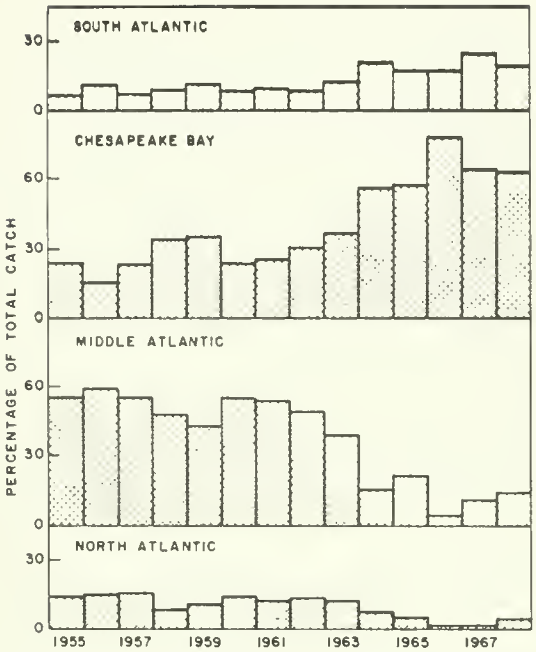

Figure 25.—Catch of Atlantic menhaden by area (%), summer fishery, 1955-68.

areas in the summer fishery (Fig. 25). In 1964, for the first time, the catch in Chesapeake Bay exceeded the catch from the Middle Atlantic; this situation has continued in succeeding years. In 1968, the Chesapeake Bay catch was 63% of the total summer catch of Atlantic menhaden. With a major portion of the catch made in Chesapeake Bay, it is obvious that what happens in Chesapeake Bay has a significant effect on the total resource.

The percentage of the total catch of a given year class caught in the Middle Atlantic and Chesapeake Bay Areas through the 1966 year class (Table 1) was another comparison to show the changes that have taken place in the fishery. The present comparison is limited to fish up to age 3 since relatively few older fish are caught in the present day fishery. Of the total catch of 0-, 1-, 2-, and 3-year-old menhaden from the 1954 year class caught in the Chesapeake Bay and Middle Atlantic Areas, only 32% were caught in the Chesapeake Bay Area and 68% in the Middle Atlantic Area. The percentage of fish of these ages caught in the Chesapeake Bay area increased quite consistently for subsequent year classes. For the last 3 year classes listed (1964-66), over 90% of the

Table 1.—Estimated millions of menhaden of different year classes caught as ages 0, 1, 2, and 3 in the Chesapeake Bay and Middle Atlantic Areas and percentage of the catch taken in each area, 1954-66.

Year Class	Catch			Percentage of total catch	
	Chesapeake	Middle Atlantic	Total	Chesapeake Bay	Middle Atlantic
1954	404	859	1,263	32	68
1955	868	1,069	1,937	45	55
1956	1,633	1,364	2,997	54	46
1957	697	483	1,180	59	41
1958	2,924	2,804	5,728	51	49
1959	392	333	725	54	46
1960	701	267	968	72	28
1961	423	259	682	62	38
1962	674	245	919	73	17
1963	346	61	407	85	15
1964	973	49	1,022	95	5
1965	482	36	518	93	7
1966*	660	75	735	90	10

*Preliminary

fish ages 0-3 caught in these two areas were taken in Chesapeake Bay. Thus, for the percentages shown for the 1966 year class, even if the 1966 year class were the same size as the 1954 year class, the Middle Atlantic catch would have been only about one-seventh as large for the 1966 year class as it had been for the 1954 year class.

One of the major reasons for the increased importance of the Chesapeake Bay Area is the increased effort in that fishery, coupled with the decreased effort in the Middle and North Atlantic Areas (Fig. 26). For example, in 1955, the fishing effort in Chesapeake Bay (689 standard vessel days) was only 24% of the total effort for the Atlantic menhaden fishery. In 1968, in spite of a 22% reduction in effort from the previous year in Chesapeake Bay, the fishing effort in Chesapeake Bay (2,291 standard vessel days) had climbed to 58% of the total Atlantic effort. This increased proportion of the fishing effort in Chesapeake Bay was the obvious result of the decreased abundance of fish in the other area.

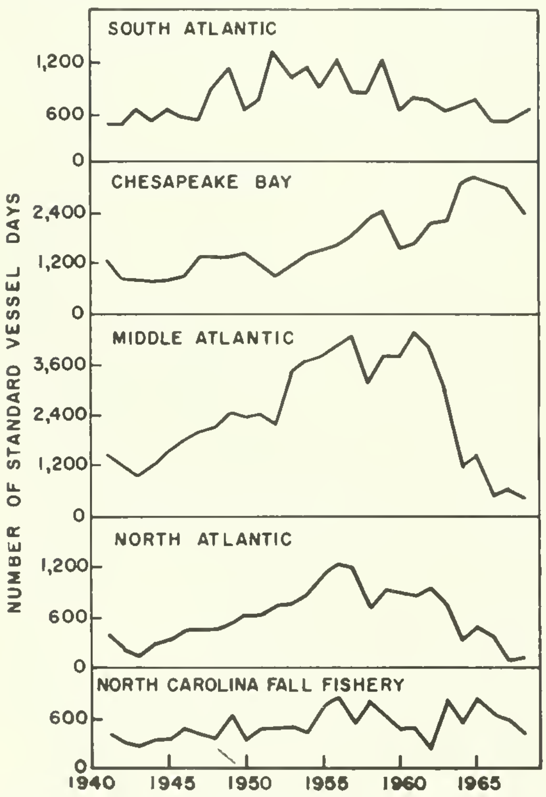

Figure 26.—Atlantic Menhaden fishing effort in standard vessel days by area, 1941-68.

Fishing effort dropped in Chesapeake Bay in 1968 when a number of the boats did not fish. Unfortunately, the reduction of boats was not sufficient to reduce the catch; in fact, the catch in 1968 actually increased. We are not yet certain why the catch increased, although I do not believe it indicates a significant improvement in the Atlantic menhaden stocks for the following reasons. For most year classes, more menhaden are caught in Chesapeake Bay as 1-year-old fish than any other age group. However, for the 1966 year class, more were caught as 2-year-olds in 1968 than as 1-year-olds in 1957. This, I believe, was a major factor in the increased catch in 1968. Better catches were made mainly during July and there is some evidence, particularly from our tagging studies, that this may have been due to increased availability of the fish rather than to increased abundance. The 1969 Atlantic menhaden catch for the entire coast was about 30% below 1968, a circumstance which tended to indicate that the stocks had not significantly improved.

In my 1965 publication I pointed out that after 1962, although the fishing effort in Chesapeake Bay increased, the catch did not increase proportionally. This phenomenon of course resulted in a decreased catch per unit of fishing effort. The catch per unit of effort declined not only in Chesapeake Bay but also in the Middle and North Atlantic Fishing Areas (Fig. 27). This declining catch per unit of effort continued through 1967.

Although a substantial increase in the catch per unit of effort in 1968 also is shown for the Middle and North Atlantic Areas as well as for the North Carolina fall fishery, these should not be given too much importance. In view of the low level of fishing effort in the Middle and North Atlantic Areas and the more selective nature of the current fishery, I do not believe the catch per unit of effort in 1968 was a true measure of the relative abundance of the stock in comparison with previous years. In the North Carolina fall fishery fishing is so limited in time and adversely affected by weather that I do not believe the catch per unit of effort has much significance. You will note that there has not been a decreasing trend in the catch per unit of effort in the North Carolina fall fishery as there has been in the other areas.

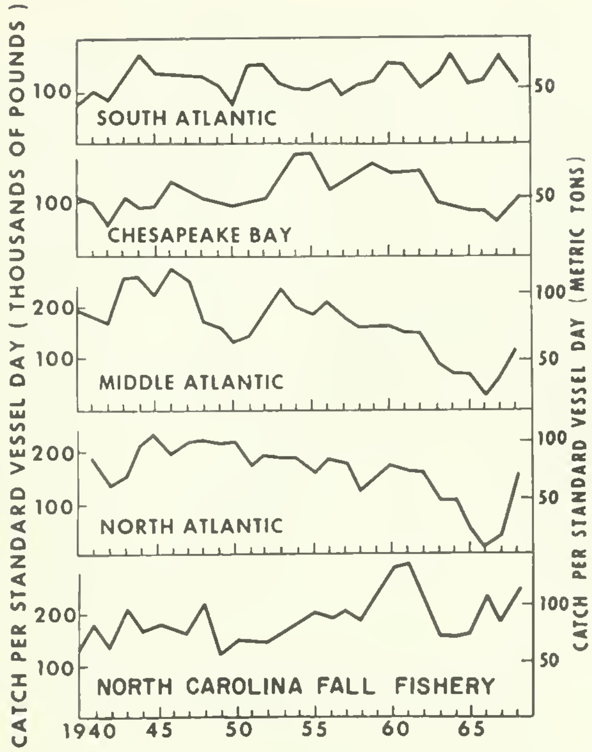

Figure 27.—Atlantic menhaden catch per unit of effort by area, 1940-68.

