S E D A R

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Age, Growth and Reproduction of Gulf Menhaden

Prepared by
Douglas S. Vaughan, Joseph W. Smith
and Amy M. Schueller

NOAA Fisheries
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SEDAR
The South Atlantic Fishery Management Council
4055 Faber Place #201
North Charleston, SC 29405
(843) 571-4366

Introduction

Gulf menhaden are euryhaline species that inhabit nearshore marine and estuarine waters from Cape Sable, Florida to Veracruz, Mexico with centers of abundance off Louisiana and Mississippi (Lassuy 1983). Spawning generally occurs during the cooler months in the marine environment, eggs hatch at sea, and the larvae are transported to estuaries by ocean currents where they undergo metamorphosis and develop into juveniles (Ahrenholz 1991). Unlike Atlantic menhaden, "(g)ulf menhaden do not exhibit extensive migratory pattern. During late spring and summer they distribute along the U.S. Gulf coast in nearshore waters. Beginning in October, they move offshore into deeper waters for winter." Ahrenholz (1991) further notes that the results of tagging failed to identify any east-west component to the annual migration of gulf menhaden.

Ageing

In 1964 the National Marine Fisheries Service (NMFS) Beaufort Laboratory (formerly the U.S. Bureau of Commercial Fisheries) began monitoring the gulf menhaden purse-seine fishery for size and age composition of the catch (Nicholson 1978). From the outset, program managers realized using otoliths to age gulf menhaden was impractical because 1) sagittal otoliths were so small and fragile, and 2) large amounts of time and effort would be required to extract, process, and read whole or sectioned sagittae. Moreover, large numbers of ageing parts (> ca. 10,000) would be required to adequately characterize the fishery with annual landings of several hundred thousand metric tons. Thus, scales were selected for gulf menhaden ageing.

Chapoton (1967) determined that scale development on gulf menhaden began on larval specimens at ca. 21 mm FL and was complete in specimens > ca. 27 mm FL. Gulf menhaden scales are generally thin and translucent (**Figure 1**). Unlike most herrings, the posterior margin of gulf menhaden scales is pectinate or serrated. The anterior field is embedded in the integument. The entire scale is sculptured with fine circuli, which are roughly semi-circular and parallel the anterior and lateral margins. The largest and most symmetrical (nearly rectangular) scales occur in a median lateral band above the lateral line and below the dorsal fin. Scale samples for ageing are removed from this area.

A scale patch is removed with a blunt-edged scalpel and placed in a small vial of water. The patch is removed from the vial, blotted dry, and rubbed between the thumb and forefinger to remove residual integument. Individual scales are then mounted between two glass microscope slides. Ten individual scales (two rows of five) are placed on the first slide with pectinations pointing down, and then covered with the second slide. Slides are fastened together with short lengths of transparent tape. The cover slide is labeled with a unique port and specimen number combination.

Age Determination

Gulf menhaden scales, which are mounted between microscope slides, are viewed on an Eberbach macro-projector at 48x magnification. Age rings on gulf menhaden scales are defined as compressions or interruptions of uniformly spaced circuli in the anterior field of the scale, which are continuous through the lateral fields. Under transmitted light age rings form narrow, continuous, dark bands roughly paralleling the lateral and anterior margins of the scale. A focus is arbitrarily chosen near the center of the posterior field at the base of the circuli. Straight-line measurements are made from the focus to successive scale rings and the scale edge (**Figure 1**).

Nicholson and Schaaf (1978) found that ageing gulf menhaden with scales was problematic, citing that only about 50% of the fish examined during 1971-1973 could be aged by scale annuli. They determined that many fish had well-defined scale rings, but others had no rings, or rings that were oddly spaced. Their criteria for scale ageing were based on appearance of the scales, number and spacing of the rings, and fish fork length at time of capture. Although admitting some subjectivity, they determined that fish with one or two scale rings displayed true annuli. For fish with oddly-spaced rings, it was possible to separate out age classes by ring location. Finally, for fish with no discernable rings, they believed age could be estimated by length frequency distributions.

In an attempt to increase the probability of encountering legible scales with true annular rings, Menhaden Program personnel at the Beaufort Laboratory in the early 1990s instructed port agents to mount ten scales for ageing per specimen versus the previous directions to mount six scales. Percent legibility increased; for example in fishing year (2003), 86% (6,780 of 7,839) of gulf menhaden scale samples had legible annular rings (compared to ca. 50% by Nicholson and Schaaf [1978]; see above). Age assignments based on ring spacing and/or length frequencies were only required for 14% of the samples.

Gulf menhaden spawn between October and April, with peak activity from December through March (Turner 1969, Fore and Baxter 1972). Scale annuli form in winter, and by convention the birth date for gulf menhaden is January 1. Since the purse-seine fishery operates April through October, advancing ages because of calendar date (and unformed rings) is not an issue relative to the fishing season.

Ageing error matrix

The data for the ageing error analysis comes from two unpublished studies conducted at the NMFS Beaufort Laboratory. The first was a scale-to-otolith comparison by Smith and Levi[1], and the second was a scale-to-scale comparison by Smith and Hall[2]. The comparison between

[1] Ageing gulf menhaden, *Brevoortia patronus*, using sagittal otoliths, with a critique of present scale reading criteria for the species, Smith, J.S. and E.J. Levi. 1990, unpublished ms, NMFS Beaufort Laboratory.
[2] Precision of paired readings of gulf menhaden scales. Smith, J.W. and E.A. Hall. 2009. unpublished ms, NMFS Beaufort Laboratory.

scale and otolith readings was completed by two separate readers, one for the scales and one for the otoliths (n=228). The comparison between scale readings was completed by one reader who read all of the scales from the 2005 fishing season, then re-read 54.9% of the scales from that same fishing season (n=3,405).

Accounting for error in age estimation is important for age composition data used in stock assessments (Punt et al. 2008). Thus, to account for any error associated with the age estimation process for gulf menhaden and to get contemporary precision estimates, an ageing error analysis was completed using a program called “agemat” developed by André Punt. Agemat uses age estimation data from multiple readers to 1) estimate the coefficient of variation and standard deviation associated with age estimates and 2) to provide an ageing error matrix. This program has been used to create ageing error matrices for other SEDAR assessments (ASMFC 2010; Anonymous 2010 (SEDAR 24)).

Agemat requires some model specifications, such as the minimum and maximum age of the species, a reference age, and the type of standard deviation to be estimated, in addition to inputting the ageing data and number of readers in the appropriate format. The minimum age used for this analysis was age 0, and the maximum age used was age 6. The reference age was age 2. The standard deviation was estimated using an asymptotic function. The maximum allowable standard deviation was input as 5; however, the standard deviation for neither comparison came near that bound. All specifications were the same for both comparisons analyzed.

For the scale-to-otolith comparison, the standard deviation was an increasing, asymptotic curve, which started at a low of 0.16 at age 0 and increased to a maximum of 0.55 for fish age 6 (**Figure 1**). The coefficient of variation was a curve which increased from 0.16 at age 0 to 0.20 at age 2, and then decreased to 0.09 at age 6 (**Figure 2**). The ageing error matrix is provided in **Table 1**.

For the scale-to-scale comparison, the standard deviation was an increasing, asymptotic curve, which started at a low of 0.041 at age 0 and increased to maximum of 0.54 for fish age 6 (Figure 2). The coefficient of variation was a curve which increased from 0.041 at age 0 to 0.17 at age 2, and then decreased to 0.09 at age 6 (**Figure 3**). The ageing error matrix is provided in **Table 2**.

Both comparisons indicate a relatively low level of ageing error and had similar ageing error matrices. The scale-to-otolith comparison gives an indication of the error using scales compared to the true age of the fish. This comparison requires the assumption that the otolith provides an accurate true age for each individual[3]. The scale-to-scale comparison looks at reader error within a reader because the reader is ageing scales multiple times to determine precision of age estimates.

[3] Ongoing work at Old Dominion University with Atlantic menhaden, *B. tyrannus*, indicates good agreement between paired scale and otolith age estimates ages 0 through 3 (J. Schaffler, ODU, pers. comm., June 17, 2009).

Longevity, Maximum Size, and Contemporary Age Composition:

Gulf menhaden as old as age 6 occur in the annual NMFS biostatistical data bases (from port samples); however, these specimens are rare and only seven age 6 individuals have been sampled (in 1981 [2], 1982 [2], 1990 [1], 1992 [1], and 1993[1]) from almost 510,000 aged fish processed from 1964 to 2010. Gulf menhaden older than age 4 are uncommon in the landings, including eighty-two age 5 gulf menhaden and the seven age 6 gulf menhaden already mentioned.

Maximum fork length of gulf menhaden as recorded in the NMFS biostatistical data bases is about 341 mm FL (n=538,393); maximum weight of gulf menhaden from the same data bases is about 610 grams (n=538,393). Because of the size of this data base, more realistic values for maximum size might be based on 99^{th} percentiles; e.g., 213 mm for fork length and 203 grams for weight. Fork length frequencies by age for 2010 port samples of gulf menhaden are shown in **Figure 4**.

Growth

Weightings by catch in numbers by year, season and fishing area were applied to the gulf menhaden biostatistical data base to calculate average fork lengths (mm) and weights (g) by age and year (**Tables 3 and 4**). Values based on a single fish are highlighted in color. These mean values represent mean size at age at approximately mid-fishing year (July).

