

Disclaimer! This report has not been peer-reviewed or updated since I wrote it as an 18-year-old undergraduate in 2010.

Therefore, this report may contain errors, bias, and may express opinions not shared by my present self, mentors, or the South Carolina Department of Natural Resources.

An Update of the Population Dynamics of Black Sea Bass, *Centropristis striata*, off the coast of the southeastern U.S.

Stephan Bitterwolf

Joseph C. Ballenger

Marcel Reichert

Marine Resources Research Institute

South Carolina Department of Natural Resources

217 Fort Johnson Road

Charleston, SC 29412

Phone: 864-953-9046

Fax: 843-953-9280

Email: stephanbitterwolf@gmail.com

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Abstract

The National Marine Fisheries Service (NMFS) is the responsible entity, of the U.S Government, for setting fishing rules and regulations in federal waters (Wallace and Fletcher, 1996). The SEDAR process is used in the south east fisheries management to conduct stock assessment updates. In the fall and winter of 2010 there will be a stock assessment for Black Sea Bass *Centropristis striata*, a protogynous hermaphrodite of great importance to the fisheries. The purpose of this study was: to confirm the annual deposition of seasonal otolith growth rings and the month of deposition via marginal increment analysis, to create various length to age/weight regressions, assess total, natural and fishing mortality, to evaluate length/age at 50% maturity, and determine sex ratio of black sea bass. All factors analyzed in this report have been confirmed and determined. Marginal increment analysis confirms an annual deposition in the month of April. Our von Bertalanffy growth curves have been found to vary periodically, with decrease in size at age as time has progressed (1978-2009) indicating regressive evolution. Natural mortality remained constant while total and fishing mortality varied between years. Sex ratio was determined to be in favor of the female sex as reported in previous studies. The spawning season was evaluated for the months of April through March. In conclusion the decrease in size at age for black sea bass may be associated with fisheries related length limits as well as fishing mortality being greater than natural mortality by year. The results of the upcoming SEDAR stock update will guide new fishery management regulations.

Introduction

The National Marine Fisheries Service (NMFS) is the responsible entity, of the U.S Government, for setting fishing rules and regulations in federal waters (Wallace and Fletcher, 1996). In the southeast region, the South Atlantic Fisheries Management Council (SAFMC), a regional division of the NMFS, is responsible for setting regulations on federally managed species. In the determination of the status of the stocks in the southeast region, the SAFMC utilizes what is known as the Southeast Data, Assessment and Review (SEDAR) process, which uses data from both fishery-dependent and –independent sources when assessing the status of the stock (SEDAR, 2005; Wallace and Fletcher, 1996). Fishery-dependent data is acquired from commercial fishing boats, which target known fish locations and are quantity/length restricted by management, while fishery-independent data is gathered by biologists with a standardized sampling scheme with no fishery related restrictions (Wallace and Fletcher, 1996; SEDAR, 2003).

In the southeast region, the Marine Resources Monitoring, Assessment, & Prediction (MARMAP) program is the only fishery-independent program that targets reef fish species living on live bottom habitat, with data being collected continuously since 1972. Data collected by MARMAP is often used in the SEDAR process and includes data on biological (i.e., Catch Per Unit Effort, age, length and reproductive data) and associated non-biological data (i.e., capture depth, bottom water temperature, bottom salinity, and spatial location). Currently, live bottom habitats are sampled primarily with chevron traps and short bottom long-lines, although other gears have been used in the past.

One such reef fish species that is of vital commercial and recreational importance along the southeastern U.S. coast are black sea bass (*Centropristis striata*), which are currently scheduled for a SEDAR update during the fall and winter of 2010. Previous research indicates that black sea bass are protogynous hermaphrodites, with a common range along the U.S. Atlantic coast from Cape Cod to Florida (McGovern *et al.*, 2002; Cupka *et al.*, 1973; Robert A. Low, 1982). Being a protogynous hermaphrodite, black sea bass initially mature as females and at the age of 2-3 years begin transitioning to the male sex. Although male specimens can be found throughout the fish's lifespan, females dominate in frequency during their early stages of life (between 1-3 years of age), though this may differ

in southern habitats such as Florida (McGovern *et al.*, 2002). Females and transforming black sea bass were found to be shorter than males in most age ranges (McGovern *et al.*, 2002). Over the last 32 years, however, the mean length and population size of black sea bass have decreased due to various factors, including on-going overfishing of the species (SEDAR; McGovern *et al.*, 2002).

Black sea bass, as with other fish species, are aged by counting alternating light and dark bands in their otoliths, but the bands need to be validated as forming annually (Campana, 2001). The last black sea bass age validation study was completed in 1990 (20 years ago) using chemically marked fish ear bones (Collins *et al.* 1996; Joseph C. Ballenger, SC-DNR, pers. comm.). While it was a robust validation method, there was a small sample size (n=5; Collins *et al.*, 1996). It is necessary that we conduct another age validation for black sea bass. This will be imperative for accurate age data for the upcoming SEDAR stock assessment update. This data is essential for correctly assessing the status of black sea bass along the southeastern U.S. Atlantic coast (Wallace & Fletcher, 1996).

Methods

Sampling

The Marine Resources Monitoring, Assessment, & Prediction (MARMAP) program at the South Carolina Department of Natural Resources (SCDNR) supplied all data for analysis. We collected samples between 1972-2009, from live bottom habitat along the continental shelf from Cape Hatteras, NC south to Cape Canaveral, FL. As fishery-independent sampling generally only occurred between April and September, fishery-dependent samples were collected to ensure year-round samples for analysis (Table 1).

MARMAP used various gears throughout the study period (Table 2). Yankee and fly-net trawls were utilized in the early years of the program (1972-1978), followed by traps and baited hooks in later years (1979-present). Seven different trap types were employed during the 1978-2009 era. Black fish traps were used first but were found to be selective on fish length, thus the chevron trap has been the preferred method used since 1988.

MARMAP trap samples were collected from 2500+ randomly selected stations, with each station selected being at least 200 m away from any other station, resulting in 600-700

stations chosen each year. Due to sampling constraints, only 300 to 500 stations were sampled within any given year. Trap soak times were approximately 90 minutes, but actual soak times generally ranged between 80-120 minutes. Black sea bass were collected from depths ranging from 2 m to 130 m, but most samples were obtained from 16 m to 33 m. In addition, various hook-and-line gears are deployed on a semi-*ad hoc* basis to collect additional specimens for life history analysis.

For each gear deployment, we individually measured all black sea bass for length (total length (TL) or standard length (SL); mm) and the total biomass (g) per trap was recorded. Subsequently, individuals kept for age, growth and reproductive analysis were weighed individually, lengths were recorded (TL or SL), otoliths removed, and a posterior section of the gonad was removed for histological analysis (see Wyanski *et al.*, 2000 for methodology). For some individuals, we also recorded gonad weight.

Table 1: Sample size of *C. striata* caught from 1978-2009 based on Month and fishery type. * indicate months in which dependent sampling supplied most of data.

| Month | Dependent | Independent | Total | % Dependent | % Independent |
|-----------|-----------|-------------|-------|-------------|---------------|
| January* | 313 | 2 | 315 | 0.993650794 | 0.006349206 |
| February* | 483 | 0 | 483 | 1 | 0 |
| March | 247 | 359 | 606 | 0.407590759 | 0.592409241 |
| April | 264 | 8805 | 9069 | 0.029110155 | 0.970889845 |
| May | 102 | 8410 | 8512 | 0.011983083 | 0.988016917 |
| June | 248 | 9919 | 10167 | 0.024392643 | 0.975607357 |
| July | 250 | 8082 | 8332 | 0.030004801 | 0.969995199 |
| August | 64 | 6688 | 6752 | 0.009478673 | 0.990521327 |
| September | 1 | 3657 | 3658 | 0.000273373 | 0.999726627 |
| October | 118 | 234 | 352 | 0.335227273 | 0.664772727 |
| November* | 430 | 153 | 583 | 0.737564322 | 0.262435678 |
| December* | 189 | 0 | 189 | 1 | 0 |

Table 2: Sample size of *C. striata* caught off the East Coast based on Gear typed employed from 1972-2009 with the years of use stated in the “Year” column. Gear types averaging less than 200 samples were combined in the “Miscellaneous” category.

| Gear | Sample Size | Year |
|-----------------------------|--------------------|----------------------------|
| Chevron Trap (MARMAP) | 19896 | 1988-2009 |
| Black Fish Trap | 12182 | 1978-1989, 1999, 2004-2006 |
| Snapper Reel | 9653 | 1978-1997, 2000-2005, 2007 |
| Florida “Antillean” Trap | 3465 | 1980-1989, 2004-2006 |
| Yankee Trawl | 1831 | 1973, 1974, 1977-1980 |
| Unknown* | 1303 | 1978, 1979, 1980, 2002 |
| Fine Mesh Trap | 581 | 1978, 1979 |
| Hook and Line | 264 | 1985, 1987-1993, 2004-2006 |
| Mini Antillean S- Trap | 239 | 1978 |
| 40/54 Fly Net | 216 | 1980-1981 |
| Experimental Trap | 212 | 1980, 1991, 2008, 2009 |
| Miscellaneous | 185 | - |

Age determination and marginal increment analysis

Previous MARMAP personnel determined increment count, edge type, and quality by counting alternating light and dark bands (Tables 3 & 4). These readers counted the number of mineral rich or mineral deficient rings under a dissecting microscope (7.5-75x magnification). Otoliths deemed unreadable (quality = “A”) were not aged and excluded from age analyses. To reduce bias readers had no knowledge of fish length or capture date. Bias and consistency in otolith reading among readers was tested using a subsample of 500 otoliths. Bias potential was assessed using five statistical tests (Hoenig *et al.*, 1995) – a paired *t*-test, a Wilcoxon signed-rank test, a linear regression with *t*-tests, Bowker’s (1948) symmetry test – and bias plots (Campana *et al.*, 1995). To assure consistency, we computed

commonly used measures of precision: mean coefficient of variation (CV), the percent agreement, and average percent error (APE) (Campana *et al.*, 1995; Hoenig *et al.*, 1995; DeVries and Frie, 1996). Once a lack of bias and consistency in age readings among readers was insured, otoliths were aged by a single reader.

Based on the results of a southeastern aging workshop it was determined that all otoliths appearing to have 5 or fewer annuli would be aged whole (Figure 1), while otoliths with 6 or more annuli counts would be sectioned and aged (Figure 2; Joseph C. Ballenger, SC-DNR, pers. comm.). There was no indication of bias or inconsistencies in age readings when determining ages via whole otoliths versus sectioned otoliths (Joseph C. Ballenger, SC-DNR, pers. comm.). Otoliths were sectioned along the transverse plan to an approximate thickness of 0.4 mm using a low-speed Buehler Isomet saw, and then mounted on a slide. Due to concerns surrounding potential differences in age readings obtained via aging individuals with sections and whole otoliths, participants of the aging workshop aged 100 black sea bass via both whole otoliths and sections and looked for potential biases or inconsistencies in age readings using the same tests as described above (Joseph C. Ballenger, SC-DNR, pers. comm.). There was no indication of bias or inconsistencies in age readings when determining ages via whole otoliths versus sectioned otoliths (Joseph C. Ballenger, SC-DNR, pers. comm.).

To validate the period of increment formation a marginal increment analysis (MIA) was performed on a random selection of specimens (n =1288) collected from 1978-2009. MIA is a standard technique used to validate otolith annulus deposition rate indirectly (Casselman 1987; Hyndes *et al.*, 1992). As all individuals had previously had increment counts determined, previous increment counts were used to select individuals from all age classes across all months in a stratified random sampling design. In general, efforts were made to select 20 individuals per increment class from every month of capture. In situations when more than 20 individuals were available in a month, a random number generator was used to randomly select 20. Because of the low sample sizes of black sea bass containing 6 or more increments across months, these individuals were pooled into a plus group and a random sample of 20 per month was selected from this plus group. In addition, in total only 12 individuals have been collected in the month of December, thus all increment groups were pooled, and all individuals selected for this month. Once selected, these were independently examined for annuli count, edge type and quality using the same

methods used by the previous analyzers. When disagreements arose between the previously determined increment count and the current increment count, it was assumed that the current increment count was correct, and it was added to the number of samples from that month and increment count combination. If possible, an additional individual was selected to replace the one lost due to its change in increment count to maintain the minimum sample size of 20 per month and increment combination (Table 5).

MIA was performed on a dissecting microscope outfitted with an image analysis system (Image Pro Plus V5.1, Media Cybernetics Inc.). Fish selected for the MIA had the translucent margin from the last annulus to the edge of the otolith, along with the distance between the last annulus and the previous annulus, digitally measured. For whole otoliths, if possible, distances along the antero-ventral axis on the sagittal plane were measured (Figure 1), while for sectioned otoliths distances along the dorsal sulcal groove along the frontal plane were measured (Figure 2; Panfili *et al.*, 2002). From these data, an index of completion was determined:

$$C = \frac{W_n}{W_{n-1}} * 100,$$

where W_n is the length of the marginal increment and W_{n-1} is the width of the previous increment. The average relative margin completion within capture month and increment count was then determined prior to plotting. A single period of below average marginal completion during the year for each increment count was interpreted as confirming that a single annulus formed during an individual year (Hyndes *et al.*, 1992).