A relation between the Chesapeake Bay and Middle Atlantic menhaden fisheries can be shown by a comparison of catch per unit of effort for various ages of fish caught in the two areas (Fig. 28). This relation between the catch per unit of effort of 1- and 2-year-old menhaden in Chesapeake Bay and the catch per

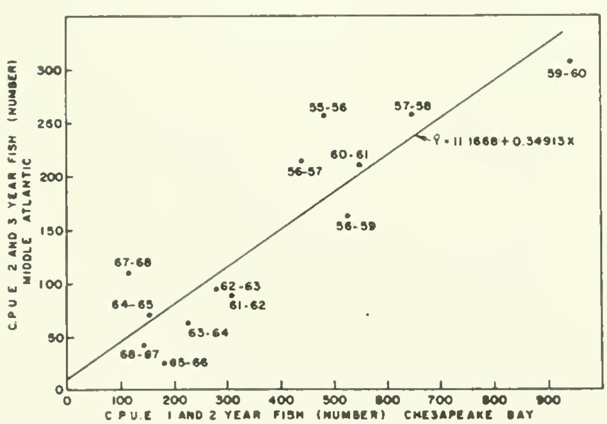

Figure 28.—Catch per unit of effort of 1- and 2-year-old menhaden in Chesapeake Bay compared to CPUE of 2- and 3-year old menhaden (1 year later) in Middle Atlantic Area.

unit of effort of 2- and 3-year-old menhaden 1 year later in the Middle Atlantic Area is highly significant (r = 0.91, $P < 0.01$, 9 df). The relation that exists between these two areas is further substantiated by tagging studies currently being conducted. The 1967 tagging studies showed that a significant number of menhaden tagged in Chesapeake Bay migrated to the Middle Atlantic Area and were later recaptured in the Middle Atlantic fishery, both in the same year the tags were applied and in the following year (Henry and Kutkuhn, 1970).

DYNAMICS OF THE POPULATION

A series of relatively strong year classes of Atlantic menhaden occurred in the 1950's. Since age data are only available since 1955, we can only speculate on the sizes of the year classes before that time. However, the good catch of 4-year-old fish in 1955 indicates that the 1951 year class must have been good. The 1955 and 1956 year classes also were abundant, followed by the superabundant 1958 year class from which over 8 billion fish were caught (Table 2). Most of the catch from a year class is 1- and 2-year-old fish. Coupled with these good year classes was a major increase in fishing effort, which went from 5,500 standard vessel landing days (SVLD) in the early 1950's

Table 2.—Number of Atlantic menhaden caught in the purse seine fishery by year class, 1955-68.

Year class	Number of fish Billions
1955	4.32
1956	3.80
1957	2.12
1958	8.04
1959	1.07
1960	1.96
1961	1.29
1962	1.46
1963	1.29
1964	1.70*
1965	1.10*
1966	1.65*

*Preliminary—partially estimated.

to over 8,000 SVLD in the early 1960's. A large portion of this increased fishing effort occurred in the Chesapeake Bay fishery, which catches mainly immature, age-1 and age-2 fish. The dominant role that the 1958 year class played in the catches through the early 1960's can better be seen from Figure 29, where the annual catches by age are shown.

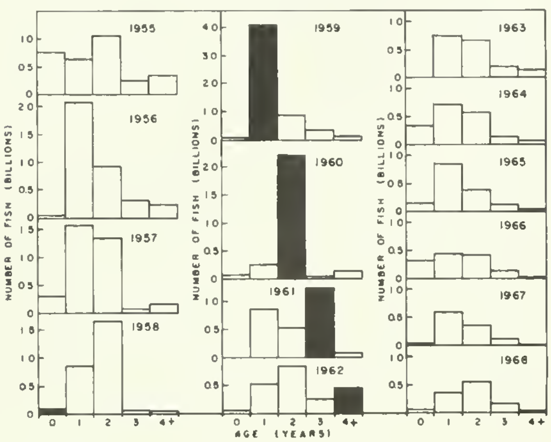

Figure 29.—Number of Atlantic menhaden of ages 0-4+ caught in the purse seine fishery, 1955-68 (black areas show 1958 year-class).

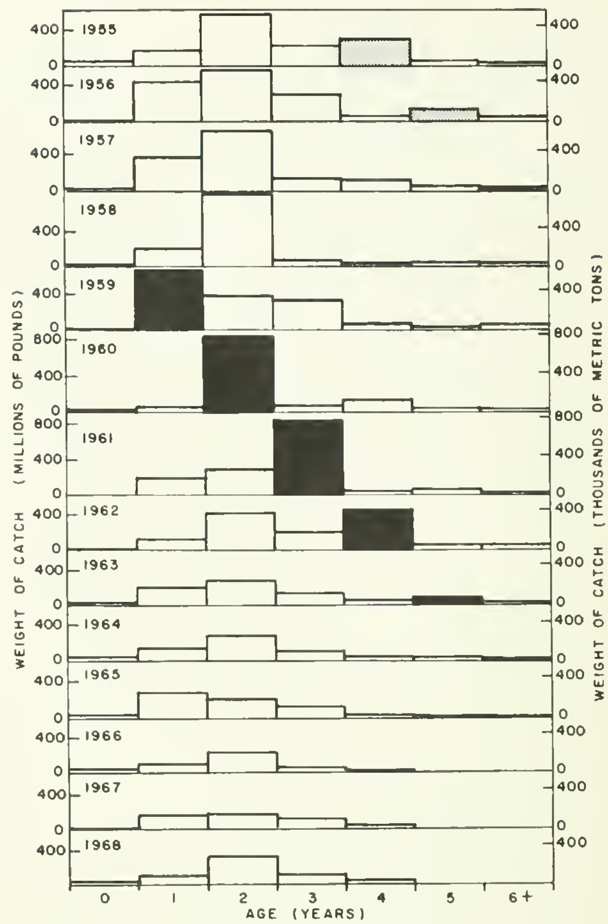

Figure 30.—Total weight, by age, of catch of Atlantic menhaden, 1955-68. (Shaded areas show 1951 year-class; black—1958 year-class).

To see the true effect of the 1958 year class on the annual catches, the numbers of each age group caught annually should be weighted by the average weight of the fish to give the catch in weight. This has been done in Figure 30. Thus, in 1959, the age-1 fish from the 1958 year class contributed more weight to the catch than any other age group. Again, as 2-year-old fish in 1960, 3-year-olds in 1961 and 4-year-olds in 1962, this year class contributed more weight to the annual catch for any given age than any other year class during this period. This can be seen a little easier in Figure 31 where the catch by weight is grouped by age of fish and year class. When the 1958 year class virtually disappeared from the catch in 1963 and there were no subsequent strong year classes, it is not surprising that the landings declined.

Thus, in the early 1960's the Atlantic menhaden resource was in the predicament of high levels of fishing effort, magnified by improved efficiency of the fishery (Henry, 1968), coupled with the lack of any strong year classes. The decline in the fishery for older fish and the increased dependency on younger fish was inevitable. The decline in the catches would have been even greater except for the increased size of fish and increased fishing effort in Chesapeake Bay.

Recruitment Predictions

Of major importance to the proper management of any fishery is the ability to estimate the strength of the year class, before it enters the fishery. One phase of the Atlantic menhaden research program has been a project to estimate the relative strength of the incoming year class by sampling in various estuaries along the Atlantic coast (Reintjes, 1969). During the summer, and before seaward migration,

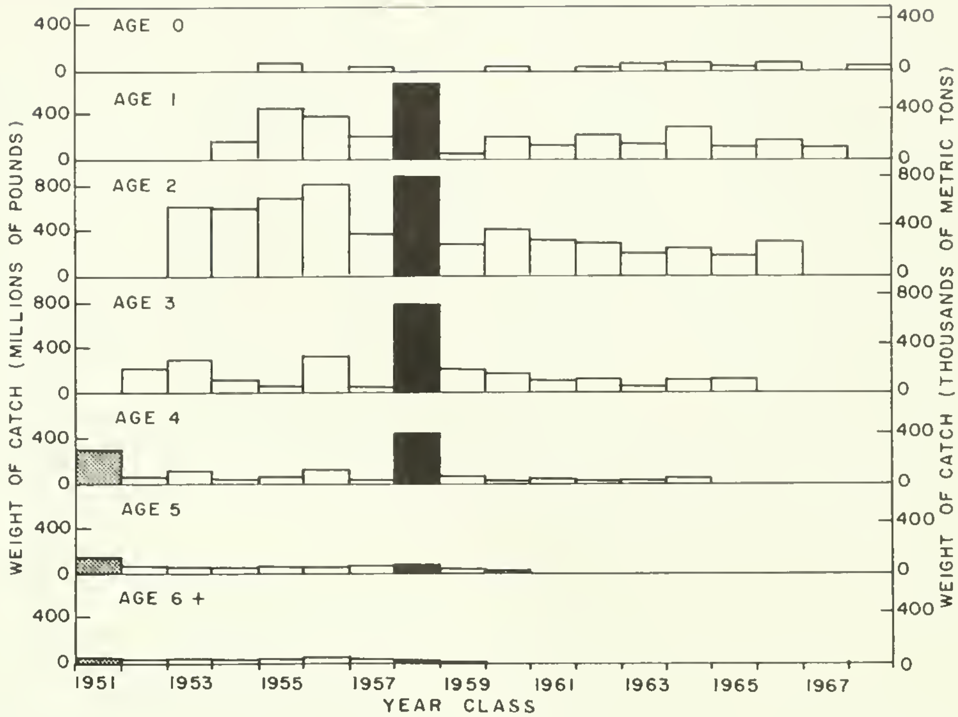

Figure 31.—Total weight, by age and year-class, of catches of Atlantic menhaden, 1951-68.

