Biological Analysis of Two Management Options for the Atlantic Menhaden Fishery

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Introduction

The Atlantic menhaden, *Brevoortia tyrannus*, is a euryhaline species found in coastal and inland tidal waters from Nova Scotia, Can., to West Palm Beach, Fla. (Fig. 1) (Reintjes, 1969). They form surface schools in spring and move slowly northward along the Atlantic coast, stratifying by age and size during summer (older and larger fish are generally found farther north) (Nicholson, 1972, 1978). In fall a southern migration begins and by late December or early January surface schools disappear off the Carolinas. Menhaden spawn at sea where the eggs hatch and the larvae are moved into estuaries by ocean currents (Nelson et al., 1977) where they metamorphose and develop into juveniles. In late fall and early winter, the juveniles leave the estuaries and move into large bays or the ocean.

ABSTRACT—Biological implications of two managment options (the closed corridor and the recommended shortened season (Option 7) options) for the Atlantic menhaden, Brevoortia tyrannus, *fishery are reported based on purse-seine landings and port sampling data from 1970 to 1984 and captain's daily fishing reports from 1978 to 1982. Large catches of age-0 menhaden raise concern for growth overfishing. Area-specific yield-per-recruit analyses are used to investigate the biological consequences of these management options. The closed corridor option indicates coastwide gains in yield-per-recruit ranging from 0.3 to 7.2% depending on changes in fishing activity with most areas showing gains. The shortened fishing season indicates coastwide gains in yield per recruit ranging from 0.4 to 10.2% depending on fishing year with most geographic areas showing gains. The shortened fishing season option offers the greatest gains when large numbers of young menhaden would be caught late in the fishing year, while gains from the closed corridor option depend on how the fishing fleet responds to that management plan. The shortened season offers greater potential coastwide gains to the fishery, but also may result in greater losses to the North Carolina fall fishery. The analytical approach is applicable to the management of other coastal migratory fish stocks that fall under the Atlantic States Marine Fisheries Commission or other interstate management groups.*

A commercial fishery for Atlantic menhaden has existed since colonial times (Frye, 1978). Modern menhaden reduction plants produce fish meal and solubles, used in poultry and livestock feeds, and oil, used in paints and as an edible oil in Europe and Canada. Atlantic menhaden landings and fishing effort peaked in the late 1950's, declined sharply during the 1960's, and rose gradually during the 1970's and early 1980's (Fig. 2). These landings historically have depended primarily on age-1 and age-2 fish in terms of numbers (Fig. 3). However, large landings of age-3 and age-4 fish in 1961 and 1962, respectively, resulted from the large 1958 year class (note age-1 fish landed in 1959 and age-2 fish landed in 1960). Also, landings of age-0 fish (or "peanuts") exceeded landings of age-1 fish (and age-2 fish as well in 1984) in 1979, 1981, 1983, and 1984. In particular, most Atlantic menhaden landed during the North Carolina fall fishing season are age-0 fish (Fig. 4). The increased dependence of the fishery on age-0 fish (four of the last six years) has increased the concern that growth overfishing may be occurring; that is, Atlantic menhaden are harvested at too young an average age for the full potential harvest from a year class to be attained.

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In October 1981 the Atlantic States Marine Fisheries Commission (ASMFC) adopted the Atlantic Menhaden Management Plan (AMMB, 1981). The plan proposed adjustments to fishing activity which included a combination of two approaches: 1) Reducing the catch of age 0, 1, and 2 fish to enhance the survival of menhaden to sexual maturity and increase yield per recruit, 2) reducing the catch of age 3+ menhaden to enhance the number of individuals in the spawning stock. The Atlantic Menhaden Advisory Committee (AMAC) developed a series of management options (actions) for the Atlantic Menhaden Implementation Subcommittee (AMIS) (AMAC, 1982) which were directed at increasing yield per recruit through protection of prerecruit menhaden via area closure, season closure, mesh size limit, or effort reduction. Detailed yield-per-recruit analyses are presented for the closed corridor option and the shortened season management option (Option 7) preferred by AMIS/AMMB.

The closed corridor management option would prohibit purse-seine fishing in an area extending from the beach to 1 mile offshore from Cape Henry, Va., to Cape Fear, N.C., during the period November through January (AMAC, 1982). The intent of this option was to protect a significant fraction of age-0 Atlantic menhaden ("peanuts") thought to occur predominantly within the 0-1 mile zone as they migrate south during the North Carolina fall fishery. As proposed, the option did not address inside waters (rivers and sounds).

Seven season options were investigated (AMAC, 1982), ranging from a curtailment of the fishing season by 1

