

## ABSTRACT

Schwenke, Kara Laurice. Age, growth and reproduction of dolphin (*Coryphaena hippurus*) caught off the coast of North Carolina. (Under the supervision of Jeffrey A. Buckel)

The common dolphin (*Coryphaena hippurus*) supports economically important fisheries along the east coast of the United States. In recent years, landings of dolphin from the United States Atlantic have increased dramatically. For example, recreational landings in the US South Atlantic Bight have increased from 162,000 dolphin in the 1960s to over 1.3 million dolphin in recent years. The last age and growth study of North Carolina dolphin was conducted in the early 1960s. It is hypothesized that life history parameters may have changed due to increased exploitation. Age, growth and reproduction were studied on dolphin (n=802; size range=89 to 1451 mm FL) collected between May 2002 and May 2004 from commercial and recreational catches in North Carolina. Annual increments from scales (n=541) and daily increments from sagittal otoliths (n=126) were examined; estimated von Bertalanffy parameters were  $L_{\infty} = 1299$  mm FL and  $k = 1.08 \text{ yr}^{-1}$ . The maximum age observed was 3 years. No major change in length at age has occurred since the early 1960s. Daily growth increments for age-0 dolphin reduced much of the variability in length-at-age values for age-0 dolphin and provided an average growth rate of 3.78 mm/day in the first six months, which is extremely fast for a teleost fish. Growth of North Carolina dolphin is similar to that found in Florida and the Mediterranean but differs from observed growth in the Caribbean and Gulf of Mexico. Age at 50% maturity was around 4 months for female dolphin and 6 months for male dolphin. Monthly length-adjusted gonadal weights suggest that peak spawning occurs from April through July off North Carolina; back-calculated hatch dates from age-0 dolphin along with prior studies on the east coast of Florida suggest that

dolphin spawning occurs year round with highest levels from January through June. This study provides an updated and improved (year-round sampling and otolith daily ages) age-length function for dolphin caught off the coast of North Carolina using both scale annuli and daily growth increments and provides some of the first comprehensive data on North Carolina dolphin reproduction. The life history of dolphin, including fast growth and early maturity, allows for high levels of exploitation.

**AGE, GROWTH AND REPRODUCTION OF DOLPHIN (*CORYPHAEHAENAHIPPURUS*)  
CAUGHT OFF THE COAST OF NORTH CAROLINA**

by  
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## BIOGRAPHY

Kara Laurice Schwenke was born September 16<sup>th</sup>, 1977 in Naples, Italy. Her father, George, a meteorologist for the United States Navy was stationed in Sigonella, Sicily, where her mother, Janet and her two brothers, Kris and Erik, had also re-located. The Schwenke family later moved back to the states and grew by two more girls, with the addition of Kara's younger sisters, Amy and Lise. In 1995, Kara graduated from Broadneck High School in Annapolis, MD and attended Salisbury State University on the eastern shore of MD. Kara majored in the marine science dual-degree program through Salisbury State University and graduated in December 1999 with a biology degree from Salisbury and an environmental science degree from the University of Maryland Eastern Shore. After graduation, she soon went on to work for the Maryland Department of Natural Resources as a Natural Resource Biologist. Her stint at the DNR allowed her to participate in an array of field work, but her primary job responsibility while there was to collect biological information that would be used to quantify the health of aquatic ecosystems. While at the DNR, she pulled many a beach seine, collected water quality information, was a member of a "rapid-response" team trained to respond to *Pfiesteria* outbreaks, sampled macroalgae in the coastal bays of MD in mid-November (not recommended to anyone!) and most importantly, met a lot of good friends. After working for the Maryland Department of Natural Resources for 2 years, she decided it would be a good stopping point, and began actively looking for graduate programs in fisheries biology. In March of 2002, she interviewed with Dr. Jeff Buckel, and two months later, she packed up her bags and moved south to Morehead City, North Carolina to begin her masters research at North Carolina State University.

Kara lived in Morehead City, North Carolina from May 2002 through August 2002 to start her data collection, and then once again packed up her bags to move to NCSU's main campus in Raleigh, NC. Kara took the majority of her coursework during that time, and also had the opportunity to student teach a Zoology laboratory section. Although she enjoyed the big city life, she yearned for life (and fishing) on the coast. In May 2003, she returned to Morehead City, NC, where she has remained throughout her graduate tenure working at North Carolina State University's Center for Marine Science and Technology.

Kara has accepted a job with the North Carolina Division of Marine Fisheries out of Morehead City, NC working as a recreational saltwater sportfishing specialist. She will be the new coordinator for the North Carolina Saltwater Fishing Tournament and will be assisting with recreational sportfishing tournaments throughout the coast of North Carolina. She is extremely grateful that she will be able to remain in an area she has grown to treasure, surrounded by people she loves.

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Thanks to all the CMAST technicians, past and present, especially: Paul Rudershausen, Josh Arnott, Carrie Kennedy, Carole Yoder, Melyssa May, Andrew Flynt and Jason Edwards. Paul Rudershausen served as the independent reader for scale readings, so I thank him for that as well. I'd like to thank all of the faculty, staff and graduate students at both CMAST and the Zoology department at NC State University, especially my fellow Buckel-lab graduate students: Nate Bacheler, Jack Tuomikoski and Jim Morley. An extra thanks to Jim for being my office mate and providing me with statistical advice and much-needed laughter breaks. Thanks in particular to a past CMAST graduate student – Anna Barrios, who has proven to be not only a good roommate, but a great friend as well.

Perhaps my biggest thank you goes out to my family. Mom and Dad, there are no words to describe how grateful I am to both of you. No matter what path I chose, you supported me 100%. You have been there through all of the turmoil and triumphs, and for that I dedicate all of my hard work to you. Kris, Erik, Amy (and Abbey!) and Lise, thank you so much for supporting me through everything – I love you guys so much. To all of my close friends, I thank you too for the constant support and friendship. Lastly, I'd like to thank my best friend, Jay. You have introduced me to so many feelings and experiences that I now can't imagine myself without. Thank you for all of your love and patience and for making me feel so at home here.

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# **Age, Growth and Reproduction of Dolphin (*Coryphaena hippurus*) caught off the coast of North Carolina.**

## **1.1 INTRODUCTION**

In order to gain insight into the degree of exploitation a stock may endure without declining, relevant biological data on vital rates (growth, maturity, fecundity, mortality) are essential. The knowledge of age and growth in fishes is fundamental for fishery biology and management, and age-determined parameters such as growth, mortality and maturity support population dynamics models used by stock assessment biologists (DeVries and Frie, 1996). For a species that is both recreationally and commercially important, it is particularly important to obtain modern life history data that can be used in fishery management plans to ensure a sustainable harvest.

The common dolphin (*Coryphaena hippurus*) is an oceanic pelagic fish found worldwide in tropical and subtropical waters. The range for dolphin in the western Atlantic is from George's Bank, Nova Scotia (Vladykov and McKenzie, 1935; Tibbo, 1962) to Rio de Janeiro, Brazil (Ribeiro, 1918; Scherbachev, 1973). However, it is generally considered to be common only from North Carolina throughout the Gulf of Mexico and Caribbean to the northeastern coast of Brazil and is only seasonally abundant at these locations (Oxenford, 1999). This species supports economically important recreational and commercial fisheries from North Carolina through the Gulf of Mexico and within the Caribbean Sea.

In recent years, landings of dolphin from the Atlantic (Figure 1), Caribbean and Gulf of Mexico waters have increased. Recreational landings have increased gradually to a level of about 10-14 million pounds whereas commercial landings have increased dramatically,

with recent landings varying between approximately 600,000 and 1.4 million pounds (Figure 1). Although dolphin are fast growing and mature early, concern has been raised about recent increases in landings and how that could result in localized depletion of stocks and a shift in the historical levels of catch between commercial and recreational fishers.

Charter boats and private boats take the majority of the recreational catch of dolphin, and the charter boat sector depends on dolphin as one of the main attractions for their clientele (SAFMC, 2003). Since the size of fish caught and catch success rates are important determinants of the quality of the recreational charter boat fishing experience, gear selectivity is often biased towards larger fish. However, selectively harvesting larger and older specimens from a fish population may have detrimental effects. Conover and Munch (2002) found that when a marine fish population undergoes intensive positive size-selective mortality, somatic growth, yield and population biomass are negatively influenced. Sinclair et al. (2002) suggested that size-selective mortality has important impacts on the growth potential of a population and its effects may remain long after fishing is reduced. Thus there may have been selection for slower dolphin growth rates over the past 30-40 years due to intensive size-selective fishing.

Dolphin are under the jurisdiction of the federal Fishery Management Councils. In 2004, the South Atlantic Fishery Management Council approved the Fishery Management Plan for dolphin [and wahoo (*Acanthocybium solanderi*)] of the Atlantic, Caribbean, and Gulf of Mexico. The ultimate goal of the plan is to take a precautionary and risk-averse approach to protecting the southeast's dolphin fishery (SAFMC, 2003). Presumably brought on by the dramatic increase in commercial and recreational dolphin landings, the fishery management plan addresses the following issues/problems: localized reduction of fish

abundance due to high fishing pressure; conflict and/or competition between recreational and commercial user groups of dolphin; reduced social and economic benefits; bycatch; and the lack of biological, habitat, economic, and social information about dolphin stocks and fisheries.

Prager (2000) conducted the first comprehensive stock assessment for dolphin based on landings from the U.S. Atlantic and Gulf of Mexico. The life history of dolphin and estimates generated by Prager (2000) suggest the species may be able to withstand a relatively high rate of exploitation. However, Prager (2000) indicates that under excessive mortality rates, even a species resistant to exploitation may undergo geographically or temporally localized depletion. Furthermore, the current stock structure is only based on limited evidence and the estimates of vital rates are several decades old (Prager, 2000).

Some information on the life history of dolphin is already available. There is general agreement that all dolphin in the western central Atlantic reach sexual maturity in the first year of life, and that females reach maturity at a smaller size, but similar age to males (Oxenford, 1999). The presence of several size classes of eggs in the ovaries indicates that they are batch spawners and probably spawn at least two or three times in each spawning period (Oxenford, 1999). Reproduction studies based on gonad observations, egg diameter measurements and counts of maturing eggs indicated that female dolphin can produce 80,000-1,000,000 eggs at each spawning (Beardsley, 1967). Several Atlantic dolphin age and growth studies have shown that dolphin are a short-lived, fast-growing species (e.g. Rose and Hassler, 1968, Beardsley, 1967). Marked differences in first year growth rates can occur between locations, but most agree that dolphin in the western central Atlantic grow extremely fast and have an average longevity of less than 2 years (Oxenford, 1999).

Little attention has been paid to conducting biological stock assessments and developing management strategies for western Atlantic dolphin. Given the importance of dolphin to North Carolina's commercial and recreational fisheries, it would be valuable to have up-to-date information from locally caught fish. The age and growth data currently available for North Carolina dolphin were last obtained in the 1960s using scale annuli, a method which has lost some validity since the study was completed. Additionally, reproductive information presented here is some of the first for dolphin collected throughout the year in North Carolina. Current life history information can be used to examine whether life history parameters have changed due to the recent increases in recreational and commercial landings.

This study aims to update the age, growth and reproduction data that are currently available for North Carolina dolphin. Specific objectives were to: 1) collect a broad range of dolphin sizes from recreational and commercial landings; 2) collect fishery independent samples of underrepresented dolphin (small age-0 dolphin); 3) determine daily ages of age-0 dolphin; 4) determine the best method of aging age-1+ dolphin (otolith or scale annuli), and to determine the annual ages of age-1+ dolphin; 5) validate annuli; and 6) collect reproductive information on dolphin captured in North Carolina.

## **1.2 METHODS**

### **1.2a Recreational and Commercial Dolphin Sampling**

Dolphin from recreational fishery-dependent sources were obtained every month between May 2002 and May 2004 except for December 2002 and 2003, January 2003 and February 2004 from Morehead City, NC. Recreational fishers typically fished for dolphin up to 130 km offshore. Sampling was conducted in other areas along the coast (Hatteras,

Wilmington) if convenient (Figure 2). In the months of April through September, the primary source of dolphin was recreational charter catches. During the fall and winter months, recreational and commercial sampling was conducted in Morehead City when fish were available, but more intense recreational sampling was conducted in Hatteras, NC since many Gulf Stream charter trips are still made during that time. In the summers of 2002-2003, various sportfishing tournaments held in these same areas provided a large sample size of older fish for age and growth analysis.

Sampling took place soon after the catch was brought to the dock. Each dolphin was measured to the nearest mm for fork length (FL) and total length (TL), sexed externally (determined from the sexual dimorphism of the species), weighed (to the nearest 0.1 kg), and tagged with a unique label. Date and location captured (Morehead City, Wilmington or Hatteras) were recorded for each dolphin sampled. Scale samples were collected according to methods established by Beardsley (1967). Twenty to thirty scales from each fish were collected from an area just above the lateral line behind the tip of the pectoral fin. Dolphin were then filleted, which does not damage the gonads. The tagged carcasses were brought back to the lab for otolith and gonadal extraction.

Gulf Stream recreational charter trips off the coast of North Carolina are typically only made in the months of March through November, and therefore sampling of commercial catches were conducted in the winter months with hopes that dolphin would be available. Additionally, “Dolphin wanted” flyers were posted at commercial fish houses. Commercial dolphin samples came from local fish markets and wholesale suppliers. Sampling of commercially-caught dolphin was not done in an attempt to characterize the

commercial fishery, but simply to increase the sample sizes available for this age and growth analysis.

Small dolphin were not readily available through recreational and commercial sampling, so sample sizes were augmented using two different methods. Four fishery-independent trips were made aboard the F/V Old Smokey in August 2003 and July 2004. During these trips, the distance traveled offshore averaged 12 miles, which is considerably shorter than typical offshore charter boat recreational fishing trips. Additionally, small lures were trolled as opposed to large dead/artificial baits. A second method of obtaining small dolphin was from stomachs of larger dolphin and yellowfin tuna caught by the recreational charter boat sector.

Length-weight relationships were determined using a nonlinear function of the form:

$$W=aL^b$$

where W is the weight (kg) and L is the fork length (mm). The parameters a and b were estimated for both males and females to test for isometry. When b = 3, growth is defined as isometric (unchanging body form with growth). When b is not equal to 3, then the fish is exhibiting allometric growth. Length-weight relationships (separate male and female) were determined by season (December–February, March–May, June–August, September–November) to detect if there was a significant seasonal difference in body weight. This analysis was performed by log transforming the above length-weight equation into a linear equation of the form:

$$\log(W) = \log(a) + b * \log(L).$$

Analysis of covariance (ANCOVA) was used to compare dolphin body weight between seasons with ln fork length as covariate for both males and females. If ln (body weight) was significantly different between seasons, the univariate test of significance for planned comparisons was used to determine which seasons were significantly different from one another. Significance levels were adjusted within each season using the standard Bonferroni technique (a/number of tests).