sampling crews visit a number of these tributaries and estimate the abundance of juvenile menhaden on the basis of catches in a surface trawl hauled between two boats. Relative abundance estimates are also made from aerial surveys later in the fall to corroborate these earlier findings. Although the relative abundance estimates have been made since 1962, more extensive coverage of the myriad of tributaries along the Atlantic coast has been achieved only in recent years; sampling techniques also have improved markedly over earlier years.

These estimates of abundance of juvenile menhaden are the first indication of the strength of the year class. Consequently, they are of vital importance to the fishing industry and would be important in any management plan for the resource. The relation between the index of juvenile menhaden abundance, based on the catch per 5-minute towing of a surface trawl in a number of related and comparable streams along the Atlantic coasts, and the total catch from the year classes in the purse seine fishery, is shown in Figure 32. The indices for the 1962 and 1963 year classes obviously were

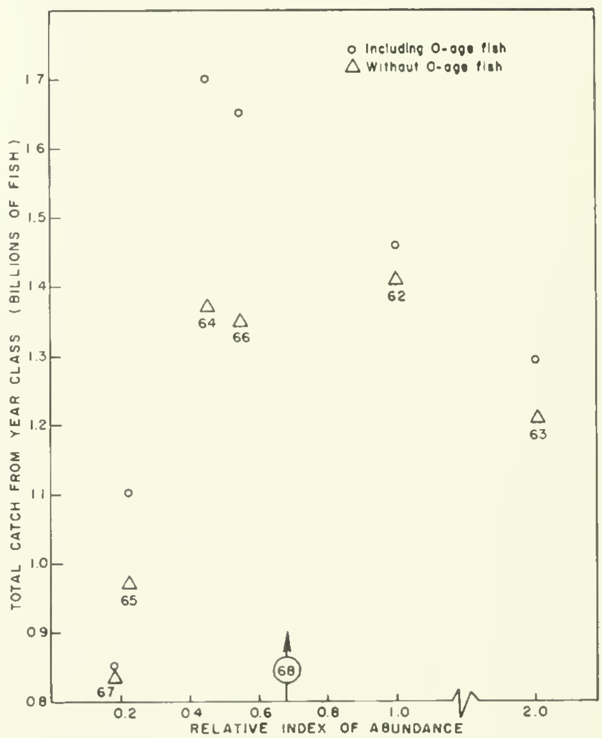

Figure 32.—Relation between relative index of juvenile abundance and total catch of Atlantic menhaden by year-class, 1962-68.

much too large in comparison with the ultimate total catch from the year class. A positive relation appears for the next four year classes, however.

Admittedly, the total catch of these four year classes is partially estimated since they have not yet passed completely through the fishery. The bulk of the catch has already been made from them, however, so any change in the estimates will not materially affect the relation shown. Considering the additional refinement that can be applied to these data, such as weighting the relative abundance indices for tributaries or sections of the coast on the basis of actual contribution to the fishery (which will be possible as the result of contemplated tagging studies), I believe this work is very encouraging and extremely important to the menhaden studies. The total catch data are not yet available for the 1968 year class, but the relative index of abundance for this year class (0.68) is noted in Figure 32. This would indicate a potential total catch of about 1.5 billion fish from this year class.

Another possible estimate of the strength of the year class is a relation between the catch of 0-age fish and the total catch of the year class. This relation permits us to go back before our juvenile abundance surveys were undertaken, to when our aging work started in 1955. Two sets of data are plotted in Figure 32 for each year class: total catch of the year class including 0-age fish and total catch excluding 0-age fish. These 0-age fish are only partially available to the fishery, and their inclusion could mask a relation that might exist for the older fish. However, these data show that the two largest year classes (1964 and 1966) also had the largest catch of 0-age fish.

To avoid correlating the 0-age group with itself to some extent, I have compared the catch of 0-age fish with the total catch of all other ages for the year class (Fig. 33). It is apparent that the 1956 and 1958 year classes do not fit the relation which is indicated for the other year classes. If we temporarily ignore these two aberrant year classes, there is a significant correlation for the other 10 year classes (r = 0.889, 8 df), and a linear regression line for these data is plotted on the graph.

Returning to the 1956 and 1958 year

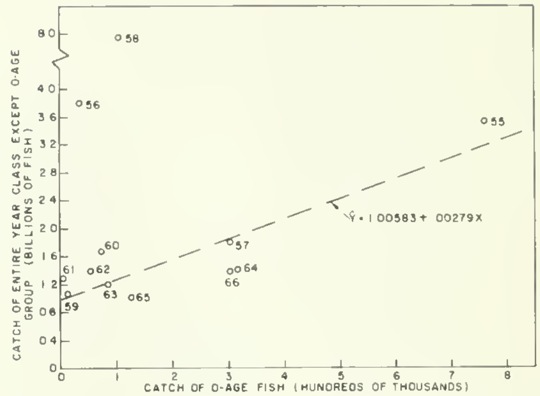

Figure 33.—Relation between catch of 0-age fish and total catch of all other ages, Atlantic menhaden, 1955-66 year-class.

classes, there must be some valid reason for excluding them from the analysis, or this relation is of doubtful value. Fortunately, if we look at Appendix Figure 1, which shows the weight data for menhaden caught in Chesapeake Bay, we see that the 1956 and 1958 year classes produced the smallest fish on record during this period (i.e., as 1-year-olds in 1957 and 1959 and as 2-year-olds in 1958 and 1960). It may well be that these fish were too small as 0's to enter the catch in proportion to their abundance. It appears that there is a definite relation between the catch of 0-age fish and the catch of all other ages, by year class, except that this relation must be modified by the size of the fish. I do not plan to pursue this, but hope this preliminary analysis will stimulate additional study.

To verify our estimates of year-class strength based on: (1) relative juvenile abundance estimates and (2) catch of 0-age fish in the commercial fishery, we can make an additional comparison between the catch of age-1 fish in the fishery and the total catch of ages 0-3, by year class (Fig. 34). I limited the analysis to fish of ages 0-3 so final figures for each year class could be available within 4 years. Only a small percentage of the catch of a year class is from fish over age 3, so these data basically reflect the year-class strength. As the data become available, total catch of the year class could be used in this analysis. Here again a positive relation exists (r = 0.98, $P < 0.01$), and the low abundance of recent year classes can be

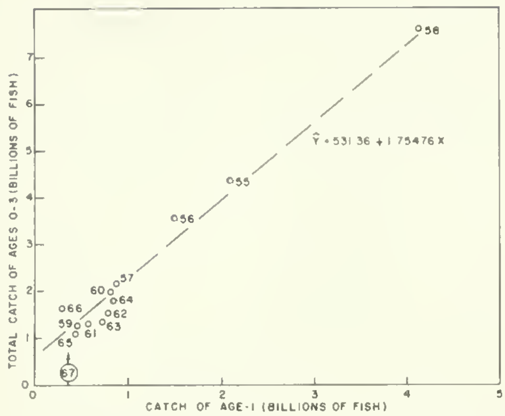

Figure 34.—Catch of age-1 Atlantic menhaden compared to total catch of ages 0-3 by year-class, 1955-67.

seen readily. Although the total catch data are not yet available for the 1967 year class, I have listed the catch of age 1 fish in 1968 from the 1967 year class. This catch, 0.382 billion age 1 fish, would indicate a potential total catch from the 1967 year class, through 1970, of less than 1 billion fish.

Mortality Rates

Mortality rates of Atlantic menhaden have been estimated, although accurate separation of natural mortality and total mortality is not yet possible. On the basis of the catch-effort data, mortality curves (natural logarithm of the catch per standard vessel day by age group) were computed by year class for the five fishing areas separately and for various combinations of the areas. The curves for the Chesapeake Bay data and the total Atlantic data are shown in Figures 35 and 36, respectively. The mortality rate for the total Atlantic data appears to be increasing in recent years. The average mortalities calculated are listed in Table 3. Since there is considerable interchange of menhaden between the different fishing areas and age groups are fished at different levels of effort, I have combined the data for the areas in various combinations to see what effect this would have on the mortality estimates. These mortalities were calculated by taking the annual natural logarithms of the catch per standard vessel day for the years indicated in Table 3 and computing the slope

Table 3.—Estimated apparent mortalities of Atlantic menhaden, based on catch effort and age data, by area.

