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Growth and Reproduction of Atlantic Menhaden

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Introduction

Atlantic menhaden are euryhaline species that inhabit nearshore and inland tidal waters from Florida to Nova Scotia, Canada (Ahrenholz 1991). Spawning occurs principally at sea with some activity in bays and sounds in the northern portion of its range. Eggs hatch at sea and the larvae are transported to estuaries by ocean currents where they undergo metamorphosis and develop into juveniles. Adults stratify by size during summer, with older, larger individuals found farther north. During fall, Atlantic menhaden migrate south and disperse from near shore surface waters off North Carolina by late January or early February. Schools of adult menhaden reassemble in late March or early April and migrate northward. By June the population is redistributed from Florida to Maine (Ahrenholz 1991).

Age

The seminal study on ageing Atlantic menhaden was conducted by June and Roithmayr (1960) at the NMFS Beaufort Laboratory; their study materials were mostly from purse-seine landings during 1952-1956. They validated rings on the scales of menhaden as reliable age marks based on timing of scale ring deposition (generally March through May) and marginal increment analyses. Comparison of independent readings of scale ages showed a high percentage of agreement (= precision, >90%). Additionally, they examined scales from fish impounded for up to 14 months to further demonstrate that only one ring forms annually on menhaden scales.

In the field, port agents measure specimens for fork length (mm) and weight (grams), then remove a scale patch (ca. 20-25 scales) from the mid-portion of the flank below the dorsal fin. Six scales per specimen are mounted between two microscope slides and labeled with a unique specimen number. At the laboratory, scales are viewed on an Eberbach macro-projector under 40x magnification. Specimens are assigned an age (in yrs) based on the number of scale rings. Through the early 1970s, scales were 'read' by two independent readers, with a third reader used to decide discrepancies. Since then, only one reader has been utilized and she has been reading menhaden scales at the NMFS Beaufort Laboratory since 1969.

Fish as old as age-8 were present in the spawning population during the 1950s and early 1960s, but fish older than age-6 have been uncommon since 1965. The oldest specimens aged from NMFS biological sampling were several 10-year old fish landed in 1955 (2), 1956 (3), 1958 (1) and 1964 (1) from more than 495,000 Atlantic menhaden aged between 1955 and 2008 (**Table 1**). Smith and O'Bier (1996) described an exceptionally large (433 mm FL; 1,551g; age-7) Atlantic menhaden from Chesapeake Bay taken in August 1996.

In two of three years since 2006, age-2 Atlantic menhaden have comprised 65% or more of the total numbers of fish landed. In 2006 the age composition of the coastwide landings for reduction was 1% age-0s, 40% age-1s, 40% age-2s, and 19% age-3+s; in 2007, it was <1% age-0s, 26% age-1s, 65% age-2s, and 8% age-3+s; and in 2008, it was 1% age-0s, 9% age-1s, 68% age-2s, and 22% age-3+s.

Growth

The growing season begins in spring and ends in fall as water temperatures rise above and decline below 15^{o} C (Kroger et al. 1974). Atlantic menhaden reach lengths of about 500 mm total length (TL) and weights of over 1.5 kg (Cooper 1965). Fish as old as age-8 were present in the spawning population during the 1950s and early 1960s, but fish older than age-6 have been rare since 1965. The oldest fish aged from NMFS biological sampling were several 10-year old fish landed in 1955 (2), 1956 (3), 1958 (1) and 1964 (1) from almost 500,000 Atlantic menhaden aged between 1955 and 2008 . Smith and O'Bier (1996) described an exceptionally large (433 mm FL; 1,551g; age-7) Atlantic menhaden caught in the Chesapeake Bay during August 1996.

Due to their greater migratory range, larger fish of a given age are captured farther north than smaller fish of the same age (Nicholson 1978; Reish et al. 1985). This fact complicates any attempt to estimate overall growth for the entire stock from size-at-age data compiled from any individual area along the coast. To account for this, catch in numbers by year, season and fishing area were developed for weighting corresponding weights of individual Atlantic menhaden at age sampled when calculating mean fish weights (**Figure 1**) for 1955-2008. These "weighted" mean weights increased during the 1960s when stock size and recruitment are known to have declined, and then mean weights declined dramatically during the 1970s, and remained low during most of the 1980s when the stock was thought to have rebuilt. Increasing mean weights are estimated during the 1990s while recruitment was declining, followed by recent declines in mean weight. It has been suggested in various publications that density dependent growth is prevalent with Atlantic menhaden (**Reish et al. 1985, Ahrenholz et al. 1987, Ahrenholz 1991, Vaughan and Smith 1988).** That is, there is an inverse relation between size of menhaden (size of age-0 menhaden) and recruits at age 0. In **Figures 2**, we plot annual values of weighted mean weight of age-0 menhaden against estimated recruits to age 0 from the last Atlantic menhaden stock assessment (ASMFC 2006). A statistically significant correlation of this inverse relation explains 49% of the annual variability in weighted mean weights ($R^2 = 0.49$).

Weighting by catch in numbers by year, season and fishing area are also applied to calculate average fork lengths (mm) and weights (g) by age and year (**Tables 1 and 2**). When sample size was less than 10 fish, substitution was accomplished by one of two methods: (1) use average of pre- and post-year values for that age when missing cell(s) are embedded between estimated values, or (2) average across all values when no post-year value is available. These mean values represent mean size at age at approximately mid-fishing year (August-September).

Pair-wise Pearson correlations were estimated for these time series of weighted mean lengths and weights aligned by cohort (yearclass) or by calendar year (**Table 3**) for age 0-4. The differences in these correlations between these two alignments suggest that the relationship is stronger when aligned by cohort, so that density-dependent size at age is a more a characteristic of the cohort more so than calendar year.

Annual regressions of weight (W in g) on fork length (FL in mm) are conducted based on the natural logarithm transformation:

$$ln\ W = a + b\ ln\ FL, \quad (1)$$

and corrected for transformation bias (root MSE) when retransformed back to:

$$W = a(FL)^b. \quad (2)$$

Annual estimates for parameters ***a*** and ***b*** along with sample size and root MSE are summarized in **Table 4**. We also have plotted annual estimates of b against recruits to age 0 to test whether there is a density dependent component to this parameter over time. No significant correlations were found.

As in previous menhaden assessments, regressions of fork length (mm) on age (yr) are based on the von Bertalanffy growth curve:

$$FL = L_\infty(1 - \exp(-K(age - t_0))) \quad (3)$$

using the Marquardt algorithm for the nonlinear minimization (PROC NLIN in SAS). Annual parameters for these regressions are summarized with sample sizes in **Table 4**. Matrices of weight at ages-0 to -8 for 1955-2005 were developed from these equations to represent the average size-at-age of menhaden at the start of the fishing year (e.g., spawning biomass for appropriate ages) and middle of the fishing year (i.e., weight of fish landed) for use in population modeling. Parameters from regressions for (2) and (3) were averaged for the most recent eight years (2001-2008) and used to calculate lengths and weight at age at the middle of the fishing year (age+0.5; **Table 5**). Note that length and weight for age-0 menhaden is offset to 0.75 since they are not recruited to the fishery until late summer.

An alternate set of von Bertalanffy fits were made with the size at age data aligned by cohort (yearclass). Because of concerns that density-dependent growth is a characterstic of the cohort, it was felt that this would be a better approach. Attempts were made to fit the von Bertalanffy growth equation to each yearclass from 1947 (age 8 in 1955) to 2008 (age 0 in 2008). For most cohorts, a full range of ages were available (1955-2001). For the incomplete cohorts at the beginning of the time period (1947-1955), all fits converged, although specific parameter estimates became progressively unrealistic for the earlier years (especially 1947-1949). However, these fits are only used for interpolation and not extrapolation, and were found useful for this limited purpose. Similarly, incomplete cohorts for the recent time period (2002-2008) generally converged with the exception of the last two years (2007-2008). With the exception of the two years for which the fits did not converge, reasonable estimates of the von Bertalanffy parameters were obtained, and estimate size at age interpolated from these fits.

We compare the estimated lengths at ages 2 and 3 (mid-year) from the two series of fits to the von Bertalanffy growth equation with observed weighted mean lengths (**Figure 3**). Based on these two series of fits to the von Bertalanffy growth equation, annual estimates of fork length at age are interpolated from the annual and cohort based von Bertalanffy growth fits to represent the start of the fishing year (March 1) for use in estimating population fecundity (**Tables 6 and 7**). Similarly annual estimates of length-at-age are interpolated to represent the middle of the

fishing year (September 1) and converted to weight-at-age (Eq. 2) for use in the statistical catch-at-age models when comparing model estimated catch to observed catch. (**Tables 8 and 9**).

Reproduction

Spawning Times and Locations

Analysis of eggs and larvae collected at various locations along the Atlantic coast during 1953-75 (e.g., Judy and Lewis 1983) generally confirmed earlier knowledge of spawning times and location based on observations of adults with maturing or spent ovaries (e.g. Reintjes and Pacheco 1966). During December-March, most spawning-age fish congregate in offshore waters south of Cape Hatteras. Maximum spawning probably occurs at this time. Checkley et al. (1988) reported maximum spawning off North Carolina in January 1986 during periods of strong northeast winds in up-welled water near the western edge of the Gulf Stream. Spawning continues at a decreasing rate closer inshore as fish migrate north in late March. By May, most spawning is restricted to coastal waters north of Cape Hatteras. Spawning reaches a minimum in June, but continues at a low level until September north of Long Island. As mature fish migrate south in October, spawning increases from Long Island to Virginia.

Adults move inshore and northward in spring and stratify by age and size along the Atlantic coast (Rogers and Van Den Avyle 1989). During this northern migration, spawning occurs progressively closer inshore and by late spring, some spawning occurs within coastal embayments. There are definite spring and fall spawning peaks in the middle and north Atlantic regions, with some spawning occurring during winter in the shelf waters of the mid-Atlantic region. Atlantic menhaden mature at smaller sizes at the southern end of their range - 180 mm fork length (FL) in the south Atlantic region versus 210 mm FL in the Chesapeake Bay area and 230 mm in the north and middle Atlantic regions because of latitudinal differences in size-at-age and the fact that larger fish of a given age are distributed farther north than smaller fish of the same cohort (Lewis et al. 1987).