## **1.2b Age Determination**

*Daily ages of age-0 dolphin.* To determine if daily rings were present on sagittal otoliths of age-0 dolphin, the otoliths were removed, cleaned and stored dry until mounting. To avoid differences in inter-otolith variability, only the left otolith was used for reading. Otoliths were prepared for reading following methods established by Elisabeth H. Laban from NOAA's Center for Coastal Fisheries and Habitat Research, Beaufort, NC. The left sagittal otolith was placed, sulcus down, in a piece of drinking straw approximately 0.2 mm tall that had been previously secured to a glass slide. The otolith was completely covered in Embed 812 embedding resin, and allowed to dry for 24 hours. When the circle of resin was completely dry, the excess resin was trimmed away from the otolith using an Isomet saw. A transverse cross section of the sagitta was used to age dolphin since this section contains increments in all peripheral regions (Figure 3). Polishing was done on a polishing wheel with a nylon polishing cloth and 25.0 micron aluminum oxide powder. Fine polishing was done with a microcloth and 0.3 micron alpha alumina powder. Once a suitable section was thin enough to be observed at the magnifications required to detect the increments (x400, x1000), the slide with the otolith was dried again and stored until reading. Before reading, a

drop of immersion oil was placed on top of the otolith to facilitate light transmission and clarity. Reading was done using a light microscope equipped with a closed circuit video camera. The image from the camera was transmitted to a computer and examined using Image-Pro Plus software (Image-Pro, 2001). Growth increments were counted from the core to the edge of the pararostrum (Oxenford and Hunte, 1983, Massuti et al, 1999) (Figure 4). Incremental counts were made by beginning at the first clearly defined mark that encircled the primordium, which defined the outer edge of the nucleus (Massuti et al, 1999). To determine the precision of juvenile dolphin ages, blind readings of daily growth increments were conducted twice in random order by the same investigator. Error in reading precision greater than 10% for an individual otolith caused that otolith to be rejected. If error in reading precision was less than or equal to 10%, then the average between the first and second readings was taken as the final age.

Massuti et al (1999) and Uchiyama et al (1986) confirmed that the deposition of increments in dolphin otoliths begins on the first day of life, and that rings are laid down daily. Thus, no adjustment was required to estimate age from incremental counts of sagittae and it was assumed that a ring was laid down daily.

*Annual ages of dolphin.* The annual age of dolphin was estimated using scales. Scales were mounted, sculptured side down, on sheets of cellulose acetate, 0.5 mm thick. Eight to ten scales from one fish were mounted on a slide and then placed on a scale press to make impressions. Scale impressions were examined with a microfiche reader at 32x magnification to detect the circuli, annuli, and other features of the scale. Age groups were classified according to the number of annuli present (see Beardsley, 1967 for example of

scale annuli). The most common and useful indicators of an annulus on dolphin scales are the abrupt narrowing and then widening of the spacing between the circuli (Beardsley, 1967), the splitting and disruption of the even pattern of the circuli, and the cutting-over of the circuli in the posterior-lateral field.

To determine the precision of dolphin age estimates, blind readings of scale annuli were conducted twice by the same investigator. If agreement between the first and second reading was not 100%, then the scale was re-read, in random order, a third time. If the third reading did not agree with either the first or second reading, then that scale was thrown out. Additionally, blind readings of a subsample ( $n=50$ ) of dolphin scales were conducted by an independent reader who was trained to identify annuli on dolphin scales.

To validate annuli in dolphin scales, an indirect validation based on marginal increment analysis was used. When plotted as a function of month or season, the mean marginal increment should describe a sinusoidal cycle with frequency of one year (Campana, 2001). Marginal increment widths were determined by measuring the distance from the outer edge of the scale to the closest annulus. Marginal increment width was measured only on dolphin with one annulus in order to standardize the methodology, and because the majority of dolphin aged with scale annuli were 1-yr old. Measurements (mm) were taken from the magnified (x32) scale image on a Micron microfiche reader along a straight line from the lateral edge of the scale to the outermost annulus using a digital caliper. Marginal increment widths were analyzed using analysis of variance (ANOVA) to test for an effect of month. Marginal increment widths were only analyzed for the months of March through November due to the low sample sizes of dolphin scales from the winter months (December through February).

The relationship between the marginal increment width and dolphin fork length was analyzed using linear regression. To differentiate between changes in the marginal increment width attributed to potentially sampling different cohorts of age-1 dolphin, the monthly mean fork length of all age-1 dolphin whose scales were measured for a marginal increment width was calculated.

*Annual ages from otoliths.* A subsample of transverse cross-sections of dolphin sagittal otoliths (determined to be age-1+ based on scale annuli) was analyzed to determine whether or not annuli could be detected in these structures. The transverse cross-section of the otolith was viewed under the light microscope (x100, x400) to detect whether annuli could be observed.

*Analyses of age and growth data:* The von Bertalanffy growth curve was fitted to dolphin age-length data for three scenarios: 1) daily ages from all sizes of age-0 dolphin and scale annuli from age-1+ dolphin; 2) daily ages from age-0 dolphin with a fork length less than 650 mm and scale annuli from age 1+ dolphin; and 3) relative ages that were assigned to fish by using a birthdate of April 15 based on trends in gonadosomatic indices and the known average spawning dates of dolphin in the Atlantic (Beardsley, 1967; this study). The von Bertalanffy model has the following form:

$$L_t = L_{\infty} (1 - \exp (-k * (t - t_0)))$$

Where  $L_t$  is the length at time  $t$ ,  $L_\infty$  is the asymptotic maximum length,  $k$  is the rate at which  $L_\infty$  is achieved and  $t_0$  is the theoretical age at which the fish would have zero length, assuming that the fish always grew according to the pattern described by the model (Ricker, 1975). The parameters from the von Bertalanffy growth function were estimated using a nonlinear least squares approach.

Because of sexual dimorphism, separate von Bertalanffy growth parameters were calculated using nonlinear least square regression for male and female dolphin (Uchiyama et al., 1986), and were compared using likelihood-ratio tests (Kimura, 1980; Cerrato, 1990; Haddon, 2001). To determine individual dolphin growth rates, the fork length at capture was divided by the daily age for all age-0 fish less than 650 mm FL. To detect if any significant changes in growth have occurred, the mean size-at-age values from Rose and Hassler (1968; collections made June, July and August and aged using scale annuli) were plotted in the von Bertalanffy growth curve fit using current age-1+ dolphin ages estimated while assuming a biological birthdate of April 15. To compare von Bertalanffy growth parameters estimated from past studies within different regions, the growth performance index ( $\Phi' = \log K + 2\log L_\infty$ ) of Pauly and Munro (1984) was calculated based on the growth parameters estimated from each method. Additionally, regional growth curves were compared.

### **1.2c Reproduction**

*Sexual maturity and spawning.* Gonadosomatic indices and back-calculated hatchdates were used to determine timing of spawning. Maturity staging was used to determine length at maturity. When available, intact gonads were removed, weighed to the nearest 0.1g and assigned a maturity stage determined by gross examination of the gonads. Maturity stages

for both male and female dolphin have been described by several authors (Beardsley, 1967; Oxenford, 1985; Perez et al., 1992) and all describe similar criteria. Beardsley (1967) described 5 maturity stages for females, and 2 maturity stages for males and his criteria were used in this study (Tables 6 and 7). The recorded external sex of the species was based on external characteristics, but was confirmed through macroscopic examination of the gonads.

A gonadosomatic index (GSI), a relative measure of gonad development, was calculated as:

$$GSI = (\text{gonad weight} / (\text{body weight} - \text{gonad weight})) * 100$$

Monthly GSI values for 2002-2004 were calculated for both male and female dolphin. Since dolphin body weight and length are correlated with GSI values (Chatterji and Ansari, 1982) and dolphin size differed significantly by month (see below), ANCOVA was used to compare  $\ln(\text{gonadal weight})$  by month with  $\ln(\text{fork length})$  as the covariate for males and females separately. To determine which months had significantly different gonadal weights, the length-adjusted mean  $\ln(\text{gonadal weight})$  value was compared among months for both male and female dolphin using ANCOVA univariate test of significance for planned comparisons. Significance levels were adjusted using the standard Bonferroni technique (a/number of tests) to account for the multiple comparisons.

Hatch dates were determined by subtracting age in days (determined from age-0 otoliths) from the catch date. Since the daily deposition of increments in dolphin sagittal otoliths begins on the first day of life (Uchiyama et al., 1986; Massuti et al., 1999) and because ripe eggs hatch within 50-60 hours after fertilization (Palko et al., 1982), back-

calculated hatch dates provide an estimate of spawning dates that result in surviving offspring.

*Size at maturity.* The length at which 50% of the fish had become mature was determined for both sexes using logistic regression analysis. The maturity ogive was based on the following equation:

$$\% \text{ Maturity} = 1/(1 + e^{(-Q * (L - L_{50}))})$$

where Q=model parameter, L = fork length (mm) and L<sub>50</sub>=fork length where 50% of individuals are mature. Female dolphin were considered mature if classified as stage II or higher by gross examination, based on criteria developed by Beardsley (1967). Male dolphin were classified as mature based on the presence or absence of milt in their gonads (Beardsley, 1967).

## 1.3 RESULTS

### 1.3a Collections

A total of 802 dolphin were sampled during 2002-2004 (Table 1) with the majority (n=611, 76%) from the recreational charter fishery and 45 (6%) from commercial catches. Sampling various sportfishing tournaments resulted in collection of 130 (16%) large-sized dolphin (>850mm). Fishery-independent sampling yielded 12 (2%) dolphin from hook and line fishing and 4 (1%) dolphin from gut-sampling. There was a seasonal trend in the total amount of dolphin collected by month, with nearly half (45%, n= 364) of all dolphin collected in the

summer months of June, July and August. Only 17 fish (2%) were obtained in the winter months (November, December and January; Table 1).

The size range for all dolphin, regardless of sampling method, was 89 to 1451 mm FL (mean =736 mm FL, SE=9.3) (Figure 5). Sampled males (n=257) ranged in length from 310 to 1451 mm FL and females (n=422) ranged in length from 205 to 1435 mm FL. The mean length and weight of all males sampled was 855 mm FL (SE=16.0) and 6.44 kg (SE=0.4). The mean length and weight of all females sampled was 655 mm FL (SE=9.0) and 3.13 kg (SE=0.2). There were significant differences in female dolphin mean weight (Kruskal-Wallis ANOVA:  $\chi^2=85.1$ , df=9, p<0.001) and fork length (  $\chi^2=140.0$ , df=10, p<0.001) sampled in 2002-2004 by month. There were also significant differences in male dolphin mean weight (Kruskal-Wallis ANOVA:  $\chi^2=80.6$ , df=9, p<0.001) and fork length (  $\chi^2=98.9$ , df=9, p<0.001) sampled in 2002-2004 by month (Table 2).

The length-weight relationships ( $W= aL^b$  ) for females (n=274) and males (n=218) show a general trend for males to be heavier than females above a fork length of about 600-700 mm (Figure 6; Table 3). Pre-filleted dolphin weights were not always available while sampling recreationally-caught dolphin, therefore the sample size for the length-weight relationship is much lower than the total number of dolphin sampled in this study. Most dolphin greater than 1200 mm FL and 10 kg were males. Results from the homogeneity of slopes test showed a significant difference between sexes in the slope of the length-weight relationship (p=<0.001). A separate-slopes ANCOVA detected a significant difference (p=<0.001) between length adjusted weight values between the sexes; males were heavier at a given length compared to females. There was no significant effect of season (ANCOVA: p=0.93) on length-adjusted weights for males, however length-adjusted weights for female

dolphin were significantly higher in the spring when compared with summer ( $p=0.000055$ ) and fall ( $p=0.001381$ ).

### **1.3b Age and growth**

The sagittae of dolphin are small, relative to fish size, generally butterfly-shaped and have a complex structure with convex sides and a pronounced rostrum and antirostrum (Oxford and Hunte, 1983), (Figure 3a). Due to the complex morphology, counts were typically made on the dorsal side (pararostrum) of the otolith since that region was the easiest to follow a clear increment sequence (Figure 3b). Alternating light and dark bands were clearly visible on the lateral or convex surface of the sagittae from the primordium to the margin (Figure 4a,b). The alternating bands, assumed to be daily increments (see methods), varied in width, with tightly-packed increments located more toward the core and outer edge of the sagittae, and wider increments located more in the center of the dorsal wing.

A total of 200 dolphin otoliths were examined (150 age-0 otoliths, 50 age-1+ otoliths). Daily increment counts were possible on a total of 126 (84%) otoliths from age-0 dolphin [designated age-0 because of lack of annuli on scales (see below)]. Of these, 76 were from female dolphin (mean FL=558; range= 278-852 mm) and 44 were from males (mean FL=564; range= 310- 810 mm). Sex could not be determined for five of the smallest dolphin whose sagittae were examined (mean FL = 152; range= 89-285 mm) and was not recorded for one of the larger dolphin aged with daily growth increments (FL= 575 mm). Minimum and maximum age estimates ranged from 32 to 270 days. Four (3%) age-0 dolphin otoliths were rejected because percent agreement between the first and second count exceeded 10%, and 20 (13%) age-0 otoliths were unreadable because of problems in cross-

sectioning and/or polishing. A total of 9 (18%) age-1+ otoliths [designated age-1+ from scale annuli (size range 800 to 1148 mm FL)] could be read. Forty-one (82%) age-1+ dolphin otoliths were unable to read due to problems in methodology leading to eroded marginal zones. Age in days based on daily increments for these larger dolphin ranged from 151 to 293. When daily ages from age-1+ dolphin and annual ages of age-1+ dolphin were plotted together and for the same size interval, the daily ages from age-1+ dolphin gave an estimate between 0.5 to 0.9 year, while scale annuli gave an age estimate of 1-3 years. Therefore, it was assumed that daily ages of age-1+ dolphin underestimate the age. No annular increments could be detected in transverse cross-sections of sagittal age-1+ dolphin otoliths.

From May 2002 – May 2004, 567 dolphin scale samples were collected. The fillets had already been removed from some dolphin when sampled thus scale samples were not collected from every dolphin sampled in this study. Out of 567 fish with scale samples, 307 (54%) were determined to be age-0 (Figure 7). A total of 241 scales were classified as age 1 or older (87 females, 154 males). Fourteen fish were excluded due to distortion in the scale impression, most likely caused by problems in the methodology or dirty scales. Five scale samples were discarded due to error in reading ( $3^{\text{rd}}$  reading did not match up with either the  $1^{\text{st}}$  or  $2^{\text{nd}}$  reading; see below). Age-1+ dolphin were classified as follows: 182 age-1 dolphin ranging from 575 to 1435 mm FL (mean=938 mm, SE=9.8), 46 age-2 dolphin ranging from 925 to 1451 mm FL (mean =1197 mm, SE=17.3) and 13 age-3 dolphin ranging from 1095 to 1334 mm FL (mean =1249 mm, SE=17.9). Agreement between the first and second reading of scale annuli by the same investigator was 88%. Agreement between the third reading with either the first or second reading was 99%, and this reading was taken to be the final age. An

independent reader who was trained to identify annuli on dolphin scales examined a subsample of 50 age-1+ dolphin scales and agreement between the independent reader's reading with the first reader's final age was 69%.