Pair-wise Pearson correlations were estimated for the time series of weighted mean lengths and weights aligned by cohort (year class) or by calendar year (**Table 5**) for ages 1 to 4. The differences in the correlations between these two alignments suggest that the relationship is stronger when aligned by cohort for lengths, but not for weights.

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

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

using the Marquardt algorithm for the nonlinear minimization (PROC NLIN in SAS). Overall and annual parameters for these regressions are summarized with sample sizes (number of fish measured) in **Table 6**.

Because of the increased significance in correlations among lengths at age when aligned by cohort rather than annually, we investigated an alternate set of von Bertalanffy fits with the size at age data aligned by cohort (year class). Parameters have been summarized in **Table 7**. Attempts were made to fit the von Bertalanffy growth equation to each year class from 1960 (age 4 in 1964) to 2009 (age 1 in 2010). For most cohorts, a full range of ages were available (1963-2005). For the incomplete cohorts at the beginning of the time period (1960-1962), fits for 1961 and 1962 converged, while 1960 did not. However, these fits for 1961 and 1962 are only used for interpolation and not extrapolation, and were found useful for this limited purpose. Similarly, incomplete cohorts for the recent time period (2009-2010) generally converged, although generally of limited usefulness. With the exception of 1960 for which the fits did not converge, estimates of the von Bertalanffy parameters were obtained, and estimated sizes at age were interpolated from these fits. We compared the estimated fork lengths at ages 1 and 2 (at mid-year) from the two series of fits to the von Bertalanffy growth equation with observed weighted mean lengths (**Figure 5**).

Overall and annual regressions of weight (W in g) on fork length (FL in mm) were conducted based on the natural logarithm transformation:

$$\ln W = a + b \ln FL, \qquad (2)$$

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

$$W = a(FL)^b. \qquad (3)$$

Annual estimates for parameters ***a*** and ***b,*** along with sample size and root MSE, are summarized in **Table 6**. For purposes of representing recent length and weight at age, parameters from regressions for (1) and (3) were averaged for the most recent ten years (2000-2009) and used to calculate lengths and weight at age at the middle of the fishing year (age+0.5; **Table 8**). 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.

Based on the annual von Bertalanffy growth fits, matrices of weight at ages-0 to -6 for 1964-2010 were developed from equations (1) and (3) to represent the average size-at-age of menhaden at the start of the fishing year (i.e., spawning biomass for appropriate ages) and middle of the fishing year (i.e., weight of fish landed) for use in population modeling (**Tables 9 and 10**, respectively). Age-0 weights are included in **Table 10**.

Based on the cohort von Bertalanffy growth fits, additional matrices of weight at ages-0 to -6 for 1964-2010 were also 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 (**Table 11 and 12**, respectively). Age 0 weights were included in **Table 12**. Also note that estimates are lacking for the oldest ages in the earliest years (1964-1966) and age 1 in 2010.

Reproduction

Spawning Times and Locations

In general, gulf menhaden life history is typical of the cycle followed by most estuarine-dependent species in the Gulf of Mexico. Spawning occurs offshore, and young move into estuarine nursery areas where they spend the early part of their lives (Reid 1955). Maturing adults return to offshore waters to spawn completing the cycle.

Peak spawning periods for gulf menhaden fluctuate from year to year probably in response to varying environmental conditions (Suttkus 1956). Lewis and Roithmayr (1981) agreed with several earlier researchers (Suttkus and Sundararaj 1961, Combs 1969, Turner 1969, Fore 1970, Christmas and Waller 1975) that spawning in gulf menhaden generally begins in October and ends about March with a peak between December and February. Combs (1969) and Lewis and Roithmayr (1981) reported that gulf menhaden were multiple, intermittent spawners with ova being released in batches or fractions over a protracted spawning season. The duration of individual, batch spawns has not been reported. Spawning periods and areas have been substantiated by collections of eggs, larvae, juveniles, and adults with ripe gonads and by the examination of ovarian components.

Actual spawning sites have not been delineated, but data indicate that gulf menhaden spawn offshore. Turner (1969) presented indirect evidence of spawning areas in the eastern Gulf from collections of menhaden eggs and larvae off Florida. He observed that eggs were collected within the five fathom curve and suggested that spawning takes place nearshore in Florida waters. Combs (1969) did not delineate the geographical areas of gulf menhaden spawning, but he provided evidence that spawning occurs only in high-salinity waters.

Based on the distribution of eggs, Fore (1970) indicated that spawning of gulf menhaden occurs mainly over the continental shelf between Sabine Pass, Texas, and Alabama. Greatest concentrations were found in waters between the 4 - 40 fathom (ca. 8 - 70 m) contours off Texas and Louisiana and near the Mississippi Delta. Sogard et al. (1987) found high densities of larvae near the Mississippi River supporting the conclusions of Fore (1970) and Christmas and Waller (1975) that spawning is concentrated near the mouth of the Mississippi River.

Shaw et al. (1985) found highest egg densities between the ten and 23 m isobaths and at temperatures of 15-18 degrees C and salinities of 30-36 ppt, respectively. Christmas and Waller (1975) found highest egg densities at temperatures >15 degrees C and salinities >25 ppt.

Maturity Schedule

Lewis and Rothmayr (1981) concluded "that gulf menhaden spawn for the first time at age 1, after they have completed two seasons of growth, and then continue to spawn each year thereafter." In our model, fish surviving two seasons of growth would become age 2 fish on January 1, our theoretic birth date. The maturity schedule shown in **Table 8** (age 0 and age 1 immature, and full maturity for ages 2 and older) has been used in subsequent stock assessments (Nelson et al. 1986,Vaughan 1987, Vaughan et al. 1996, 2000, 2007). A sensitivity run was added to the last stock assessment with 20% of the age 1 fish assumed to be mature (Vaughan et al. 2007).

Fecundity

Batch fecundity estimates have not been calculated, and estimates of egg production have been based on the total number of ova produced by individual fish over an entire season. The number of eggs spawned by a mature female usually increases with the size of the fish. Suttkus and Sundararaj (1961) examined ovaries of female gulf menhaden at age 1, 2, and 3 and reported that the mean numbers of eggs per fish per age group were 21,960; 68,655; and 122,062, respectively. Lewis and Roithmayr (1981) examined spawning age and egg number per cohort to determine the reproductive potential of gulf menhaden. Lewis and Roithmayr (1981) provide the following relationship for gulf menhaden

$$E = 0000516\ L^{3.8775} \qquad (4)$$

Estimates from Eq. (4) are useful in stock assessments because they ascribe a measure of relative reproductive value for larger (and older) fish in the population. Many stock assessments for which such a relationship is unavailable will use female or spawning stock biomass. **Figure 6** illustrates the difference in perspective between using egg production and spawning stock biomass. Assuming a 1:1 sex ratio, annual fecundity at age was calculated and summarized in **Tables 13 and 14** as determined from von Bertalanffy growth equation parameters summarized in **Tables 6 and 7**, respectively.

Vaughan et al. (2007) estimated that total fecundity for the entire stock of spawners in the 1964-2004 data set varied from 7.9 to 164.9 trillion eggs with an average fecundity of approximately 24,450 eggs per mature female, somewhat higher that the average fecundity for age 2 gulf menhaden (22,100). Fecundity increased with length and age, but since numbers of older fish constitute only a small fraction of the overall spawning population, age 2 fish contributed the bulk of stock fecundity. The contribution of eggs from age 2 gulf menhaden to total population fecundity shows a general decline since early 1990s as obtained from the last gulf menhaden stock assessment (**Figure 7**).

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Table 1. Ageing error matrix from a scale to otolith comparison of ages.

	0	1	2	3	4	5	6
0	1.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	1.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.11	0.78	0.11	0.00	0.00	0.00
3	0.00	0.00	0.16	0.68	0.16	0.00	0.00
4	0.00	0.00	0.00	0.17	0.65	0.17	0.00
5	0.00	0.00	0.00	0.00	0.18	0.64	0.18
6	0.00	0.00	0.00	0.00	0.00	0.18	0.82

Table 2. Ageing error matrix from a scale to scale comparison of ages.

	0	1	2	3	4	5	6
0	1.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	1.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.08	0.85	0.08	0.00	0.00	0.00
3	0.00	0.00	0.14	0.71	0.14	0.00	0.00
4	0.00	0.00	0.00	0.16	0.67	0.16	0.00
5	0.00	0.00	0.00	0.00	0.17	0.65	0.17
6	0.00	0.00	0.00	0.00	0.00	0.17	0.82

Table 3. Weighted mean fork length (mm) at age, with weightings based on annual catch in numbers by season and area. Shaded areas sampled only 1 fish.

