Age, Growth and Sex Maturity of Greater Amberjack (*Seriola dumerili*) in the Gulf of Mexico

Debra J. Murie and Daryl C. Parkyn

SEDAR33-RD13

3 April 2013

Please cite as:

Murie, D.J. and D.C. Parkyn. 2008. Age, Growth and Sex Maturity of Greater Amberjack (*Seriola dumerili*) in the Gulf of Mexico. SEDAR33-RD13. SEDAR, North Charleston, SC. 41 pp.

Technical Report for

Age, Growth and Sex Maturity of Greater Amberjack (*Seriola dumerili*) in the Gulf of Mexico

Debra J. Murie and Daryl C. Parkyn
Program of Fisheries and Aquatic Sciences
School of Forest Resources and Conservation
University of Florida, 7922 NW 71st Street
Gainesville, FL 32653

MARFIN Final Report
(NA05NMF4331071)

27 September 2008

Introduction

Greater amberjack (*Seriola dumerili*) is widely distributed throughout warm temperate and tropical waters and has long been acknowledged as an important recreational and commercial fishery in the Gulf of Mexico (Browder et al. 1978; Burch 1979; Parrack 1993a,b; Manooch and Potts 1997; Thompson et al. 1999). Recreational catch for amberjack in the Gulf of Mexico has historically exceeded commercial and headboat landings on a Gulf-wide basis, despite some degree of imprecision in records of catch (Berry and Burch 1977; Manooch and Potts 1997; Cummings and McClellan 2000). Recreational catch peaked in 1986 at 3,420 MT, but also rapidly declined, with landings dropping to 458 MT in 2000. A small peak in recreational landings occurred in 2003 at 1,096 MT but have since declined to 449 MT in 2007 (NOAA Fisheries personal communication). Landings from the west coast of Florida have dominated commercial, recreational and headboat catches in the Gulf, despite some mistrust of this fish as a foodfish in Florida due to incidents of ciguatera poisoning, most recently in the early 1990s, and Gulf-wide because of the incidence of parasitic worms (Baldy 1992; CDC 1993; Manooch and Potts 1997). Since 1990, regulations have been instituted for Gulf of Mexico greater amberjack, starting with Florida designating it as a “restricted” species with daily bag and possession limits. Increasing regulations culminated by 1998 in a reduction in the daily bag limit, an imposition of a minimum size limit, and a prohibition of selling amberjacks (greater, lesser, almaco, or banded rudderfish) during March to May. In 2006, Gulf of Mexico greater amberjack were declared “overfished” in the stock assessment review (SEDAR 9 Assessment Report 2, 2006).

In the previous two stock assessments, however, there has been concern raised by the lack of adequate age, growth and reproductive data for greater amberjack in the Gulf of Mexico necessary for reliable stock assessments (Turner et al. 2000; SEDAR9 2006). In particular, this paucity of basic biological information on greater amberjack increases the uncertainty and risks associated with the total allowable catch estimated from an age-structured stock assessment. For example, in the most recent stock assessment for Gulf of Mexico greater amberjack, catch at length is converted to catch at age through the use of the growth curve derived by Thompson et al. (1999, which is inclusive of Beasley's 1993 data). Although this growth curve represents greater amberjack caught in various fisheries and gears, only fish from Louisiana were sampled (Thompson et al. 1999). This growth model was preferred by the NMFS stock assessment scientists compared to an alternate growth model by Manooch and Potts (1997), however, because although the latter study was Gulf-wide, it only sampled fish from headboats (Cummings and McClellan 2000). Choice of a growth model for greater amberjack is critical because they exhibit a large variation in size at age. This is of particular concern when the growth model being used may not be representative of growth of greater amberjack throughout its range in the fisheries (i.e., is the Louisiana growth curve representative of growth of amberjack off of the west coast of Florida?). It is unlikely that either of these growth models is adequate to capture the variability in the growth of greater amberjack from various regions or from various fisheries and gears.

The difficulty in extracting the very small otoliths of greater amberjack have lead to attempts to age greater amberjack with aging structures other than otoliths, e.g., dorsal and anal spines and vertebrae, although not successfully so (Thompson et al. 1999). Burch (1979) used scales to age greater amberjack in South Florida, although Manooch and Potts (1997) considered scales to be unreliable for aging amberjack. Alternatively, we proposed to age greater amberjack using fin rays. Finrays have been used to age a diverse group of fishes, primarily (although not exclusively) from cold temperate regions where the annuli in the aging structures (whether otoliths, scales, or fin-rays) are relatively wide and distinct (Chilton and Beamish 1982). In contrast to scales, the fin-ray method of aging has been used for relatively old fish, for example, lingcod (*Ophiodon elongatus*), a hexagrammid that is routinely aged using dorsal finrays reliably up to 21 years of age (Chilton and Beamish 1982). Recently, warm temperate reef fishes in Florida have been aged using dorsal finrays, including the white grunt (*Haemulon plumieri*) (Murie and Parkyn 1999), gag (*Mycteroperca microlepis*) (Debicella 2005), and goliath grouper (*Epinephelus itajara*) (Murie et al. *in press*). One potential disadvantage of using finrays rather than otoliths is the accumulation of annuli on the edge of the finray in relatively older fish (e.g., >10 or more years, depending on species), making it difficult to distinguish and count each individual annulus (Beamish 1981). The age at which this accumulation occurs is species-specific. From previous studies, most greater amberjack are expected to be <15 years and so this problem may not occur within the age range of the species.

In addition, estimates of age- and size- at sexual maturity are fundamental to predicting (through stock assessment models) the potential productivity of the stock. These data are currently limited or lacking for greater amberjack in the Gulf of Mexico. Beasley (1993) estimated that spawning for greater amberjack in the northern Gulf of Mexico (off Louisiana) peaked in April to June, based on an increasing gonadosomatic index until June. This is similar to Burch’s (1979) earlier study in South Florida, which also indicated that the maximum gonad development occurred in the spring months. However, age and size at sexual maturity for greater amberjack from either South Florida or Louisiana was less definitive. Cummings and

McClellan (2000) regarded maturation information provided by Burch (1979) may not be applicable to greater amberjack in the Gulf, and that maturation may have changed in the intervening decades (Burch sampled from 1977-78). They considered Thompson et al. (1992) and unpublished data they received from Thompson (pers. comm.) as the most current data available for greater amberjack in the Gulf of Mexico. Thompson also identified May and June as peak spawning months in the Gulf. Based on histological sections, he also estimated that greater amberjack were all mature by age 4, 50% were mature by age 3, and 0% were mature at age 2. Thompson's study is not a definitive study, however, since his sample was apparently hampered by a large number of ovaries that were infected with a pathogen. These reproductive parameters are essential to determining productivity of the stock (Cummings and McClellan 2000).

Our overall goal was to determine age and growth, and age and size of sexual maturity of greater amberjack (*S. dumerili*) in the Gulf of Mexico. The specific objectives necessary to accomplish this goal were to:

1. Establish aging criteria for greater amberjack in the Gulf of Mexico based on sectioned otoliths, which would include validating the method using marginal-increment analysis (i.e., amount of growth on the edge).
2. Investigate comparative aging criteria for greater amberjack using finrays (dorsal, pectoral, and pelvic rays) as an alternative aging method. Finrays may provide a more logistically feasible method of obtaining aging structures from amberjack. This comparative aging will specifically test the null hypothesis that ages of greater amberjack determined using these two aging methods (otoliths versus fin rays) do not differ significantly from one another.

3. Model age and growth of greater amberjack for major fisheries in the Gulf of Mexico, including charterboat, private recreational, headboat, and commercial.
4. Determine reproductive seasonality and age and size at sexual maturity of greater amberjack in the Gulf of Mexico.

Methods

Collection of Fish Samples

Sources of Samples

Greater amberjack samples were obtained from ongoing sampling programs conducted by the National Marine Fisheries Service (NMFS) (coordinated through Panama City laboratory), the Florida Marine Research Institute (FMRI) in St. Petersburg, FL, and the Gulf States Marine Fisheries Commission (GSMFC). Samples from the latter agency were sent directly by the individual states. These established sampling programs provided otolith samples based on sampling landed catches. Supplemental sampling targeting sublegal-size fish was conducted through scientific sampling by the University of Florida under a scientific permit. UF-Fisheries supplemental sampling specifically targeted collections for paired otoliths/fin ray samples over the age range of amberjack, as well as sampling for sexual maturity

All samples and associated data obtained through ongoing state or federal sampling programs was catalogued upon arrival at UF-Fisheries. Specific data included with these samples that are relevant to the present study, included: unique sample and fish identification, date, state, fishing mode, fishing gear, fish forklength (FL, in mm), fish whole weight (WT, in kg), and sex. Not all of these data were available for all fish collected. In addition, the Louisiana Department of Fish and Wildlife collaborated in collecting pectoral fins from larger greater amberjack, specifically fish over 1 m in FL. This agency also collaborated in sampling amberjack for gonads. Finray and gonad samples were frozen and shipped to UF-Fisheries for processing.

All greater amberjack collected through UF-Fisheries sampling were measured for total length and fork length (nearest mm) and weighed (nearest 1 g). Sagittal otoliths were removed and stored dry. The left pectoral fin was also removed and processed for finray aging (see below). Gonads were removed, weighed, and a subsample was preserved in 10% buffered formalin for later processing.