The capture of a 138 mm juvenile Atlantic menhaden in an estuary on the Maine coast in October 1990 (T. Creaser, Maine DMR, pers. comm as cited in ASMFC 1992) suggests that a limited amount of spawning may occur as far north as the Gulf of Maine. Some ripening female menhaden were offloaded on to the Soviet processing ship near Portland, Maine in August and September 1991 (S. Young, Maine DMR observer on the M/V RIGA, pers. comm. as cited in ASMFC 1992). Egg and larval surveys have been restricted to waters south of Cape Cod (Judy and Lewis 1983) and, thus, would not have produced any evidence for spawning in the Gulf of Maine.

Maturity

Some Atlantic menhaden become sexually mature during their second year (late age-1), but most do not mature until their third year (late age-2) (Higham and Nicholson 1964; Lewis et al. 1987).

Spawning occurs year-round throughout much of the species' range, with maximum spawning off the North Carolina coast during late fall and winter. Thus, most Atlantic menhaden spawn for the first time at age-2 or -3 - just before or after their third birthday (by convention on March 1) and continue spawning every year until death. First-spawning age-3 fish has accounted for most of the stock's egg production since 1965 (Vaughan and Smith 1988).

Lewis et al. (1987) tabularized maturity schedules (number and percent of specimens by ages-1 and -2) for female Atlantic menhaden from their field collections and those of Higham and Nicholson (1964). Percent age-1 females with active ovaries ranged from 1.5% to 27.8%, while percent age-2 females with active ovaries ranged from 67.4% to 97.1% (see table below). All age-3 and older females were judged to be sexually mature.

	1956[a]		**1957**[a]		**1958**[a]		**1959**[a]		**1981**[b]	
Age	N	%	N	%	N	%	N	%	N	%
1	292	7.5	67	1.5	187	27.8	77	2.6	38	2.6
2	103	97.1	179	67.6	262	96.6	123	92.7	138	67.4

[a] From Higham and Nicholson (1964, Table 7)
[b] From Lewis et al. (1987)

The last peer review panel (ASMFC 2004) made the following recommendation regarding maturity of Atlantic menhaden:

> • *Conduct new size/age at maturity research by geographic regions along the Atlantic coast.*

Although Atlantic menhaden may spawn year-round, previous age-at-maturity work was conducted during the fall fishery along the North Carolina coast, no doubt because of the availability of specimens and proximity to the NMFS Beaufort Laboratory. In an attempt to try and replicate studies by Higham and Nicholson (1964) and Lewis et al. (1987), ripening female Atlantic menhaden were collected from ocean catches near Beaufort, NC, during November and December 2004. Specimens were measured for fork length (mm) and weighed (g), then a scale patch was removed for ageing. Ovaries of females were removed and weighed to the nearest 0.1 g. An 'ovary index' (OI), analogous to a gonosomatic index or GSI, was computed based on the formula of Higham and Nicholson (1964):

$$OI = (\text{ovary weight} * 10^7) / \text{fork length}^3 \quad .$$

Specimens with an OI >= 4 were considered sexually mature with maturing and ripe ova (*in sensu* Higham and Nicholson [1964]), while those with an OI < 4 were considered sexually immature. Results of maturity observations on female Atlantic menhaden from the fall fishery 2004 based on these criteria are shown below.

Age	N	FL range (mm)	Immature n w/ OI < 4	Mature n w/ OI < 4	Percent Mature
1	3	238-247	0	3	100
2	71	192-308	12	59	83.1
3	64	250-330	1	63	98.4
4	18	268-331	0	18	100
5	1	268-331	0	1	100
Total	157				

Clearly, the sample size of age-1 specimens (n = 3) is inadequate to resolve the question of the proportion of fish in this age class that reach sexual maturity as they approach their second birth date. However, results herein for age-2+ specimens tend to support earlier work of Higham and Nicholson (1964) and Lewis et al. (1987) that indicate a high proportion of age-2 fish become sexually mature as they approach their third birth date, while nearly all fish age-3 and older are sexually mature.

In 2005 the last menhaden reduction plant in Beaufort, NC, closed and additional study specimens were unavailable in subsequent years from purse-seine catches off North Carolina. Attempts were made in 2005-2007 to acquire specimens from Virginia purse-seine vessels that fished along the North Carolina Outer Banks in fall. Unfortunately, these collections were generally from Virginia waters and in early November; ovarian development was noticeably less advanced than for fish which might have been available several weeks later and from waters farther south, i.e., the former North Carolina fall fishery.

In November and December 2008 specimens from one purse-seine catch and several gill net catches became available from the North Carolina Outer Banks. A total of 143 females (range: 194 – 297 mm FL) were examined. Ovary indices were calculated for these specimens, however, scales have not yet been 'read' as of submission date of this document. Maturity observations for these specimens could be available shortly after the Data Workshop.

Fecundity

Atlantic menhaden are relatively prolific spawners. Predicted fecundities range from 38,000 eggs for a small female (180 mm FL) to 362,000 for a large female (330 mm FL) (**Figure 4**) according to the equation derived by Lewis et al. (1987):

$$\text{Number of maturing ova} = 2563 * e^{0.015 * FL} \quad (4)$$

This equation was derived by fitting an exponential model to length-specific fecundity data for fish collected during 1956-1959 (Higham and Nicholson 1964), 1970 (Dietrich 1979), and 1978, 1979, 1981 (Lewis et al. 1987). Fish in all three studies were collected from the North Carolina fall fishery, which harvests fish of all ages. In addition, fish were collected from Gloucester, MA, Port Monmouth, NJ, and Reedville, VA in 1978 and 1979. Lewis et al. (1987) concluded, "…no

detectable changes have occurred in the fecundity relationship. The among-year variation in the annual fecundity of Atlantic menhaden prevents the determination of any historical trends from the limited amount of earlier data available … and the lack of fish above 310 mm available in the current fishery". Such fecundity-length relationships are useful in stock assessments to the extent that they accurately reflect the relative (not absolute) increase in egg production of a female with increasing size. Often reproductive capacity of a stock is modeled using female weight at age, primarily because of lack of fecundity data. To the extent that egg production is not linearly related to female weight, indices of egg production (fecundity) are a better measure of reproductive output of a stock of a given size and age structure. Most importantly, fecundity better emphasizes the importance of older, and larger individual menhaden contribution to population egg production. Annual estimates of fecundity (no. of maturing or ripe ova) at age are summarized for both annually-based von Bertalanffy growth fits (**Table 10**) and yearclass-based von Bertalanffy growth fits (**Table 11**).

Related to this issue, is the contribution of young (e.g., first age spawners) to the overall reproductive effort. This was noted in Vaughan and Smith (1988), and we have updated this analysis from output from the last menhaden stock assessment (ASMFC 2006). In earlier assessments prior to 2003, females were assumed to be fully mature with age 3 (late age 2) and immature at younger ages. For this analysis age 2 (11.8% mature) and age 3 (86.4%) females are treated as "first age spawners". We compare the number and biomass of these first year spawners to total, 1955-2005, in **Figure 5**. With the exception 1955 and 1962, these proportions have been high for the full assessment period. The exceptions result from the passage of two exceptionally large year classes (1951 and 1958) through the stock. Otherwise a general decline in this proportion can be seen since the peak values in 1967.

Lewis et al. (1987) surmised that Atlantic menhaden "are probably determinate multiple spawners, which spread their spawn over a broad geographical and temporal range." Ahrenholz (1991) summarized spawning seasonality noting, "some spawning occurs during virtually every month of the year…some spawning occurs in the more northerly portions of the fishes' range as the fish begin moving southward in September…spawning continues with increasing intensity as the fish move progressively farther southward in October and November…spawning intensity is believed to peak in waters off the North Carolina coast in winter…spawning continues, but with decreasing levels of intensity as the fish move northward in the following spring and early summer." Despite the broad geographic range of spawning activity, most fecundity studies of Atlantic menhaden have concentrated on acquiring gravid females off the North Carolina coast during the fall fishery when most age classes in the stock tend to be available (Higham and Nicholson 1964, Dietrich 1979, Lewis et al. 1987). It can be argued that existing fecundity studies of Atlantic menhaden are underestimates of absolute spawning potential. Nevertheless, the extant studies focused on fall or early winter concentrations of gravid fish off the North Carolina coast, which is believed to be the area of greatest spawning intensity (Ahrenholz 1991). For assessment purposes, modeling increasing egg production with size is preferable to female biomass as a measure of reproductive ability of the stock. With density-dependent growth and fecundity a function of growth (in length), there is the potential that a larger, slower growing cohort will produce fewer eggs overall than a smaller, faster growing cohort.

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Table 1. Weighted mean fork length (mm) at age, with weightings based on annual catch in numbers by season and area. Shaded areas had no or insufficient (n<10) samples and are either averaged with pre- and post-year values or averaged across all available years.

Year	0	1	2	3	4	5	6	7	8
1955	126.8	187.5	242.5	275.4	288.8	304.0	319.2	330.9	327.5
1956	118.4	179.2	248.6	284.3	298.9	312.6	318.9	327.0	337.2
1957	129.8	181.9	234.2	278.8	307.9	314.9	319.7	324.4	324.7
1958	116.6	183.3	229.3	263.2	305.5	321.0	325.0	328.2	329.9
1959	153.6	164.7	229.5	261.0	309.2	320.3	326.5	333.0	338.3
1960	122.4	185.2	222.5	280.3	303.9	316.4	326.7	332.9	336.8
1961	131.9	180.1	240.5	255.4	290.1	310.1	324.6	333.2	336.8
1962	141.4	192.4	238.1	276.2	286.3	317.1	326.4	338.0	335.2
1963	144.5	186.2	223.5	282.8	306.6	314.7	327.0	329.9	338.6
1964	147.6	202.3	236.4	278.4	297.4	327.2	333.7	340.3	342.3
1965	144.9	198.5	235.3	284.4	300.1	325.1	345.0	352.0	334.2
1966	156.0	187.9	248.4	281.6	290.7	288.3	320.6	333.6	334.2
1967	157.1	192.4	236.2	296.6	304.0	313.9	320.6	333.6	334.2
1968	161.9	180.8	243.1	278.8	291.8	306.6	320.6	333.6	334.2
1969	163.9	194.1	226.9	306.2	318.0	330.6	320.6	333.6	334.2
1970	145.7	198.7	224.2	294.9	326.6	322.1	320.6	333.6	334.2
1971	140.1	202.2	251.1	293.3	311.1	313.6	320.6	333.6	334.2
1972	118.1	195.9	264.2	308.0	318.2	300.2	320.6	333.6	334.2
1973	130.9	204.8	220.2	294.0	333.3	300.2	320.6	333.6	334.2
1974	122.7	183.1	224.2	290.3	325.5	300.2	320.6	333.6	334.2
1975	120.6	163.2	206.2	277.1	302.7	300.2	320.6	333.6	334.2
1976	108.8	159.8	205.7	285.5	298.4	300.2	320.6	333.6	334.2
1977	116.4	155.2	189.9	256.9	280.1	286.7	320.6	333.6	334.2
1978	120.3	157.2	193.3	227.0	289.6	297.3	320.6	333.6	334.2
1979	116.2	170.9	201.9	251.1	281.1	295.9	320.6	333.6	334.2
1980	117.6	153.6	196.8	239.6	277.9	291.3	296.1	333.6	334.2
1981	107.7	159.4	192.2	218.4	280.8	294.4	300.1	333.6	334.2
1982	118.3	165.7	193.8	208.1	265.1	296.3	303.7	333.6	334.2
1983	121.8	159.5	197.6	245.4	271.9	295.5	303.7	333.6	334.2
1984	111.1	159.4	198.9	247.8	279.0	286.2	303.7	333.6	334.2
1985	109.3	166.9	203.7	245.3	289.5	300.6	307.2	333.6	334.2
1986	116.4	156.2	195.4	217.8	283.3	292.6	287.2	333.6	334.2
1987	117.3	158.9	199.1	234.6	275.6	289.2	287.3	333.6	334.2
1988	111.8	147.8	205.8	235.5	267.9	285.7	287.3	333.6	334.2
1989	126.2	176.7	195.1	236.6	270.5	283.6	287.3	333.6	334.2
1990	129.2	195.2	223.0	252.9	273.5	281.6	287.3	333.6	334.2
1991	137.3	174.8	223.8	258.5	271.3	281.9	287.3	333.6	334.2
1992	123.1	195.9	216.8	258.3	277.1	285.4	284.8	333.6	334.2
1993	137.0	182.4	234.6	258.1	281.0	286.5	315.0	333.6	334.2
1994	117.6	174.0	215.8	272.2	280.6	289.8	315.0	333.6	334.2
1995	114.3	184.9	232.5	274.4	286.3	297.3	315.0	333.6	334.2
1996	114.9	178.1	249.0	286.1	296.9	300.9	315.0	333.6	334.2