The von Bertalanffy growth function was calculated based on the age-length relationships from daily sagittal growth increments in age-0 dolphin ( $n=126$ ), and scale annuli in age-1+ dolphin ( $n=234$ ), (Massuti et al., 1999), (Figure 8a; Table 4). Ages determined from scale annuli of 3 age-1+ female and 4 age-1+ male dolphin were not incorporated in the von Bertalanffy growth curve because fork length was not recorded while sampling. Because daily ages were considered to be underestimates of age for dolphin that were classified using scales as age-1+ (see above), these data were not used when fitting the von Bertalanffy growth function. After fitting the von Bertalanffy to the remaining data, it appeared that daily ages from age-0 dolphin with a fork length  $> 650$  mm also appeared to be underestimating age; additionally, otoliths from dolphin  $> 650$  mm FL were difficult to read because daily increments were packed closely together (see methods) and daily increments have not been validated on dolphin  $> 650$  mm FL (Uchiyama et al., 1986, Massuti et al., 1999). For these reasons, a second von Bertalanffy growth function was calculated based on the age-length relationships from daily sagittal growth increments in age-0 dolphin with a fork length  $\leq 650$  mm ( $n=107$ ), and scale annuli in age-1+ dolphin ( $n=234$ ) (Figure 8b; Table 4).

Growth in dolphin was extremely fast and maximum longevity was 3 years, although only 13 male dolphin lived to be 3 years. Female dolphin appeared to have a slower growth and shorter longevity than male dolphin, with only 3 female dolphin reaching age 2. There was no significant difference between the male and female von Bertalanffy growth models

(likelihood ratio tests:  $\chi^2=6.52$ , df=3, p=0.08), although the test statistic did approach significance. Average growth rate was 3.78 mm FL/day for all age-0 fish less than 650 mm FL.

A third von Bertalanffy growth function (calculated as above, but assuming a biological hatch date of April 15) showed that males grow faster and reach a larger maximum size than females (likelihood ratio test:  $\chi^2=10.14$ , df=3, p=0.02) (Figure 9; Table 4). By using a biological hatch date, model fit was improved from an  $r^2$  of 0.67 for the combined von Bertalanffy growth function calculated without using an April 15 hatch date, to an  $r^2$  of 0.73 for the combined von Bertalanffy growth function calculated with a biological hatch date (Table 4). Relative ages of age-0 dolphin estimated using scale annuli and assuming a biological hatch date of April 15 are shown in Figure 9, but were not used to fit the von Bertalanffy growth function. Additionally, the mean length-at-age values for dolphin collected in June, July and August 1961-1962 (plotted while assuming a mean capture date of July 15; Rose and Hassler, 1968) are shown in Figure 9, and are similar to length-at-age values for the present study.

Length-at-age data for dolphin from past studies from different regions show an apparent trend in regional groupings (Figure 10; Table 5). The von Bertalanffy growth functions calculated in the Gulf of Mexico and Caribbean all display extremely fast growth rates and an average longevity of less than one year. Dolphin collected from Florida, North Carolina and the Mediterranean all display similar growth characteristics, with a maximum age of 3 or 4 years (Table 5).

Marginal increment widths from age-1 dolphin (n=182) were greatest in May, June and July, dropped slightly in August, and then dropped considerably during the fall and

stayed low during winter months (Figure 11). There was a significant difference in the marginal increment width per month (ANOVA:  $p=<0.001$ ) for the March through November period. May was significantly higher than April (Tukey HSD:  $p=0.03$ ) and October ( $p=0.03$ ) while June was significantly higher than April ( $p<0.001$ ), September ( $p=0.04$ ) and October ( $p<0.001$ ). All other comparisons were non-significant.

The marginal increment width was found to be correlated with dolphin fork length ( $p=<0.001$ ,  $r=0.50$ ). The mean fork length of dolphin whose scales were measured for a marginal increment width was lowest in March (720 mm) then increased dramatically during April, May and June (mean FL = 881 mm, 921 mm and 1019 mm, respectively) (Figure 12). Mean dolphin fork length then dropped slightly in the fall months, and stayed relatively low throughout the late fall and winter.

### **1.3c Reproduction**

The mean size of immature males ( $n=16$ ) was 572 mm FL ( $SE=19.7$ , range=453-735 mm FL) while the mean size of mature males ( $n=41$ ) was 821 mm FL ( $SE=24.1$ , range=568-1143 mm FL). The mean size of immature females ( $n=13$ ) was 516 mm FL ( $SE=14.3$ , range=410-635 mm FL). The mean size of early maturing females ( $n=9$ ) was 574 mm FL ( $SE=34.2$ , range=445-780 mm FL). The mean size of late maturing female dolphin ( $n=56$ ) was 740 mm ( $SE=14.4$ , range=515-966 mm FL). The mean size of mature female dolphin ( $n=47$ ) was 727 mm FL ( $SE=24.1$ , range=473-1275 mm FL). Female dolphin were considered mature when they were staged as “early maturing” (Beardsley, 1967). No female dolphin were classified as spent. Females reached 50% maturity at a smaller size than males (Figure 13). At 519 mm FL, 50% of female dolphin were mature, while 100% were mature

at a fork length of about 800 mm FL. Males reached 50% maturity at a fork length of 606 mm and 100% maturity was reached at a fork length of 775 mm.

Female (n=199) GSI values ranged from 0.16 to 8.19 (mean=2.71, SE=0.12) (Figure 14a). They were highest in the late spring and summer, and then decreased dramatically in August through November. Male (n=173) GSI values ranged from 0.08 to 1.62 (mean=0.52, SE=0.02) (Figure 14b). Male GSI values were high and variable in the late spring and summer months, and then gradually decreased in August through November.

There was a significant difference (ANCOVA: p<0.001) in the slopes of length-adjusted mean gonadal weights by month for both males and females, so a separate-slopes ANCOVA model was used. Length-adjusted mean gonadal weights were significantly different by month (ANCOVA: p<0.001) for both male and female dolphin (Table 8). In separate sex analyses, length-adjusted mean gonadal weights followed the same trend as the monthly mean GSI values, with the highest gonadal weight values in the summer, and the lowest values in the fall (Figure 15). Gonad weights from January were not included because of low sample size (n=9). There were significant differences in the length-adjusted gonadal weight of females between almost every month, but most differences were found for October, which was significantly lower than May, June, July and August (p<0.001 for all) (Figure 15; Table 9a). Comparison of male monthly gonadal weights revealed that September gonadal weights were significantly lower than May and June gonadal weights (Figure 15; Table 9b); all other comparisons were non-significant.

In 2002, the majority of age-0 dolphin sampled (83%) had back-calculated hatch dates in the months of January through June (Figure 16). Similarly, 76% of age-0 dolphin had back-calculated hatch dates for this same period in 2003. For both the 2002 and 2003

samples, a limited number of age-0 dolphin had back-calculated hatch dates in other months particularly November and December.

## **1.4 DISCUSSION**

### **1.4a Seasonality and size**

The dolphin fishery off the coast of North Carolina is essentially a seasonal fishery with catches occurring predominantly between April and September. However, dolphin were obtained from most months, including four dolphin from February 2003, and eight dolphin from January 2004. The fact that dolphin were caught off the coast of North Carolina in January and February is a surprising result since the existing proposed migration circuits of northeastern dolphin suggest they should be off the coast of Puerto Rico at that time (Oxenford and Hunte, 1986a). This proposed northeastern circuit is based on the seasonality of dolphin fisheries by location and mean size at capture. Other data sources support this northeastern migration route. Beardsley (1967) proposed that dolphin most likely move north from Florida during the spring and summer, and Gibbs and Collette (1959) suggested that the spring abundance of dolphin in Puerto Rico may be a prespawning migration. Although this study did not attempt to investigate or characterize the western Atlantic dolphin stock, the fact that dolphin were caught in months (January, February) where existing accepted stock hypotheses have placed them off the coast of Puerto Rico suggests that the Atlantic dolphin stock may be more complex with a portion of the stock (or a separate stock) having disparate migration routes and timings.

The mean size of recreationally caught dolphin differed by month, which is in agreement with Rose and Hassler (1968) who encountered the majority of their older (and

consequently larger) dolphin in June and the fewest age-1+ fish in the late summer. In this study, the longest (and heaviest) dolphin were caught in June, while the smallest dolphin were caught in September. There were numerous sportfishing tournaments held in the early summer months of both 2002 and 2003 with the number of participants sometimes exceeding 200 boats. The opportunity to sample large-sized dolphin in these months increased significantly due to the large numbers caught during these tournaments; however large-sized dolphin would most likely have been caught by the recreational charter fleet during these months regardless of whether or not fishing tournaments targeted them. The difference in mean size per month is most likely attributed to a number of factors including spawning, migration, area fished and type of tackle. Rose and Hassler (1968) believed their monthly size discrepancy was caused by a greater amount of fishing pressure applied to older fish (age II and III) during the early part of the season, while in the late summer, fewer boats were fishing offshore and were heavily concentrated more inshore near tide-lines where age-0 dolphin congregate. Because present day fishermen troll far offshore from spring through the late fall, Rose and Hassler's (1968) hypothesis may be incorrect. The larger dolphin are most likely migrating through North Carolina waters in the late-spring and early summer, and were present in low numbers in our area during late summer/ fall. Other possibilities include being scattered (SAFMC, 2003) and/or depleted due to fishing mortality.

The length-weight relationships showed negative allometry in both males and females. Negative allometry was stronger in females than in males, which is in agreement with several previous studies (Rose and Hassler, 1968; Palko et al., 1982; Oxenford, 1985; Chatterji and Ansari, 1985; Massuti et al., 1999). Male dolphin exhibit a “bull” forehead that is fully developed by the time it reaches 600 mm FL (Rose and Hassler, 1974), therefore the

observed stronger negative allometric growth observed in females is in accordance with the sexual dimorphism of the species. This study found that male dolphin first became heavier than females between a fork length of 600-700 mm, which is most likely a result of the strongly defined bull forehead in large male dolphin. A similar divergence between male and female length-weight relationships was noted by Beardsley (1967) and Rose and Hassler (1968).

Most of the longest and heaviest dolphin sampled in this study were males. Rose and Hassler (1968) speculated that males require a greater amount of food to sustain body metabolism since they are heavier than females per unit of length. The need of additional food causes males to exhibit more voracious feeding patterns, which may result in increased selection by the recreational fishery (Rose and Hassler, 1968). Because all of the fish from this study were from hook and line fisheries, this study may be biased by this same phenomenon.

Condition of male dolphin (determined from length-adjusted weights) did not vary significantly by season, however condition of female dolphin was higher in the spring (March, April and May) than it was in the summer (June, July and August) and fall (September, October and November). One possible explanation for this could be the spawning condition of female dolphin. In this study, female dolphin begin their spawning season in the spring, and reach the peak of their spawning condition in May. One would expect to see the high condition trend continue into the summer months where spawning continues to peak (Beardsley, 1967; this study), however most of the dolphin collected in this study from the summer were collected from the month of August, which is a month where female spawning slows considerably (Beardsley, 1967) and gonadal weight values drop (this

study). Condition of female dolphin in the winter should differ from months when peak spawning occurs, however the lack of significance could be due to low sample sizes in the winter (n=4).

#### **1.4b Age and Growth**

This study is the first study to use transverse cross-sections of sagittal dolphin otoliths to determine daily ages of dolphin. Daily ages of larger dolphin (>650 mm FL) were considered to be underestimates most likely because of the complex morphology of the sagittal otoliths. This complexity increases with ontogenetic development, often resulting in concave and fragile otoliths in larger fish. Daily growth increments in dolphin > 650 mm FL were no longer formed, or were too close together to differentiate. Furthermore, it is more difficult to obtain a section of the otolith that contains all of the increments in one complete sequence; therefore counts were made on multiple axes which could have introduced underestimation error into the count. Massuti et al (1999) also found that the age of larger dolphin from whole otolith mounts was underestimated and considered ages from dolphin > 650 mm FL to be biased. Their technique for reading was similar to that used in this study (following a circuitous path and multiple axes to complete a set of counts).

No annular mark could be detected on sagittal otoliths of age-1+ dolphin. Massuti et al. (1999) also looked for annuli in dolphin otoliths, but were unable to detect any due to potential limitations of their method. The whole-mounting method used by Massuti et al. (1999) did not allow for interpretation of the outer edges of adult otoliths, and possibly prevented detection of annuli (Beatriz Morales-Nin, Joan Massuti, personal communication, Mediterranean Institute for Advanced Studies, May 2003). A cross-sectional preparation of

age-1+ dolphin otoliths was used in this study in an attempt to obtain a view of the outer edges, but the extreme complex morphology of age-1+ dolphin sagittal otoliths may have prevented detection of any annular mark. Additionally, since no other studies have reported observing annuli in dolphin otoliths, annuli may not exist on dolphin sagittal otoliths.

There was good agreement between readings for the estimated daily ages of small dolphin ( $\leq 650$  mm FL). Additional support for the validity of the daily ages is that estimated birthdates were in good agreement with known spawning dates (Beardsley, 1967; this study). Similarly, Massuti et al (1999) were able to use this independent comparison to establish the validity of their daily age data.

To date, scales seem to be the most appropriate hard part for determining the age of dolphin in years. Numerous other studies on Atlantic (Beardsley, 1967; Rose and Hassler, 1968) and Mediterranean (Massuti et al, 1999) dolphin stocks have obtained similar results from this method. Beardsley (1967) studied the age, growth and reproduction of 511 dolphin captured in the Straits of Florida using scale annuli, and determined a maximum life span of four years. Rose and Hassler (1968) determined age and growth estimates from scale annuli of 738 dolphin captured off the coast of North Carolina during June, July and August of 1961, 1962, and 1963, and observed a maximum age of three years. In the Mediterranean, Massuti et al. (1999) also reported a maximum age of three years, based on daily ages from otoliths for 176 dolphin between 165 and 585 mm FL, and scale ages for 150 dolphin between 650 and 1240 mm FL.

The annuli on age-1+ dolphin scales were relatively easy to interpret with the criteria described by Beardsley (1967). Percent agreement was extremely high between readings performed by the same investigator. Percent agreement was moderate between two readers.

This was most likely caused by lack of experience and over-examination from the independent reader. Although within lab agreement was good, this does not establish that the ages were correct.

