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Nesting Behavior, Growth Rates, and Size Distribution of  
Loggerhead Sea Turtles (*Caretta Caretta*) on Blackbeard  
Island National Wildlife Refuge: An Evaluation of  
Recruitment In Georgia

Heather L. Cason

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NESTING BEHAVIOR, GROWTH RATES, AND SIZE DISTRIBUTION OF LOGGERHEAD SEA  
TURTLES (*CARETTA CARETTA*) ON BLACKBEARD ISLAND NATIONAL WILDLIFE REFUGE:  
AN EVALUATION OF RECRUITMENT IN GEORGIA.

by

HEATHER L. CASON  
(Under the Direction of David C. Rostal)

ABSTRACT

An eight year study of loggerhead sea turtles (*Caretta caretta*) was conducted on Blackbeard Island National Wildlife Refuge (BLB NWR). A 3 month in-water survey also was conducted in 2008 along the coast of Georgia and Northern Florida. The nesting trends on BLB NWR were evaluated to provide updated information for existing management plans as well as to determine if recruitment was occurring. The in-water study also shed insight on the status of recovery for the population as a whole. The remigration interval, a key nesting trend, averaged 2.93 years, higher than previous studies in Georgia. Females nesting on BLB NWR grew an average of 0.48 cm/yr. The population was composed of mostly medium-sized individuals, although the newly PIT tagged individuals were classified in the small to medium size classes (based on curved carapace length). In-water captures were composed mostly of medium-sized juveniles with very low numbers of adults (>85cm), although surveys were conducted during the nesting season. Only 0.47 % of the in-water observations were recaptures. Due to the increase in small, newly tagged individuals on BLB NWR and the low number of recaptures from the in-water study, the result of this study suggests that recruitment is taking place in the *C. caretta* population of Georgia, and the population is on its way to recovery.

INDEX WORDS: *Caretta caretta*, Nesting, Behavior, Size, Georgia, Recruitment, Growth, Age

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MASTER OF SCIENCE

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CHAPTER 1

INTRODUCTION

Conservation has become increasingly important as the number of species facing extinction continues to increase (Baillie, 2004). According to the U.S. Fish & Wildlife Service's (USFWS) Threatened and Endangered Species System (TESS), 1,994 species are threatened or endangered in the United States (2008). Threatened species have the potential to become endangered, and endangered species are already on the brink of extinction, having experienced a drastic reduction in population and even extirpation in some cases. All organisms terrestrial, aquatic, and marine may face peril equally. However, organisms that use a combination of these habitats, like sea turtles, may face even greater dangers. All sea turtle species that utilize the coastline of the U.S. are listed as either threatened or endangered (USFWS 2008). This includes the loggerhead sea turtle (*Caretta caretta*).

The loggerhead sea turtle belongs to the family Cheloniidae. Its diet consists mostly of crabs, various mollusks, and cnidarians (Plotkin et al. 1993, Godley et al. 1997). In the U.S., the distribution of *C. caretta* occurs in warm, temperate waters in the Atlantic and Pacific, and nesting occurs along the Atlantic and Gulf coast (NMFS and USFWS, 2008). Female loggerheads lay multiple clutches (nests) during the summer nesting season (Frazer and Richardson, 1985, Pike et al., 2006). Each clutch contains an average of 100 eggs (Hatase et al., 2004). The sex of the hatchlings is determined by the incubation temperature of each clutch. This is known as Temperature-dependent Sex Determination (TSD) (Standora and Spotila, 1985, Matsuzawa et al., 2002). Loggerheads also exhibit indeterminate growth, where energy is still allocated to growth after they have reached sexual maturity (Carr and Goodman, 1970, Price et al., 2004).

Before reaching sexual maturity, loggerheads circumnavigate the Atlantic Ocean (Carr, 1986, Bjorndal et al., 2000). The hatchlings leave the coast of the U.S., and begin a swimming frenzy. They are propelled out to the Sargasso Sea via the Gulf Stream, where they float among

rafts of brown macroalgae (*Sargassum*). The young turtles continue their route along the European coastline and finally migrate back to the U.S. by way of the North Equatorial Current. It takes about 8-10 years for loggerheads to make this journey. By this time, they are considered to be juveniles with a Curved Carapace Length (CCL) of >40cm (Shoop et al., 1999). The juveniles forage in the neritic zone, along the eastern coastline until they become adults (NMFS and USFWS 2008). Adults reach sexual maturity in 25-35 years or at a size of approximately 85cm CCL (Dodd, 1988). They forage and mate in neritic and oceanic zones (NMFS and USFWS 2008). Females nest on land and have shown evidence of site fidelity, depositing their clutches in the same area each time they nest (Bowen et al., 1993, Weishampel et al., 2004). Adults also migrate, but they do not typically traverse the Atlantic, rather migrate north and south along the eastern coastline of the U.S. (Seaturtle.org 2009).

Due to the migratory behavior of loggerheads, a unified management plan is difficult to enforce. Without protection many sea turtles are left vulnerable to harvesting methods such as longline fishing, gillnets, and trawling (Lewison et al., 2004). Turtle Excluder Devices (TEDs) were finally implemented in 1991, based on regulations outlined by the National Marine Fisheries Service (NMFS) in 1987, to combat sea turtle mortality associated with trawling (Lewison et al., 2003). A TED is an opening in trawling nets that allows turtles to escape the fate of drowning while still retaining the targeted catch which is typically shrimp. It is still uncertain how effective TEDs are in lowering sea turtle mortality. It is even possible that they are selecting against certain size classes due to the size constraint of the opening (Epperly and Teas, 1999, Shoop et al., 1999).

All of these factors have contributed to the decline of the loggerhead population, and in 1978 they were listed as threatened under the Endangered Species Act (enacted in 1973). Since that time, loggerheads have received protection from the Federal government in the U.S. In 1984, a

recovery plan was approved for the U.S. population. Two revisions have since been made, in 1991 and 2008, for the Northwest Atlantic Population.

The 2008 recovery plan outlines five recovery units (NMFS and USFWS). The Northern Recovery Unit (NRU), which includes North Carolina (NC), South Carolina (SC), and Georgia (GA), is the focus of this study. In order for recovery to take place in GA there has to be an increase in total number of nests. Currently, 2,800 is the nest total that must be obtained for recovery. An increase in number of females also has to be observed in order for recovery to be obtained. The number of female loggerheads in GA is determined by the following formula (National Research Council, 1990):

$$\frac{\text{(the total \# of nests in GA} \div \text{the average number of clutches a female deposits within a season)}}{\text{(the proportion of females seen in one season)}}$$

The recovery of the loggerhead population in GA is extremely important. In 1994, three mitochondrial genotypes were identified in GA (Bowen et al., 1994). Two of the genotypes were unique to GA. The population found there provides key genetic variation to the loggerhead population. Genetic variation is vital to the survival of a species.

The first objective of this study was to provide updated nesting trends for management plans. Most nesting trends have not been revisited in twenty years or more and are still being used to manage the species although new technology has aided in better calculations and estimates for many nesting patterns. The environment is constantly changing, and it is possible that the behavior of the turtles is also changing. This has already been suggested by one study where earlier nesting seasons for loggerheads were observed due to warmer temperatures (Weishampel et al., 2004).

The second objective of this study was to calculate the average growth rate of females on BLB NWR. Growth rates have not been calculated for this study site. Growth rates can be used to

estimate the age of nesting females. This can provide insight into the life span of loggerhead sea turtles. It can also determine if adult females are continuing to grow and display indeterminate growth.

The third objective of this study was to determine if recruitment is taking place in the *C. caretta* population of Georgia, and the fourth objective was to determine if the population in Georgia has reached, or is nearing projected nest totals and population estimates for recovery. Following threatened and endangered species is the key to tracking their recuperation and the progress and precision of management strategies. Without these observations, the recovery efforts would be futile.

## CHAPTER 2

### METHODS

#### *Nesting Population*

This study was conducted on Blackbeard Island National Wildlife Refuge (BLB NWR), a barrier island located off the coast of GA in the southeastern U. S., from 2001-2008. The refuge is a protected area with strict regulations that keep the island as pristine as possible; this includes the

beach where *C. caretta* nesting occurs. Data were collected during each nesting season (2001-2008). Data entries were recorded and later compiled into a spreadsheet.

Beach surveys were conducted nightly in order to monitor loggerhead nesting. The patrols were performed constantly to ensure that every nesting female would be encountered. However, some females were missed, and therefore the only data collected was for the nest itself. Saturation tagging was conducted on BLB NWR but not on adjacent islands. The goal of saturation tagging is for every individual in a population to be marked with the appropriate tags determined for a given project. This is a common method used in sea turtle population studies (Boulon et al., 1996, Richardson et al., 1999, Balazs and Chaloupka, 2004).

In this study, every untagged turtle was fitted with a series of tags during each nesting observation. The initial observation did not necessarily represent the first nesting event of a primiparous female, defined as one that has not previously nested. The loggerheads that received tags were identified distinctively upon subsequent observations. Metal inconel tags were placed externally, on the trailing edge of the front flippers (right and left). Each inconel tag bore a unique identification code, consisting of three letters and three numbers. A Biomark® PIT (passive integrated transponder) tag was placed subcutaneously in the right front flipper, near the shoulder, where the radius and ulna meet the humerus. The PIT tags also bore a unique identification code that was a combination of letters and numbers. These tags were used in order to establish a series of intraseasonal and interseasonal nesting trends as well as establishing a size distribution for this population and calculating growth rates.

In general, sea turtles do not nest every year but may deposit up to seven clutches within a single season (Lenarz et al., 1981, Frazer and Richardson, 1985, Crouse et al., 1987, Pike et al.,

2006). The remigration interval refers to the number of years between seasonal nesting events for a single female. PIT tags were sorted in a spreadsheet with the corresponding nesting year. The tag identification code was used to identify the initial year a female was observed nesting on BLB NWR. The initial year was subtracted from the successive year the same turtle was observed, giving the remigration interval. Some individual turtles displayed multiple remigration events. The events were averaged for those turtles. Inconel tags were not as reliable as PIT tags and, therefore, were not used for long term observations such as the remigration interval. However, they were used to determine within season nesting trends such as internesting intervals and size distribution.