Year	0	1	2	3	4	5	6
1964	122.4	154.7	184.9	201.7	213.5		
1965	113.0	148.5	183.9	205.7	237.1		
1966	116.0	154.3	182.4	203.3	227.0		
1967	98.8	151.6	182.1	204.1			
1968	109.4	155.9	183.8	218.2	235.0		
1969	122.8	150.0	186.3	208.1			
1970	105.9	158.7	181.2	207.8			
1971	110.9	156.2	188.7	203.2	221.4		
1972	108.1	161.1	187.7	210.6	212.9		
1973	119.5	164.8	188.5	214.2	240.4		
1974	102.0	163.1	200.3	214.6			
1975	119.6	162.9	196.3	219.6	258.0		
1976		154.7	192.1	221.7			
1977		146.4	182.3	210.7	237.6		
1978		154.5	183.1	208.8	230.8		
1979		157.7	188.0	204.1	213.7	223.0	
1980	91.8	149.3	187.4	206.7	216.9	227.6	
1981		147.1	178.1	202.2	214.4	223.0	229.4
1982		149.9	183.6	201.2	212.8	229.3	240.1
1983		154.2	185.5	203.5	215.7	224.5	
1984		148.8	183.7	204.5	214.3	227.0	
1985		148.9	181.0	206.2	213.9		
1986		139.8	175.7	198.8	214.4	216.9	
1987		146.3	173.1	195.8	210.1		
1988		144.2	174.6	200.1	205.8		
1989		147.8	176.7	199.4	210.5		
1990		148.6	182.7	201.9	209.1	223.0	225.0
1991		160.3	179.9	204.1	216.2	218.6	
1992		155.0	184.3	202.6	211.7	218.3	228.0
1993	118.8	156.3	185.0	204.1	213.4	217.5	233.0
1994		155.7	183.5	205.6	216.0	224.6	
1995		158.3	183.7	207.3	210.6	223.0	
1996		154.6	182.2	205.4	215.9	225.4	
1997		155.0	183.7	203.6	212.0	217.8	
1998		154.6	180.0	203.7	211.4	217.6	
1999		162.2	185.8	202.6	214.6		

Table 3. (cont.)

Year	0	1	2	3	4	5	6
2000		156.2	181.8	202.2	210.0	218.5	
2001		168.2	187.7	205.9	213.1	223.0	
2002		158.9	184.5	204.0	212.8		
2003		149.5	177.9	200.9	212.0		
2004		149.8	177.6	194.6	205.5		
2005	128.0	151.2	176.7	196.3	204.0		
2006		152.0	177.1	192.3	200.3		
2007		152.5	177.0	195.5	205.8	208.0	
2008		158.4	181.9	196.9	203.2		
2009		163.1	183.6	200.3	204.5	221.0	
2010		153.6	180.9	197.0	202.9	209.0	

Table 4. Weighted mean weight (g) at age, with weightings based on annual catch in numbers by season and area. Shaded areas sampled only 1 fish.

Year	0	1	2	3	4	5	6
1964	34.2	71.3	130.7	178.9	213.2		
1965	29.0	66.4	134.3	192.0	285.9		
1966	30.7	76.3	130.6	176.4	229.0		
1967	18.2	68.3	124.3	172.6			
1968	25.3	78.0	131.1	218.4	289.0		
1969	35.8	67.2	136.0	197.6			
1970	26.8	80.6	124.4	186.7			
1971	26.7	78.2	142.6	181.1	224.1		
1972	23.6	83.0	137.7	186.8	191.1		
1973	34.3	97.6	152.1	219.2	299.6		
1974	26.0	89.4	167.0	203.1			
1975	32.1	88.3	157.1	215.4	359.0		
1976		74.6	138.6	199.8			
1977		60.2	116.6	177.0	243.2		
1978		73.6	125.3	189.8	251.2		
1979		75.3	133.4	169.7	188.4	213.5	
1980	26.7	63.4	137.2	184.3	213.4	264.3	
1981		65.8	116.4	166.6	196.6	218.4	229.8
1982		67.0	129.2	168.2	195.2	234.0	270.4
1983		73.2	135.1	178.6	207.9	224.3	
1984		67.0	129.9	180.2	209.3	217.0	
1985		63.8	117.1	172.3	189.6		
1986		56.8	114.0	160.9	179.5	215.9	
1987		62.2	105.0	151.0	185.0		
1988		61.0	108.3	156.5	171.1		
1989		66.5	115.5	162.9	183.0		
1990		70.8	133.0	183.6	197.0	212.0	252.0
1991		86.2	126.4	185.2	224.3	212.5	
1992		83.1	135.2	172.9	195.6	216.6	218.0
1993	29.8	85.2	141.1	184.3	211.9	219.6	255.0
1994		76.1	125.3	173.6	198.4	219.0	
1995		84.6	136.2	190.1	195.5	227.0	
1996		73.9	125.8	181.7	208.8	226.3	
1997		75.3	128.7	174.2	198.4	223.9	
1998		75.6	120.9	169.4	187.6	197.8	
1999		87.7	135.6	175.0	200.5		

Table 4. (cont.)

Year	0	1	2	3	4	5	6
2000		70.2	112.9	149.8	164.9	186.4	
2001		100.8	144.5	188.0	205.4	235.3	
2002		78.5	126.1	169.1	189.0		
2003		65.0	111.1	152.3	176.7		
2004		67.7	117.2	152.4	176.1		
2005	42.0	69.6	115.4	156.2	178.6		
2006		68.4	112.5	143.5	160.2		
2007		72.5	117.0	157.5	185.4	176.0	
2008		79.0	125.9	161.9	170.7		
2009		86.2	123.1	156.3	168.2	180.0	
2010		73.6	121.1	153.9	168.6	187.0	

Table 5. Correlation analysis (Pearson correlation coefficients) of gulf menhaden weighted mean fork length-at-age (L1-L4) and weighted mean weight-at-age (W1-W4). Cohort correlations are lagged to line up lengths and weight by year class, while annual (year) correlations are unlagged.

Correlations by fishing year

	l2	l3	l4
l1	0.632	0.398	0.046
l2		0.744	0.426
l3			0.755

	w2	w3	w4
w1	0.699	0.516	0.251
w2		0.802	0.577
w3			0.836

Correlations by cohort

	l2	l3	l4
l1	0.654	0.431	0.123
l2		0.778	0.570
l3			0.742

	w2	w3	w4
w1	0.521	0.288	0.048
w2		0.561	0.361
w3			0.506

Table 6. Overall and annual estimated parameters obtained from weight-length and length at age regressions from biological sampling of gulf menhaden, 1964-2009.

	Weight-Length				***Von Bertalanffy Curve***			
Year	**n**	**a**	**b**	**RMSE**	**n**	**Linf**	**K**	**t0**
1964	12376	-12.695	3.365	0.0095	12260	236.9	0.429	-0.958
1965	15673	-12.481	3.329	0.0081	15185	427.8	0.128	-1.790
1966	12705	-11.592	3.157	0.0070	12429	284.2	0.269	-1.303
1967	14401	-11.270	3.085	0.0083	14065	234.2	0.506	-0.516
1968	15831	-11.668	3.167	0.0076	15273	284.1	0.316	-0.911
1969	15044	-11.374	3.107	0.0087	14764	426.4	0.121	-2.148
1970	10531	-11.959	3.224	0.0056	10402	231.3	0.537	-0.535
1971	7848	-12.192	3.269	0.0080	7654	239.5	0.474	-0.691
1972	9975	-11.756	3.180	0.0080	9886	222.5	0.674	-0.372
1973	8954	-11.663	3.181	0.0078	8953	343.2	0.198	-1.592
1974	10085	-10.793	2.995	0.0097	10086	227.9	0.800	-0.066
1975	9528	-11.562	3.144	0.0078	9527	565.7	0.092	-2.022
1976	13532	-10.791	2.988	0.0077	13389	335.8	0.233	-1.102
1977	14910	-11.382	3.098	0.0060	14897	374.7	0.167	-1.448
1978	12983	-12.052	3.239	0.0058	12944	409.8	0.122	-2.336
1979	11618	-12.238	3.268	0.0053	11121	243.4	0.392	-1.149
1980	9948	-13.045	3.427	0.0229	9883	234.3	0.606	-0.095
1981	10405	-11.682	3.166	0.0100	10273	240.1	0.435	-0.636
1982	10678	-12.669	3.361	0.0110	10341	282.4	0.230	-1.845
1983	14837	-12.256	3.280	0.0082	14523	232.8	0.509	-0.572
1984	15955	-11.906	3.215	0.0072	15936	232.2	0.542	-0.336
1985	13227	-11.531	3.131	0.0075	13225	232.0	0.533	-0.391
1986	16495	-11.782	3.194	0.0061	16494	235.5	0.480	-0.339
1987	16458	-11.707	3.173	0.0056	16458	258.7	0.285	-1.370
1988	12403	-11.363	3.110	0.0113	12402	222.5	0.552	-0.345
1989	13951	-11.819	3.202	0.0072	13950	247.8	0.347	-1.051
1990	11500	-11.707	3.184	0.0117	11456	232.3	0.481	-0.600
1991	11637	-12.178	3.274	0.0082	11378	239.6	0.383	-1.269
1992	15231	-10.408	2.932	0.0095	14214	234.1	0.443	-0.920
1993	15347	-11.308	3.111	0.0116	14576	243.5	0.364	-1.280
1994	16785	-10.976	3.030	0.0072	16062	238.5	0.456	-0.741
1995	14275	-12.036	3.248	0.0077	13489	238.3	0.416	-1.060
1996	13052	-12.576	3.339	0.0177	12115	243.8	0.393	-1.004
1997	10634	-11.640	3.162	0.0058	9923	224.7	0.568	-0.481
1998	10034	-10.969	3.034	0.0053	9043	230.4	0.466	-0.834
1999	11774	-11.701	3.177	0.0057	10641	242.4	0.354	-1.565

Table 6. (cont.)