Table 3: Readability codes employed in MARMAP quality assessments.

| Readability | |
|--------------------|--|
| C | Description and analysis consequence |
| o | |
| d | |
| e | |
| A | Omit otolith from analysis |
| B | Age estimate between readers are expected to be >2 year for young, and > 4 yrs. for old fish (>10 yrs.) Agreement on age may be difficult to reach in which case the otolith should be classified as A and omitted from analysis |
| C | Age estimates between readers should be within 2 years in young and within 4 years in old fish. Agreement after second reading is expected after some discussion |
| D | Age estimates between readers should be within 1 year for young, to 2 years in old fish. Agreement after second reading is expected without much discussion |
| E | Age estimates between readers should be the same |

Table 4: Edge type codes employed in MARMAP edge type determinations.

| Edge Type | |
|------------------|--|
| Code | Description |
| 1 | Opaque zone on the edge |
| 2 | Narrow translucent zone on edge Width less than about 30% of previous increment |
| 3 | Medium translucent zone on edge Width about 30-60% of previous increment |
| 4 | Wide translucent zone on edge Width more than about 60% of previous increment |



Figure 1: Whole *C. striata* sagittal otolith captured from 1978-2009 in the South Atlantic Bight.

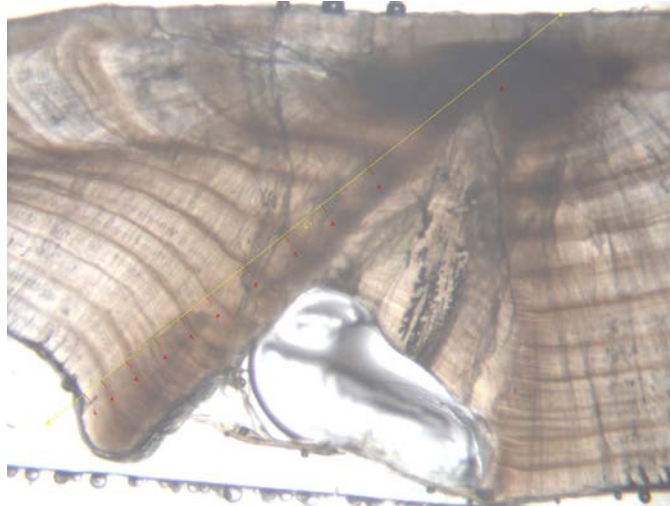


Figure 2: Sectioned *C. striata* sagittal otolith captured from 1978-2009 in the South Atlantic Bight.

Table 5: Sample size grouped monthly between 6 age groups with Year 6+ including all ages observed above 6.

| Month | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6+ |
|--------------|---------------|---------------|---------------|---------------|---------------|----------------|
| Jan | 24 | 21 | 21 | 23 | 20 | 7 |

| | | | | | | |
|-----|----|----|----|----|----|----|
| Feb | 1 | 21 | 24 | 23 | 20 | 17 |
| Mar | 7 | 24 | 22 | 23 | 22 | 10 |
| Apr | 22 | 24 | 20 | 20 | 24 | 21 |
| May | 22 | 23 | 20 | 22 | 21 | 20 |
| Jun | 24 | 21 | 23 | 20 | 20 | 20 |
| Jul | 22 | 21 | 20 | 20 | 20 | 21 |
| Aug | 20 | 21 | 21 | 21 | 20 | 23 |
| Sep | 20 | 21 | 22 | 25 | 21 | 22 |
| Oct | 21 | 20 | 21 | 14 | 5 | 2 |
| Nov | 6 | 20 | 23 | 22 | 20 | 4 |
| Dec | 0 | 1 | 5 | 2 | 3 | 1 |

Growth

Length to length relationships for SL and TL were defined through a linear relationship. A weight at length analysis was conducted using the power equation:

$$W = \alpha L^{\beta},$$

where W is the weight in g, L is TL in mm, and α and β are the parameters being estimated. Subsequently, a Student's t -test was used to confirm whether growth in weight was isometric.

Length-at-age data were modeled with the von Bertalanffy growth curve (VB; von Bertalanffy, 1938; Ricker 1975). The VB equation is a three-parameter growth model,

$$L(t) = L_{\infty}(1 - e^{-k(t-t_0)}),$$

where $L(t)$ represents the TL (in mm) at age t (in years), while L_{∞} illustrates mean maximum TL, k is the Brody growth coefficient and t_0 is the postulated age at which length is equal to zero. L_{∞} , k and t_0 were estimated through non-linear least squares regression.

In the development of appropriate weight-length and length-at-age regressions, we explored the possibility that additional explanatory variables other than year could help explain variability. Thus, we used Kimura's (1980) likelihood ratio test to determine if there was a difference in models developed for inner continental shelf versus outer continental shelf captured black sea bass and a difference in models developed for black sea bass captured north of the 32° N latitude parallel and south of the 32° N latitude parallel. In addition, we used AIC (Akaike 1973) and BIC (Schwarz 1978) to determine whether including period of capture as an extra explanatory variable improved model fits. Fish captured in waters shallower than 30 m in depth were considered to be inner-shelf fish while those

captured in depths greater than or equal to 30 m were considered outer-shelf fish. Three time periods were defined as follows: 1978-1989 equals the “early” period, 1990-1999 equals the “mid” period, and 2000-2009 equals the “late” period.

Mortality

Multiple models were used to estimate the instantaneous natural (M) and total (Z) mortality rates of black sea bass. The models for M were Alverson & Carney (1975), Beverton (1992), Hoenig (1983), Pauly (1980), Ralston (1987) and Lorenzen (1996). Parameters required to estimate natural mortality were: age at 50% maturity (A_M), k , L_∞ , water temperature and the observed maximum age. The age at 50% maturity (required for the Hoenig method) parameter came from the female all combined Gompertz model fit for black sea bass (Table 6). The parameters, k and L_∞ , were determined in the von Bertalanffy combined length-at-age growth model. Though we recommended not using an all parameter combined von Bertalanffy length-at-age curve, but rather one taking into account depth, region, and period of capture, we found little effect on natural mortality parameter estimates using the different k and L_∞ values from these curves (Figure 3), thus the use of the parameter estimates from an all data combined von Bertalanffy model for estimation of natural mortality rates was warranted. Water temperatures, T , (required for the Pauly (1980) model) were assumed to be constant at 17^o Celsius, which is the same assumed water temperature for the Pauly (1980) natural mortality estimate used in the recent SEDAR 24 on red snapper of the SAB (Joseph C. Ballenger, SC-DNR, pers. comm.).

Table 6: Age and length at 50% maturity for female and transitional *C. striata* for various year bins. Female maturity data in bold

| Years | Type | Maturity | |
|-----------|---------------|-------------|---------------|
| | | Age at 50% | Length at 50% |
| Combined | Female | 0.83 | 124.08 |
| | Transitional | 3.54 | 289.32 |
| 1978-1983 | Female | 0.88 | 138.64 |
| | Transitional | 3.49 | 299.98 |
| 1984-1989 | Female | 0.77 | 124.95 |
| | Transitional | 3.92 | 282.62 |
| 1990-2009 | Female | 0.82 | 149.48 |
| | Transitional | 3.49 | 284.65 |
| 1990-1999 | Female | 0.81 | 144.63 |
| | Transitional | 3.50 | 280.26 |
| 2000-2009 | Female | 0.83 | 163.79 |
| | Transitional | 3.44 | 287.50 |

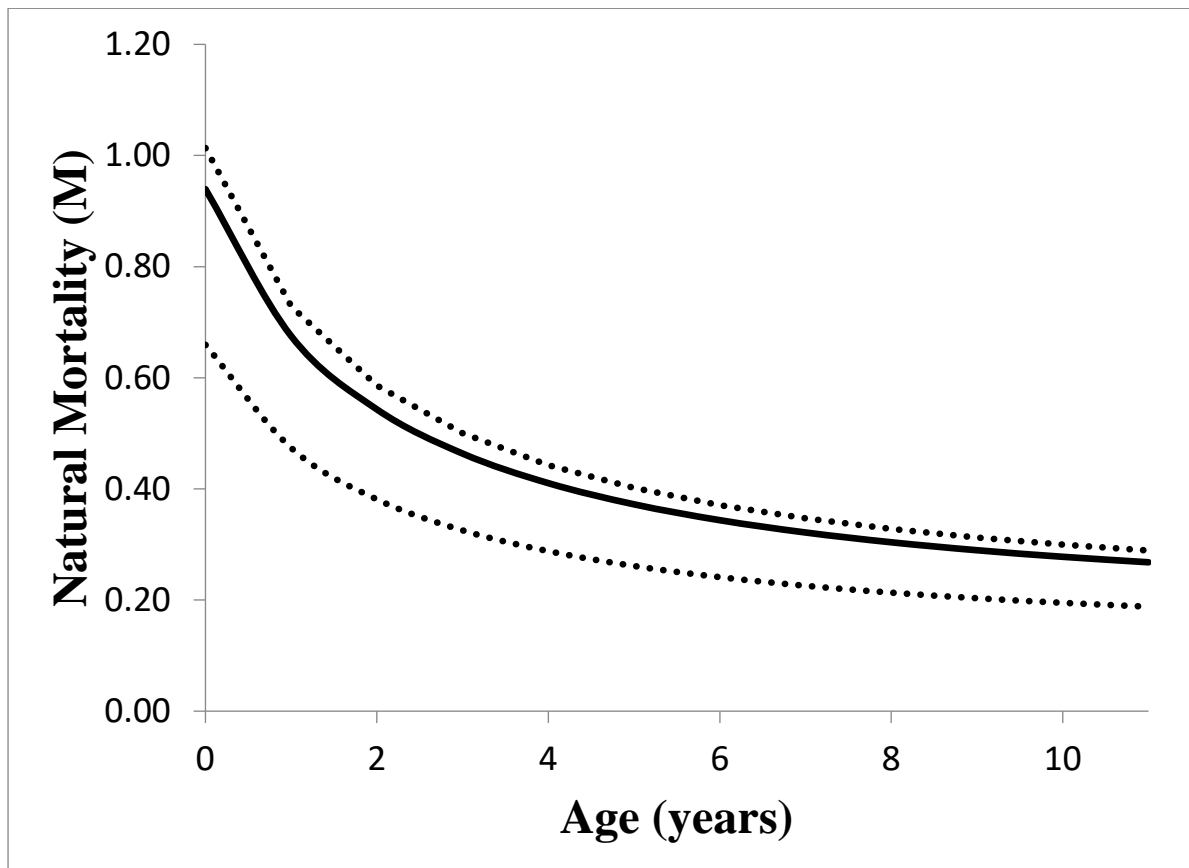


Figure 3: Lorenzens age specific natural mortality (M) scaled to 1, (dotted line) 1.4 (solid line) and 5 % (dotted line) of total *C. striata* reaching the maximum age of 11.

Total mortality (Z) was estimated through a catch curve analysis, Heincke's method (citation), and the Chapman-Robson (Chapman and Robson, 1960) method using only ages that were fully recruited to our gear (all gear combined; used age at peak number + 1 year). The Z value was then converted to annual survival (S) and mortality rates (AM) using the following conversions, respectively:

$$S = e^{-Z} \text{ and } AM = 1 - S$$

F, the instantaneous fishing mortality rate, was calculated via difference, since $F = Z - M$ (Slipke & Maceina, 2002). The annual exploitation rate (u) was then calculated using the relationship:

$$u = \frac{F(1 - S)}{Z}$$

Year specific Z and F values were also investigated to determine whether any trends could be discerned regarding black sea bass mortality.

Reproduction

The sex ratio (female : transitional : male) was determined for all ages combined, and by age class. We also investigated the possibility that the sex ratio could differ among regions (north vs. south), depth of capture (inner shelf vs. outer shelf) and periods. For all sex ratios, a Chi-squared test was conducted to determine if the ratio of females to males significantly differed from a 1 to 1 relationship.

Length and age at maturation were determined for females using logistic regression. TL data were binned in 25 mm bins prior to length at maturity regression analysis. The percentages of male individuals observed at each age and length bin were also determined in an attempt to determine the average age at which transition from female to male occurred. In addition, we also modeled the length and age of maturation for females and transition to males in various time periods as defined by previous SEDAR assessments of black sea bass. The data was split into three or four time periods, depending on the analysis, those time periods being from 1978-1983, 1984-1989, 1990-2009 and a subsequent splitting of the 1990-2009 data into two time periods: 1990-1999 and 2000-2009. For all length and age at maturity and transition analyzes, logistic regression was used to model the relationship.