The internesting interval defines the number of days between nesting events within a season. Inconel tags and associated nesting dates were sorted in a spreadsheet. Each female's nesting events were grouped together. Then, the nesting dates were sorted chronologically for each individual turtle. The date of the first clutch of a season for each turtle was determined. Then, the date of the successive nest was determined. The successive nest date was subtracted from the original nest date, determining the internesting interval. Some turtles nested more than twice, up to six times. In these cases multiple internesting intervals were calculated .

A series of curved carapace (shell) measurements also were taken in centimeters, to the nearest millimeter, using a measuring tape. The length of the carapace was measured using two methods. The first measurement was taken from the nuchal notch to the supracaudal notch, notch to notch (N-N) (Fig. 1a). The second measurement was taken from the nuchal notch to the supracaudal tip, notch to tip (N-T) (Fig. 1b). A measurement of the carapace width also was taken, at the widest point, typically along the posterior edge of the second bilateral pair of costal scutes (Fig. 1c). These measurements were used to classify individuals by size as well as to calculate growth rates. Nuchal describes the scute, on the anterior edge, at the midline of the carapace (Fig.

1d). The supracaudals are the paired posterior marginal scutes; marginals define the perimeter of the carapace (Fig. 1e).

Notch to notch CCLs were used to generate size distributions. Inconel tags and associated PIT tags were sorted in a spreadsheet for each nesting season. A comparison of the two types of tags was used to determine if there were individuals that were observed more than once. Comparing both the inconel and PIT tags corrected most human error that occurred while the data were recorded in the field. Due to the low lighting conditions, some tag information was written incorrectly. If there were repeated measurements for a single turtle within a single year, the measurements were averaged together, eliminating any possibility of pseudo replicates. The progress of the saturation tagging was tracked by comparing previously tagged individuals to newly tagged individuals; this only included individuals with valid carapace measurements. The smallest size class was developed based upon the smallest nesting female observed (84.6 cm) within the eight year study period. Each size class was delineated down into 2.9 cm intervals. Ten size classes were developed for this population.

The number of females observed each season also was recorded. The size distributions were used to determine the number of individuals. However, the size distributions only included turtles with valid carapace length measurements. Therefore, tagged individuals without measurements were not included. In order to obtain the total number of nesting females observed each season, the inconel and PIT tags were compared and those tagged individuals that did not have recorded measurements were added to the total number of females that were included in the size distributions.

The number of nests does not usually remain constant throughout a season. Therefore, the nesting distribution for each season also was determined. A temporal scale was used to show this pattern, beginning with the first date of the earliest recorded nest on BLB NWR (22 April). The nest numbers and associated laying dates were counted and recorded for each week of the nesting season. The last week of the nesting season was determined, using the last nesting date also recorded on BLB NWR (15 August). Seventeen weeks defined the nesting season on BLB NWR. Across all years, the number of nests for BLB NWR also was determined, and compared to statewide totals.

Growth rates were calculated using the N-N curved carapace measurements. Measurements were averaged together within a season. The mean N-N measurement from the second nesting season observation was subtracted from the mean N-N measurement of the initial nesting season observation. This was divided by the remigration interval. A paired t-test was used to determine if the growth rates were significantly different than zero, implying that there was growth or no growth.

Female population estimates for Georgia also were determined (National Research Council, 1990). The total number of nests used to calculate population estimates represented the state totals each year (Dodd and Mackinnon, 2001-2007). The clutch frequencies used to make estimates were observed by Frazer and Richardson (1985). The lowest clutch frequency calculated was 2.39, and the highest was 4.18 (Frazer and Richardson 1985). Females on BLB NWR deposited as many as six clutches within a single nesting season and this too was included in calculating population estimates (Drake 2001). The average remigration interval was used to determine the proportion of females that nested each year (1/3).

Once a female had laid her nest and covered it, a GPS point of the nest was taken. It was later determined whether the nest would be relocated, depending on its proximity to the spring high tide line. If a nest was to be relocated, it was excavated and the number of eggs was counted, and then placed in a newly created nest.

### *In-Water Survey*

This portion of the study was conducted on the Georgia Bulldog Research Vessel (RV), affiliated with the University of Georgia Marine Extension, and was part of a federally funded project that was implemented by the South Carolina Department of Natural Resources (SCDNR). From June until August of 2008, five day cruises were taken for a total of seven weeks. Trawling was conducted in near-shore coastal waters (15 - 40') from Winyah Bay, South Carolina, to St. Augustine, Florida, in the southeastern United States. The target species was sea turtles, in general, including *C. caretta*, which was the most abundant species caught. The Georgia Bulldog Research Vessel traveled along the coast of Florida and Georgia, while a sister vessel, the Lady Lisa, sampled the waters off the coast of South Carolina. Each vessel trawled approximately 250 stations.

Stations represented the center coordinates for every square mile of trawlable bottom in the prescribed survey area; they were randomly and proportionately (for each of three sub-region strata) selected from a station universe each year. Stations were assigned various priority levels to facilitate repetitive trawling throughout the region over the seven week sampling period. Daily station order was established on-site in order to account for efficient vessel operation as well as minimization of auto-correlations (i.e., not all shallow stations trawled in the morning or vice-versa). Stations were sampled for 20 minutes (bottom time), and at least one point of the trawl

transect line must intersect a radii extending 0.5 nm from the station coordinates. The twenty minute trawls were conducted approximately twelve hours a day, from 7:30am to 7:30pm.

Trawl nets were the standard ‘turtle nets’ (paired otter/flat trawl such that one net is towed on each side) approved by NMFS. Trawl perimeter around the mouth was 137’ (60’ head rope + 65’ foot rope + 2 x 6’ wing end height); however, the effective fishing ‘swath’ was 12 m (Dickerson et al., 1995). Trawl design was 4-seam, 4-legged, 2-bridal, and trawl webbing (dipped nylon) was 4” bar and 8” stretch-mesh (Top’s sides of #36 twisted with the bottom of #84 braided nylon line). Net length was 60’ (corkline to cod end), and the cod end consists of 2” bar and 4” stretch mesh. The large mesh limited by-catch collected and “mud rollers” were included on the foot rope to reduce damage to bottom habitats and sampling gear.

The objective of this study was to catch and record data on any sea turtles collected in the nets. This provided insight into the health and abundance of the sea turtle population, specifically *C. caretta*. Therefore TEDs were not used. Bycatch was sorted and counted; priority species also were weighed and measured. This was done in order to assess their collection frequency and relative abundance.

The same tagging and measuring protocols from the BLB NWR study site were implemented during the in-water surveys (Fig. 1a-c). Carapace measurements were used to create a size distribution of the in-water captures of *C. caretta*. Another series of measurements were taken in order to determine carapace wear and if there was a correlation between carapace length and wear. Marginal scutes 2, 8, and 11 were measured to calculate a ratio of anterior to posterior scute lines (Fig. 2). Ratios were calculated to control for size. The anterior and posterior scute lines were measured in each of the aforementioned scutes, as well as a diagonal measurement, from the top of the anterior line to the tip of each marginal or bottom of the posterior line. A ratio of the

anterior to posterior scute line was calculated for each individual turtle and plotted against CCL. A regression was fitted for each marginal ratio to examine the relationship between CCL and scute wear.

## CHAPTER 3

### RESULTS

#### *Nesting Population*

The nesting season on Blackbeard Island NWR spans a seventeen-week period. The earliest recorded nesting event took place on 22 April 2003; whereas, the latest recorded nesting event took place on August 15, 2008. Throughout the study period, the first clutch for each female was deposited in May (weeks 2-6), excluding the 2003 season. In 2003, the first nest was deposited in April (week 1). In every season, excluding 2003 and 2004, the first nest was laid in weeks two, three, or four (5 May – 19 May). The largest number of clutches deposited, within a week, occurred in weeks seven through twelve, for all seasons, including 2004. Excluding 2004, the largest number of nests laid within a week, occurred during weeks nine, ten, and eleven.

Ninety females were identified in 2008 (Fig. 4). During the 2007 nesting season, only thirty nine turtles were identified. The number of females was unknown for the 2004 season because nightly surveys were not conducted, but morning surveys were performed to determine nesting dates and nest numbers.

The size distribution of females on Blackbeard ranged from 84.6 cm to 111.1 cm, with an average of 98.5 cm ( $0.26 \pm \text{SE}$ ) (Fig. 5). Saturation tagging, using both PIT and inconel tags, began in 2001. During this initial study year, only 45.45% of nesters were tagged with PIT tags.. A greater number of females, 54.54%, were tagged with inconel tags only. In the 2002 season , 95.08% of individual turtles were PIT tagged. There were no remigrants from 2001 to 2002. In 2003, the first remigration events were observed. Out of 76 females observed in the 2003 season, 13 (17.11%) were returning individuals while 63 (82.89%) were newly tagged.

The number of previously tagged turtles increased in 2005 to 37.5% even though tagging was not conducted in the previous year (2004); previously tagged individuals (42.67%) increased further still in 2006 (Fig. 5). This growing trend continued in 2007 (61.54%) but dropped in 2008 (44.71%). Newly tagged individuals appeared in all size classes across the study period. However, an inverse relationship was exhibited in some seasons, especially 2008, where newly tagged individuals decreased with increasing size and previously tagged individuals decreased with decreasing size.

The greatest number of turtles displayed a twelve-day interesting interval. There were 118 (24.93%) twelve-day interesting events out of the 479 observations (Fig. 6). Most of the observations were between eight and seventeen days. There were 395 (82.46%) interesting observations recorded in the former range, 8-17, while only 64 (13.36%) were recorded in the

range of twenty one to thirty one days. Only 2.92% of interesting intervals were recorded at 31+ days.

54 remigrants were observed returning to Blackbeard Island NWR to nest. Across the eight year study period, twenty one individuals displayed multiple seasonal nesting events while 33 displayed single seasonal nesting events, in which they were observed returning to Blackbeard only once, from 2001-2008. The remigration interval ranged from 1 to 7 years (Fig 7). Three females nested in intervals less than two years, and three females re-nested in intervals exceeding four years. Thus, the majority of nesters (88.89%) remigrated in 2 to 4 year intervals. Twenty three individuals (42.59%) exhibited a three year remigration interval. Eleven individuals (20.37%) displayed a two year remigration interval. The average remigration interval was 2.93 years ( $0.14 \pm$  SE).