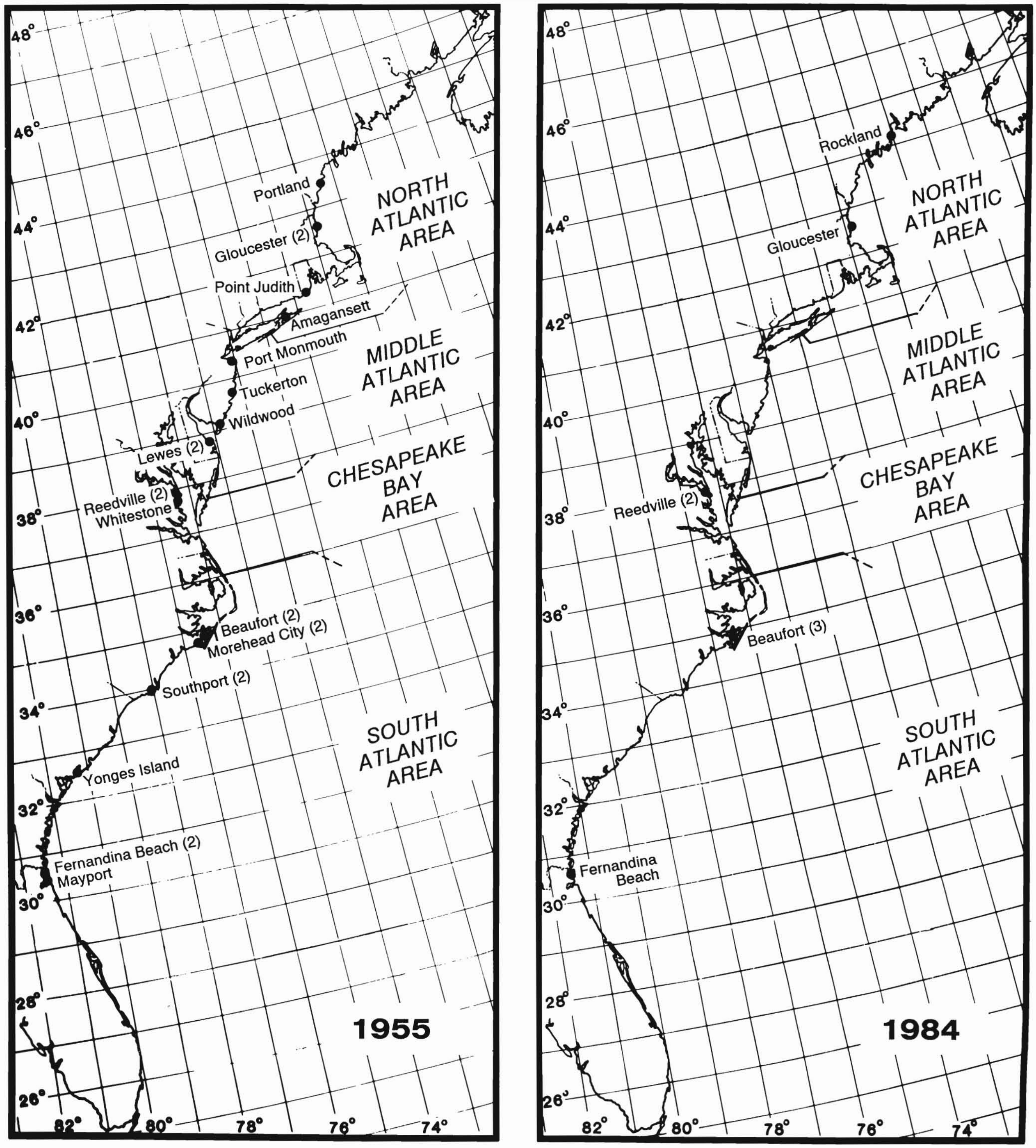

Figure 1.—Geographic fishing areas for the Atlantic menhaden purse-seine fishery, and landing ports for 1955 and 1984. The number of plants operating at each port is given in parentheses when greater than one.

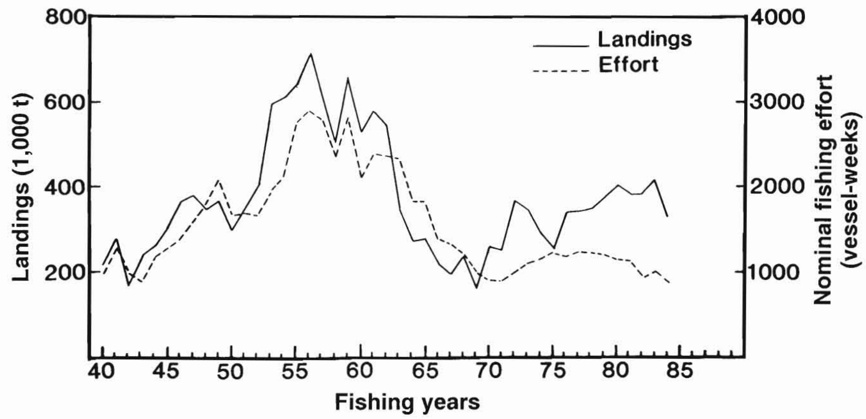

Figure 2.—Catch of Atlantic menhaden in thousands of metric tons and fishing effort in vessel weeks from 1940 to 1984.

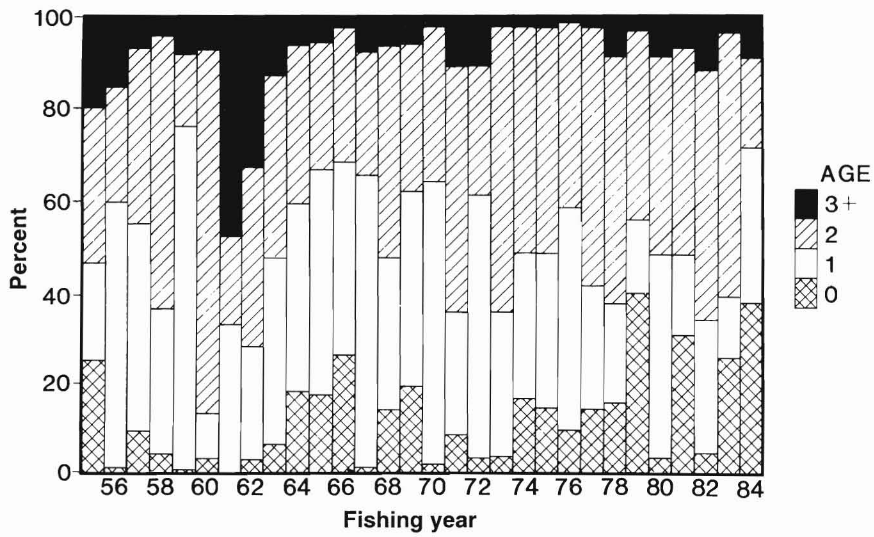

Figure 3.—Contribution in percent of total numbers of Atlantic menhaden landed by age group from 1955 to 1984.