We classified female ovaries to maturity stage, as defined in Table 5, using histological sections of ovarian tissues. By plotting the relative distribution of various ovary maturity stages across month of capture, it was possible to determine the spawning season for black sea bass along the southeastern U.S. Months in which there were relatively larger percentages of gonads staged as being in the actively spawning stage identify the spawning season in black sea bass (Wyanski *et al.*, 2000).

Table 7: Definition of reproductive terms for female *C. striata* used in this report.

| Reproductive Stage | Description |
|---------------------------|---|
| Developing | Gonadal tissue developing incapable of spawning |
| Spawning | Currently creating oocytes |
| Regressing | Not spawning |
| Regenerating | Capable of spawning, currently not spawning. |

Results

Sampling

In all 50,027 specimens were collected for analysis (Table 2). Of the 50,027, we collected 3,720 (7.44 % of total) black sea bass via fishery-dependent sampling, with the majority of data collected during the late fall and winter months being derived from the fishery-dependent samples (Table 1). The remaining samples were fishery-independent samples collected via MARMAP sampling, with the majority of sampling conducted from April through September (Table 1). Fishery-independent sampling supplied the majority of data for the summer months, while dependent sampling supplied nearly all data for the winter months (Table 1).

Age Determination and Marginal Increment Analysis

Increment counts were determined for 48,247 otoliths, with the number of increments ranging from 0-11 increments. Of those otoliths, 426 (0.88% of the total) were determined to be of unusable (“A”) quality.

Marginal increment analysis (MIA) was performed using 1,446 (3.00% of the aged fish) otoliths (Table 5). Rapid growth, and therefore increment deposition, occurs in young (0-2 years old) black sea bass, distorting the interpretation of marginal increments as the

width between the increments is drastically reduced among those increments. Therefore, we constrained further MIA to those fish identified as having three or more increments (n = 1019; Table 5). Due to the low sample size per age class in December a single index of completion was determined for the month of December based on data from all increment classes combined. The MIA confirmed an annual increment deposition in the months of March-May (ages 3, 4 and 5) and March – July (Age 6+; Figure 4). Both combined age MIA for whole (n = 693) and sectioned (n = 326) otoliths suggested the formation of an annulus between March-June (Figure 5). The results of the MIA agree with our edge type plot based on all ages combined (Figure 6).

Calendar ages, for individual black sea bass, were determined using the month of April as the month of peak annulus formation. Subsequently, we calculated fractional ages based upon observed peak spawning in the month of March. Calendar ages ranged from 0-11 years old after conversion from annuli counts, while fractional ages ranged from a minimum of 0.167-11.33 based upon the month of peak spawning.

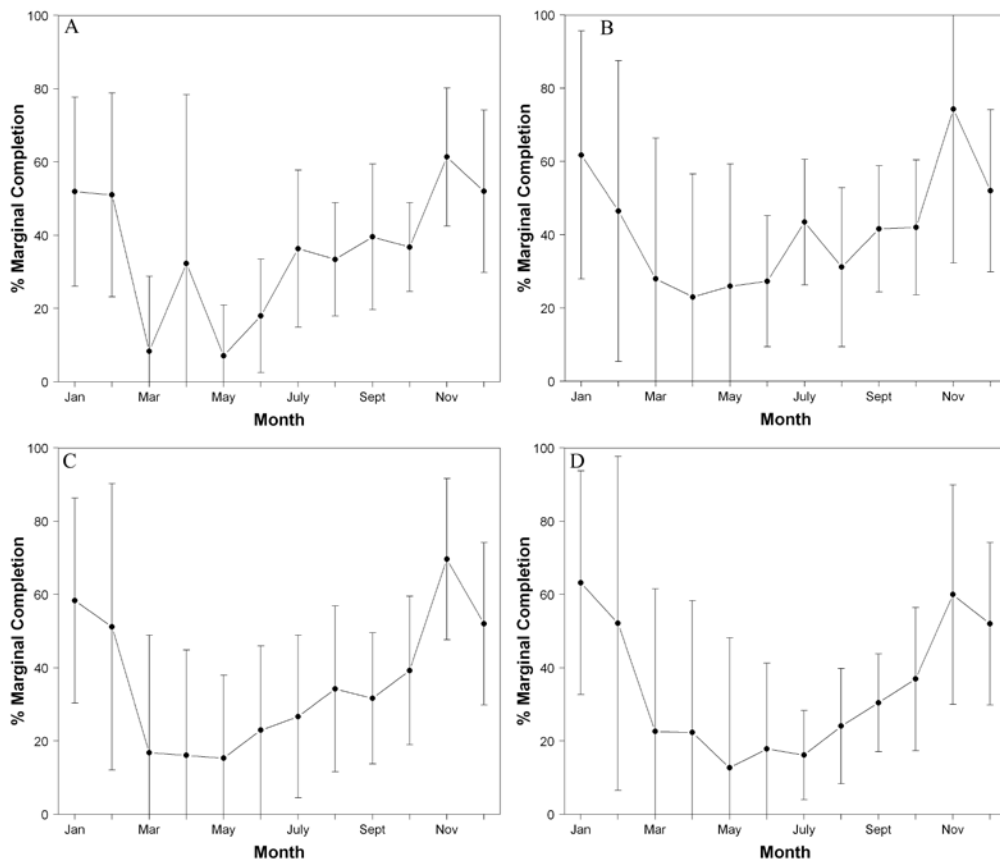


Figure 4: Percent Marginal Completion observed for Age 3 (A), Age 4 (B), Age 5 (C) and Age 6 (D) *C. striata*. For the month of December all samples were employed regardless of age due to a small sample size.

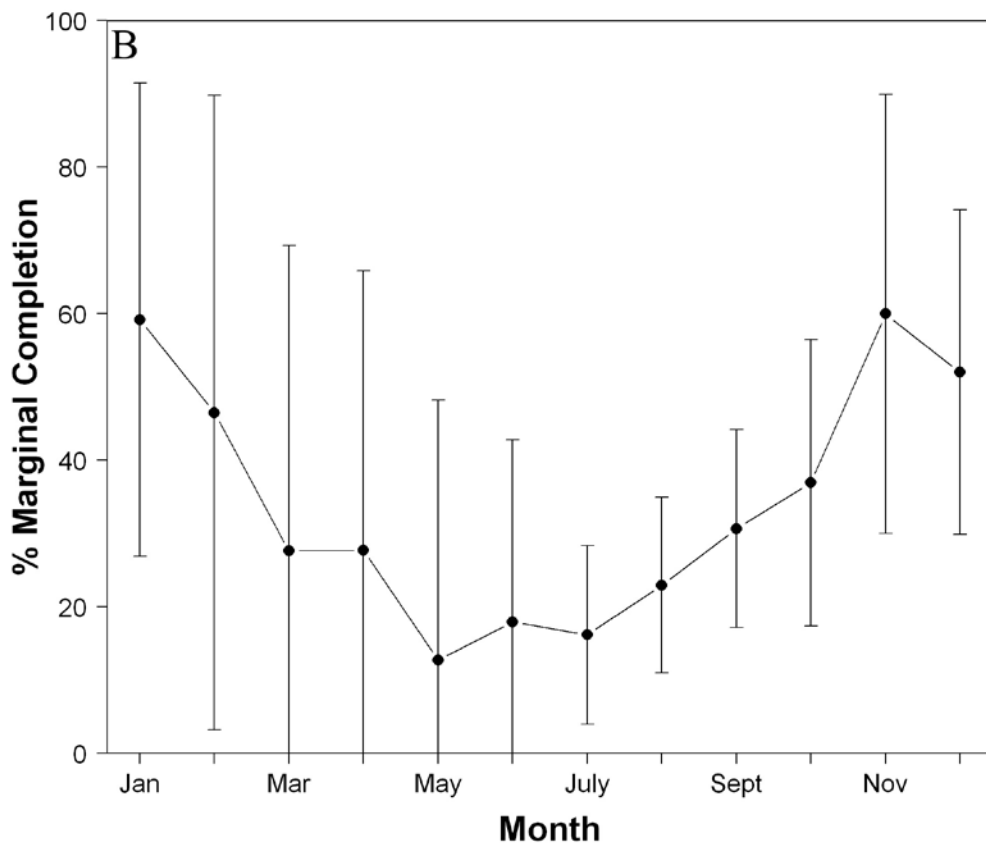
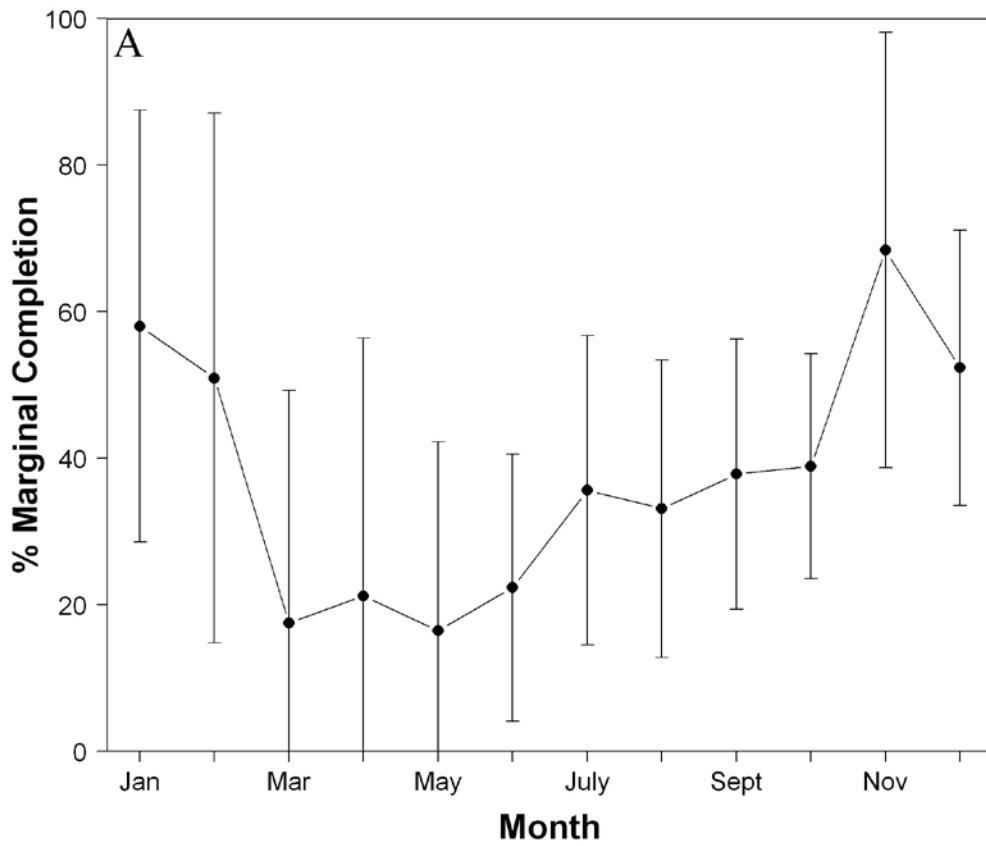


Figure 5: Percent marginal completion for otoliths read whole 3+ (A) and otoliths read sectioned (B). For the month of December all samples were employed regardless of age due to a small sample size.