Establish Aging Criteria using Sectioned Otoliths

One otolith (sagitta) of each pair (usually the left) was embedded in 5-min epoxy resin (Devcon) in bullet molds, annealed to a fully-frosted slide with Crystalbond 509 thermoadhesive, and cross-sectioned through the core into 0.5 mm width sections using a Buehler® Isomet 1000 digital sectioning saw. Three sectioning blades fitted with 0.5 mm spacers were used simultaneously in sectioning to ensure consistent section widths. This resulted in two sections per otolith that were permanently mounted on slides using Crystalbond. Sections were then covered using Flotexx® to increase optical clarity. This process eliminated the need to sand and polish the otolith sections. Otolith sections were viewed using a stereomicroscope (20-100X) with transmitted light. Under transmitted light, amberjack annuli appear as opaque brown rings against an otherwise translucent background (Figure 1). For aging purposes, the opaque zones were enumerated along the primary dorsal sulcus (P1 axis), and a subset were enumerated along the dorsal axis (P2 axis), as well as along the secondary ventral sulcus axis (S1 axis) and the ventral axis (S2 axis) (Fig. 1). Aging along P2, S1 and S2 axes was necessary to evaluate the occurrence of additional annuli apparent on these axes that are not observed on the P1 axis. For the purposes of the present study, one complete annulus in an otolith was defined as the combination of one opaque growth zone and one translucent growth zone. To assign ages using otoliths, the number of opaque zones was enumerated and the amount of translucent growth on the edge of the otolith was reported as: 0, opaque zone at edge with no translucent margin; 1, translucent growth <1/3 of the previously completed increment; 2, translucent growth >1/3 and <2/3 of the previously complete increment; and 3, translucent growth >2/3 of the completed increment. Fish were then assigned an age class based on the number of opaque zones and the amount of translucent growth on the edge of their otolith with respect to their collection date and time of opaque zone deposition relative to January 1st. This ensured that fish collected at various times of the year would be assigned into an appropriate age class that kept cohorts together. All age estimates were also graded as to clarity and ease of reading as: A=clear annuli and edge; B=annuli and edge observable but one or more annuli not absolutely clear; C=one or more annuli not readily apparent except with manipulation of section positioning; D=one or more annuli not readily apparent due to faintness, irregular pattern, or occlusions in the otolith; and F=unreadable.

Identification and position of the core and first annulus in amberjack otoliths was evaluated by measuring radii to the core, first annulus and second annulus on the P1 axis using an image processing system (Motic®, version 1.3; Motic, Inc., Richmond B.C.). Radii for the core and first and second annuli were then plotted as a function of age class to determine if any overlap in size occurred between these features. Overlap in radii, especially with increasing fish age, would indicate that the first annulus was misidentified when ageing fish (Penha et al. 2004, Murie et al. *in press*).

All otoliths were aged by one of two primary readers that used a standardized aging protocol. Both readers reviewed an age-stratified subsample of otoliths prior to aging, and designated protocols to identify the first annulus, edge codes, and aging on axes other than P1. Between-reader precision was assessed using a random sample of otoliths. Aging precision (i.e., repeatability) was estimated by calculating: 1) the percent agreement between two independent readers; 2) the average percent error (APE) (Beamish and Fournier 1981); 3) the coefficient of variation (CV) (Kimura and Lyons 1991); and 4) the concordance correlation (r_c) (Lin 1989). The APE and CV methods are considered to be "age independent." In addition, Lin (1989) determined that the concordance correlation was superior to comparison of coefficients of variation, to paired t-tests, and to regression. It has therefore also been used as a more powerful and robust method of assessing reproducibility (precision) of aging (Murie and Parkyn 2005). The concordance correlation ranges from 0 (no reproducibility) to 1.0 (perfect reproducibility).

Validation of Age Determination

Timing and periodicity in the annulus formation in otoliths was examined by examining the relative amount of marginal increment (growth) on the edge of the otolith ranging from 0 (opaque zone at edge, no translucent growth) to 3 (a lot of translucent growth at the edge). A plot of the monthly mean edge codes over a 12-month period was used to examine the number and timing of minima present. Bimodality in the plot would indicate that greater amberjack lay down two annuli each year, whereas a unimodal plot would indicate that they deposit only one annulus per year. Minimal mean edge code indicates the period of deposition of the opaque zone in amberjack otoliths.

Establish Comparative Aging Criteria between Fin Rays and Otoliths

Finrays (positions 3-6) were removed from the mid-central region of the rayed portion of the dorsal, pectoral, and pelvic fins by cutting across the basal structures of the fins. The finrays were then cleaned of excess muscle and skin tissue using simmering water and forceps, and allowed to air-dry. Dried finrays are then epoxied in a two-part thermal epoxy resin (Hysol), thin-sectioned (~0.5-0.8 mm thick) using a variable high-speed sectioning saw, and mounted on glass slides using Flotexx®. Finray sections were examined using a stereomicroscope with transmitted light, with or without a green filter for contrast enhancement.

For finrays, the translucent zone of the annulus is usually counted for ageing because it is typically the narrowest and most distinct (Chilton & Beamish 1982). Debicella (2005), however, observed that in gag the translucent zone of finrays was deposited at the opposite time of the year as the opaque zone in their otoliths, and that the opaque zone in the finrays was deposited in synchrony with the opaque zone in their otoliths. For comparative ageing, translucent and opaque zones of the annuli were counted beginning from the central core of the finray outwards toward the edge following ageing criteria established for gag (Debicella 2005) and goliath grouper (Murie et al. *in press*). Fish were assigned an age class based on the combination of the number of opaque zones and the amount of translucent zone growth at the edge of the finray, similar to otoliths, in order to assign fish to comparable age classes.

Finray ages were compared to otolith ages from the same fish. Agreement in ages assigned using the two methods was used to indirectly estimate the accuracy of the finray ageing method;

whereby the otolith ageing method was assumed to be the most reliable method of ageing fish. Accuracy was estimated by comparing the ages from different structures for individual fish (agreement or disagreement) and then calculating the percent agreement among the sets of ages for all fish combined (Sikstrom 1983). These comparisons were visualized by plotting the finray age as a function of otolith age for each fish. A line denoting the ideal 1:1 relationship was used for reference (Beamish & Harvey 1969, Sikstrom 1983). As with otolith precision, aging accuracy of finrays was also assessed using CV, APE, and ρ_c.

Growth of Amberjack

The relationship between the FL and whole weight (WT) of amberjack was described by the relationship $\log_{10} WT = \log_{10} a + b\log_{10} FL$. Differences in the length-weight relationship between sexes was tested using analysis of covariance (Zar 1996; Murie and Parkyn 2002).

Age and growth of greater amberjack was modeled by fitting a von Bertalanffy growth curve to observed length at observed age data (Ricker 1975) using nonlinear regression with a Marquardt algorithm (PROC NLIN in SAS). The form of the von Bertalanffy growth curve for length-at-age is:

$$L_t = L_\infty \left[1 - e^{-k(t - t_0)}\right]$$

where L_t = predicted length at time t (age); L_∞ = asymptotic length; k = growth coefficient; and t_0 = theoretical age when length would be 0. Growth models were compared between sexes or among fisheries (charterboat, headboat, recreational private boats, commercial, and scientific) using likelihood ratio tests for coincident curves (Kimura 1980; Cerrato 1990; Haddon 2001). Growth curves were fit and compared only over a similar range of fish age (Haddon 2001).

Reproductive Seasonality and Age and Size at Sexual Maturity

Gonads were weighed whole to calculate the gonadosomatic index (GSI), which is the weight of the whole gonad calculated as a percentage of the whole weight of the fish. Gonads were only weighed whole if they were intact, since gonads of amberjack are asymmetrical. The GSI was then plotted for females as a function of month of the year. Peak GSIs indicate the timing of the peak spawning period and can be used to preliminarily identify spawning from non-spawning fish.

After weighing, gonads were visually inspected for gross reproductive stage and a subsample was examined under a stereomicroscope. This visual assessment was used to note the presence of visible eggs in ovaries and milt in the central sperm duct of males, both indicating a mature status. Gonads were then subsampled for histological examination of maturity and staging. For consistency, a tissue sample of ~1-3 g was removed from the medial portion of one of the ovaries or testes. Tissue samples were fixed in 10% neutral buffered formalin for preservation and storage until processed (Hinton 1990). During processing, tissue samples were trimmed of excess tissue, embedded in paraffin, and sectioned to ~7 μm thickness. Sections were stained with Mayer's hematoxylin and counter-stained with eosin-Y (Humason 1979; Hinton 1990). Maturity stages of females were determined by the percentage of oocytes differentiated into primary, vitellogenic, and hydrated stages. Testes were differentiated into stages based on the presence of spermatogonia, spermatocytes, spermatids, spermatozoa, packed sperm in the testicular lumina (ripe), and empty lumina (spent) (Marte and Lacanilao 1986; Render and Wilson 1992).

Age and size of sexual maturity of amberjack was determined by staging the gonads of males and females during the potential spawning season based on the GSI analysis and histological staging of gonads. This is the time of the year when determining the reproductive status of the fish is the most definitive. Females with vitellogenic or hydrated oocytes, or spent ovaries with post-ovulatory follicles (POFs) were considered to be mature during the spawning season. Males were considered functionally immature or mature on the basis of the presence or absence of spermatozoa or sperm in the testes during the spawning season. Sexual maturity of males and females was derived by modeling the proportion of mature fish as a function of age and size for each region.

