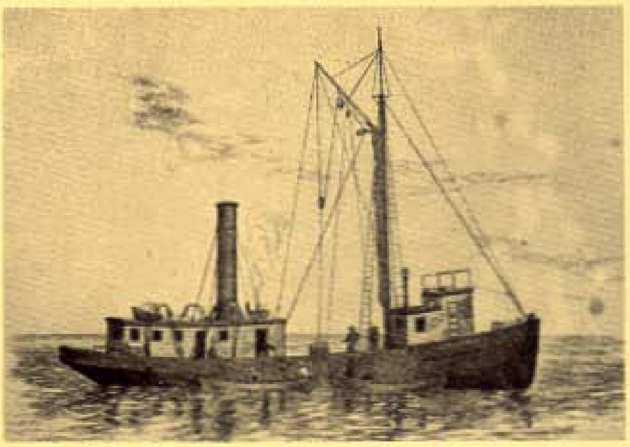
NOAA Technical Memorandum NMFS-SEFC-262

ASSESSMENT OF THE STATUS OF THE ATLANTIC MENHADEN STOCK WITH REFERENCE TO INTERNAL WATERS PROCESSING

Douglas S. Vaughan



June 1990

U.S Department of Commerce
National Oceanic and Atmospheric Asministration
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, NC 28516-9722

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U.S DEPARTMENT OF COMMERCE
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EXECUTIVE SUMMARY

This assessment of the status of Atlantic menhaden stock was undertaken at the request of the Atlantic Menhaden Advisory Committee (AMAC) for the Atlantic States Marine Fisheries Commission (ASMFC) in its role of providing advice to the individual states for responding to Internal Waters Processing (IWP) applications. The ASMFC adopted a resolution for undertaking reviews of IWP applications and the 1989 New England Governors Conference requested guidance from ASMFC for Atlantic sea herrings IWPs. One Atlantic menhaden IWP operated during the 1988 and 1989 fishing years with a quota of 40,000 metric tons. Two applications for Atlantic menhaden were received for the 1990 fishing year, both for 40,000 t in Maine. This report was developed to provide currently available scientific information on the status of the Atlantic menhaden stock relative to IWP applications in New England waters.

Data used in this analysis are from the Atlantic menhaden reduction fishery and include landings information from 1940 through 1989, fishing effort from 1941 through 1989, and estimated landings in numbers by age (from NMFS biostatistical port sampling) from 1955 through 1988. Coastwide Atlantic menhaden landings rose during the 1940s and early 1950s (peaking at 712,000 t in 1956), declined rapidly during the mid-1960s (bottomed out at 161,600 t in 1969), rose again during the 1970s (recent peak of 418,600 t in 1983. Landings in 1989 amounted to about 322,000 t. Coastwide landings averaged 341,300 t during the 1980s, while those from the North Atlantic area averaged 38,900 t. The relative spawning potential of older menhaden caught in the North Atlantic area is considerably greater to the spawning stock than that of younger menhaden caught from other areas, especially from the Chesapeake Bay area where landings in numbers and weight predominate. In addition to the higher relative value of older menhaden to the stock through a greater contribution of eggs, the older menhaden are also more valuable to the reduction fishery because of greater content of oil per unit weight of fish.

Catch in numbers by age are used in virtual population analysis to estimate age-specific fishing mortality and population size (including recruits and spawners). Recruitment to age-1 was high during the 1950s, low during the 1960s, rose during the 1970s, and variable but generally high during the 1980s. Mean fishing mortality has been highly variable, rising from an average F of 0.67/yr in the 1950s, to 0.89/yr during the 1960s, to 1.08/yr during the 1970s, and then declining to 0.99/yr during the 1980s.

Estimates of population size and fishing mortality rates are used in developing surplus production models, spawner-recruit relationships, estimates of spawning stock ratio, and in population projections. The surplus production model suggests maximum sustainable yield lies in the interval 397,000 t to 571,000 t, while landings during the 1980s ranged from 238,000 t to 418,600 t. Although statistically significant spawner-recruit relationships are derived for Atlantic menhaden, there is considerable scatter about the predicted curves. Spawning stock ratios (both in weight and index of egg production) have not exceeded 10% since 1961, suggesting that continued high fishing mortality rates on both pre-spawners and spawners should not continue. Since the spawning stock ratio is already low, it is unreasonable to recommend any increase in IWP allotments over that taken [i.e., allotments should not exceed recent historical catches from the North Atlantic area (38,900 t)]. If the stock is to continue rebuilding, estimated spawning stock ratios suggest that coastwide fishing mortality should be reduced.

INTRODUCTION

This assessment of the Atlantic menhaden stock was undertaken at the request of the Atlantic Menhaden Advisory Committee (AMAC) for the Atlantic States Marine Fisheries Commission (ASMFC) in its role of providing advice to the individual states for responding to Internal Waters Processing (IWP) applications. The ASMFC adopted Resolution Number 1 during the 48th annual meeting that resolved for its geopolitical sections to "undertake a semi-annual collateral review procedure for IWP applications" and "that recommendations relative to allocation of fishery resources be developed consistent with the advice of the ASMFC's Interstate Fisheries Management Program." Resolution 102 of the New England Governors Conference (December 1989) requested ASMFC to provide guidance for Atlantic sea herrings IWPs. During the 1988 and 1989 fishing years, one IWP operated in Maine waters with a quota of 40,000 metric tons (t). For the 1990 fishing year, two IWP applications have been received by March 30 for Atlantic menhaden, both for 40,000 t in Maine. Given these resolutions and applications, this report was developed to provide the best available scientific information on the current status of the Atlantic menhaden stock, relative to IWP ventures in New England waters.

The data employed in this analysis were collected from the Atlantic menhaden reduction fishery. Landings information are available from 1940 through 1989, fishing effort (in vessel weeks) from 1941 through 1989, and estimated landings in numbers by age (from NMFS biostatistical port sampling) from 1955 through 1988. First, historical landings are presented for the entire Atlantic menhaden reduction fishery and for the North Atlantic area (Long Island north through the Gulf of Maine). Second, estimates of fishing mortality, population size, recruits and spawners are presented as obtained from an application of virtual population analysis on annual catch estimates at age from 1955 through 1988. Third, the results of several modelling exercises are presented, including those from surplus production models, spawner recruit models, and spawning stock ratios. Finally, several projections are made based on mean 1980s data and a Ricker spawner recruit model with increasing landings for the North Atlantic area representing different increasing levels of IWP exploitation. Much of the historical data and greater details of the analytical procedures are presented in Ahrenholz et al. (1987), Nicholson (1975), Smith et al. (1987), and Vaughan and Smith (1988).

HISTORICAL INFORMATION

Menhaden landings (in weight) generally rose during the 1940s and early 1950s, peaking at 712,100 t in 1956 (Figure 1). Landings then declined rapidly during the mid-1960s (bottomed out at 161,600 t in 1969), rose again during the 1970s to a recent peak of 418,600 t in 1983. Landings in 1989 amounted to about 322,000 t. Fishing effort in vessel weeks tracked landings well during the 1940s and

1950s, lagged behind landings during the collapse in the 1960s, and again tracks landings well during the 1970s and 1980s (Figure 1).

Nine plants on the Atlantic coast closed permanently during the 1980s, while two new operations began (Table 1). In 1989 five reduction plants with 37 vessels processed Atlantic menhaden for fish meal and oil. In the U.S., land-based plants are located at Beaufort, NC (1), and Reedville, VA (2); an IWP venture has operated in Maine waters since 1988, and menhaden are also caught off the coast of Maine and transported to a reduction plant in Blacks Harbor, New Brunswick, Canada. The recent low landings of 238,000 t in 1986 resulted from the temporary closure of one plant in Reedville, VA.