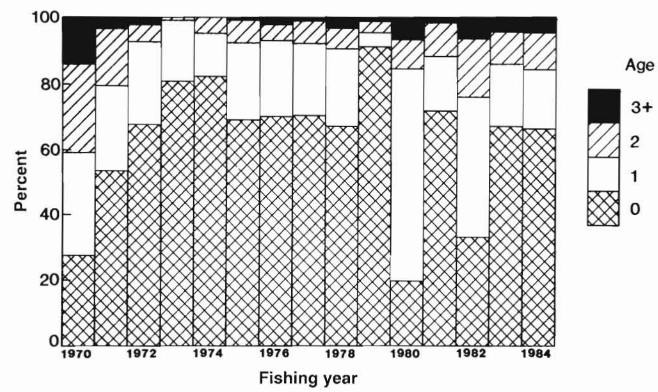

Figure 4.—Contribution in percent of total numbers of Atlantic menhaden landed in the North Carolina fall fishery (Area 5) by age group from 1970 to 1984.

month in a single geographic area (Option 1) to 1 month in all four geographic areas (Option 7). In May 1982, the Atlantic Menhaden Management Board (AMMB) approved a reduction of the fishing season in each reporting area by 4 weeks to be effective in 1983 (Option 7). Proposed opening and closing by week ending dates (Saturday) were:

	Opening Period	Closing Period
North Atlantic	5/17 - 5/23	10/04 - 10/10
Middle Atlantic	5/17 - 5/23	10/11 - 10/17
Chesapeake Bay	5/17 - 5/23	11/08 - 11/14
South Atl. and N.C. fall fishery	4/12 - 4/18	12/13 - 12/19

As of April 1987, six of the 15 member states of the Atlantic States Marine Fisheries Commission (ASMFC) have adopted the approved shortened season management option in compliance with the coastwide Atlantic menhaden fishery management plan. Because of the migratory nature of Atlantic menhaden and multiple jurisdiction of the Atlantic coastal states, it is necessary to consider the differential effect of fishing on different components of the stock. This paper compares two major management options considered by the AMMB in terms of the relative gains in yield per recruit across geographic areas. This approach would be applicable to other highly migratory fish stocks that fall under interstate jurisdiction or the jurisdiction of several councils such as striped bass or weakfish.

Methods

The Beaufort Laboratory of the NMFS Southeast Fisheries Science Center has maintained records of all daily menhaden vessel landings and fishing activity since 1955. Port sampling of catches for weight, length, and age composition are used in conjunction with vessel landings to estimate number of fish landed at each age by plant and area, to determine growth rates, and to estimate fishing mortality (Ahrenholz et al., 1987; Smith et al., 1987). Captain's daily fishing reports, maintained since 1978 on the Atlantic coast, contain specific information about individual purse-seine sets, such as location and distance from shore. An overview of the life history and stock structure of the Atlantic menhaden is presented in Ahrenholz et al. (1987).

June and Reintjes (1959) divided the Atlantic coast into four geographic fishing areas and one temporal fishing area (Fig. 1) for purposes of summarization and analysis. A change in boundary line between the South Atlantic and Chesapeake Bay areas was reported by Nicholson (1975). The divisions are the North Atlantic Area, the Middle Atlantic Area, the Chesapeake Bay Area, the South Atlantic Area, and the North Carolina fall fishery. Historically, the North Carolina fall fishery takes place from Cape Hatteras, N.C., south to the southern border of North Carolina. It begins between the last week of October and the second week of November, depending on the arrival of migratory menhaden from more northerly waters, and lasts to the end of February of the next calendar year, although fishing usually stops by mid-January. For standardized data summary, we use the week which ends (on Saturday) between 8 November and 14 November as the first week of the North Carolina fall fishery.

Closed Corridor Option

The analysis of this option uses estimates of fishing mortality and growth in Ahrenholz et al. (1987) and methods presented in Vaughan (1985). The North and Middle Atlantic fishing areas were combined, and the North Carolina fall fishery was split into three areas: 1) Inside waters including bays and sounds, 2) closed corridor (0-1 mile offshore), and 3) outside waters greater than 1 mile offshore. Quarters of the fishing year were adjusted so that the fourth quarter would coincide with the North Carolina fall fishery and the period of the closed corridor. Quarters began on 1 March, 24 May, 16 August, and 8 November.

Three types of data are used in the following analyses: Vessel landings, port sampling, and captain's daily fishing reports (CDFR). The intersection of the port sampling data base, containing information on the age of the fish, and the CDFR's, containing information on set size and distance from shore, can be used to obtain estimates of the landings in numbers at age for inside waters, the proposed closed corridor (0-1 mile), and outside waters (>1 mile) during the North Carolina fall fishery. Availability of CDFR's from the North Carolina fall fishery is incomplete. Thus, we must assume that the matched data set (i.e., intersection of port sampling and CDFR data sets) adequately describes the catch from Cape Henry, Va., to Cape Fear, N.C., during the North Carolina fall fishery. About 10% of the landings in Virginia after 8 November were caught in the closed corridor area; in biomass this was equal to about 2% of the landings from the North Carolina fall fishery. Over 99% of the landings at North Carolina plants after 8 November were caught between Cape Henry and Cape Fear. Our analysis also assumed that reported catches equal landings and that estimates of catches in numbers at age from inside, closed corridor, and outside waters between the capes during the North Carolina fall fishery could be restricted to North Carolina plants.