Results and Discussion

Fish Collections

A total of 1,907 greater amberjack were collected throughout the Gulf of Mexico during 1990 to 2008 from a variety of agency sources, states, and fisheries. Fish sampled from charterboats and headboats had been caught using hook-and-line gear. The majority of fish landed and sampled from recreational private boats had been caught using hook-and-line gear, with a few caught by spearfishing. Amberjack sampled from the commercial fishery were mostly caught using handline gear (hook-and-line, bandit rigs, electric reels), with a small number caught with longline gear and by spearfishing. The majority of amberjack sampled through scientific research activities were caught using hook-and-line gear and spearfishing, with additional fish caught using trawls, longlines and castnets.

LengthFrequencies

Lengths were available for 1,787 amberjack and fish ranged in size from 74-1829 mm FL (Fig. 2), with the majority of fishery landings truncated at minimum size limits. Charterboat fish ranged from 535-1829 mm FL, with the majority of fish between 700 and 1050 mm FL. Fish sampled from private recreational vessels were similar in size and ranged from 590-1474 mm FL, with the majority between 700 and 1200 mm FL. Headboat amberjack were smaller in comparison and ranged from 287-1245 mm FL, with most fish between 700 and 1000 mm FL. Amberjack sampled from commercial landings were from 680-1476 mm FL, with most fish between 900 and 1150 mm FL. As with the recreational fisheries having most landings truncated at 711 mm FL (28 inch minimum size limit), length frequencies were also truncated at minimum size limit for commercial fisheries (914 mm FL or 36 inches). In contrast, scientific sampling targeting sublegal-sized fish sampled amberjack ranging from 74 to 1241 mm FL, with the majority of fish between 400 and 600 mm FL.

Male amberjack ranged from 74 to 1278 mm FL and females from 180 to 1772 mm FL (Fig. 3). Females were on average 813 mm FL (± 6) (Mean ± 1 SE) (n=991) and were larger (t-test: $P<0.005$) than males (875 ± 8 mm FL, n=558). Log_{10}Weight (LWT) as a function of $\log_{10}$FL (LFL) was not different between males and females (ANCOVA: slopes P=0.72; intercept P=0.79), and was given by: $LWT = -7.1207 + 2.747LFL$ (r^2=0.98, n=841) (Fig. 4).

Age Determination

Identification of the First Annulus: Sectioned amberjack otoliths showed a distinct core with an adjacent core-ring (Fig. 5); the core-ring was not enumerated as an annulus. The first annulus followed a distinctive translucent zone adjacent to the core. Core, first annulus, and second annulus radii were all clearly separated from one another, showing that they were consistently identified in age classes up to 8 years (Fig. 6).

Validation of the Ageing Method: Average marginal growth from January to December, as recorded through codes ranging from 0 (opaque growth on edge) to 1-3 (amount of translucent zone growth), showed one minimum in a 12-month period (Fig. 7). This indicated that greater amberjack deposit one opaque and one translucent zone in their otolith each year. Marginal growth was at a minimum from April to August for both younger age classes (0-2 years), as well as older fish (>2 years of age), indicating the period of time when the opaque zone was deposited. The timing of deposition was variable within individual fish, however, as indicated by the graded marginal growth (i.e., the average marginal code does not decrease to zero during any one month).

Timing of annulus formation in greater amberjack differs slightly among aging studies. Manooch and Potts (1997) used marginal-increment analysis and determined that the annulus in greater amberjack collected from headboats throughout the Gulf was laid down between March and May. Burch (1979), collecting greater amberjack from South Florida, noted that the marginal-increment was at a minimum between February and April. In Louisiana, however, Thompson et al. (1999) were unable to use marginal-increment analysis to determine the timing of annulus formation. Instead, they looked at tagged and recapture greater amberjack that had been injected with oxytetracycline and determined that the annulus must have been deposited sometime between November and March in 2- and 3-year old fish. From the present analysis it appears that opaque zone formation in amberjack otoliths occurs at a slightly later time of the year than previously recorded. However, the deposition is variable and observing the marginal growth at the edge of sectioned otoliths was difficult for many otoliths.

Aging using Otoliths: In total, 1709 amberjack were sampled for both fork length and age. Some otoliths (<5%) were deemed unreadable due to lack of clear annuli or embedding and sectioning difficulties. Most otoliths exhibited a defined pattern of opaque and translucent growth zones in both young and older fish (Fig. 8). In some older fish, additional annuli were apparent on the P2 and S2 axes that were not apparent on the P1 axis (Fig. 9).

The maximum age for an amberjack sampled in the present study was 15 years. Age frequencies varied among major fisheries, with amberjack caught in charter and private boat fisheries ranging in age from 2-15 and 2-10 years, respectively (Fig. 10). The majority of fish caught in these fisheries were 2, 3 and 4 years of age. Amberjack sampled from headboats ranged in age from 0-7 years, with the vast majority of fish in age class 3. Although fish landed in the commercial fisheries had a broader range of ages (2-15 years), the majority of fish were also in age classes 3 and 4. Amberjack caught in scientific sampling targeting sublegal-sized fish ranged from 0 to 6 years of age, with the majority in age classes 1, 2 and 3.

Between-reader precision was high for a random subsample of amberjack aged independently. Overall, 89% of otolith ages agreed perfectly (n=100) and all agreed within ±1 year. The coefficient of variation was 2.3% and the average percent error was 1.6%, both indicating high precision in aging amberjack.

Aging using Pectoral Finrays: Pectoral finrays of amberjack showed distinct opaque zones alternating with translucent zones (Fig. 11). Comparison of ages assigned using finrays compared to ages assigned using otoliths indicated that finrays were a precise aging method for amberjack over age classes 0 to 5 (Fig. 12). Agreement was 91% (n=100) for perfect agreement, and 100% for agreement ±1 year. Average percent error between finray and otolith aging was

7.8%. Lin's correlation coefficient (r_c) was 0.908 ± 0.086, indicating it was not significantly different from a 1:1 relationship between otolith and finray ages (P= 0.1239).

Growth of Greater Amberjack

Greater amberjack were sexually dimorphic with respect to their growth, with females on average larger at age than males. For example, this difference in size at age was apparent in greater amberjack sampled from Florida (Fig. 13) (Maximum Likelihood Ratio (MLR): P<0.001). Although greater amberjack are dimorphic, the sex of the majority of the landed catch in all fisheries is unreported. Therefore, on a fisheries-specific basis both males and females were pooled with unknown-sex fish to determine overall growth models.

Growth of amberjack based on length at observed-age was similar for headboat and charterboat fisheries (Fig. 14) (MLR: P>0.10). Amberjack landed by the private recreational fisheries were slightly larger at age than fish landed by the headboat or charterboat fisheries (MLR: P<0.025). Growth of amberjack landed in the commercial fisheries were larger at age when 2 and 3 years old, but were smaller at age for ages over 7 years. Amberjack caught in scientific research surveys were smaller at age than amberjack sampled in any other fisheries activities. Scientific collections were not regulated by minimum size limits, however, whereas recreational fisheries were restricted to fish over 711 mm FL (28 inch limit) and commercial fisheries were restricted to fish over 914 mm FL (36 inch limit). When the scientific collections were restricted to only fish >711 mm FL, to be comparable to amberjack landed in the recreational fisheries, then the length at age of the fish were similar to amberjack landed in charterboat, headboat, and private recreational fisheries (Fig. 15). Although this was based on a small sample size, it preliminarily indicated that amberjack caught in the recreational fisheries are the fastest-growing component of the cohorts.

Reproductive Seasonality

Female greater amberjack appeared to have a peak spawning period in the Gulf of Mexico during March to May (Figure 15). Although sample size of spawning and post-spawning females was small, it appeared that by June females were spawned out. Additional sample will be required over the spawning season to confirm this observation. Immature females had GSI values that were consistently low throughout the year. This indicated that the method used to categorize females as mature or immature was adequate.

Sexual Maturity

The proportion of sexually mature females increased markedly at lengths between 800 to 1000 mm FL (Figure 16). Approximate 50% maturity in females occurred around 900 mm FL.

Based on age class, 4.2% of female amberjack were sexually mature by age 2, 8.6% by age 3, 85.7% by age 4 and 100% by age 6 and older. This indicated that female amberjack were maturing at a slightly older age than previously reported.

Acknowledgements

This study would not have been possible if not for the collaboration of port samplers throughout the Gulf of Mexico. We are especially indebted to samplers in Louisiana that provide some of the gonad and finray samples. Many people were involved in processing otoliths and fish in this study, and for this we are grateful to E. Leonard, D. Colle, G. Smith, F. Carvalho, J. Hargrove.

Literature Cited

Baldy, L. 1992. Ciguatera. Florida Journal of Environmental Health. 137:10-13.

Beamish, R.J. 1981. Use of fin-ray sections to age walleye pollock, Pacific cod, and albacore, and the importance of this method. Trans. Am. Fish. Soc. 110: 287-299.

Beamish, R.J., and D.A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38: 982-983.

Beasley, M. 1993. Age and growth of greater amberjack, *Seriola dumerili*, from the northern Gulf of Mexico. M.S. Thesis, Dept. of Oceanography and Coastal Sciences, Louisiana State University. 85 p.