	Weight-Length				*Von Bertalanffy Curve*			
Year	**n**	**a**	**b**	**RMSE**	**n**	**Linf**	**K**	**t0**
2000	9588	-10.027	2.833	0.0118	8383	230.1	0.466	-0.851
2001	7351	-10.896	3.027	0.0085	6222	247.7	0.301	-2.184
2002	6611	-11.339	3.097	0.0054	5597	227.3	0.520	-0.736
2003	9239	-11.142	3.056	0.0048	7839	238.1	0.420	-0.795
2004	7655	-11.850	3.204	0.0055	6644	224.0	0.450	-0.908
2005	7202	-11.041	3.046	0.0087	6206	244.9	0.278	-2.042
2006	5763	-11.359	3.105	0.0061	4698	210.7	0.577	-0.631
2007	5151	-11.782	3.192	0.0056	3989	218.5	0.506	-0.829
2008	5877	-12.256	3.284	0.0057	4663	210.6	0.644	-0.643
2009	7419	-10.871	3.007	0.0064	6193	251.8	0.253	-2.569
2010	4530	-11.065	3.048	0.0067	3678	212.2	0.689	-0.313

Table 7. Cohort estimated parameters obtained from length at age regressions from biological sampling of gulf menhaden, 1960-2009 year classes. Ages represented in regression for cohort shown in last column.

	Von Bertalanffy Curve (Year Class)				
Year Class	**n**	**Linf**	**K**	**t0**	**Ages**
1960	12	213.4	NE	NE	4-4
1961	333	474.6	0.143	-0.381	3-4
1962	4098	995.3	0.027	-5.190	2-4
1963	10609	236.2	0.463	-0.752	1-4
1964	14932	383.3	0.140	-2.004	0-3
1965	11242	462.6	0.121	-1.723	0-3
1966	17541	299.7	0.251	-1.277	0-3
1967	13113	238.3	0.520	-0.466	0-4
1968	15750	236.9	0.439	-0.772	0-4
1969	9110	450.9	0.114	-2.181	0-4
1970	8416	255.4	0.432	-0.627	0-3
1971	9919	612.1	0.085	-1.836	0-4
1972	8896	243.5	0.595	-0.370	0-3
1973	11655	275.1	0.363	-0.941	0-4
1974	8089	236.7	0.628	-0.235	0-5
1975	13853	244.6	0.387	-1.106	0-6
1976	16927	260.4	0.332	-0.998	1-6
1977	13229	237.6	0.489	-0.625	1-5
1978	12001	233.1	0.464	-0.910	1-5
1979	6516	245.6	0.381	-0.907	1-5
1980	11635	225.8	0.645	-0.079	0-4
1981	13123	226.8	0.602	-0.284	1-5
1982	12074	231.2	0.535	-0.479	1-4
1983	14976	222.8	0.583	-0.336	1-4
1984	20644	239.0	0.348	-1.280	1-4, 6
1985	13072	242.2	0.416	-0.526	1-5
1986	13136	243.5	0.363	-0.980	1-6
1987	12380	243.5	0.403	-0.685	1-6
1988	14643	224.2	0.629	-0.156	1-5
1989	12726	241.5	0.422	-0.722	1-5
1990	11661	243.3	0.374	-1.297	1-5
1991	13698	238.2	0.433	-0.887	1-5
1992	16057	226.7	0.571	-0.490	1-5
1993	17768	233.5	0.424	-1.090	0-5
1994	12700	234.6	0.414	-1.149	1-4
1995	9100	230.4	0.500	-0.670	1-5
1996	11450	248.7	0.329	-1.397	1-5
1997	8079	224.1	0.586	-0.473	1-4
1998	10558	237.3	0.391	-1.351	1-4
1999	7837	221.0	0.675	-0.236	1-4

Table 7. (cont.)

	Von Bertalanffy Curve (Year Class)				
Year Class	**n**	**Linf**	**K**	**t0**	**Ages**
2000	5161	217.7	0.493	-1.393	1-4
2001	6722	230.8	0.330	-1.947	1-4
2002	5340	213.1	0.603	-0.449	1-5
2003	7800	225.2	0.429	-1.007	1-4
2004	4693	259.5	0.247	-2.045	1-5
2005	4138	233.4	0.329	-1.788	0-5
2006	5927	209.9	0.775	-0.152	1-4
2007	6219	215.5	0.577	-0.786	1-3
2008	2124	184.0	2.072	0.507	1-2
2009	1944	163.8	5.105	0.969	1-1

Table 8. Estimated fork lengths and weights for gulf menhaden calculated at middle of fishing year averaged over 2000-2009 (annual estimates), and female maturity at age from Lewis and Roithmayr (1981).

Year	FL (mm)	Wgt (g)	Maturity (%)
0	118.7	31.9	0
1	152.4	70.4	0
2	183.1	126.1	100
3	202.8	174.6	100
4	215.5	211.8	100
5	223.7	238.4	100
6	229.0	256.7	100

Table 9. Weight (g) at ages 1-6 on January 1 (start of fishing year) estimated from annual von Bertalanffy growth parameters presented in Table 4.

Year	1	2	3	4	5	6
1964	45.0	99.3	152.7	196.7	229.7	253.2
1965	39.8	90.5	162.7	253.1	357.7	471.9
1966	45.2	97.2	157.3	217.5	272.8	321.1
1967	38.1	94.9	147.8	187.8	215.1	232.8
1968	41.4	101.4	171.0	238.6	298.0	347.2
1969	47.6	94.2	155.5	228.7	310.4	397.8
1970	41.8	103.4	159.2	200.0	226.9	243.8
1971	43.6	104.6	163.4	209.9	243.0	265.4
1972	46.0	111.8	162.3	193.3	210.5	219.6
1973	54.9	116.8	194.3	279.7	366.6	450.5
1974	45.1	125.9	181.8	211.5	225.8	232.5
1975	50.7	108.6	190.7	295.4	420.2	561.5
1976	42.9	100.3	171.2	246.6	319.9	387.3
1977	36.3	82.7	144.6	216.9	294.6	373.5
1978	48.8	95.0	155.7	228.1	309.3	396.1
1979	48.4	99.2	149.2	191.5	224.4	248.8
1980	24.2	93.3	163.3	214.2	246.2	265.0
1981	34.4	87.0	140.8	185.7	219.4	243.3
1982	46.5	91.2	143.6	198.1	250.5	298.7
1983	39.2	98.7	155.0	197.9	227.3	246.4
1984	32.4	94.2	153.7	198.1	227.7	246.2
1985	33.1	90.0	143.4	183.0	209.4	226.1
1986	26.6	82.0	140.7	188.7	223.4	247.0
1987	39.0	80.6	127.0	172.0	212.4	246.7
1988	31.3	86.1	136.7	173.4	197.3	212.0
1989	39.4	87.5	139.1	186.2	225.3	256.2
1990	39.0	96.6	152.1	195.6	226.4	247.0
1991	53.9	106.0	156.9	200.0	233.7	258.8
1992	52.3	104.7	152.0	188.7	215.1	233.3
1993	55.3	106.8	157.3	200.6	235.1	261.3
1994	44.4	98.8	149.6	189.6	218.3	237.9
1995	52.0	107.7	161.3	205.2	238.4	262.2
1996	42.9	95.5	149.7	196.6	233.6	261.1
1997	40.5	99.3	150.4	186.1	208.6	222.2
1998	47.4	99.2	145.8	181.6	206.7	223.6
1999	60.7	108.8	154.9	194.2	225.6	249.6
2000	46.1	91.2	130.4	159.8	180.2	193.9
2001	75.9	119.5	160.8	196.9	226.8	250.8
2002	47.3	100.9	146.8	179.9	201.9	215.7
2003	38.1	86.0	133.0	171.9	201.2	222.2
2004	41.4	88.3	132.2	167.0	192.2	209.5
2005	55.3	92.1	128.9	162.6	191.7	216.0
2006	41.3	89.0	127.6	153.6	169.7	179.2
2007	44.9	94.1	136.9	168.3	189.4	203.0
2008	50.3	105.2	146.4	171.9	186.5	194.5
2009	66.3	101.5	136.2	168.0	195.9	219.5
2010	39.9	97.1	139.8	165.3	179.2	186.5

Table 10. Weight (mm) at ages 1-6 on July 1 (middle of fishing year) estimated from annual von Bertalanffy growth parameters presented in Table 4.