Landings are converted to estimated number of fish at age by weekly port sampling data that have been collected since 1955. Landings in weight and numbers are compared in Figure 2 and generally follow one-another well. The large number of Atlantic menhaden landed in 1959 (5.4 billion) were due primarily to a large number of age-1 menhaden landed (4.0 billion) that year from the an exceptionally strong 1958 year class. The proportion of landings in numbers by age clearly shows the dominance of subadults (age 0-2) (Figure 3). The large landings of adult menhaden in 1961 and 1962 resulted from the 1958 year class which were ages-3 and -4, respectively, in those fishing years.

Since 1955 most menhaden have been landed in the Middle Atlantic (including Chesapeake Bay) and South Atlantic areas (Figure 4). Although adult age menhaden (3+) dominate the North

Atlantic catches in most years (Figure 5), subadults (mostly age 2) were caught in large numbers in some years. Catches in the North Atlantic area declined during the 1960s from a high of 195 million menhaden weighing 98,500 metric tons in 1956 to a low of 3 million menhaden weighing 1,930 metric tons in 1966. During the 1980s catches have averaged about 124 million fish weighing 38,900 metric tons (Figure 6).

Different age frequencies of menhaden are found in the catches from the different fishing areas (Figure 7). Age-2 menhaden dominated the 1988 catches from the South Atlantic area with relatively large numbers of age-0, -1 and -3 fish also caught. Age-2 menhaden were even more dominant in the 1988 catches from the Middle Atlantic area (including Chesapeake Bay) with small numbers of age-0, -1 and -3 fish caught relative to the South Atlantic area. However, age-3 and age-4 menhaden dominated the 1988 catches from the North Atlantic area with a few age-2 and -5 fish caught. The number and weight of menhaden caught for four fishing areas (Chesapeake Bay is separated out from the Middle Atlantic area) are compared in Figure 8. In addition, an index of future egg production was developed based on mean fishing mortality during the 1980s and egg/length relationship of Lewis et al. (1987); that is, all individuals of a given age caught are projected through the remainder of their lifetime and corresponding egg production at age is calculated and summed. In terms of number and weight of menhaden landed, the Chesapeake Bay area clearly dominates the Atlantic coast menhaden reduction fishery (69% and 71%, respectively). However, in terms of future egg production (and the future of the stock), the North Atlantic area (39%) is most important, followed by the Middle (27%) and South Atlantic (21%) areas, with the Chesapeake Bay area (13%) the least important. The population projections presented at the end of this report reflect the importance of the spawning stock and their potential egg production.

VIRTUAL POPULATION ANALYSIS

As described in Ahrenholz et al. (1987) and Vaughan and Smith (1988), virtual population analysis (VPA) was applied to catch in numbers at age from 1955 through 1988 (Table 2; annual, rather than quarterly, estimates were used) to estimate age-specific population size and fishing mortality rates. The method of Murphy (1965) was applied to all complete or near complete year classes (cohorts) with natural mortality, M, set at 0.45. To bring population and fishing mortalities as current as possible, fishing mortalities for the 1988 fishing year were estimated by separable VPA (1985-1988 fishing years, Pope and Shepherd 1982) using a program provided by Douglas Clay (Fisheries and Oceans Canada, Moncton, New Brunswick). Murphy's (1965) method was then applied to these final F's to estimate younger population size and fishing mortality. Large variability in population estimates and fishing mortality in 1988 precluded their use in the following analyses. Population size in numbers at age at the beginning of the fishing year, population size in weight at age at mid-season, and fishing mortality at age are averaged by decade (Table 3).

Recruitment to age-1 was high during the late 1950s (averaging 6.9 billion menhaden), peaked in 1959 with 15.1 billion menhaden, then declined rapidly; it remained low during the 1960s (averaging 2.0 billion menhaden), rose during the 1970s (averaging 3.8 billion menhaden), and was variable, but generally higher during the 1980s (averaging 4.8 billion menhaden) (Figure 9). Population size (age-1 through age-8 menhaden) closely paralleled recruitment to age 1 with an average of 10.0 billion menhaden during the 1950s, 3.9 billion menhaden during the 1960s, 5.6 billion menhaden during the 1970s, and 7.6 billion menhaden during the 1980s.

Fishing and natural mortality estimates were used to convert population size in numbers at the start of the fishing year to population size in numbers at mid-season [0.5(M+F)]. Population size in weight was then estimated by multiplying by mean weight at age (Figure 10). As with population size in numbers, population weight averaged 755,400 t during the 1950s, 537,000 t during the 1960s, 506,500 t during the 1970s, and 597,000 t during the 1980s. Peak population weight of 2,347,900 t occurred in 1959, and was over 1,000,000 t in 1960 and 1961 fishing years, which elevated the 1960s average. Population weight remained under 500,000 t from 1963 through 1975, and dipped below 500,000 t again in 1983 and 1984.

Mean fishing mortality (F) has been highly variable between 1955 and 1987 (Figure 11). Mean F averaged 0.673/yr during the

1950s when population size was large. Mean F rose to 0.894/yr during the 1960s as recruitment and population size fell. During the 1970s mean F was highly variable (averaging 1.077/yr) with an extremely high value of 1.755/yr in 1973. Between 1955 and 1987 F has generally increased on age-0 fish and declined on age-1 fish.

SURPLUS PRODUCTION MODEL

Surplus production models compare the rate of change in population weight to changes in fishing mortality (Ricker 1975). Generally fishing effort is used as an index of fishing mortality and catch per unit effort is an index of population weight. Nominal or observed fishing effort (vessel weeks) for Atlantic menhaden does not follow trends in estimated mean F from the VPA (Figure 12). In the formulation of the surplus production model, the parameter "q" is generally assumed to be constant. However, for the Atlantic menhaden, and other purse seine fisheries, it has been noted that the parameter q has increased with improvements in gear and inversely decreased with population size (Figure 13). Hence, fishing effort needs to be adjusted so that q is fixed. Choosing 1988 as a base year, and multiplying nominal effort by the ratio q/q_{88} converts nominal effort to effective effort (Figure 14). Note that the effective catching power in the late 1950s and early 1960s was considerably less than the nominal fishing effort indicates. Hence, although nominal effort as represented by vessel weeks declined rapidly during the 1960s, effective effort has generally increased from the late 1950s to present. Catch per unit of nominal effort indicates a slight rise between 1941 and the late 1980s, suggesting a slow rise in population weight. However, catch per unit of effective effort (Figure 15) indicates a decline in population weight near 1960, with low and highly variable population weight since then.

The program PRODFIT (Fox 1975) was used to estimate the parameters of the generalized surplus production model of Pella and Tomlinson (1969) using annual reduction landings in metric tons and effective fishing effort in vessel weeks (nominal effort normalized to the 1988 base year). Maximum sustainable yield from this model fit is estimated as 484,000 t (±87,000 t) with 415 vessel weeks (±53 vessel weeks) of effective fishing effort (Figure 16). The estimate of effective fishing effort is equivalent to an estimate of F equal to 0.544/yr. The estimates of MSY and F agree well with those of Vaughan and Smith (1988; 487,000 t at F = 0.42/yr). Virginal population weight is estimated at 1,914,000 t and optimum population weight at 704,000 t. Only in the late 1950s was population weight at or above this optimum value (Table 3).