Adult females from the BLB NWR population exhibited growth significantly greater than zero ( $t=-6.251$ ,  $df=48$ ,  $P < 0.001$ ). The average growth rate was 0.48 cm/year ( $0.06 \pm$  SE). Growth rates ranged from 0.03 to 2.10 cm/year (Fig. 8). The smallest amount of growth was displayed by a female with a CCL of 103.9 cm (Fig. 8). Ten other turtles in this size class (103-105.9 cm) displayed higher growth rates, ranging from 0.12 to 1.18 cm/year. The female exhibiting the largest amount of growth measured 95.1 cm in length, however, four females in the same size class (94-96.9 cm) exhibited lower growth rates. Smaller adults did not grow faster than larger adults, but it was apparent that younger turtles (hatchlings and juveniles) did exhibit higher growth rates than adults (Fig. 9). Using the average growth rate, it was estimated that the largest turtle (111.1 cm CCL) on BLB NWR was approximately 90 years old. The amount of total growth also was examined for each turtle. Females exhibiting longer remigration intervals displayed more growth than females exhibiting shorter remigration intervals ( $f=4.09$ ,  $df=41$ ,  $p=0.050$ ) (Fig. 10).

When comparing the number of nests on BLB NWR with statewide totals, a pattern of increasing and decreasing nest totals was evident ( $r^2=.95$ ,  $p=<0.001$ ,  $n=8$ ). The lowest recorded nesting season occurred in all of GA, including BLB NWR, in 2004.(Fig. 11). Only 35 clutches were deposited on BLB NWR in 2004, and 332 clutches were deposited for the remaining sites in Georgia. The 2008 season showed the highest total of nests at 257 within the eight year study period.. Similarly, nesting totals were at their highest, 1,389, in 2008 for the remaining barrier islands of Georgia (Dodd and Mackinnon, 2001-2008).

Female population estimates for Georgia displayed a wide range of values, for each season. The number of nests used in calculating these estimates changes from year to year, contributing to the seasonal variability. Also, clutch frequency can be attributed to this spread of population estimates. The 2004 nesting season yielded the lowest range, 183.50-460.67 (Table 1); the highest estimate for this year does not even come near the most conservative estimate, 1,001.50, for 2008, which yielded the largest number of nests during the 2001-2008 study period.

### *In-Water Surveys*

The overall size distribution for the in-water survey ranged from 51.6 to 90.7 cm (CCL) (Fig. 12). The majority of these turtles fell into a medium juvenile size range, where juveniles are defined as measuring 8.5cm (oceanic) to 85cm (neritic) CCL (Dodd 1988, NMFS and USFWS 2008). A general physical examination was used for sex determination, which is unreliable when assessing at the critical point between juvenile and adult classification. Therefore, sex was not defined in the size distribution for in-water captures; further lab work would need to be done in order to sex individuals appropriately. A small number of individuals were classified in the

transitional range from juvenile to adult for the in-water captures as well as for the BLB NWR population.

The marginal measurements taken did not show a pattern of wear. The ratio of anterior to posterior scute borders did not increase with size (Fig. 13). A linear regression showed no significant difference in the ratio of these measurements from smaller to larger turtles. Therefore, no correlation of “wear” to carapace length could be determined.

## CHAPTER 4

### DISCUSSION

#### *Nesting Population*

##### *Nesting trends*

Analyzing nesting trends is an integral part in developing and implementing managements plans as well as utilizing appropriated funds set aside for species of interest. These trends illustrate the progress of the recovery efforts that have already been enforced. Providing updated nesting trends is essential for the effective management of threatened and endangered species. Long term studies such as this one are needed to predict future nesting patterns.

Temporal nesting patterns were displayed in the Blackbeard population. The number of nests laid within each week increased toward the middle of the season, then tapered off as it ended.

Females' nesting periods overlapped one another, starting and ending at different times, creating a stacking effect that was exhibited in the number of nests, on a temporal scale.

The number of females nesting each season as well as the number of clutches deposited follows the three year remigration interval calculated for the Blackbeard Island population. The trend predicts that next year will be the largest nesting season since the study began in 2001, assuming the same long term pattern observed in previous years, attributed to the remigration interval, remains the same. If only 39 individuals were observed in 2007, there were probably even fewer nesting females in 2004, based on clutch frequency estimates and the number of clutches deposited in that season. According to PIT and inconel tags, 483 females have been observed nesting on BLB NWR, from 2001-2008.

The CCL size range of the BLB NWR population was 84.6 to 111.1 cm (CCL). Kraemer (1979) measured the size range in another population of coastal Georgia (94.6 – 114.9 cm). The average size range of that population was 105.1 cm, greater than the 98.5 cm average observed in the Blackbeard population ( $0.26 \pm SE$ ). Due to the continuous surveillance methods used on BLB NWR, a much larger sample size was acquired each season compared to Kraemer's ( $n = 25$ ). Without a larger sample size, some size classes could be misrepresented or missed altogether. Representation of smaller individuals in the population is a key component in assessing recruitment of primiparous females.

Along with establishing a size distribution, the progress of tagging efforts also were tracked. The percent of previously tagged turtles increased with each nesting season, which reflects the goal of saturation tagging, to tag every individual observed within a population. This trend was apparent, beginning in 2003, the initial year remigration was observed. The percentage of newly

tagged individuals was higher (54.12%) during 2008 than in previous years, extinguishing the growing trend of previously tagged females. The newly tagged individuals, with the exception of one larger individual (108.3 cm CCL), were seen in the small and medium size classes. The larger individual was more than likely a transient female from a neighboring island or possibly one that had been missed in an earlier season because females continue to grow throughout their life and they reach sexual maturity at a much smaller size of approximately 85 cm CCL.

Calculations of interesting intervals on BLB NWR were similar to those reported in Caldwell's 1962 study of Cumberland Island. The interesting interval on Cumberland Island ranged from 12 to 15 days. A large percentage (58.66%) of BLB NWR turtles exhibited this range for the interesting interval. A slightly larger percent (67.64%) of females nested every 11 to 14 days on BLB NWR.

Although many individual turtles nested in the 11-14 day interval, a range of 10-16 days better defines the BLB NWR population. 80.58% of the nesting observations used to determine interesting intervals fall in the 10-16 day range, totaling 386. Another 13.36% of observations were recorded for intervals in multiples of the ten to sixteen day range. It is more than likely the case that the interesting intervals from 20-32 represent two interesting intervals, where one observation of an individual nesting was missed, or the nesting occurred on a nearby beach, outside of the study site.

The remigration interval is a key nesting trend. It is displayed in the number of clutches deposited each year as well as the number of females that nest within a season. It is important that it is calculated properly, or it can potentially cause error in the management of nesting beaches and possibly in future status assessment of the species.

In a study of Melbourne, Florida, where remigration intervals were determined, 46.6% of the individuals remigrated in two year intervals while only 34.8% of individual turtles displayed three year remigration intervals (Bjorndal et al., 1983). A similar study conducted on Cumberland Island, the southernmost barrier island of GA, found similar results, where 55.8% of nesting females returned every two years and only 31% re-nested in three year intervals (Richardson et al. 1978). This differs in the BLB NWR population where the majority (42.6%) of females returned to nest in three year intervals as opposed to two years (20.4%), with an average of 2.93 years ( $0.14 \pm$  SE). A higher percentage of turtles remigrated in two year intervals, on Cumberland Island (55.8%) compared to those that remigrated in three year intervals (31.0%) (Richardson et al. 1978). Either a slight shift in this nesting trend occurred over time, or the mark and recapture method used to determine this nesting trend was not as reliable as the more advanced PIT tagging method used today. The latter is more than likely the case.

Other studies suggest that the PIT tagging method is more reliable for examining nesting trends, increasing the confidence of analyses (Broderick and Godley, 1998, McDonald and Dutton, 1996, Parmenter, 1993) . The Florida study used monel metal tags, similar to the inconel tags used on BLB NWR (Bjorndal 1983). Both the monel and inconel tags are applied externally to sea turtles. PIT tags were not introduced until the mid-1980's (Gibbons and Andrews, 2004). The inconel tags did not prove to be as effective in determining interseasonal, long term, nesting trends on BLB NWR. Inconel tags were often torn from the flipper and replaced multiple times within a season. Without the PIT tag comparison, this could easily lower the clutch frequency and increase the number of females observed. Therefore, PIT tags were used when calculating the remigration interval on BLB NWR and have become the common tagging method, where funding is available, supplementing older mark and recapture efforts in many studies. They were even used on BLB

NWR for comparison in calculating intraseasonal, within season, nesting trends because the inconel tags proved to be less reliable; some females were externally tagged up to three times, in one season. Another study in South Carolina, also found that loss of external tags affected their results (Talbert et al., 1980).

The type of surveillance method is also important when comparing remigration interval calculations. In Bjorndal's 1983 study, nightly surveys were not performed, and therefore, encountering every nesting female was not possible. In many cases, the terrain may limit sampling abilities, denying access to certain areas due to mode of transportation or tidal inundation. It is important to constantly monitor nesting beaches in order to calculate nesting trends accurately.

Overall, BLB NWR mirrors the statewide nesting totals each year. Statewide nesting totals in 2008 were the highest that they have been in the past eight years. If next year is even higher, as is predicted, the nest totals could possibly reach the pre-listing level (2,800), which is the number expected to be produced for a recovered population. However, a multitude of other requirements must be met before the process of delisting the population from its threatened status can take place. For example, some females contributing to the nesting population may die before the following nesting season, no longer contributing to future generations. Therefore, the number of nests would decline unless an equal number of newly reproductive females were recruited into the population at the same time.

### *Growth*

Apart from nesting trends, female loggerheads displayed indeterminate growth, on BLB NWR, throughout the 2001-2008 study period. This is a typical growth pattern observed in turtles (Berry and Shine 1980); loggerheads are able to continue growing throughout their life. The

average growth rate on BLB NWR, 0.48 cm/yr, was similar to Bjørndal's (1983) average growth rate, 0.57 cm/yr, in Melbourne, Florida. Both of these calculations were greater than those reported by Limpus (1979) in Australia; however, there were only two turtles that contributed growth rates to that study, yielding a 0.26 cm/yr average.