Year	0	1	2	3	4	5	6
1964	33.3	71.4	126.9	176.1	214.6	242.5	262.0
1965	30.6	62.4	124.1	205.8	303.9	413.9	531.4
1966	34.6	69.6	126.8	187.8	245.9	297.9	342.3
1967	26.0	65.8	122.8	169.5	202.9	224.9	239.0
1968	29.8	69.3	135.9	205.6	269.5	323.9	368.0
1969	38.4	68.9	123.2	190.8	268.7	353.6	442.7
1970	28.5	72.0	133.0	181.5	215.0	236.4	249.5
1971	30.6	73.1	135.2	188.4	228.0	255.3	273.5
1972	30.5	79.6	139.7	179.9	203.2	215.8	222.4
1973	42.7	83.4	154.1	236.5	323.3	409.1	490.3
1974	26.3	86.9	157.7	199.2	220.0	229.8	234.3
1975	40.0	76.6	146.7	240.4	355.5	489.0	637.3
1976	31.8	69.3	134.7	208.8	283.8	354.5	418.2
1977	27.6	57.3	112.1	179.8	255.4	334.1	412.4
1978	39.7	69.9	123.7	190.6	267.8	352.1	440.7
1979	37.1	73.1	124.9	171.5	209.1	237.6	258.2
1980	12.6	56.0	130.2	191.4	232.2	256.9	271.1
1981	23.8	59.5	114.6	164.6	203.9	232.4	252.3
1982	37.2	67.5	116.9	170.9	224.7	275.3	320.7
1983	26.7	68.0	128.2	178.3	214.1	237.9	253.1
1984	20.2	62.0	125.5	178.0	214.5	238.0	252.5
1985	21.5	60.6	118.2	165.0	197.7	218.8	231.8
1986	16.3	52.4	112.2	166.3	207.6	236.4	255.5
1987	30.3	58.7	103.7	150.0	192.9	230.3	261.5
1988	20.0	57.9	112.9	156.8	186.7	205.6	217.0
1989	29.4	62.3	113.5	163.5	206.8	241.8	268.8
1990	26.9	66.9	125.6	175.6	212.5	237.8	254.4
1991	42.1	79.4	132.1	179.6	218.0	247.2	268.6
1992	40.0	78.5	129.5	171.7	203.1	225.1	240.1
1993	43.6	80.5	132.7	180.1	219.0	249.1	271.7
1994	32.3	71.1	125.3	171.1	205.2	229.0	245.0
1995	39.6	79.3	135.4	184.6	223.1	251.3	271.3
1996	31.7	68.1	123.2	174.4	216.3	248.4	271.8
1997	27.4	69.6	126.7	170.1	198.7	216.3	226.8
1998	35.4	73.1	123.7	165.1	195.3	216.1	229.8
1999	49.5	84.5	132.5	175.5	210.9	238.5	259.2
2000	35.3	68.8	112.0	146.3	171.0	187.7	198.8
2001	65.3	97.7	140.7	179.6	212.6	239.5	260.8
2002	34.8	74.2	125.4	165.0	192.1	209.6	220.5
2003	27.8	61.3	110.3	153.7	187.7	212.6	230.1
2004	30.9	64.5	111.2	150.9	180.7	201.7	215.9
2005	46.6	73.4	110.7	146.3	177.8	204.4	226.3
2006	29.8	65.5	109.9	142.0	162.7	175.1	182.3
2007	33.4	69.5	116.8	154.0	180.0	197.0	207.7
2008	36.5	78.7	127.9	160.8	180.3	191.1	197.0
2009	57.8	83.8	119.1	152.6	182.5	208.2	229.8
2010	26.3	69.2	120.8	154.3	173.3	183.5	188.7

Table 11. Weight (g) at ages 1-6 on January 1 (start of fishing year) estimated from annual weight-length parameters presented in Table 4 and cohort length parameters in Table 8.

Year	1	2	3	4	5	6
1964	41.3	105.2	122.9			
1965	43.5	101.8	159.8	240.9		
1966	43.5	92.4	156.4	216.8	363.1	
1967	43.0	93.3	144.8	186.9	268.8	471.1
1968	39.6	96.0	169.9	219.6	224.4	365.1
1969	40.7	102.2	155.9	254.7	286.1	237.4
1970	50.1	93.6	165.6	228.8	379.5	385.3
1971	40.3	101.8	147.4	214.3	297.9	513.3
1972	42.4	103.5	167.0	184.5	235.8	338.6
1973	52.5	107.5	186.3	274.7	237.6	281.5
1974	54.3	125.4	175.6	216.3	322.8	228.4
1975	39.9	118.5	192.6	286.0	263.9	438.6
1976	49.4	110.5	177.8	221.7	377.2	270.1
1977	37.1	94.8	167.6	235.0	248.4	524.1
1978	41.4	87.7	152.1	226.5	313.2	291.6
1979	46.7	97.7	139.3	190.5	246.1	346.3
1980	35.3	101.5	160.1	201.6	238.6	279.3
1981	26.9	88.0	151.3	199.2	237.3	251.1
1982	32.6	92.9	144.7	199.4	245.0	294.6
1983	37.5	97.7	154.4	190.7	223.7	259.9
1984	33.2	100.2	157.0	196.6	229.1	242.5
1985	42.0	87.6	146.6	182.8	204.5	237.7
1986	28.3	88.8	147.7	200.9	223.6	236.8
1987	36.9	77.4	129.5	178.7	220.1	228.9
1988	34.1	85.0	134.3	170.1	203.2	238.1
1989	29.9	85.9	136.6	187.6	208.4	224.7
1990	39.0	97.7	144.9	185.5	230.7	238.3
1991	55.1	93.8	157.9	196.1	225.7	263.8
1992	51.1	109.3	148.5	189.2	220.3	236.3
1993	46.5	107.1	162.9	202.6	224.1	263.7
1994	51.5	102.0	146.6	185.8	214.6	213.5
1995	53.3	105.6	165.4	205.9	241.9	268.5
1996	40.4	99.2	147.4	195.4	229.4	257.8
1997	48.7	99.4	147.6	184.6	215.3	245.7
1998	44.3	96.1	150.1	182.9	208.6	224.4
1999	58.1	104.1	144.3	192.7	217.3	236.5
2000	38.9	97.8	136.2	160.6	184.7	198.3
2001	73.1	109.2	156.7	192.8	223.9	236.3
2002	57.2	109.1	150.3	180.2	199.7	235.6
2003	36.4	92.0	139.7	177.2	202.0	206.4
2004	42.4	90.1	133.2	175.6	211.4	242.3
2005	52.0	88.5	132.8	160.5	186.3	212.9
2006	54.0	87.9	127.8	159.5	183.1	195.7
2007	36.7	93.8	131.6	166.6	183.8	210.6
2008	51.5	101.3	133.0	174.9	195.7	197.7
2009	32.2	101.1	139.2	154.8	193.6	194.1
2010		109.1	141.3	165.7	183.4	228.3

Table 12. Weight (g) at ages 0-6 on July 1 (middle of fishing year) estimated from annual weight-length parameters presented in Table 4 and cohort length parameters in Table 8.

Year	0	1	2	3	4	5	6
1964	33.1	69.1	129.0	175.1			
1965	31.4	65.2	131.6	190.6	310.6		
1966	33.6	67.7	121.2	179.2	251.2	436.0	
1967	26.6	66.8	126.3	176.6	202.1	305.6	541.8
1968	29.2	70.7	127.0	214.4	257.2	235.6	411.0
1969	40.9	65.9	132.8	187.6	304.2	323.7	244.4
1970	27.8	73.6	121.0	190.9	261.9	439.7	427.4
1971	32.3	71.2	135.3	171.0	232.3	328.9	579.9
1972	30.9	66.6	137.0	206.4	201.2	246.5	363.6
1973	41.7	94.9	148.9	218.4	324.9	250.6	288.9
1974	26.3	85.2	159.3	222.3	236.7	366.9	235.7
1975	37.6	76.5	154.0	217.9	348.4	279.8	490.1
1976	29.5	73.0	142.1	206.9	235.7	440.0	279.7
1977	28.7	59.1	118.8	189.6	259.9	257.0	598.9
1978	36.4	70.5	115.9	175.5	241.7	335.7	297.3
1979	26.3	72.7	126.9	166.0	208.7	254.6	363.0
1980	12.4	59.1	129.0	185.8	227.5	253.9	284.5
1981	21.3	58.0	114.2	171.4	215.6	255.9	260.7
1982	24.0	64.1	127.1	170.8	215.7	257.4	311.3
1983	20.0	67.1	128.9	177.7	211.2	234.4	267.6
1984	33.8	62.1	130.2	179.1	210.4	244.4	249.4
1985	17.9	61.9	113.8	167.3	195.3	211.6	247.8
1986	28.0	52.3	111.8	168.6	216.3	231.7	241.1
1987	22.6	58.8	105.1	149.5	191.5	229.4	233.3
1988	17.8	58.3	109.6	159.3	186.6	210.8	243.8
1989	26.7	61.6	114.4	160.3	208.6	222.2	229.4
1990	44.6	65.8	130.0	171.1	205.5	246.5	248.8
1991	34.0	81.1	123.7	181.3	217.8	241.9	275.5
1992	33.5	77.8	133.4	171.3	201.3	233.9	246.4
1993	42.8	78.8	135.4	185.6	222.1	231.8	274.7
1994	41.3	75.4	128.5	167.3	201.6	227.0	217.2
1995	31.2	79.3	131.8	187.4	224.2	256.3	279.0
1996	35.8	68.1	124.3	168.6	209.3	242.3	268.2
1997	28.7	71.0	126.4	167.5	199.6	223.1	253.9
1998	47.9	74.2	119.3	170.0	197.2	218.7	228.7
1999	23.6	82.7	132.1	166.9	207.6	228.5	244.0
2000	55.7	68.2	117.1	151.5	175.1	192.0	204.1
2001	53.6	96.8	138.3	176.2	204.7	238.5	242.2
2002	24.8	75.2	127.0	167.8	194.6	206.4	246.4
2003	32.2	61.4	108.9	152.1	186.8	212.2	210.2
2004	41.7	64.8	114.3	149.6	185.0	217.3	250.7
2005	46.4	70.2	109.7	148.4	172.9	191.9	215.7
2006	22.4	72.8	107.7	145.3	169.2	193.0	199.3
2007	39.4	69.9	113.5	152.4	180.5	189.8	218.7
2008	6.2	79.0	128.3	151.1	195.1	206.1	201.3
2009		81.6	121.4	152.4	167.6	208.4	200.0
2010		71.5	119.6	155.4	172.5	193.8	241.5

Table 13. Overall and annual estimates of fecundity (no. of maturing or ripe ova in billions) at ages 1-6 on January 1 (start of fishing year) by applying Eq. (4) to fork lengths at age on January 1.