SPAWNER-RECRUIT MODEL

Spawner-recruit models relate spawning stock size (in numbers, weight, or potential egg production) to subsequent recruitment of young fish to the fishable stock (Ricker 1975). Spawning stock size in numbers for Atlantic menhaden is estimated as half the fish age-3 and older (proportion of females is 0.5), while spawning stock size in weight is estimated as half the weight of fish age-3 and older at the start of the fishing year. Figure 17 illustrates the importance of age-3 Atlantic menhaden (first age at maturity) to the spawning stock, especially between 1965 and the present. With the exception of 1985 when 53% by number and 42% by weight of spawners were age-3, 70% to 90% of the spawning stock were age-3. The low ratio for age-3 spawners in 1985 results from poor recruitment from the 1982 year class (2.4 billion age-1 menhaden in 1983). However, poor spawning stock in 1985 (76 million spawners weighing 19,200 t) produced good recruitment to age-1 in 1986 (4.7 billion age-1 menhaden). Nevertheless, this dependence of spawning stock on the first age at maturity raises concern that in general poor recruitment one year may lead to subsequent poor recruitment three years later.

Non-linear regressions were conducted using Ricker's spawner-recruit model:

$$R = \alpha S \exp(- \beta S) \qquad (1)$$

where α, β are parameters to be estimated, R is observed recruitment in numbers to age-1, and S is spawning stock size in numbers and weight. These parameters were estimated for Atlantic menhaden with spawners from 1955 through 1986 and recruits from 1956 through 1987. Significant fits were obtained with female spawning stock in numbers (α = 57.8 ± 12.7, β = 0.0038 ± 0.0008 with R, S in millions); and with female spawning stock in weight (α = 0.167 ± 0.034, β = 0.000010 ± 0.000002 with R in millions and S in 1000 t). Asymptotic standard error of the parameters are given following the parameter estimates. All parameters were found to be significantly different from zero. The estimated curves are plotted against the observed data in Figures 18 and 19, with maximum recruitment at about 250 million spawners (ages 3-8) or 100,000 t of spawners (ages 3-8). During the 1980s the number of spawners varied between 76 million in 1985 and 316 million in 1982, while weight of spawners varied between 17,300 t in 1986 and 57,700 t in 1980. Although number of spawners during the 1980s was probably adequate during the 1980s, weight of spawners was probably too low.

Although about 70% of the total variability in recruitment can be explained by prior spawning stock size, about the same amount of variability is explained by the model where recruitment equals its mean (independent of spawning stock). Considerable scatter about the theoretical curve remains, suggesting that environmental conditions may be more important in explaining recruitment variability.

SPAWNING STOCK RATIO

Gabriel et al. (1984, 1990) developed an index of maximum spawning potential as a ratio of spawning stock size calculated when fishing mortality is equal to that observed/estimated divided by the spawning stock size calculated when F is equal to 0 (unfished spawning stock). This index or ratio assumes that compensatory mechanisms such as increased growth rate or earlier maturity when a fish stock is reduced from fishing have already occurred (Goodyear 1989). It was thought that this index might provide ratios below which this index should not be allowed to decline to protect the stock from recruitment overfishing. These ratio estimates are calculated under the assumption of equilibrium; that is, the annual age-specific F is used to project a fixed number of recruits throughout their lifespan and sum the spawning stock weight or index of egg production. Spawning stock is estimated as the sum over all ages of the product of: (1) population in number of fish at the start of the year at each age, (2) proportion of fish that are female, (3) proportion of females that are mature, and (4) mean weight of females at the start of the year at each age. Survivors from one age to the next in the numerator of the ratio are reduced by $\exp(-(M+F))$, where M is natural mortality and F is age-specific fishing mortality; while survivors from one age to the next in the denominator of the ratio are reduced by $\exp(-M)$. This ratio can also be calculated based on an index of egg production [using egg-length relation in Lewis et al. (1987)]. When calculated for age-specific fishing mortality rates from a given fishing year, the estimates of spawning stock ratio assume equilibrium conditions. When calculated from age-specific fishing mortality rates from a cohort, equilibrium conditions are not required. Similarly results are obtained from both methods, but the nonequilibrium estimates shows smaller year-to-year variation.

Estimated equilibrium spawning stock ratios for Atlantic menhaden from 1955 through 1986 are compared in Figure 20. Spawning stock ratio based on spawning stock weight averaged about 11% during the late 1950s, fell to about 5% during the 1960s, declined again to about 4% during the 1970s, and rose slightly to 5% during the 1980s. Slightly lower but similar results were obtained from spawning stock as an index of egg production. Only in 1960 did the equilibrium estimate of spawning stock ratio exceed 20%. Although Gabriel et al. (1990) suggest a 30% spawning stock ratio to be the minimum required to achieve replacement for current Georges Bank halibut recruitment levels, lower levels appear adequate for Atlantic menhaden.

POPULATION PROJECTIONS

Projections for twenty-six years (1989 through 2015) were conducted with mean conditions for the 1980s (initial population size, fishing mortality rates, and fish lengths and weights at age). An age specific factor for incrementing fishing mortality rate was developed from the ratio of catch at age from the North Atlantic area to coastwide catch at age. Multiplying these by the coastwide age specific F's provide estimates of age specific F's for the North Atlantic area. Hypothetical increments in North Atlantic landings can be represented by multiplying these estimates of F for the North Atlantic by factors 1 through 5. Adding these hypothetical North Atlantic F's back onto the coastwide estimates of F, the Atlantic menhaden population can be projected for a fixed number of years (26) representing the increased landings in the North Atlantic (in increments of the mean 1980 landings, 38,900 t).

Several population level variables (recruits, spawning stock weight, population weight, landings, and spawning stock ratio in weight) are calculated for each projection year. The final year of the projections, normalized across factor levels, is compared in Figure 21. The baseline (factor = 0) represents mean 1980 conditions with about 38,900 t landed from the North Atlantic area. A factor of one implies an additional landing of 38,900 t in the North Atlantic area, while 2 represents an additional landing of 79,800 t in the North Atlantic area, and so forth. With increasing landings in the North Atlantic area, there is a decline in all variables retained. Recruits and landings decline at the slowest rate, population declines at a slightly greater rate, spawning stock ratio follows, and absolute spawning stock declines most rapidly. Since recruitment is declining, absolute spawning stock will decline more rapidly than spawning stock ratio.

As the mean F (0.99 for the 1980s) is decreased proportionally across ages, the spawning stock ratio increases (Figure 22). When mean F is 0, then the spawning stock ratio is 1. Fishing mortality would need to be reduced to about 40% of the mean 1980s F to attain a spawning stock ratio of 20%.

CONCLUSIONS

Recent historical catches of 38,900 t of Atlantic menhaden from the North Atlantic area during the 1980s suggest that this amount at least would be available in the future from this area. Maximum sustainable yield, as estimated from the generalized production model, suggest greater landings are available from the Atlantic menhaden stock coastwide and for the North Atlantic area as well. But the relative value of menhaden caught in the North Atlantic area is considerably greater to the spawning stock than younger menhaden caught from other areas, especially from the Chesapeake Bay area where landings in numbers and weight predominate. In addition to the higher relative value of older menhaden to the stock through a greater contribution of eggs, the older menhaden are also more valuable to the reduction fishery because of greater content of oil per unit weight of fish.