1997	128.3	167.6	239.0	285.9	301.3	308.5	315.0	333.6	334.2
1998	148.2	167.1	233.5	286.2	306.9	316.3	315.0	333.6	334.2
1999	138.9	180.0	229.1	280.0	301.0	327.3	315.0	333.6	334.2
2000	117.9	190.6	252.4	279.1	297.0	309.8	315.0	333.6	334.2
2001	143.3	204.3	260.6	288.5	304.5	309.5	315.0	333.6	334.2
2002	132.3	197.0	250.4	285.7	300.5	310.0	315.0	333.6	334.2
2003	142.4	200.9	241.9	287.5	303.2	301.0	315.0	333.6	334.2
2004	122.4	178.8	222.9	270.4	282.6	301.0	315.0	333.6	334.2
2005	122.9	160.3	234.2	271.0	287.5	292.0	315.0	333.6	334.2
2006	139.9	190.8	226.7	272.4	283.5	294.1	315.0	333.6	334.2
2007	142.6	188.7	222.0	270.3	285.3	296.1	315.0	333.6	334.2
2008	145.2	193.2	238.8	264.5	280.1	295.5	315.0	333.6	334.2

Table 2. Weighted mean weight (g) at age, with weightings based on annual catch in numbers by season and area. Shaded areas had no or insufficient (n<10) samples and are either averaged with pre- and post-year values or averaged across all available years.

Year	0	1	2	3	4	5	6	7	8
1955	35.6	118.7	250.6	387.7	445.6	527.2	611.7	688.0	669.9
1956	28.0	103.7	289.9	426.9	491.9	559.5	605.8	639.5	702.9
1957	36.9	104.9	234.4	416.0	568.0	588.9	622.1	656.1	652.7
1958	26.2	109.6	223.7	368.2	569.6	662.4	689.2	710.1	662.5
1959	64.4	74.8	216.4	335.6	568.1	619.2	672.0	700.0	744.7
1960	32.4	114.2	194.6	449.1	581.7	656.3	726.7	758.5	726.5
1961	43.0	103.8	252.3	309.1	484.8	593.1	652.5	715.2	726.5
1962	53.6	134.5	254.9	380.8	428.5	599.2	649.0	717.2	708.3
1963	55.0	123.4	222.2	426.6	562.0	606.2	667.4	711.2	757.0
1964	56.5	152.9	248.2	402.2	512.7	720.9	733.6	796.6	769.1
1965	56.4	145.6	251.1	447.4	549.5	706.1	790.5	875.6	708.4
1966	70.4	123.7	285.5	408.0	468.6	412.3	657.9	724.4	708.4
1967	66.9	136.1	253.9	489.8	535.7	629.6	657.9	724.4	708.4
1968	79.6	116.9	290.6	419.6	468.0	507.0	657.9	724.4	708.4
1969	85.1	147.6	235.6	566.5	642.7	722.0	657.9	724.4	708.4
1970	67.8	160.1	224.3	497.9	648.3	643.9	657.9	724.4	708.4
1971	45.5	166.1	311.7	465.0	561.6	565.8	657.9	724.4	708.4
1972	27.6	130.8	336.7	510.4	589.3	540.3	657.9	724.4	708.4
1973	39.7	162.0	190.2	499.8	640.0	540.3	657.9	724.4	708.4
1974	30.7	114.9	201.8	443.0	599.9	540.3	657.9	724.4	708.4
1975	29.9	76.5	156.2	398.7	507.6	540.3	657.9	724.4	708.4
1976	21.6	70.1	163.2	449.4	511.8	540.3	657.9	724.4	708.4
1977	25.8	66.9	123.3	343.2	456.4	514.7	657.9	724.4	708.4
1978	28.4	71.1	132.1	228.2	473.8	511.5	657.9	724.4	708.4
1979	23.3	88.6	156.4	311.2	426.0	494.1	657.9	724.4	708.4
1980	27.7	67.2	138.1	281.5	434.0	488.6	525.4	724.4	708.4
1981	21.0	70.2	128.8	200.9	429.7	492.0	475.3	724.4	708.4
1982	30.2	85.2	133.5	173.9	378.4	488.9	482.2	724.4	708.4
1983	30.9	72.6	136.5	286.4	387.7	513.7	482.2	724.4	708.4
1984	22.7	77.1	150.3	301.0	421.9	461.8	482.2	724.4	708.4
1985	21.1	83.8	150.4	280.5	429.8	482.0	489.1	724.4	708.4
1986	24.1	65.6	130.7	191.9	400.2	449.9	418.6	724.4	708.4
1987	26.4	72.5	149.7	242.9	371.7	429.2	406.0	724.4	708.4
1988	21.5	57.4	160.9	241.6	338.2	408.4	406.0	724.4	708.4
1989	34.4	94.5	132.6	249.4	367.8	409.8	406.0	724.4	708.4
1990	35.2	141.8	205.3	298.1	366.8	398.2	406.0	724.4	708.4
1991	44.4	100.7	211.6	308.3	353.7	388.6	393.3	724.4	708.4
1992	28.2	132.4	185.0	311.6	361.9	396.9	389.4	724.4	708.4
1993	42.3	110.7	231.4	325.6	422.6	422.4	594.8	724.4	708.4
1994	24.7	94.9	176.1	355.3	387.3	457.5	594.8	724.4	708.4

1995	22.8	108.1	221.9	350.2	408.9	463.0	594.8	724.4	708.4
1996	23.3	103.1	291.1	436.2	483.3	512.1	594.8	724.4	708.4
1997	33.7	83.3	258.4	444.3	511.5	536.4	594.8	724.4	708.4
1998	56.6	83.6	233.8	434.0	548.5	592.7	594.8	724.4	708.4
1999	43.2	106.5	213.7	378.6	472.6	632.3	594.8	724.4	708.4
2000	26.0	131.0	286.8	386.3	469.6	530.6	594.8	724.4	708.4
2001	49.9	155.8	306.0	418.0	503.3	525.0	594.8	724.4	708.4
2002	39.7	147.4	293.8	425.9	504.1	554.1	594.8	724.4	708.4
2003	48.7	163.4	281.4	474.9	540.9	483.7	594.8	724.4	708.4
2004	30.1	103.9	198.2	356.0	403.6	483.7	594.8	724.4	708.4
2005	32.3	77.0	227.8	337.0	391.6	413.2	594.8	724.4	708.4
2006	44.3	122.6	208.3	353.3	396.6	427.0	594.8	724.4	708.4
2007	48.4	117.6	186.1	327.8	378.5	440.7	594.8	724.4	708.4
2008	52.6	129.5	230.8	323.3	381.2	437.4	594.8	724.4	708.4

Table 3. Correlation analysis (Pearson correlation coefficients) of Atlantic menhaden fork weighted mean length-at-age (L0-L4) and weighted mean weight-at-age (W0-W4). Cohort correlations are lagged to line up lengths and weight by yearclass, while annual (year) correlations are unlagged.

Correlations by cohort

	L0	L1	L2	L3	L4	W0	W1	W2	W3	W4
L0	1.00	0.62	0.61	0.68	0.69	0.98	0.65	0.64	0.68	0.63
L1		1.00	0.73	0.72	0.58	0.60	0.98	0.73	0.70	0.53
L2			1.00	0.81	0.71	0.58	0.70	0.98	0.78	0.62
L3				1.00	0.78	0.66	0.70	0.81	0.97	0.69
L4					1.00	0.73	0.58	0.74	0.80	0.95
W0						1.00	0.65	0.63	0.68	0.66
W1							1.00	0.71	0.69	0.52
W2								1.00	0.80	0.65
W3									1.00	0.74
W4										1.00

Correlations by year

	L0	L1	L2	L3	L4	W0	W1	W2	W3	W4
L0	1.00	0.56	0.49	0.49	0.36	0.98	0.58	0.51	0.49	0.36
L1		1.00	0.70	0.66	0.49	0.50	0.98	0.69	0.63	0.42
L2			1.00	0.75	0.49	0.44	0.67	0.98	0.66	0.39
L3				1.00	0.77	0.48	0.66	0.75	0.97	0.68
L4					1.00	0.38	0.51	0.50	0.82	0.95
W0						1.00	0.55	0.47	0.50	0.41
W1							1.00	0.68	0.65	0.45
W2								1.00	0.69	0.43
W3									1.00	0.79
W4										1.00

Correlation Differences (cohort-year)

	L0	L1	L2	L3	L4	W0	W1	W2	W3	W4
L0	0.00	0.06	0.12	0.18	0.34	0.00	0.06	0.13	0.19	0.27
L1		0.00	0.03	0.06	0.09	0.09	0.00	0.04	0.07	0.12
L2			0.00	0.06	0.22	0.14	0.03	0.00	0.12	0.23
L3				0.00	0.01	0.18	0.04	0.06	0.00	0.01
L4					0.00	0.34	0.07	0.24	-0.03	0.00
W0						0.00	0.10	0.16	0.18	0.25
W1							0.00	0.03	0.04	0.06
W2								0.00	0.11	0.22
W3									0.00	-0.05
W4										0.00

Table 4. Annual estimated parameters obtained from weight-length and length at age regressions from biological sampling of Atlantic menhaden, 1955-2008.