	Eggs per Ages for Female Gulf Menhaden					
Year	1	2	3	4	5	6
1964	9,310	23,161	38,020	50,894	60,852	68,067
1965	7,720	20,105	39,791	66,601	99,636	137,605
1966	8,448	21,657	39,110	58,210	76,903	93,932
1967	7,075	22,273	38,862	52,492	62,257	68,759
1968	7,855	23,500	44,562	66,991	87,952	106,037
1969	9,294	21,812	40,772	65,957	96,602	131,641
1970	8,074	24,020	40,373	53,114	61,822	67,380
1971	8,615	24,348	41,351	55,631	66,195	73,483
1972	9,188	27,162	42,783	52,917	58,718	61,851
1973	10,122	25,417	47,259	73,668	102,448	131,694
1974	8,302	31,388	50,499	61,438	66,887	69,449
1975	10,185	26,047	52,154	89,510	138,212	197,648
1976	8,135	24,503	49,053	78,743	110,383	141,465
1977	7,080	19,862	39,982	66,398	97,379	131,056
1978	9,954	22,119	39,955	63,125	90,862	122,174
1979	10,391	24,331	39,507	53,133	64,133	72,468
1980	4,816	22,174	41,800	56,802	66,500	72,282
1981	6,401	19,909	35,899	50,373	61,802	70,159
1982	9,570	20,845	35,182	50,972	66,853	81,877
1983	7,692	22,931	39,107	52,201	61,492	67,638
1984	5,874	21,289	38,409	52,161	61,675	67,769
1985	6,243	21,518	38,301	51,818	61,236	67,321
1986	4,489	17,635	33,953	48,483	59,524	67,232
1987	7,392	17,956	31,283	45,328	58,633	70,406
1988	5,324	18,838	33,512	45,084	52,962	57,937
1989	7,230	18,982	33,275	47,351	59,674	69,717
1990	6,904	20,835	36,215	49,185	58,758	65,328
1991	10,585	23,594	37,548	50,055	60,193	67,925
1992	9,136	22,873	37,426	49,828	59,258	65,977
1993	10,052	22,850	37,031	50,148	61,099	69,688
1994	8,296	23,083	39,286	53,176	63,683	71,092
1995	10,001	23,829	38,581	51,452	61,526	68,927
1996	8,830	22,398	37,748	51,799	63,263	72,001
1997	7,601	22,869	38,026	49,370	56,817	61,389
1998	8,730	22,434	36,724	48,589	57,354	63,419
1999	12,299	25,058	38,570	50,845	61,040	69,049
2000	8,846	22,503	36,686	48,445	57,127	63,135
2001	15,164	27,114	39,653	51,381	61,585	70,052
2002	9,419	24,290	38,868	50,145	57,907	62,926
2003	7,201	20,208	35,159	48,665	59,421	67,389
2004	7,877	19,700	32,115	42,592	50,483	56,052
2005	10,773	20,634	31,671	42,563	52,493	61,083
2006	7,744	20,214	31,712	39,984	45,281	48,475
2007	8,597	21,106	33,281	42,765	49,371	53,703
2008	10,110	24,183	35,707	43,176	47,531	49,944
2009	14,042	24,338	35,553	46,606	56,803	65,796
2010	7,259	22,489	35,755	44,264	49,063	51,613

Table 14. Cohort-based estimates of fecundity (no. of maturing or ripe ova in billions) at ages 1-6 on January 1 (start of fishing year) by applying Eq. (4) to fork lengths at age on January 1.

	Eggs per Ages for Female Gulf Menhaden					
Year	1	2	3	4	5	6
1964	8,421	24,732	29,584			
1965	8,569	23,046	38,987	62,865		
1966	8,061	20,339	38,817	57,994	109,256	
1967	8,238	21,775	37,845	52,162	82,393	166,749
1968	7,439	21,971	44,203	60,497	62,141	112,771
1969	7,661	24,144	40,911	75,458	87,247	69,108
1970	10,045	21,313	42,313	62,450	114,750	116,875
1971	7,853	23,598	36,585	57,045	84,288	160,732
1972	8,321	24,722	44,299	49,992	67,432	104,846
1973	9,590	22,953	44,884	72,073	60,376	74,237
1974	10,567	31,245	48,301	63,271	106,235	67,868
1975	7,577	29,011	52,798	85,992	77,878	145,730
1976	9,765	27,778	51,493	68,591	136,701	88,615
1977	7,273	23,548	48,072	73,384	78,675	200,284
1978	8,182	20,109	38,860	62,583	92,232	84,688
1979	9,949	23,916	36,416	52,807	71,540	107,308
1980	7,378	24,409	40,872	53,041	64,192	76,693
1981	4,736	20,201	39,195	54,920	68,032	72,899
1982	6,362	21,273	35,477	51,378	65,138	80,573
1983	7,302	22,672	38,922	49,971	60,353	72,065
1984	6,052	22,923	39,392	51,658	62,129	66,560
1985	8,368	20,801	39,357	51,723	59,463	71,612
1986	4,851	19,419	36,034	52,318	59,585	63,894
1987	6,912	17,090	32,028	47,485	61,238	64,251
1988	5,941	18,532	32,786	44,016	54,946	66,958
1989	5,178	18,558	32,544	47,786	54,284	59,471
1990	6,907	21,127	34,133	46,117	60,139	62,533
1991	10,866	20,414	37,845	48,913	57,773	69,491
1992	8,857	24,207	36,286	49,996	61,143	67,085
1993	8,105	22,940	38,677	50,756	57,552	70,496
1994	10,037	24,071	38,280	51,817	62,324	61,912
1995	10,282	23,279	39,767	51,634	62,609	70,903
1996	8,237	23,414	37,082	51,433	61,969	70,950
1997	9,544	22,883	37,153	48,912	59,049	69,445
1998	8,006	21,553	38,091	49,043	58,032	63,704
1999	11,643	23,746	35,390	50,359	58,320	64,644
2000	6,999	24,749	38,950	48,809	59,096	65,131
2001	14,453	24,150	38,345	50,032	60,576	64,913
2002	11,944	26,798	40,026	50,250	57,131	70,266
2003	6,794	22,013	37,414	50,572	59,726	61,393
2004	8,119	20,192	32,403	45,264	56,670	66,846
2005	9,972	19,613	32,883	41,849	50,620	59,974
2006	10,827	19,913	31,775	41,928	49,801	54,114
2007	6,733	21,034	31,727	42,241	47,596	56,172
2008	10,396	23,108	31,891	44,071	50,308	50,928
2009	5,531	24,195	36,554	41,952	55,953	56,142
2010		26,085	36,258	44,398	50,530	66,775

Figure 1. Scale sample from age-2 gulf menhaden.

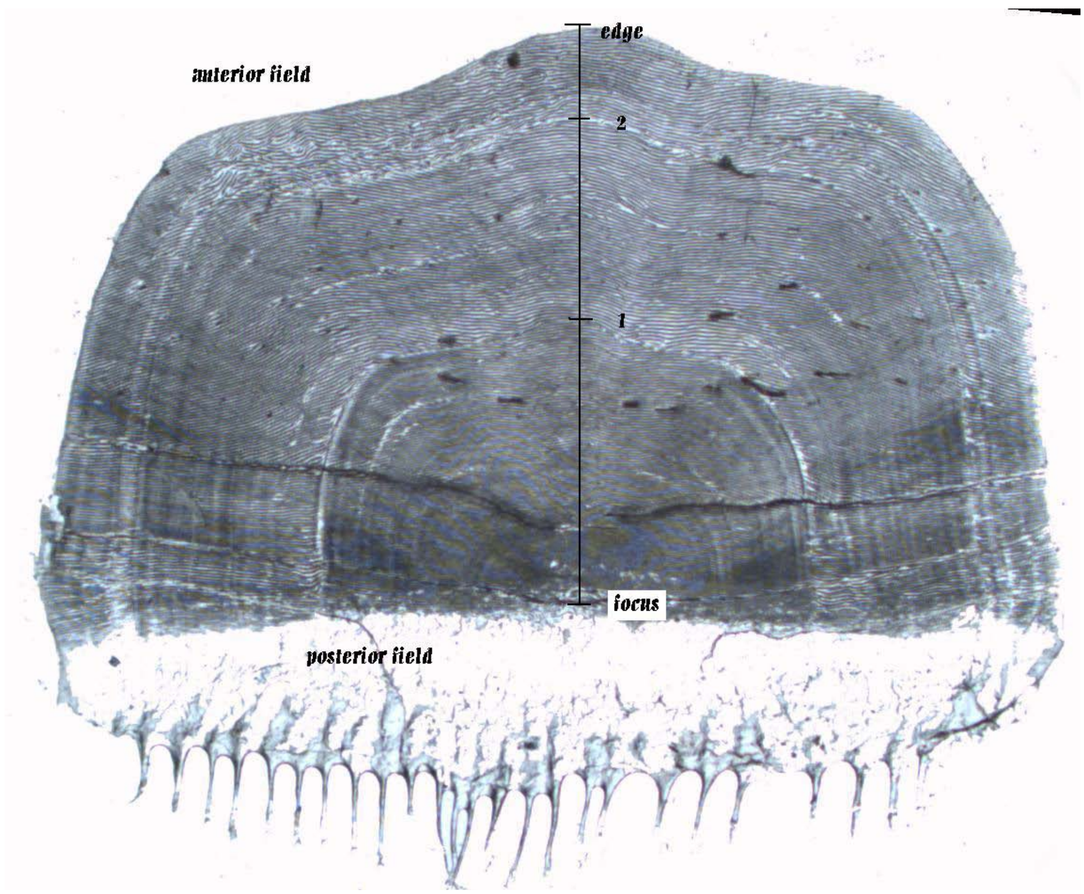


Figure 2. The estimated coefficient of variation (CV) and standard deviation for gulf menhaden using data from paired age estimates of scales and otoliths and the program agemat.