Although statistically significant spawner-recruit relationships are derived for Atlantic menhaden, there is considerable scatter about the predicted curves. Spawning stock ratios (both in weight and index of egg production) have not exceeded 10% since 1961. They suggest that continued high fishing mortality rates on both pre-spawners and spawners should not continue. Population projection results suggest that a large decline in spawning stock ratio (a 32% drop from 4.7% with a factor of 0 to 3.2% with a factor of 5), and a more rapid fall in absolute spawning stock (42% between factor 0 and factor 5). However, note that factor 5 represents an IWP of about 195,000 t on top of current landings in the North Atlantic area. Since the spawning stock ratio is already low, it is unreasonable to recommend any increase in IWP allotments over that taken [i.e., allotments should not exceed recent historical catches from the North Atlantic area (38,900 t)]. If the stock is to continue rebuilding, estimated spawning stock ratios suggest that coastwide fishing mortality should be reduced.

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Table 1. Atlantic menhaden reduction plants active during the 1980s.

Company	Location	Year[a]
Inactive:		
Seacoast Products Co.	Port Monmouth, NJ	1981
Pt. Judith By Products	Pt. Judith, RI	1982
Pine State Products	South Portland, ME	1983
Standard Products	Southport, NC	1983
Standard Products	Beaufort, NC	1984
Lipman Marine Products Co.	Gloucester, MA	1984
Sea and Sound Processing Co.	Beaufort, NC	1986
Nassau Oil and Fertilizer	Fernandina Beach, FL	1987
Sea Pro Inc.	Rockland, ME	1988
Currently Active:		
Beaufort Fisheries	Beaufort, NC	1980
AMPRO Fisheries Inc.[b]	Reedville, VA	1980
Zapata Haynie Corp.	Reedville, VA	1980
Connor Brothers	Blacks Harbor, NB	1987
Resource Trading Co. (IWP)	Maine	1988

[a] For inactive plants, year is last fishing year that plant operated; and for currently active plants, year is first year plant operated, 1980 is given if plant was active at start of 1980s.

[b] AMPRO Fisheries Inc., formerly Standard Products, did not fish during the 1986 fishing season.

Table 2. Landings (in millions) of Atlantic menhaden from the reduction fishery by age, 1955-1989.

Fishing Year	Age (yr) 0	1	2	3	4	5	6	7	8+	Total
1955	761.01	674.15	1057.68	267.31	307.21	38.07	10.53	1.84	0.64	3,118.44
1956	36.37	2073.26	902.72	319.60	44.78	150.68	28.70	6.72	1.99	3,564.82
1957	299.58	1599.98	1361.77	96.73	70.80	40.52	36.93	4.26	1.10	3,511.67
1958	106.06	858.16	1635.35	72.05	17.25	15.94	9.09	4.88	0.43	2,719.21
1959	11.40	4038.72	851.29	388.27	33.41	11.87	12.36	4.55	1.77	5,353.64
1960	72.17	281.01	2208.63	76.37	102.20	23.77	7.95	2.36	0.65	2,775.11
1961	0.25	832.42	503.60	1209.57	19.18	29.38	2.86	0.81	0.24	2,598.31
1962	51.58	514.11	834.52	217.25	423.37	30.75	24.60	2.98	0.70	2,099.86
1963	96.89	724.23	709.20	122.53	44.97	52.38	10.42	3.33	0.56	1,764.51
1964	302.59	703.95	604.98	83.50	17.94	7.85	6.62	1.31	0.32	1,729.06
1965	259.12	745.21	421.40	77.76	12.17	1.81	1.22	0.75	0.07	1,509.48
1966	349.45	550.82	404.14	31.70	3.89	0.36	0.11	0.11	0.04	1,340.61
1967	6.95	633.20	265.67	72.78	5.09	0.49	0.01	0.0	0.0	984.18
1968	154.26	377.36	538.95	65.69	10.68	0.98	0.06	0.0	0.0	1,147.98
1969	158.13	372.33	284.31	47.81	5.44	0.15	0.01	0.0	0.0	868.18
1970	21.42	870.85	473.92	32.63	4.02	0.11	0.0	0.0	0.0	1,402.96
1971	72.85	263.29	524.32	88.29	17.84	2.51	0.0	0.0	0.0	969.10
1972	50.16	981.27	488.47	173.06	19.12	1.86	0.0	0.0	0.0	1,713.95
1973	55.98	588.47	1152.94	38.63	7.00	0.34	0.0	0.0	0.0	1,843.36
1974	315.55	636.68	985.97	48.59	2.49	1.35	0.0	0.0	0.0	1,990.63
1975	298.64	719.96	1086.53	50.24	6.63	0.20	0.10	0.0	0.0	2,162.30
1976	274.23	1611.96	1341.09	47.97	7.95	0.28	0.0	0.0	0.0	3,283.47
1977	484.62	1004.54	2081.77	83.46	17.80	1.41	0.11	0.0	0.0	3,673.71
1978	457.41	664.09	1670.91	258.12	31.19	3.48	0.0	0.0	0.0	3,085.20
1979	1492.46	623.14	1603.29	127.93	21.76	1.47	0.09	0.0	0.0	3,870.13
1980	88.29	1478.09	1458.23	222.71	69.23	14.36	1.43	0.0	0.0	3,332.32
1981	1187.57	698.66	1811.46	222.20	47.47	15.37	1.27	0.0	0.0	3,984.02
1982	114.12	919.44	1739.55	379.67	16.33	5.78	0.53	0.32	0.0	3,175.72
1983	964.41	517.22	2293.06	114.35	47.37	5.01	0.23	0.0	0.46	3,942.11
1984	1294.22	1024.17	892.09	271.50	50.34	15.21	0.51	0.0	0.0	3,548.04
1985	637.19	1075.85	1224.62	44.06	35.63	6.25	1.68	0.0	0.0	3,025.29
1986	100.28	224.99	1527.45	48.72	10.18	6.38	1.15	0.0	0.0	1,919.16
1987	44.93	541.78	1652.04	143.87	25.47	2.23	0.75	0.0	0.0	2,411.08
1988	429.16	314.09	1180.64	309.28	70.74	6.77	0.52	0.23	0.0	2,311.43

Table 3. Mean age specific population numbers (at start of fishing year), population weight at mid-season, and fishing mortality rates for Atlantic menhaden.

Fishing Period	Age (yr) 0	1	2	3	4	5	6	7	8	Total
					Population (millions of fish)					
1950s	a	6889.0	2112.1	532.3	271.8	114.0	36.9	9.5	2.7	9968.4
1960s	a	1951.1	1368.2	378.0	114.7	29.2	8.8	1.9	0.5	3852.3
1970s	a	3760.0	1632.8	163.5	22.7	2.1	0.1	0.1	0.0	5581.4
1980s	a	4831.5	2381.9	315.6	62.5	12.8	1.7	0.3	0.2	7606.7
					Population (thousands of metric tons)					
1950s	401.6	413.7	237.4	120.3	82.4	35.9	11.9	3.4	1.0	755.4
1960s	147.8	146.0	140.1	64.6	26.2	9.0	2.6	0.6	0.2	537.0
1970s	135.1	244.3	95.9	25.9	4.7	0.4	0.1	0.0	0.0	506.5
1980s	155.3	250.4	124.5	34.7	10.9	2.1	0.4	0.1	0.0	597.0
					Fishing Mortality Rate (1/yr)					(Mean[b])
1950s	0.037	0.398	1.164	0.693	0.490	0.674	1.001	0.905	0.745	0.673
1960s	0.059	0.471	1.389	1.491	1.871	1.761	1.506	1.023	0.803	0.894
1970s	0.054	0.314	1.803	1.372	1.651	1.763	0.719	0.0	0.0	1.077
1980s	0.104	0.241	1.625	1.132	1.252	1.727	1.299	0.039	0.199	0.991

[a] Not given, but relative index of number of eggs produced could be obtained from Lewis et al. (1987).