	Weight-Length				*Von Bertalanffy Curve*			
Year	**n**	**a**	**b**	**RMSE**	**n**	**Linf**	**K**	**t_0**
1955	16037	-11.808	3.157	0.0097	15009	342.00	0.410	-0.446
1956	19873	-11.823	3.161	0.0152	17963	335.60	0.543	0.008
1957	19674	-12.262	3.242	0.0091	18389	337.20	0.440	-0.407
1958	15315	-12.348	3.263	0.0083	14303	334.00	0.493	-0.062
1959	17935	-12.359	3.262	0.0060	17938	357.70	0.319	-0.906
1960	13505	-12.736	3.332	0.0078	12783	348.90	0.384	-0.464
1961	13184	-12.688	3.323	0.0092	12898	355.10	0.316	-0.914
1962	15771	-11.378	3.083	0.0073	15458	355.00	0.332	-0.964
1963	13001	-11.959	3.194	0.0159	12716	365.10	0.314	-0.909
1964	10438	-11.830	3.169	0.0635	10286	367.30	0.322	-0.974
1965	19518	-11.970	3.193	0.0121	18955	379.70	0.314	-0.848
1966	15633	-11.541	3.110	0.0148	15486	353.50	0.314	-1.161
1967	15426	-12.232	3.238	0.0146	14653	327.60	0.451	-0.717
1968	26830	-11.869	3.176	0.0142	25888	336.50	0.361	-1.047
1969	15114	-11.797	3.167	0.1100	14858	454.30	0.195	-1.544
1970	8426	-11.651	3.139	0.0078	8239	449.10	0.221	-1.083
1971	8269	-11.364	3.079	0.0129	8118	334.80	0.511	-0.391
1972	6552	-11.673	3.130	0.0107	6198	361.80	0.548	0.067
1973	6351	-11.232	3.055	0.0103	6348	424.41	0.275	-0.671
1974	5421	-11.743	3.146	0.0122	5361	529.17	0.185	-0.735
1975	7278	-11.864	3.171	0.0130	7262	392.04	0.289	-0.465
1976	6725	-12.348	3.266	0.0141	6401	732.80	0.108	-0.778
1977	7276	-12.555	3.308	0.0138	7266	397.48	0.230	-0.660
1978	7094	-12.337	3.266	0.0097	7025	570.94	0.113	-1.303
1979	6365	-12.392	3.277	0.0161	6231	363.47	0.282	-0.593
1980	7291	-12.385	3.277	0.0183	7046	349.83	0.286	-0.592
1981	9201	-12.523	3.298	0.0142	8870	389.16	0.221	-0.759
1982	9066	-11.645	3.139	0.0113	8552	432.36	0.151	-1.483
1983	11533	-11.577	3.117	0.0093	11279	367.73	0.238	-0.903
1984	11689	-11.554	3.121	0.0164	11594	336.74	0.313	-0.516
1985	8498	-11.598	3.121	0.0093	8507	352.86	0.317	-0.458
1986	5828	-12.262	3.245	0.0071	5826	348.74	0.266	-0.767
1987	7618	-11.784	3.160	0.0097	7548	373.49	0.226	-1.014
1988	7349	-11.628	3.125	0.0141	7349	355.64	0.261	-0.703
1989	7027	-12.461	3.282	0.0092	6374	379.62	0.207	-1.328
1990	6838	-12.346	3.260	0.0091	6790	297.86	0.489	-0.526
1991	7770	-11.754	3.147	0.0087	7614	318.90	0.352	-0.918
1992	5680	-12.139	3.215	0.0094	5440	299.93	0.532	-0.289
1993	5488	-11.941	3.182	0.0065	5348	312.55	0.391	-0.921
1994	5278	-12.251	3.238	0.0089	4862	318.19	0.452	-0.257
1995	4996	-11.781	3.145	0.0083	4504	311.74	0.556	-0.115

1996	4628	-12.279	3.247	0.0070	4275	322.35	0.569	0.037
1997	4465	-12.197	3.234	0.0070	3982	332.42	0.454	-0.256
1998	4558	-12.002	3.196	0.0083	3688	387.79	0.261	-1.065
1999	4279	-11.914	3.175	0.0092	3468	351.68	0.371	-0.523
2000	3669	-11.900	3.171	0.0074	3068	324.71	0.570	-0.031
2001	5012	-11.546	3.106	0.0082	4102	332.64	0.500	-0.473
2002	4370	-11.279	3.065	0.0093	3654	317.91	0.623	-0.065
2003	3945	-12.031	3.211	0.0052	3108	346.20	0.418	-0.556
2004	4600	-11.603	3.120	0.0049	3759	370.20	0.303	-0.609
2005	3940	-11.012	3.007	0.0041	3102	336.90	0.382	-0.412
2006	4209	-11.456	3.090	0.0054	3300	349.80	0.325	-0.880
2007	5320	-10.713	2.949	0.0070	3759	299.30	0.522	-0.514
2008	4438	-11.029	3.010	0.0072	3204	318.10	0.419	-0.826

Table 5. Estimated fork lengths and weights for Atlantic menhaden calculated at middle of fishing year averaged over 2001-2008 (annual estimates), and female maturity at age as summarized from Higham and Nicholson (1964), Dietrich (1979), and Lewis et al. (1987).

Age	Fork Length (mm)	Weight (g)	Maturity (% Female Mature)
0	139	46	0
1	192	124	0
2	240	247	11.8
3	271	359	86.4
4	292	448	100
5	305	516	100
6	314	565	100

Table 6. Fork length (mm) at age on March 1 (start of fishing year) estimated from annual von Bertalanffy growth parameters presented in Table 2.1.

Year	0	1	2	3	4	5	6	7	8
1955	109.9	152.9	216.5	258.7	286.7	305.3	317.6	325.8	331.3
1956	78.6	139.7	221.8	269.4	297.2	313.3	322.6	328.1	331.2
1957	111.0	155.6	220.3	261.9	288.7	306.0	317.1	324.2	328.8
1958	80.8	136.2	213.2	260.2	288.9	306.5	317.2	323.7	327.7
1959	129.2	162.8	216.0	254.7	282.8	303.2	318.1	328.9	336.7
1960	107.9	150.0	213.5	256.7	286.1	306.1	319.8	329.1	335.4
1961	127.9	161.0	213.6	251.9	279.8	300.2	315.1	325.9	333.8
1962	136.5	169.9	222.1	259.6	286.5	305.9	319.7	329.7	336.8
1963	130.7	164.8	218.8	258.3	287.1	308.1	323.5	334.7	342.9
1964	138.7	172.7	226.2	265.1	293.2	313.6	328.4	339.1	346.8
1965	130.8	166.9	224.2	266.0	296.6	319.0	335.3	347.3	356.0
1966	143.7	174.2	222.6	257.9	283.7	302.5	316.3	326.3	333.6
1967	138.3	176.5	231.3	266.2	288.5	302.7	311.7	317.5	321.2
1968	144.0	175.8	224.5	258.4	282.1	298.6	310.0	318.1	323.6
1969	149.3	177.6	226.6	266.9	300.1	327.4	349.9	368.4	383.6
1970	132.6	165.8	222.0	267.1	303.2	332.1	355.4	374.0	388.9
1971	122.3	170.2	236.0	275.5	299.2	313.4	322.0	327.1	330.2
1972	76.4	144.7	236.3	289.2	319.8	337.5	347.8	353.7	357.1
1973	116.8	156.4	220.8	269.8	306.9	335.2	356.6	372.9	385.3
1974	108.1	145.3	210.1	264.0	308.8	346.0	376.9	402.7	424.0
1975	95.4	135.3	199.8	248.0	284.2	311.2	331.5	346.7	358.1
1976	94.5	128.0	189.9	245.5	295.4	340.2	380.4	416.5	448.8
1977	93.1	126.1	181.9	226.2	261.4	289.3	311.6	329.2	343.2
1978	105.2	130.8	177.8	219.8	257.4	290.9	320.8	347.5	371.4
1979	96.4	131.5	188.5	231.5	263.9	288.4	306.8	320.8	331.3
1980	93.8	128.0	183.1	224.6	255.8	279.2	296.7	309.9	319.9
1981	94.5	125.3	177.7	219.6	253.2	280.2	301.8	319.1	333.0
1982	111.9	135.2	176.8	212.6	243.4	269.9	292.7	312.3	329.1
1983	104.4	133.9	183.5	222.5	253.2	277.5	296.6	311.7	323.5
1984	91.7	127.2	183.5	224.7	254.8	276.8	292.9	304.7	313.3
1985	92.4	130.6	191.0	235.0	267.0	290.3	307.3	319.7	328.7
1986	99.8	130.8	181.7	220.7	250.6	273.5	291.1	304.6	314.9
1987	108.2	136.6	184.5	222.7	253.2	277.5	297.0	312.4	324.8
1988	95.8	127.6	180.0	220.3	251.4	275.4	293.8	308.0	319.0
1989	119.6	145.2	189.0	224.6	253.6	277.2	296.3	311.9	324.6
1990	117.5	156.6	211.3	244.7	265.3	277.9	285.6	290.3	293.3
1991	125.3	156.6	204.7	238.6	262.4	279.2	291.0	299.3	305.1
1992	102.8	148.9	211.2	247.8	269.3	281.9	289.4	293.7	296.3
1993	133.2	165.1	212.8	245.1	266.9	281.7	291.7	298.4	303.0
1994	92.2	137.9	203.5	245.2	271.7	288.6	299.4	306.2	310.6
1995	90.3	144.0	215.6	256.6	280.1	293.6	301.3	305.8	308.3
1996	74.7	136.0	216.9	262.6	288.5	303.2	311.5	316.2	318.9

1997	96.6	144.5	213.1	256.6	284.3	301.8	313.0	320.1	324.6
1998	130.0	161.6	213.5	253.6	284.4	308.2	326.4	340.5	351.4
1999	111.1	151.8	213.8	256.5	286.0	306.4	320.4	330.1	336.8
2000	84.8	144.3	222.7	267.0	292.1	306.3	314.3	318.8	321.4
2001	128.1	173.4	236.0	274.1	297.1	311.1	319.6	324.7	327.8
2002	94.3	154.2	230.1	270.8	292.6	304.4	310.6	314.0	315.8
2003	123.5	165.5	227.2	267.9	294.6	312.3	323.9	331.5	336.5
2004	105.5	142.7	202.1	246.0	278.4	302.4	320.1	333.2	342.8
2005	99.1	140.5	202.9	245.5	274.5	294.3	307.8	317.1	323.4
2006	126.3	159.8	212.5	250.6	278.1	298.0	312.3	322.7	330.2
2007	123.1	163.6	218.8	251.5	271.0	282.5	289.3	293.4	295.8
2008	135.4	169.9	220.6	253.9	275.9	290.3	299.8	306.1	310.2

Table 7. Fork length (mm) at age on March 1 (beginning of fishing year) estimated from yearclass von Bertalanffy growth parameters.