Area	Year Class	Instantaneous mortality		Annual mortality, common
		Common	Total	
North Atlantic (NA)	(50-56)	1.31	1.33	.730
Middle Atlantic (MA)	(52-61)	1.29	1.32	.725
South Atlantic (SA)	(53-59)	3.12	3.42	.956
Chesapeake Bay (CB)	(53-58)	2.51	2.37	.919
North Carolina				
Fall fishery (NCF)	(50-56)	1.19	1.14	.696
Combination of areas				
MA + NA	(52-56)	1.02	1.04	.639
CB + MA	(52-56)	1.23	1.25	.708
CB + MA + NA	(52-56)	1.09	1.12	.664
CB + MA + NA + NCF	(53-56)	1.16	1.18	.687
CB + MA + NA + NCF + SA	(53-56)	1.18	1.20	.693

of the regression line. From these data it appears that a reasonable first approximation for the total mortality coefficient of Atlantic menhaden during this period would be about $Z = 1.20$. The mortality estimates for Chesapeake Bay and South Atlantic are higher than for the other areas. This is due, in part at least, to the extensive migrations from these areas as the fish approach maturity. It should be noted that fishing through only the early 1960's is included in these estimates—about up to the time the landings began to decline drastically.

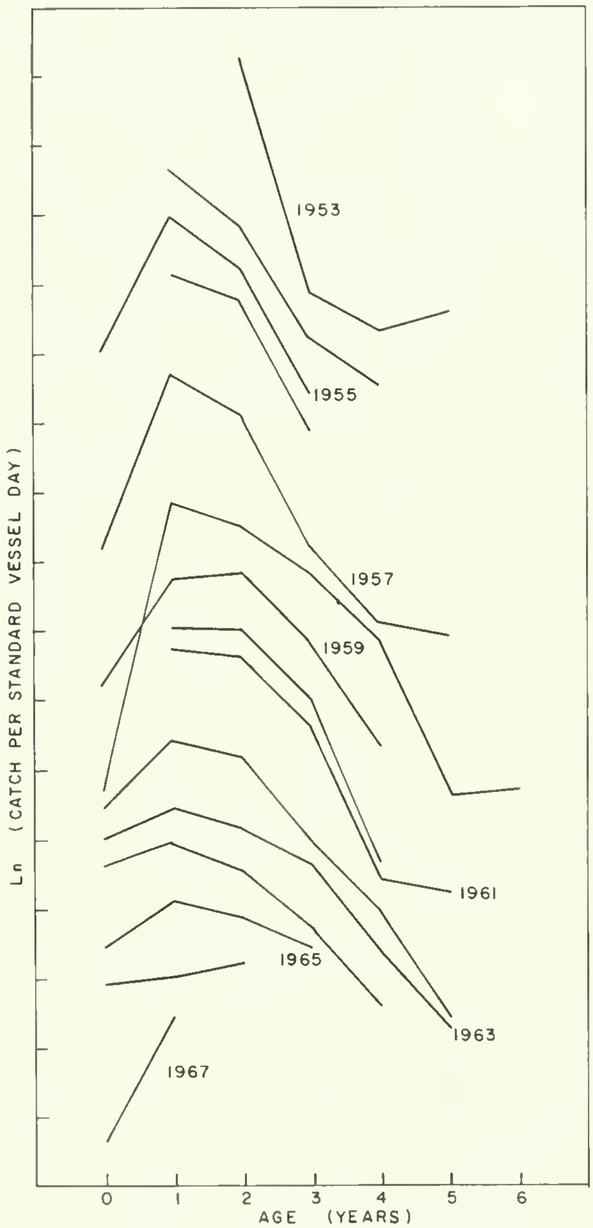

Figure 35.—Natural logarithm (ln) of the catch per standard vessel day in the Chesapeake Bay Area, by age and year-class, 1950-65.

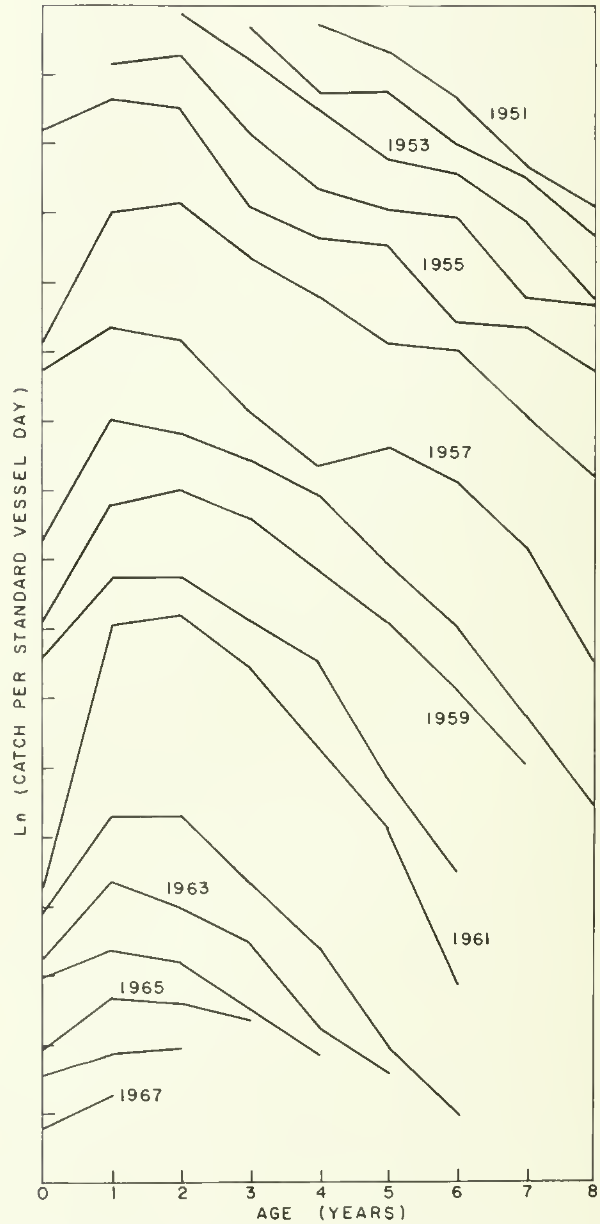

Figure 36.—Natural logarithm (ln) of the catch per standard vessel day for the total Atlantic coast menhaden fishery, by age and year-class, 1947-63.

Relation Between Catch and Effort

A Schaefer-type curve and relation is a useful method for examining catch and effort data. I have constructed a Schaefer-type curve (Fig. 37) for the Chesapeake Bay fishery to show the relations between the total effort and (1) catch per unit of effort and (2) total catch. Although the Schaefer-type analysis does not use all available mortality and growth data and Chesapeake Bay menhaden admittedly do not constitute a closed population, Chesapeake Bay and the South Atlantic are the two areas where the fish are exploited at a very early age (1 and 2 years) and are not, to any great extent, exposed to an intensive fishery in some other area earlier. In my opinion the data in Figure 37 give every indication in recent years of at least economic overfishing if not biological overfishing. It is interesting to compare similar data for the South Atlantic Area which also fishes on the age groups before they are heavily exploited in other areas (Fig. 38). Fishing effort in this area has been relatively low in recent years. I believe the effort in this area is at such a low level as to have virtually no effect on the stock present. The high mortality estimate was due primarily to migrations from the area. Since the stocks in the other three fishing areas are heavily dependent on what escapes from the Chesapeake Bay and South Atlantic Areas, a similar analysis for the other areas is not warranted.

I have limited the analyses in Figures 37 and 38 to data collected since 1955 when our age analyses were initiated. The analyses were also limited to these years because drastic changes have taken place in the menhaden fishery, beginning about the middle of the 1950's, including the use of airplanes and power-blocks (Henry, 1968). These changes have markedly increased the efficiency of the fleet. The extent of the increased efficiency of the gear is not known, but it is obviously substantial. Therefore, a comparison of data in recent years with inaccurate catch per-unit-of-effort data from previous years would be of little value and could give a completely false impression. The fact that the catch per-unit-of-effort has declined rather drastically in spite of the greatly increased efficiency makes the situation even more alarming. Although accurate estimates of natural mortality are not available, preliminary analyses indicate that with any reasonable natural mortality (0.5 or less) the total yield would be increased if the catch of 1 and 2 years old fish in Chesapeake Bay were reduced.

The very low levels of abundance; continued high level of fishing effort on young, immature fish; low catch per unit of effort; and the continued absence of a strong year class for 10 consecutive years are all disturbing signs that should not be taken lightly.

