1-1-2002

Beach Crawl Width as a Predictive Indicator of Carapace Length in Loggerhead Sea Turtles (Caretta caretta).

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By

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A Thesis Submitted to the Faculty of
Nova Southeastern University Oceanographic Center
In Partial Fulfillment of the Requirements for the
Joint Degree in a Masters of Science for:

Marine Biology and Coastal Zone Management

Nova Southeastern University

2002

MASTER OF SCIENCE
WITH SPECIALTY IN
MARINE BIOLOGY AND
COASTAL ZONE MANAGEMENT
THESIS

OF

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ABSTRACT

Carapace lengths and widths of nesting loggerhead sea turtles (*Caretta caretta*) were measured at Pompano Beach and Fort Lauderdale, Florida to determine if plastron and/or track crawl widths were predictive of carapace size. Straight and curved carapace measurements were taken.

Plastron and track crawl width were measured at four points on each crawl: 1) emerging at the tide line; 2) mid-way to the nest; 3) mid-way returning to the surf; and 4) at the tide line returning to the surf. All four measurements were significantly different from each other ($P < 0.005$) along each crawl. Crawl width was the most variable factor in all comparisons.

Maximum straight carapace length correlated with emergent track crawl width at the tide mark ($r = 0.8464$, $P < 0.001$), indicating that track width was predictive of straight carapace length (+/- 3.95 cm standard error of estimate). Clutch size correlated with notch-to-tip straight carapace length ($r = 0.6635$, $P < 0.0005$) and with emergent track crawl width measured mid-way to the nest ($r = 0.5735$, $P < 0.005$). Carapace and crawl width measurements were predictive of clutch size (+/- 21 eggs and 23 eggs standard error of estimate, respectively).

ACKNOWLEDGEMENTS

I would like to state my sincere appreciation to Dr. Curtis Burney for the support he provided throughout the duration of this project. Without his viewpoints and guidance this work would not have been possible.

My deepest gratitude to Lou Fisher for the patience, insight and generosity of time he rendered throughout this endeavor. His knowledge on sea turtles, permit processing and writing skills has proven invaluable.

I would also like to thank Dr. Edward Keith for the calipers he purchased, which were integral to this research. The advice he shared with me will always be appreciated.

A special thanks to Larry Wood who shared his knowledge of proper measuring techniques using calipers and a flexible measuring tape on the nesting female turtles.

I am most thankful for my family and friends, both near and far, for their encouragement and prayers. Their moral support and companionship will always be cherished.

Finally, I would like to dedicate this thesis in loving memory to my grandparents, Bill and Alice Miller. The two most generous, loving and precious people who have always been with me through everything – Thank You.