[b] Weighted mean of age-specific fishing mortality rates, weighted by catch in numbers at age.

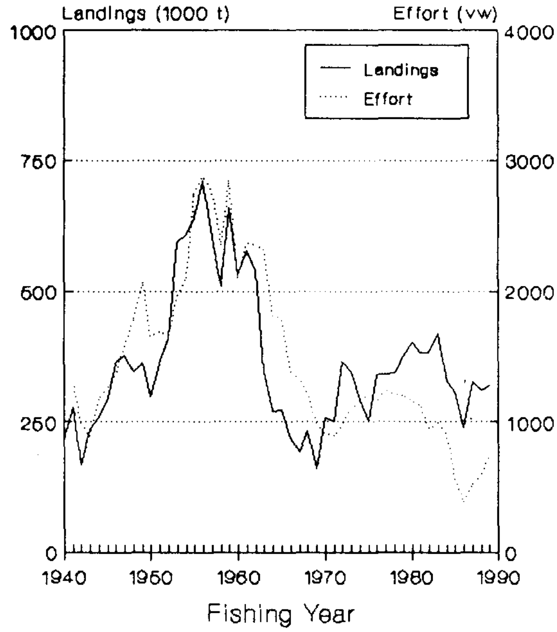

Fig. 1. Landings and fishing effort of Atlantic menhaden, 1940-1989.

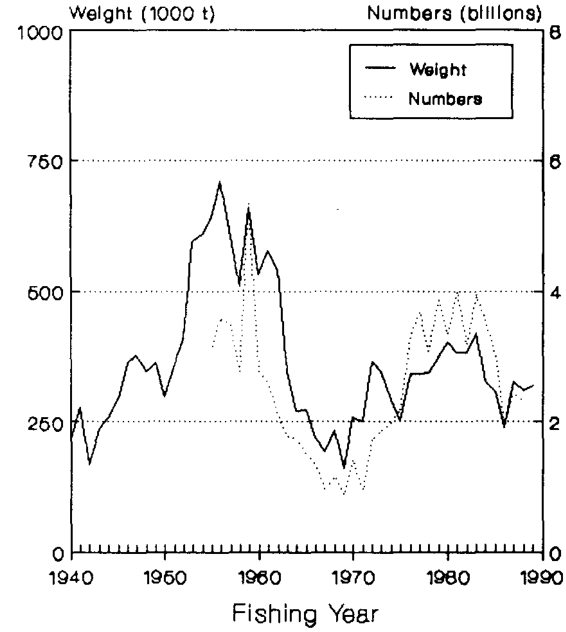

Fig. 2. Landings in weight and numbers of Atlantic menhaden, 1940-1989.

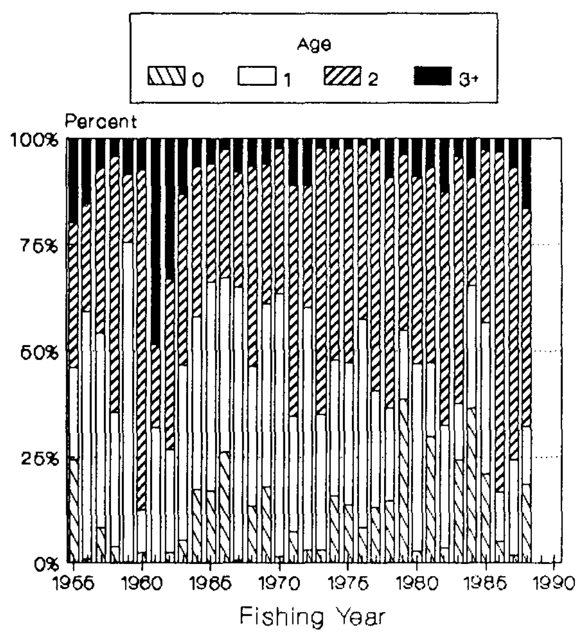

Fig. 3. Landings in numbers by age for Atlantic menhaden, 1955-1988.

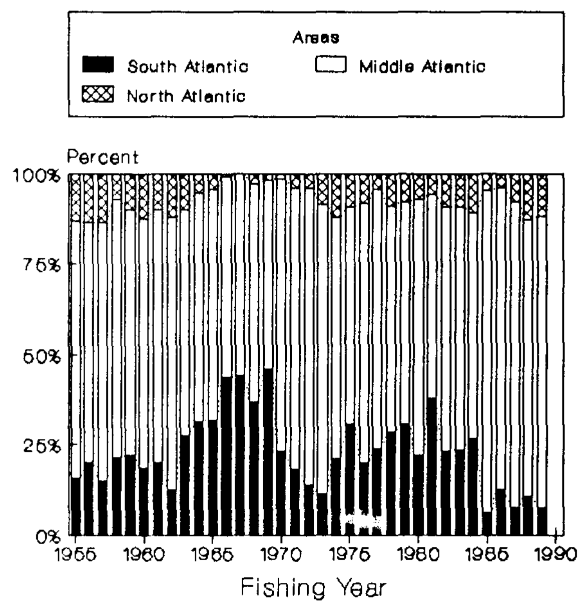

Fig. 4. Catch by area landed for Atlantic menhaden, 1955-1989. (Ches. Bay included in Middle Atlantic)

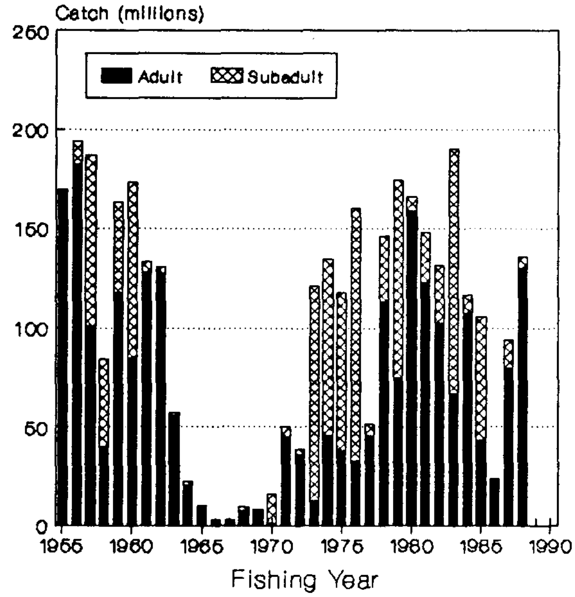

Fig. 5. Catch in numbers by age group in North Atlantic, 1955-1988. (1955-64 based on NA landings)