Year	0	1	2	3	4	5	6	7	8
1955	110.6	158.6	222.1	264.5	277.7	296.5	296.1	322.1	289.7
1956	92.3	149.9	222.5	269.6	289.9	302.3	312.5	323.1	334.7
1957	119.7	138.5	211.2	265.4	298.0	307.9	317.4	322.6	323.3
1958	95.1	155.1	207.6	254.9	294.2	315.0	320.5	326.8	329.0
1959	140.0	132.9	211.8	254.2	286.1	313.6	325.2	329.4	332.6
1960	104.4	169.9	195.0	253.8	285.5	308.3	326.6	331.3	335.7
1961	126.2	151.9	220.5	242.5	284.9	306.7	324.2	335.3	334.9
1962	130.5	163.9	220.6	261.0	278.9	308.0	320.9	335.4	341.2
1963	136.0	169.4	219.5	264.7	293.4	306.7	325.0	330.5	343.5
1964	138.5	171.7	225.4	256.4	293.1	319.2	328.0	337.7	337.0
1965	130.8	172.4	225.9	261.1	280.7	311.3	339.9	344.3	347.1
1966	137.2	162.4	227.2	263.2	283.9	296.9	322.9	356.5	356.8
1967	143.2	176.0	217.1	268.2	288.9	298.5	307.6	330.4	369.7
1968	149.9	168.7	234.7	262.1	298.8	306.6	307.8	314.6	335.3
1969	144.5	175.5	216.2	274.9	299.0	321.7	318.8	313.7	319.3
1970	122.8	183.2	221.9	259.6	302.5	329.4	338.9	327.2	317.5
1971	123.5	173.0	243.1	262.8	299.1	321.4	354.3	351.7	332.9
1972	82.0	161.1	241.7	285.3	298.8	335.1	334.4	374.8	361.3
1973	116.7	144.6	220.9	282.8	315.1	330.5	367.9	343.2	391.7
1974	101.7	152.2	221.9	264.7	307.3	336.0	358.3	397.9	349.3
1975	104.3	139.1	207.5	261.8	296.9	322.0	350.8	382.9	425.1
1976	84.3	133.1	196.8	246.8	282.4	320.5	330.7	361.3	404.5
1977	91.1	123.4	181.9	237.6	274.7	293.1	337.7	335.9	368.6
1978	107.6	127.9	184.2	220.9	266.4	294.6	298.6	350.4	339.1
1979	104.9	134.8	186.3	227.4	252.1	286.7	308.7	301.4	359.7
1980	92.7	127.9	181.0	229.1	258.2	277.1	301.1	318.8	302.8
1981	88.5	129.1	170.1	218.4	260.6	280.0	297.1	311.2	326.0
1982	99.0	128.6	186.2	207.6	248.5	283.6	295.5	313.1	318.3
1983	110.9	131.9	190.1	227.4	241.0	272.9	300.5	306.5	325.9
1984	97.0	136.0	185.9	232.9	257.0	270.7	292.5	312.9	314.4
1985	93.3	130.3	180.2	227.1	262.7	278.3	297.1	308.4	322.0
1986	98.3	128.1	183.5	217.4	258.7	283.4	293.7	320.6	321.2
1987	101.2	133.7	183.0	222.8	248.8	282.8	297.8	304.7	341.6
1988	95.8	132.6	188.2	222.9	251.9	275.2	301.3	307.8	312.7
1989	114.0	140.4	184.0	226.5	251.7	273.3	297.5	315.5	314.8
1990	114.7	155.4	204.2	223.2	253.3	272.7	289.1	316.2	326.3
1991	127.3	148.0	213.5	244.6	253.1	272.1	287.9	300.8	332.0
1992	101.8	164.4	200.7	249.3	270.2	276.0	285.3	299.0	309.4
1993	127.2	142.8	219.4	239.2	271.4	286.3	293.4	294.5	307.0
1994	84.5	162.3	206.1	256.0	267.2	285.0	296.6	306.7	301.0
1995	86.9	144.3	217.1	250.7	280.4	287.7	293.5	303.0	316.8
1996	76.3	138.1	224.6	256.1	282.2	296.6	302.6	298.6	307.1

1997	101.2	130.4	211.9	271.1	284.0	304.3	307.4	313.5	301.8
1998	137.3	142.3	206.7	259.4	298.1	304.0	319.9	314.6	321.5
1999	107.8	169.5	206.1	254.0	289.9	313.7	318.2	330.8	319.4
2000	87.0	158.9	222.3	251.5	283.5	309.4	322.7	328.3	338.6
2001	125.1	149.2	228.9	262.5	283.8	301.8	322.0	328.0	335.5
2002	108.2	170.0	227.6	270.5	293.2	306.9	313.2	330.1	331.0
2003	125.0	153.7	226.7	269.3	295.3	316.7	323.3	320.3	335.3
2004	99.4	159.1	216.6	257.0	291.4	310.1	334.5	334.9	324.7
2005	105.1	136.1	211.9	254.6	273.2	303.2	318.9	348.2	343.3
2006	119.6	151.4	196.2	249.3	277.6	281.9	309.4	324.2	358.6
2007		158.5	214.1	241.9	275.7	291.6	286.5	312.7	327.3
2008			219.5	250.9	276.8	294.5	300.0	289.0	314.5

Table 8. Weight (g) at age on September 1 (middle of fishing year) estimated from annual weight-length parameters presented in Table 1 and annual lengths at age in Table 5.

Year	0	1	2	3	4	5	6	7	8
1955	20.8	58.9	176.6	309.9	428.7	522.7	592.4	642.0	676.4
1956	7.3	44.6	192.3	355.9	485.0	573.1	628.9	663.1	683.5
1957	20.3	60.7	187.2	328.2	450.1	543.4	610.1	655.9	686.7
1958	7.3	40.1	172.9	331.5	466.4	565.3	632.4	675.9	703.5
1959	33.1	70.5	177.3	303.4	427.0	536.2	626.8	699.0	755.0
1960	17.6	52.7	170.5	315.1	452.4	566.9	655.5	721.2	768.5
1961	31.1	66.9	170.9	295.7	419.5	529.8	622.1	696.1	753.8
1962	43.9	86.2	197.1	318.9	432.2	528.5	605.9	666.0	711.5
1963	37.1	77.7	192.3	326.5	457.8	573.8	670.3	747.5	807.5
1964	46.2	92.5	217.6	359.4	494.8	612.4	708.6	784.5	842.9
1965	36.5	79.6	204.0	352.4	498.8	629.0	737.8	825.0	893.1
1966	50.2	91.4	195.8	309.5	416.2	508.3	583.7	643.3	689.3
1967	42.0	92.4	221.9	349.9	453.8	530.0	583.0	618.6	642.1
1968	50.5	95.1	206.8	323.5	427.3	511.8	577.1	625.8	661.4
1969	61.0	105.8	228.9	384.4	557.2	734.1	905.9	1066.4	1212.3
1970	40.3	81.1	202.7	362.1	539.3	718.1	887.7	1041.9	1177.9
1971	31.3	86.4	236.5	380.8	491.0	566.5	615.3	646.0	664.9
1972	6.7	49.6	230.0	433.0	593.2	702.2	771.0	812.8	837.7
1973	27.6	67.2	192.8	355.5	527.5	690.2	834.2	956.2	1056.5
1974	20.0	50.7	161.9	332.0	543.5	777.5	1017.9	1252.7	1474.0
1975	13.4	40.6	139.7	277.5	427.2	570.1	696.4	802.8	889.3
1976	12.4	33.3	120.9	279.5	511.4	810.9	1167.8	1570.0	2005.0
1977	11.6	31.6	106.2	218.3	352.2	493.0	629.6	755.6	867.4
1978	17.7	36.1	98.4	196.6	328.9	490.5	675.4	877.1	1089.7
1979	13.3	36.8	119.7	234.7	360.6	482.1	590.7	683.1	759.1
1980	12.3	33.9	109.7	214.2	327.8	436.8	533.6	615.4	682.3
1981	12.0	30.5	96.3	193.7	309.8	432.5	552.6	664.3	764.6
1982	23.8	43.1	100.0	178.5	272.9	377.3	486.5	596.2	703.0
1983	18.5	40.2	107.1	195.3	292.4	388.9	478.6	558.5	627.6
1984	12.9	35.8	112.4	211.4	313.0	405.4	483.6	546.9	596.6
1985	12.6	37.1	121.3	231.7	345.3	448.4	535.5	605.8	660.7
1986	14.6	35.0	101.8	191.4	289.0	384.0	469.9	544.2	606.3
1987	20.6	42.9	110.9	201.1	301.6	403.0	499.0	585.9	662.3
1988	14.0	34.2	100.2	188.5	284.7	378.3	463.2	536.9	598.7
1989	25.7	48.5	115.2	203.2	302.5	404.9	504.2	596.5	679.8
1990	24.5	62.4	165.6	267.5	347.9	404.7	442.6	467.0	482.4
1991	31.6	63.6	148.1	239.7	323.5	393.0	447.6	489.0	519.6
1992	15.8	51.9	159.9	267.4	349.4	404.9	440.2	461.9	475.0
1993	37.7	74.5	167.2	262.0	343.7	408.0	455.8	490.3	514.6
1994	11.0	40.7	143.3	262.2	365.7	444.6	500.5	538.5	563.7
1995	10.9	47.2	167.7	290.0	382.1	443.1	480.8	503.5	516.7
1996	5.6	39.5	179.6	334.5	454.1	533.4	582.3	611.3	628.2

1997	13.3	48.9	171.7	313.4	436.3	529.7	595.7	640.4	670.0
1998	35.2	70.4	171.6	297.1	428.7	554.0	666.1	762.4	842.9
1999	21.0	56.7	168.0	299.7	423.5	526.8	607.3	667.6	711.5
2000	8.9	47.9	189.7	337.3	448.3	521.0	565.5	591.8	607.1
2001	34.2	87.4	228.0	362.5	465.9	537.4	584.2	613.9	632.4
2002	14.3	64.5	220.2	362.9	460.2	519.0	552.6	571.2	581.3
2003	31.0	79.4	219.8	372.8	506.1	609.8	685.5	738.8	775.3
2004	18.8	48.3	143.3	264.6	389.4	503.9	601.8	681.9	745.6
2005	16.6	47.4	143.0	253.5	354.9	437.6	500.9	547.4	580.8
2006	33.1	68.5	165.1	274.8	379.2	469.4	542.9	600.7	644.9
2007	32.5	75.3	177.6	267.9	333.7	377.3	404.9	421.9	432.2
2008	42.5	84.2	184.6	282.0	361.9	421.9	464.9	494.7	515.0

Table 9. Weight (g) at age on September 1 (middle of fishing year) estimated from annual weight-length parameters presented in Table 1 and annual lengths at age in Table 6.

