Analytical Report

Age, growth, and reproduction of greater amberjack, *Seriola dumerili*, in the southwestern north Atlantic.

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December 2004

This work represents partial fulfillment of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Program contract (No. 50WCNF606013) sponsored by the National Marine Fisheries Service (Southeast Fisheries Center) and the South Carolina Department of Natural Resources.

Introduction

The greater amberjack, *Seriola dumerili*, is a pelagic and epibenthic member of the family Carangidae (Manooch and Potts, 1997a). This large jack is distributed from Nova Scotia through the Caribbean to Brazil, the Gulf of Mexico, and throughout the Pacific, Indian and Eastern Atlantic Oceans as well as the Mediterranean Sea (Fischer, 1978; Manooch, 1984; Shipp, 1988; Manooch and Potts, 1997a; b; Thompson et al., 1999). Greater amberjack are often found near reefs, rocky outcrops or wrecks off the southeastern United States, in depths ranging from 18-72 m (Fischer, 1978; Manooch and Potts, 1997b). Due to association with reefs and similar habitats, greater amberjack are included in the snapper-grouper complex and are managed by the South Atlantic Fishery Management Council (SAFMC) off the coast of the southeastern United States.

Recreational fishing for greater amberjack began in the early 1950s from New York to Texas (Manooch and Potts, 1997a). There was not a targeted fishery until charter boat fishermen popularized this fish in the 1970s because of its aggressive fighting behavior when hooked (Manooch and Potts, 1997a; Cummings and McClellan, 1999). Commercial landings for Atlantic greater amberjack increased from 6,344 pounds in 1962 to 2,232,479 pounds in 1991 (Cummings and McClellan, 1999). This increase in landings may be due to hook and line fishermen shifting from snapper, groupers and king mackerel to greater amberjack during the mid 1980s when consumer consumption of this fish increased (Cummings and McClellan, 1999). In April 1991, the SAFMC established a minimum size limit of 36 inches fork length for commercially harvested greater amberjack with a recreational bag limit of 3 fish per person per day (SAFMC, 1991). Commercial landings declined from 1991 to 1993 with the implementation of the new regulations, stabilized from 1993 to1995 and then declined steadily since 1995 to a low

of 195 metric tons in 2003 (Figure 1). In 1998, additional regulations were established for greater amberjack, including a reduced bag limit of 1 fish per person per day, a 1,000 pound daily commercial trip limit, prohibition of harvest and possession in excess of bag limit during April, fishing year beginning on May 1 and a quota of 63% of 1995 landings (SAFMC, 1998). Spawning potential ratio (SPR) for greater amberjack in the southeastern Atlantic was reported to be 84% in 1993 and the stock is currently being managed using an SPR value of 40% (SAFMC, 1998 and 1999).

Studies on greater amberjack along the southeastern coast of the United States are limited and focused primarily on age and growth. Burch (1979) aged greater amberjack from the Florida Keys using scales and Manooch and Potts (1997a) utilized sectioned otoliths to age 323 fish from North Carolina to Florida. Nothing is known about the reproductive biology of greater amberjack off the southeastern coast of the United States.

Management of greater amberjack has been based on insufficient and incomplete life history data, therefore, the purpose of this study is to assess age structure, growth, sex ratio, size and age at maturity, spawning season, and determination of annual fecundity for this species from the southeastern coast of the United States.

Materials and Methods

Sampling

Greater amberjack were collected by personnel of the Marine Resource Monitoring Assessment and Prediction (MARMAP) program using fishery-independent gear (chevron traps, H&L gear, bottom longlines). In addition, up to 150 specimens were obtained from commercial fish houses (Cape Hatteras, NC to Key West, FL) each month to validate increment formation and to assess spawning seasonality. In 2003, a directed

effort was made to sample greater amberjack during the spawning season to obtain fecundity samples. Sampling was conducted in the Florida Keys, a well-known spawning area, during March, April and May. A minimum of 100 specimens per month were sampled from four participating fishing vessels. This effort was continued in 2004, however sampling was restricted to fecund females, as sampling in 2003 identified very few females with hydrated oocytes. Only one vessel was utilized for specimen collection in 2004. Total length, fork length, standard length (TL, FL, SL) and whole weight were measured for each fish sampled. Left and right (when possible) sagittal otoliths were removed and temporarily stored in vials of ethanol. The entire gonad of each fish was removed, weighed and a section from the posterior portion retained for histological processing. Whole ovaries were preserved for fecundity analyses if hydration was evident upon visual inspection.

Age Determination

In the laboratory, otoliths were rinsed clean and stored dry in vials to minimize breakage. Prior to sectioning, whole unbroken otoliths were weighed (0.00001g). Several methods of otolith preparation were tested to determine which method produced a clear view of the core and increments. Otoliths were mounted whole and polished to the core; transverse sections through the core were made and polished on one or both sides, and transverse sections (0.5 mm) were made and viewed unpolished. The last method produced the most consistent results, and was utilized as the protocol for preparation of all amberjack otoliths. All sections were aged by two readers working independently using a dissecting microscope using transmitted and reflected light without knowledge of the size, sex or date of capture of any specimen. Each reader aged each fish once, and designated the edge type of each section aged and re-examined

simultaneously when assignments differed. Specimens which were deemed unreadable by either or both readers as well as specimens for which the difference between readers was 5 years or greater, were discarded from the age analyses. Periodicity of increment formation was validated using the percentage of opaque margins by month.

Mean lengths, ages and observed lengths at age were compared between sexes using Student's t-test. A von Bertalanffy growth curve was fit to raw observed lengths at age for both sexes combined.

Reproductive biology

The posterior portion of gonad tissues collected were fixed in 10% seawater-formalin solution for 7-14 days and transferred to 50% isopropanol for an additional 7-14 days. Reproductive tissue was processed in a Modular Vacuum Tissue Processor®, and blocked in paraffin. Three transverse sections (6-8 μm) were cut from each sample with a rotary microtome, mounted on glass slides, stained with double-strength Gill hematoxylin, and counterstained with eosin-y.

Sex and reproductive stages were determined independently by two readers without knowledge of date of capture and specimen length or age, and re-examined simultaneously when assignments differed. Reproductive stages were assigned using histological criteria described in Harris et al. (2004) for blueline tilefish. All samples collected in 2004 and one collection from 2003 were not included in sex ratio calculations as they were specifically targeted toward sampling fecund females.

Fecundity

Total fecundity, batch fecundity, potential annual fecundity, determinate fecundity, and indeterminate fecundity have been defined by Hunter et al. (1992). Total fecundity refers to the standing stock of advanced (stage-3) yolked oocytes; batch

fecundity is the number of hydrated oocytes released in one spawning event. Potential annual fecundity is the total number of advanced yolked oocytes matured per year uncorrected for atretic loss. Determinate fecundity refers to a fixed potential annual fecundity, whereas indeterminate fecundity refers to potential annual fecundity not being fixed prior to the onset of spawning as unyolked oocytes continue to mature and be spawned throughout the spawning season.

Oocyte stages referred to here as hydrated, migratory nucleus (MN), stages 2 and 3, as defined by Hunter et al. (1992), were identified and counted. Oocyte diameters were measured using Global Lab® image analysis software. The size distributions from these measurements were used to address whether or not greater amberjack exhibited indeterminate fecundity.

To determine random distribution of the various stages of oocytes within the ovary, samples from each lobe were taken at anterior, middle, and posterior positions, for a total of six 25-30 mg samples from each of twelve fish. A two-way analysis of variance without interaction was used to test for the effects of location and individual fish on oocyte density (no. of stage-2 and stage-3 oocytes per g of ovary).

To estimate total fecundity of the sizable greater amberjack ovary, a logistical strip measuring approximately 3 cm x 10 cm of fresh ovarian tissue was preserved in 10% buffered seawater formalin. From this strip, two 25-30 mg samples were randomly selected and weighed using a Sartorius® digital balance (±0.0001 g). Total fecundity was estimated by multiplying the preserved ovary weight by oocyte density (the number of stage-3 oocytes divided by the sample weight). Preservation of all of the whole ovaries collected was not feasible; therefore, fresh gonad weights were converted to preserved weights with a regression equation (Preserved wt (g) = fresh wt (g) * 0.966 - 15.531; adj.

r^2=0.997, n = 24). The relationship between total fecundity and FL was described for three months (March, April, and May) and the effect of each month on total fecundity was examined using ANCOVA.

Greater amberjack exhibited evidence of indeterminate fecundity; therefore, batch fecundity and spawning frequency were estimated to calculate potential annual fecundity. The hydrated oocyte method of Hunter et al. (1985) were used to determine batch fecundity, but we used a larger sample weight and immersed samples in a 1-5% formalin solution to enumerate oocytes. Two 75-mg samples were taken from random locations in the ovaries of 28 specimens undergoing final oocyte maturation. The MN and hydrated oocytes were counted; MN oocytes were predominant in 25 of 28 specimens, as fishing generally occurred during morning hours, apparently several hours prior to the time of oocyte hydration. The equation to convert fresh gonad weight to preserved weight was the same as that for total fecundity. The effect of month on batch fecundity was examined using ANCOVA.