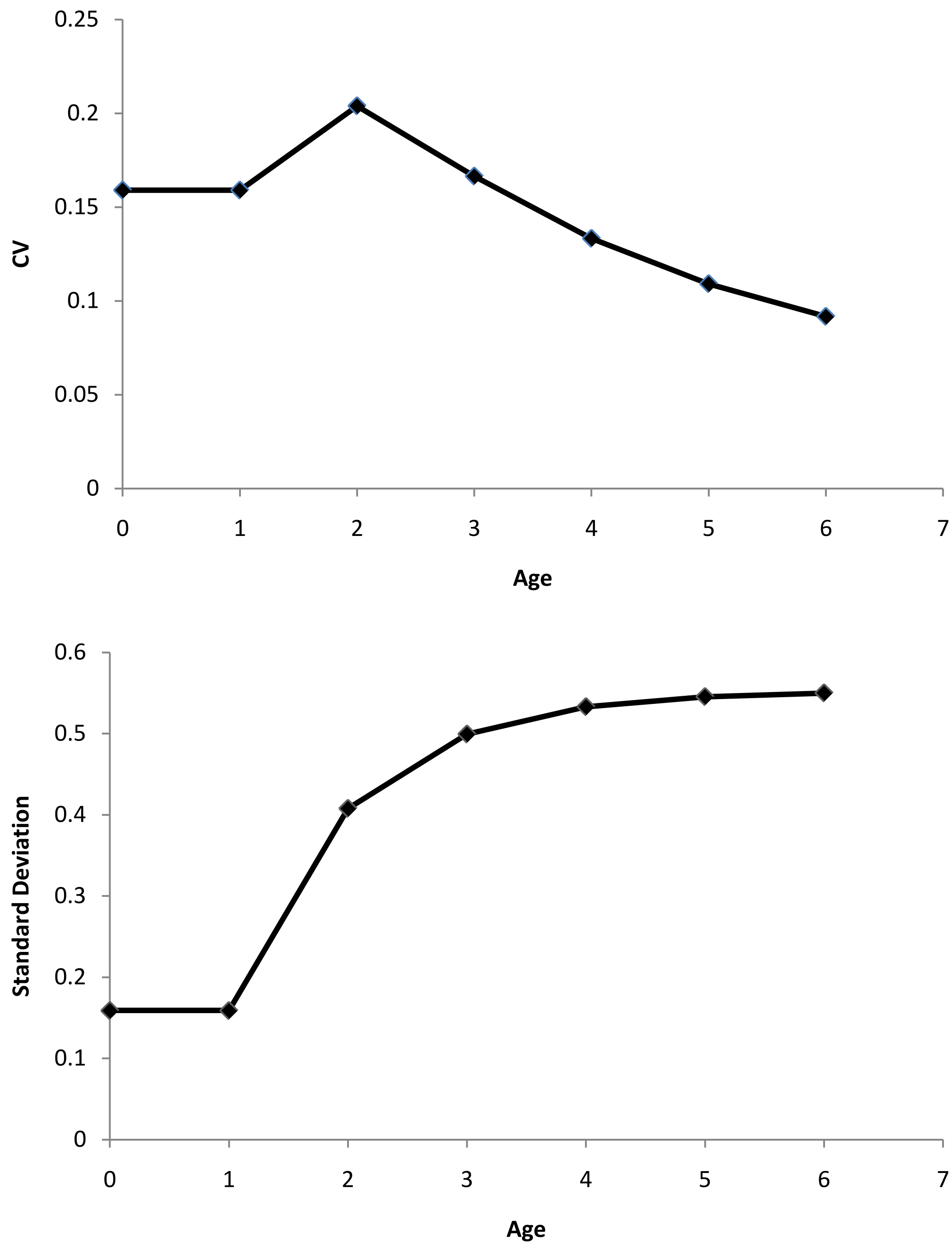
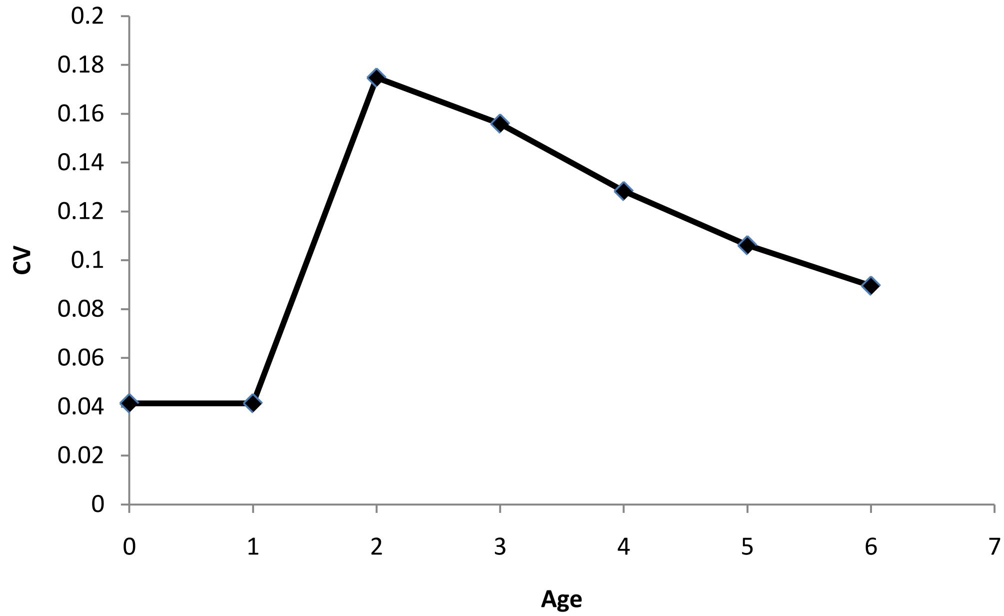


Figure 3. The estimated coefficient of variation (CV) and standard deviation for gulf menhaden using data from paired age estimates of scales and the program agemat.



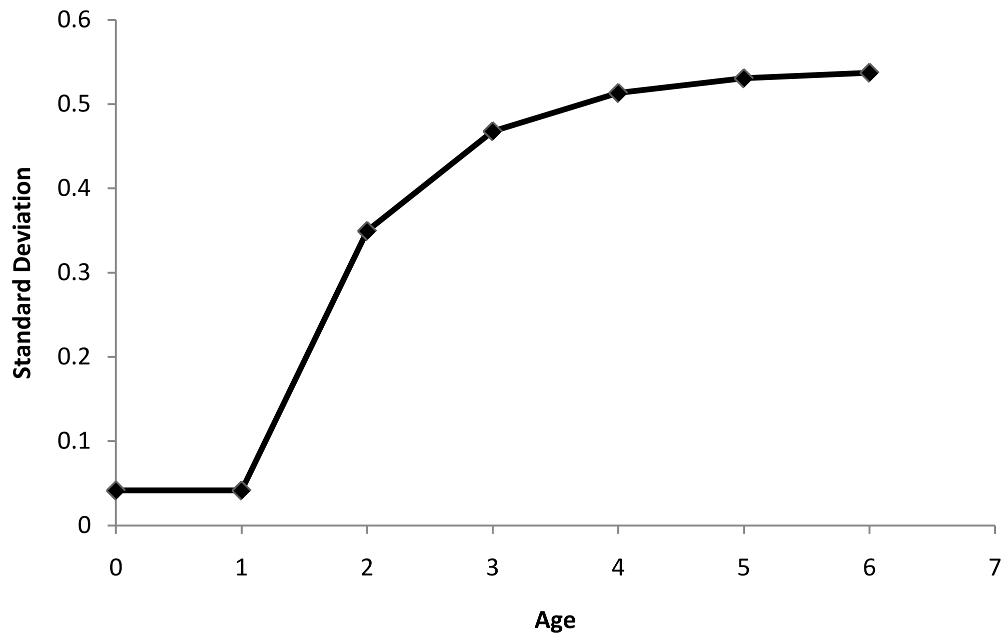


Figure 4. Fork length (cm) frequencies by age of gulf menhaden in the 2010 port samples.