Berry and. R.K. Burch. 1979. Aspects of the amberjack fisheries. Proceedings of the 31st Annual Gulf and Caribbean Fisheries Institute. Cancun, Mexico. 179-194.

Browder, J.A., J.C. Davis, and C.B. Austin. 1978. Study of the structure and economics of the recreational paying passenger fisheries of the Florida Gulf coast and Keys from Pensacola to Key West. Final Report to NMFS Southeast Fisheries Center, Miami, FL. Contract #NOAA/03/7/042/35132.

Burch, R.K. 1979. The greater amberjack, *Seriola dumerili*: its biology and fishery off Southeastern Florida. Unpublished M.S. Thesis. University of Miami. 112 pp.

CDC (Center for Disease Control and Prevention). 1993. Ciguatera fish poisoning – Florida 1991. Morbidity and Mortality Weekly Report 42(21).

Cerrato, R.M. 1990. Interpretable statistical tests for growth comparisons using parameters in the von Bertalanffy equation. Can. J. Fish. Aquat. Sci. 47: 1416-1426.

Chilton, D.E., and R.J. Beamish. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Can. Spec. Publ. Fish. Aquat. Sci. 60. 102 pp.

Cummings, N.J. and D.B. McClellan. 2000. Trends in the Gulf of Mexico greater amberjack fishery through 1998: Commercial landings, recreational catches, observed length frequencies, estimates of landed and discarded catch at age, and selectivity at age. U.S. Dept of Commerce, National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Sustainable Fisheries Division.

Debicella, J.M. 2005. Accuracy and precision of fin-ray aging for gag grouper (*Mycteroperca microlepis*). Master's Thesis, University of Florida, Gainesville, FL

Dutka-Gianelli, J., and D.J. Murie. 2001. Age and growth of sheepshead, *Archosargus probatocephalus* (Pisces: Sparidae), from the northwest coast of Florida. Bull. Mar. Sci. 68: 69-83.

Haddon, M. 2001. Modelling and quantitative methods in fisheries. Chapman & Hall/CRC Press, New York. 406 p.

Hinton, D.E. 1990. Histological techniques. *Pages* 191-211 *in* Methods for fish biology. *Edited by* C.B. Schreck and P.B. Moyle. Am. Fish. Soc., Bethesda, Maryland.

Humason, G.L. 1979. Animal tissue techniques, 4th ed. Freeman, San Francisco, CA.

Kimura, D.K. 1980. Likelihood methods for the von Bertalanffy growth curve. Fish. Bull. 77: 765-776.

Kimura, D.K., and J.J. Lyons. 1991. Between-reader bias and variability in the age-determination process. Fish. Bull., U.S. 89: 53-60.

Lin, L. I-K. 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics 45: 255-268.

Marte, C.L., and F. Lacanilao. 1986. Spontaneous maturation and spawning of milkfish in floating net cages. Aquaculture 35: 115-132.

Manooch, C.S. and J.C. Potts. 1997. Age, growth, and mortality of greater amberjack, Seriola dumerili, from the U.S. Gulf of Mexico headboat fishery. Bulletin of Marine Science 61: 671-683.

Murie, D.J., and D.C. Parkyn. 1999. Age, growth, and sexual maturity of white grunt in the eastern Gulf of Mexico: Part II. Final Report to the Florida Department of Environmental Protection, Florida Marine Research Institute, St. Petersburg.

Murie, D.J., and D.C. Parkyn. 2002. Comparison of total mortality of white grunt from the headboat fishery on the Gulf coast of Florida during spawning and postspawning seasons. N. Am. J. Fish. Management 22: 806-814.

Murie D.J., and D.C. Parkyn . 2005. Age and growth of white grunt (*Haemulon plumieri*): a comparison of two populations along the Florida west coast. Bull. Mar. Sci. 76(1): 73–93.

Murie D.J., D.C. Parkyn, C.C. Koenig, F.C. Coleman, J. Schull, and S. Frias-Torres (*In Press*). Evaluation of finrays as a non-lethal ageing method for protected goliath grouper *Epinephelus itajara.* Endangered Species Research.

Parrack, N.C. 1993a. The exploitation status of Atlantic amberjack fisheries through 1991. U.S. Dept. of Comm., NOAA, NMFS, SEFSC, Miami Laboratory Cont. No. MIA-92.93-30. 98p.

Parrack, N.C. 1993b. Updated fisheries information for greater amberjack through 1992. US. Dept. of Comm., NOAA, NMFS, SEFSC, Miami Laboratory Cont. No. MIA-92.93-77. 32p.

Penha, J.M.F., L.A.F. Mateus, M.P. Petrere, Jr. 2004. A procedure to improve confidence in identification of the first annulus in fin-spines of fishes. Fish. Manage. Ecol. 11:135-137

Render, J.H., and C.A. Wilson. 1992. Reproductive biology of sheepshead in the northern Gulf of Mexico. Trans. Am. Fish. Soc. 121: 757-764.

RFSAP (Reef Fish Stock Assessment Panel). 2000. December 2000 report of the Reef Fish Stock Assessment Panel: Final Version-28 December 2000. December 4-7, 2000, meeting, NMFS, SEFSC, Miami, FL.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 p.

Rien, T.A., and R.C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Trans. Am. Fish. Soc. 123: 255-265.

Tanaka, K., Y. Mugiya, and J. Yamada. 1981. Effects of photoperiod and feeding on the daily growth patterns in otoliths of juvenile *Tilapia nilotica*. Fish. Bull., U.S. 79: 459-465.

Thompson, B.A., C.A. Wilson, J.H. Render, M. Beasley, and C. Cauthron. 1992. Age, growth, and reproductive biology of greater amberjack and cobia from Louisiana waters. Final report to Marine Fisheries Research Initiative (MARFIN) Program, NMFS, St. Petersburg, FL. NA90AA-H-MF722, 77 p.

Thompson, B.A., M. Beasley, and C.A. Wilson. 1999. Age distribution and growth of greater amberjack, *Seriola dumerili*, from the north-central Gulf of Mexico. Fishery Bulletin 97: 362-371.

Turner, S.C., J. Cummings, and C.E. Porch. 2000. Stock assessment of Gulf of Mexico greater amberjack using data through 1998. NMFS/SEFSC, Miami Laboratory. Document SFD 99/00-100. 27 p.

Zar, J.H. 1996. Biostatistical analysis, 3rd ed. Prentice-Hall, New Jersey. 662 p.

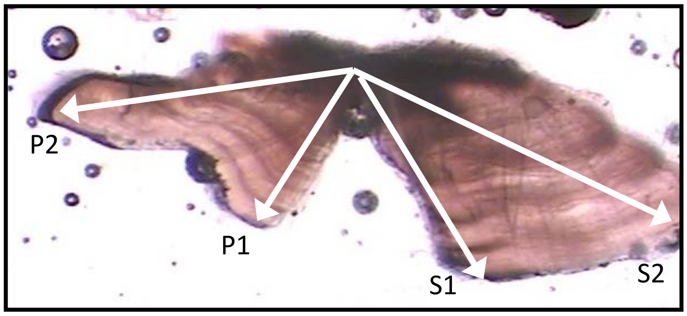


Figure 1. Cross-section of a 5-year old amberjack showing the primary aging axis (P1), as well as the secondary aging axis (S1). In addition, P2 and S2 axes, on the leading growth areas of the otolith, are also noted.