Two estimates of spawning frequency were based on histological criteria (presence of: 1) MN or hydrated oocytes, and 2) postovulatory follicles (POFs) < 24 hr old) that indicate imminent or recent spawning. Estimates of spawning frequency represented the proportion of specimens with each criterion among reproductively active females (i.e., those with oocytes undergoing vitellogenesis).

All statistical analyses were performed in SAS (SAS Institute, Inc. 1989), and the results were considered significant at $\alpha < 0.05$.

Results

Sampling

A total of 2,729 amberjack were sampled during the sampling season. Samples were collected from 24^{o}N to 34^{o}N, encompassing almost the entire range of greater amberjack off the southeastern United States (Figure 2). The vast majority of the samples were obtained by fishery-dependent sampling (n=2,695).

The mean fork length of all fish sampled was 950 mm FL (± 154 mm; range 233-1,445, n=2,700; Figure 3a). The mean length of males (933 mm FL (± 133); range 267-1,445, n=823, Figure 3b) was significantly smaller than that for females (969 mm FL (±165); range 352-1,435, n=1,139; $P<0.0001$). The length frequency distributions for the two sexes were significantly different (Kolmogorov-Smirnov test; $P< 0.001$; Figure 3b).

Age determination

Of the 2,335 otoliths collected, 1,996 were successfully aged (85.4%). Agreement between readers was 42.5.3%, and was 85.4% for ages differing by one year or less. The mean age of all fish aged was 3.98 years old (±1.66; range 0-13; Figure 4a), while the mean age of males was 3.87 (±1.61; range 0-13, n=583) and females was 4.01 (±1.68; range 0-13, n=816; Figure 4b). There were no significant differences between the mean ages of male and female greater amberjack, or between the age frequency distributions of male and female amberjack (K-S test; $P>0.05$).

Otolith weight was a reasonably precise predictor of age (Figure 5). A significant regression ($P<0.05$; $r^2=0.49$) was fitted, and strongly suggests that otolith weight might be a usable predictor of age.

Sexual dimorphism was evident in greater amberjack, albeit with females being larger at age than males (Figure 6). Females were significantly larger than males for ages

3-9, and age 11 (Figure 6). A von Bertalanffy growth curve was fitted to using all age data as well as for each sex, with females having the largest L_∞ and lowest k, while males had the smallest L_∞ and highest k (Table 1).

A comparison of all age data combined, without regard to sex, to previous studies, showed our results had a larger size at age for ages 1 through 4 than one study from the Gulf of Mexico (Beasley 1993), after which the size at age of fish from this study where smaller than those from the Gulf (Figure 7). However, our results showed a greater size at than two additional studies from the Atlantic (Manooch and Potts 1997a) and the Gulf of Mexico (Manooch and Potts 1997b) for almost all ages (Figure 7).

Reproduction

A total of 2,537 gonad samples were obtained from the 2,729 fish sampled. Sex and reproductive stage was assigned to 2,517 of these. The overall male:female sex ratio for greater amberjack was 1:1.22, significantly different from a 1:1 ratio (Table 2), although this appears to be a function of females dominating the larger size classes, where the sex ratio was significantly biased toward females (Table 2). Although sex ratio was significantly biased toward females for four age classes, no obvious trends were evident in these data (Table 2).

Immature specimens comprised 4.5% (n=115) of the specimens for which reproductive stage was established. Correct assignment of reproductive tissue to the immature and resting categories is indicated by the near or complete overlap in the left tail of length histograms for specimens that were definitely mature (i.e., developing, ripe, and spent) and specimens that were resting and by the minimal overlap in he histograms for immature and resting specimens (Figure 8). The smallest mature male was 267 mm

FL and the youngest was age 0; the size at 50% maturity was 643 mm FL (age 0.5), and the largest immature male was 771 mm FL (age 3). All males were mature at 795 mm FL and age 3.5. The smallest mature female was 352 mm FL, and the youngest was age 0; the size at 50% maturity was 733 mm FL (age 1.4), and the largest immature female was 826 mm FL, and the oldest was age 4. All females were mature by 865 mm FL and age 4.2.

Based on the occurrence of migratory nucleus oocytes and postovulatory follicles (POFs), spawning occurred from January through June, with peak spawning in April and May (Figure 9). Although fish in spawning condition were captured from North Carolina through the Florida Keys (Figure 2), spawning appears to occur primarily off south Florida and the Florida Keys (Figure 2). Greater amberjack in spawning condition were sampled from a range of depths, although the bulk of samples were from the shelf break (Figure 2).

Fecundity

There was no significant difference in the density of advanced yolked oocytes (stage 3) among six selected locations in the ovaries of 12 specimens ($F=1.86$, $P=0.1155$, $df=5$), which indicated that samples for estimating total fecundity and batch fecundity could be taken from any location without bias.

Total fecundity as a function of total length was essentially constant throughout the spawning season and did not exhibit a declining trend over time (Figure 10). The interaction term in an ANCOVA showed that the slopes of the equations were not significantly different among months ($P=0.2578$; Table 3); however, the intercept of the March equation was lower than that for April ($P=0.0151$) because oocyte development

was at an earlier stage of vitellogenesis. No difference in intercepts was noted between April and May (P=0.0779).

Annual fecundity in greater amberjack is indeterminate because total fecundity did not decrease during the spawning season and no size gap between stage-3 and stage-2 yolked oocytes developed at any time during the spawning season (Figure 11). Continuous production of oocytes was also evident, as the percentage of stage-3 yolked oocytes did not progressively decrease over time.

Estimates of spawning frequency and batch fecundity, necessary to estimate potential annual fecundity, were based on MN and hydrated oocytes; for comparative purposes, spawning frequencies based on the occurrence of POFs were also estimated. The proportion of specimens with hydrated or MN oocytes among females with oocytes undergoing vitellogenesis was similar to the proportion with POFs < 24 hr old (0.213 vs. 0.241; Table 4). The average of the two proportions was 0.227, which corresponded to a spawning periodicity of approximately 5 days. With a spawning season of approximately 60 days off South Florida (12 March through 10 May; see Figure 9), an individual female could spawn approximately 12 times.

Statistically significant relationships were developed between batch fecundity and total length, fork length, and age (Table 5). Batch fecundity as a function of FL did not differ between April and May, as indicated by the lack of differences in slopes (F=0.15, P=0.702, df=1) and intercepts (F < 0.01, P=0.977, df=1). Given the similarity of the equations, data from both months were combined to estimate the relationship between batch fecundity and fork length (Figure 12). Multiplying the estimated number of spawning events (12) by batch fecundity (BF) estimates (BF = 8.192*FL – 6,394,879; Table 5 and Figure 12) for greater amberjack 936-1296 mm FL produced estimates of

potential annual fecundity that ranged from 15,274,000 to 50,663,400 oocytes. Relative to age, estimates of potential annual fecundity ranged from 19,558,400 to 41,571,300 oocytes for ages 3-7.

Discussion

Although greater amberjack were sampled over a period of four years for this study, we feel the results presented provide an accurate reflection of the current life history parameters of the greater amberjack population off the southeastern United States. Samples were collected from almost entire region, from the Dry Tortugas off the Florida Keys to Cape Lookout in North Carolina. Furthermore, the number of specimens sampled is the largest in any study of greater amberjack to date.

The otoliths of greater amberjack are very small, making the production of consistent section quite problematic. Furthermore, the sections were quite difficult to interpret, as has been documented in previous studies (Manooch and Potts, 1997a; 1997b). Nonetheless, we feel we were able to reliably and accurately age specimens, as evidenced by the 65% agreement within one year, and that the ages generated reflect the age structure of the population off the southeastern US coast. We were unable to validate the periodicity of increment formation using the presence/absence of the opaque zone at the otolith edge primarily because of the difficulty of clearly establishing whether an opaque edge was due to increment formation or an artifact of embedding and sectioning. However, Manooch and Potts (1997a; b) used marginal increment analyses to show increments were formed annually between March and April in the Atlantic and March and May in the Gulf of Mexico. Furthermore, Thompson et al. (1999) used the combined

information from six otoliths marked with oxytetracycline to show increment formation between November and March in two and three year old specimens.

Greater amberjack are extremely fast growing and relatively short-lived. While the ages reported reflect the age relative to the timing of increment formation (i.e. an age 0 specimen was hatched 8-12 months prior to capture), and not a birthdate of January 1, the size at age is still larger for all ages up to age 6 than has been previously reported (Beasely, 1993), and larger for all ages than has been previously reported for the Atlantic (Manooch and Potts, 1997a). Although sexual dimorphism was previously documented by Beasely (1993), he suggested it might due to females living longer than males. Beasely (1993) did compare von Bertalanffy growth curve sums of squares fitted to male and female amberjack and found no differences.

The sex ratio of greater amberjack reflects the sexual dimorphism observed, as females grow to dominate the larger size classes, with no differences apparent for the smaller size classes. No trends were apparent in the age-based sex ratio, confirming that there is no difference in longevity between males and females. Female biased sexual dimorphism has been reported for several species, including wreckfish off the coast of South Carolina, although no ages were associated with these data (MARMAP, unpublished data), spotted seatrout (Wenner, pers comm.). Greater amberjack is an extremely fecund species, producing from 15 to 50 million eggs per individual female in a single spawning season. Females might attain a larger size because fecundity increases so much as size increases. The gains of increased egg production are presumably outweigh the increased costs of achieving a larger size.