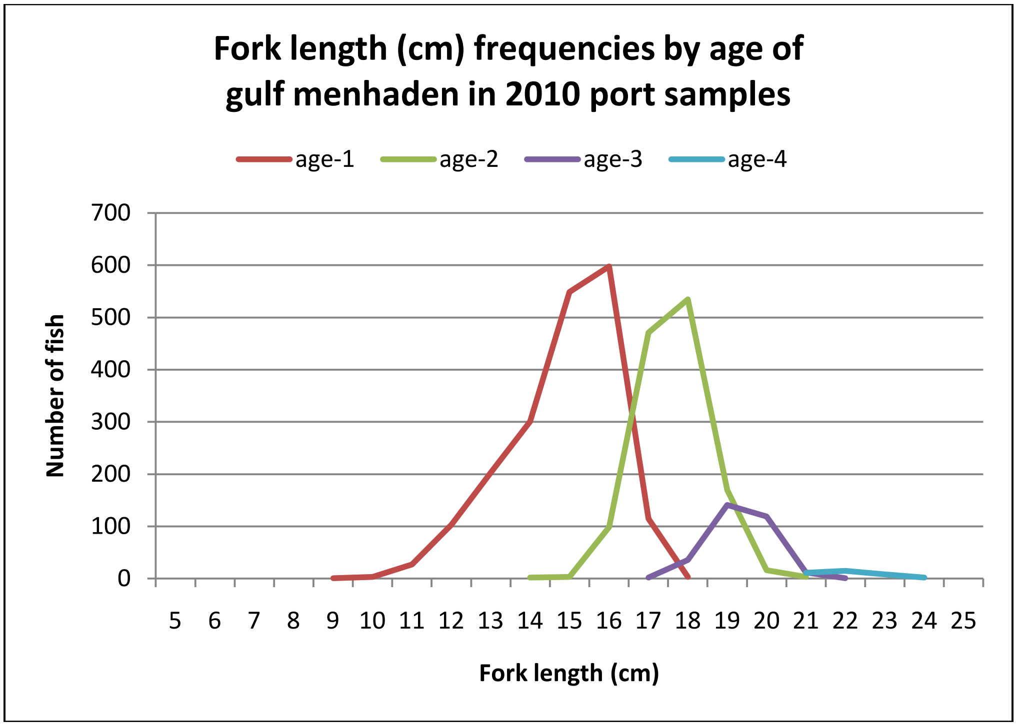


Figure 5. Comparison of predicted lengths at age (ages 1 and 2) between parameters obtained from annual and cohort based von Bertalanffy fits (**Tables 5 and 9**).

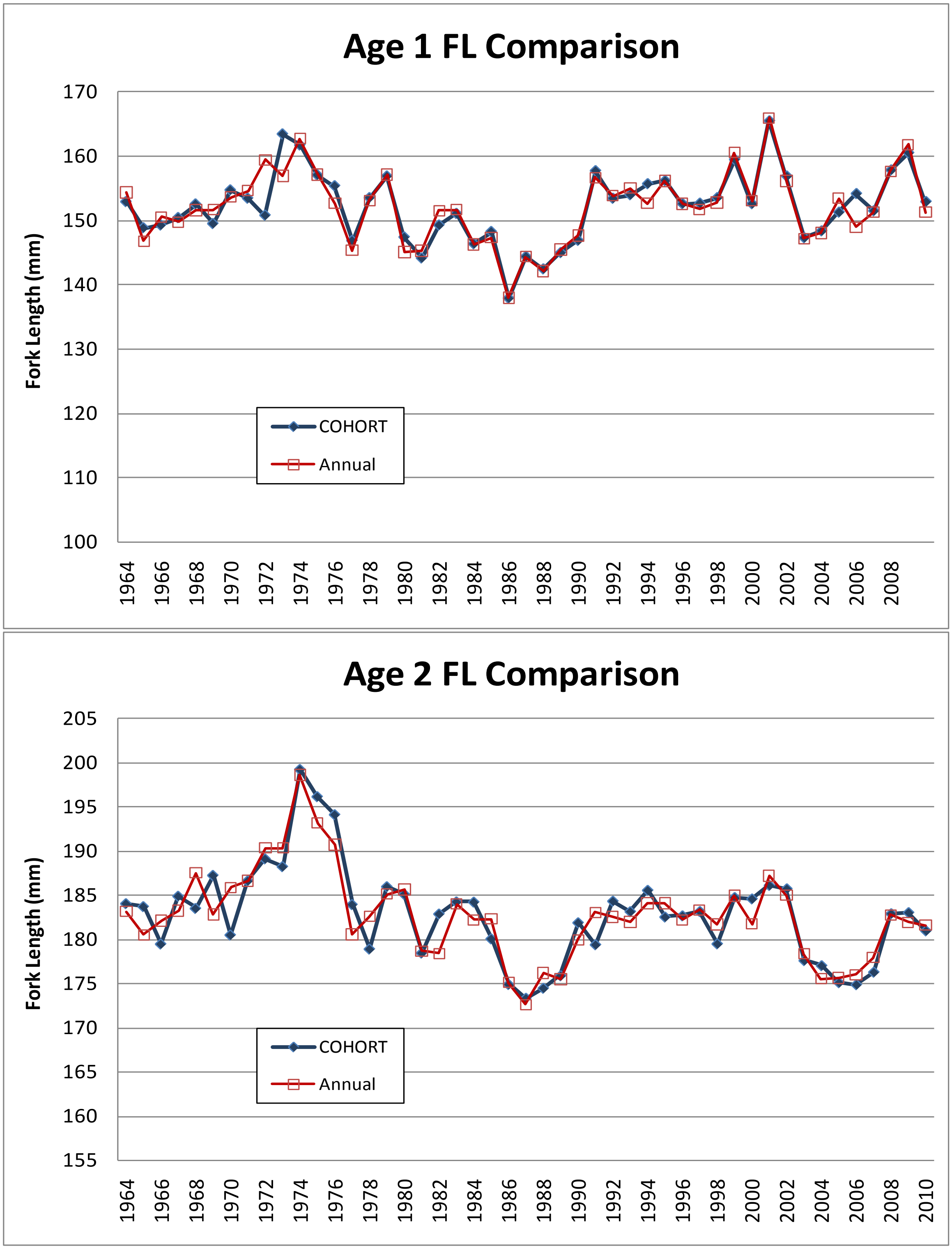


Figure 6. Comparison of female weight and fecundity (no. of maturing or ripe ova) as a function of fork length (mm) for gulf menhaden. Fecundity relationship from Lewis and Roithmayr (1981).

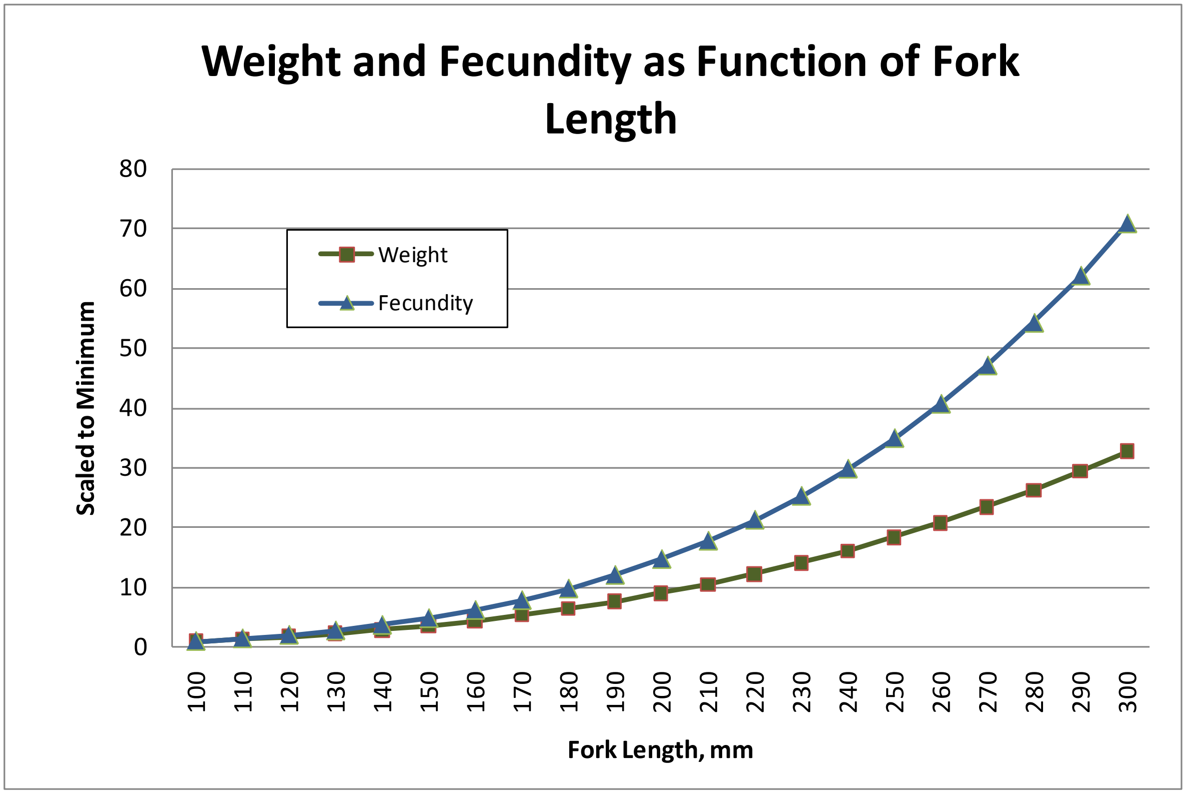


Figure 7. Proportion of eggs from age 2 spawners (first time spawners) to total population egg production as estimated in latest stock assessment (Vaughan et al. 2007), 1964-2004.