Few studies have attempted to validate scale annuli in dolphin. Beardsley (1967) measured the distance between the last annulus and the margin of the scale for all dolphin with one or more year marks and November was considered to be the period of annulus formation since there was an abrupt decrease in width of the increments from October to November, and an increase in the width of marginal increments from November through October of the following year. Scale analysis completed by Rose and Hassler (1968) demonstrated that as dolphin grew from June to July, the edge of the scale became increasingly distant from the last annulus. Given only two months were examined, Rose and Hassler's (1968) analysis is not a true marginal increment analysis.

The monthly pattern in marginal increment widths observed in this study was somewhat similar to prior work in Florida (Beardsley, 1967). There are various factors that cause fish to lay annuli in scales, including reproduction, availability of food and temperature. Rose (1966) stated that the temperature of the Gulf Stream and neighboring coastal water, off the North Carolina coast, is variable enough to cause a decrease in growth rate during the winter. The general pattern of the largest mean marginal increment found in the summer, and the lowest mean marginal increment found in the winter lends support to the hypothesis that dolphin lay an annulus in the winter as a result of decreased water temperature.

It is surprising that in this study, the mean marginal increment width drops during late summer and fall. One would expect that marginal increment widths would increase since those months have some of the warmest water temperatures. This is most likely due to the

fact that dolphin are a highly migratory species, and the majority of age-1 dolphin that were available for sampling in the late summer and early fall were from a different cohort than the dolphin that were sampled in the previous spring/summer months. It is possible that the age-1 dolphin that were sampled in the late summer/fall could have been the result of a late fall spawn the year before, and therefore would have a smaller marginal increment width because of their smaller size. This is supported when the mean fork length values of all marginal increment width dolphin are examined. It appears that this study was sampling from a single cohort through the months of March through June since the mean fork length values keep increasing. However, during the month of July through August, the fork length decreases from the previous months, which suggests we were sampling from a separate cohort. This phenomenon continues between September and October, and then no pattern can be detected in the late fall/winter months because of low sample size. Since marginal increment width was found to correlate with dolphin body size, monthly differences in the mean fork length could affect the monthly marginal increment width. Beardsley (1967) also noted wide variation in marginal growth in any given month.

Additionally, the assumption of a winter-laid annulus was supported by a scale from a dolphin that had previously been tagged. The dolphin was tagged October 18, 2003 off Hudson Canyon, NJ at a fork length of 660 mm through the South Carolina Department of Natural Resources (SCDNR) Dolphin Tagging Program (Don Hammond, personal communication, SCDNR, May 2004). The dolphin was re-captured on May 16, 2004 off Morehead City, NC at a fork length of 864 mm. Analysis of scale samples from this dolphin estimate the age to be 1 year old, with a clearly laid annulus. This scenario supports the assumption that dolphin lay down an annulus after having lived through a winter. The

likelihood that this dolphin had already laid down an annulus when tagged is slim, since 98% of the fish that were aged to be 1 had a fork length greater than 660 mm.

The peak spawning season of dolphin in the Atlantic occurs January through June (Beardsley, 1967; this study). Although the period of annulus formation coincides with the beginning of the spawning season, it is believed that the scale marks interpreted here as annuli are not produced by spawning activity. This is evident from the fact that scale annuli were detected in sampled dolphin before the peak spawning season in North Carolina had begun. Additionally, many dolphin that were staged to be running ripe showed no scale annuli. Beardsley (1967) and Rose and Hassler (1974) described similar results in their study.

Although past studies (Beardsley, 1967; Rose and Hassler, 1968) on north Atlantic dolphin age and growth have relied on scale annuli for age estimates, more recent studies have relied only on daily growth increments in otoliths. In Barbados, Oxenford and Hunte (1983) examined the sagittal otoliths of 558 dolphin caught between January 1981 and June 1982. An average growth rate was determined to be 4.71 mm/day for all fish, and an average growth rate of 1.43 mm/d for adults (700-1100 mm SL) (Oxenford and Hunte, 1983). Monthly length-frequency distributions of adult dolphin landings (from the same population otolith analysis was performed on) inferred a similar average growth rate (1.53 mm/d, size range 600-1200 mm SL; Oxenford and Hunte, 1983). In the Gulf of Mexico, Bentivoglio (1988) used daily growth increments in sagittal otoliths of dolphin and reported an average first year growth rate of 4.15 mm FL/day for fish in a size range of 250-1200 mm SL, and a growth rate of 0.61 mm FL/day for large-sized fish (850-1200 mm SL). Betancourt (1994) used daily growth increments in the sagittal otoliths of dolphin from a size range of 550 to

1325 mm FL, and reported an average first year growth rate of 2.52 mm FL/day. Using daily growth increments, this study predicted an average growth rate of 3.78 mm FL/day for all fish in the first 6 months. As in the above studies, daily growth rates were extremely fast, which is a common characteristic of large, pelagic fish. Similar growth rates have been reported for Atlantic bluefin tuna, with first year growth rates ranging from 1 to 6 mm/day (Brothers et al., 1983).

Comparison of the growth performance index ( $\Phi'$ ) show similar values between those calculated from growth parameters determined from scale annuli (Beardsley, 1967; Rose and Hassler, 1968). Those values calculated from growth parameters determined solely from daily increments in sagittal otoliths (Oxenford, 1985; Bentivoglio, 1988; Rivera and Appeldoorn, 1999) were higher ( $\Phi'=6.71$ , 6.62 and 6.67, respectively) presumably because of the fact that these age and growth studies were performed using only daily increments in all size dolphin, a method that may underestimate age of older larger fish (Massuti et al., 1999); this study). The growth performance index calculated in this study ( $\Phi'=6.32$ ) is very similar to the growth performance index determined from Massuti et al. (1999) ( $\Phi'=6.30$ ), who used daily growth increments in juvenile dolphin and scale annuli in adult dolphin to determine their von Bertalanffy growth parameters. Other determining factors, besides differences in methodology, need to be considered when comparing dolphin age and growth studies from different regions. Massuti et al. (1999) noted that temperature can explain the slower growth of dolphin in the western North Atlantic when compared to dolphin in warmer Caribbean waters, where feeding occurs throughout the year and can cause dolphin to grow continuously (Uchiyama et al., 1986). Additionally, dolphin in these areas may have different life histories and represent different populations.

After comparing the mean length-at-age values of Rose and Hassler (1968) with age estimates from the present study, it appears that no major change in length-at-age has occurred. For the hypothesis of a change in length-at-age due to size-selective harvesting to be supported, length-at-age values in the current population would be smaller than in the less exploited population of the early 1960s (Pitcher and Hart, 1982). If anything, the opposite pattern was found for most age classes. Thus, increased harvest in the 1980s and 1990s has not influenced size-at-age in this species.

The method of using daily growth increments to age small dolphin in this study has reduced much of the variability in length-at-age of age-0 dolphin from past studies that relied solely on scale annuli. Rose and Hassler (1968) determined that out of a sample size of 738 dolphin, 593 (80%) were age-0. The size range of age-0 dolphin in Rose and Hassler's (1968) study was from about 250 mm FL to about 1000 mm FL.

After looking at von Bertalanffy growth curve where age-0 dolphin ages estimated from scale annuli are shown (Figure 9), it is evident that lengths of age-0 dolphin are highly variable, and that age-0 dolphin comprised the majority of the sampled population in this study. Previous western Atlantic dolphin age and growth studies have relied solely on scale annuli for their age estimates, and obtained all of their samples through fishery dependent sources. Because dolphin do not become fully recruited to the fishery until they are ~400 mm FL, past length-at-age curves may be biased because smaller dolphin are not represented. By obtaining small, fishery-independent dolphin and having the ability to age young dolphin in days, rather than years, this study not only reduces the variability associated with length-at-age of age-0 dolphin, but also provides a much more accurate estimate of first year growth rates.

### **1.4c Reproduction**

Gonadal weight suggests that peak spawning in dolphin occurs from May to July off the coast of North Carolina. Previous studies have confirmed this finding. Schuck (1951) reported spawning dolphin off the coast of North Carolina in May and June, and Rose (1966) found that spawning occurred off the North Carolina coast most intensely during the months of June and July. However, the latter study was restricted to the months of June, July and August only. This study was able to collect reproductive data from dolphin collected in almost every month of the year and not only update Rose's (1966) findings, but provide a more thorough estimate of the spawning season of dolphin caught in North Carolina waters. In the Florida Current, the presence of very young dolphin throughout most of the year suggests that dolphin spawn there year round (Gibbs and Collette, 1959; Beardsley, 1967; Shcherbachov, 1973; Fahay, 1975; Powles and Stender, 1976). Beardsley (1967) reported a spawning season from November to July in the Florida Straits, with peak spawning occurring from January to March.

This study, along with past studies, provides evidence that the peak spawning season of western North Atlantic dolphin extends from January through July, although back-calculated hatchdates show that spawning appears to occur in all months. However, there were interannual differences in peak hatchdates. Massuti et al. (1999) found inter-annual variation in hatchdates between subsequent years as was observed in this study, and attributed it to changes in the spawning peak or to differential mortality. Given the lack of information on dolphin mortality, corrections for mortality in hatchdate distributions were not made.

In this study, April 15 was chosen as the hatching date since that date fell in the middle of the proposed January through July spawning season of western North Atlantic dolphin. The use of assigning one biological hatchdate to all age-1+ dolphin in this study reduced much of the variability associated with length-at-age for 1-year old dolphin seen in the von Bertalanffy growth curve where a biological hatchdate was not used. Some variability in length-at-age still exists, however, although that may be a result of other environmental factors experienced by an individual dolphin (water temperature, differences in prey consumption and diet quality). The fact that dolphin have a protracted spawning season is perhaps one of the biggest factors responsible for the variability in length-at-age. For example, some of the age-1 dolphin could have been the result of a fall spawn, therefore they would have been assigned an untrue hatch date and would be much smaller than the cohort of spring-spawned 1-year olds.

The range of dolphin lengths for each maturity stage was highly variable, often times with overlapping values. This is due to the fact that dolphin mature very early and the onset of spawning may be variable (Beardsley, 1967; Schekter, 1982; Oxenford, 1985; Bentivoglio, 1988; Perez et al., 1992). This study found that at a fork length of 519 mm, 50% of female dolphin are mature. Females first start to become mature just at about 450 mm FL, which is close to the 500 mm first maturity length proposed by Rose (1966). Beardsley (1967) reported that female dolphin first begin to mature at about 350 mm FL, are 50% mature at 450 mm FL, and are 100% mature at a fork length of 550 mm FL. This study found that 100% of female dolphin were mature at a fork length of about 800 mm FL, which is higher than Beardsley's value, although 91% of the females in this study were mature at a fork length of 675 mm. It was found in this study that males first begin to mature at a fork

length of about 575 mm, which is also higher than Beardsley's (1967) observation of a mature male with a fork length of 427 mm. For both males and females, the low sample size of small fish in this study may bias the estimate of size at first maturity. Additionally, size discrepancies between past studies size at maturity with the present study may be caused by the fact that some larger size dolphin (both male and female) were sampled later in the spawning season after having already spawned at least once and were incorrectly classified as immature.

Several other studies have provided estimates for female dolphin size at 50% maturity including Oxenford (1985) who estimated size at 50% maturity to be around 840 mm SL; Bentivoglio (1988) who reported size at 50% maturity to be 450 mm FL; and Massuti (1997) whose estimate of size at 50% maturity for female dolphin was 545 mm FL, which is very close to the estimated value from this study. With the exception of Oxenford (1985), all previous studies seem to be in agreement that size at 50% maturity is obtained by female dolphin between 450-535 mm FL.

#### **1.4d Summary and Future Direction**

This study provides modern life history data for dolphin caught off the coast of North Carolina. Using scale annuli and daily growth increments from otoliths, an updated age-length function has been determined. Furthermore, comprehensive seasonal estimates of gonadal weight and marginal increment widths as well as back-calculated hatch dates and daily growth rate estimates are the first for dolphin in North Carolina waters. Due to the fact that this species is highly migratory, a much broader study encompassing the U.S. east coast or western North Atlantic may be needed in order to truly characterize dolphin reproduction

and marginal increment widths. Future work should also include intensive predator gut-sampling or net-sampling of sargassum in order to acquire a larger sample size of small (<100mm) dolphin. Direct validation through mark and recapture could also confirm scale annuli and provide good estimates of growth rates if tagged dolphin remain at large through suspected periods of annulus deposition.

If intense size-selective mortality had resulted in changes in life history parameters, then lower size-at-age and size-at-maturity compared to past studies in this area would have been expected. There has been no major change in size-at-age of dolphin caught in North Carolina waters compared to 40 years ago; therefore, we reject this hypothesis. Due to their high growth rates and small size at maturity, dolphin appear to be an ideal fishery resource species capable of withstanding high rates of fishing mortality.

Table 1. Number of dolphin sampled from North Carolina recreational and commercial catches (see Methods for details) during each month for 2002-2004.

<b>Year</b>	<b>Month</b>	<b>n</b>
2002	May	99
	June	94
	July	53
	August	41
	September	37
	October	39
	November	2
	December	--
	January	--
	February	4
	March	6
	April	15
2003	May	47
	June	57
	July	32
	August	87
	September	19
	October	21
	November	7
	December	--
	January	8
	February	--
	March	20
	April	72
2004	May	42
		<b>802</b>

Table 2. a) Male and b) Female dolphin mean ( $\pm$ SE) fork length (mm) for January – November, range, and total sample size (n) and c) Male and d) Female dolphin mean ( $\pm$ SE) body weight (kg) for Jan, March - November, range and total sample size (n). Samples per month are pooled for the 2002-2004 sampling period. SE=standard error.