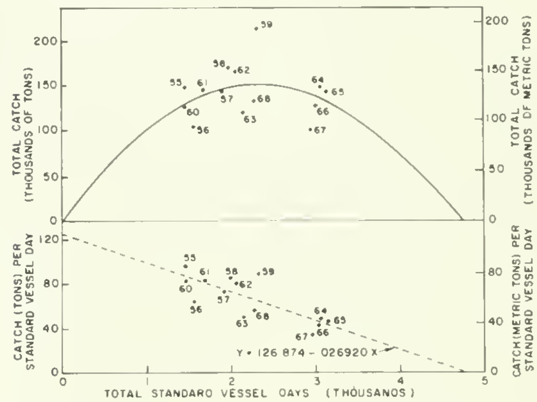

Figure 37.—Analysis of catch-effort statistics, Chesapeake Bay menhaden purse seine fishery, 1955-68.

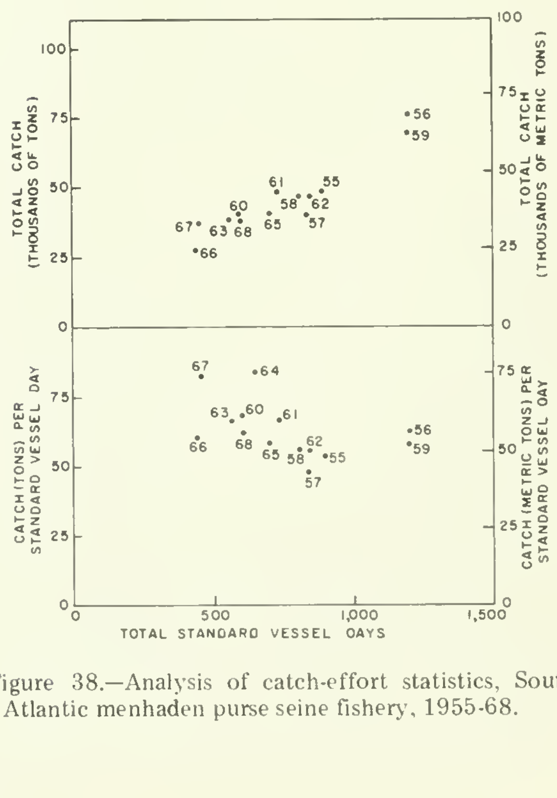

Figure 38.—Analysis of catch-effort statistics, South Atlantic menhaden purse seine fishery, 1955-68.

Relation Between Spawning Stock and Recruitment

Unfortunately, it has not been possible with menhaden to establish a reliable relation between the spawning stock and subsequent recruitment to the fishery. This has been partially due to the fact that the menhaden research program has never had funding for oceanic studies during the time of menhaden spawning. Consequently, little is known about what is probably the most critical time in their life history.

Nevertheless, an examination of the data from the Middle Atlantic area in relation to spawning stock and resulting progeny is perhaps indicative of possible adverse effects from the present low population levels of Atlantic menhaden. The catch-per-unit effort (SVD) for the Middle Atlantic Area was used as a measure of the spawning population, and the total catch from each year class (Table 2) was used as a measure of year-class abundance. If we assume a reproduction curve of the type proposed by Ricker (1958), i.e.,

$$R = P \cdot e^{(P_r - P)/P_m}$$

where

R = Reproduction
P = Spawning stock
P_r = Stock size at which $R = P$
P_m = Stock size giving maximum reproduction in the absolute sense
e = the base of natural logarithm (2.71828+),

the relations shown in Figures 39 and 40 can be computed.

It is apparent that the largest year classes occurred when the catch-per-unit-effort in the Middle Atlantic area was the highest, and that current low catches per unit of effort in that area are related to small year classes. A stock size reflected by a catch-per-unit-effort of at least 0.8 appears to be a desirable goal. The theoretical maximum reproduction *(Pm)* would be achieved at a catch-per-unit-effort of 1.08—considerably above present day levels. The data again suggest the desirability of increasing the escapement of Atlantic menhaden into the Middle Atlantic Area. Since this increased escapement would essentially be mature fish, it would actually result in an increase in the spawning population.

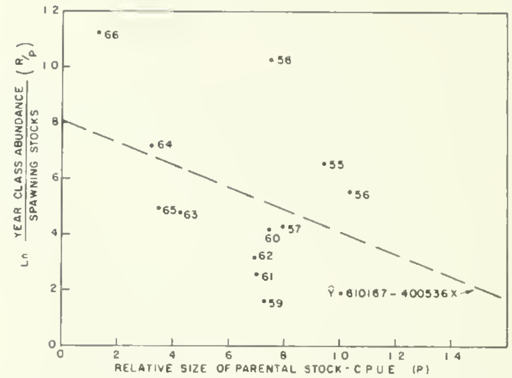

Figure 39.—Relation between relative size of the parent stock, as measured by Middle Atlantic catch per unit of effort, and the natural logarithm (ln) of R/P where R=year-class abundance and P=spawning stock (Numbers indicate year classes).

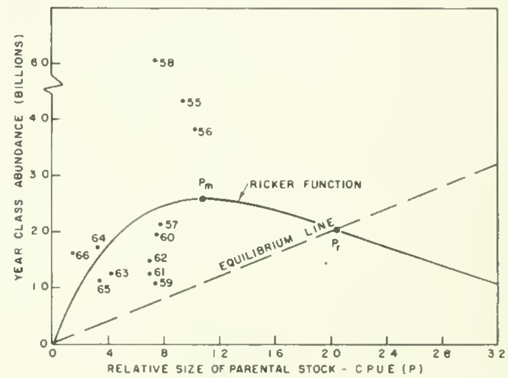

Figure 40.—Relation between relative size of the parent stock, as measured by Middle Atlantic catch per unit of effort and year-class abundance (Numbers indicate year classes).

There might be some question as to why the catch-per-unit-effort for the Middle Atlantic Area was used as a measure of the spawning population. Catches in some of the other areas consist of a large number of immature fish (ages 0 and 1), which do not contribute to spawning success (Chesapeake Bay, South Atlantic, and North Carolina fall fishery). The age 2 fish, one of the most abundant age groups in the spawning population, are not fully recruited into the North Atlantic Area fishery. Finally, the North Carolina fall fishery is of short duration and can be seriously affected by bad weather. Consequently, the Middle Atlantic appears to be the area in which all mature age groups are fished and in which the fishery extends over a long enough period that the catch-per-unit-effort might be considered representative of the abundance of the stocks.

The decline in the catch of Atlantic menhaden probably was due principally to a series of poor year classes since 1958. Overfishing did not cause the initial decline, but there are strong indications that the reduced stocks may subsequently have been overfished and that this contributed to the continued reduced abundance and failure of the resource to recover. McHugh (1969) compared the Atlantic menhaden and the Pacific sardine *(Sardinops caerulea)* fisheries and the similarity in the decline in abundance of the two resources. With increased fishing effort the average age of the stocks was reduced and the first to suffer were the more northern areas which were dependent on the older fish. As fishing effort on the younger fish remained high and year-class strength continued poor, the fishery became more dependent on the younger fish and, in the case of the sardine, the resource declined and the fishery eventually disappeared. McHugh pointed out "A fishery based on a single species, highly variable in abundance, is not likely to be a stable fishery." He also said, "Moreover, the time lag of a year or two in building vessels and plants usually may provide maximum catching and processing capability when the resource is already declining. In the absence of effective fishing regulation, disaster is probably almost inevitable."

I am concerned that the stocks of Atlantic menhaden may have been reduced to a level that is having an adverse effect on recruitment. Unfortunately, the 1968 catch increased over the previous year. This made many people, particularly in industry, believe the decline had ended. Small fluctuations of this nature can be expected; they occurred in the sardine fishery also, but will have no lasting effect unless the fishery is properly managed. The menhaden industry has begun to recognize the need for some changes in the fishery. In 1968, it voluntarily implemented certain beneficial policies.

Although we do not have sufficient data to manage the Atlantic menhaden on a completely scientific basis, I agree with McHugh (1969) "It is not necessary to wait until indisputable scientific evidence is available before taking action to manage a fishery. History has shown that such caution usually leads to disaster." We do have a considerable amount of data on Atlantic menhaden that are being used as a basis for management, and I believe it important that the available data, even though incomplete, continue to be used for subsequent analyses and management of this resource.

SUMMARY

Menhaden support the largest U.S. commercial fishery in terms of pounds landed. In recent years the fishery has experienced a serious decline in production. This decline occurred principally in the Atlantic coast fishery where the catch declined from 1.3 billion pounds (0.590 million metric tons) in 1962 to 0.55 billion pounds (0.249 million metric tons) in 1968—a 58% decline.

The Atlantic fishery is divided into four fishing areas; North Atlantic, Middle Atlantic, Chesapeake Bay, and South Atlantic. In addition there is a fall fishery off North Carolina. Although all areas have experienced a decline in production, the greatest decline has occurred in the North Atlantic and Middle Atlantic fisheries. An analysis of the catch and effort data indicate that the North Carolina and Florida catches should not be combined in the South Atlantic Area in future analyses.