Estimation of growth in weight by age and area used the weight (or cubic) version of the von Bertalanffy (1938) growth equation. The port sampling data base for fishing years 1978-82 provided estimates of weight at age for the North Atlantic, Middle Atlantic, Chesapeake Bay, and South Atlantic fishing areas by averaging across fishing years; the estimates of weight for the North and Middle Atlantic areas were then averaged. Comparable estimates of weight at age for the three areal divisions of the North Carolina fall fishery were obtained using the matched data from port sampling and CDFR's. Mean weights at age were also computed for the entire fishery (coastwide) using catch in numbers at age as the weighting factor for each area. Estimates of weight at age at the start of each quarter were generated from estimated parameters in Vaughan (1985: Table 8).

Sensitivity of our conclusions to variability in estimated instantaneous fishing mortality rates was investigated by selecting minimum and maximum estimates of instantaneous fishing mortality rates for each age in quarters from the smallest and largest annual values of the instantaneous fishing mortality rate, respectively (Vaughan, 1985: Table 6). Yield-per-recruit analyses depend on these sets of age-specific mortality rates. Four sets of yield-per-recruit analyses are made: 1) No implementation of the closed corridor management option (used as the base data for comparisons), 2) closed corridor option implemented and no shift of fishing effort from the closed corridor to any other fishing area (Hypothesis I), 3) all fishing effort in the closed corridor redirected to outside waters (>1 mile) (Hypothesis II), and 4) all fishing effort is proportionally divided between the inside waters and outside waters (Hypothesis III). A constant relationship between fishing effort and catch per unit of fishing effort within the same quarter of any given fishing year (i.e., 1978-82) had to be assumed to evaluate the hypotheses. The assumption appears tenable when comparing catches within any given geographic area and season (e.g., North Carolina fall fishery), but is less so across major geographic areas or seasons. Under Hypothesis II all fishing effort is redirected to outside waters, thus fishing effort for the closed corridor simply is multiplied by catch per unit effort for outside waters to estimate catch from outside waters. Hypothesis III divides fishing effort for the closed corridor among inside and outside waters proportional to the catch in numbers for the two areas, and when multiplied by their respective catch per unit effort yields catch. The ratio of these extra catches at age from inside or outside waters to the total catch from the closed corridor allows calculation of the instantaneous fishing mortality rate from the closed corridor that can be applied to inside or outside waters.

Shortened Season Option (Option 7)

The analysis of this option was performed as an adjunct to an updated stock assessment of Atlantic menhaden (Vaughan and Smith, 1988). The fishing year was divided into four approximately equal periods beginning 1 March, 1 June, 30 August, and 30 November, for which a given fishing year extends to the end of February of the following calendar year. Fork lengths at age are arranged quarterly by cohort (1970-81) and fit by area and coastwide to the von Bertalanffy (1938) growth equation to determine growth rates. Weight is determined from length by an allometric relationship. Observed length and weight data are assumed to represent the midpoint of a quarter, calculated weights and lengths represent values at the beginning of each quarter, and are used in yield-per-recruit analyses.

Quarterly virtual population analysis (VPA) for all year classes from 1970 through 1981 provided estimates of population size at the start of each quarter and quarterly fishing mortality rates for each fishing year 1976 through 1981 (Vaughan and Smith, 1988). Estimates of population size at age 0.5 were made for year classes 1976 through 1981 based on differing assumptions as to the catch of age-0 menhaden versus the landings of age-0 menhaden which are sampled. The sensitivity of our conclusions to underestimation of age-0 menhaden in the catches was investigated by conducting four sets of quarterly virtual population analyses. In these analyses the number of age-0 menhaden estimated in the landings were multiplied by 1 (base), 1.5, 2, and 4 to reflect increasing underestimation of age-0 menhaden in the landings (age-0 multiplicative factor). One reason for raising this issue is the statement "[i]t is generally acknowledged [that] the fishing process will sometimes kill additional numbers of small fish" (AMAC, 1982). Furthermore, Chester (1984) demonstrated that in the North Carolina fall fishery, when most age-0 fish are landed, there is a significant bias towards underestimating the numbers of age-0 fish in the landings. This uncertainty was felt to be most critical in our analysis of the potential gains from Option 7.

No change was made in the growth rates with and without Option 7 for the yield-per-recruit analyses. Fishing mortality rates were recalculated from a virtual population analysis approach. All fish landed after the closing date for each fishing year were subtracted from the total landings by area and season. Assuming the same population size at age at the beginning of the quarter during which the closing date occurred, new exploitation rates were calculated, from which coastwide instantaneous fishing mortality rates (F) were calculated iteratively (Ricker, 1975):

$$F=u(F+M)/(1-\exp(-(F+M))), \quad (1)$$

where exploitation rate (u) and natural instantaneous mortality rate ($M=0.45$/year) are known. Proportional F's by area were determined as before, except that catches reflected those with Option 7 in place.