Although females in spawning condition were sampled all along the southeast coast, we were unable to locate ovaries containing hydrated oocytes during the first two

years of the study. Anecdotal information identified the Florida Keys as a primary spawning area, and that area was targeted for sampling during the spawning season in 2003. Our data confirm this as the area where the bulk of spawning of greater amberjack appears to occur, and demonstrate that the further north a female amberjack occurs, the less likely it will be in spawning condition. It appears that although amberjack is a wide-ranging species, moving all along the southeast coast and into the Gulf of Mexico (MARMAP unpub. data), a single spawning area might exist. The extent to which spawning events north of 25^{o}N contribute to recruitment is unknown, however, our data suggests the spawning occurring off the Florida Keys between March and May may generate the bulk of recruitment. Although we did not obtain samples from the Florida Keys during June, sampling through May failed to identify individuals in spawning condition beyond May 10, confirming that spawning likely ceases in May.

Although commercial landings of greater amberjack have decreased markedly over time, there has been no indication that greater amberjack is being overfished or experiencing overfishing. However, a relatively large fishery has existed for the species for some time, and there is little long term data to compare current life history parameters to in order to identify any changes that may have occurred over time. However, amberjack were larger at age than the only other age and growth study examining amberjack off the southeastern US, perhaps suggesting the early stages of overexploitation as population numbers decrease, and more resources become available for fewer fish. The growth and reproductive characteristics of amberjack – extremely fast growth, early maturation, very high fecundity, and wide distribution, make them an unlikely candidate for overexploitation at this point in the development of the fishery.

The potential negative impact of fishing during the spawning season has been largely curtailed by a fishery closure during April, the month of peak spawning.

A full stock assessment has not been conducted for amberjack off the southeastern United States. In the absence of one, and the lack of long-term historical life history data, it is difficult to ascertain the current status of the population. However, it would seem that the robust nature of the species would make it an unlikely candidate to experience overfishing in the current fishery.

Project Personnel

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Table 1. The parameters derived from the von Bertalanffy growth equation fitted to individual size at age data for greater amberjack, 2000-2004.

Sex	L_∞	k	t_0
Combined	1241.5	0.28	-1.56
Male	1105.6	0.36	-1.42
Female	1351.6	0.22	-1.83

Table 2. The sex ratio of greater amberjack sampled off the southeastern United States during 2000-2003 for 100 mm length classes, and ages. Only collections during which amberjack were randomly sampled were used to derive sex ratio.

Length Class (mm FL)	Male	Female	Sex Ratio (male:female)	χ^2	*p*	H_0
201-300	1	0	1:0			
301-400	5	5	1:1			
401-500	3	8	1:2.6	2.27	0.132	Accept
501-600	5	12	1:2.4	2.88	0.089	Accept
601-700	34	47	1:1.4	2.08	0.148	Accept
701-800	136	134	1:0.98	0.015	0.9	Accept
801-900	269	269	1:1			
901-1000	351	280	1:0.79	7.98	0.005	Reject
1001-1100	259	294	1:1.14	2.22	0.136	Accept
1101-1200	39	211	1:5.4	118.3	<0.0001	Reject
1201-1300	3	77	1:25.7	68.5	<0.0001	Reject
1301-1400	2	15	1:7.5	9.94	0.0016	Reject
1401-1500	0	2	0:1			
Age class (year)						
0	1	4	1:4			
1	11	11	1:1			
2	89	118	1:1.34	4.06	0.04	Reject
3	298	329	1:1.1	1.53	0.22	Accept
4	218	241	1:1.1	1.15	0.28	Accept
5	113	146	1:1.29	4.2	0.04	Reject
6	45	76	1:1.69	7.94	0.005	Reject
7	16	31	1:1.94	4.79	0.029	Reject
8	12	19	1:1.58	1.58	0.21	Accept
9	6	11	1:1.83	1.47	0.22	Accept
10	4	5	1:1.25	0.11	0.73	Accept
11	3	4	1:1.33			
12	1	1	1:1			
13	3	1	1:0.33			

Table 3. Linear regression coefficients for the relationship between fork length (FL in mm) and total fecundity (TF) of greater amberjack, 2000-2004. The effect of month on this relationship was evaluated with analysis of covariance. **p<0.0001; *p<0.01.

Linear equation TF = a + bFL						Analysis of covariance			
Month	a	b	adj. r^2	F	n	Variables	df	F	P
March	-1982884	22411	0.519	**25.82	24	Month	2	1.47	0.2367
April	-1324035	17591	0.330	*13.84	27	FL	1	54.94	<0.0001
May	-9027906	12760	0.344	*16.18	30	Month * FL	2	1.38	0.2578
						Error	75		
						Total	80		

Table 4. Number of female greater amberjack with hydrated oocytes or migratory nucleus (MN) oocytes, < 24 h old postovulatory follicles (POFs), and total number of mature females with oocytes undergoing vitellogenesis in samples collected off the Florida Keys with snapper reels by commercial fishers during February through April of 2001-2004. The proportions were averaged to estimate spawning frequency.

Date	No. with MN or hydrated oocytes	No. with < 24 h old POFs	Total mature females
February	-	1	3
March	9	6	53
April	45	46	195
May	15	25	73
Total	69	78	324
Proportion of total	0.213	0.241	

Table 5. Linear regression coefficients for the relationship between batch fecundity (BF; number of migratory nucleus and hydrated oocytes) and total length (mm), fork length (mm), and age in greater amberjack, *Seriola dumerli*. Specimens were collected off the Florida Keys with snapper reels by commercial fishers during March and April of 2003-04. **P<0.0001 and *P<0.001.

Linear equation BF = a + bX

X	a	95%CI	b ($x10^3$)	95%CI ($x10^3$)	Adjusted r^2	F	N	Range
Total length (mm)	-8,184,324	± 3,342,577	8.690	± 2.744	0.6053	42.40**	28	1080-1425
Fork length (mm)	-6,394,879	± 3,155,960	8.192	± 2.938	0.5413	32.87**	28	936-1296
Age	254,065	± 1,374,902	458.601	± 276.033	0.3567	12.09*	21	3-7

Figure Legends

Figure 1. Commercial and recreational landings of greater jack off the southeastern United States.

Figure 2. Capture locations for greater amberjack 2000-2004. Fishery-dependent location data may be approximate.

Figure 3. Length frequency of all greater amberjack (a) and males and females (b) sampled during 2000-2004.

Figure 4. Age frequency of all greater amberjack (a) and males and females (b) sampled during 2000-2004.

Figure 5. The relationship between otolith weight and age for greater amberjack sampled during 2000-2004. A total of 397 otoliths were weighed. Error bars represent ± 1 standard error.

Figure 6. The mean size at age for male and female greater amberjack, 2000-2004. The von Bertalanffy growth curve is that fitted to the combined data set. Error bars represent ± 1 standard error.

Figure 7. A comparison study of the mean size at age of greater amberjack from several studies in the Gulf of Mexico and Atlantic.

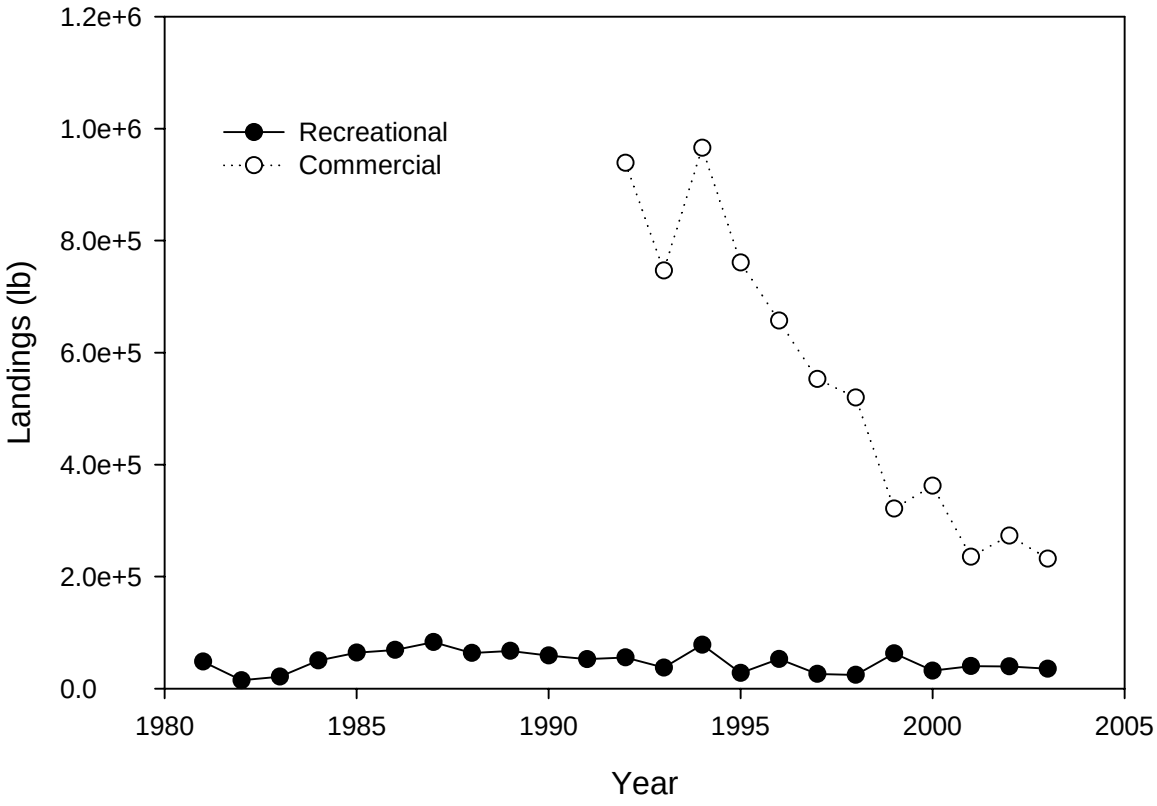
Figure 8. Comparison of length frequencies of female (A) and male (B) greater amberjack collected during fishery-dependent and fishery-independent sampling in 2000-04 that were categorized as immature, definitely mature, or resting. Definitely mature specimens were developing, ripe, or spent.