Year	0	1	2	3	4	5	6	7	8
1955	36.2	124.3	274.3	390.3	451.5	523.3	610.8	681.9	674.8
1956	25.2	105.1	267.1	428.1	498.1	558.8	601.7	633.0	710.4
1957	41.2	91.3	230.8	413.4	553.1	595.6	645.8	668.9	649.8
1958	22.8	109.9	231.7	382.2	555.5	655.8	686.9	719.8	728.9
1959	60.5	75.2	231.4	373.5	507.5	643.9	697.1	726.6	739.2
1960	32.2	129.6	189.6	375.4	513.3	636.2	738.3	752.7	789.3
1961	48.3	116.0	258.4	336.7	512.9	618.3	727.6	789.9	771.3
1962	60.1	131.0	267.1	394.1	466.5	591.0	644.3	731.1	754.8
1963	63.5	145.6	257.7	424.9	567.3	635.0	727.1	742.6	835.6
1964	67.1	150.4	281.1	380.3	550.2	721.1	767.2	811.7	786.5
1965	53.0	145.8	275.5	386.3	462.2	621.2	835.8	853.3	852.3
1966	66.8	121.9	278.1	387.7	455.6	509.7	648.2	899.7	887.3
1967	62.1	157.6	252.4	434.2	507.2	535.7	581.5	722.8	1063.5
1968	74.7	128.1	316.8	424.3	583.3	596.3	583.3	620.6	751.8
1969	83.3	152.8	268.9	500.0	649.2	759.4	705.9	655.1	689.9
1970	58.7	185.4	269.3	419.1	595.1	790.4	814.4	705.8	631.7
1971	50.6	169.4	341.9	406.3	589.4	654.5	905.8	844.3	695.9
1972	24.7	122.7	328.9	493.1	566.4	800.0	713.2	1048.6	897.8
1973	43.1	121.1	263.3	475.2	636.9	752.9	1039.3	764.4	1175.1
1974	28.7	103.4	263.0	408.7	582.0	764.0	968.3	1344.6	817.8
1975	27.1	84.5	214.8	379.8	560.5	666.2	877.0	1204.4	1682.8
1976	17.3	67.4	192.4	345.3	474.1	732.6	761.3	1023.0	1543.4
1977	20.2	64.4	151.3	317.3	471.6	533.0	878.5	821.9	1126.2
1978	28.4	68.7	163.2	252.6	420.4	556.1	543.8	944.0	817.6
1979	24.8	68.7	168.8	279.1	366.8	516.4	638.4	562.1	1028.2
1980	21.7	56.6	148.1	288.8	391.6	482.0	593.8	702.3	573.1
1981	19.5	68.2	118.8	239.7	396.9	475.8	575.8	637.1	732.7
1982	26.7	76.2	167.7	212.4	341.0	486.7	533.9	643.0	650.7
1983	31.4	70.8	171.6	258.4	303.4	414.5	534.0	553.5	675.8
1984	25.6	71.9	165.8	291.7	368.6	440.4	525.8	623.9	621.0
1985	22.6	68.4	139.3	260.6	374.2	430.8	546.0	579.3	641.6
1986	24.3	64.4	149.8	230.7	375.2	470.7	516.2	715.8	683.0
1987	26.6	75.5	153.6	249.4	338.2	476.8	533.3	566.0	847.6
1988	27.8	69.4	159.9	241.3	329.2	429.6	541.5	556.9	580.4
1989	39.1	91.1	150.3	256.1	341.1	427.5	567.7	657.1	632.2
1990	35.8	113.1	208.5	248.2	340.4	419.4	494.0	670.6	713.7
1991	52.0	92.8	224.1	309.7	334.8	393.4	461.9	521.5	723.5
1992	28.3	123.1	186.4	318.7	392.3	420.5	445.0	512.0	565.8
1993	49.8	93.4	243.6	294.7	396.0	457.6	501.1	488.5	553.9
1994	23.5	118.8	214.3	355.7	395.0	450.3	504.8	572.6	523.3
1995	22.6	112.6	229.7	331.8	423.1	453.4	456.3	501.1	586.3
1996	17.0	96.5	288.8	371.6	483.5	529.8	564.3	517.7	564.7

1997	28.8	87.6	246.6	447.0	491.0	594.2	585.9	625.8	536.0
1998	60.3	93.9	227.2	390.9	547.0	574.4	662.1	608.2	654.1
1999	39.1	131.1	214.0	354.9	496.6	597.8	627.1	699.9	612.1
2000	27.1	131.5	252.7	345.5	456.5	577.9	633.4	674.5	736.3
2001	55.0	125.1	280.6	382.9	462.1	522.0	624.5	643.7	697.6
2002	40.4	149.4	290.1	422.1	526.3	581.0	588.9	683.6	677.6
2003	49.5	121.7	277.0	440.1	557.5	701.6	725.3	678.0	779.9
2004	27.0	113.9	238.6	339.2	482.6	572.9	738.6	722.8	638.4
2005	37.3	81.3	214.5	328.6	369.5	495.8	572.7	760.5	714.6
2006	45.3	111.1	185.4	321.5	411.2	407.1	537.6	619.3	862.4
2007	50.2	119.8	219.0	297.3	390.9	434.4	399.2	514.3	588.0
2008	52.4	123.8	247.9	313.7	424.9	473.5	479.2	419.4	539.6

Table 10. Annual estimates of fecundity (no. of maturing or ripe ova in billions) at age on March 1 (start of fishing year) by applying Eq. (4) to fork lengths at age on March 1 in Table 5.

Year	2	3	4	5	6	7	8
1955	65949.3	124197.1	189046.2	249843.2	300637.5	339930.3	368805.1
1956	71350.8	145893.6	221082.0	281485.0	323903.6	351431.8	368491.4
1957	69755.9	130231.2	194694.2	252253.7	298049.8	331859.9	355641.4
1958	62742.6	127047.7	195469.1	254297.0	298619.5	329403.9	349743.6
1959	65429.2	116854.9	178156.9	242095.8	302576.0	355843.2	400376.6
1960	62993.1	120421.0	187223.2	252866.1	310306.2	356727.7	392258.9
1961	63108.8	112118.2	170487.9	231438.3	289228.2	340281.9	383110.9
1962	71738.6	125907.4	188539.5	251921.3	310174.4	360122.5	400861.1
1963	68266.4	123392.5	190115.2	260675.8	328248.8	388419.2	439216.3
1964	76304.0	136584.7	208296.4	282833.5	353041.4	414595.2	465819.1
1965	74006.1	138638.3	219348.0	306734.5	391922.9	468807.4	534383.2
1966	72242.9	122686.2	180619.5	239570.0	294453.5	342326.2	382136.8
1967	82336.0	139039.8	194152.9	240185.9	275062.4	299885.0	316859.3
1968	74287.6	123609.2	176275.6	225754.4	268244.0	302506.4	328945.3
1969	76710.2	140455.0	231049.2	348010.3	487504.9	643343.8	808304.8
1970	71604.5	140774.6	242018.5	373657.9	529258.9	699614.4	874983.4
1971	88365.5	159805.9	228041.3	282284.4	320851.1	346482.3	362837.4
1972	88728.3	196295.5	310676.5	405139.4	472357.8	516201.3	543385.8
1973	70335.3	146577.5	256029.5	391089.0	539542.8	688932.1	829478.9
1974	59921.8	134467.6	263246.2	460078.9	731729.1	1076050.9	1482614.4
1975	51290.4	105786.3	181934.0	273083.1	370174.3	464899.7	551412.2
1976	44269.7	101891.2	215330.4	421508.4	770273.3	1323361.4	2151052.9
1977	39237.7	76253.5	129278.7	196647.3	274423.1	357615.1	441350.2
1978	36925.0	69332.6	121707.7	201181.0	315162.1	470598.9	673230.3
1979	43339.1	82589.6	134324.8	193857.3	255656.9	314994.2	368700.6
1980	39976.0	74456.1	118800.2	168756.6	219677.7	267808.6	310786.5
1981	36818.3	69066.1	114365.7	171354.7	236961.6	307287.6	378470.8
1982	36367.8	62232.2	98767.9	146927.2	206735.1	277293.6	356937.8
1983	40164.7	72126.8	114419.2	164610.1	219259.9	274847.9	328429.0
1984	40211.1	74572.2	117144.1	162986.1	207507.4	247588.0	281717.2
1985	44961.5	86963.9	140606.2	199518.0	257437.6	309949.5	354820.0
1986	39114.8	70228.3	109981.4	155105.5	201865.7	247041.6	288398.4
1987	40796.0	72388.1	114377.0	164748.9	220418.4	278035.1	334619.2
1988	38136.8	69853.3	111339.6	159442.0	210247.3	260173.2	306576.1
1989	43649.8	74502.2	115064.4	163838.7	218371.0	275830.6	333519.5
1990	60942.8	100724.9	137073.8	165583.4	185926.2	199618.7	208509.6
1991	55259.4	91855.1	131315.3	168839.1	201484.3	228155.5	249000.8
1992	60880.2	105438.8	145585.1	175964.5	196686.9	209979.9	218203.7
1993	62377.1	101231.3	140459.4	175289.6	203623.3	225341.2	241329.3
1994	54230.6	101392.7	150988.4	194532.8	228572.0	253272.0	270362.0
1995	65011.7	120287.6	171189.3	209589.0	235382.6	251583.5	261372.9
1996	66284.8	131710.6	194282.2	242100.8	274216.6	294250.9	306234.3

1997	62616.1	120348.4	182241.7	237188.9	280399.6	311843.8	333620.3
1998	63070.8	114972.2	182580.8	260720.6	343046.8	423793.2	498730.8
1999	63278.6	120156.4	187032.6	253818.4	313348.1	362383.8	400626.2
2000	72340.6	140656.9	204867.5	253413.8	285798.9	305913.1	317908.6
2001	88394.0	156324.1	220904.5	272453.7	309414.3	334233.4	350246.9
2002	80846.3	148907.9	206625.7	246312.6	270651.3	284681.1	292503.0
2003	77468.7	142516.7	212892.6	277274.3	329956.0	369992.6	398967.8
2004	53106.2	102593.2	166887.1	239086.0	311830.7	379455.7	438678.4
2005	53759.4	101801.8	157389.1	211880.0	259533.1	298064.7	327591.3
2006	62088.5	109903.4	166054.9	223767.3	277603.3	324409.6	363078.9
2007	68215.4	111497.2	149230.4	177403.4	196571.1	208907.7	216589.6
2008	70113.7	115614.9	160674.2	199526.3	230086.4	252706.9	268791.9

Table 11. Annual estimates of fecundity (no. of maturing or ripe ova in billions) at age on March 1 (start of fishing year) by applying Eq. (4) to fork lengths at age on March 1 in Table 6.