Yield-Per-Recruit Analyses

The yield-per-recruit approach evaluates effects of the rates of growth and mortality (including fishing) to determine whether as much yield is obtained from the fishable population given the observed number of recruits (Ricker, 1975). If the number of recruits is constant from year to year and the other parameters do not change, then total yield from a cohort equals the annual yield from all cohorts present. Recruitment to age-1 for Atlantic menhaden has been relatively constant during the period 1976-81, ranging from 4.3 to 6.9 billion fish, compared to an historical range of 1.4-14.8 billion fish (Vaughan and Smith, 1988).

The computer program MAREA (Epperly et al., 1986) is modified from a multiple-gear extension (MGEAR) (Lenarz et al., 1974) of the Ricker-type yield-per-recruit model to accommodate a multiple area fishery. Ricker (1975) subdivided the exploited phase into segments during which mortality and growth rates can be assumed constant (e.g., quarterly). The effects of varying instantaneous natural and fishing mortality rates during the fishable life span and any general growth pattern can easily be assessed. Total equilibrium yield per recruit would be the sum of the yield in each segment over the total segments in the fishable life span. However, since equilibrium is unlikely to occur, the use of equilibrium yield per recruit is useful only for comparing the productivity of the stock under different exploitation regimes. Although density-dependent growth during the first year of life has been demonstrated in Atlantic menhaden, length at age beyond the first year is independent of population size (AMMB, 1981; and Reish et al., 1985).

Results

Yield-per-recruit analysis (Fig. 5) suggests that the fishery is harvesting the Atlantic menhaden stock at too young an age, and shows that increased age at entry increases potential yield from the stock. Estimates of annual yield per recruit are made to observe the hypothetical change in equilibrium yield per recruit given implementation of a management option during that fishing year. For the shortened season (Option 7), averaging over several fishing years would tend to mask year-to-year variability in gains in yield per recruit due to temporal variations in migration of age-0 Atlantic menhaden (i.e., recruitment or availability of juveniles to fishing gear).

Closed Corridor Option

Yield-per-recruit analyses (MAREA) were conducted for the base condition (no implementation of the closed corridor management option) and three hypothetical scenarios (Hypotheses I-III) for redeployment of fishing effort from the closed corridor. Each situation (base condition and three hypothetical scenarios) were repeated for minimum, mean, and maximum estimates of instantaneous fishing mortality rates (Table 1) to assess the sensitivity of the conclusions to variability in estimates of the instantaneous fishing mortality rates.

Largest coastwide gains in yield per recruit are from no redeployment of fishing effort from the closed corridor (1.3-7.2%, Hypothesis I) and the least gains are from redeployment of fishing effort to both inside and outside waters (0.3-3.6%, Hypothesis III) (Table 1). The Chesapeake Bay area makes the largest contribution to yield per recruit (without regulation) and the next largest is from the South Atlantic area, excluding the North Carolina fall fishery. Some of the gains that would otherwise accrue are lost when effort is redirected to outside waters (Hypothesis II) or to both inside and outside waters (Hypothesis III), due to the additional catches by the redirected fishing effort. Inside waters contribute the next largest catch in numbers of age-0

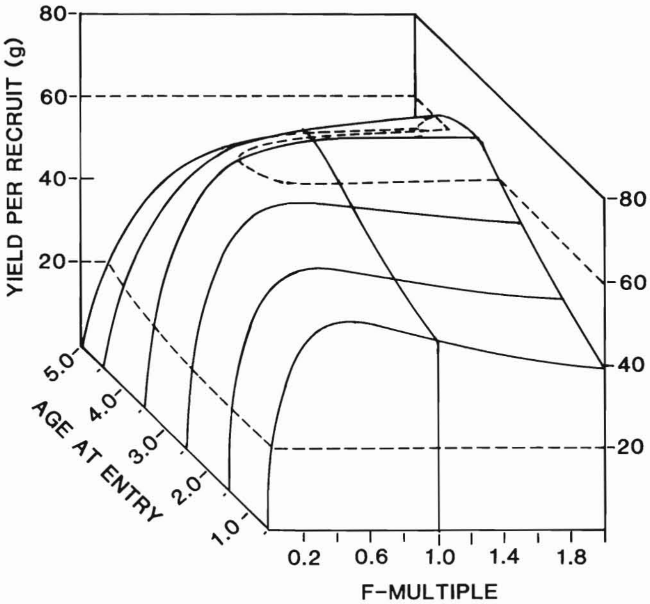

Figure 5.—Overall yield per recruit of Atlantic menhaden under current conditions (F-multiple of 1.0 and age at entry of 0.5) using average fishing mortality values by quarter for the 1981 fishing season.

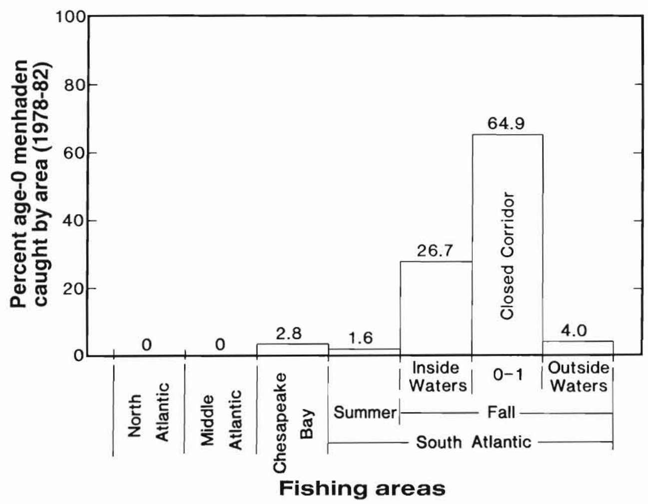

Figure 6.—Proportion of age-0 Atlantic menhaden caught by fishing areas used on the "Closed Corridor" analyses for fishing years 1978-82.