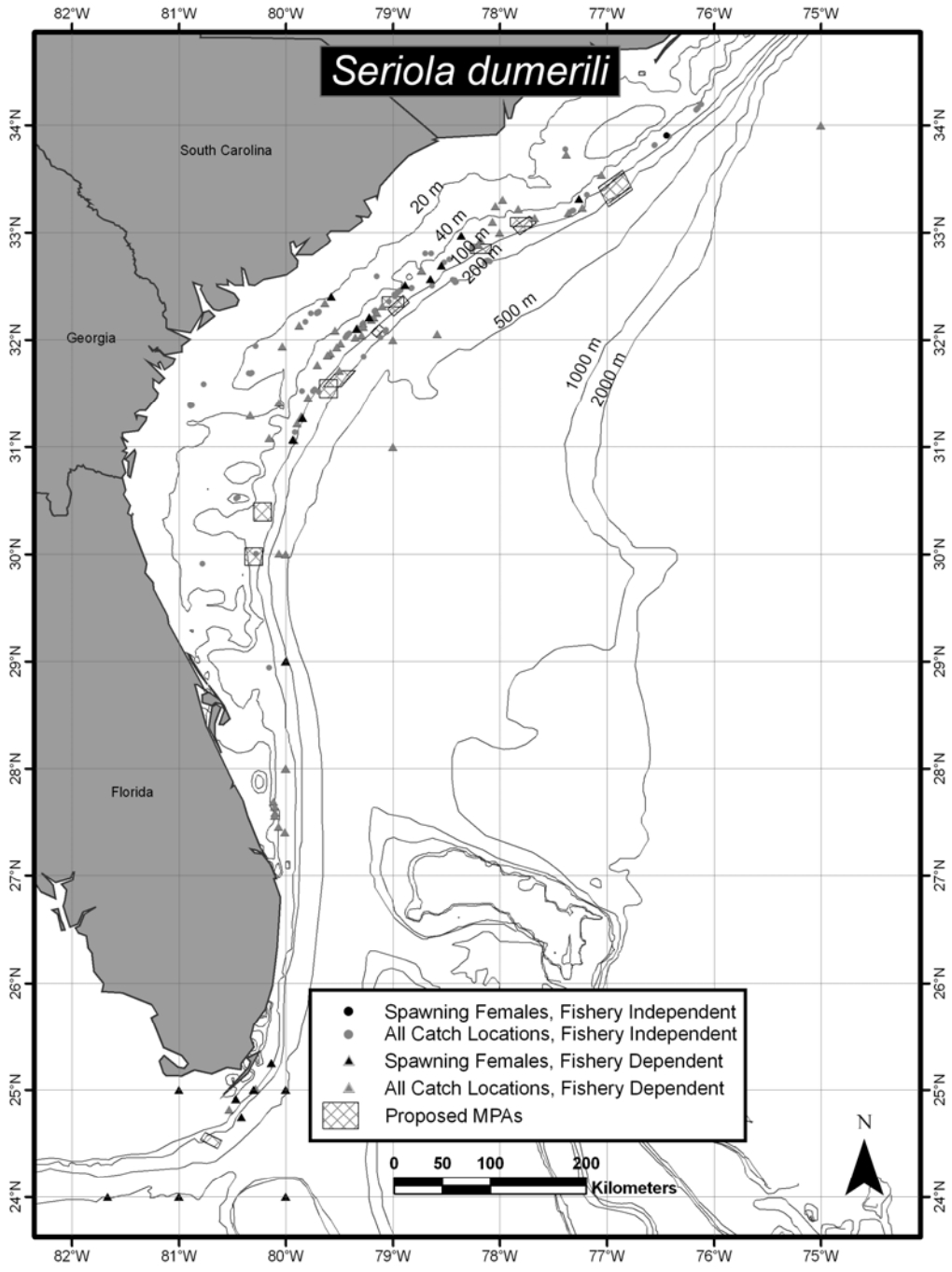
Figure 9. Spawning by month of female greater amberjack for three latitudinal zones. Male spawning season is not shown as most males were in spawning condition well before and well after the female spawning season.

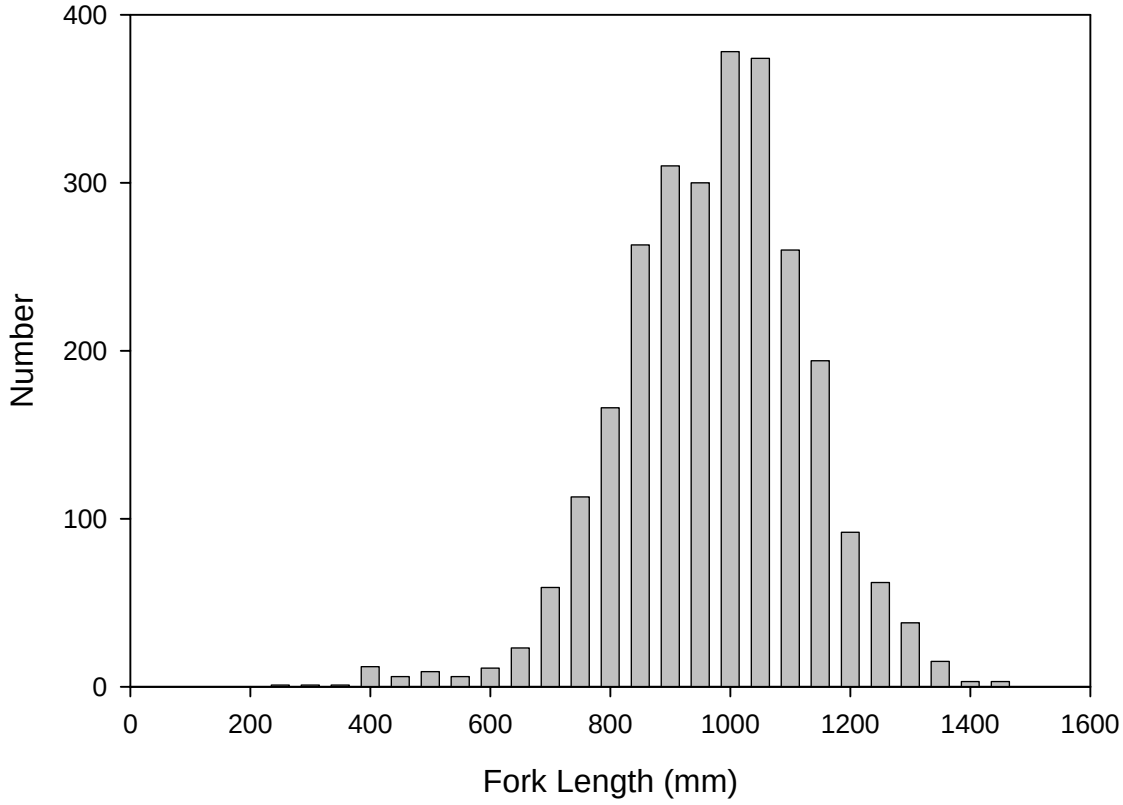
Figure 10. Estimates of total fecundity in greater amberjack relative to fork length during March, April and May.