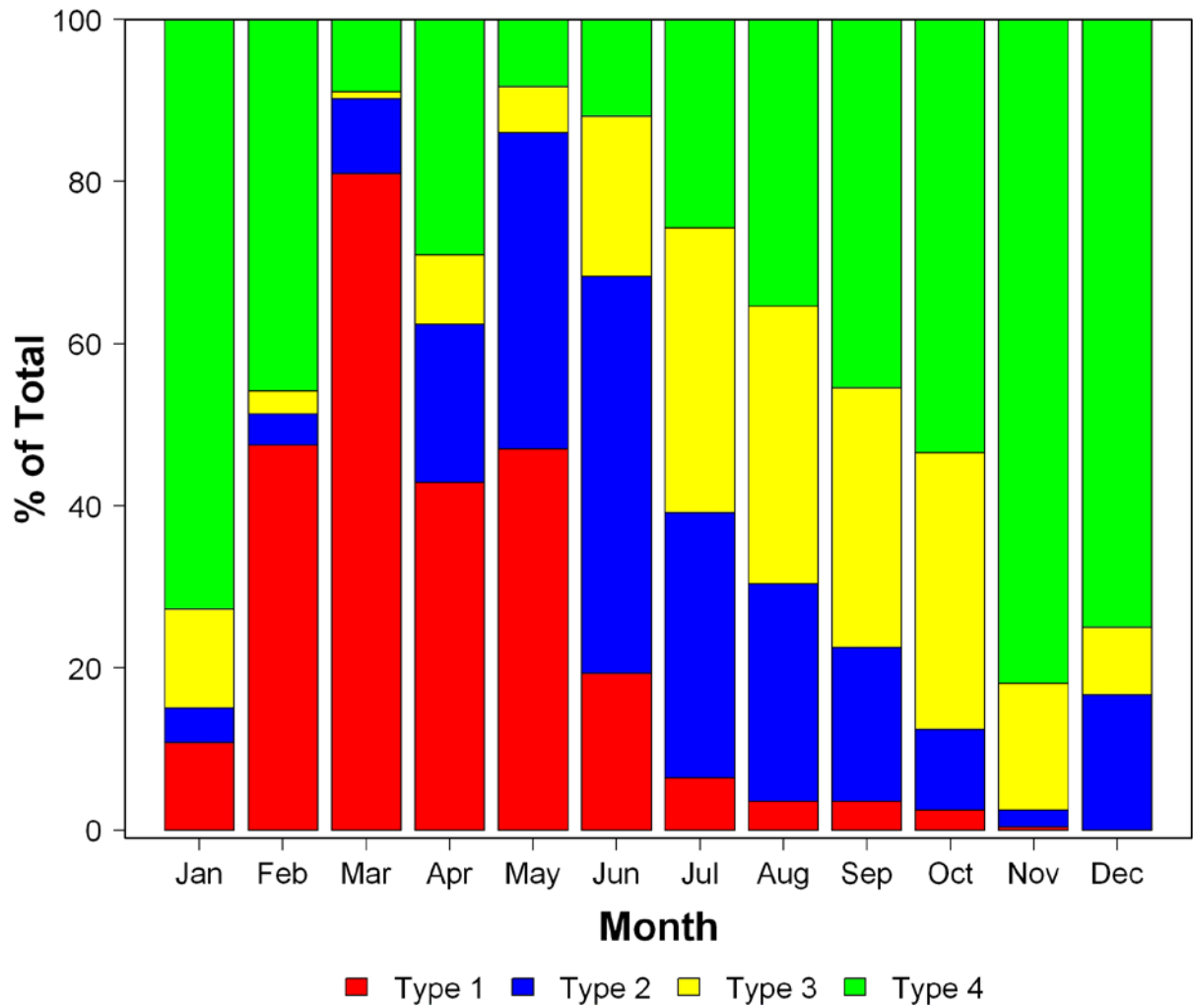


Figure 6: Edge types observed based on 48,247 *C. striata* previously assessed by MARMAP. Edge type one corresponds to an Increment being formed on edge, type 2 corresponds to a translucent zone less than 30% the width of the previous translucent zone, Type 3 corresponds to 30-60% previous width, and Type 4 corresponds to a translucent zone greater than 60% of the previous margin.

Growth

Length-Length

We found that natural log transformed, length to length linear regressions, between TL and SL, met our model's underlying assumption of normality of all data better than the non-transformed length to length regressions, thus, we propose the conversions found in Table 8 be used to convert length measurements.

Table 8: Standard to Total Length regressions formulas with sample size as n.

| Length-Length | | | | | | |
|-----------------|-----------------------|-------|--------|----------|------------------|-------------------|
| Source | Equation | Units | n | χ^2 | a | b |
| TL - SL | TL = aFL + b | mm | 49,415 | 0.981 | 1.354 (0.001) | 10.722 (0.170) |
| SL - TL | TL = aSL + b | mm | 49,415 | 0.981 | 0.725 (0.000) | 11.500 (0.119) |
| Ln(TL) - Ln(SL) | Ln(TL) = a*Ln(SL) + b | mm | 49415 | 0.984 | 1.036 (0.001) | 0.072 (0.003) |
| Ln(SL) - Ln(TL) | Ln(SL) = a*Ln(TL) + b | mm | 49415 | 0.984 | 0.950 | 0.017 (0.003) |

Weight-Length

We needed a natural log transformation of both the weight (g) and length (TL, mm) data in order to meet our models assumption of homogeneity of variance and normality of residuals. Initially, we created a weight-length regression on all weight and length data combined (Figure 7). However, a high degree of variance observed about the fitted line suggested we should explore the possibility that additional factors could help describe the weight-length regression. Thus, we explored the possibility of depth, location, and time period of capture having an effect on the observed weight-length relationship through the use of Kimura's (1980) likelihood ratio test, AIC and BIC. Since it is known that black sea bass are protogynous heremaphrodites with the largest at age transitioning from males and females, we did not consider sex as an extra explanatory variable. Results suggested that each extra explanatory variable had a significant effect on the relationship (Table 9). However, upon further graphical inspection (graphs in appendix), it appeared there was little biologically significant difference in the various weight-length regressions, thus we recommend all data be pooled and a single weight-length regression curve be used to describe the relationship between weight and total length for black sea bass off the

southeastern U.S. Atlantic coast (Table 10). A subsequent test for isometric growth ($t=1.7959$, $d.f.=11$, $p\text{-value} = <0.0001$) suggests that growth in weight as a function of TL is not isometric ($\beta \neq 3$), but rather allometric.

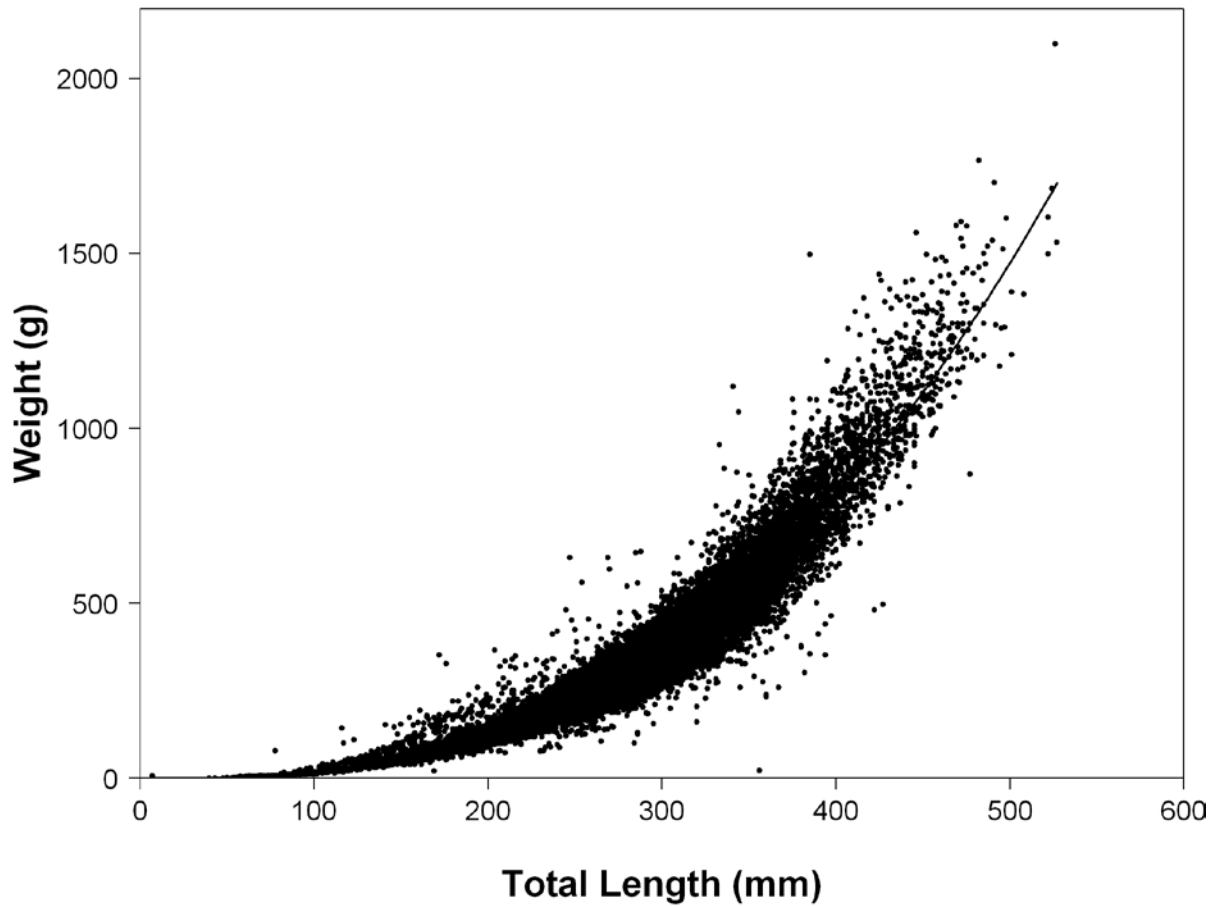


Figure 7: Weight to length regression for *C. striata* with high variance observed about the fitted line suggesting a more in-depth analysis.

Table 9: Weight at length AIC and BIC results between 3 explanatory variables: Depth, Region and Period. AIC and BIC rank values of 1 indicate the appropriate model based on greatest negative value.

| Test | AIC | BIC | AIC Rank | BIC Rank |
|----------------------------|------------|------------|----------|----------|
| All Different* | -46493.215 | -46381.549 | 1 | 1 |
| Regions Combined | -46272.395 | -46177.908 | 2 | 2 |
| Depths Combined | -45991.121 | -45896.635 | 3 | 3 |
| Periods Combined | -45801.204 | -45741.076 | 4 | 4 |
| Regions & Depths Combined | -45741.304 | -45663.997 | 5 | 5 |
| Regions & Periods Combined | -45680.6 | -45637.652 | 6 | 6 |
| Depths & Periods Combined | -45261.836 | -45218.887 | 7 | 7 |
| All Combined | -45122.121 | -45096.352 | 8 | 8 |

Table 10: Weight at length multi-parameter regression for *C. striata*. Growth seemed to be non-isometric ($\beta \neq 3$). Early (1978-1989) Mid (1990-2000) Late (2000-2009). South (<32.00 $^\circ$) North ($\geq 32.00^\circ$). Inshore (<30 meters) Offshore (≥ 30 meters).

| Period | Region | Depth | Sample | | |
|--------|-----------------|----------|--------|-------------|-----------|
| | | | size | β | |
| | | | | -9.68 | 2.73 |
| | Combined | | 42,358 | (-9.68) | (0.00268) |
| Early | South | Inshore | 2272 | -9.6306297 | 2.7162841 |
| | | Offshore | 563 | -10.2195562 | 2.8170937 |
| | North | Inshore | 11341 | -9.5779213 | 2.7112105 |
| | | Offshore | 4004 | -10.1668478 | 2.8120201 |
| Mid | South | Inshore | 1649 | -9.3968968 | 2.6804538 |
| | | Offshore | 731 | -9.9858233 | 2.7812634 |
| | North | Inshore | 5925 | -9.3441884 | 2.6753802 |
| | | Offshore | 1713 | -9.9331149 | 2.7761898 |
| Late | South | Inshore | 2642 | -9.5910885 | 2.7248677 |
| | | Offshore | 901 | -10.180015 | 2.8256773 |
| | North | Inshore | 1589 | -9.5383801 | 2.7197941 |
| | | Offshore | 6203 | -10.1273066 | 2.8206037 |

Length-at-Age

Length in TL (mm) versus age (years) was modeled using the von Bertalanffy growth model. We initially modeled the relationship with all data combined, however, as with the weight-length regression, high variance about the fitted line (Figure 7) suggested that we should look at extra explanatory variables once again. As with the weight-length regression, we explored the possibility that depth, location, and time period were important factors in explaining the length-at-age relationship. Kimura's (1980) likelihood ratio test, AIC and BIC all suggested that each factor was important (Table 11), and thus we developed an extended von Bertalanffy growth model taking each extra explanatory variable into account. AIC and BIC suggest that a von Bertalanffy model taking all parameters into account was most appropriate, thus models for each possible combination of explanatory variable factors were developed (Table 12).