Table 1.—Percent change in yield per recruit by area and for the entire Atlantic menhaden purse-seine fishery for three hypothetical scenarios based on the "Closed Corridor" management option compared to the fishing regime for the 1978-82 fishing years. Analysis performed for three levels of instantaneous fishing mortality rates (minimum, mean, and maximum).

Area	Yield per recruit (g)	Change (%) hypotheses[1] I	II	III
Minimum fishing mortality assumed				
North/Middle Atlantic	5.41	9.4	6.8	1.7
Chesapeake Bay	25.38	14.3	4.7	1.2
South Atlantic	9.13	6.9	5.1	1.3
N.C. fall fishery	3.12	−66.0	−47.1	−15.7
Inside waters	0.71	5.6	4.2	193.0
Closed corridor	2.11	−100.0	−100.0	−100.0
Outside waters	0.30	3.3	203.3	83.3
Entire fishery[2]	45.66	1.3	1.0	0.3
Mean fishing mortality assumed				
North/Middle Atlantic	7.69	23.5	17.0	4.2
Chesapeake Bay	25.08	13.8	10.1	2.5
South Atlantic	9.70	14.7	10.8	2.7
N.C. fall fishery	5.33	−63.2	−45.0	−15.8
Inside waters	1.26	14.3	10.3	186.5
Closed corridor	3.61	−100.0	−100.0	−100.0
Outside waters	0.46	13.0	234.8	91.3
Entire fishery[2]	50.29	6.0	4.4	1.1
Maximum fishing mortality assumed				
North/Middle Atlantic	5.92	27.4	19.6	5.1
Chesapeake Bay	25.06	16.2	12.5	3.0
South Atlantic	9.51	17.4	12.7	4.1
N.C. fall fishery	5.54	−63.4	−44.9	2.5
Inside waters	1.29	14.7	10.9	255.0
Closed corridor	3.78	−100.0	−100.0	−100.0
Outside waters	0.47	17.0	244.7	134.0
Entire fishery[2]	48.38	7.2	5.3	3.6

[1] Hypotheses are defined as follows: I, no redistribution of fishing effort from closed corridor; II, all fishing effort from closed corridor is redeployed into outside waters; and III, all fishing effort from closed corridor is proportionally redeployed to inside and outside waters.
[2] The sum of areas is slightly different from the entire fishery due to the nature of the yield-per-recruit program (MAREA), which calculates yield per recruit for individual areas and then calculates overall yield per recruit instead of summing the areas. Thus, differences are due primarily to using a separate set of weights derived from the entire fishery.

menhaden (27%) after the closed corridor (65%) (Fig. 6), thus redirecting effort only to outside waters (Hypothesis II) will result in higher yield per recruit than redirecting some of that effort to inside waters (Hypothesis III). Further, the higher catch per unit of fishing effort for inside waters compared to outside waters (for the matched data set) also contributes greater gains in yield per recruit from Hypothesis II than from Hypothesis III.

Shortened Season Option (Option 7)

Yield-per-recruit analyses (MAREA) were conducted for Option 7 for fishing years 1976-81 and for four levels of the age-0 multiplicative factor (f = 1.0, 1.5, 2.0, and 4.0) (Table 2). Concurrent with these analyses, the total closure of the North Carolina fall fishery was addressed for comparative purposes only. Assuming the estimated landings of age-0 fish accurately reflect age-0 fish caught or killed (f = 1.0), then coastwide gains accruing from Option 7 range from 0.4% in 1981 to 10.2% in 1979. Although large numbers of age-0 fish were estimated as landed in both fishing years (Fig. 7), most age-0 menhaden (94%) landed in 1979 were caught after the proposed closing date compared to only 3% caught in 1981 after the closing date. Gains in yield per recruit are almost identical with a closed North Carolina fall fishery in

1979 and 1981 (Table 2). With large numbers of age-0 menhaden caught in 1983 and 1984 (68% for both years after proposed closure), large gains in yield per recruit for these fishing years would result. Since few age-0 menhaden were landed in 1980 (and in 1982), computed gains in yield per recruit would be small even when compared to a total closure of the North Carolina fall fishery (Table 2). The annual estimates of yield per recruit are not necessarily intended to represent absolute yield per recruit attainable. They permit interyear comparisons to show how timing of the migration patterns of age-0 menhaden would effect the gains accrued from the Option 7 management strategy.

With increasing underestimation of age-0 fish caught or killed (e.g., increasing age-0 multiplicative factor), the gains in yield per recruit from Option 7 also increase because greater numbers of age-0 fish would actually have been saved (Table 2). For an age-0 multiplicative factor of 4.0, a dramatic increase to a 33.8% gain is noted for the 1979 fishing year, and to a 9.5% gain for the 1976-78 fishing years. Gains from Option 7 would have been negligible for the 1980 and 1981 fishing years since small percentage of age-0 fish were in the landings after the proposed closing date.

Changes in yield per recruit also vary with fishing area (Table 3). Generally all areas experience a gain in yield per recruit except the North Carolina fall fishery. Gains to the North Atlantic area mostly benefit small plants in Gloucester, Mass., and Rockland, Me. (Fig. 1). Two large plants in Reedville, Va., benefit from gains in yield per recruit to all geographic fishing areas, since they land fish caught between Cape Hatteras, N.C., and Rhode Island. The North Carolina and Florida plants show a gain during the summer fishery (South Atlantic area), but the North Carolina plants suffer losses during the North Carolina fall fishery. To the extent that North Carolina vessels fish in other areas, those plants can benefit from gains in yield per recruit to those areas. For example, a North Carolina vessel caught fish in the Middle Atlantic area during 1984, so some gain in yield per recruit for the Middle Atlantic area would have accrued to the South Atlantic area.