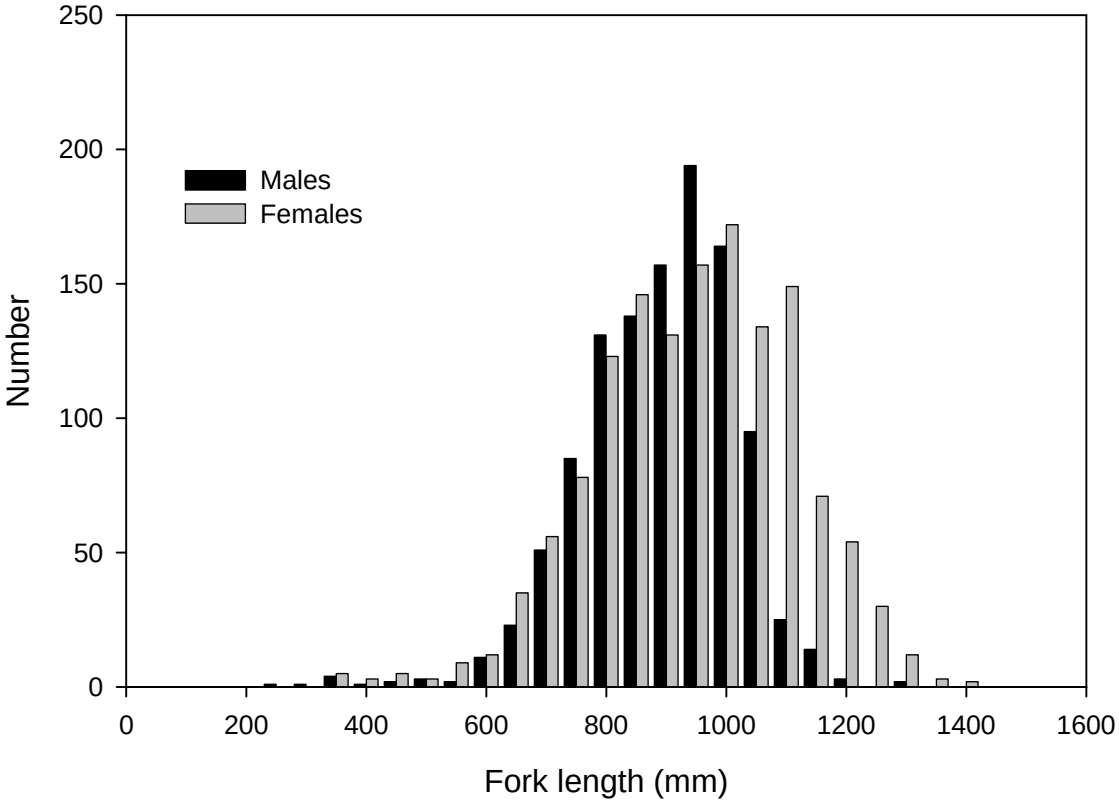
Figure 11. Percentage frequency by diameter for two stages of vitellogenic oocytes stages (see Hunter et al. 1992) in 15 greater amberjack (five specimens per month). Specimens were collected off the Florida Keys with snapper reels by commercial fishers during February through April of 2001-04.

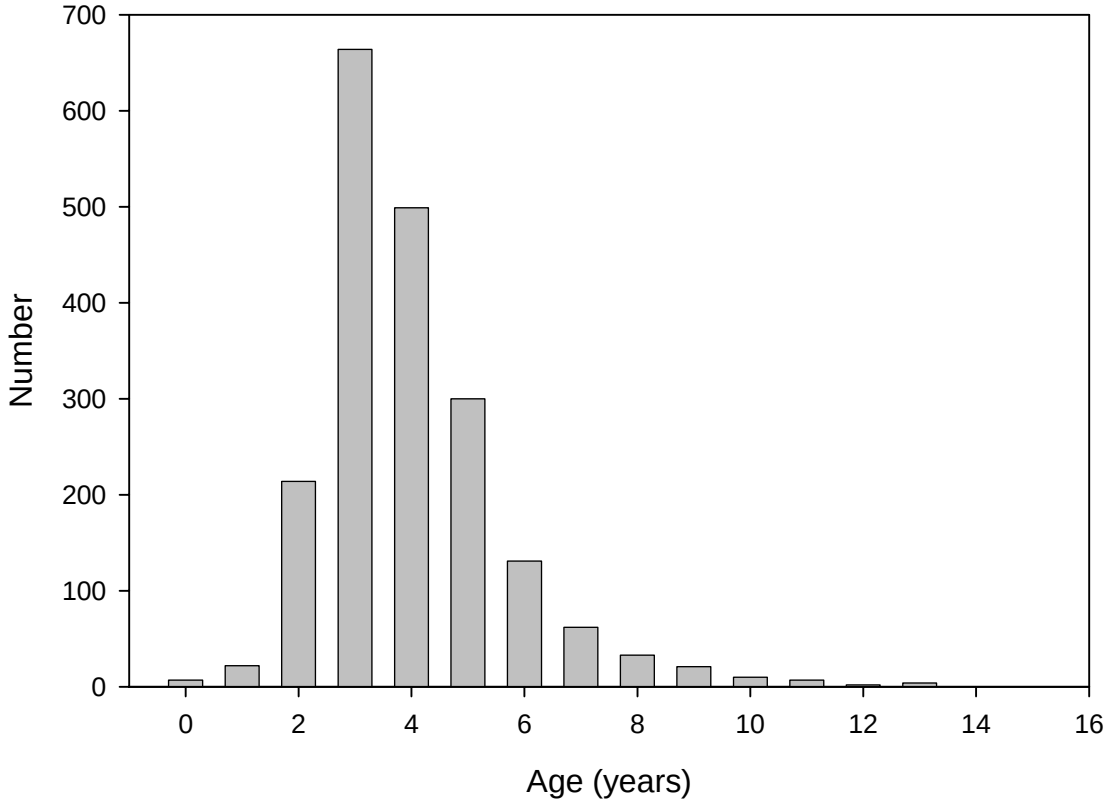
Figure 12. Estimates of batch fecundity in greater amberjack relative to fork length during March and April. Migratory-nucleus and hydrated oocytes were counted in 28 specimens that were captured off the Florida Keys with snapper reels in the commercial fishery during 2003-04.

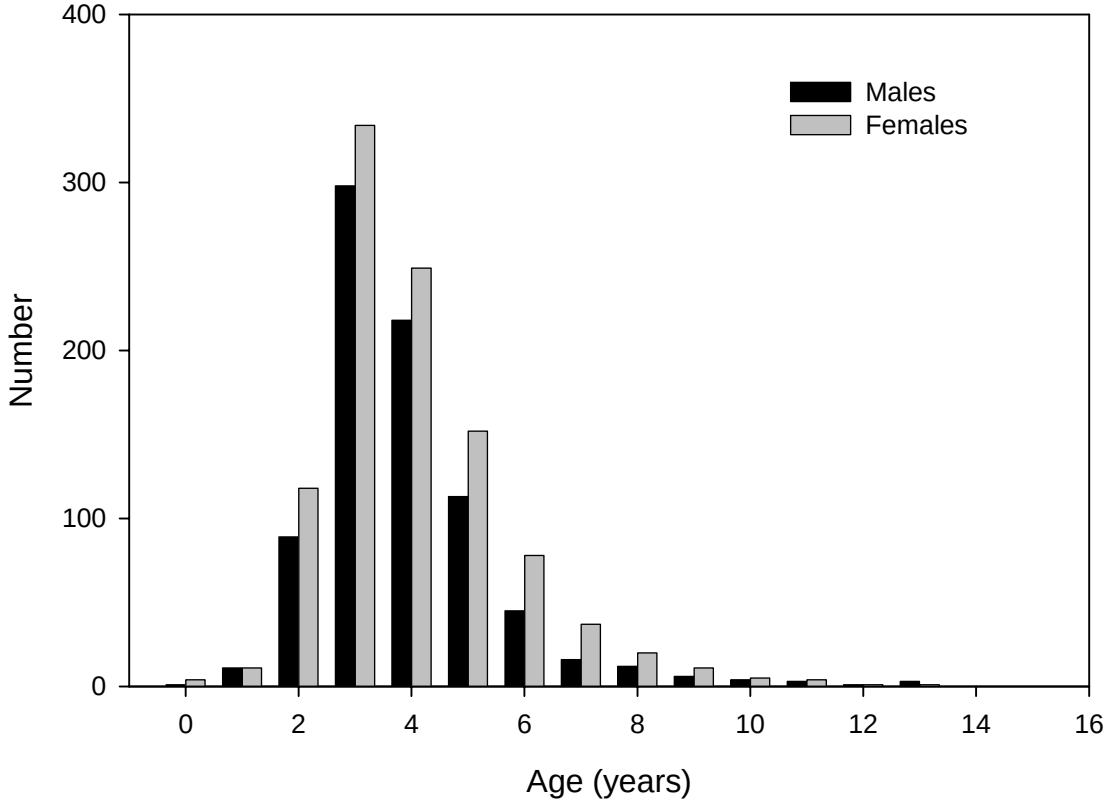

1.2e+6
1.0e+6
8.0e+5
6.0e+5
4.0e+5
2.0e+5
0.0
Landings (lb)
Recreational
Commercial
1980
1985
1990
1995
2000
2005
Year