Year	2	3	4	5	6	7	8
1955	71746.5	135469.3	165103.0	219032.1	217740.1	321214.8	197636.0
1956	72101.7	146295.9	198364.8	238714.9	278271.9	326058.9	387984.5
1957	60931.2	137238.2	224018.7	259559.1	299712.5	323917.3	327224.5
1958	57709.7	117363.6	211476.4	289036.4	313736.4	344903.3	356688.9
1959	61418.3	116011.4	187290.0	282759.0	336617.2	358599.7	376132.3
1960	47771.5	115336.1	185701.6	261358.4	343689.8	368737.1	394034.3
1961	70012.3	97434.6	183959.9	254960.3	331451.9	391833.4	389392.5
1962	70150.0	128511.8	168105.1	259983.0	315659.2	392634.8	427907.7
1963	68998.5	135948.5	208853.0	255173.2	335925.7	364506.9	443038.6
1964	75369.9	119891.7	207921.9	307939.1	351182.9	406165.6	401611.8
1965	75931.9	128807.6	172835.8	273147.7	420038.6	448401.7	467516.7
1966	77430.6	132904.1	181346.3	220185.2	325456.6	538379.7	540607.8
1967	66557.2	143143.8	195394.4	225602.4	258463.6	364216.3	656568.9
1968	86617.7	130603.6	226649.3	254766.3	259346.1	287396.6	391507.4
1969	65678.2	158388.4	227291.6	319609.4	305825.1	283479.5	308310.1
1970	71523.3	125825.5	239545.2	358395.7	413288.6	346808.1	300046.0
1971	98268.8	132073.9	227585.6	318079.5	521103.1	500891.0	378172.8
1972	96288.1	185087.5	226596.6	390623.1	386318.9	708822.3	578341.6
1973	70423.5	178247.8	289225.2	364405.4	639177.6	441371.0	912764.0
1974	71533.1	135920.3	257500.9	396200.1	553580.4	1001314.7	483572.6
1975	57577.3	130162.3	220146.2	320777.2	494627.6	799846.0	1507571.6
1976	49093.0	103811.8	177277.6	313544.5	365765.6	578387.4	1105787.7
1977	39217.1	90510.0	157887.4	207919.5	406384.1	395594.0	645832.0
1978	40638.0	70425.4	139390.9	212756.8	225750.7	491521.0	414559.3
1979	41903.8	77700.7	112507.8	189066.7	263043.8	235543.2	565096.5
1980	38722.3	79680.8	123163.9	163675.8	234455.7	305896.6	240761.9
1981	32854.9	67809.1	127673.3	170869.8	220931.7	272912.2	340565.5
1982	41866.7	57672.8	106595.3	180426.7	215632.6	280867.9	303797.8
1983	44385.3	77593.2	95158.3	153582.4	232534.3	254407.9	340343.7
1984	41641.0	84315.7	121001.4	148589.2	206248.0	280103.7	286134.6
1985	38259.9	77327.9	131778.5	166630.6	220915.9	261679.2	321082.5
1986	40211.0	66869.5	124164.0	179808.9	209811.6	314420.0	317126.5
1987	39899.6	72506.8	107027.8	178376.7	223223.1	247684.1	430450.4
1988	43139.6	72525.0	112059.2	159064.3	235350.1	259481.7	279124.6
1989	40485.7	76555.8	111879.1	154548.9	222090.4	290944.2	288136.5
1990	54851.7	72906.0	114475.2	153220.9	195959.8	294199.2	342190.6
1991	63019.2	100508.4	114208.9	151802.4	192481.2	233508.3	372828.0
1992	52052.2	107864.2	147452.8	160861.0	185035.0	227120.4	265781.3
1993	68848.3	92672.9	150264.8	187929.0	208909.7	212599.2	256088.9
1994	56432.9	119239.0	141156.7	184363.1	219108.9	255019.7	234349.9
1995	66500.4	110186.9	171898.0	191874.1	209152.0	241463.1	296939.1
1996	74449.0	119510.8	176525.7	219312.3	240032.1	226078.4	256774.4

1997	61582.4	149569.4	181601.6	246019.9	257939.6	282627.8	237196.1
1998	56880.8	125461.7	224088.8	244804.8	310819.9	287368.7	318397.4
1999	56378.7	115805.7	198169.6	283247.6	302967.2	366459.5	308807.7
2000	71927.3	111448.6	180156.5	265804.7	324434.9	352754.9	411526.9
2001	79355.5	131543.7	181047.5	237106.0	320982.0	350990.4	393221.1
2002	77920.9	148231.0	208482.5	255752.8	281249.5	362327.9	367362.8
2003	76840.2	145559.5	215084.2	296236.4	327067.9	312738.2	391655.1
2004	65996.0	121074.9	202863.4	268488.9	387279.9	389663.9	334063.3
2005	61521.3	116790.2	154372.8	241982.8	306414.8	475127.0	441406.0
2006	48597.1	107765.5	164961.6	175773.6	265744.9	331510.3	555314.3
2007	63580.9	96542.4	160274.7	203292.5	188400.4	279302.4	347428.0
2008	68957.5	110407.6	162892.4	212288.9	230685.1	195515.4	286783.3

Figure 1. Weighted mean weight at age for Atlantic menhaden for ages 1 through 3.

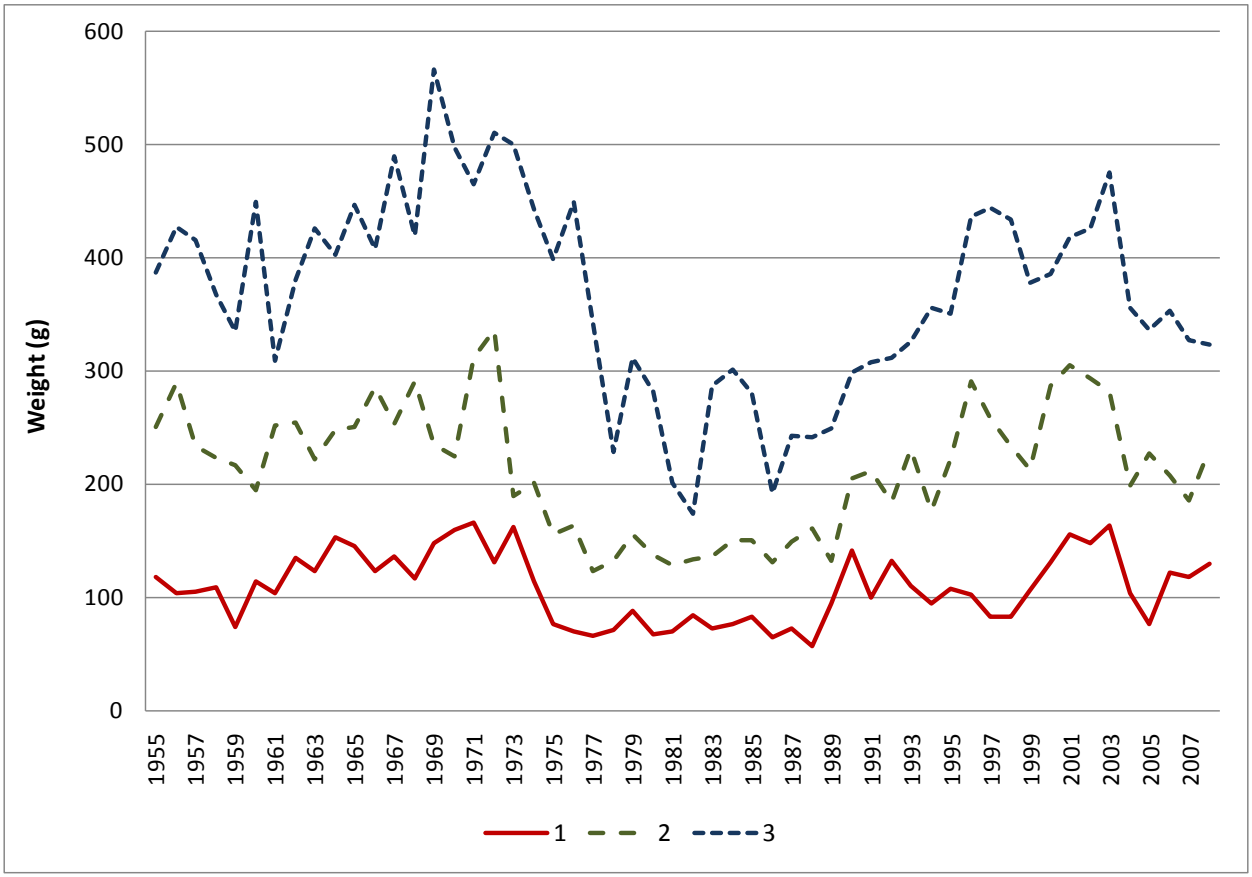

Figure 2. Weighted mean weight at age 0 plotted against recruits to age 0 obtained from latest Atlantic menhaden stock assessment (ASMFC 2006) for 1955-2005. A statistically significant forty nine percent ($R^2 = 0.49$) of the variability in mean weight is explained by variability in recruits to age 0.