The unit of fishing effort currently used for the menhaden fishery, catch-per-standard-vessel day, adequately portrays the trends in fishing effort but grossly underestimates actual effort, particularly in recent years, because it does not take into consideration fishing days with no catches. Since the early 1960's fishing effort has declined drastically in the North Atlantic and Middle Atlantic fisheries, but has reached record high levels in Chesapeake Bay.

A significant relation exists between the relative fishing power of menhaden vessels on Chesapeake Bay and the length of the vessel, but not for the gross tonnage of the vessels. The catch-per-unit-of-effort is at a low level in most fishing areas.

Before 1964 the largest annual catches of

menhaden were made in the Middle Atlantic Area. Since 1964 the largest annual landings have been from Chesapeake Bay. These increased catches from Chesapeake Bay have been achieved by extending the fishing season into late October and November and by increasing the fishing effort. Over 20% of the Chesapeake Bay catch now occurs in November whereas almost no fish were landed in Chesapeake Bay in November before 1964.

The 14-year (1955-68) mean average age of Atlantic menhaden in the catch is 3.7 years in the North Atlantic, 2.3 years in the Middle Atlantic, 1.4 years in Chesapeake Bay, 1.4 years in the South Atlantic and 1.7 years in the North Carolina Fall Fishery. The average age for all areas combined is 1.67 years. In recent years about 90% of the total catch has been immature fish (less than age-3).

Since the early 1960's almost all ages of menhaden caught in the Chesapeake Bay, Middle Atlantic and North Atlantic fisheries have been considerably larger than average. Thus, the decline in the catch of Atlantic menhaden would have been even more drastic if this significant increase in the growth of the fish had not occurred.

The decline in the catch of Atlantic menhaden was due principally to a series of poor year classes following the superabundant 1958 year class. There is a strong indication that the reduced stocks may subsequently have been overfished and that this contributed to the continued reduced abundance and failure of the resource to recover.

Estimates of the year-class strength of Atlantic menhaden are made by a variety of methods: (1) relative abundance indices of juvenile menhaden in the tributaries, (2) the catch of age-0 menhaden in the fishery, and (3) the catch of age-1 menhaden in the fishery.

An analysis of mortality rates of Atlantic menhaden, based on catch-effort data, suggest that total mortality (natural and fishing) would be about $Z = 1.20$.

A Schaefer-type analysis of the catch-effort data for Chesapeake Bay strongly suggests that there has been at least economic overfishing if not biological overfishing as well.

A relation between stock size, as measured by the catch-per-unit-of-effort in the Middle Atlantic fishery, and the size of the resulting year class indicates that the present spawning stock is considerably below optimum size. The data suggest the desirability of increasing the escapement of menhaden into the Middle Atlantic Area. This also would result in an increase in the size of the spawning population.

ACKNOWLEDGMENTS

Many colleagues have made helpful suggestions concerning this paper. In particular I acknowledge the comments of George Hirschhorn of the Biometrics Institute, National Marine Fisheries Service Biological Laboratory, Seattle, Washington. Also, I appreciate the comments of the staff members at the National Marine Fisheries Service Center for Estuarine and Menhaden Research, Beaufort, N.C. Many of the staff members at that laboratory, in particular the Fishery Aides, were instrumental in collecting the data utilized in this paper.

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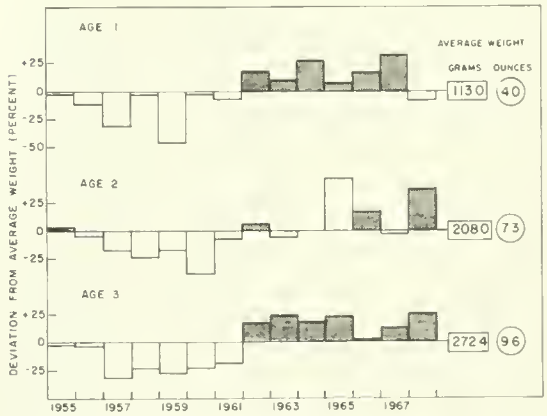
APPENDIX

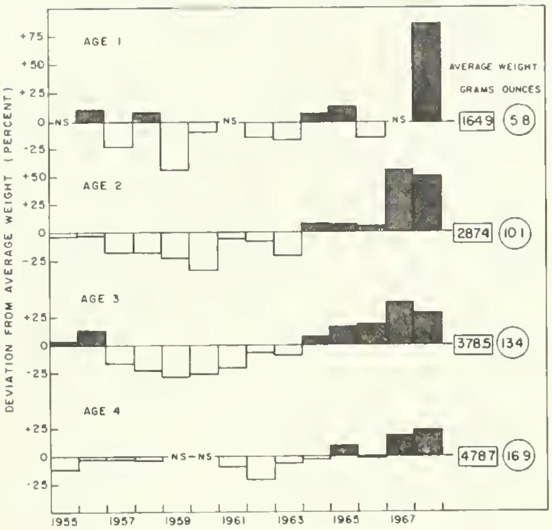
From 1955 through 1968 the average age of menhaden in the annual catch in the North Atlantic Area varied between 2.9 and 4.8 years with a mean value for the 14 years of 3.7 years; in the Middle Atlantic Area, between 1.5 and 3.2 years—mean of 2.3 years; in the Chesapeake Bay Area, between 1.1 and 1.8 years—mean of 1.4 years; in the South Atlantic Area, between 1.0 and 1.9 years—mean of 1.4 years, and in the North Carolina fall fishery between 0.3 and 3.0 years—mean of 1.7 years.

In the North Atlantic Area, the increase in the average age from 1962 through 1964 was due to the catch of large numbers of the 1958 year class as 4-, 5-, and 6-year-old fish coupled with decreased abundance of younger age groups. The virtual disappearance of this year class from the catch in 1965 is reflected by the sharp drop in average age. In the Middle Atlantic Area, the 1958 year class contributed significantly as 2-year-old fish in 1960, was present in numbers through 1962, and subsequently was of relatively little importance. The 1958 year class contributed in significant numbers as 1-year-old fish in 1959 to the catches of both the Chesapeake Bay and South Atlantic Areas, causing the average age of the fish to decline. The average age fluctuated most in the North Carolina fall fishery.

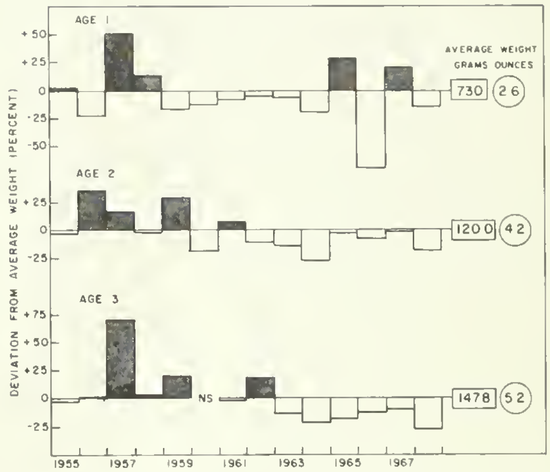
The sudden drop in the percentage of the catch less than 3 years old in 1961 (Fig. 7) reflects the large catch of 3-year-old fish from the 1958 year class. The contribution of the 1958 year class, which mainly reached maturity in late 1960, not only caused a drop in the percentage catch of immature fish that year but also resulted in an increase in the average age of the catch from 1960-62. The relatively low percentage of immature fish in the catch in 1955 (80%) reflects the presence of the strong 1951 year class, which was caught in relatively large numbers in 1955 as 4-year-old fish. The low average ages in 1955, 1957, 1964, 1965, and 1966 reflect the relatively large catches of 0-age fish in those years.



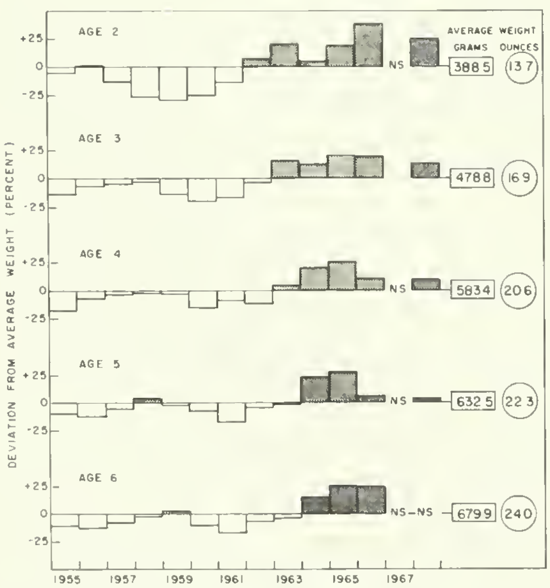
Appendix Figure 1.—Weight frequencies of menhaden in July, expressed as percentage deviation from average weight, Chesapeake Bay, 1955-68.