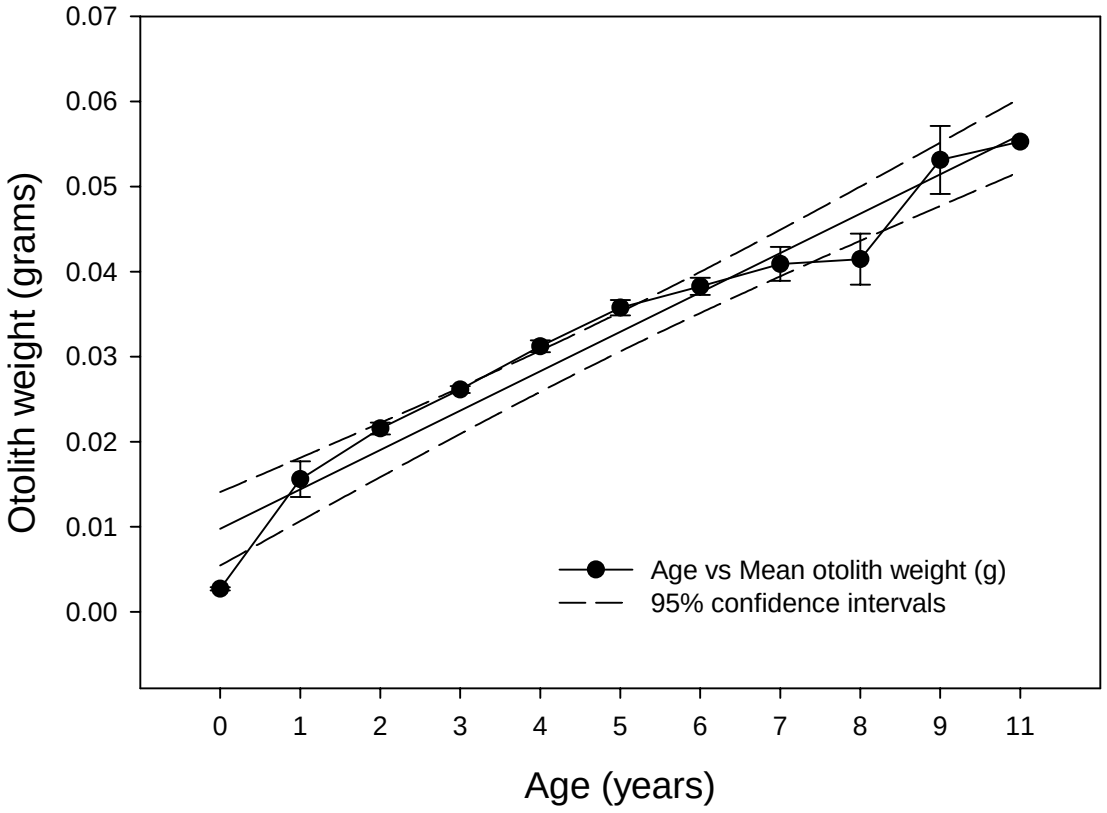

Seriola dumerili
South Carolina
Georgia
Florida
20 m
40 m
100 m
200 m
500 m
1000 m
2000 m
Spawning Females, Fishery Independent
All Catch Locations, Fishery Independent
Spawning Females, Fishery Dependent
All Catch Locations, Fishery Dependent
Proposed MPAs
0 50 100 200
Kilometers
N
82°W
81°W
80°W
79°W
78°W
77°W
76°W
75°W
34°N
33°N
32°N
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N

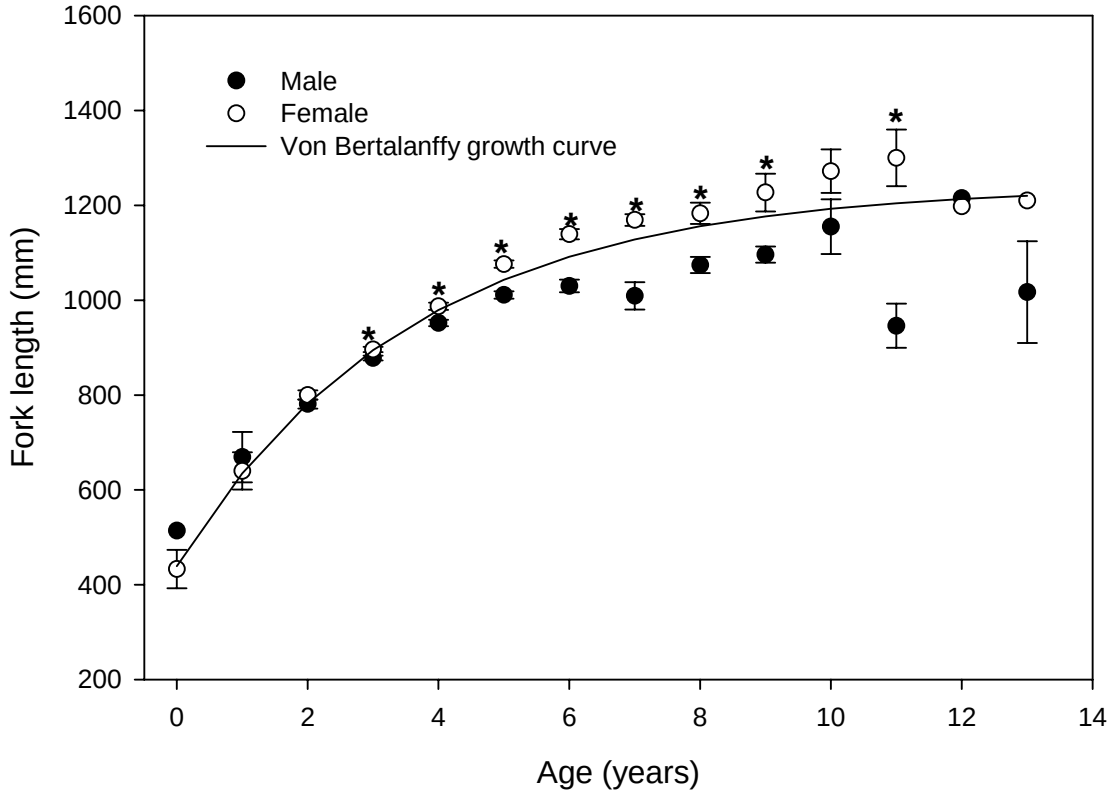

400
300
200
100
0
Number
0
200
400
600
800
1000
1200
1400
1600
Fork Length (mm)

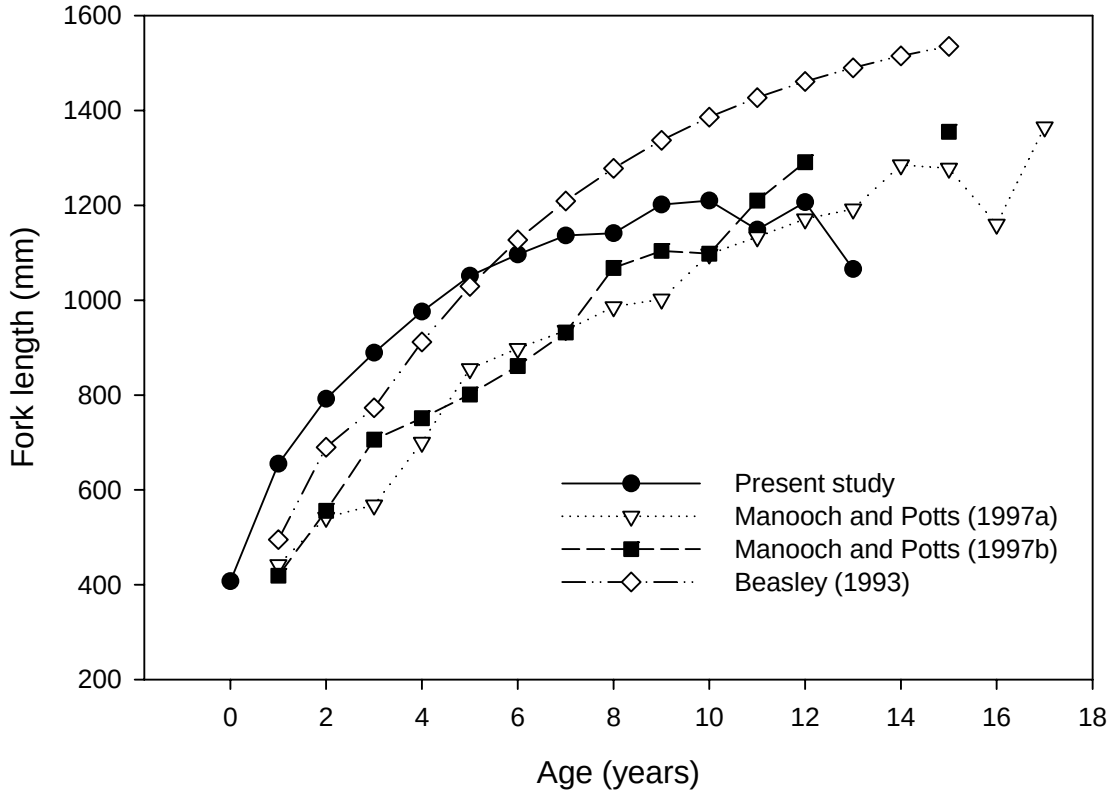

250
200
150
100
50
0
Number
Males
Females
0
200
400
600
800
1000
1200
1400
1600
Fork length (mm)