Calculating the average growth rate for this population provided a way to estimate age in female loggerheads. Published size and age correlations (Dodd, 1988, NMFS and USFWS, 2008) allowed the growth rate for hatchlings to juveniles and juveniles to adults to be established. Then, using the average growth rate on BLB NWR, the age could be determined according to a female's CCL. The estimates determined for adult females depend greatly on the approximate size and age of juveniles and adults which are both very elusive calculations in the wild. However, calculating the oldest female in the BLB NWR population provides great insight into the life span of *C. caretta*. Based on the average growth rate (0.48 cm/yr,  $0.26 \pm \text{SE}$ ) of females on BLB NWR, I estimated that the largest turtle is at least 90 years old.

Age determination also aids in determining the difference between new recruits and transient females. This enables recruitment to be examined in the BLB NWR population. Unlike other methods of aging turtles, growth rate-based estimates can be applied to adults without causing harm. Studies that use the technique of counting growth rings on the carapace or plastron can only put turtles into an age class. Even then, this method can only be used in age classification of younger turtles that have not yet reached sexual maturity (Chen et al., 2002, Wilson et al., 2003, Stone et al., 2005). Skeletochronology is another way to estimate age, but this approach cannot be used on live animals because a cross section of bone is required for examination (Coles et al., 2001).

### *Recruitment*

The evidence from the 2008 nesting season on BLB NWR suggests that recruitment may be taking place. The size classes in which newly tagged individuals were classified supports this. The newly tagged individuals, with the exception of one larger individual (108.3 cm CCL), were seen in the small and medium size classes. The larger size classes were nearly saturated. Growth rates suggest smaller turtles are younger. Therefore, newly tagged individuals, in the small to medium size classes were more than likely new recruits.

A study on female hawksbill sea turtles (*Eretmochelys imbricata*) also examined recruitment and calculated the rate of recruitment of the study site in the West Indies (Richardson et al., 1999). In this study, all untagged individuals were included in the recruitment rate at Jumby Bay. Size was not taken into account. However, laparoscopy was suggested as a method to determine the difference between new recruits entering the population and transient females that may have nested before in another location. Although an estimate for recruitment can be determined, there are many factors that contribute to the uncertainty of this calculation. *In-Water Survey*

When combining the size distribution for in-water and nesting observations for 2008, a slight dip can be seen where the two groups overlap. Typically there would be just as many, if not more, large juveniles present, compared to medium-sized juveniles because survivorship increases once a certain size threshold has been reached for the type III survivorship curve. However, since TEDs have been introduced, it has been hypothesized that they select against larger juveniles (Shoop et al. 1999) and even adults (Epperly and Teas 1999) due to the size constraint of the TED opening, increasing the mortality of these size classes. This could explain the drop off in the small

adults from the in-water surveys and in the BLB NWR population, or it may simply be a matter of time until the full effects of TED implementation will be observed. Due to the long period of time it takes for loggerheads to reach sexual maturity, more time is needed to determine if TEDs are a help or a hindrance.

Although trawling events took place during the nesting season, only 15.46% of the individuals caught by the Georgia Bulldog represented size classes seen on Blackbeard Island. Either the females are further inshore (in waters <15 feet deep), possibly in the sounds and creeks, or they may be too fast to be caught by trawling efforts. More than likely, females are further inshore.

It is also possible that loggerheads can outswim the trawl nets. They have been reported to swim in excess of 10 km/hr in short bursts. However, typical migratory swimming speeds (1.0 – 2.8 km/hr) recorded for loggerheads do not match the vessel speed (~5.56 km/hr) of the RV(Papi et al., 1997). Moving in-water sampling efforts closer to shore would be an important step in determining where these females are at during the nesting season and whether or not they are outswimming the nets. As for the marginal measurements, there were no significant findings between marginal wear and carapace length. However, this does not mean that wear is not occurring. This method simply did not prove to be an effective measure of age.

### *Recovery*

Population estimates vary from year to year because seasonal nest totals are an integral part of the equation  $[(\#nests/clutch\ frequency)/(1/3)]$ , as shown, and these numbers fluctuate yearly. When using the prelisting nesting level (2,800), the female population size can be estimated. If the nest levels were to rise to 2,800, in Georgia, the size of the female population should increase to a

range of 1,400.00-3,514.64. The population estimates for 2008 are the highest compared to years past. With the prediction that nest numbers will increase next year, we could possibly see population estimates nearing the totals for a recovered population.

Overall, many of the nesting trends remain the same or similar to previous studies conducted in Georgia. The average growth rate was calculated and used to estimate the age of adult loggerheads on BLB NWR, providing insight into the life span of the species (*C. caretta*). The increase in newly tagged individuals, especially in smaller size classes (CCL), suggests that recruitment is taking place on BLB NWR and neighboring barrier islands. Both the BLB NWR and the in-water study show evidence that the population is recovering. The elevated nest totals and number of females in GA suggest recovery for the nesting population. The extremely low recapture rate (0.47%) must mean that there are high numbers of loggerheads in the ocean, also suggesting recovery. All of these observations are very promising. After many years of recovery efforts, all of the work may finally be paying off for sea turtle biologists and conservationists.

Future efforts should be focused on the neritic zone, close to shore, as well as estuaries and sounds, in order to better understand the movement of adult females during the nesting season. Analyses of long term studies on Georgia's barrier islands will remain an efficient management tool. Although nesting beaches have long been the focus of conservation efforts, the in-water studies are just as important, though less accessible. As for any other organism, the key to managing and protecting loggerhead sea turtles is understanding all the stages of its life.

Table1. Female population estimates calculated for GA. Statewide nest totals were used, in order to determine the population for the entire state (Dodd and Mackinnon 2001-2008). A range of clutch frequencies were used to show the lowest and highest estimates (Murphy and Hopkins 1985, Drake 2001). The 2009 projection was determined by the previous three-year trend (2004-2006). Population estimates for recovery also were included for comparison.

Clutch Frequency	2001	2002	2003	2004	2005	2006	2007	2008	2009 Projection	Recovery
2.39	1070.7	1297.9	1887.9	460.7	1490.0	1752.3	864.9	2066.1	2514.2	3514.6
4.18	612.2	742.1	1079.4	263.4	851.9	1001.9	494.5	1181.3	1437.6	2009.6
5.20	492.1	596.5	867.7	211.7	684.8	805.4	397.5	949.6	1155.6	1615.4
6.00	426.5	517.0	752.0	183.5	593.5	698.0	344.5	823.0	1001.5	1400.0

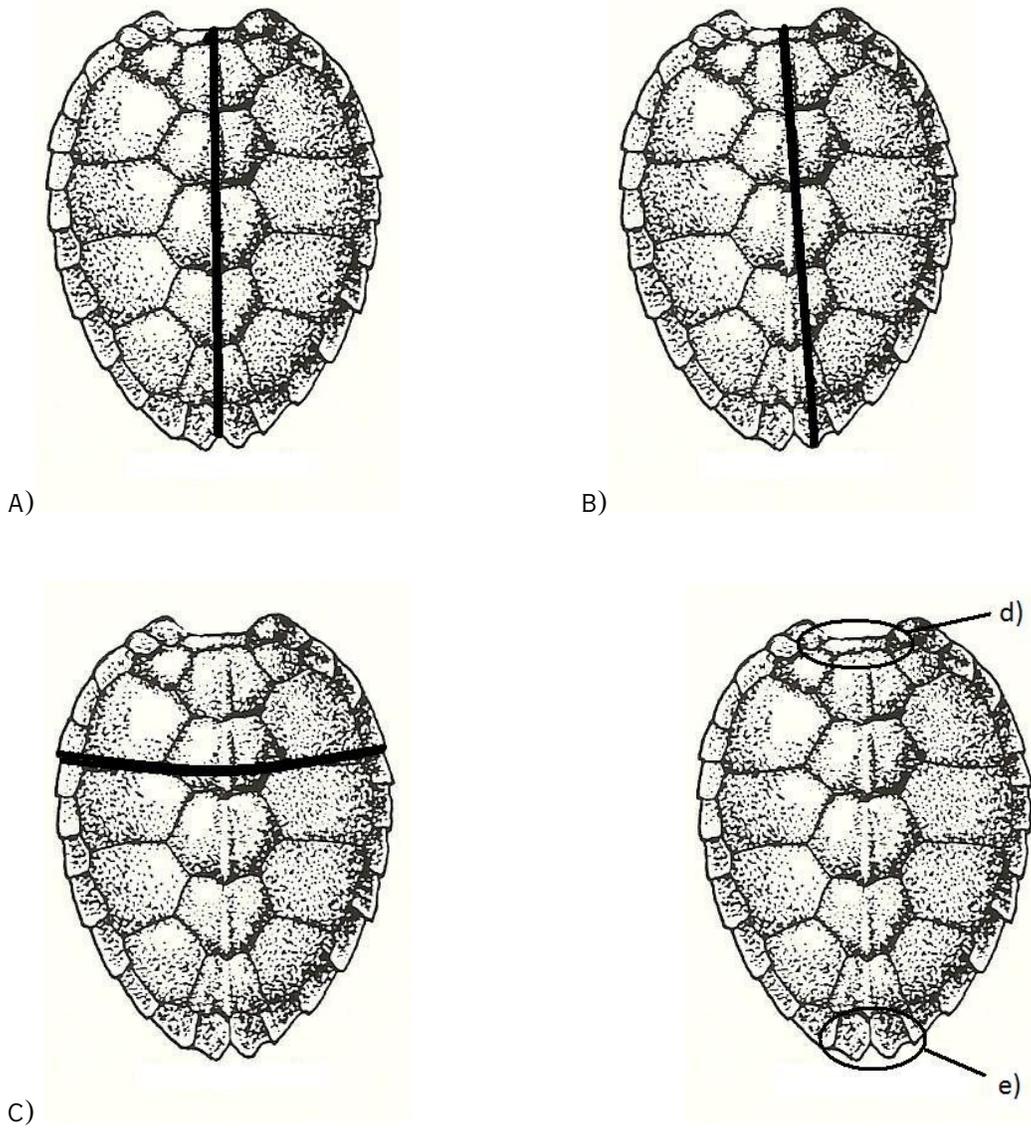


Figure 1. Curved carapace measurements taken on BLB NWR during the 2001 to 2008 nesting seasons. a) One measurement was taken from the nuchal notch to the supracaudal notch. b) A second measurement was taken from the nuchal notch to the supracaudal tip. c) The last measurement was taken at the widest point of the carapace. d) The nuchal scute is located on the anterior edge of the loggerhead sea turtle's carapace. It is adjacent to the first of the five neural scutes that run along the midline of the carapace. It also borders the first two marginal scutes on both sides of the carapace; the marginals define the perimeter of the shell. The first bilateral pair of costal scutes is also adjacent to the nuchal scute; they are located between the neural and marginal scutes. e) The supracaudals are paired marginal scutes located at the posterior edge of the carapace, adjoining the last, typically the fifth, neural scute, at the midline of the carapace.