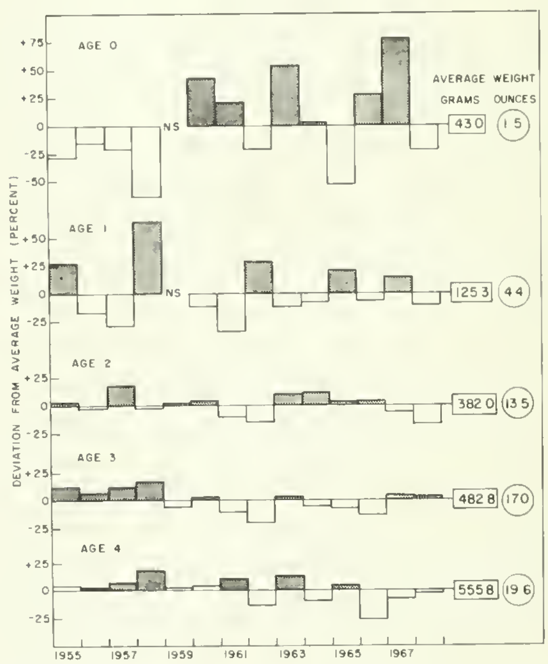
Appendix Figure 2.—Weight frequencies of menhaden in July, expressed as percentage deviation from average weight, Middle Atlantic Area, 1955-68 (NS = No sample).



Appendix Figure 4.—Weight frequencies of menhaden in July, expressed as percentage deviation from average weight, South Atlantic Area, 1955-68 (NS = No sample).



Appendix Figure 3.—Weight frequencies of menhaden in July, expressed as percentage deviation from average weight, North Atlantic Area, 1955-68 (NS = No sample).



Appendix Figure 5.—Weight frequencies of menhaden in December, expressed as percentage deviation from average weight, North Carolina fall fishery, 1955-68 (NS = No sample).

Appendix Figure 1 shows the average weights of different age groups of menhaden caught in the Chesapeake Bay purse seine fishery between 1955 and 1968. These data are expressed as annual deviations from the 14-year average. It is obvious from these data that since 1961 almost all ages of menhaden caught in the Chesapeake Bay fishery have been considerably larger than average and that the fish were particularly small during 1957-61. Since there is considerable migration of fish from Chesapeake Bay to the Middle and North Atlantic fishing areas, it might be suggested that the differences in average weight shown in Appendix Figure 1 for Chesapeake Bay are merely the result of a differential migration pattern, i.e., only the larger fish from a year class entering Chesapeake Bay or only the smaller fish leaving in recent years. If we look at similar data for the Middle and North Atlantic Areas (Appendix Figs. 2 and 3), we see that the same phenomenon exists—larger fish for every age group in recent years.

Interestingly, the weights of the fish caught in the South Atlantic Area (Appendix Fig. 4) do not follow the same pattern as those of the fish caught north of Cape Hatteras. In the South Atlantic Area most of the fish have been below average weight in recent years. The weight data for the North Carolina fall fishery (Appendix Fig. 5) do not agree with the data from the more northern areas or those from the South Atlantic summer fishery but appear to be almost a composite of the two groups. This is not too surprising since we believe there is considerable mixing of fish from the northern and southern areas in the fall fishery.

Appendix Table 1.--Calculated numbers of Atlantic menhaden caught by the purse seine fishery, by age and area, 1955-68.

Area and year	Age 0	1	2	3	4	5	6	7	8-10	Total catch
	Millions of fish									
North Atlantic										
1955	-	-	0.50	23.69	107.75	19.27	6.85	0.87	0.37	159.30
1956	-	-	1.87	35.65	13.84	79.98	12.47	2.41	0.68	146.90
1957	-	2.08	61.66	30.31	28.76	15.21	18.12	2.86	0.68	159.68
1958	-	-	46.12	20.36	7.04	5.49	4.15	1.84	0.10	85.10
1959	-	8.67	39.72	90.10	10.81	4.09	4.29	2.10	0.89	160.67
1960	-	-	70.99	33.64	42.69	8.47	1.85	0.46	0.02	158.12
1961	-	-	4.12	109.41	7.36	14.69	1.60	0.68	0.14	138.00
1962	-	-	2.22	24.31	76.23	9.70	9.08	0.85	0.43	122.82
1963	-	-	2.28	11.59	19.69	31.62	7.48	2.54	0.45	75.65
1964	-	-	0.51	4.08	4.64	7.04	6.28	1.20	0.30	24.07
1965	-	-	0.80	4.04	2.29	1.47	1.09	0.56	0.06	10.31
1966	-	-	0.11	1.28	1.11	0.15	0.10	0.11	0.03	2.89
1 1967	-	-								
1968	-	-	1.61	5.65	2.13	1.27	0.02	-	-	9.68
Middle Atlantic										
1955	-	16.31	505.38	209.96	159.93	12.81	2.26	0.94	0.16	907.75
1956	-	195.83	795.97	243.79	21.79	25.88	8.92	3.26	1.31	1,296.75
1957	-	407.96	855.19	46.96	21.21	10.38	7.76	0.52	0.39	1,350.37
1958	-	24.06	783.71	18.42	1.90	1.38	0.88	0.59	0.34	831.28
1959	-	906.86	442.50	172.23	4.33	1.87	1.90	1.53	0.31	1,531.53
1960	-	12.27	1,157.48	16.05	23.31	5.21	1.56	0.49	0.20	1,216.57
1961	-	3.74	166.08	740.14	5.44	4.99	0.85	0.13	0.10	921.47
1962	-	14.16	195.97	154.94	288.88	16.43	13.64	1.43	0.21	685.66
1963	-	160.26	206.65	67 20	16.55	11.12	1.24	0.38	0.04	462.44
1964	-	3.74	35.59	39.54	10.31	0.57	0.43	-	-	90.18
1965	-	22.87	51.78	48.78	8.59	0.25	0.14	0.06	-	132.47
1966	-	3.26	7.64	5.34	1.50	0.38	-	-	-	18.12
1967	-	3.98	10.32	18.34	2.32	0.30	0.01	-	-	35.27
1968	-	0.11	30.20	21.98	5.84	0.60	0.05	-	-	58.78
Chesapeake Bay										
1955	12.18	334.24	383.92	11.52	5.17	0.43	-	-	-	746.56
1956	-	674.37	66.90	0.49	-	-	-	-	-	741.76
1957	3.12	1,056.16	176.58	3.22	0.22	0.08	-	-	-	1,239.38
1958	0.48	490.88	561.76	5.25	0.90	0.39	-	-	-	1,059.66
1959	10.71	2,058.36	200.20	14.78	-	-	-	-	-	2,284.05
1960	-	142.58	666.94	2.64	-	-	-	-	-	812.16
1961	-	311.76	206.42	197.99	0.32	0.16	-	-	-	716.65
1962	42.40	207.34	366.13	32.28	34.69	9.27	-	-	-	683.11
1963	50.38	308.00	178.81	52.78	1.81	0.45	-	-	-	592.23
1964	240.29	165.45	299.79	36.41	0.64	-	0.73	-	-	743.31

1 No fishery

Appendix Table 1.- Calculated numbers of Atlantic menhaden caught by the purse seine fishery, by age and area, 1955-68. (Continued)

Area and year	Age									Total catch
	0	1	2	3	4	5	6	7	8-10	
	Millions of fish									
Chesapeake Bay (continued)										
1965	68.10	484.20	95.52	24.26	0.40	-	0.08	-	-	672.56
1966	177.06	226.84	209.89	34.25	3.29	0.29	-	-	-	651.62
1967	4.74	202.95	139.25	38.58	2.32	0.15	-	-	-	387.99
1968	34.78	131.99	233.12	47.52	3.23	0.24	-	-	-	450.88
South Atlantic										
1955	6.51	255.20	105.74	13.01	10.83	-	-	-	-	391.29
1956	-	1,147.88	10.91	0.63	0.23	0.02	-	-	-	1,159.67
1957	13.27	117.91	231.56	0.42	-	-	-	-	-	363.16
1958	1.47	315.20	135.39	8.52	0.26	-	-	-	-	460.57
1959	-	1,051.86	103.53	1.72	-	-	-	-	-	1,157.11
1960	13.86	111.84	273.73	-	-	-	-	-	-	399.43
1961	-	506.20	80.51	57.65	0.30	-	-	-	-	644.66
1962	2.21	297.55	250.30	1.81	-	-	-	-	-	551.87
1963	-	192.24	191.48	40.59	-	-	-	-	-	424.31
1964	1.98	518.03	182.28	20.51	-	-	-	-	-	722.80
1965	0.73	174.13	187.00	12.09	-	-	-	-	-	373.95
1966	0.23	121.04	69.96	31.33	3.87	0.11	-	-	-	226.54
1967	10.89	338.75	147.49	24.76	1.40	-	-	-	-	523.29
1968	0.11	152.71	189.93	82.93	7.49	0.09	-	-	-	433.26
North Carolina fall fishery										
1955	742.32	30.76	51.08	7.32	16.71	2.74	0.39	-	0.10	851.42
1956	36.37	60.42	26.97	37.48	9.36	46.50	7.48	1.03	-	225.61
1957	284.39	12.41	23.30	15.60	20.72	14.74	11.07	0.95	0.08	383.26
1958	104.11	29.34	98.08	19.63	7.20	8.60	4.04	2.48	-	273.48
1959	0.69	6.87	35.99	103.81	18.44	5.75	6.09	0.78	0.54	178.96
1960	58.31	14.32	38.76	22.63	35.17	10.90	4.03	1.32	0.42	185.86
1961	0.25	10.71	45.17	101.90	5.76	10.00	0.62	-	-	174.41
1962	6.97	0.71	17.17	7.61	22.10	4.15	1.82	0.50	-	61.03
1963	34.20	57.26	62.44	27.57	8.94	10.11	1.53	0.53	0.11	202.70
1964	73.43	17.33	60.20	20.17	3.32	0.64	0.26	0.09	-	175.44
1965	58.40	139.33	54.12	13.01	1.29	0.21	-	-	-	266.36
1966	126.51	70.66	125.24	33.92	2.20	0.01	-	-	-	358.54
1967	3.60	50.39	43.78	29.09	1.98	0.16	-	-	-	128.99
1968	33.93	97.30	116.30	25.85	4.16	0.70	-	-	-	278.24