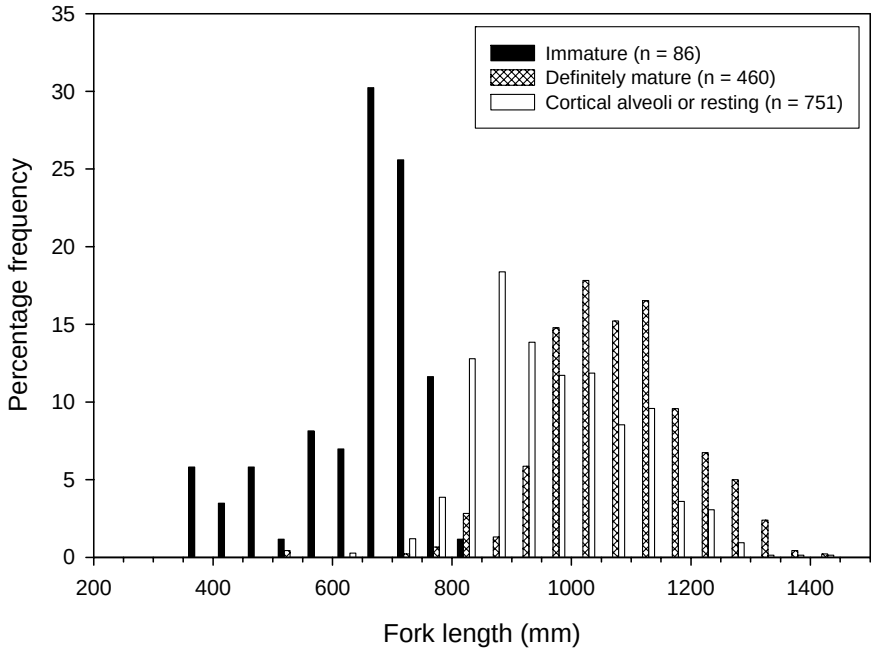

700
600
500
400
300
200
100
0
Number
0
2
4
6
8
10
12
14
16
Age (years)


400
300
200
100
0
Number
Males
Females
0
2
4
6
8
10
12
14
16
Age (years)

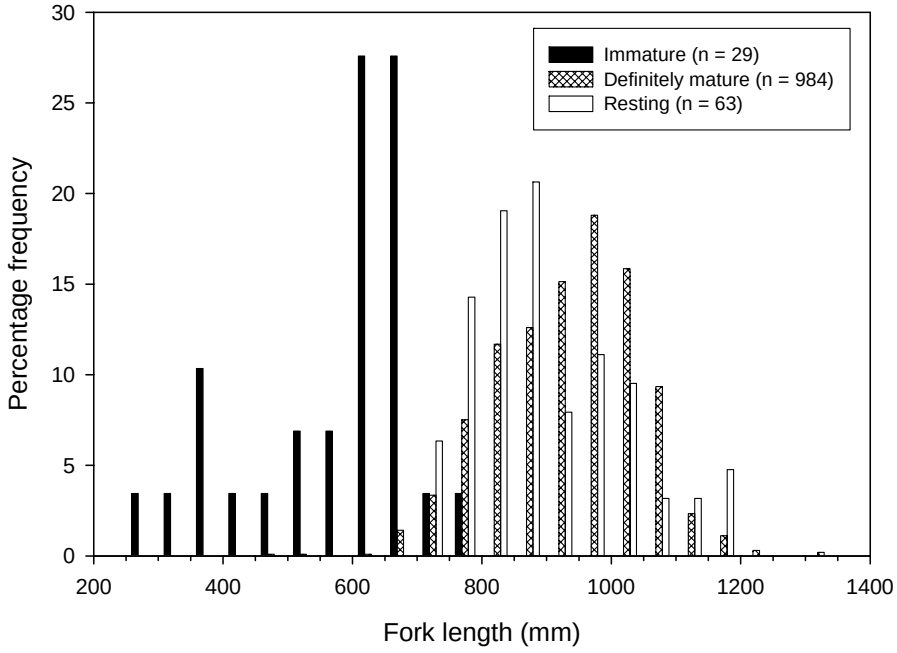

0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Otolith weight (grams)
0
1
2
3
4
5
6
7
8
9
11
Age (years)
Age vs Mean otolith weight (g)
95% confidence intervals


Male
Female
Von Bertalanffy growth curve
Fork length (mm)
Age (years)
1600
1400
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
*

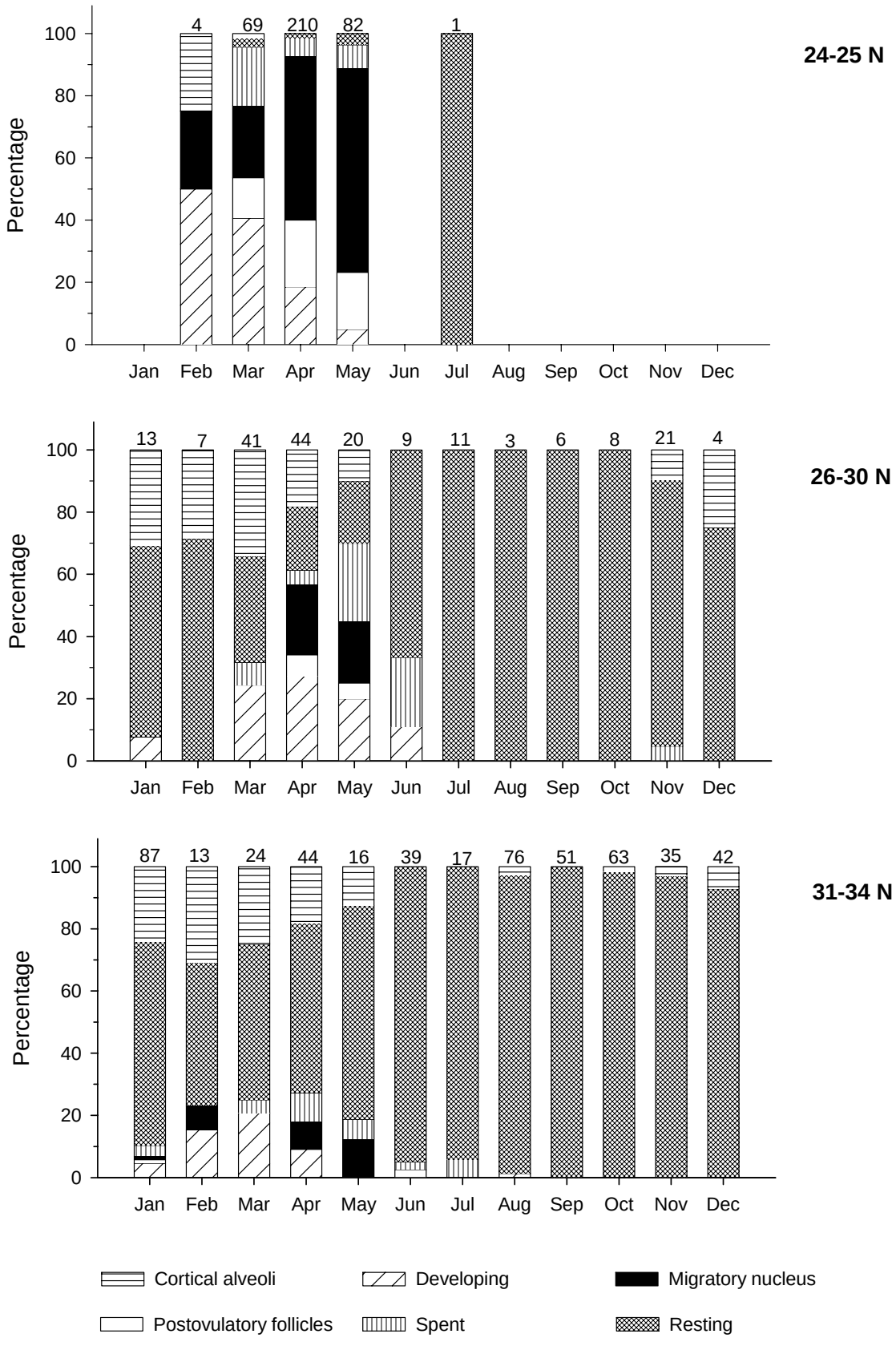

1600
1400
1200
1000
800
600
400
200
Fork length (mm)
0
2
4
6
8
10
12
14
16
18
Age (years)
Present study
Manooch and Potts (1997a)
Manooch and Potts (1997b)
Beasley (1993)

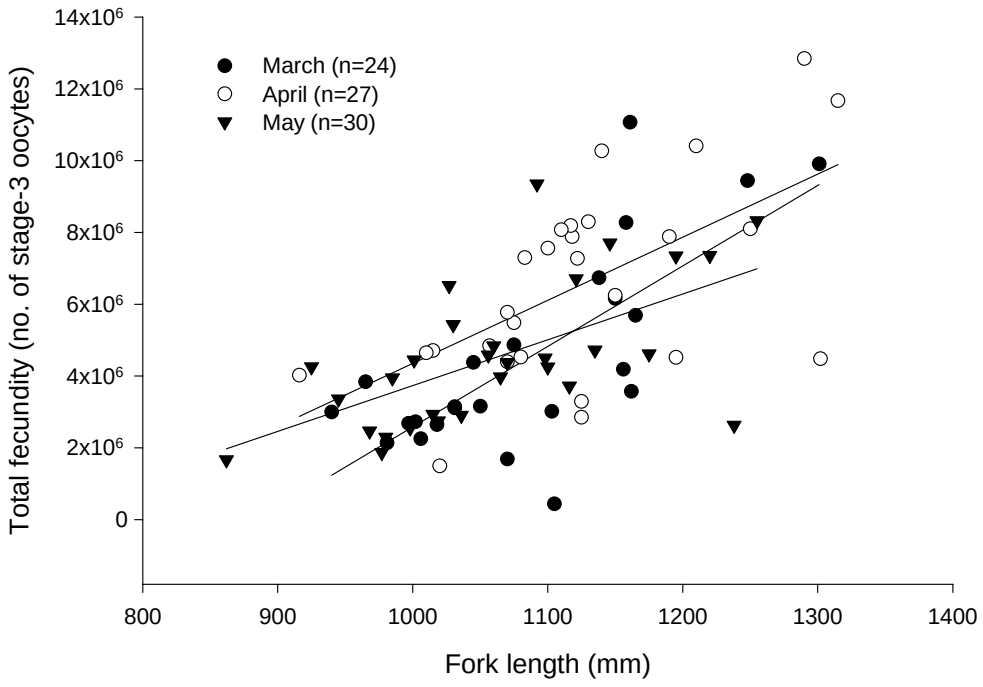

Immature (n = 86)
Definitely mature (n = 460)
Cortical alveoli or resting (n = 751)
Percentage frequency
Fork length (mm)
0
5
10
15
20
25
30
35
200
400
600
800
1000
1200
1400