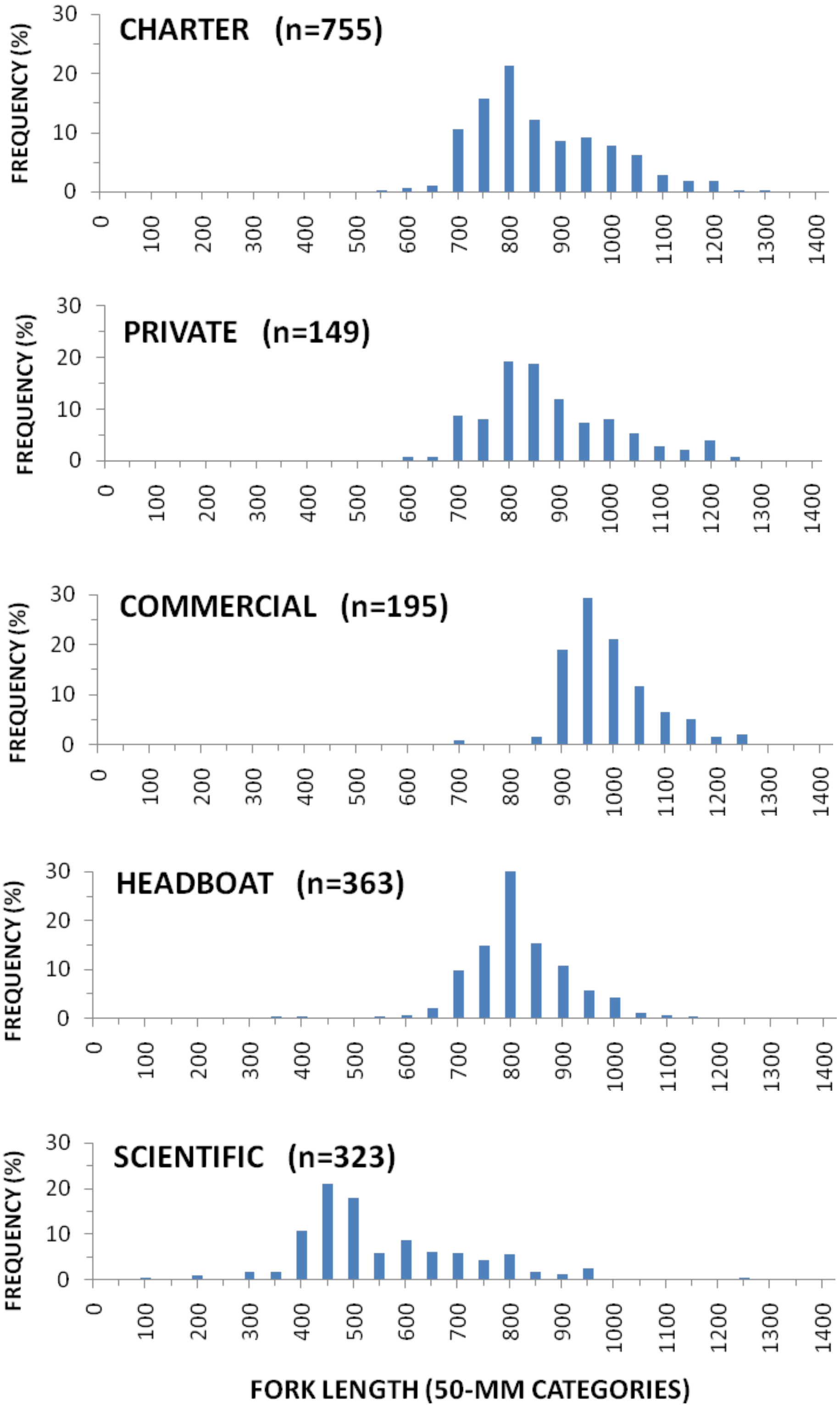


Figure 2. Length frequencies of greater amberjack sampled from various fisheries in the Gulf of Mexico (1999-2008)

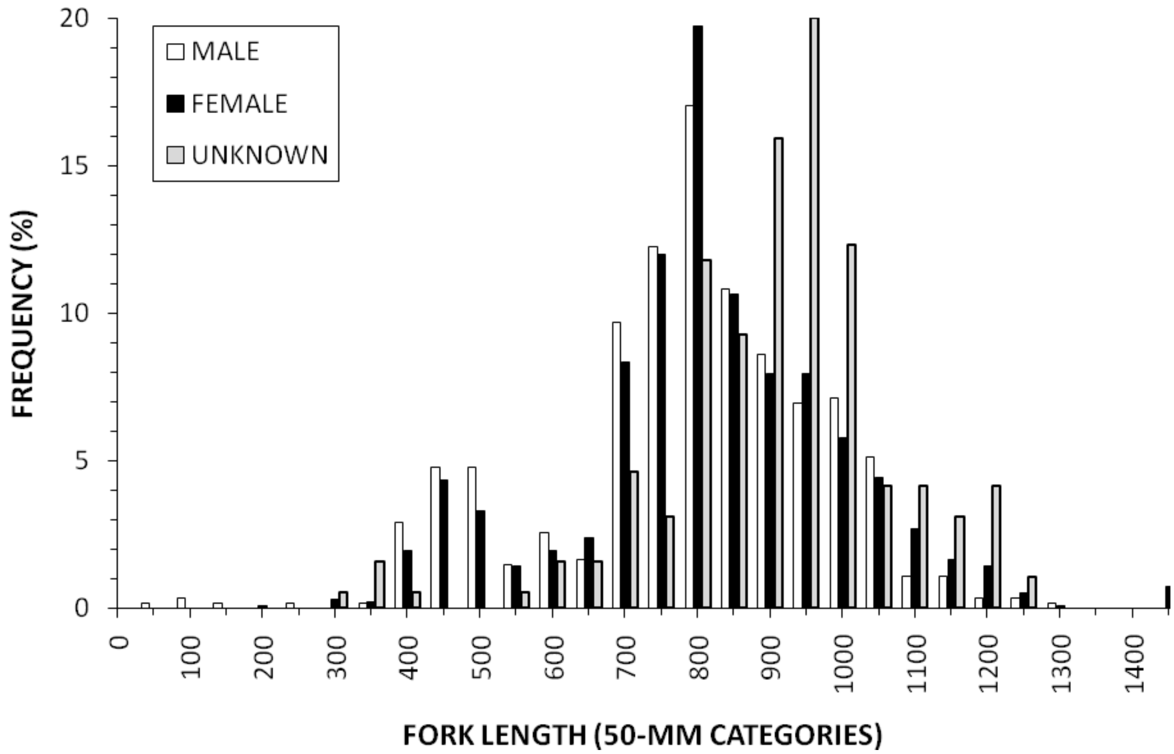


Figure 3. Length frequency distributions of female and male greater amberjack sampled from the Gulf of Mexico (1999-2008).

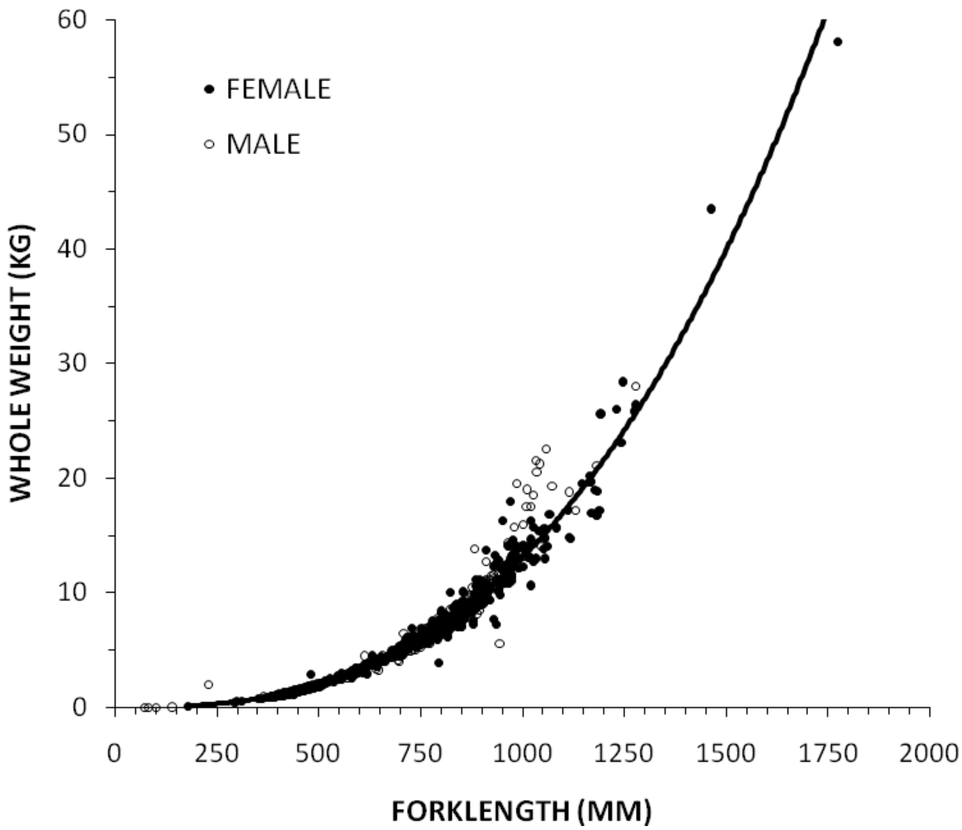
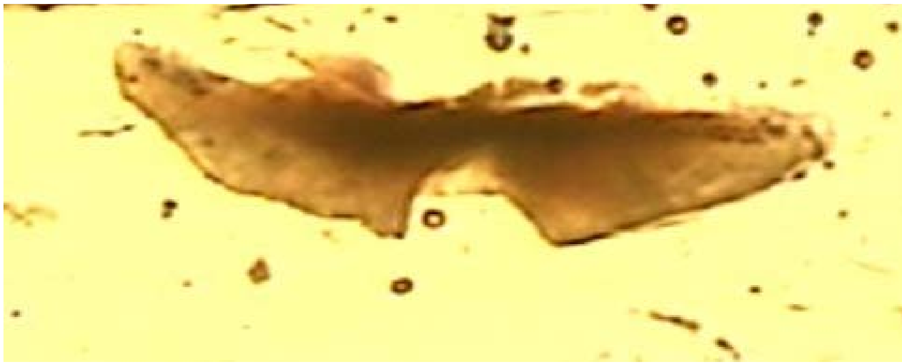


Figure 4. Weight as a function of fork length for greater amberjack sampled in the Gulf of Mexico from 1999-2008. Solid line denotes the pooled regression model.