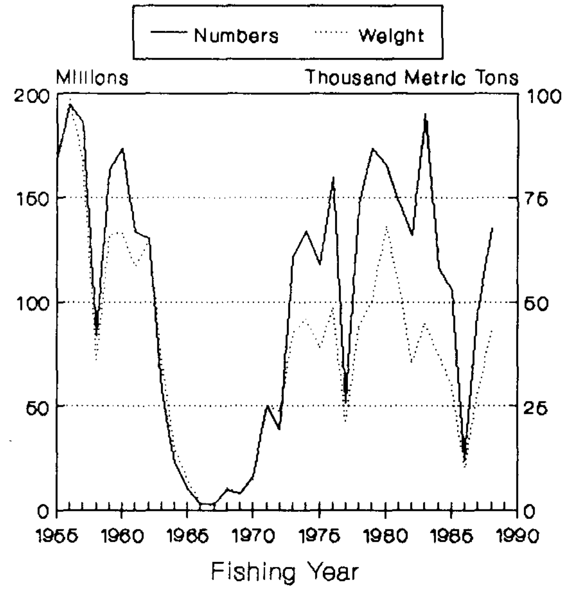

Fig. 6. Catch in numbers and weight in North Atlantic area, 1955-1988. (1955-1964 based on North Atlantic landings)

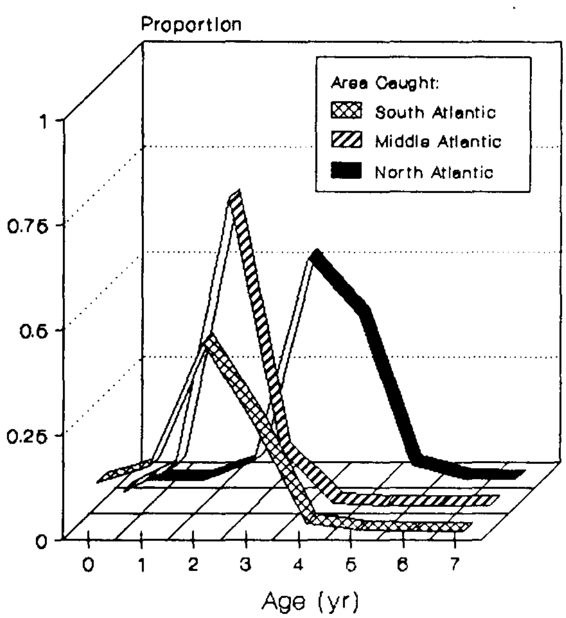

Fig. 7. Age frequency distribution of of menhaden by area caught in 1988. (Ches. Bay included in Middle Atantic)

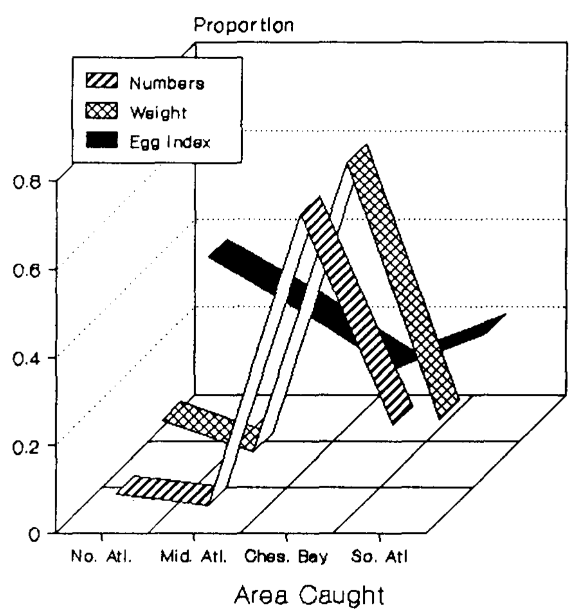

Fig. 8. Relative value of menhaden in numbers, weight, and egg index by fishing area caught in 1988.

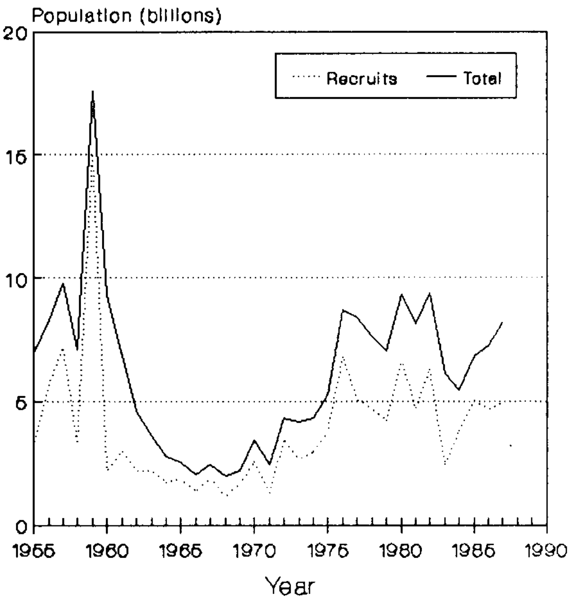

Fig. 9. Recruits (age-1) and population size (ages 1-8) in numbers for menhaden, 1955-1987.

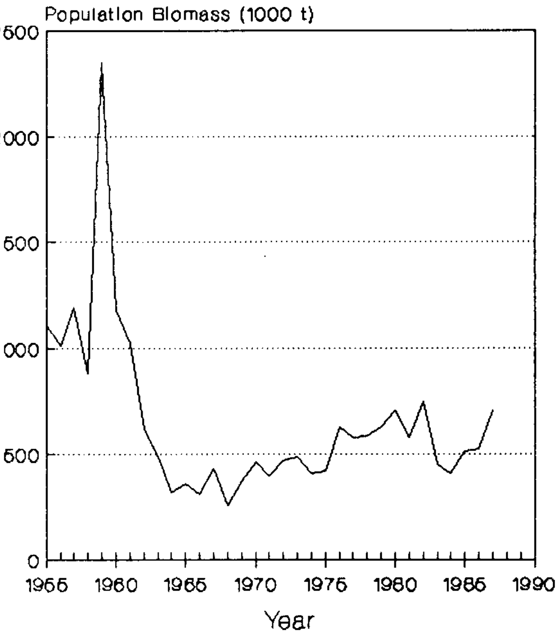

Fig. 10. Weight of Atlantic menhaden population at mid year, 1955-1987.

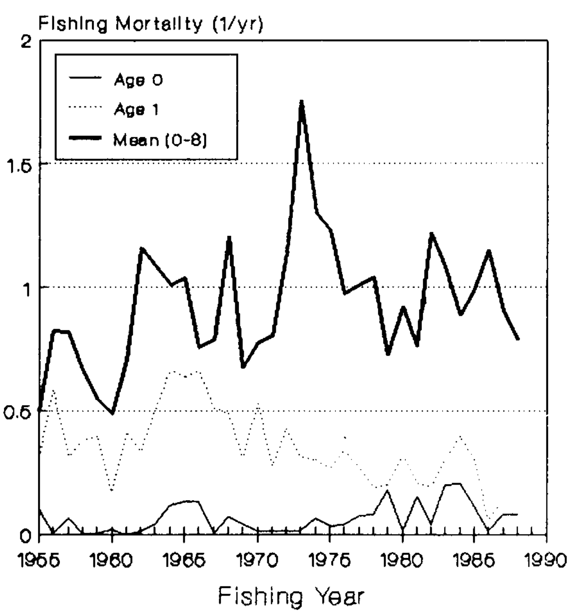

Fig. 11. Mean fishing mortality for Atlantic menhaden, 1955-1988. Also fishing mortality for ages-0 and -1.