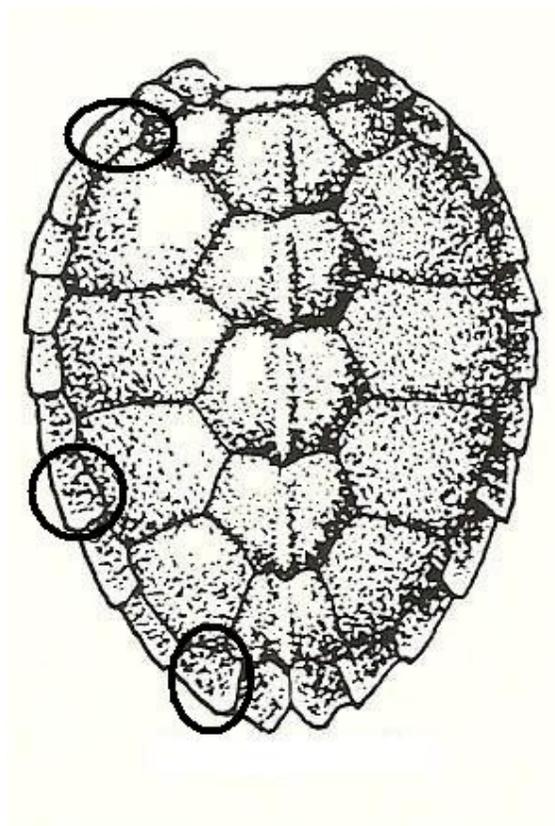


Figure 2. Three marginal scutes (2, 8, and 11) measured on the Georgia Bulldog RV, for each individual turtle. The anterior and posterior border of these scutes were measured in order to determine a ratio for each marginal measured.

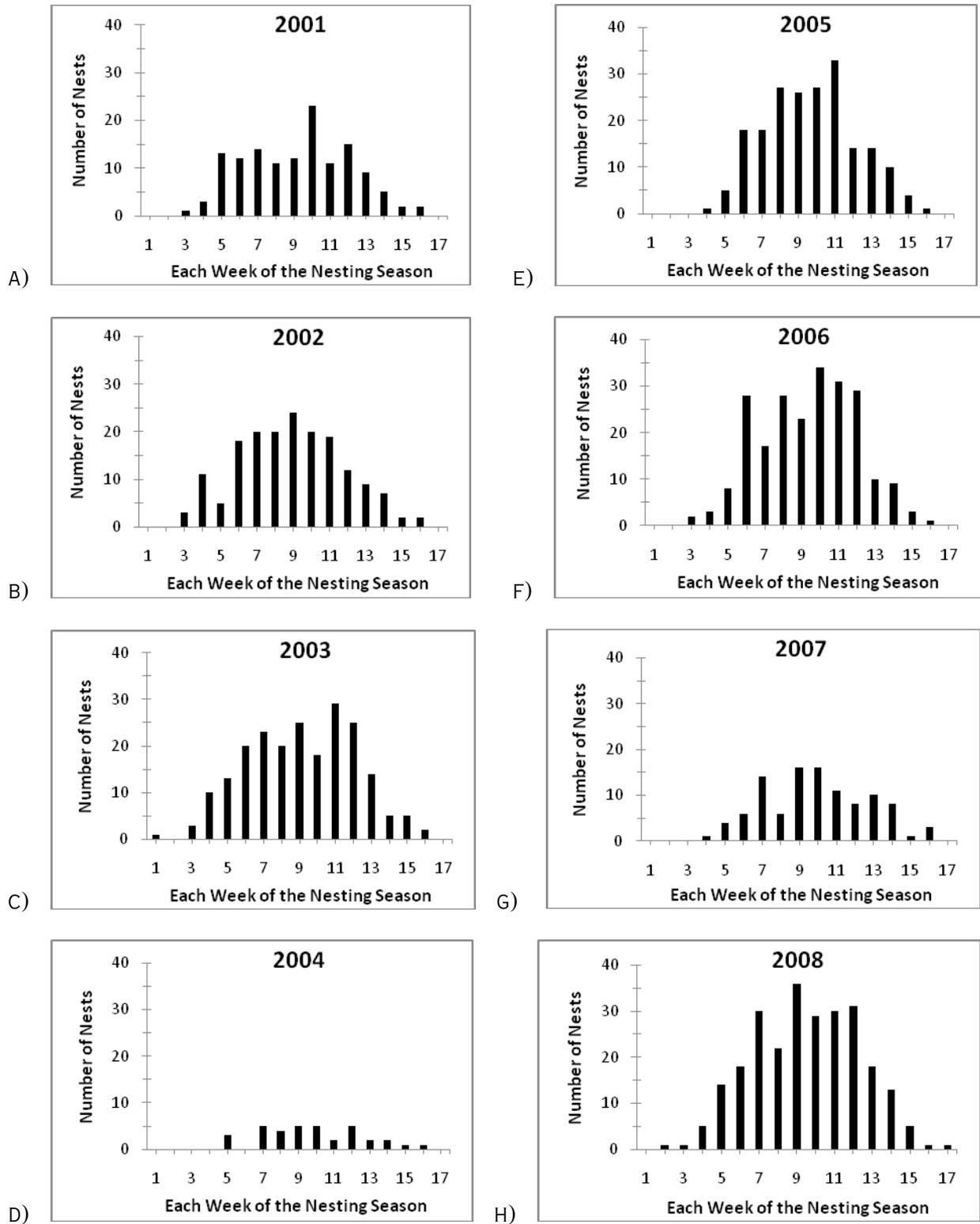


Figure 3. A temporal scale of clutch deposition on BLB NWR for each year during the 2001-2008 study period. a-h) The number of nests per week were recorded for each nesting season, by year. The season began in April (week 1: 4/22-4/28), ending in August (week 17: 8/12-8/18).

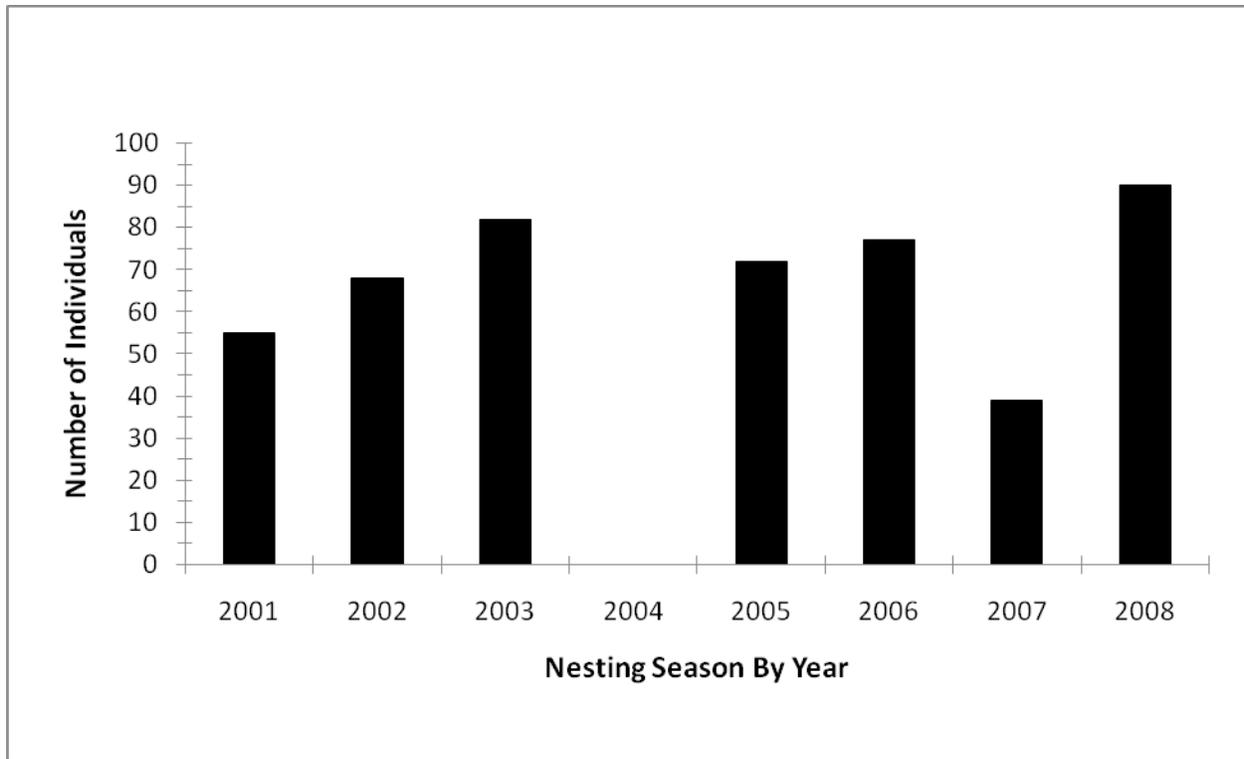
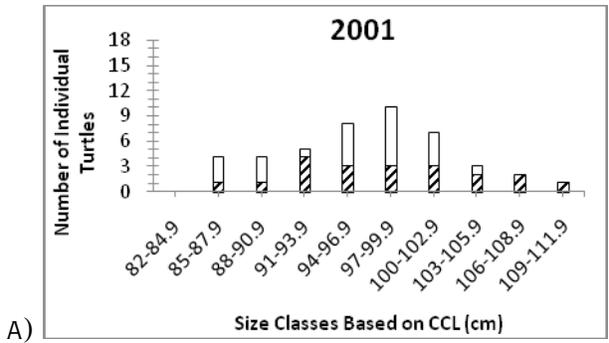
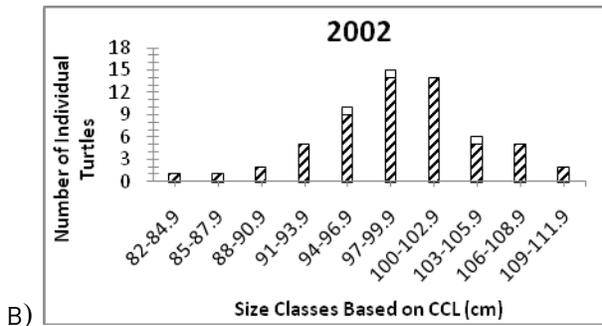
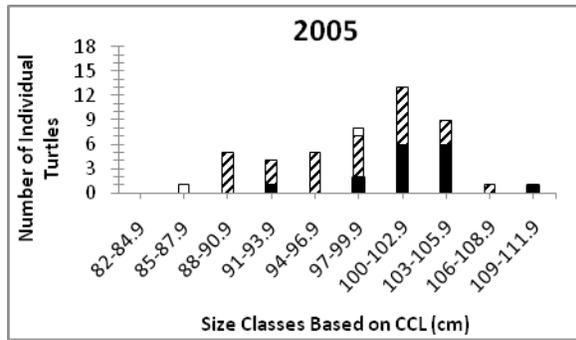


Figure 4. Total number of nesting females for each season on BLB NWR. Females were identified distinctively 1-6 times each year, using tag identification. \*\* No data were available for nesting individuals in 2004.