A



B

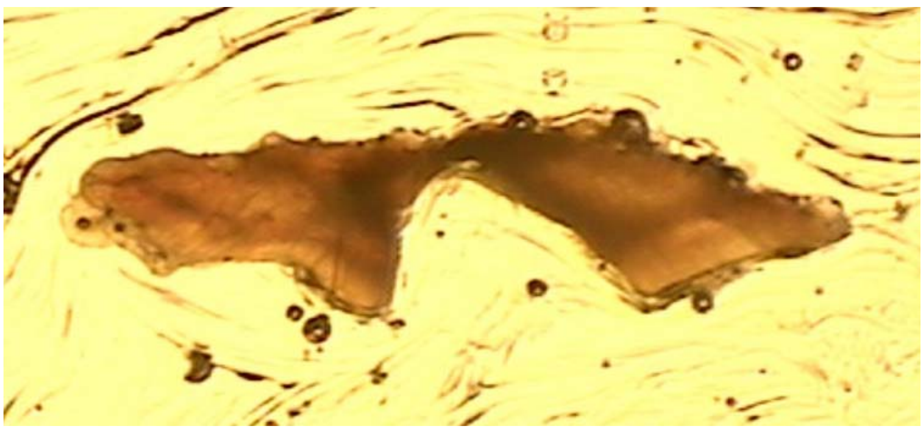


Figure 5. Cross-section of a greater amberjack otolith showing the core area in a: A) 0-age fish; and B) 1+-year old fish.

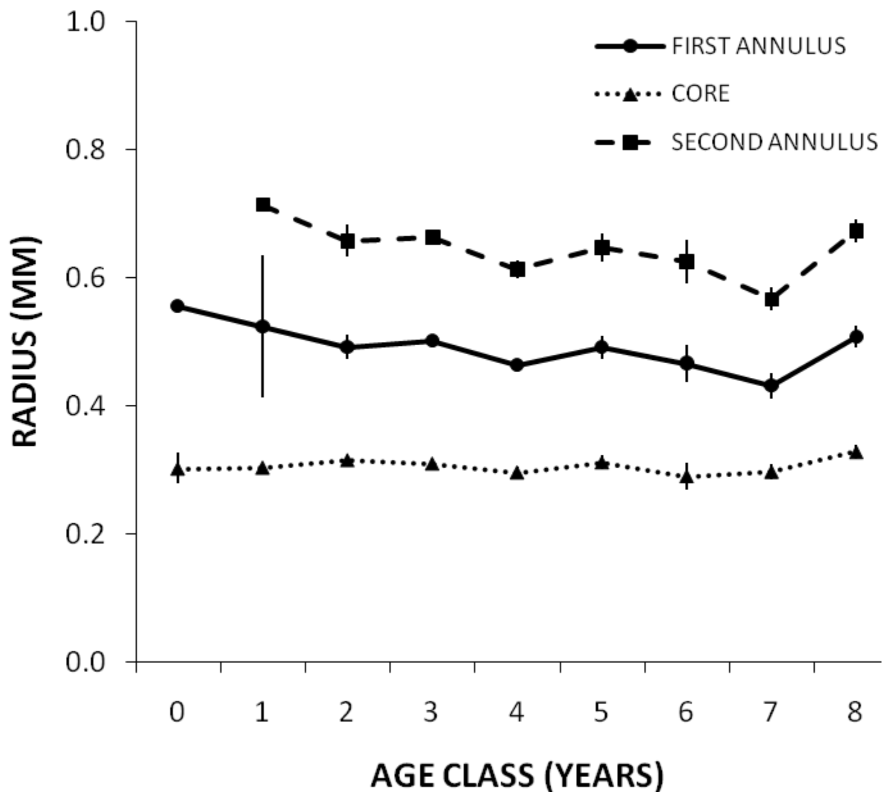


Figure 6. Mean radii of the core, and first and second annuli in otoliths of greater amberjack collected from the Gulf of Mexico. Vertical bars represent ±1 SE of the mean.

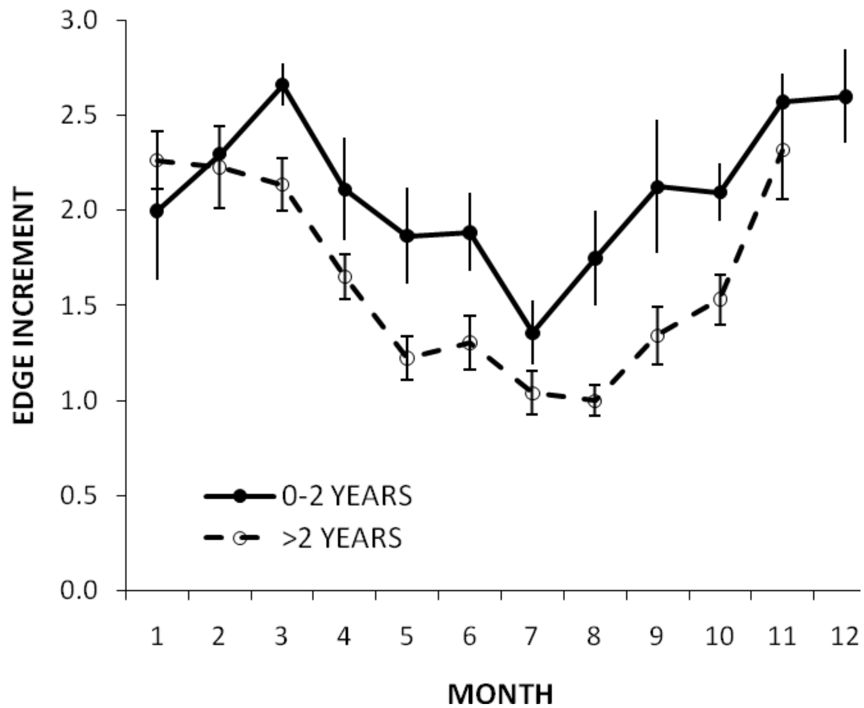
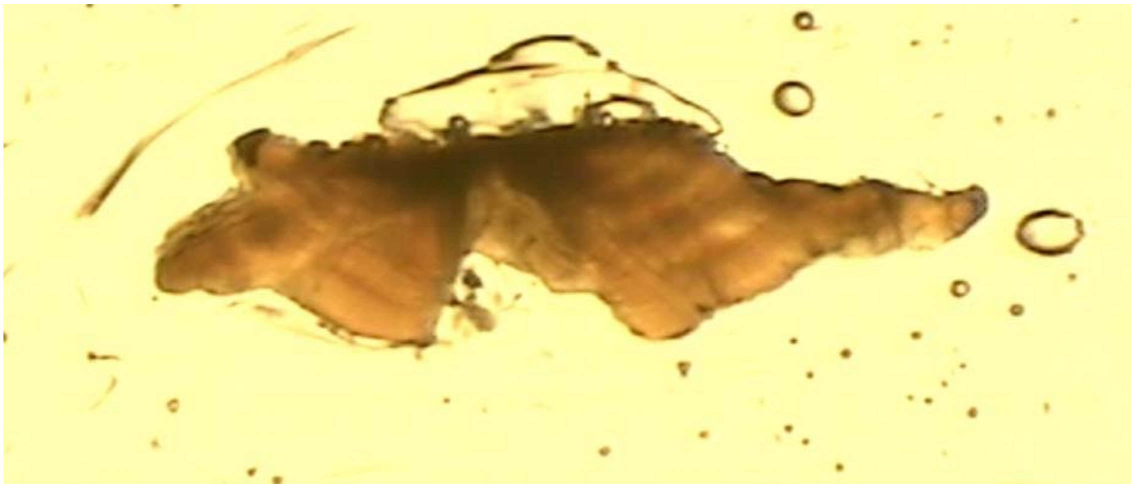


Figure 7. Mean marginal growth codes for relatively young (0-2 years) and older (>2 years) greater amberjack sampled in the Gulf of Mexico (1999-2008), where 0=opaque zone on edge of otolith and 3=large amount of translucent growth on the edge of the otolith.

A



B

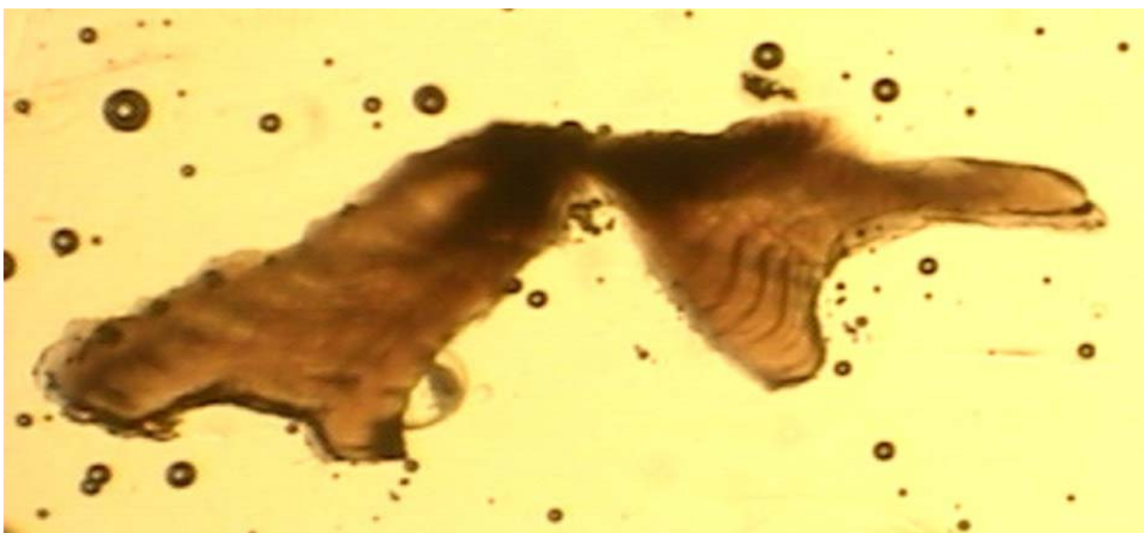


Figure 8. Sectioned otoliths from a: A) relatively young amberjack (2 opaque zones with 3rd forming on edge); and B) from a relatively older amberjack (6 opaque zones).