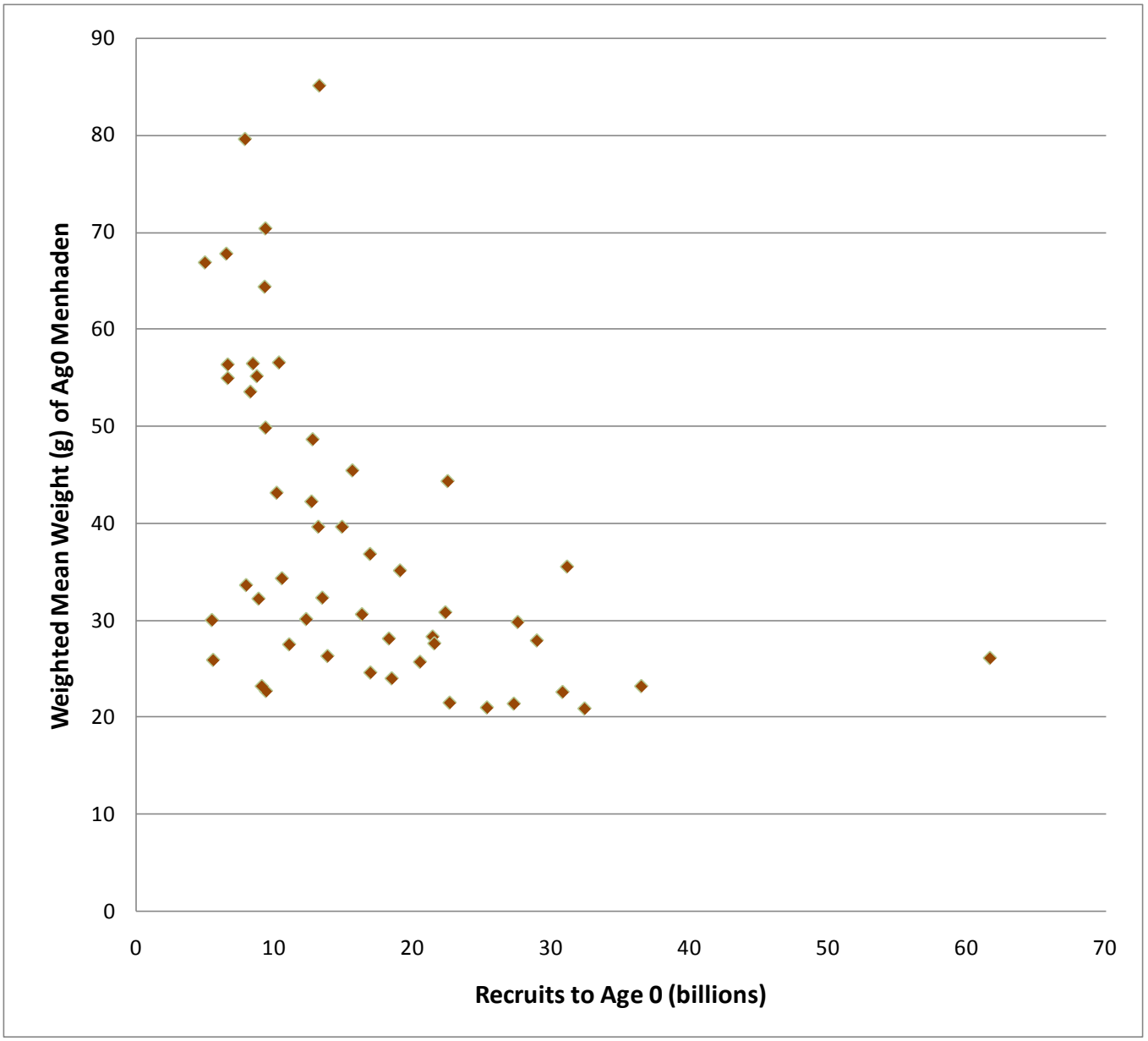

Figure 3. Comparison of observed weight mean length at age (ages 2 and 3) with values estimated form the year and cohort based von Bertalanffy growth equation for mid-year (t+0.5).

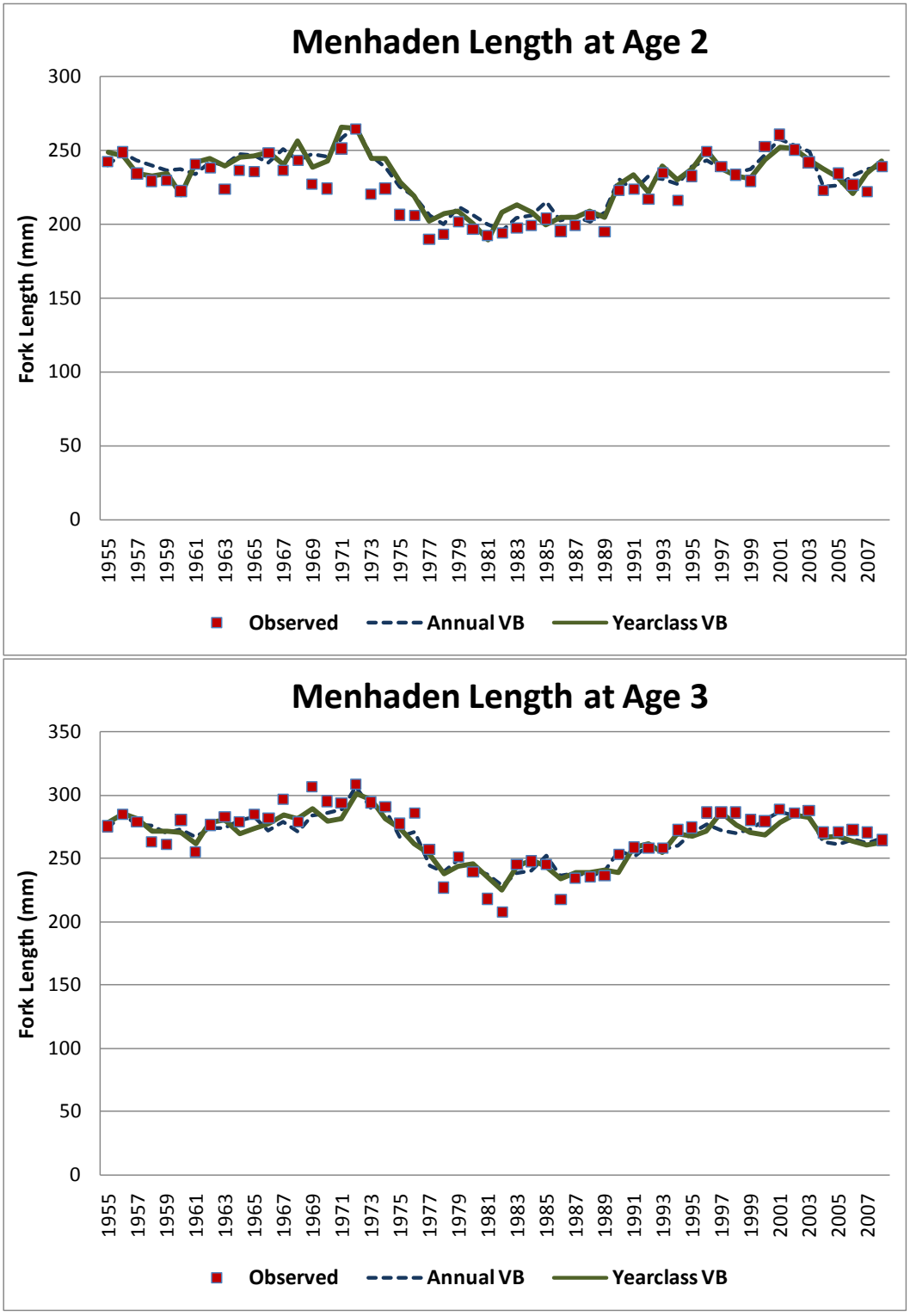

Figure 4. Fecundity (no. of maturing or ripe ova) as a function of fork length (mm) for Atlantic menhaden.

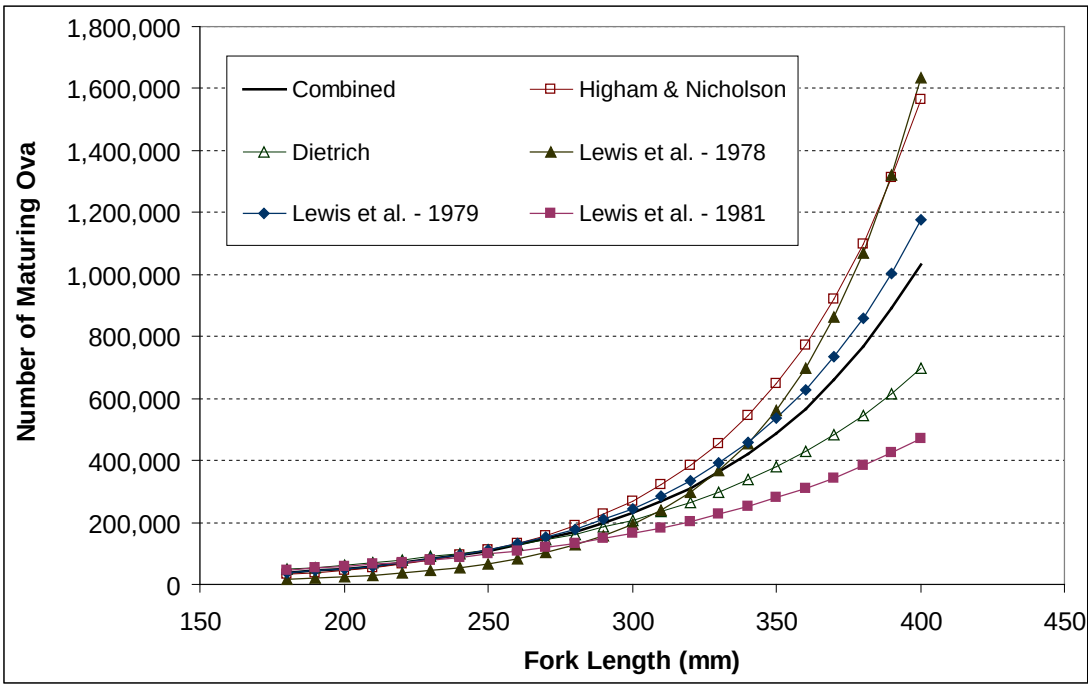

Figure 5. Proportion of age 2 (11.8% mature) and age 3 (86.4%) spawning (essentially first time spawners) to total female spawning stock as estimated in numbers and in biomass from the most recent stock assessment (ASMFC 2006), 1955-2005.