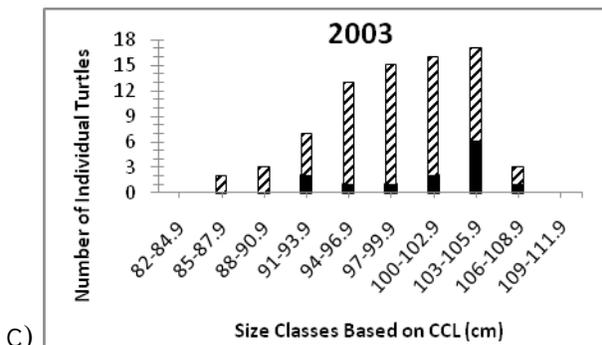
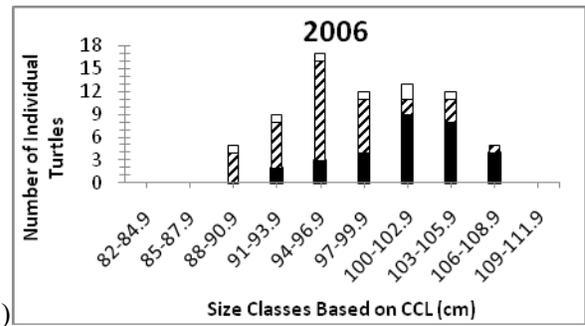
A)

D)



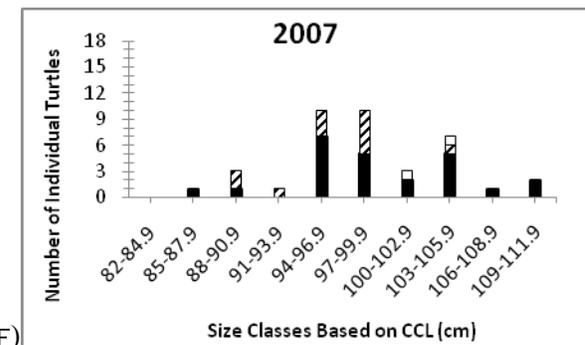
B)

E)



C)

F)



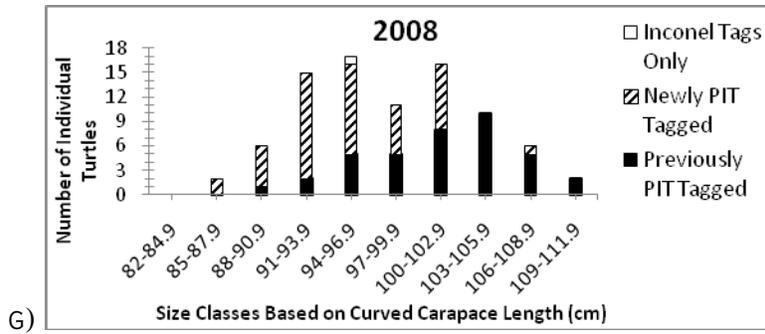


Figure 5. Size distribution for each nesting season on Blackbeard BLB NWR. There were insufficient data in 2004. Tagging efforts were not implemented in 2004 due to unusually low nesting numbers. The status of the saturation tagging effort is also displayed for each nesting season. a) 2001 was the first season that saturation tagging was initiated b) 2002 was the second year tagging was conducted. There were no remigrants from the 2001 nesting season observed in 2002. c) Remigrants were initially observed in 2003. d-g) Tagging efforts continued through 2008.

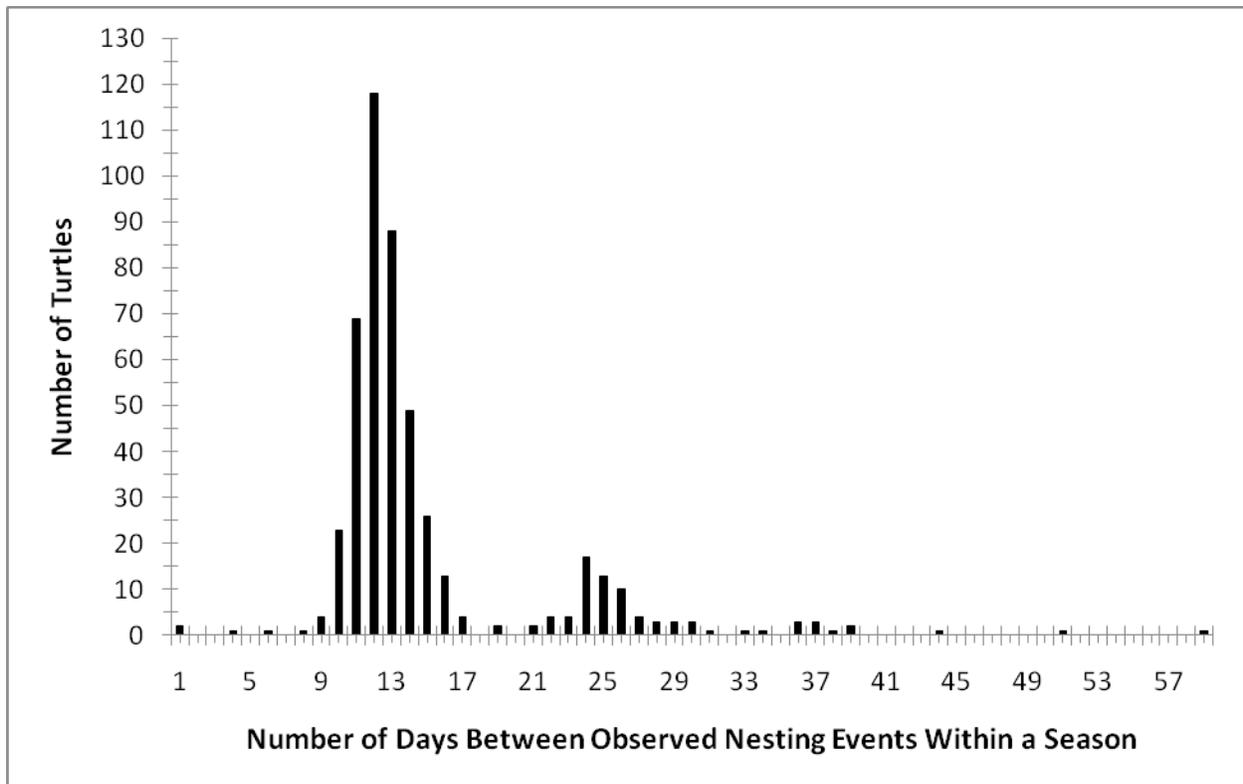


Figure 6. Interesting interval for nesting *C. caretta* on BLB NWR (2001 to 2008). A majority (82.46%) of the nesting females laid their successive nests within eight to seventeen days. Most observations (118; 24.63%) were recorded as twelve day interesting intervals.

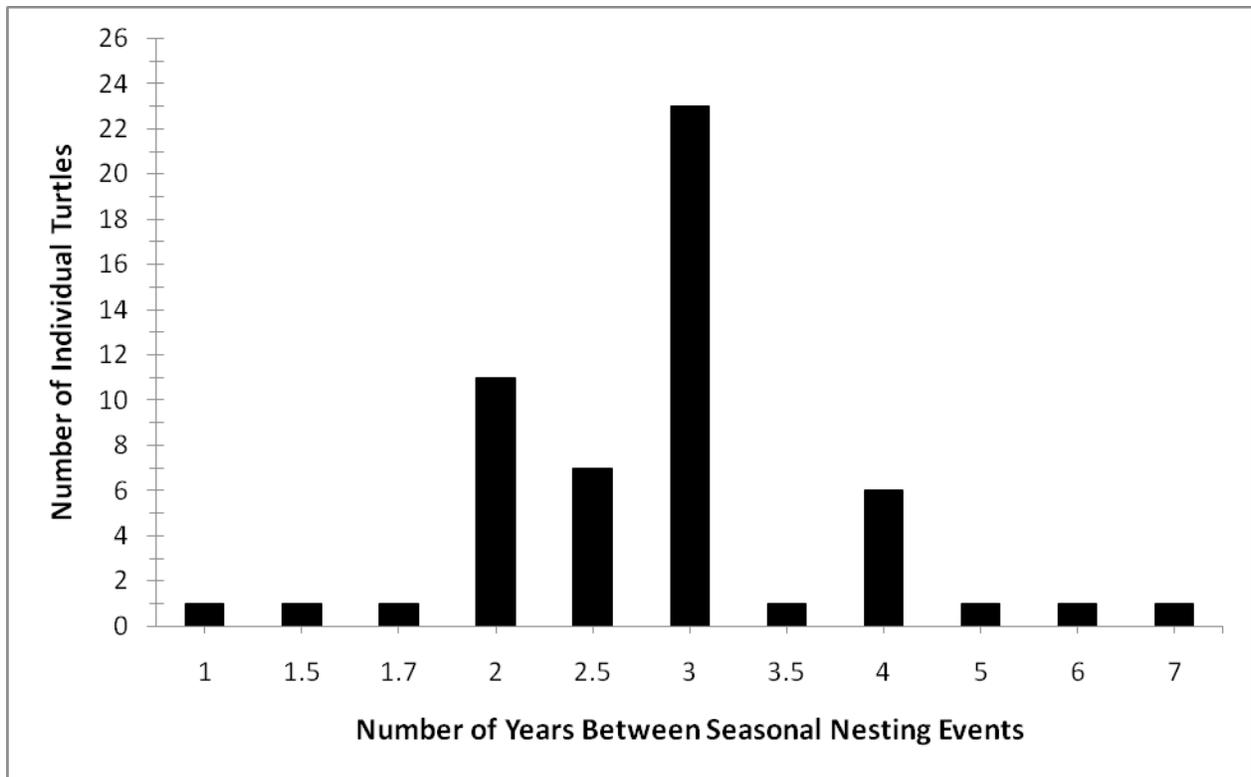


Figure 7. Remigration interval for nesting *C. caretta* on BLB NWR (2001 to 2008). A total of fifty four individuals were observed renesting within the eight year study period (n=54). The average remigration interval was 2.93 years (0.14 ± SE), with 42.59% renesting in three year intervals.