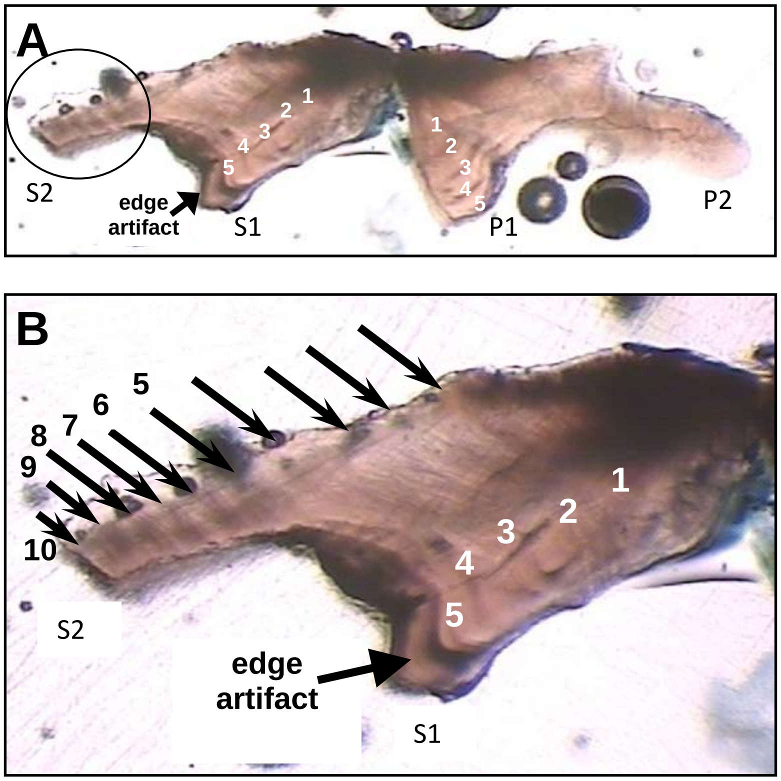


Figure 9. A) Amberjack aged as a 5-yr old fish on both sides of the sulcus using Axes P1 and S1. The edge artifact is from the depth of the section (i.e., lower portion of the section showing and on a slight angle); and B) the area circled in the upper panel is shown in greater detail with the elongated process on Axes S2 with 5 additional annuli visible (Axes P2 unreadable for this otolith).

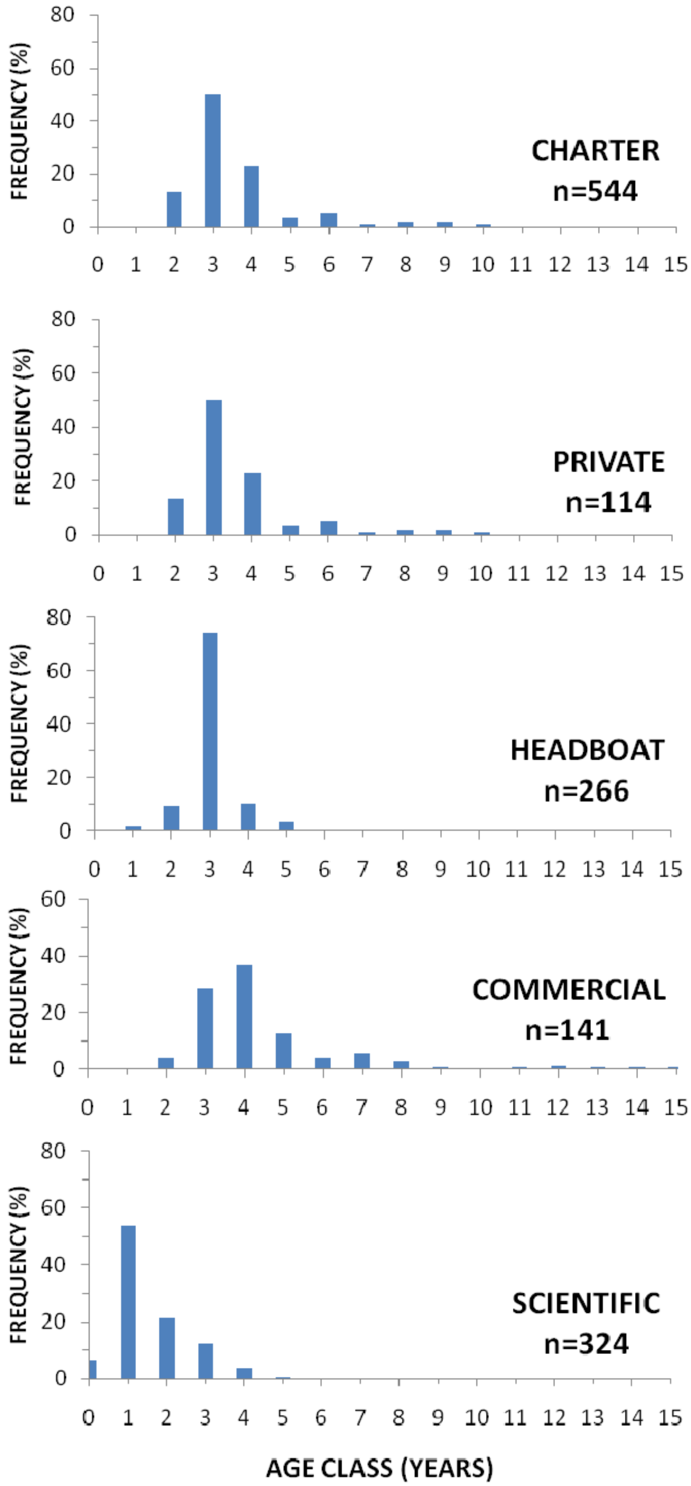


Figure 10. Age frequencies of greater amberjack sampled from various fisheries in the Gulf of Mexico (1999-2008).

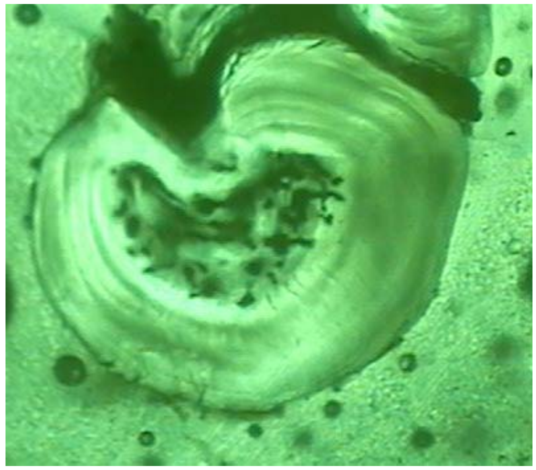


Figure 11. Cross-section of pectoral finray from a greater amberjack from the Gulf of Mexico showing three opaque zones with a lot of translucent growth on the edge.

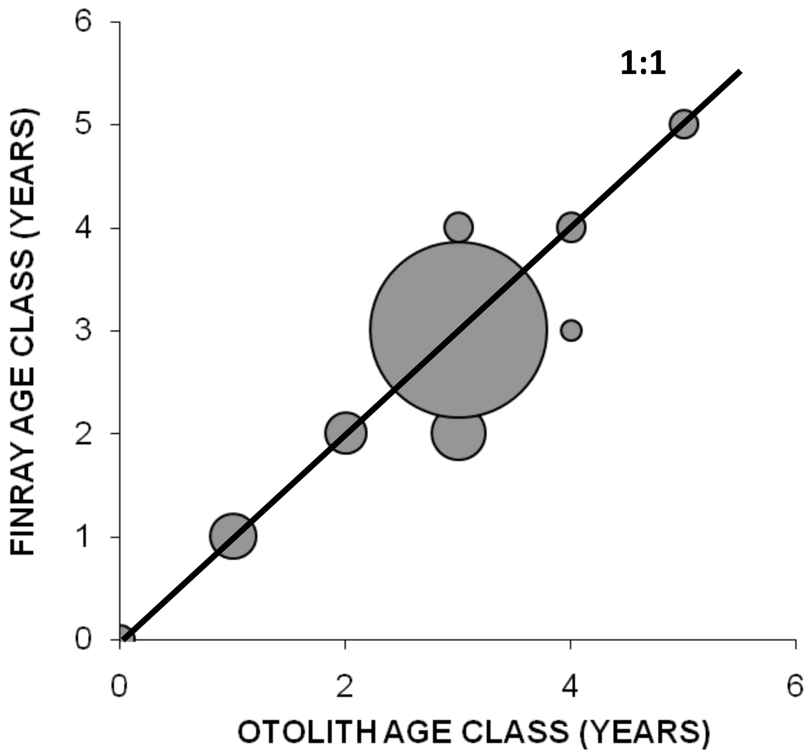


Figure 12. Paired comparison of finray ages and otolith ages from the same individual greater amberjack. The line denotes a 1:1 relationship where the finray age is identical to the otolith age. Ages below the line indicate under-ageing using the finray method, and those above the line indicate over-ageing using the finray method.