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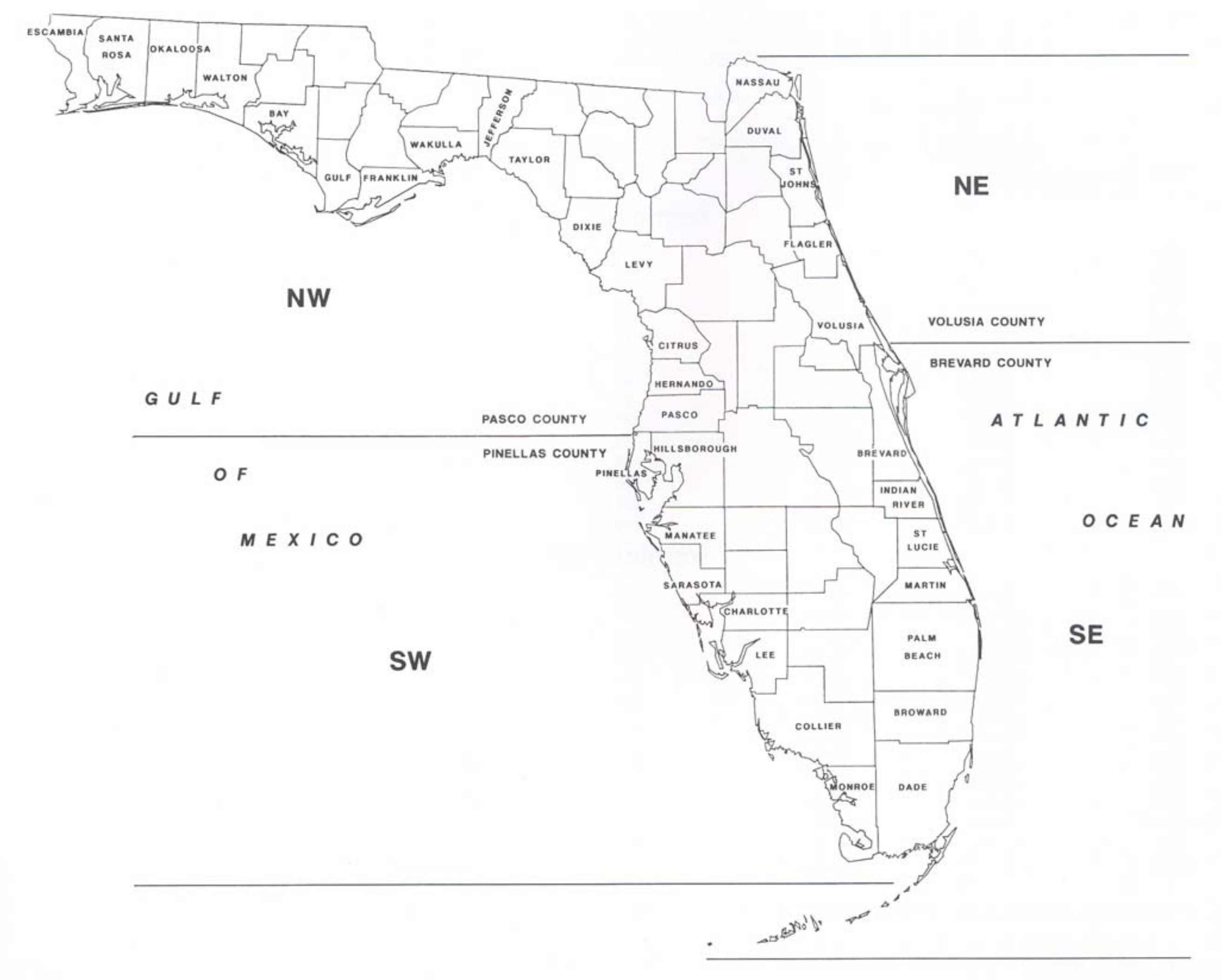
INTRODUCTION

Background

Loggerhead sea turtles (*Caretta caretta*) nest in ten demographically independent rookeries: 1) Florida, Georgia and South Carolina; 2) Yucatan Peninsula, Mexico and Columbia; 3) Cuba; 4) Brazil; 5) the Mediterranean (Greece, Turkey Syria, Libya and Tunisia); 6) Masirah, Oman; 7) Tongaland, South Africa; 8) Ryukyu and Japan Archipelago; 9) Western Australia (Shark Bay and Barrow Island); and 10) Eastern Australia (Queensland, Crab and Swain Reef Islands, Mon Repos-Bundaberg Island, Capricorn Island and Wreck Island) (EuroTurtle 2001). Florida has been divided into four demographically independent nesting populations (Figure 1) (Cornelisen et al. 1997, Encalada et al. 1998). The existence of the discrete U.S. populations has been supported by morphometric and genetic differences (Committee on Sea Turtle Conservation 1990).

The Florida population of loggerhead sea turtles has been estimated to be the largest in the world (Florida Fish & Wildlife Conservation Commission 2001). Almost 90% of the loggerhead nesting in the United States occurs on the east coast south of Cape Canaveral, Florida (Committee on Sea Turtle Conservation 1990, Meylan et al. 1995). This is estimated to comprise 30-40% of the world's population of loggerheads (EuroTurtle 2001). Broward County is the seventh highest contributing county with 3.2% of all sea turtle nesting in the state of Florida (Florida Fish & Wildlife Conservation Commission 2001).

Figure 1. The four geographic regions of Florida hosting *Caretta caretta* populations, with the counties listed for each region (Meylan et al. 1995).