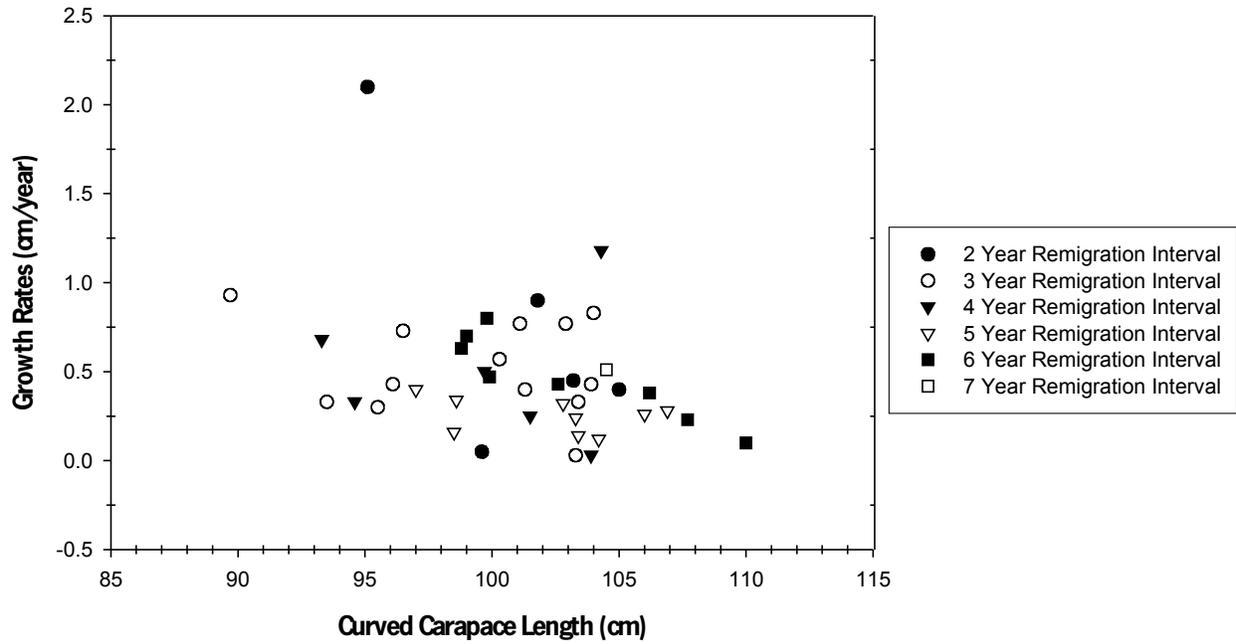


Figure 8. Growth rates calculated for adult females on BLB NWR (2001-2008). There was no significance between growth rates and carapace length (i.e. smaller turtles did not grow faster than larger ones).

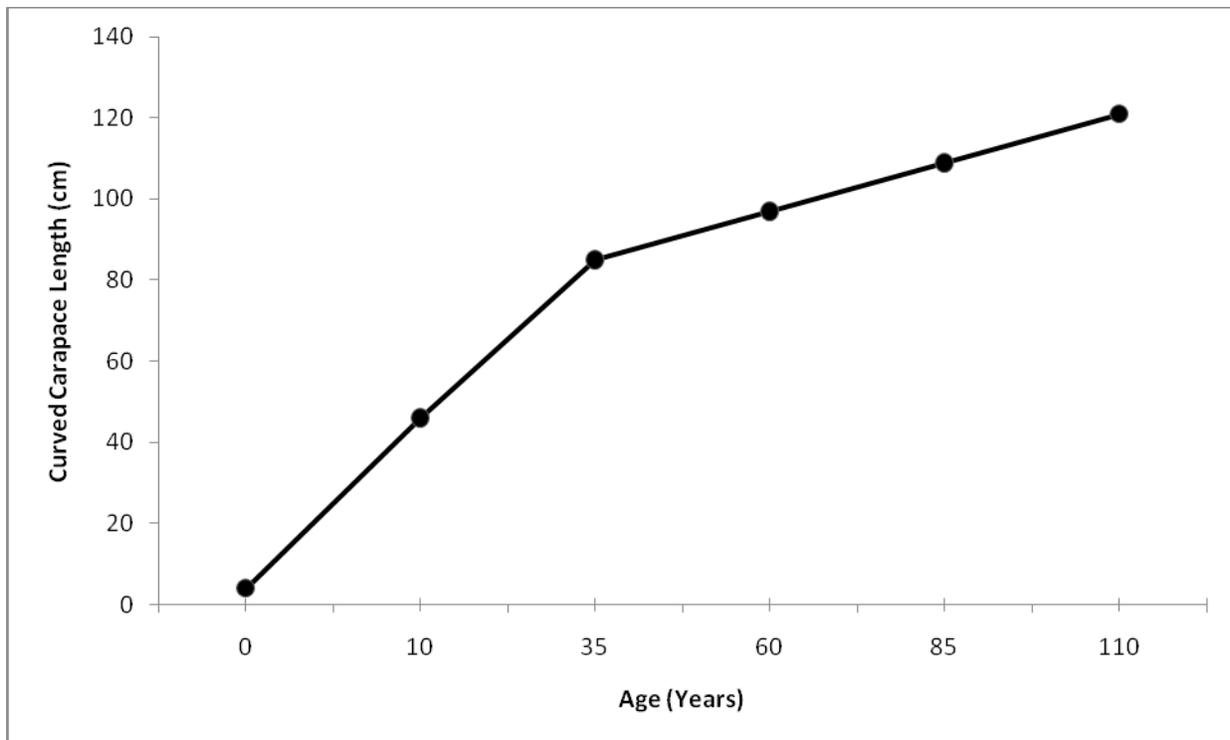


Figure 9. Growth rates of *C. caretta* life stages (hatchling, juvenile, and adult). The first three data points were derived from published figures of size (CCL) and age (Dodd, 1988, NMFS and USFWS, 2008). The last three data points were determined using the average growth rate (0.48 cm/yr) from BLB NWR females.

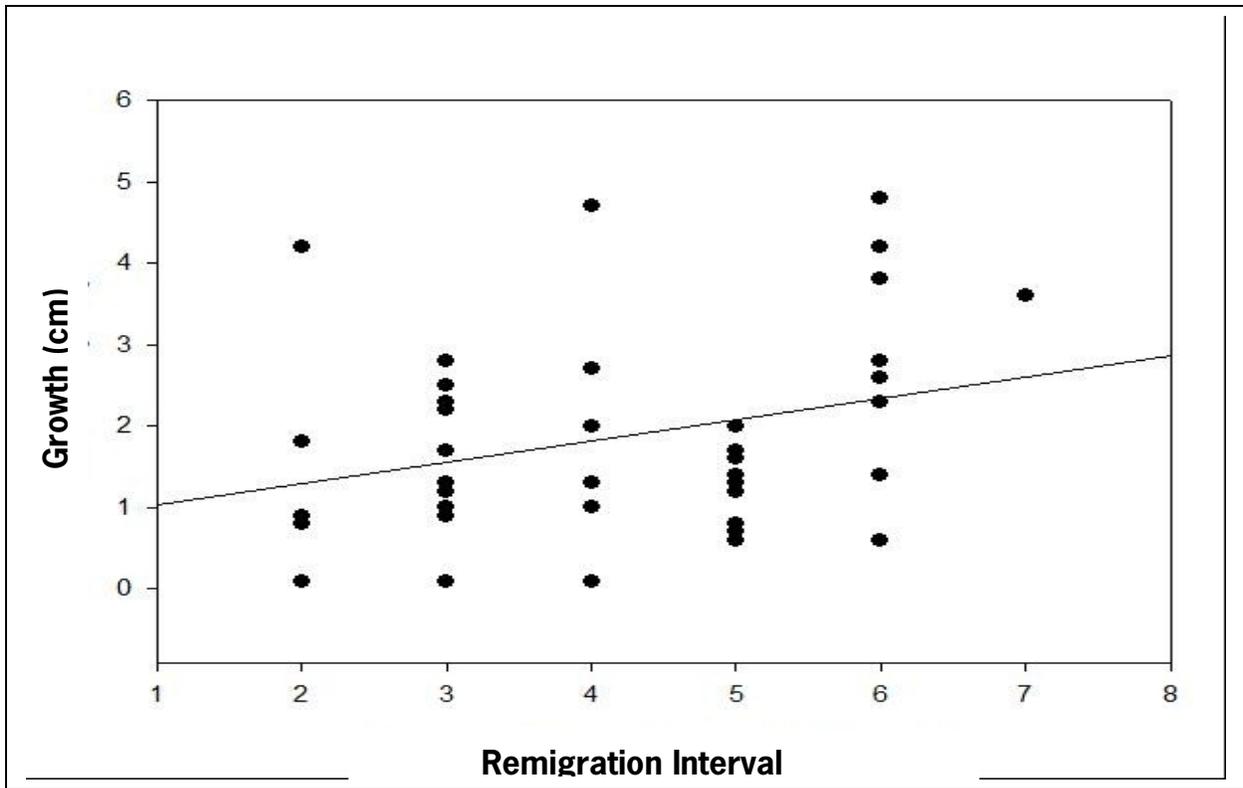


Figure 10. Raw growth of each remigrant graphed according to their remigration interval.  $F=4.089$ ,  $DF=41$ ,  $P= 0.050$