Table 11: Length at Age AIC and BIC results between 3 explanatory variables: Depth, Region and Period. AIC and BIC rank values of 1 Indicate the appropriate model based on greatest negative value. * Indicates a bad fit or unrealistic values.

| Test | AIC | BIC | AIC Rank | BIC Rank |
|-----------------------------|----------------|----------------|----------|----------|
| All Different | 458683.13 | 458849.04 | 1 | 1 |
| Depths Combined | 459252.61 | 459392.33 | 2 | 2 |
| Regions Combined | 459743.48 | 459883.19 | 3 | 3 |
| Regions & Depths Combined | 460365.52 | 460479.03 | 4 | 4 |
| Periods Combined* | 461199.59 | 461286.91 | 5 | 5 |
| Depths & Periods Combined | 461421.34 | 461482.46 | 6 | 6 |
| All Combined | 461944.82 | 461979.75 | 7 | 7 |
| Regions & Periods Combined* | Won't Converge | Won't Converge | 8 | 8 |

Table 12: Multi-parameter von Bertalanffy growth estimates based on period, latitude and depth with standard error in parentheses'. Early (1978-1989) Mid (1990-2000) Late (2000-2009). South (<32.00°) North (>= 32.00°). Inshore (<30 meters) Offshore (>= 30 meters).

| Period | Region | Depth | Sample size | L_{∞} | k | t_0 |
|--------|--------|-----------------|-------------|-----------------|------------------|-------------------|
| | | Combined | 47,768 | 656.271 (16.61) | 0.0933 (0.00395) | -1.80 (0.0506) |
| Early | South | Inshore | 2974 | 1481 | 0.0357 | -2.19 |
| | | Offshore | 624 | 1506 | 0.0350 | -2.11 |
| | North | Inshore | 15237 | 1504 | 0.0334 | -1.94 |
| | | Offshore | 6830 | 1529 | 0.0327 | -1.86 |
| Mid | South | Inshore | 1651 | 470 | 0.1589 | -1.55 |
| | | Offshore | 732 | 494 | 0.1583 | -1.47 |
| | North | Inshore | 5934 | 493 | 0.1566 | -1.30 |
| | | Offshore | 1735 | 518 | 0.1560 | -1.22 |
| Late | South | Inshore | 2645 | 393 | 0.1931 | -1.81 |
| | | Offshore | 903 | 418 | 0.1924 | -1.73 |
| | North | Inshore | 6212 | 416 | 0.1908 | -1.56 |
| | | Offshore | 1591 | 441 | 0.1902 | -1.48 |

Mortality

Total Mortality

We estimated total mortality (Z) on an annual basis from 1978-2009 implementing the catch curve, Heincke, and Chapman & Robson mortality estimators. To smooth the year to year variation in the total mortality estimates, a 3-year average of Z was used to represent the mortality in any given year. Generally peak numbers at age occurred at age 3, thus age 4+ fish were considered fully recruited to the gear. This was untrue for some sampling years in which peak numbers at age occurred at either 2 or 3 years of age, thus changing our understanding of the fully recruited. Z varied annually throughout the time series (Figure 8) with the greatest mortality of 1.55 in 2001 (Table 13). When all years are pooled, the Z estimate from catch-curve analysis was 1.3100 (± 0.0680 SE) (Table 14). The Heincke and Chapman-Robson estimates are generally less than the estimate from catch-curve.

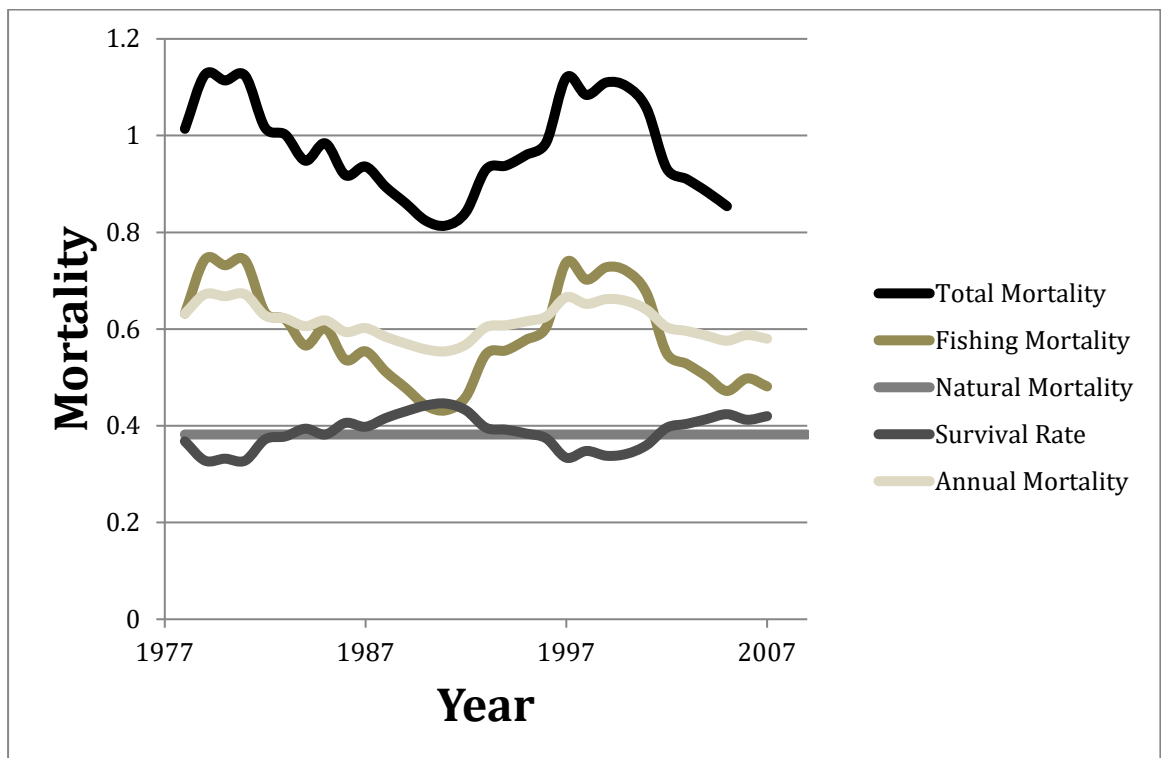


Figure 8: Total mortality, fishing mortality, natural mortality, annual mortality and survival rate for *C. striata* captured along the South Atlantic Bight from 1978-2009 smoothed to a 5-year average.

Table 13: Catch curve estimates for total, natural and fishing mortality including Survival rate and annual mortality. Z= total, M= natural, F= fishing, S= survival, and AM= annual mortality.

| Year | Mortality | | | | | |
|------|-----------|-------|-------|-------|------|------|
| | Z | M | F | S | AM | |
| 1978 | 0.73 | 0.382 | 0.382 | 0.348 | 0.48 | 0.52 |
| 1979 | 1 | 0.382 | 0.382 | 0.618 | 0.37 | 0.63 |
| 1980 | 1.18 | 0.382 | 0.382 | 0.798 | 0.31 | 0.69 |
| 1981 | 1.19 | 0.382 | 0.382 | 0.808 | 0.30 | 0.70 |
| 1982 | 0.97 | 0.382 | 0.382 | 0.588 | 0.38 | 0.62 |
| 1983 | 1.29 | 0.382 | 0.382 | 0.908 | 0.28 | 0.72 |
| 1984 | 0.94 | 0.382 | 0.382 | 0.558 | 0.39 | 0.61 |
| 1985 | 1.23 | 0.382 | 0.382 | 0.848 | 0.29 | 0.71 |
| 1986 | 0.65 | 0.382 | 0.382 | 0.268 | 0.52 | 0.48 |
| 1987 | 0.9 | 0.382 | 0.382 | 0.518 | 0.41 | 0.59 |
| 1988 | 1.02 | 0.382 | 0.382 | 0.638 | 0.36 | 0.64 |
| 1989 | 1.12 | 0.382 | 0.382 | 0.738 | 0.33 | 0.67 |
| 1990 | 0.9 | 0.382 | 0.382 | 0.518 | 0.41 | 0.59 |
| 1991 | 0.74 | 0.382 | 0.382 | 0.358 | 0.48 | 0.52 |
| 1992 | 0.69 | 0.382 | 0.382 | 0.308 | 0.50 | 0.50 |
| 1993 | 0.85 | 0.382 | 0.382 | 0.468 | 0.43 | 0.57 |
| 1994 | 0.94 | 0.382 | 0.382 | 0.558 | 0.39 | 0.61 |
| 1995 | 0.85 | 0.382 | 0.382 | 0.468 | 0.43 | 0.57 |
| 1996 | 0.88 | 0.382 | 0.382 | 0.498 | 0.41 | 0.59 |
| 1997 | 1.13 | 0.382 | 0.382 | 0.748 | 0.32 | 0.68 |
| 1998 | 0.89 | 0.382 | 0.382 | 0.508 | 0.41 | 0.59 |
| 1999 | 1.05 | 0.382 | 0.382 | 0.668 | 0.35 | 0.65 |
| 2000 | 0.98 | 0.382 | 0.382 | 0.598 | 0.38 | 0.62 |
| 2001 | 1.55 | 0.382 | 0.382 | 1.168 | 0.21 | 0.79 |
| 2002 | 0.95 | 0.382 | 0.382 | 0.568 | 0.39 | 0.61 |
| 2003 | 1.02 | 0.382 | 0.382 | 0.638 | 0.36 | 0.64 |
| 2004 | 1.01 | 0.382 | 0.382 | 0.628 | 0.37 | 0.63 |
| 2005 | 0.75 | 0.382 | 0.382 | 0.368 | 0.47 | 0.53 |
| 2006 | 0.93 | 0.382 | 0.382 | 0.548 | 0.39 | 0.61 |
| 2007 | 0.84 | 0.382 | 0.382 | 0.458 | 0.43 | 0.57 |
| 2008 | 0.89 | 0.382 | 0.382 | 0.508 | 0.41 | 0.59 |
| 2009 | 0.86 | 0.382 | 0.382 | 0.478 | 0.42 | 0.58 |

Table 14: Catch Curve, Heinecke, and Chapman-Robson total mortality (Z) estimates with standard error for the two recruitment age groups observed. * Greatest recruitment

| Source | Parameter | Catch Curve | | Heinecke | | Chapman-Robson | |
|----------------|-----------|-------------|-------|----------|-------|----------------|-------|
| | | Estimate | SE | Estimate | SE | Estimate | SE |
| Combined | | | | | | | |
| Age 3* | Z | 1.08 | 0.100 | 0.27 | 0.001 | 0.54 | 0.003 |
| Combined Age 4 | Z | 1.31 | 0.068 | 0.88 | 0.007 | 0.98 | 0.008 |

Natural Mortality

Values for natural mortality ranged from 0.211 in the Ralston (1987) method to 4.148 in the Beverton (1992) method (Table 15). Lorenzen's age specific model proposed an M ranging from 1.51 at age 0 to a low of 0.43 at age 11 (Table 16). However, once scaled to Hoenig's (1983) estimate, as done in SEDAR 24 (Joseph C. Ballenger, SC-DNR, pers. comm.), assuming 1.4% of recruits reach the maximum age (11 years), M at age estimates vary from 0.94 at age 0 to 0.19 at age 11 (Table 16, Figure 8). Upon further examination of the potential for period, depth, or regional differences in M values as estimated by the scaled Lorenzen model, there does not appear to be any biologically meaningful differences. Thus, we used the scaled Lorenzen model assuming 1.4% of recruits reach maximum age and all data pooled as our preferred model of age-specific natural mortality and Hoenig's estimate (M = 0.382) as our preferred estimate of ages pooled M.

Table 15: Natural mortality estimates for various models using parameters determined in von Bertalanffy growth and Gompertz age at 50% maturation (AM) models.

| Source | Parameters | | | | Natural Mortality | | | | |
|-------------------------|--------------------------|----------------------|---------------------------|------------------|----------------------|-------------|------------|--------------|------------------------|
| | Lin _f _m m | Lin _f _cm | k | AM - Gompertz | Alverson & Carney | Hoe- nig | Pa- uly | Rals- ton | Beverton - Gompertz |
| VB All Data Combined | 656.27 (16.61) | 65.627 (1.661) | 0.09 33 (0.0 05) | 0.70 | 0.587 | 0.38 2 | 0.2 41 | 0.21 1 | 4.147 |

Table 16: Lorenzens age specific natural mortality (M) scaled to 1, 1.4 and 5 % of total *C. striata* reaching the maximum age of 11.

| Age | M | Scaled to 1% | Scaled M to 1.4% | Scaled to 5% |
|-----|------|--------------|------------------|--------------|
| 0 | 1.51 | 1.01 | 0.94 | 0.66 |
| 1 | 1.08 | 0.73 | 0.68 | 0.47 |
| 2 | 0.87 | 0.59 | 0.54 | 0.38 |
| 3 | 0.74 | 0.50 | 0.46 | 0.33 |
| 4 | 0.66 | 0.44 | 0.41 | 0.29 |
| 5 | 0.60 | 0.40 | 0.37 | 0.26 |
| 6 | 0.55 | 0.37 | 0.34 | 0.24 |
| 7 | 0.52 | 0.35 | 0.32 | 0.23 |
| 8 | 0.49 | 0.33 | 0.30 | 0.21 |
| 9 | 0.46 | 0.31 | 0.29 | 0.20 |
| 10 | 0.45 | 0.30 | 0.28 | 0.19 |
| 11 | 0.43 | 0.29 | 0.27 | 0.19 |

Fishing Mortality

We estimated fishing mortality (F; $F = Z - M$) on an annual and combined basis from 1978-2009, using Hoenig's M and observed Z values. Combined F estimates for age 4+ in the catch curve analysis suggest a fishing mortality rate of 0.9280 (± 0.0680 SE). The estimates from the Heincke and Chapman-Robson method are once again lower.