*a) Male*

	<b>Mean FL (SE)</b>	<b>FL Range</b>	<b>n</b>
<b>January</b>	682 (81.1)	559-835	3
<b>February</b>	<i>none</i>	<i>none</i>	<i>none</i>
<b>March</b>	709 (61.3)	453-915	6
<b>April</b>	820 (26.1)	550-1130	24
<b>May</b>	935 (17.4)	582-1315	92
<b>June</b>	1123 (25.4)	552-1395	72
<b>July</b>	705 (50.9)	395-1451	31
<b>August</b>	805 (41.5)	310-1333	46
<b>September</b>	689 (51.0)	462-1280	16
<b>October</b>	594 (25.6)	432-798	17
<b>November</b>	570 (50.0)	520-620	2

*b) Female*

	<b>Mean FL (SE)</b>	<b>FL Range</b>	<b>n</b>
	708 (70.3)	575-966	5
	699 (62.4)	545-850	4
	730 (17.9)	560-889	20
	773 (12.1)	608-1020	50
	765 (14.2)	485-1275	101
	688 (31.8)	295-1145	43
	607 (25.5)	205-980	48
	650 (24.1)	295-1205	101
	510 (19.8)	278-800	40
	556 (26.1)	410-1435	41
	628 (60.7)	460-905	7

*c) Male*

	<b>Mean Wgt (SE)</b>	<b>Wgt Range</b>	<b>n</b>
<b>January</b>	3.44 (1.2)	1.62-5.78	3
<b>March</b>	3.78 (0.7)	0.90-6.36	6
<b>April</b>	5.26 (0.5)	2.04-12.22	22
<b>May</b>	8.98 (0.6)	2.14-17.86	53
<b>June</b>	14.51 (0.8)	1.62-24.70	59
<b>July</b>	4.18 (1.1)	0.53-14.96	21
<b>August</b>	6.34 (0.8)	0.37-19.14	32
<b>September</b>	4.11 (1.2)	1.08-20.90	16
<b>October</b>	2.43 (0.6)	1.20-5.02	6
<b>November</b>	1.84 (0.4)	1.44-2.24	2

*d) Female*

	<b>Mean Wgt (SE)</b>	<b>Wgt Range</b>	<b>n</b>
	3.34 (1.0)	1.86-6.30	4
	3.63 (0.3)	1.62-5.26	11
	4.31 (0.2)	1.80-7.68	43
	4.14 (0.3)	1.46-8.27	56
	3.57 (0.5)	0.88-10.36	34
	2.01 (0.3)	0.53-7.63	33
	3.56 (0.5)	0.35-11.87	52
	1.46 (0.2)	0.22-5.14	34
	2.76 (1.3)	1.08-11.50	8
	1.41 (0.2)	1.08-1.76	3

Table 3. Dolphin length-weight parameters estimated by exponential regression equations ( $W = aL^b$ ) between fork length (mm) and weight (kg). n = sample size,  $r^2$  = correlation coefficient.

<b>Population</b>	<b>n</b>	<b>a</b>	<b>b</b>	<b><math>r^2</math></b>
Males	218	$2.25 \times 10^{-8}$	2.87	0.891
Females	274	$9.40 \times 10^{-8}$	2.64	0.920

Table 4. Von Bertalanffy growth parameters calculated for dolphin by different methods. n = sample size,  $L_{\infty}$  = asymptotic length, k = growth coefficient,  $t_0$  = length at age 0,  $r^2$  = correlation coefficient,  $\Phi'$  = growth performance index, O = otolith reading.

<b>Method</b>	<b>n</b>	<b><math>L_{\infty}</math></b>	<b>k</b>	<b><math>t_0</math></b>	<b><math>r^2</math></b>	<b><math>\Phi'</math></b>
<b>Scale and Otolith (O for age-0 dolphin with FL 89-852 mm)</b>						
Males						
Males	194	1285	1.33	-0.024	0.67	6.34
Females	160	1137	1.64	-0.017	0.74	6.33
Whole	360	1279	1.30	-0.033	0.67	6.33
<b>Scale and Otolith (O for age-0 dolphin with FL ≤ 650mm)</b>						
Males						
Males	189	1285	1.33	-0.017	0.64	6.34
Females	146	1250	1.24	-0.059	0.77	6.28
Whole	341	1289	1.27	-0.028	0.67	6.32
<b>Scale (with April 15 hatch date) and Otolith (for age-0 dolphin with FL≤ 650mm)</b>						
Males						
Males	188	1299	1.18	-0.089	0.69	6.28
Females	145	1237	1.10	-0.116	0.82	6.23
Whole	339	1299	1.08	-0.086	0.73	6.26

Table 5. Von Bertalanffy growth curve parameters and growth performance index ( $\Phi'$  from Pauly and Munro, 1984) for dolphin from the North Atlantic.

<b>Location</b>	<b>L<sub>∞</sub></b>	<b>K</b>	<b>t<sub>0</sub></b>	<b>Φ'</b>	<b>Reference</b>
North Carolina	1299	1.08	-0.086	6.26	Present Study
North Carolina	1597	0.40	-0.964	6.01	Rose and Hassler, 1968
Straits of Florida	1650	0.68	0.155	6.27	Beardsley, 1967
Spain	1024	1.90	0.023	6.30	Massuti et al., 1999
Gulf of Mexico	1940	1.12	0.033	6.62	Bentivoglio, 1988
Puerto Rico	1457	2.19	-0.046	6.67	Rivera (Betancourt) and Appeldoorn, 1999
Barbados	1208	3.49	0.055	6.71	Oxenford, 1985

Table 6. Description of the macroscopic gonadal maturity staging used to classify the ovaries. Maturity stage classification taken from Beardsley (1967).

<b>Stage</b>		<b>Stage Criteria</b>
I	Immature	Ovaries long, thin, hollow tubes; diameter, 3-4 mm, eggs microscopic; ovary wine-red to pink.
II	Early Maturing	Ovary slightly enlarged; diameter, 10-15 mm; eggs visible to the naked eye through the ovary wall, but no distinct size groups distinguishable; pale yellow.
III	Late Maturing	Ovary much enlarged; at least two distinct size groups of eggs easily visible to the naked eye; bright yellow to orange.
IV	Ripe	Ovary distended, half filling the body cavity; lumen full of large, clear eggs which give the ovary a speckled appearance.
V	Spent	Ovaries flaccid, hollow tubes; a few remnants of ripe ova may remain in the lumen or folds of the ovary, usually visible by microscopic examination; dull red and discolored, particularly at the posterior ends; numerous blood clots.

Table 7. Description of the macroscopic gonadal maturity staging used to classify the testes. Maturity stage classification taken from Beardsley (1967).

<b>Stage</b>		<b>Stage Criteria</b>
I	Immature or resting	Testes small, firm to the touch; no milt extruded after cutting and squeezing.
II	Mature	Testes enlarged; milt extruded after cutting and squeezing.

Table 8. Analysis of covariance models for the monthly gonadal weight values from 2002-2004 for a) females and b) males with ln (fork length) as covariate.

<b>(a) Dependent Variable</b>	<b>Effect</b>	<b>df</b>	<b>Sum of Squares</b>	<b>F</b>	<b>p</b>
ln (gonadal weight)	Month	7	23.8	7.7	<0.001

<b>(b) Dependent Variable</b>	<b>Effect</b>	<b>df</b>	<b>Sum of Squares</b>	<b>F</b>	<b>p</b>
ln (gonadal weight)	Month	7	7.20	6.54	<0.001

Table 9. Results from ANCOVA univariate test of significance for planned comparison with ln (gonadal weight) as the dependent variable for a) females and b) males. Tests are significant at the  $p \leq .0018$  level. Bold values indicate a significant p value.

<b>(a)</b>	<i>Apr</i>	<i>May</i>	<i>June</i>	<i>July</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>
<i>Mar</i>	0.0131	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>	0.0064	0.0498	0.6911
<i>Apr</i>		0.0389	0.0576	0.1352	0.6005	0.2888	0.0031
<i>May</i>			0.7336	0.2551	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>
<i>June</i>				0.4153	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>
<i>July</i>					<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>
<i>Aug</i>						0.3162	<b>0.0000</b>
<i>Sep</i>							0.0083

<b>(b)</b>	<i>Apr</i>	<i>May</i>	<i>June</i>	<i>July</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>
<i>Mar</i>	0.1123	0.0058	0.0058	0.1992	0.2474	0.9188	0.9115
<i>Apr</i>		0.0183	0.0225	0.5993	0.5049	0.0563	0.1062
<i>May</i>			0.9157	0.0052	0.0057	<b>0.0012</b>	0.0070
<i>June</i>				0.0069	0.0071	<b>0.0013</b>	0.0070
<i>July</i>					0.8649	0.1178	0.1823
<i>Aug</i>						0.1576	0.2240
<i>Sep</i>							0.9837

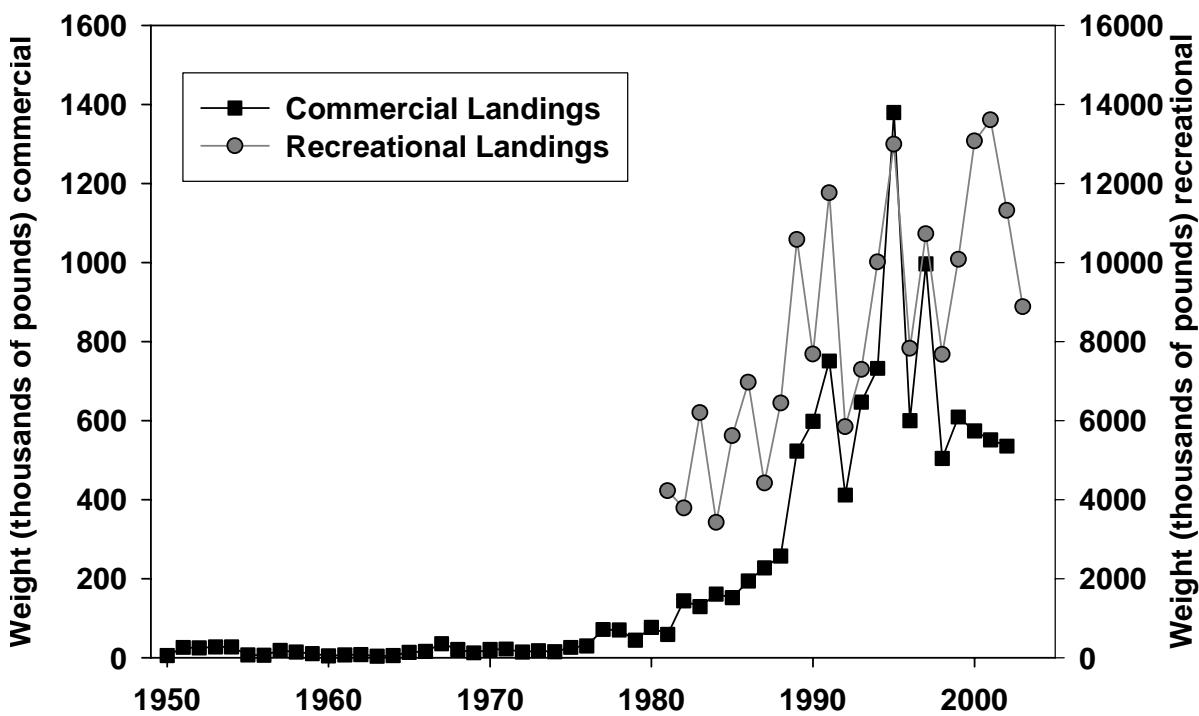


Figure 1. Annual landings of dolphin from the east coast of the United States. Annual commercial landings (left Y-axis) are shown in thousands of pounds from 1950 to 2002. Annual recreational landings (right Y-axis) are shown in thousands of pounds from 1981 to 2003. Data taken from National Marine Fisheries Service marine recreational fishery statistics survey and commercial landings data (2004a,b)

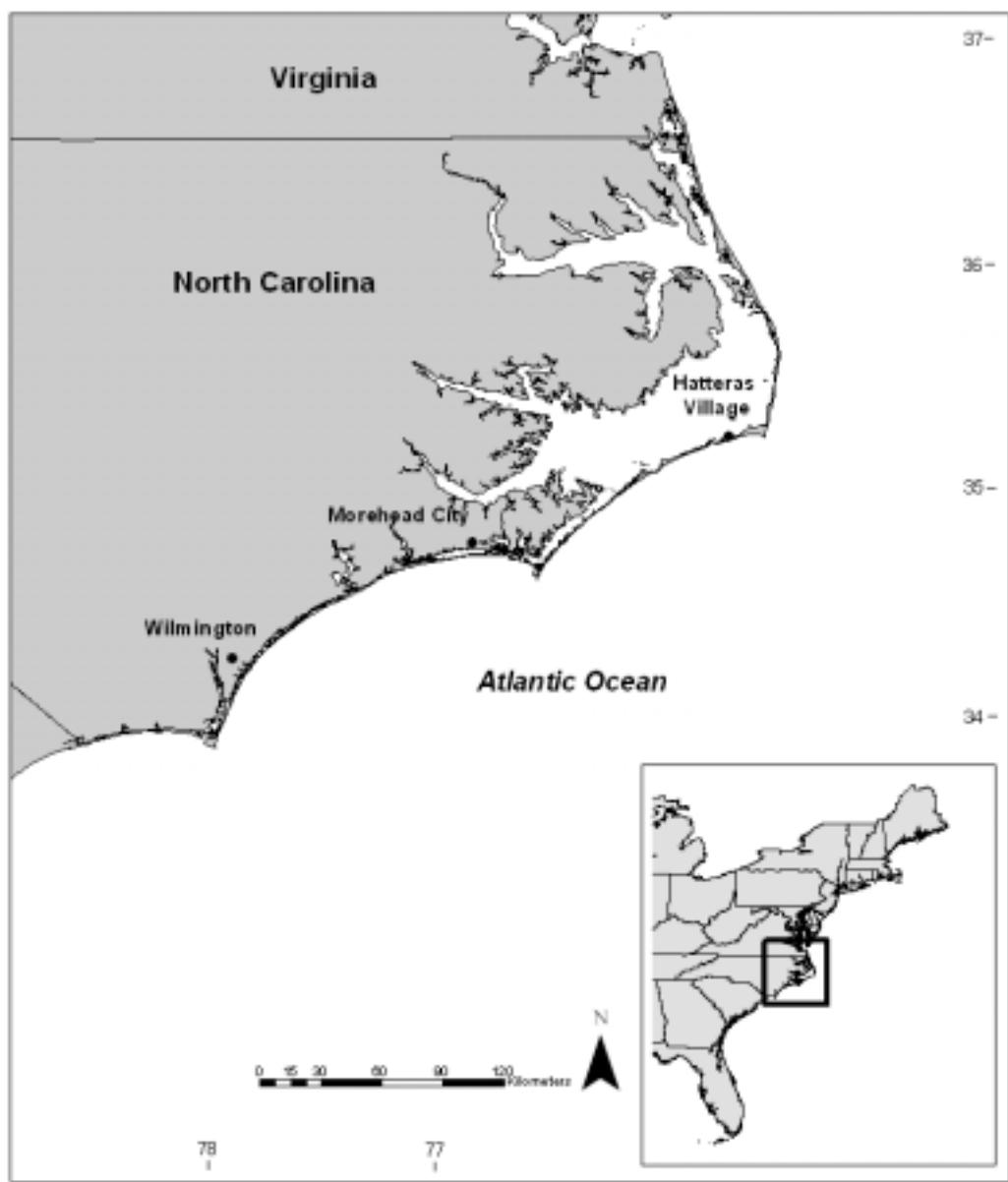


Figure 2. Coastal locations where dolphin were sampled from recreational charter boat catches and commercial fish houses.