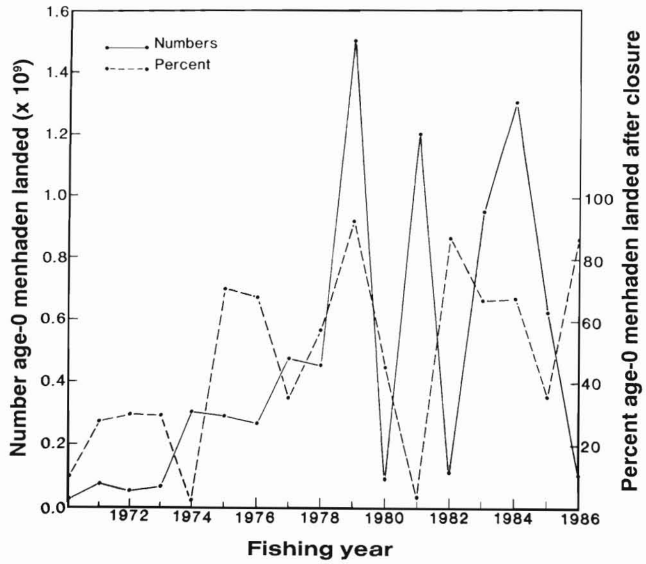

Figure 7.—Number of age-0 Atlantic menhaden landed and percent landed after "Shortened Season" closure for fishing years 1970-86.

Table 2.—Yield per recruit (g) from the entire Atlantic menhaden fishery for the fishing years 1976-81, and percent change resulting from a "Shortened Season" by 1 month (Option 7) or closure of the North Carolina fall fishery. Each comparison is made for four levels of the age-0 multiplicative factor described in text to adjust for catches of age-0 above those estimated from landings.

Age-0 multiplicative factor	Fishing year 1976-78	1979	1980	1981
Entire fishery (Base yield per recruit)				
1.0	58.62	53.04	53.84	45.95
1.5	57.34	50.79	53.60	44.36
2.0	56.15	48.85	53.38	42.98
4.0	52.12	43.23	52.49	38.77
Option 7, Shortened season (% change)				
1.0	+2.9	+10.2	+0.6	+0.4
1.5	+4.0	+14.8	+0.8	+0.5
2.0	+5.1	+19.1	+1.0	+0.6
4.0	+9.5	+33.8	+1.8	+1.0
Closed North Carolina fall fishery (% change)				
1.0	+5.5	+10.5	+1.8	+10.6
1.5	+7.8	+15.4	+2.2	+14.2
2.0	+10.0	+19.9	+2.6	+17.5
4.0	+18.3	+35.4	+4.2	+29.0

Management Implications

The Atlantic menhaden fishery has recovered somewhat from the depressed levels during the 1970's, although not to levels attained during the late 1950's when landings averaged 625,000 t (1955-59 fishing years, Fig. 2). Recent estimates of maximum sustainable yield

Table 3.—Percent change in yield per recruit by fishing areas and for the entire Atlantic menhaden fishery for the 1976 through 1981 fishing years resulting if the "Shortened Season" option had been in effect. The age-0 multiplicative factor increases the numbers of age-0 menhaden assumed caught or killed by the purse-seine fishery. (SA + NCFF combines South Atlantic and North Carolina fall fishing areas.)

Fishing area and year(s)	Percent change for age-0 multiplicative factor 1.0	1.5	2.0	4.0
1976-78 Fishing years				
North Atlantic	18.1	20.1	22.4	31.6
Middle Atlantic	2.5	4.4	6.4	14.4
Chesapeake Bay	5.2	7.3	9.3	17.5
South Atlantic	7.2	9.4	11.5	19.8
N.C. fall fishery	−45.9	−46.3	−46.6	−47.5
SA + NCFF	−8.6	−8.9	−9.2	−10.2
Entire fishery	2.9	4.0	5.1	9.5
1979 Fishing year				
North Atlantic	23.0	32.8	42.7	81.9
Middle Atlantic	2.7	11.2	19.2	52.3
Chesapeake Bay	20.8	30.4	40.1	78.4
South Atlantic	21.2	30.8	40.6	78.7
N.C. fall fishery	−49.7	−55.7	−59.7	−67.3
SA + NCFF	−11.0	−13.4	−15.2	−19.7
Entire fishery	10.2	14.8	19.1	33.8
1980 Fishing year				
North Atlantic	−0.1	0.3	0.6	2.2
Middle Atlantic	6.7	7.3	7.8	9.1
Chesapeake Bay	1.9	2.3	2.6	4.0
South Atlantic	3.7	4.0	4.4	6.2
N.C. fall fishery	−20.4	−20.7	−21.1	−22.1
SA + NCFF	−6.4	−6.5	−6.7	−6.7
Entire fishery	0.6	0.8	1.0	1.8
1981 Fishing year				
North Atlantic	−0.1	0.3	0.4	1.7
Middle Atlantic	1.5	2.2	2.3	3.6
Chesapeake Bay	1.1	1.4	1.6	2.6
South Atlantic	1.2	1.5	1.7	2.7
N.C. fall fishery	−3.0	−2.9	−2.8	−2.7
SA + NCFF	−0.7	−0.6	−0.6	−0.5
Entire fishery	0.4	0.5	0.6	1.0

range from 450,000 to 490,000 t, while recent landings have averaged 364,000 t during the 1976-81 fishing years (Vaughan and Smith, 1988).