Reproduction

Based on a sample size of 34,503 (13,072 male, 21,431 female), combining all age groups, we determined a female:male sex ratio of 1.64 ($P < 0.001$ $\chi^2 = 2025.1248$). Sex distribution by age, indicates that at younger ages (1-3 years old) *C. striata* are mainly female. While at ages 4-11 the male gender dominates (Table 17). Transitionals appear as early as age 1 with the greatest percent occurring at 4 years of age (Figure 9).

When compared on an annual basis, starting at 1978 and continuing to 2009, we noticed that generally the population remained dominated by females with the greatest female to male ratio occurring in 1991. In 1985-1987, however, the opposite was true, with a more prevalent male gender (Figure 10). This was not the case for subsequent period specific analysis. When categorized into 1978-1989, 1990-1999, and 2000-2009 period bins an average female to male ratio of 1.64 ± 0.006 SE was observed. Further data subsets into latitude and depth specific categories resulted in similar differences in which the female gender was dominant at age, though males were slightly more prevalent in offshore samples (Table 18).

We determined the age at 50% maturity for females to be 0.83 (± 0.0709 SE) years for females and age at 50% transition to males to be 3.54 (± 0.2012 SE) (Table 19). Length (mm) at 50% maturation was 124.08 (± 3.4836 SE) mm for females and length at 50% transition to males was 289.32 (± 4.8251 SE) mm (Table 19). Periodic age at 50% maturity remains fairly constant for females while length at 50% gradually increases as we progress to the present. The age at 50% transition, by period, does not reflect this with a spike of 3.92 ± 0.068 in 1984-1989 and a length at 50% decrease then increase as time progresses.

Table 17: Female to male sex ratio for *C. striata* from 1978-2009 captured off the South Atlantic Bight.

| Age | Ratio: Female:Male | # Male | # Female | Proportion | Chi-square | P-value |
|-----|--------------------|--------|----------|-------------|------------|---------|
| 0 | 24.5 | 2 | 49 | 0.960784314 | 43.3137 | <0.0001 |
| 1 | 9.347368421 | 190 | 1776 | 0.90335707 | 1279.4486 | <0.0001 |
| 2 | 5.783919598 | 1194 | 6906 | 0.852592593 | 4028.0178 | <0.0001 |
| 3 | 2.468025078 | 3190 | 7873 | 0.711651451 | 1982.3275 | <0.0001 |
| 4 | 0.829536528 | 3819 | 3168 | 0.453413482 | 60.6556 | <0.0001 |
| 5 | 0.289443814 | 2643 | 765 | 0.224471831 | 1034.8838 | <0.0001 |
| 6 | 0.156580211 | 1041 | 163 | 0.13538206 | 640.2691 | <0.0001 |
| 7 | 0.083932854 | 417 | 35 | 0.077433628 | 322.8407 | <0.0001 |
| 8 | 0.123809524 | 105 | 13 | 0.110169492 | 71.7288 | <0.0001 |
| 9 | 0.043478261 | 23 | 1 | 0.041666667 | 20.1667 | <0.0001 |
| 10 | 0 | 4 | 0 | 0 | | |
| 11 | 0 | 1 | 0 | 0 | | |

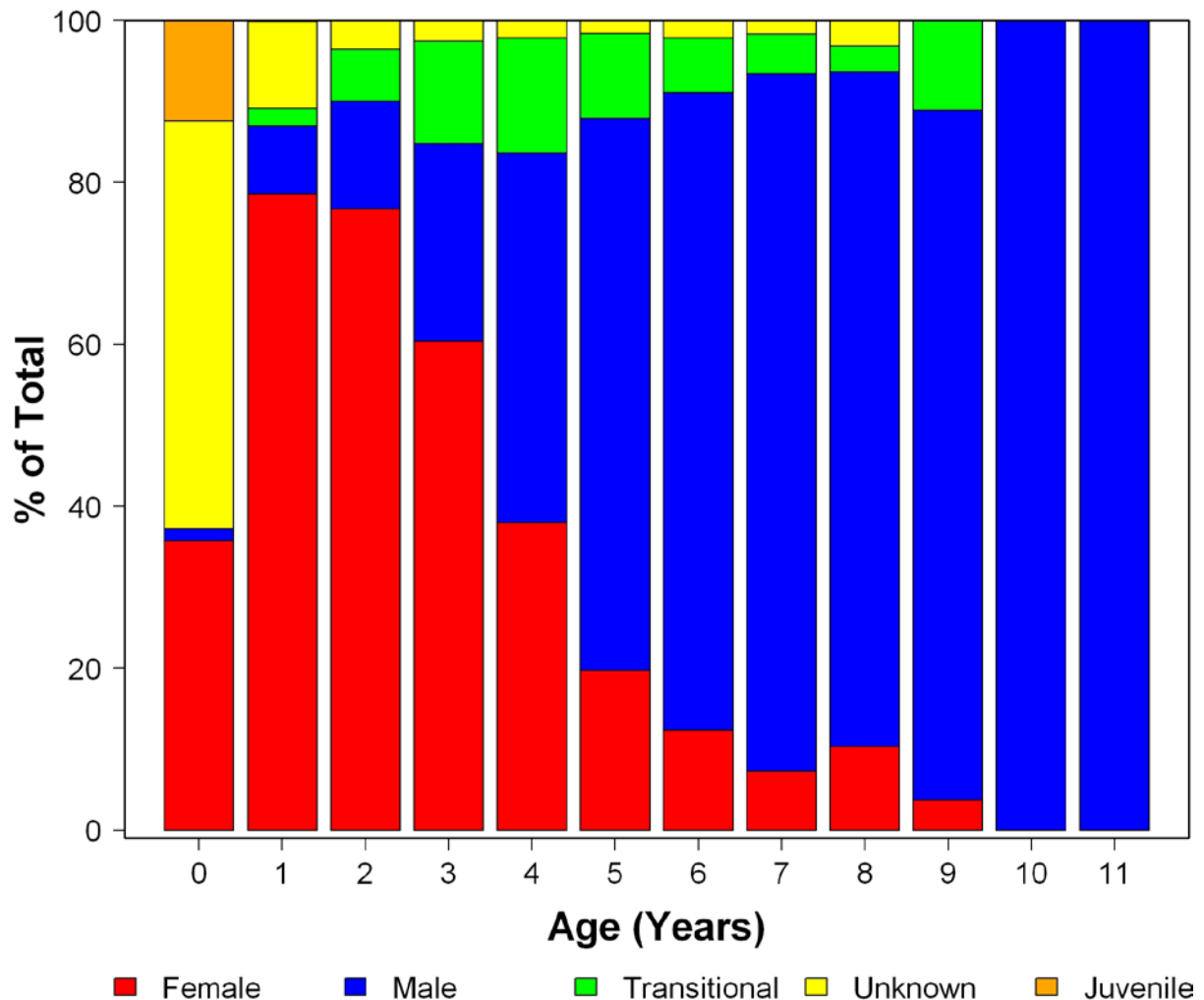


Figure 9: Percent total composition of *C. striata* by sex from 1978-2009.

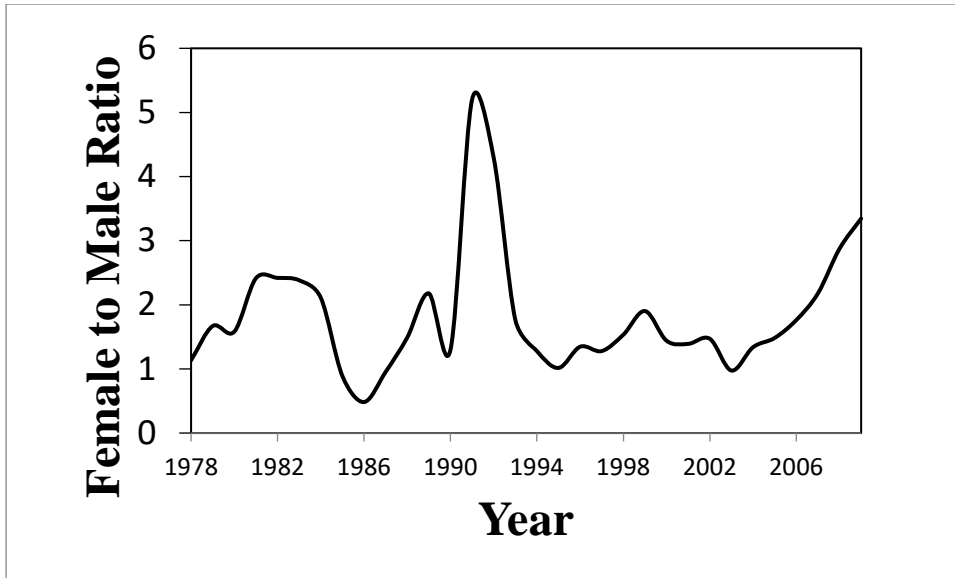


Figure 10: Female to male ratio for *C. striata* captured in the South Atlantic Bight from 1978-2009.

Table 18: Female to male ratio for Latitude and depth specific bins.

| Latitude | Ratio: Female:Male | # Male | # Female | Proportion | Chi- square | P-value |
|----------|-----------------------|-----------|-------------|-------------|----------------|---------|
| South | 1.746478873 | 2698 | 4712 | 0.635897436 | 547.3949 | <0.0001 |
| North | 1.65735 | 9701 | 16078 | 0.623685946 | 1577.4906 | <0.0001 |
| Inshore | 1.60024 | 10819 | 17313 | 0.615420162 | 1499.0771 | <0.0001 |
| Offshore | 1.35097 | 5328 | 7198 | 0.574644739 | 279.1713 | <0.0001 |

Table 19: Age and length at 50% maturity for female and transitional *C. striata* for various year bins. Female maturity data in bold

| Years | Type | Maturity | |
|-----------|---------------|-------------|---------------|
| | | Age at 50% | Length at 50% |
| Combined | Female | 0.83 | 124.08 |
| | Transitional | 3.54 | 289.32 |
| 1978-1983 | Female | 0.88 | 138.64 |
| | Transitional | 3.49 | 299.98 |
| 1984-1989 | Female | 0.77 | 124.95 |
| | Transitional | 3.92 | 282.62 |
| 1990-2009 | Female | 0.82 | 149.48 |
| | Transitional | 3.49 | 284.65 |
| 1990-1999 | Female | 0.81 | 144.63 |
| | Transitional | 3.50 | 280.26 |
| 2000-2009 | Female | 0.83 | 163.79 |
| | Transitional | 3.44 | 287.50 |

Spawning Season

We determined the spawning season from histological and reproductive data on 19,112 females. We observed 3554 developing, 2322 spawning, 2874 regressing and 10,362 regenerating black sea bass (Figure 11). A peak number of spawning individuals were observed in the month of March with most of the following months subject to regeneration (Figure 12). Thus, we believe black sea bass spawn from April through March with the most spawning occurring in the month of March.

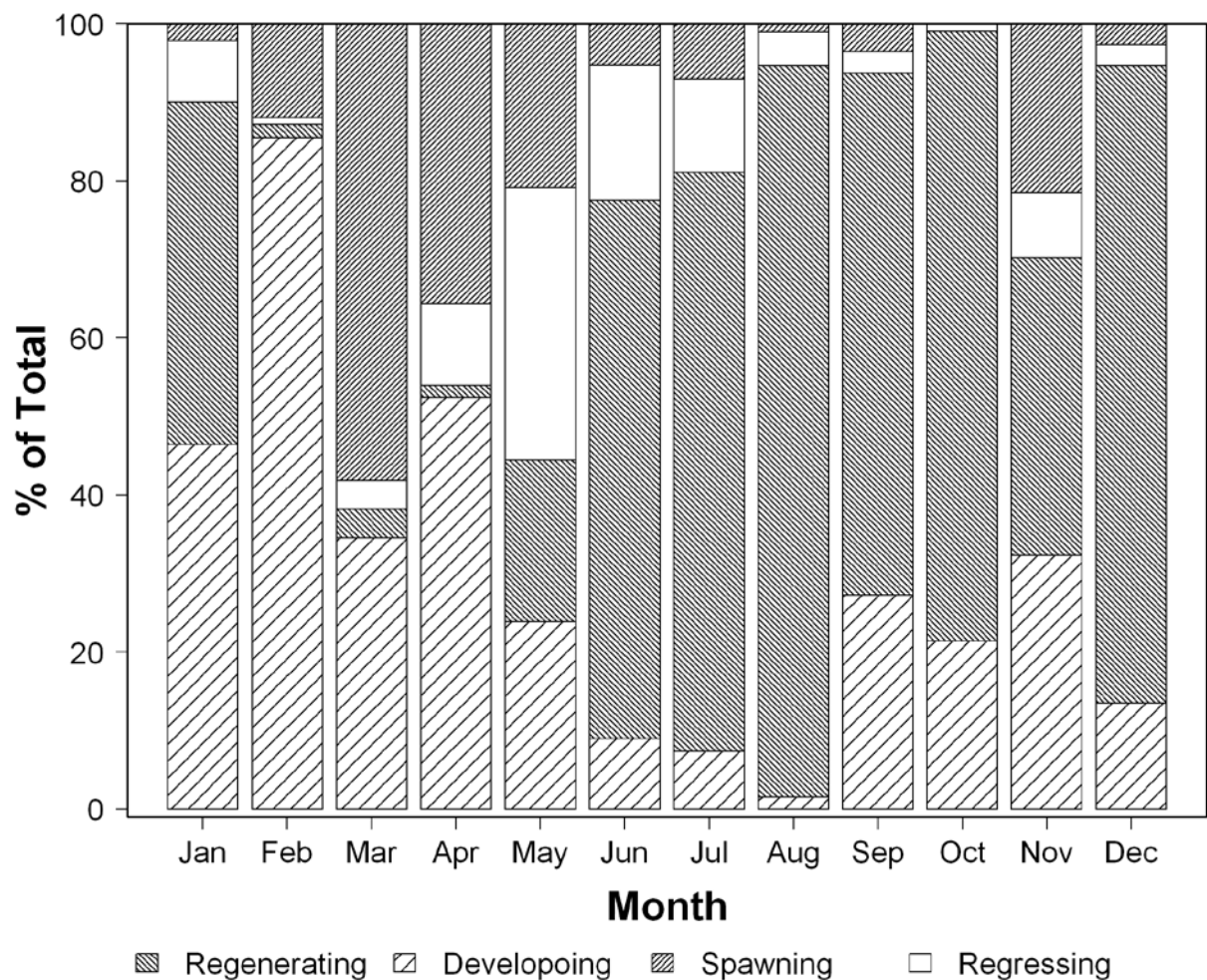


Figure 11: Gonadal stages by month of 19,112 *C. striata* from 1978-2009 captured in the South Atlantic Blight.