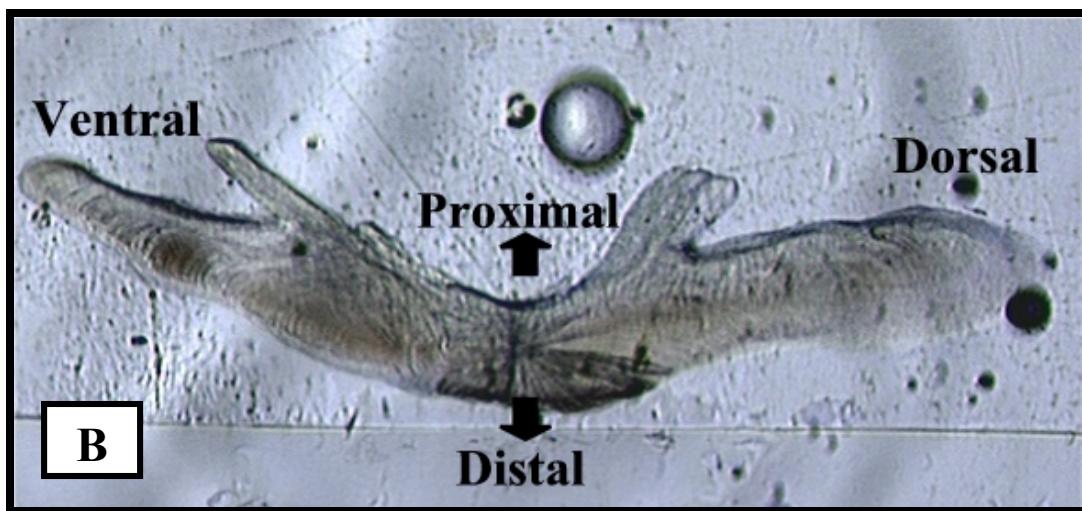
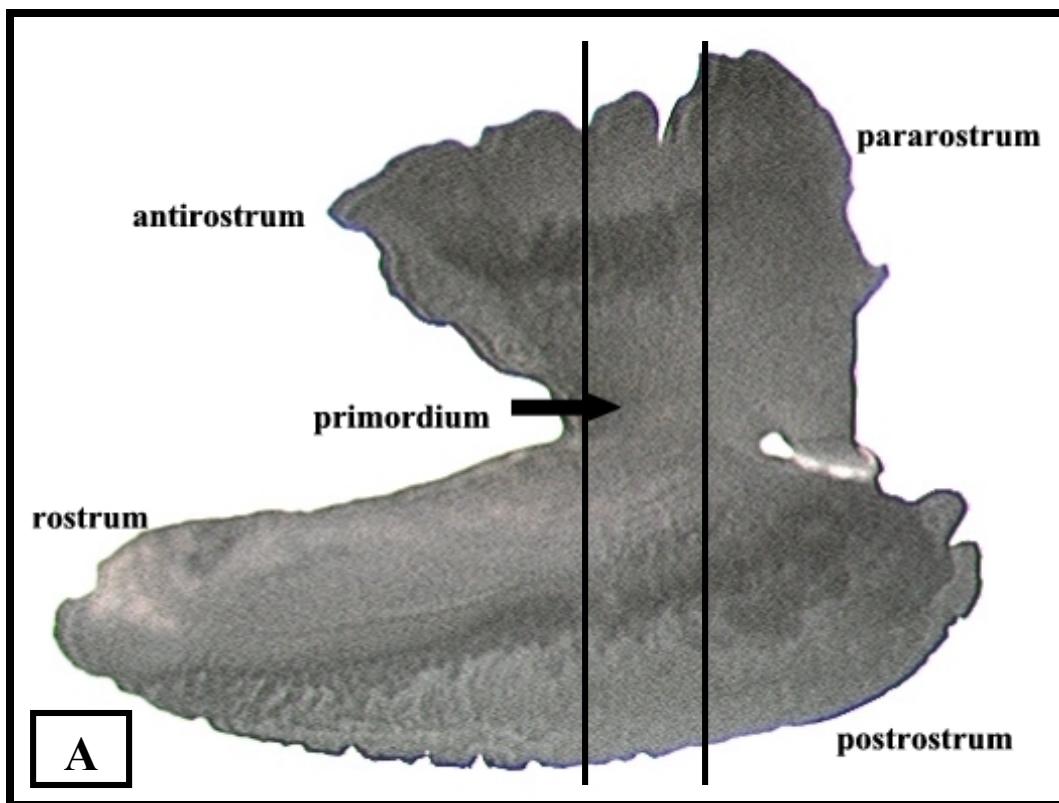


Figure 3. (A) External morphology of a left sagittal dolphin otolith showing pronounced rostrum and antirostrum. Vertical black bars represent area in otolith where the transverse cross section was cut. (B) Light micrograph of a transverse cross-section of a sagittal dolphin otolith. Reading was typically conducted on the dorsal side (pararostrum) of the otolith since that region was the easiest to follow a clear increment sequence.

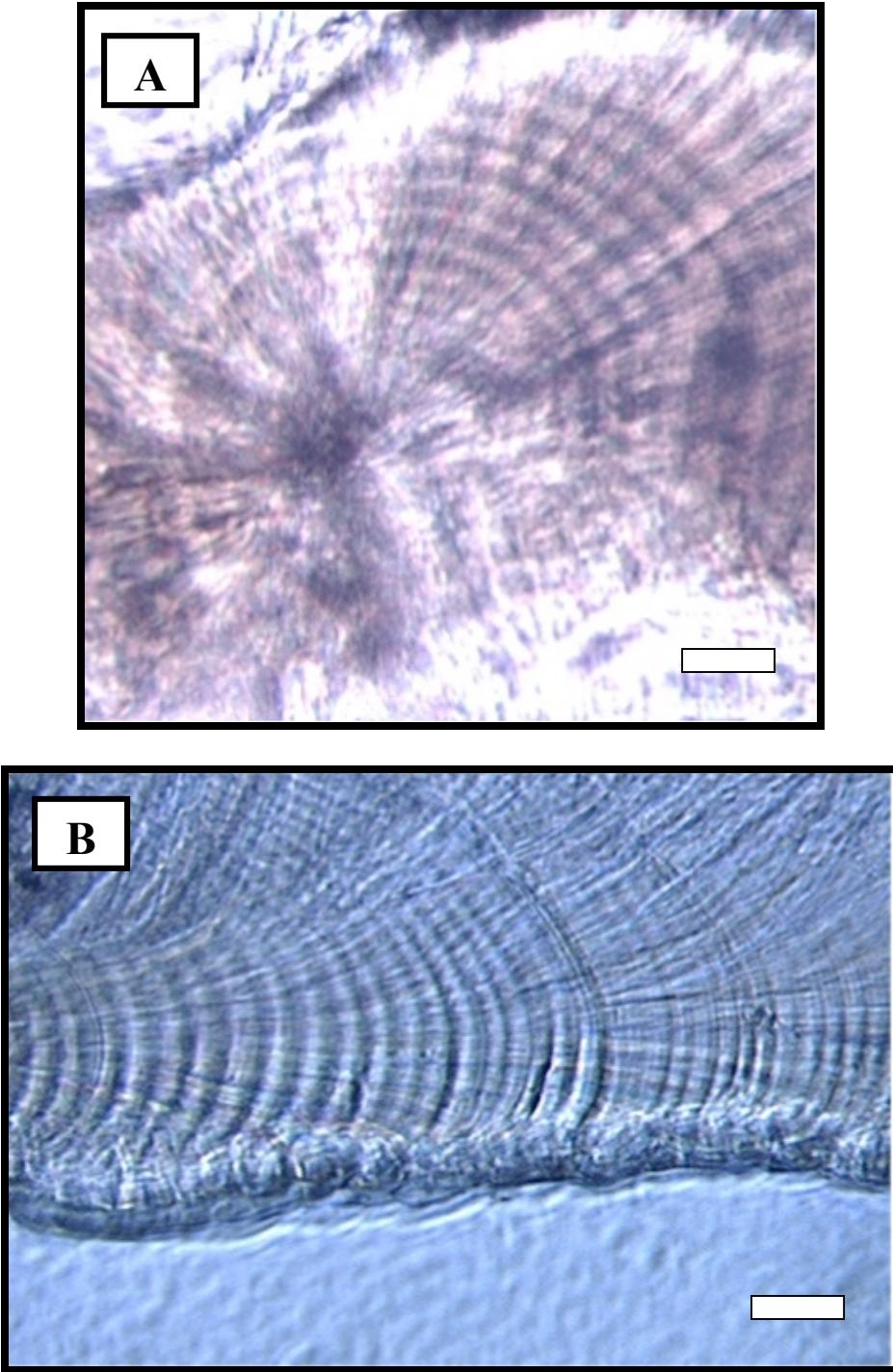


Figure 4. Light micrographs of dolphin sagittal otoliths. (A) Daily growth increments deposited around the core region of the otolith (scale bar: 10  $\mu\text{m}$ ) (B) Wide increments located towards the middle of the otolith (scale bar: 20  $\mu\text{m}$ ).

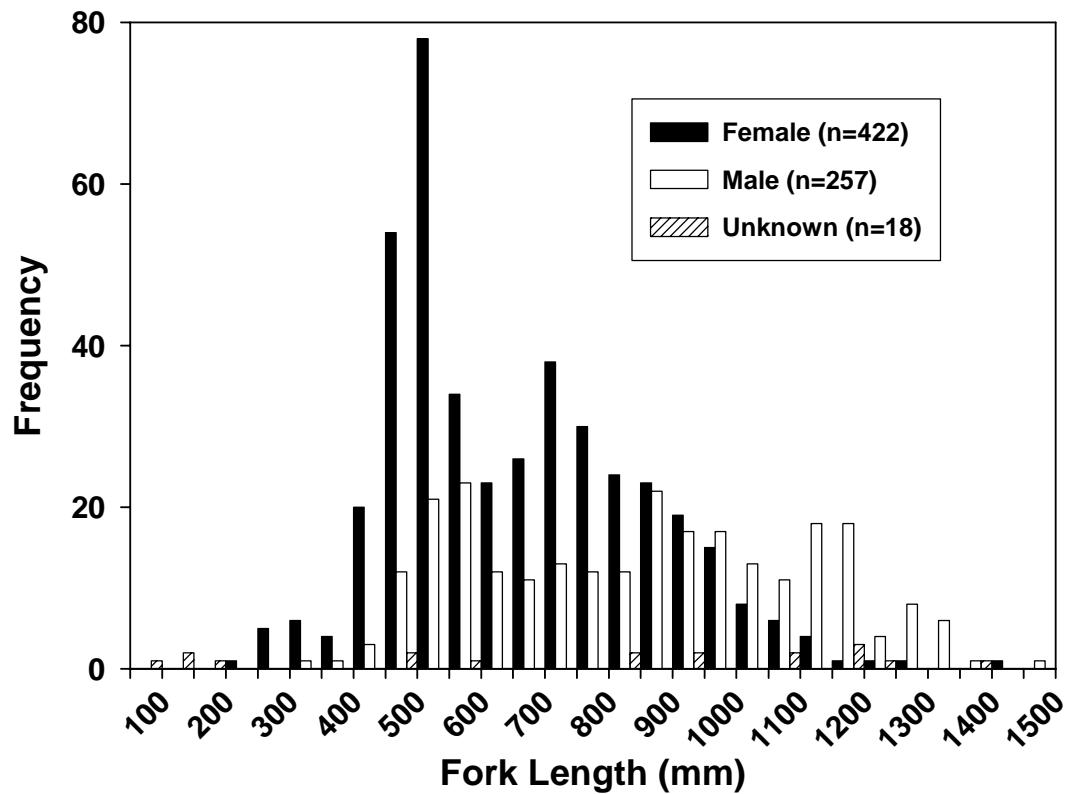


Figure 5. Length distribution of sampled dolphin from May 2002- May 2004 off the coast of North Carolina.

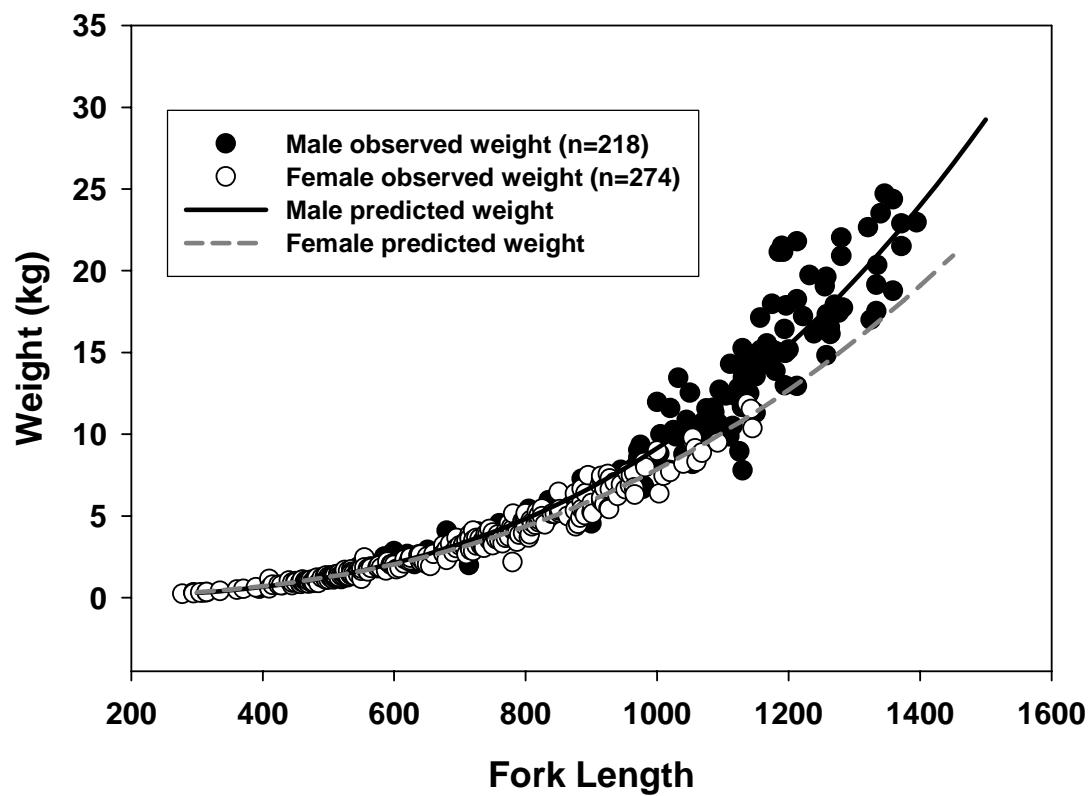


Figure 6. Observed and predicted length-weight relationships for male and female dolphin collected in North Carolina.