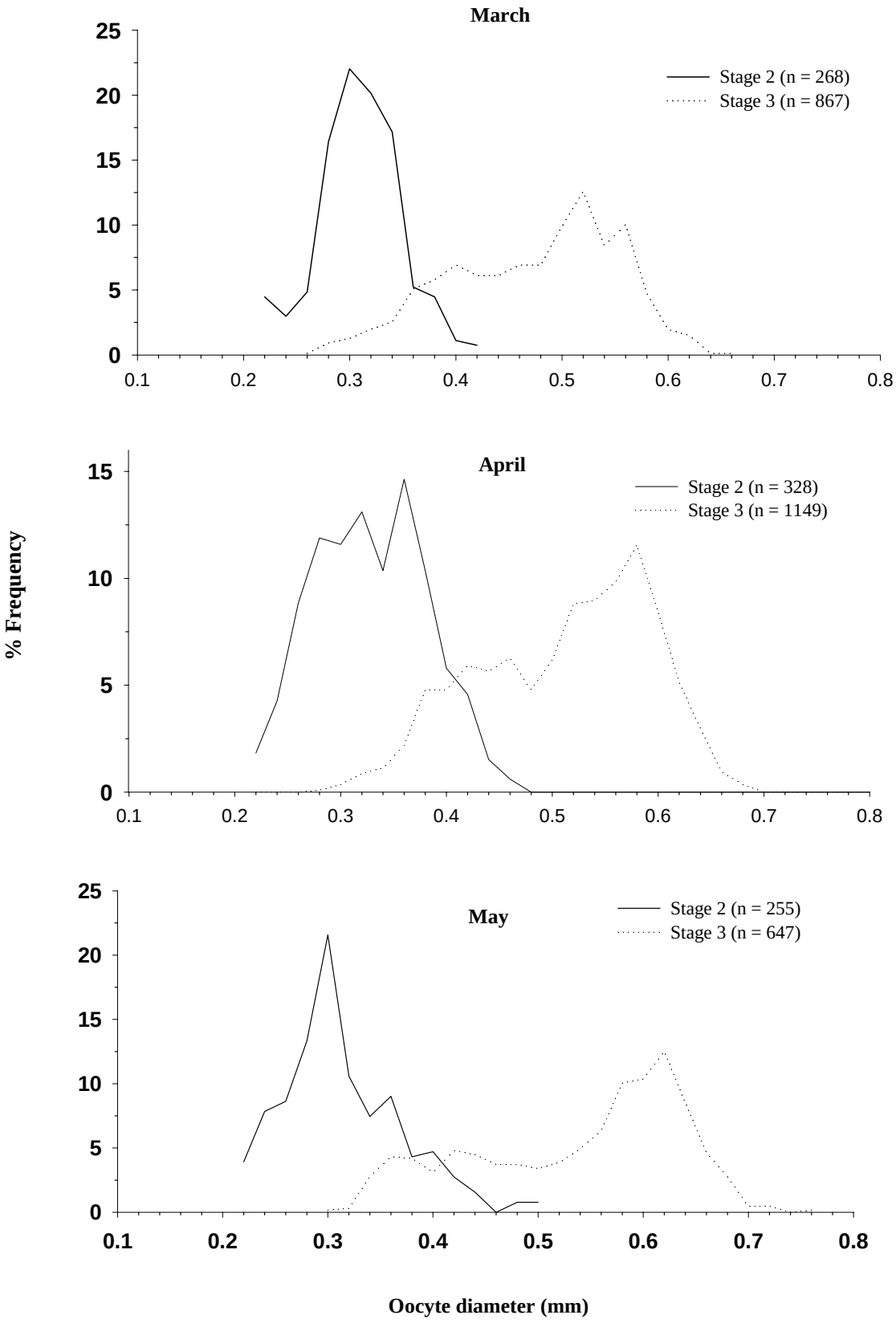
Female

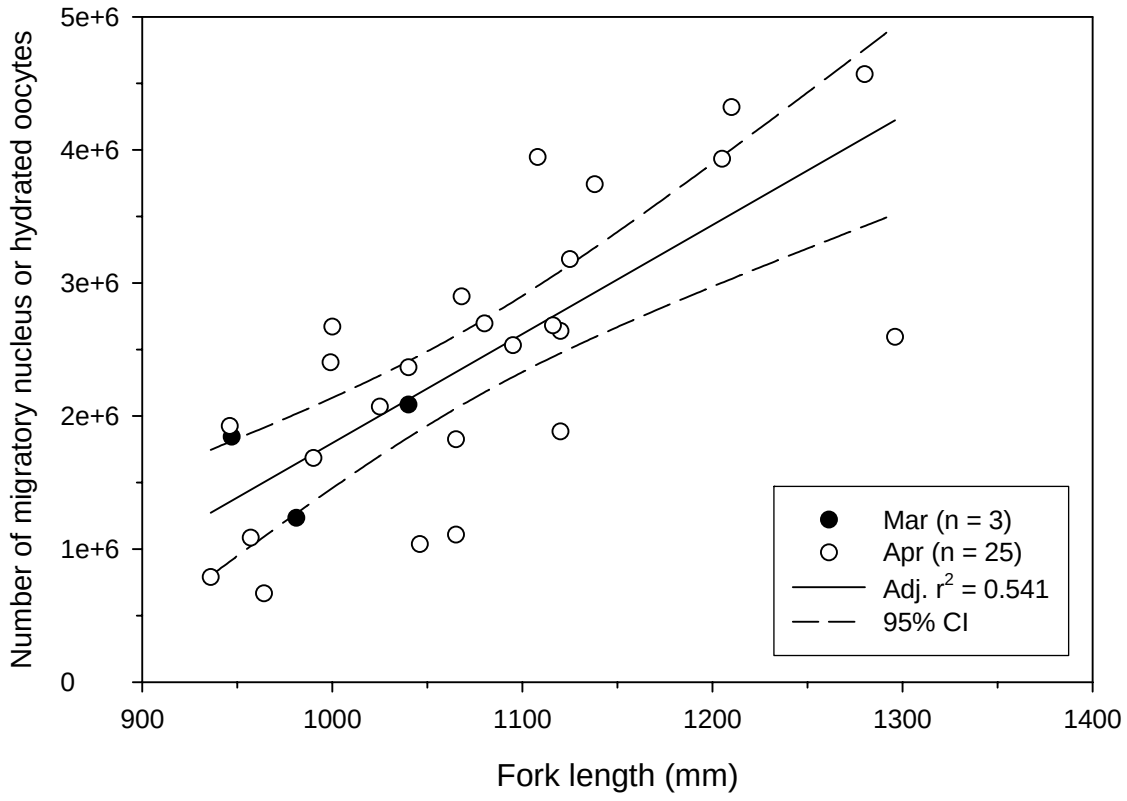

Immature (n = 29)
Definitely mature (n = 984)
Resting (n = 63)
Percentage frequency
Fork length (mm)
0
5
10
15
20
25
30
200
400
600
800
1000
1200
1400

Male


24-25 N
26-30 N
31-34 N
Percentage
0
20
40
60
80
100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
4
69
210
82
1
13
7
41
44
20
9
11
3
6
8
21
4
87
13
24
44
16
39
17
76
51
63
35
42
Cortical alveoli
Developing
Migratory nucleus
Postovulatory follicles
Spent
Resting


14x10⁶
12x10⁶
10x10⁶
8x10⁶
6x10⁶
4x10⁶
2x10⁶
0
Total fecundity (no. of stage-3 oocytes)
March (n=24)
April (n=27)
May (n=30)
800
900
1000
1100
1200
1300
1400
Fork length (mm)


March
Stage 2 (n = 268)
Stage 3 (n = 867)
April
Stage 2 (n = 328)
Stage 3 (n = 1149)
May
Stage 2 (n = 255)
Stage 3 (n = 647)
% Frequency
Oocyte diameter (mm)


Number of migratory nucleus or hydrated oocytes
5e+6
4e+6
3e+6
2e+6
1e+6
0
900
1000
1100
1200
1300
1400
Fork length (mm)
Mar (n = 3)
Apr (n = 25)
Adj. r2 = 0.541
95% CI