Appendix Table 2.--Average weight of Atlantic menhaden caught by the purse seine fishery, by age and area, 1955-68. (Numbers in parentheses are samples of less than 10 fish.)

Area and year	Age 0	1	2	3	4	5	6	7	8+
North Atlantic					Grams				
1955	-	-	(389.7)	437.3	494.0	585.7	635.7	681.8	749.5
1956	-	-	432.2	456.6	531.7	563.7	610.7	653.0	718.5
1957	-	190.0	364.2	471.3	563.8	606.2	635.7	661.1	702.6
1958	-	-	333.5	493.1	586.7	661.3	694.7	707.5	(833.3)
1959	-	178.3	326.9	420.6	582.4	630.8	682.3	726.9	752.0
1960	-	-	321.2	420.7	511.1	603.3	682.0	(705.6)	(849.0)
1961	-	-	415.0	458.2	565.9	579.8	657.9	701.3	(767.8)
1962	-	-	415.9	477.1	528.9	598.5	639.9	682.4	721.2
1963	-	-	466.0	535.3	627.5	652.8	689.4	714.1	746.6
1964	-	-	519.3	677.2	753.4	810.8	817.5	815.1	848.1
1965	-	-	489.2	626.5	739.6	831.4	858.7	886.3	(955.4)
1966	-	-	(538.7)	575.5	640.7	664.1	(846.0)	(814.0)	(792.0)
1 1967	-	-							
1968	-	-	496.9	543.9	625.2	707.4	(511.5)	-	-
Middle Atlantic									
1955	-	223.8	318.0	402.4	451.6	514.4	586.6	703.0	(633.3)
1956	-	202.7	309.0	438.8	491.0	526.7	580.1	616.8	666.6
1957	-	149.9	261.3	428.2	551.4	552.6	566.1	614.2	657.8
1958	-	183.3	254.8	342.2	500.4	558.7	601.6	613.4	676.7
1959	-	99.1	234.3	324.4	554.2	600.6	664.3	687.1	(739.1)
1960	-	178.6	208.6	478.3	597.3	670.3	727.8	796.5	(781.7)
1961	-	234.0	288.3	323.1	503.9	635.3	694.4	(763.3)	(755.0)
1962	-	163.9	303.2	390.4	438.2	606.8	656.7	719.4	(721.8)
1963	-	168.5	242.0	391.4	546.3	584.7	679.1	(756.8)	(926.0)
1964	-	162.9	333.7	429.0	487.7	536.9	(528.6)	-	-
1965	-	207.5	329.9	462.4	542.3	607.2	(879.3)	(810.0)	-
1966	-	142.1	331.8	452.3	488.1	500.3	-	-	-
1967	-	371.1	459.8	540.5	635.8	659.1	(507.0)	-	-
1968	-	503.7	479.5	533.2	606.5	535.2	(620.3)	-	-
Chesapeake Bay									
1955	57.6	137.7	214.3	253.8	266.1	(253.2)	-	-	-
1956	-	115.6	182.4	225.4	-	-	-	-	-
1957	60.3	91.3	159.9	206.1	388.6	399.4	-	-	-
1958	(32.0)	119.2	164.0	216.0	(469.0)	(480.0)	-	-	-
1959	65.8	70.0	166.2	201.9	-	-	-	-	-
1960	-	127.7	136.1	(233.3)	-	-	-	-	-
1961	-	127.6	203.3	227.9	(393.0)	(302.0)	-	-	-
1962	54.5	159.9	253.5	361.3	403.1	(421.0)	-	-	-
1963	59.8	143.9	234.2	346.2	(338.8)	(494.0)	-	-	-
1964	57.9	173.5	260.0	339.0	444.6	-	(504.0)	-	-

1 No fishery.

Appendix Table 2.—Average weight of Atlantic menhaden caught by the purse seine fishery, by age and area, 1955-68. (Numbers in parentheses are samples of less than 10 fish.) (Continued)

Area and year	Age								
	0	1	2	3	4	5	6	7	8+
	Grams								
Chesapeake Bay (continued)									
1965	75.7	173.7	315.9	365.7	(520.2)	-	(527.0)	-	-
1966	71.4	132.6	269.5	324.2	362.6	(373.8)	-	-	-
1967	105.7	194.6	274.7	413.0	454.2	(422.8)	-	-	-
1968	84.3	138.7	303.8	341.8	388.3	(459.2)	-	-	-
South Atlantic									
1955	35.0	80.7	124.6	154.7	157.3	-	-	-	-
1956	-	67.2	137.2	(176.1)	(217.0)	(224.0)	-	-	-
1957	31.4	82.7	116.6	(209.2)	-	-	-	-	-
1958	(40.0)	84.8	133.4	182.0	(157.0)	-	-	-	-
1959	-	59.9	134.2	(178.5)	-	-	-	-	-
1960	29.3	76.2	99.7	-	-	-	-	-	-
1961	-	71.9	137.1	146.7	(203.0)	-	-	-	-
1962	(64.5)	72.4	108.6	171.8	-	-	-	-	-
1963	-	58.0	103.5	121.0	-	-	-	-	-
1964	(21.0)	60.1	90.9	122.5	-	-	-	-	-
1965	97.5	90.0	111.4	131.6	-	-	-	-	-
1966	(69.7)	84.5	119.3	136.8	144.0	(190.5)	-	-	-
1967	52.4	75.3	122.5	144.3	157.2	-	-	-	-
1968	45.6	64.2	97.0	101.5	114.9	(143.4)	-	-	-
North Carolina fall fishery									
1955	30.9	167.7	353.6	448.3	563.3	645.6	(689.8)	-	(806.0)
1956	32.6	121.6	348.8	516.3	568.5	583.4	641.8	(648.2)	-
1957	31.4	91.9	448.4	541.2	603.7	632.2	641.7	663.5	(783.5)
1958	21.0	151.8	360.3	575.1	667.8	722.9	740.7	755.6	-
1959	28.1	119.4	336.9	464.9	586.0	641.8	677.5	(702.8)	(737.3)
1960	(48.7)	104.7	389.4	522.8	607.7	665.3	735.7	774.6	(748.7)
1961	35.9	105.3	342.4	419.0	605.7	659.7	(733.9)	-	-
1962	34.0	212.1	371.7	413.8	520.5	602.9	646.1	(760.8)	-
1963	56.1	153.2	392.8	476.1	636.3	656.8	713.6	(736.0)	(758.0)
1964	47.1	130.6	349.9	409.2	525.1	(661.9)	(733.0)	(945.0)	-
1965	30.4	137.2	357.8	451.0	(522.7)	(455.0)	-	-	-
1966	60.0	140.1	353.6	419.7	587.5	(885.0)	-	-	-
1967	97.6	164.6	352.7	511.8	565.2	-	-	-	-
1968	37.5	146.5	335.8	453.1	553.9	(548.3)	-	-	-

Appendix Table 2.--Average weight of Atlantic menhaden caught by the purse seine fishery, by age and area, 1955-68. (Numbers in parentheses are samples of less than 10 fish.) (Continued)

Area and year	Age								
	0	1	2	3	4	5	6	7	8+
	Grams								
Average 1955-68									
North Atlantic	-	184.2	423.7	507.2	596.2	653.5	689.4	729.1	786.3
Middle Atlantic	-	213.7	311.0	424.0	528.2	584.9	637.8	708.1	728.7
Chesapeake Bay	65.9	136.1	224.1	289.7	402.6	400.6	515.5	-	-
South Atlantic	48.6	73.4	116.6	152.1	164.3	185.4	-	-	-
North Carolina fall fishery	42.3	139.1	363.9	473.0	579.6	643.1	695.4	748.3	766.7

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