Chevron vs Blackfish Traps: Black Sea Bass

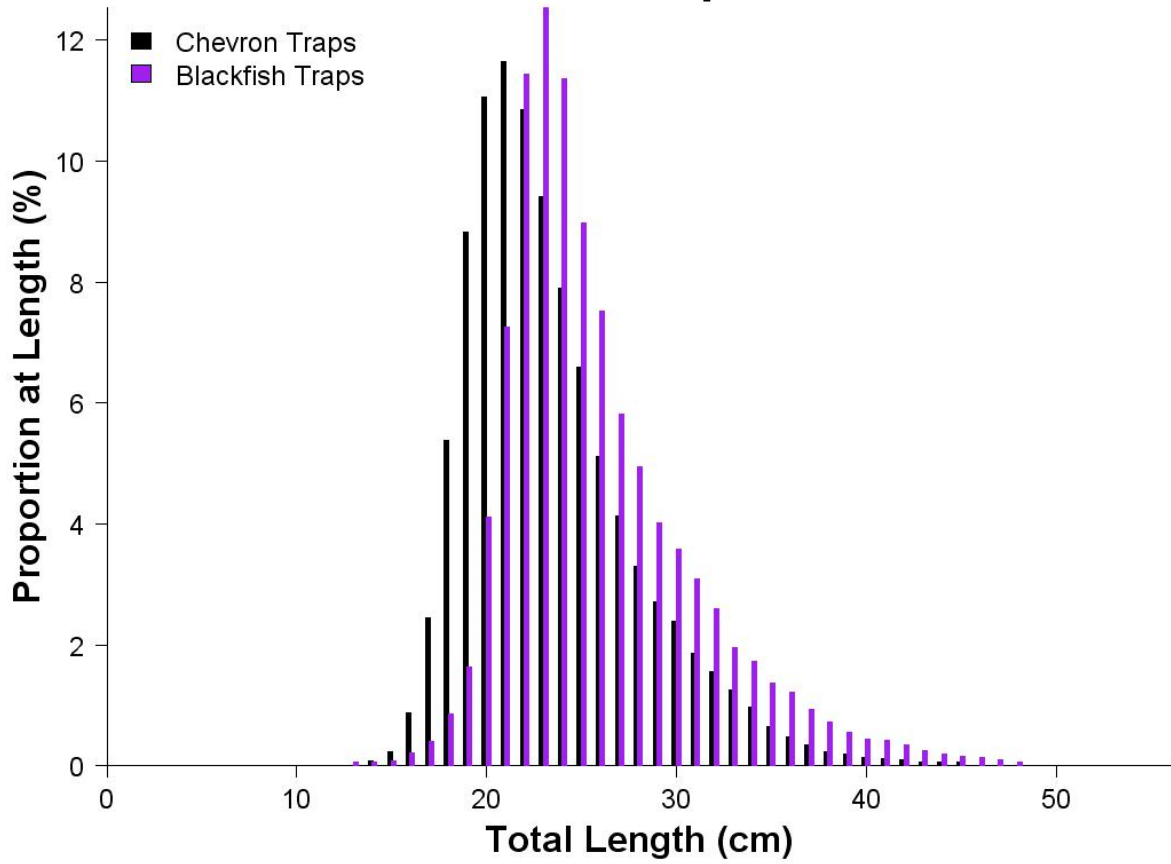


Figure 12: Comparisons between Proportion at Length for Chevron and Blackfish Traps capturing *C. striata*

Discussion

Age Determination and Marginal Increment Analysis

Black sea bass otoliths were easy to age. We believe the 426 “A” (bad) quality otoliths originated from black sea bass collected in southern waters where seasonal variations may not be as great as those experienced further north. Seasonal growth rates may not be as drastic in southern areas thus mineral rich and mineral deficient layers could be less drastic/noticeable as observed in Figure 13.

When reading sectioned black sea bass otoliths, the interpreter found it easiest to read under transmitted light. Transmitted light allowed for an improved ability to interpret the core. Reflected light usually decreased accuracy in the ability to interpret the core. However, the reader believes it bettered his ability to discern between mineral rich and deficient layers. He noted that under reflected light annuli with alternating patterns of white and dark blue, were easiest to tell apart. While under transmitted light with, light brown and dark brown alternating patterns became difficult to distinguish especially with C or B quality otoliths (Figure 14). A test of count accuracy between the varying light sources may provide some more insight to the effects of this preference.

In our process of reading we located counts, edge type and quality in the MARMAP database that differed from our readings. Normally this did not occur very often and was expected due to the qualitative nature of this increment validation technique. In certain cases, mainly otoliths read from 1978-1999, edge type and quality data were unavailable (n=16,137). This is of some concern due to possible bias between current agreed upon protocol readings of black sea bass and these pre-protocol readings leading to incorrect ages. Re-aging these otoliths is highly recommended. Nevertheless, some otoliths while they were present in the database were not available for aging. Most likely these had been discarded in earlier MARMAP years.

Year 0, 1 and 2, black sea bass otoliths had decreasing growth rates between annuli. Therefore, marginal increment analysis was unable to estimate the correct index of completion. It may have assessed an index of completion of 20% when the percent completion may have been about 80-90%. A study to correct this error would be imperative to including year 1, 2, and 3 black sea bass specimens.

Although year 1, 2, and 3 *Black sea bass* were excluded from our MIA, marginal increment analysis confirms that increments are laid down annually in the months of April/June. This differed from the proposed months of April and May by Wenner et al (1986). We believe that this difference is due to improved methods of otolith reading and measuring developed in recent years.



Figure 13: "B" quality *C. striata* otolith captured below 32° latitude.

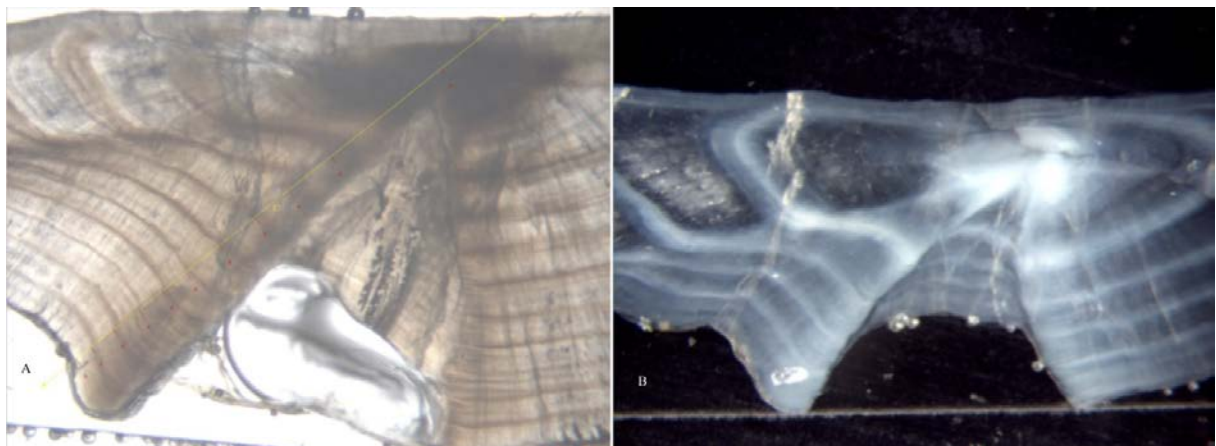


Figure 14: Sectioned *C. striata* otoliths viewed under transmitted (A) and reflected light (B).

Growth

Weight-Length

Our weight to length regressions indicate that black sea bass do not grow isometrically but grow allometrically. This may be due to improper weighing; however, we believe this to be insignificant and believe that *Black sea bass* does grow allometrically.

Statistical tests suggested we model weight-length regressions assuming differences between region, depths and period. After examining the graphs, we believe this to be related to varying sample size for we observed only minor differences. These differences are too minute to be of great importance; thus, the combined model was determined to be the most appropriate.

While we see no variation between region, depth and period, weight-length regressions seem to vary by sex. What we have found is that the female gender tends to be heavier by length as it grows past the 200 mm mark. We believe that this is caused by an unbalanced gonadal weight, since females usually have heavier reproductive organs than males (Joseph C. Ballenger, SC-DNR, pers. comm.). A study, which would compare gonad weight between sexes, may help support this for black sea bass. Another study in which female reproductive organs weights are compared by month may also be of interest.

Length-at-Age

Differences between depth, region and time period were noted as well as differences between previous von Bertalanffy growth curves proposed by Hood et al. (1994), Wenner et al. (1986) and a 2005 SEDAR stock update implementing McGovern's (et al., 2002) VB growth curve. Depth differences indicated that depths greater than 30 meters were habitats to larger black sea bass at age compared to depths less than 30m. Growth rate variations in depth were expected for black sea bass since the species is known to migrate to deeper waters as they mature (Robert A. Low, 1982). The species, however, is also known to migrate to deeper waters to spawn. A study addressing the number of individuals between 10-45 m in depth by location and month would be imperative to understanding more about the species seasonal migrations.

Growth rates by region indicated a similar trend; the north region was obtaining larger lengths at age than the southern region (in the early period this was not the case and as to why this occurred is unknown). Selectivity may be more prevalent in the southern regions, which are not subject to great temperature and food availability alterations in the winter months. These southern regions also have natural selection (predation) selecting against slow and noticeable fish (i.e. Large fish) increasing selection against larger sizes at age (Allendorf et al., 2008; Jørgensen et al., 2007; Conover et al., 2009). This may provide some reasoning as to why our southern regions attained smaller maximum lengths (Figure 15).

In respect to time period, we noticed a decline in the length-at-age as time progressed. The early period (1978-1989) was attaining larger lengths-at-age than the mid period (1990-2000) while the mid period seemed to attain larger lengths-at-age than the late period (2000-2009). This may suggest an evolutionary genetic change or phenotypic selectivity induced by heavy fishing pressures selecting faster growing fish. Because of fishery management minimum size limits for the South Atlantic, fish less than 304 mm (12 inches) TL are selected for by the fishery and those above are selected against. This is indicative to our length vs. period trend lines gradually decreasing in length-at-age (Figure x). Black sea bass who are under the size limit have greater chance of reproducing and thus are fitter than those above it, as will be their offspring. Numerous studies indicate that overfishing a population can cause an evolutionary change in the species DNA that may or may not be reversible (Allendorf et al., 2008; Jørgensen et al., 2007; Conover et al., 2009). David Conover et al. (2009) noted that genetic changes were reversible in his 10 year *Menidia menidia* experiment. His study was conducted on a short-lived species (1 year life span) and recovery was predicted to be attainable in 12 generations (Conover et al., 2009). Due to the longevity of our species (up to 15 years) a recovery may take up to 180 years.

Growth curves proposed by the previous authors differ in length at age from greatest to least as follows, SEDAR (2005), our study (1978-2009), Wenner et al study (1986), and Hood study (1994). Our VB growth curve seemed to differ significantly from other growth curves on a visual basis. This was expected for previous or earlier growth curves as proposed by Hood et al and Wenner et al, which were conducted in the 1980's and 1990's. It was less expected for the more recent 2005 SEDAR growth curve and seemed

to differ by having a smaller length-at-age ratio. This may indicate continued or increased selective pressures on black sea bass from 2002-2009. A more in-depth comparison of methodology may also provide insight to the differences observed.