The closed corridor option sought to reduce the landings of age-0 menhaden off North Carolina's coast late in the fishing season (Fig. 6). Based on the mean fishing mortality for the period 1978-82, potential gains in yield per recruit for the closed corridor option ranged from 1.1% to 6.0% depending on the hypothesis selected (Table 1). Redeployment of fishing effort to outside waters (Hypothesis II) now appears to be the most likely response of the menhaden purse-seine fleet to implementation of the closed corridor option. Coastwide gains in yield per recruit under this hypothesis range from 1.0 to 5.3%. All areas but the North Carolina fall fishery show a gain in yield per recruit from this option under all three hypotheses. Greatest losses in yield per recruit to the North Carolina fall fishery were under Hypothesis I (63.2-66.0%), and least were under Hypothesis III (gain of 2.5% to a loss of 15.8%). Under Hypothesis II some of the lost landings from the closed corridor can be recouped from outside waters.

The shortened season (Option 7) also sought to reduce the landings of age-0 and other prespawning Atlantic menhaden migrating off Virginia and North Carolina late in the fishing year (Fig. 7). Potential gains from this option range from 0.4 to 10.2% based on historical distribution of fishing mortality depending on the fishing year (Table 2). These annual variations in computed gains in yield per recruit depend primarily on the timing of the coastal movements southward of age-0 menhaden. If more age-0 menhaden are killed than are landed as cited by vessel captains, the gains from Option 7 are even greater, ranging from 0.6 to 19.1% when twice as many age-0 menhaden are killed than landed for the period 1976-81. Gains in yield per recruit accrue to all areas except for the North Carolina fall fishery (Table 3). North Carolina plants will suffer net annual losses even when gains from the South Atlantic fishing area are combined with losses from the North Carolina fall fishery.

Gains in yield per recruit from the closed corridor option depend on the consistency with which age-0 menhaden remain within the 1-mile corridor as indicated by the historical data used in the analyses (Fig. 6). Coastwide gains range more widely for Option 7 than those for the closed corridor option because the former depends both on when age-0 fish become available to the fishery and if the weather permits fishing to continue late in the fishing year. Fishing on age-0 fish during the 1984 fishing year continued into early February 1985 for the first time since the 1950's. We have greater confidence in the predicted gains from Option 7 because of the uncertainty in fishing strategy under the closed corridor option (Hypotheses I-III). Further, Option 7 is more equitable since each fishing area must initially forego 1 month of landings from their traditional fishing seasons. Season options (including Option 7) are easier to enforce than a closed corridor or area wherein distance from shore must be known accurately for enforcement.

No coastwide gains can be accrued in either case unless landings of age-0 menhaden are reduced significantly. Since age-0 fish are landed primarily in the North Carolina fall fishery (96% during 1978-82, Fig. 6), thus a loss in yield per recruit almost always occurs for this fishing area. Losses for the North Carolina fall fishery appear potentially great under both Option 7 (2.8-59.7% for $f = 2$; Table 3) and under the closed corridor option (losses of 44.9-47.1% for Hypothesis II; Table 1).

Obviously, many of the variables and parameters in these analyses have considerable variability. However, sources of potential bias that we believe are most critical to our conclusions are addressed by the use of a range in quarterly F's for the closed corridor option, and by annual MAREA computer runs and the age-0 multiplicative factor for Option 7. Assuming a constant instantaneous natural mortality rate (M) is a standard practice for stock assessments, with variability in M incorporated in F ($Z = M+F$; Ricker, 1975) through virtual population analysis. The intent of these analyses is to demonstrate the direction of changes and their relative magnitudes for critical comparison of the impacts of two management options across geographic areas which are most contentious.

In summary, yield-per-recruit analyses suggest that yields of 376,000 t ($f = 1.0$) to 403,000 t ($f = 4.0$) would have been available compared to an average of 364,000 t for the period 1976-81 if Option 7 had been in place (Vaughan and Smith, 1988). Greater gains are possible by adjusting the F-multiple and age at entry, but devising management schemes that are both enforceable and allow precise protection of young fish are difficult.

Two relevant events occurred during the 1985 fishing year. First, the North Carolina Marine Fisheries Commission adopted a regulation for the menhaden purse-seine fishery that included closure of inside waters and a 1-mile corridor for the entire North Carolina Atlantic coast from 15 January to 15 May. Purse-seine fishing beyond 1 mile is allowed year round off North Carolina. Second, the largest reduction plant normally operating during the North Carolina fall fishery did not fish during 1985. This resulted in a reduction in fishing effort for the North Carolina fall fishery from 112 vessel-weeks in 1984 to 20 in 1985. As a result, fewer age-0 menhaden were landed during this fishing year compared to the previous two years (Fig. 7). Hence, although neither management option is in effect in the North Carolina fall fishery, reduced fishing effort due to economic factors may contribute to an increase in yield per recruit for the near future.

The use of area-specific growth and mortality information were needed because of the highly migratory nature of the Atlantic menhaden and the numerous state jurisdictions across which they migrate. The MAREA computer program (Epperly et al., 1986) was modified from MGEAR (Lenarz et al., 1974) specifically to address this problem with regard to yield-per-recruit analyses. This approach can be applied readily to other highly migratory coastal species such as red drum (Mercer, 1984), weakfish and other sciaenids (Mercer, 1985), and striped bass (Anonymous, 1981), which are caught within several management jurisdictions.

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