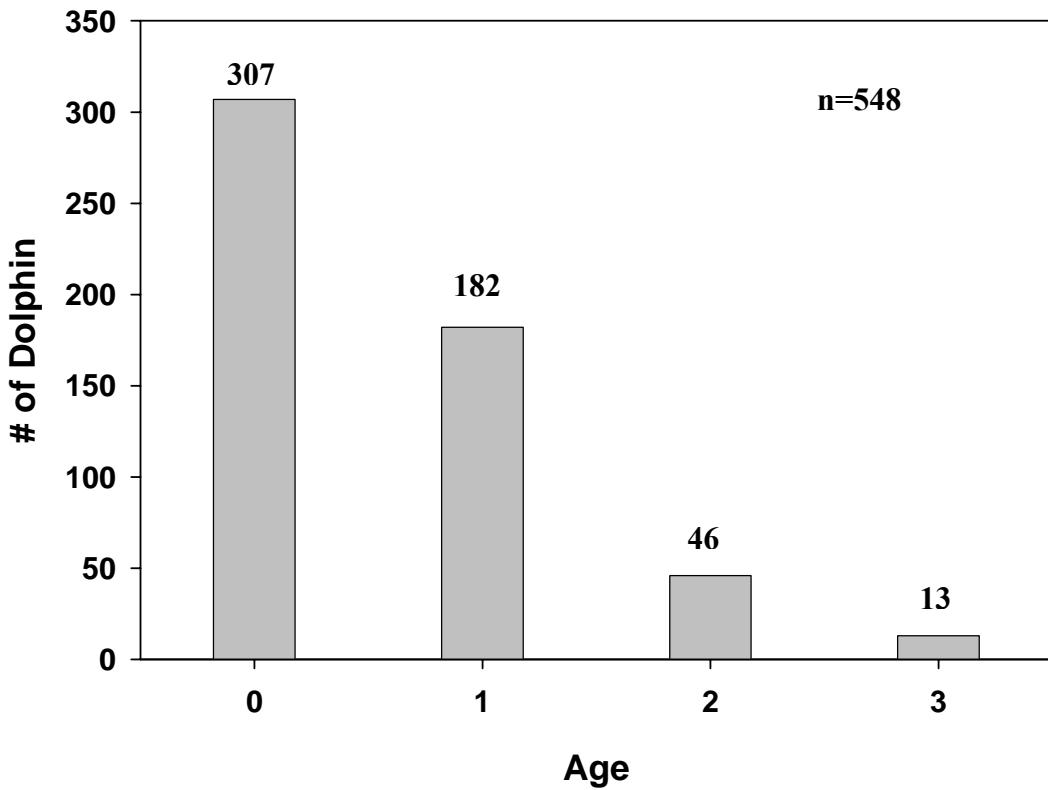


Figure 7. Number of dolphin aged using scale annuli. Sample sizes are shown for each age. Dolphin scales that were discarded due to distortion in the impression, or error in reading are not shown.

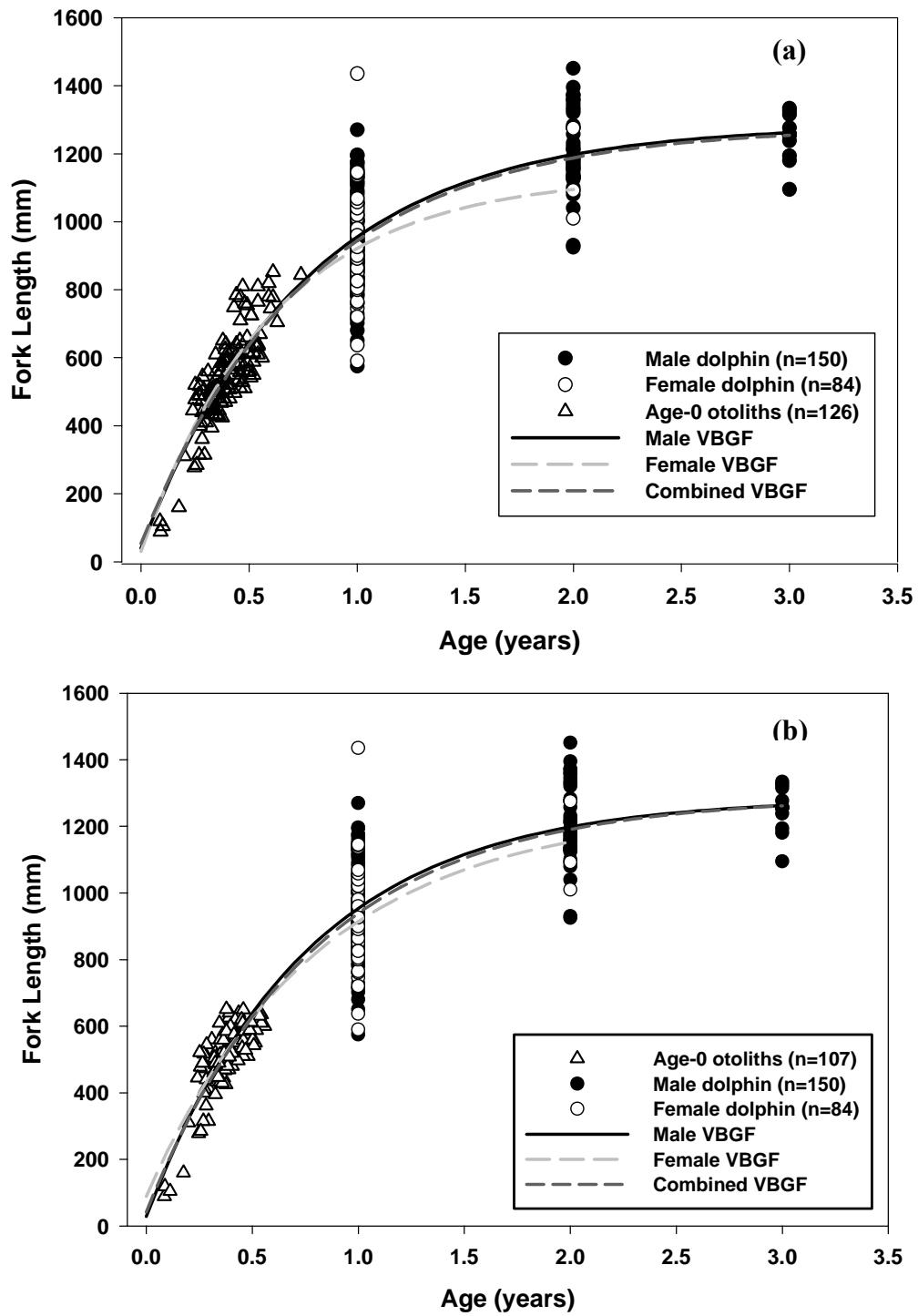


Figure 8. Length-at-age data for male and female dolphin determined by annuli in scales and daily growth increments in sagittal otoliths. Data are fit to von Bertalanffy growth function (VBGF) for male, female and combined. (a) contains length-at-age data from scale annuli from age 1+ dolphin and daily growth increments from all lengths of age-0 dolphin. (b) contains length-at-age data from scale annuli from age 1+ dolphin and daily growth increments from age-0 dolphin whose fork length was  $\leq 650\text{mm}$ .

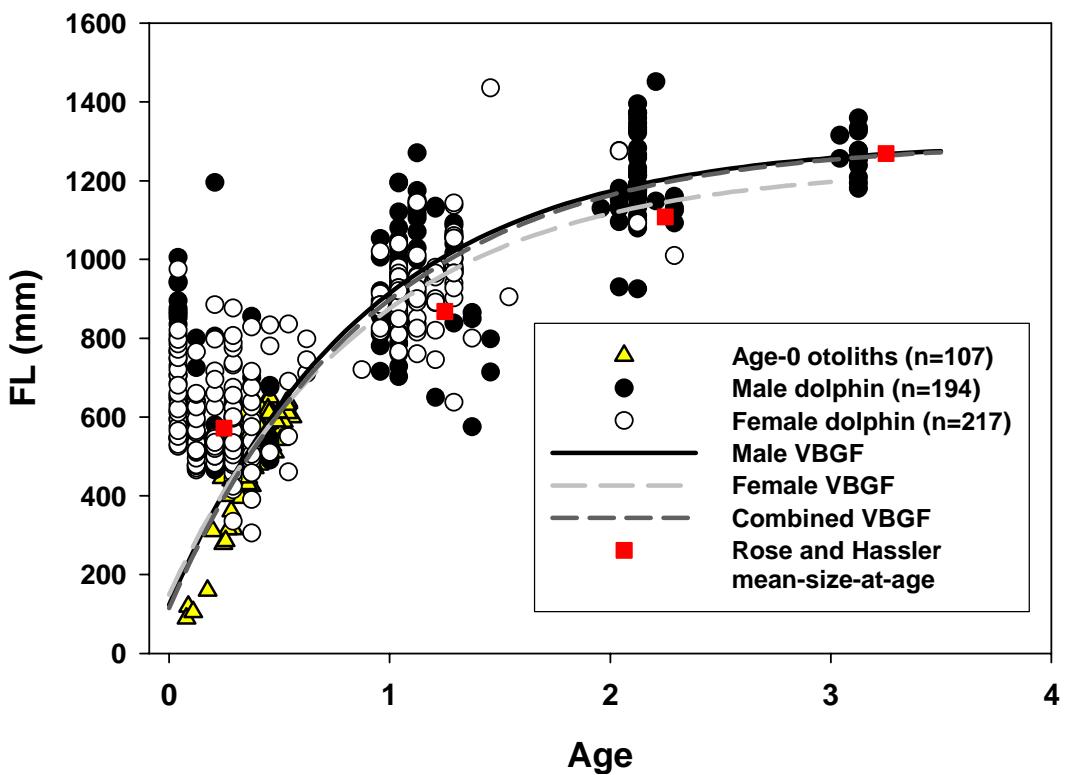


Figure 9. Length-at-age data for both male and female dolphin from scale annuli and daily growth increments from age-0 dolphin while assuming an April 15 hatch date. Data (except age estimates determined from age-0 scale annuli) are fit to von Bertalanffy growth function (VBGF) for male, female and combined. Red boxes indicate Rose and Hassler (1968) mean size-at-age values, and were also not used in any von Bertalanffy growth function.

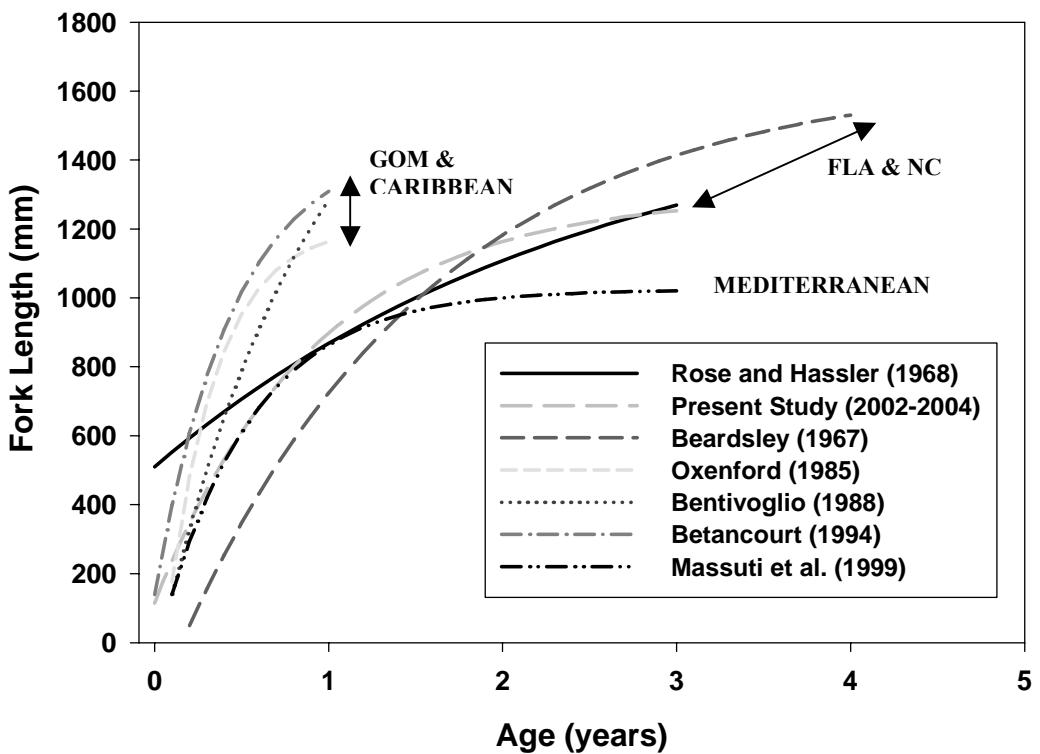


Figure 10. Calculated von Bertalanffy growth functions (VBGF) for dolphin from various locations in the north Atlantic. VBGF's were fit to mean length at age values for all other studies except the present study. The VBGF plotted for the present study is the combined VBGF as shown in Fig.9. GOM = Gulf of Mexico, FLA = Florida, NC = North Carolina.

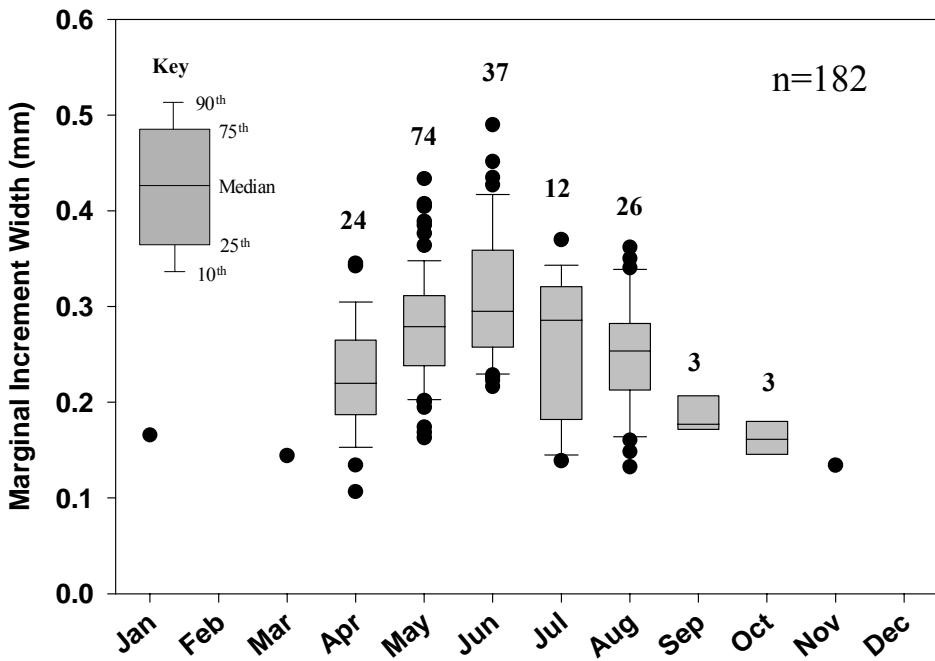


Figure 11. Box plots of the marginal increment width (mm) for age-1 dolphin from January through December for 2002-2004. Boxplots indicate the median, and the 90<sup>th</sup>, 75<sup>th</sup>, 25<sup>th</sup>, and 10<sup>th</sup> percentiles. Sample sizes are shown for each month.