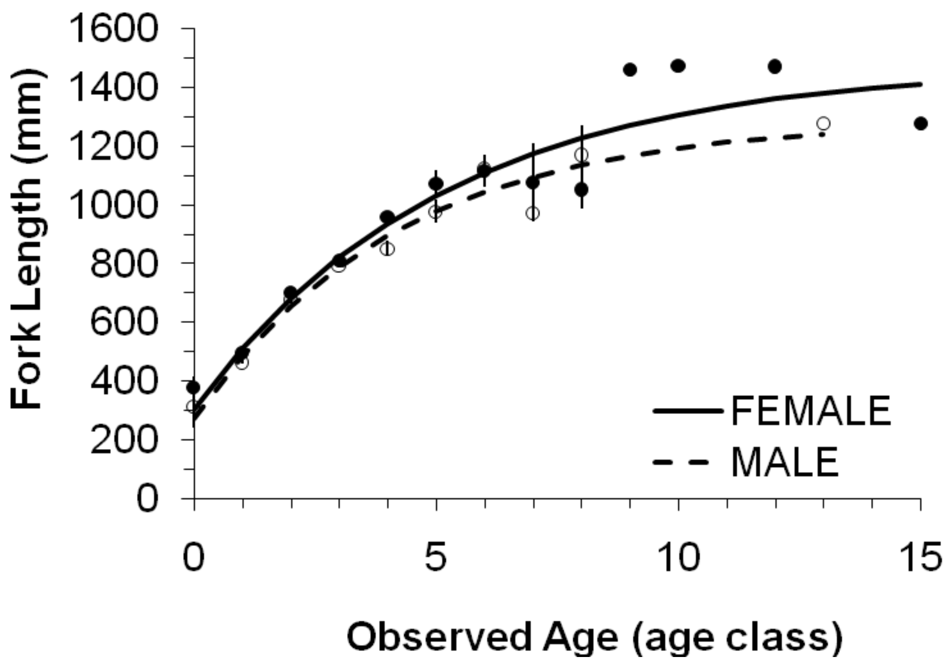


Figure 13. Sexually dimorphic growth of greater amberjack sampled from Florida, with females larger at age on average than males.

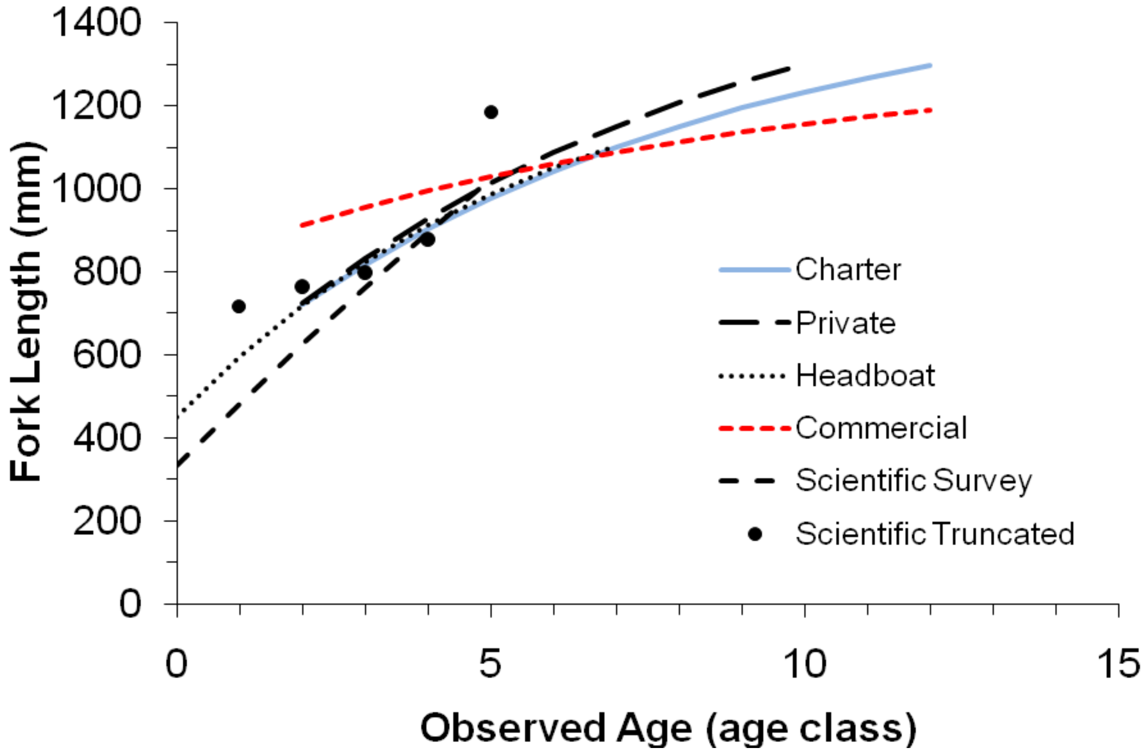


Figure 14. Fishery-specific growth of greater amberjack in the Gulf of Mexico (1999-2008), Lines represent modeled vonBertalanffy growth curves. Scientific Truncated represents average size of fish at age when the sample was restricted to fish only over 711 mm FL.

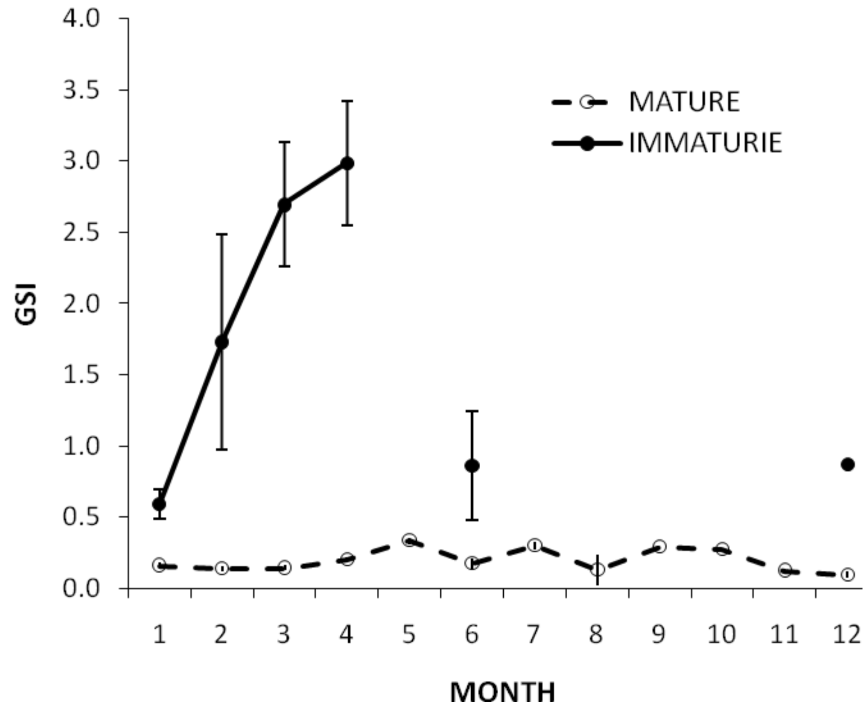


Figure 15. Gonadosomatic index for mature and immature female greater amberjack from the Gulf of Mexico.

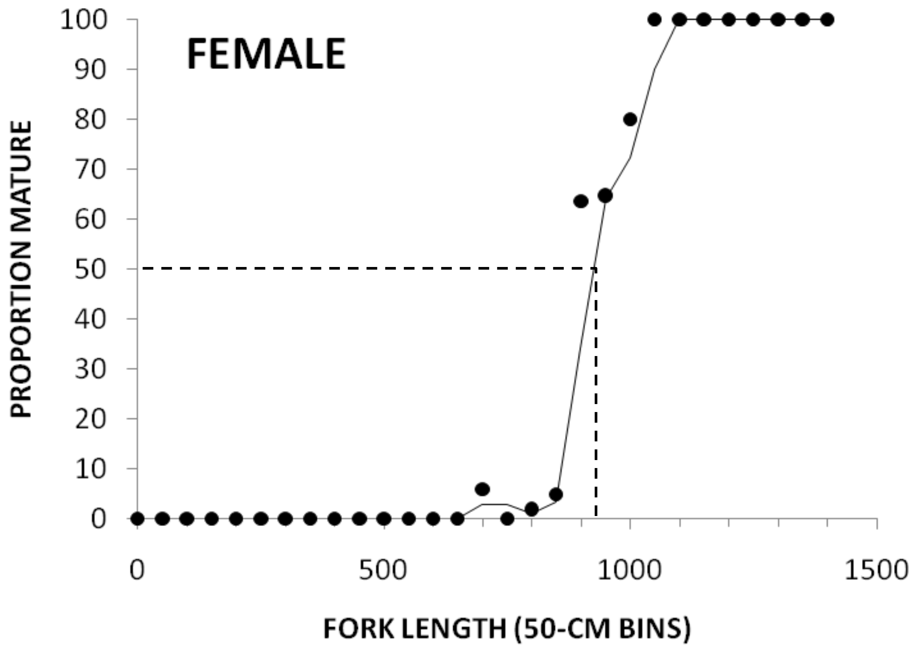


Figure 16. Proportion of mature females by length for greater amberjack in the Gulf of Mexico.