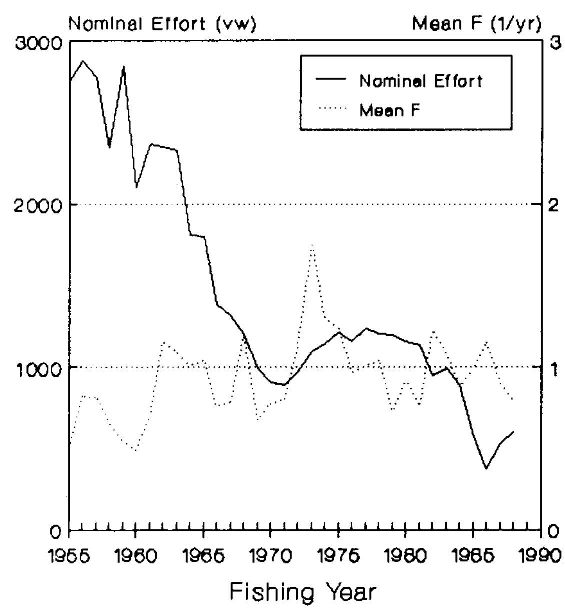

Fig. 12. Nominal fishing effort and mean F for Atlantic menhaden, 1955-1988.

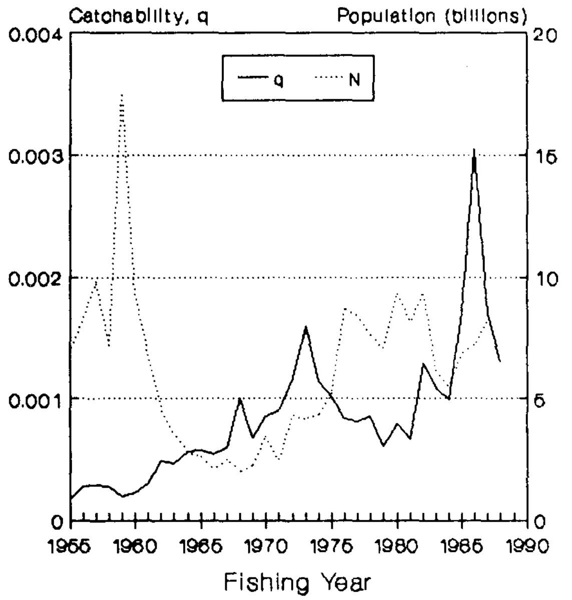

Fig. 13. Population size and q for Atlantic menhaden, 1955-1988. q is catchability coefficient.

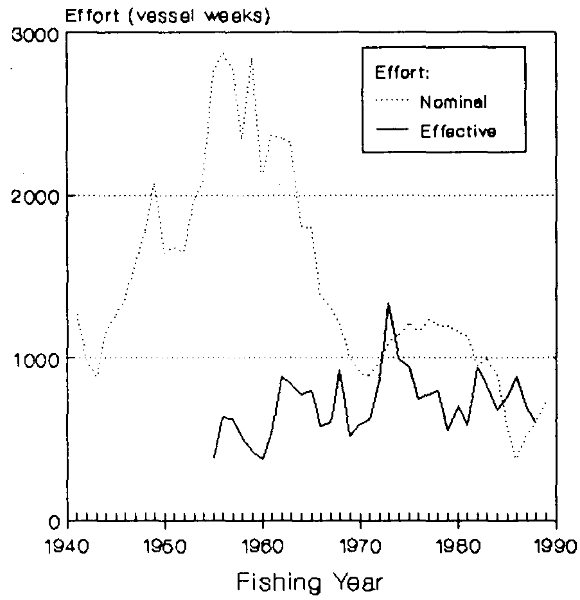

Fig. 14. Nominal and effective fishing effort for Atlantic menhaden, 1941-1989.

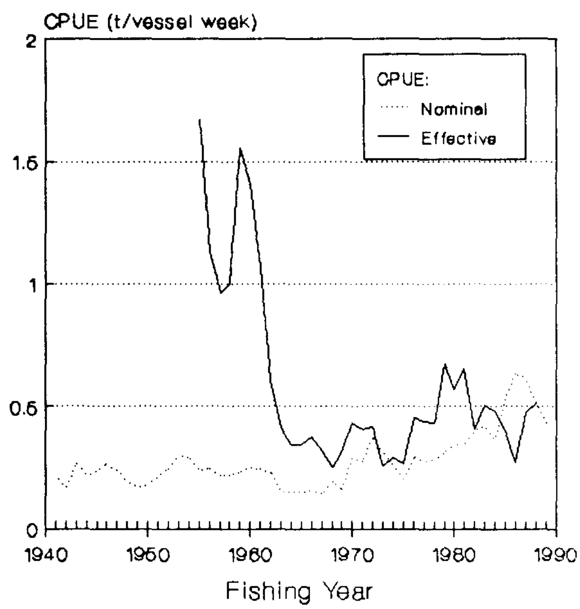

Fig. 15. CPUE with nominal and effective fishing effort for Atlantic menhaden, 1941-1989.

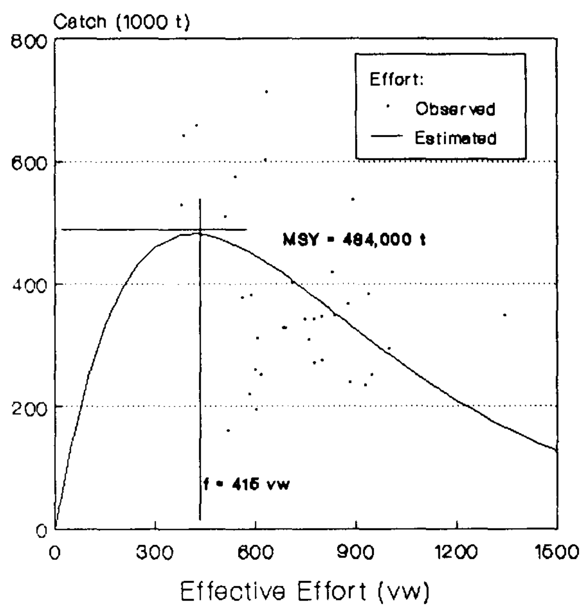

Fig. 16. Observed catch and effective effort and generalized production model for Atlantic menhaden.

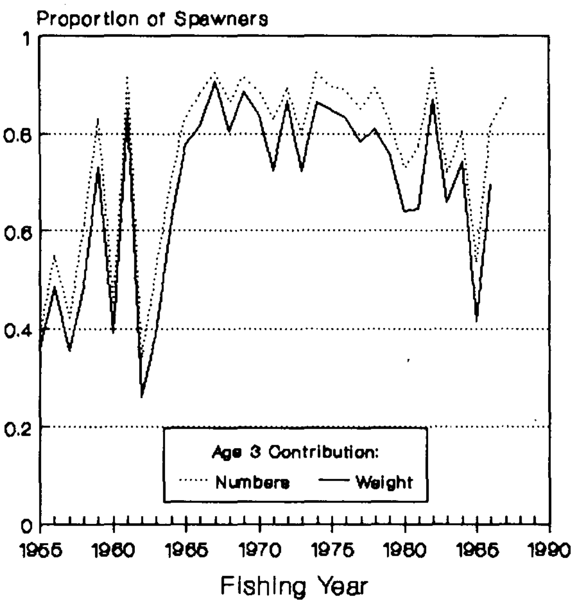

Fig. 17. Contribution of age 3 to spawning stock in numbers and weigh of Atlantic menhaden, 1955-1987.