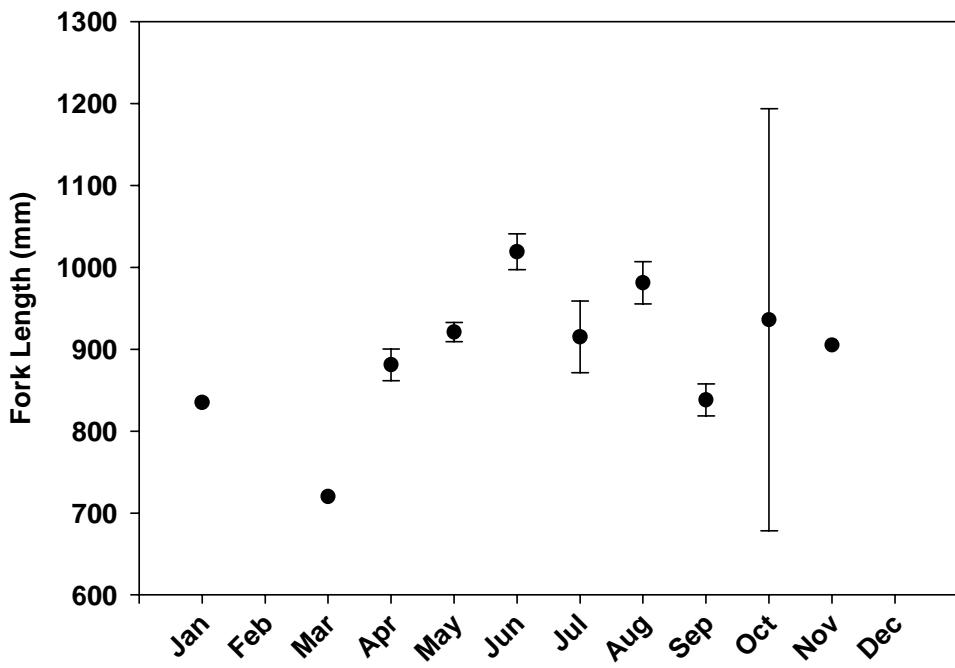


Figure 12. Monthly mean ( $\pm$ SE) fork length values of age-1 dolphin examined for marginal increment width.

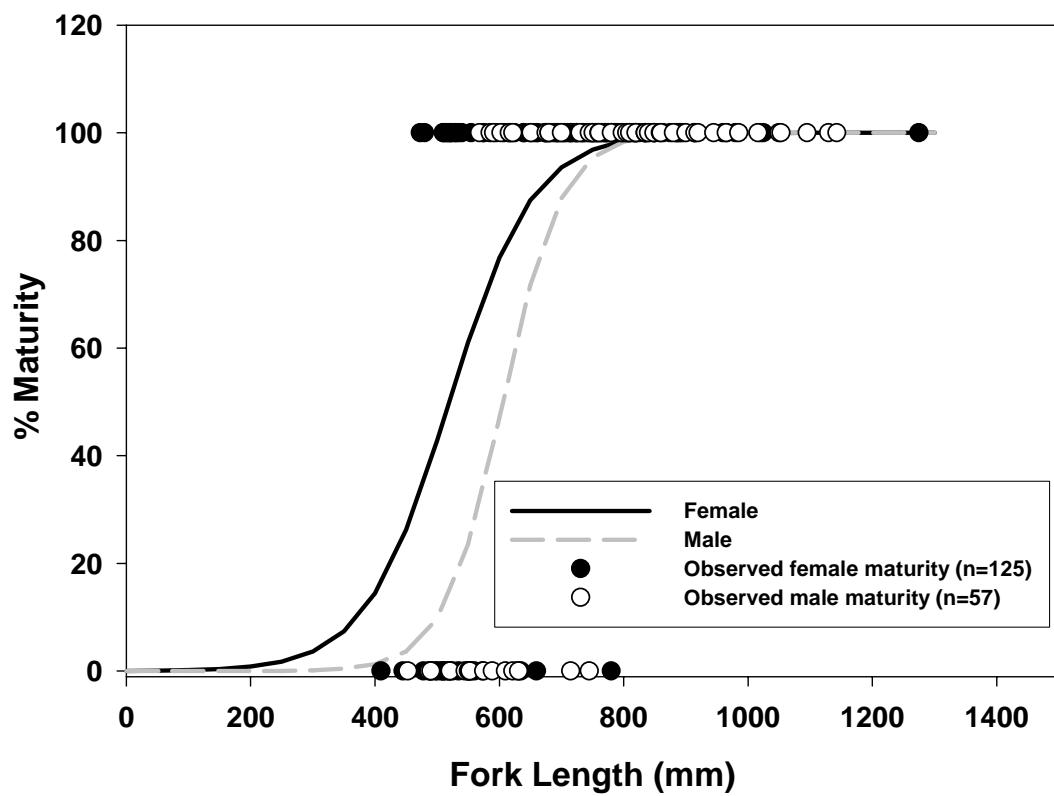


Figure 13. Observed length-at-maturity data for both male and female dolphin from May 2002- May 2004. Length-at-maturity data are fitted to logistic regression equations for male and female.

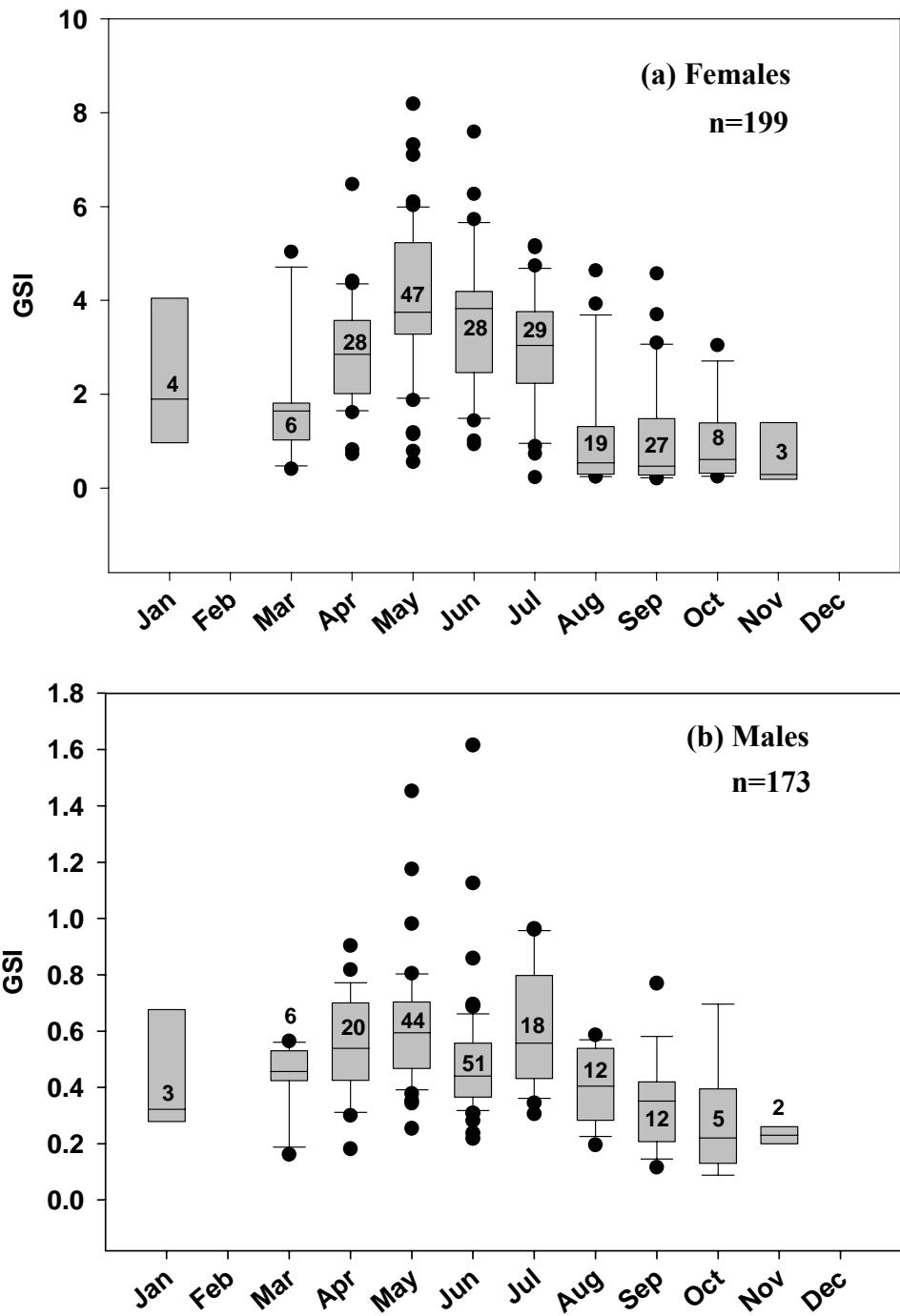


Figure 14. Box plots of gonadosomatic indices (GSI) for dolphin collected from January through December of 2002-2004 for a) females and b) males. Sample sizes are shown for each month.

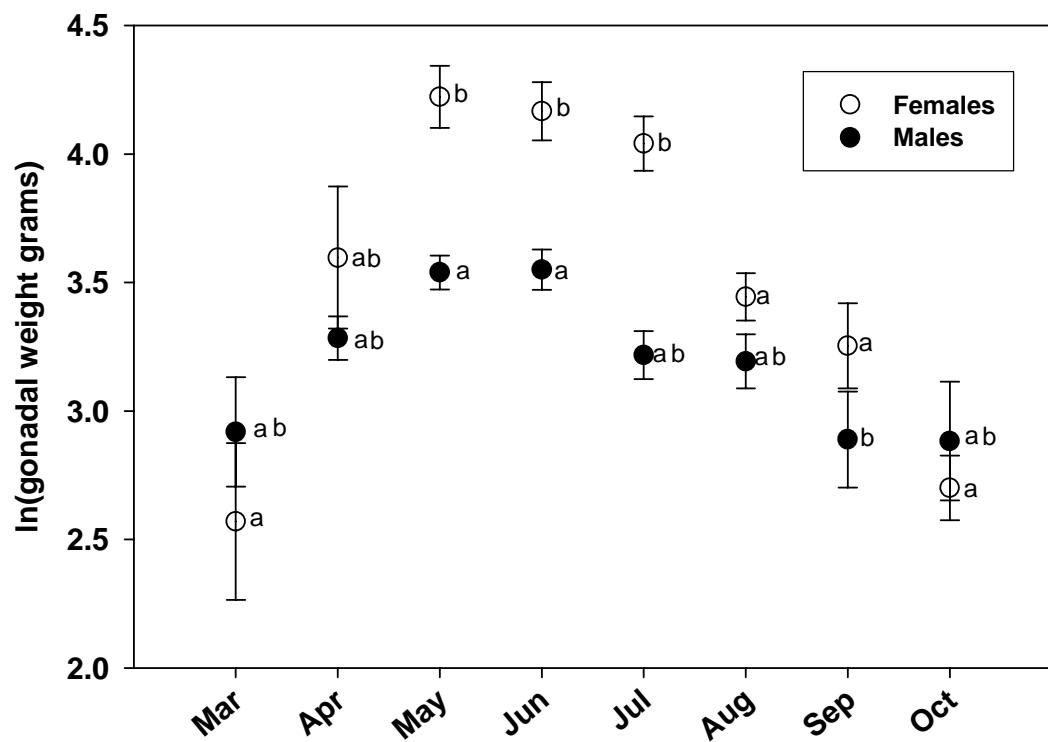


Figure 15. Mean ( $\pm$ SE) ln (gonadal weight) of male and female dolphin adjusted to a common length for March through October of 2002-2004. Like letters for each sex indicate no significant difference between months as determined with ANCOVA.

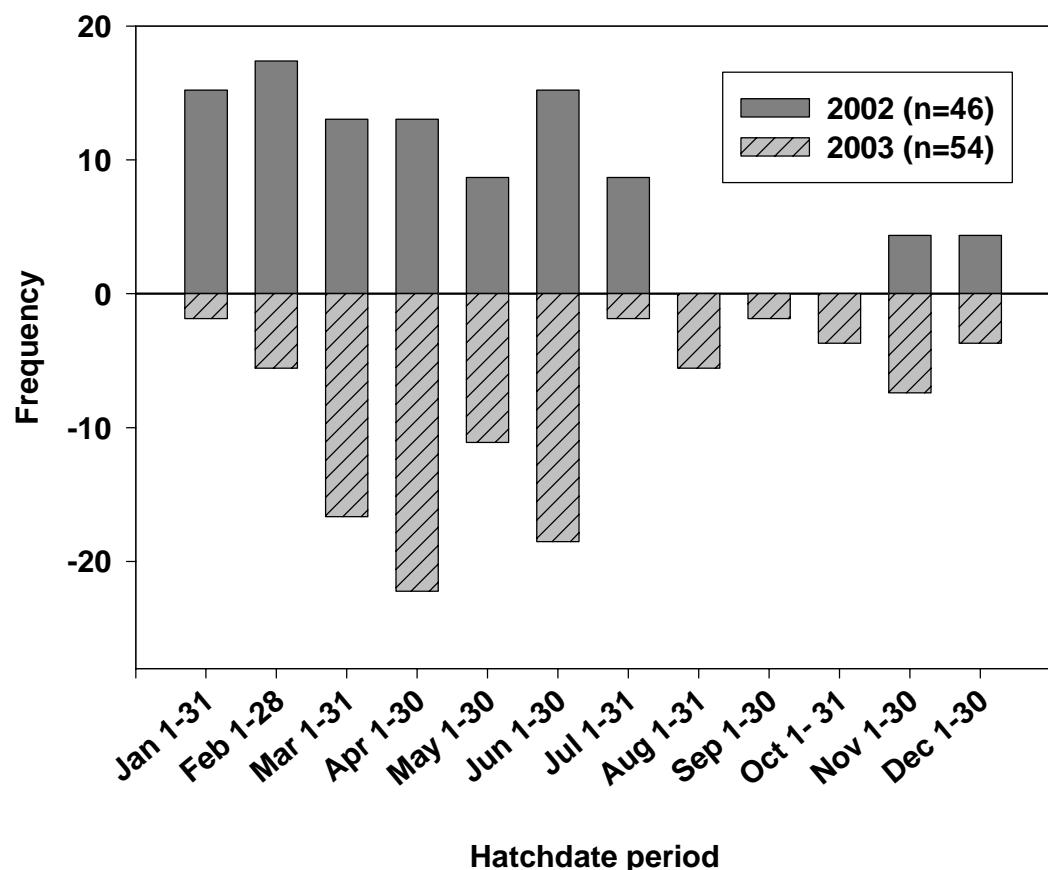


Figure 16. Frequency distributions of back-calculated hatch dates for dolphin collected in 2002 and 2003 from North Carolina.

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