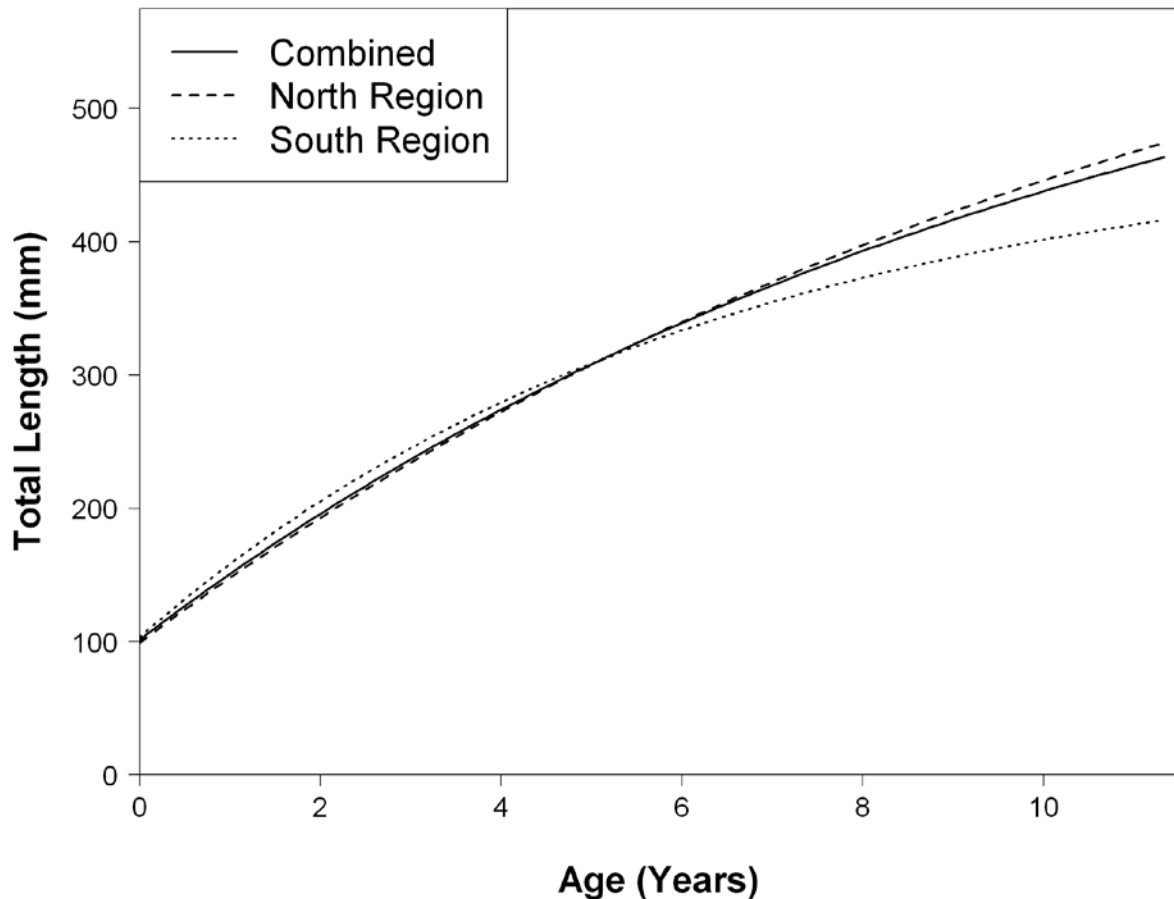


Figure 15. Total length of black sea bass by age and region caught.

Mortality

Fishing mortality was greater than natural mortality, indicating that fishing is the main source of mortality. Once again, this artificial selection could be a detriment to the quality or economic benefit of capturing black sea bass (Allendorf et al., 2008; Jørgensen et al., 2007; Conover et al., 2009). We also noticed a trend in fishing pressures as time continued. High fishing mortality (F) was observed in 1978-1980 and in 1997-2001 with low mortalities to either side. In recent years the fishing pressures have decreased indicating that restrictions implemented by fisheries management may be slowly rebuilding the South Atlantic Bight populations of black sea bass.

However, due to us fitting the data to a 3-year smoothed curve the change may be more drastic. When observed unsmoothed, we notice spikes in data up to a maximum of

about 1.5 total mortality. This is greater than any of the previous mortality studies conducted on black sea bass (Low, 1981; Sheperd et al., 1993; Wenner et al., 1986). In Wenner et al. 1986 paper, he noted a maximum total mortality (Z) of 1.430 for 1981. His study was based on recruitment to gear at age 4, which compares even worse to our age four estimate for 1981 (.30 vs. 1.19). The difference we observed may be due to sample size and gear dissimilarities. For 1981 MARMAP examined a total of 2242 aged fish while it is unknown exactly how many Wenner and his colleagues examined.

Reproduction

We found our sex ratio to be similar to that of other author's (Hood et al., 1994; Wenner et al., 1994) and also between depths, region and period. Both authors found female to be the overall dominant gender. When compared by age, however, males were found dominant at age 4 in Wenner's publication whereas this was not true for Hood's study. Hood et al (1994) found the ratio to be 1:1 for age 4. We believe this to be due to a smaller sample size of Black sea bass (n=802 in all). For our results, when compared by age, found the ratio to differ in favor of the male gender at age 4 and then on (n=6987 age 4).

In regard to sex ratio by depth, region and period no drastic ratio change was noted. However, our ratio did decrease by 0.25 when comparing depths. It seems that males are in greater numbers to females in deeper water than shallower waters. This is logical since larger Black sea bass are found in deeper waters (Robert A. Low, 1982).

The average black sea bass sex ratio was 1.84 (± 0.17 SE) for all years. However, there were some noteworthy differences in certain years. From 1985 to 1987 and in 2003 our sex ratio indicated a greater number of males than females. In all other years, females dominated the population. This could be a result of sample size and gear selectivity in the period, but the data does not fully support this. A study conducted on induced sex change in *Black sea bass* suggested that sex change might be reversed by the presence of males in a population (Benton and Berlinsky, 2006). If this were to be true, then an increase in size and length at transition would be expected for *Black sea bass* in the 1985-1987 period. The data does not seem to support this, but analysis of transition by year class may provide more information.

As for now there are no obvious explanations for this finding, but further analysis may provide clues as to possible explanations.

Our spawning estimates hold true to spawning estimates proposed by other studies on black sea bass generally ranging from December through June (Able et al., 1995; Bigelow and Schroeder, 1953; Hildebrand and Schroeder, 1928; Hood et al., 1994; SEDAR 2005; Wilson, 1891). Our results, however, indicate marginal spawning throughout the year with no spawning occurring in the month of October. This marginal spawning is believed to be within error and may be due to low sample size and possible change in spawning season throughout the sampling period of MARMAP. Further studies may help clarify our results.

Works Cited

- Able, K.W., M.P. Fahay and G.R. Shepherd. 1995. Early-life history of black sea bass, *Centropristis striata*, in the mid-Atlantic bight and a New Jersey estuary. *Fishery Bulletin* 93(3): 429-445.
- Allendorf, F. W., England, P. R., Luikart, G., Ritchie, P. A. & Ryman, N. 2008 Genetic effects of harvest on wild animal populations. *Trends Ecol. Evol.* 23, 327–337.
- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. *In: P. B.N., and C. F., (Eds). International Symposium on Information Theory, 2nd edition, pp. 267-281.*
- Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. *J.Cons. Int. Explor. Mer* 36:133–143.
- Ballenger, J. (2010, July 1). Black sea bass Aging Method. (S. Bitterwolf, Interviewer)
- Beverton, R. J. H. 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. *Journal Fish Biology* 41(Supplement B): 137–160.
- Bowker, A. H. 1948. A test of symmetry in contingency Tables. *Journal of the American Statistical Association* 43:572-574.
- Campana, S. E., M. C. Annand, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. *Transactions of the American Fisheries Society* 124(1):131-138.
- Campana, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* 59(2):197-242.
- Casselman, J. M. 1987. Determination of age and growth. Pages 209-242 *in* A. H. Weatherley, and H. S. Gill, editors. *The Biology of Fish Growth*. Academic Press, London, UK.
- Chapman and Robson, 1960. D.G. Chapman and D.S. Robson, The analysis of a catch curve. *Biometrics* 16 (1960), pp. 354–368.
- Collins, M.R., S.B. van Sant, and G.R. Sedberry 1996. Age validation, movements and growth rates of tagged gag (*Micropogonias undulatus*), black sea bass (*Centropristis striata*) and red porgy (*Pagrus pagrus*). Pages 158-162 *in* F. Arrequin-Sanches, J.L. Munro, M.C. Balgos, and D. Pauly, editors. *Biology, fisheries and culture*

- of tropical groupers and snappers. ICLARM Conference Proceedings 48, 449 p., Makati, Philippines.
- Conover, D. O., Munch, S. B. & Arnott, S. A. 2009 Reversal of evolutionary downsizing caused by selective harvest of large fish. *Proc. R. Soc. B* 276, 2015–2020
- DeVries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 in B. R. Murphy, and D. W. Willis, editors. *Fisheries Techniques*, 2nd edition. American Fisheries Society, Bethesda Maryland.
- Hood P.B., M.F. Godcharles and R.S. Barco. 1994. Age, growth, reproduction, and the feeding ecology of black sea bass, *Centropristis striata* (Pisces, Serranidae), in the eastern Gulf of Mexico. *Bulletin of Marine Science* 54(1): 24-37.
- Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin* 82: 898-903.
- Hoenig, J. M., M. J. Morgan, and C. A. Brown. 1995. Analyzing differences between 2 age determination methods by tests of symmetry. *Canadian Journal of Fisheries and Aquatic Sciences* 52(2):364-368.
- Hyndes, G. A., N. R. Loneragan, and I. C. Potter. 1992. Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead *Platycephalus speculator*. *Fishery Bulletin* 90(2):276-284.
- Jørgensen, C. et al. 2007 Ecology: managing evolving fish stocks. *Science* 318, 1247–1248.
- Kimura, D. K. 1980. Likelihood methods for the Von Bertalanffy growth curve. *Fishery Bulletin* 77(4):765-776.
- Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. *Journal of Fish Biology* 49: 627–647.
- Govern, J. C., M. R. Collins, O. Pashuk, and H. S. Meister. 2002. Temporal and spatial differences in life history parameters of black sea bass in the southeastern United States. *North American Journal of Fisheries Management* 22(4):1151-1163.
- Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. Int. Explor. Mer* 39: 175-192.
- Panfili, J., de Pontual, H., Troadec, H., & Wright, P. J. (Eds.). (2002). *Manual of Fish*

- Sclerochronology*. IRD Éditions.
- Quinn, T. J., and R. B. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford University Press, New York, NY.
- Ralston, S. 1987. Mortality rates of snappers and groupers. *In* J. J. Polovina, S. Ralston (eds.), *Tropical Snappers and Groupers: Biology and Fisheries Management*. Westview Press: Boulder, CO. pp. 375-404.
- Ricker, W.B. 1958. Handbacks of Computations for biological statistics of fish populations. *Fisheries Research Board of Canada Bulletin* 119, Ottawa. 300pp.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Fisheries Research Board of Canada Bulletin* 191:382.
- Robert A. Low, J. (1982, July). The South Carolina Fishery For Black sea bass. *South Carolina Marine Resources Center Technical Report Number 53* , pp. 1-16.
- Schwarz, G. 1978. Estimating dimension of a model. *Annals of Statistics* 6(2):461-464.
- Slipke, J. W., and M. J. Maceina. 2002. FAST v2.1. Department of Fisheries and Allied Aquaculture, Auburn, AL.
- von Bertalanffy, L. 1938. A quantitative theory of organic growth. *Human Biology* 10:181-213.
- SEDAR. (2003). *Report of black sea bass stock assessment workshop*. Beaufort: SEDAR.
- SEDAR. (2005). *Report of black sea bass stock assessment update*. Beaufort: SEDAR.
- Von Bertalanffy, L. 1938. A quantitative theory of organic growth. *Human Biology* 10:181-213.
- Wallace, R. K., & Fletcher, K. M. (1996). *Fisheries Management: A manual for understanding the Federal Fisheries Management Process, Including Analysis of the 1996 Sustainable Fisheries Act*. Auburn & Mississippi: Auburn University & University of Mississippi.
- Wenner C.A., W.A. Roumillat and C.W. Waltz. 1986. Contributions to the life history of black sea bass, *Centropristis striata*, off the southeastern United States. *Fishery Bulletin* 84: 723-741.
- Wyanski, D. M., D. B. White, and C. A. Barans. 2000. Growth, population age structure, and aspects of the reproductive biology of snowy grouper, *Epinephelus niveatus*, off North Carolina and South Carolina. *Fishery Bulletin* 98(1):199-218.