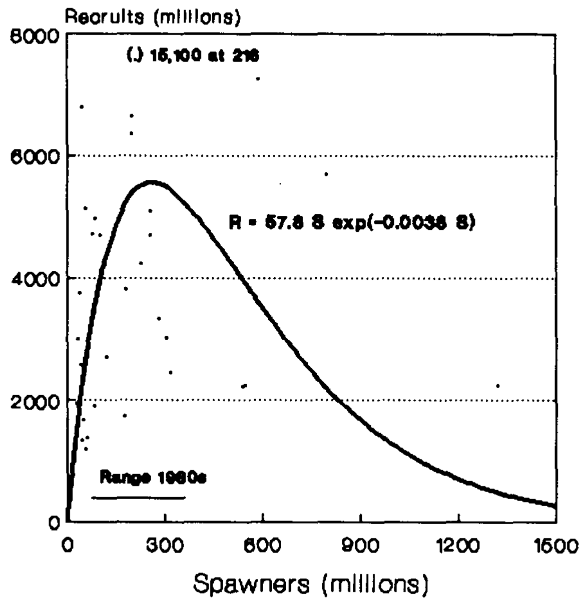

Fig. 18. Observed and estimated recruits from spawners in numbers for Atlantic menhaden, 1955-1987.

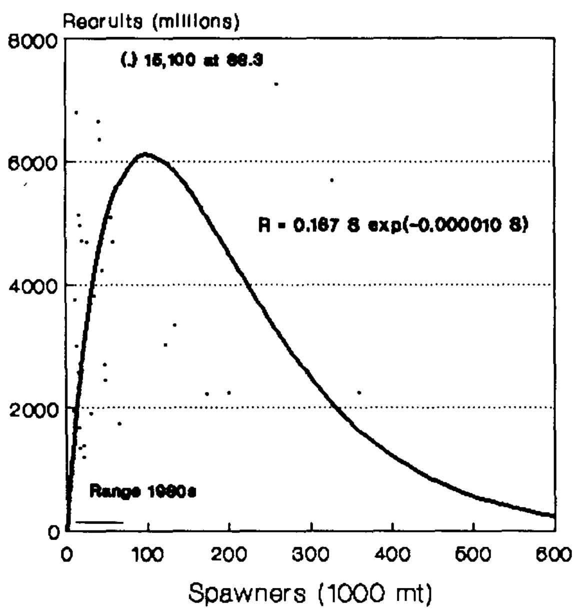

Fig. 19. Observed and estimated recruits from spawners in weight for Atlantic menhaden, 1955-1987.

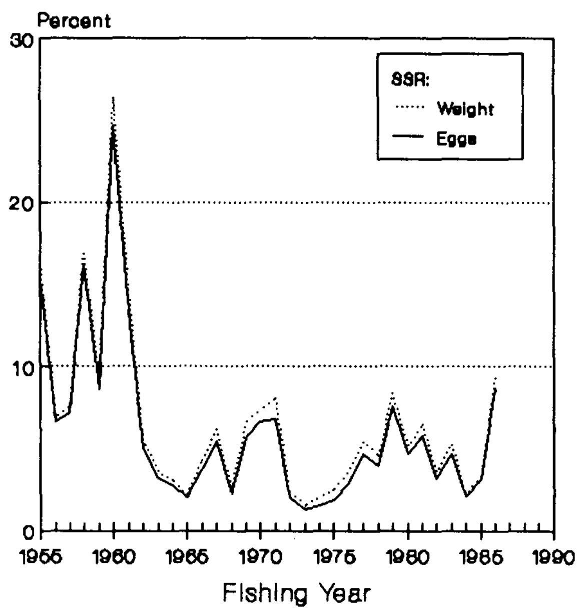

Fig. 20. Equilibrium spawning stock ratio in weight and index of eggs for Atlantic menhaden, 1955-1986.

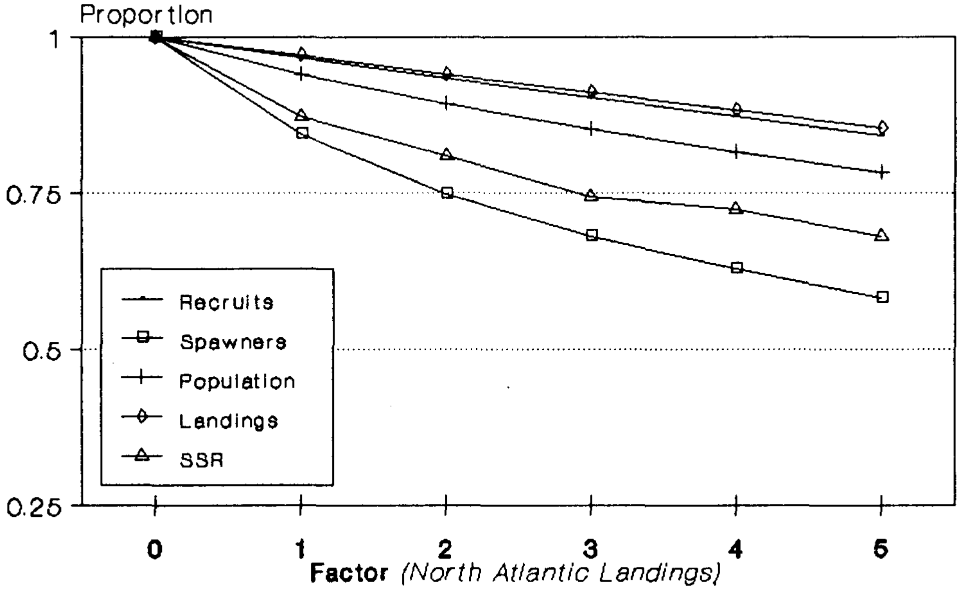

Fig. 21. Recruits, spawners, landings, population size, and SSR for Atlantic menhaden with increasing NA landings.

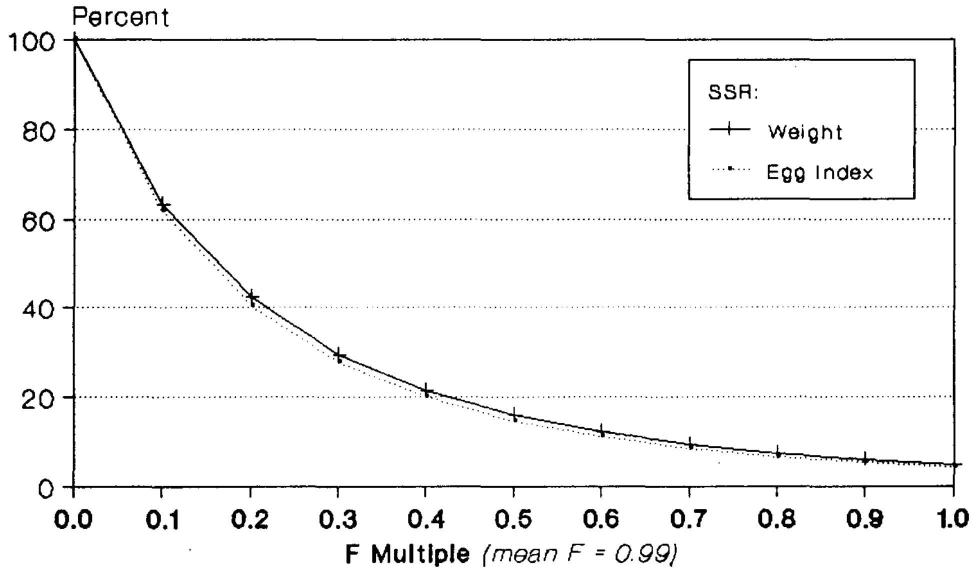

Fig. 22. Spawning stock ratio (weight and egg index) vs f multiple for Atlantic menhaden (mean 1980s).