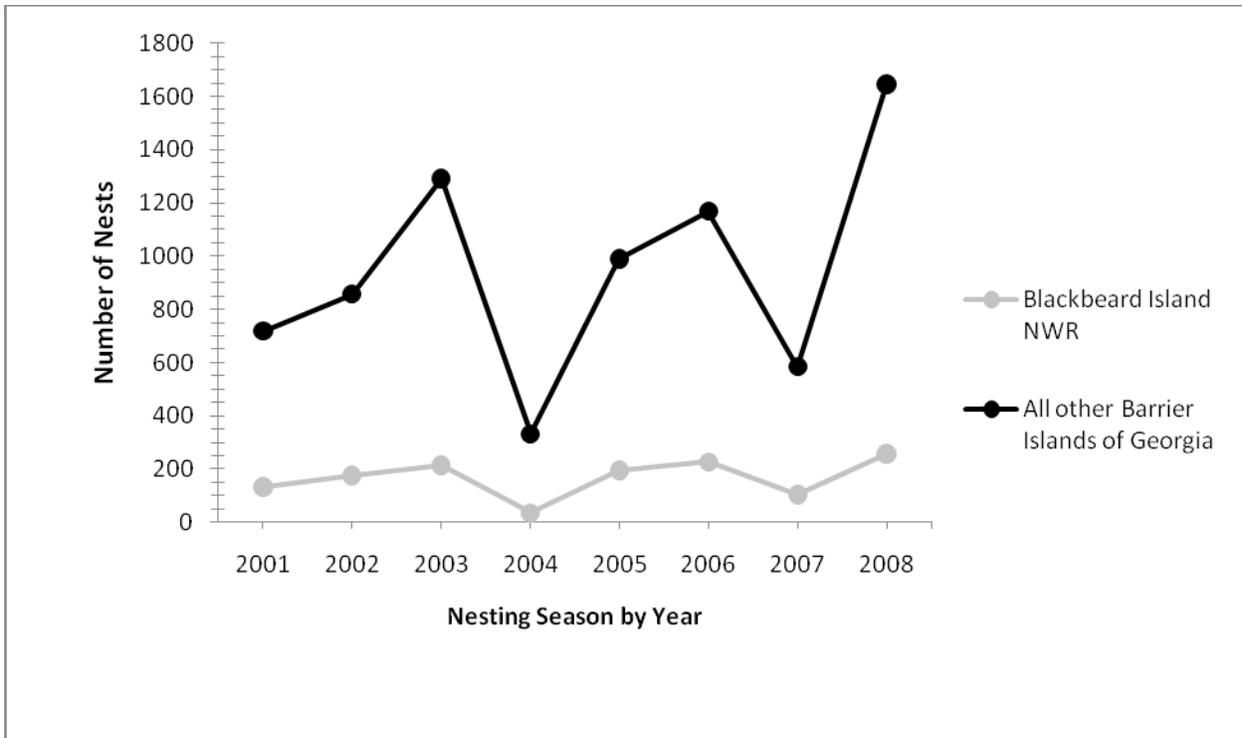


Figure 11. . Total number of *C. caretta* nests in GA. Nest totals for BLB NWR were removed from the total number of nests in GA and presented separately.

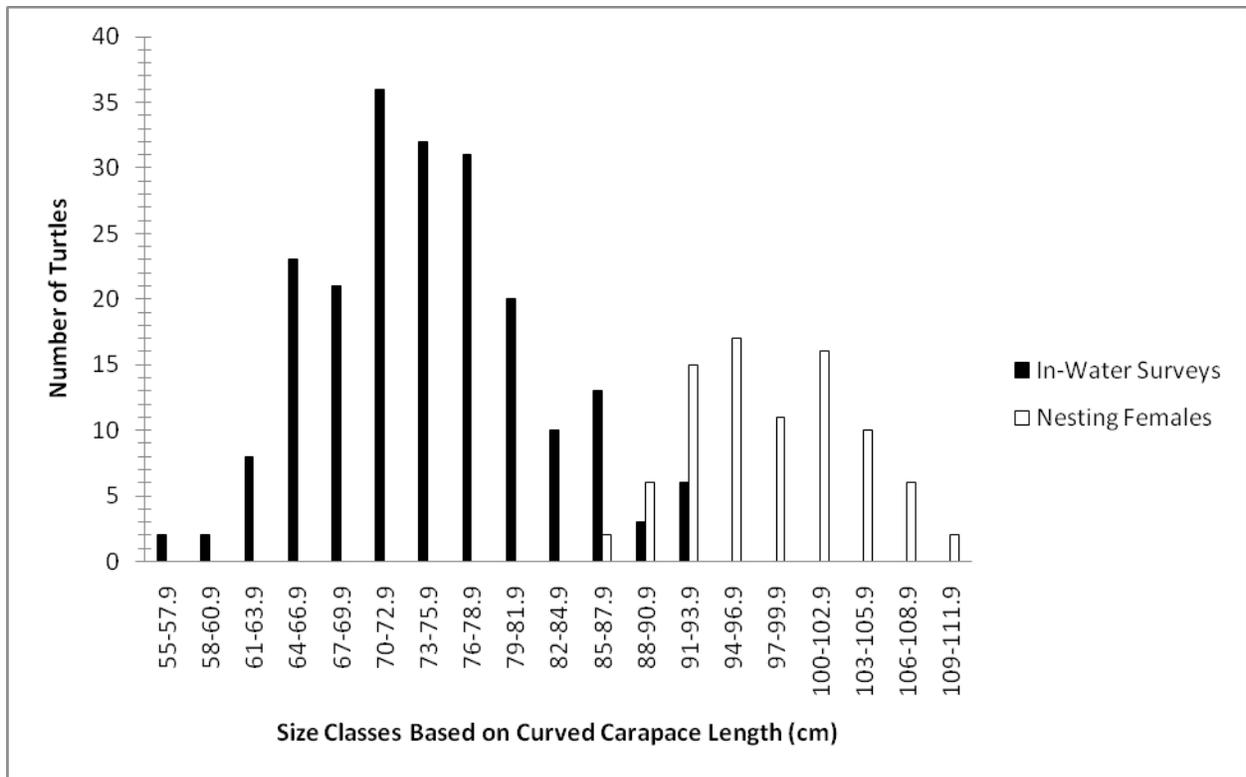


Figure 12. Size distribution based on the 2008 BLB NWR population and 2008 observations from in-water surveys.

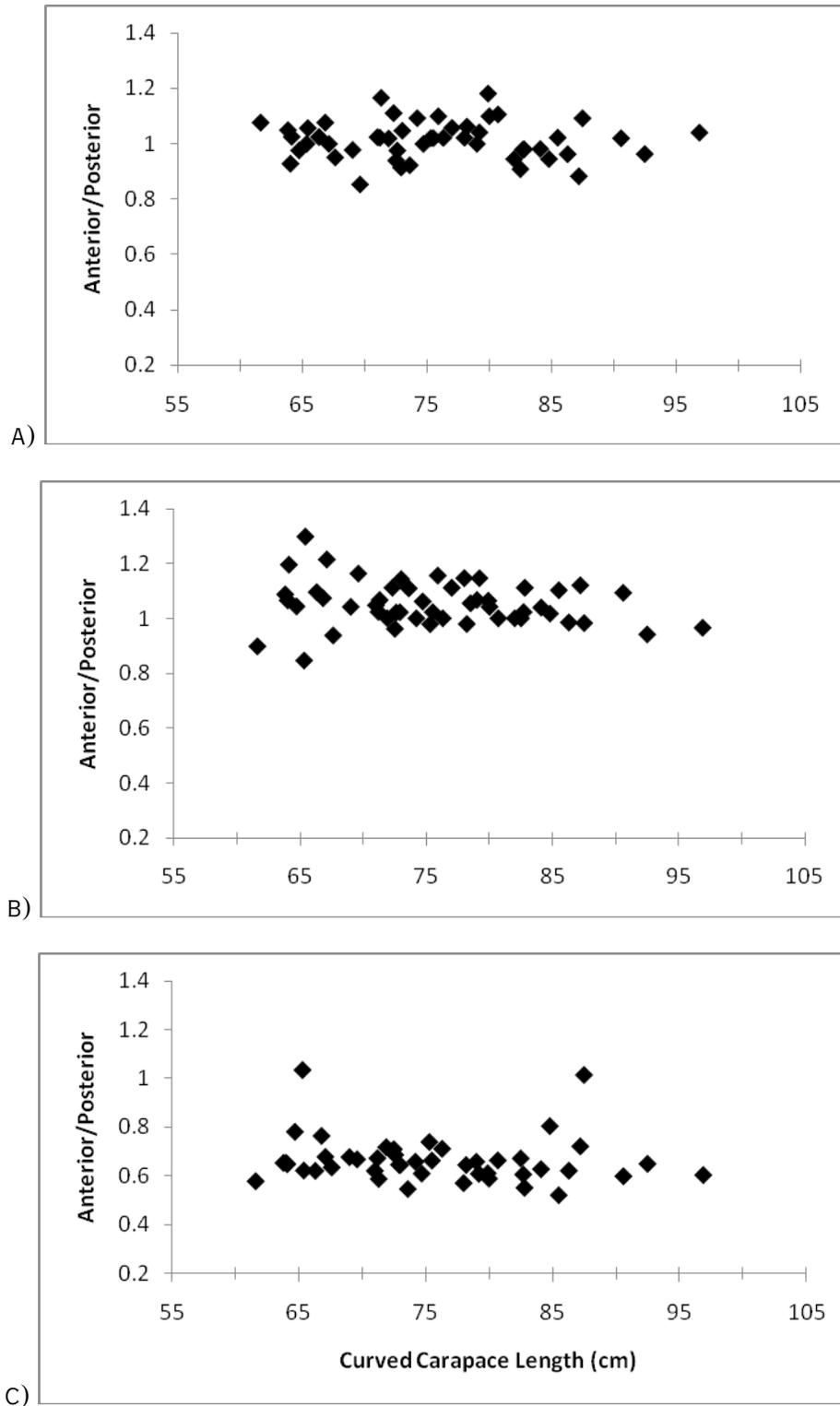


Figure 13. A ratio of marginal scute measurements compared to carapace length. a-c) Anterior measurements of scutes 2, 8, and 11 divided by the posterior measurements of these same scutes. There was not a significant correlation between the ratio and CCL.

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