A Protected Species

Hirth (1980) stated that there has been a "surge of interest in the life-history strategies of marine turtles" due to the increased awareness that some populations are endangered and economically valuable. Six species of sea turtles are found in the United States, five of these occur in the Atlantic Ocean (DeGroot and Shaw 1993). All five are listed (by the Endangered Species Act of 1973, as amended) as either endangered or threatened (Committee on Sea Turtle Conservation 1990). In 1996 the IUCN listed loggerhead sea turtles (*Caretta caretta)* as endangered (Frazier 1998). In 1999 the IUCN listed *C. caretta* as threatened (Musick 1999). In 2000 the SSC Marine Turtle Specialist Group listed them as endangered (Kemf et al. 2000). In 2001 NOAA listed loggerheads as threatened (NOAA 2001). Either threatened or endangered, loggerhead sea turtles need protection.

Life-History

Loggerhead sea turtles have long life spans, grow slowly, mature at late ages, and are very susceptible to human induced mortality (Musick 1998), either from adverse impacts to the nesting or marine habitat (NOAA 2001). Female longevity is selectively advantageous by allowing more nests to be laid over a lifetime (Frazer and Richardson 1986). Because loggerheads, like all sea turtles, are migratory (Klinger 1988) and philopatric (returning to the same area of coastline to nest each year) (EuroTurtle 2001, Encalada et al. 1998, Kemf et al. 2000, Committee on Sea Turtle Conservation 1990, Frazer 1984, Environment Associations-1 1996), it is easier and less expensive to study life-history parameters based on nesting females (Frazier 1998).

Comparisons of life-history variation between populations are an important component of evolutionary and ecological research that may support predictions about population dynamics and provide insight into responses to evolution (Van Buskirk and Crowder 1994). It has been suggested that body size should be studied first in order to understand the relationship between life-history parameters (Van Buskirk and Crowder 1994). Reproductive effort is positively correlated with body size. Larger marine turtles are physically capable of carrying larger quantities of eggs. Therefore, larger marine turtles such as loggerheads, lay more clutches (hence more eggs) within a breeding season than do smaller ones (Van Buskirk and Crowder 1994). Since age can be estimated by body size (Frazer 1984, Chaloupka 1998, Frazer and Ehrhart 1985, Frazer and Schwartz 1984), age-specific fecundity and survival can be used for predicting changes in population size (Van Buskirk and Crowder 1994). The number of nests can be used as an index that is correlated with the population size of mature nesting females, but because females nest several times a season and not necessarily every year, it is not a direct estimate (Committee on Sea Turtle Conservation 1990).

Predicting Population Size

Morphological measurements of marine turtles have been reported to correlate with reproductive output, nesting, and growth patterns. These measurements have also aided in determining minimum size at sexual maturity, female nesting size, size classes present at particular rookeries, growth rates, population demographics, and many more (Bolten 1999, Van Buskirk and Crowder 1994). Such measurements include straight carapace length (SCL) and width (SCW); and curved carapace length (CCL) and width (CCW). These findings have yielded growth models, size to age relationship curves, and predictions about population dynamics (Van Buskirk and Crowder 1994, Frazer and Richardson 1986, Bjorndal and Bolten 1988, Pinckney 1990, Klinger and Musick 1995, Mendonca 1981, Chaloupka 1998, Hirth 1982, Frazer and Ehrhart 1985, Frazer and Schwartz 1984, and Musick 1999). This includes predicting changes in population size (Van Buskirk and Crowder 1994). Population size depends on several factors: 1) the number of individuals entering the population (births and migration); 2) the number of individuals leaving the population (deaths and emigration); and 3) how rapidly individuals mature and reproduce (Crouse 1999).

Mean clutch size and average carapace lengths are directly related (Hirth 1980, Hays and Speakman 1991, Pickney 1990, Frazer and Richardson 1986). For conservation purposes, fecundity and survival based on body size of the nesting female (Van Buskirk and Crowder 1994) are useful in predicting the number of hatchlings that enter the ocean and eventually joint the breeding population (Committee on Sea Turtle Conservation 1990).

Stress Caused by Handling

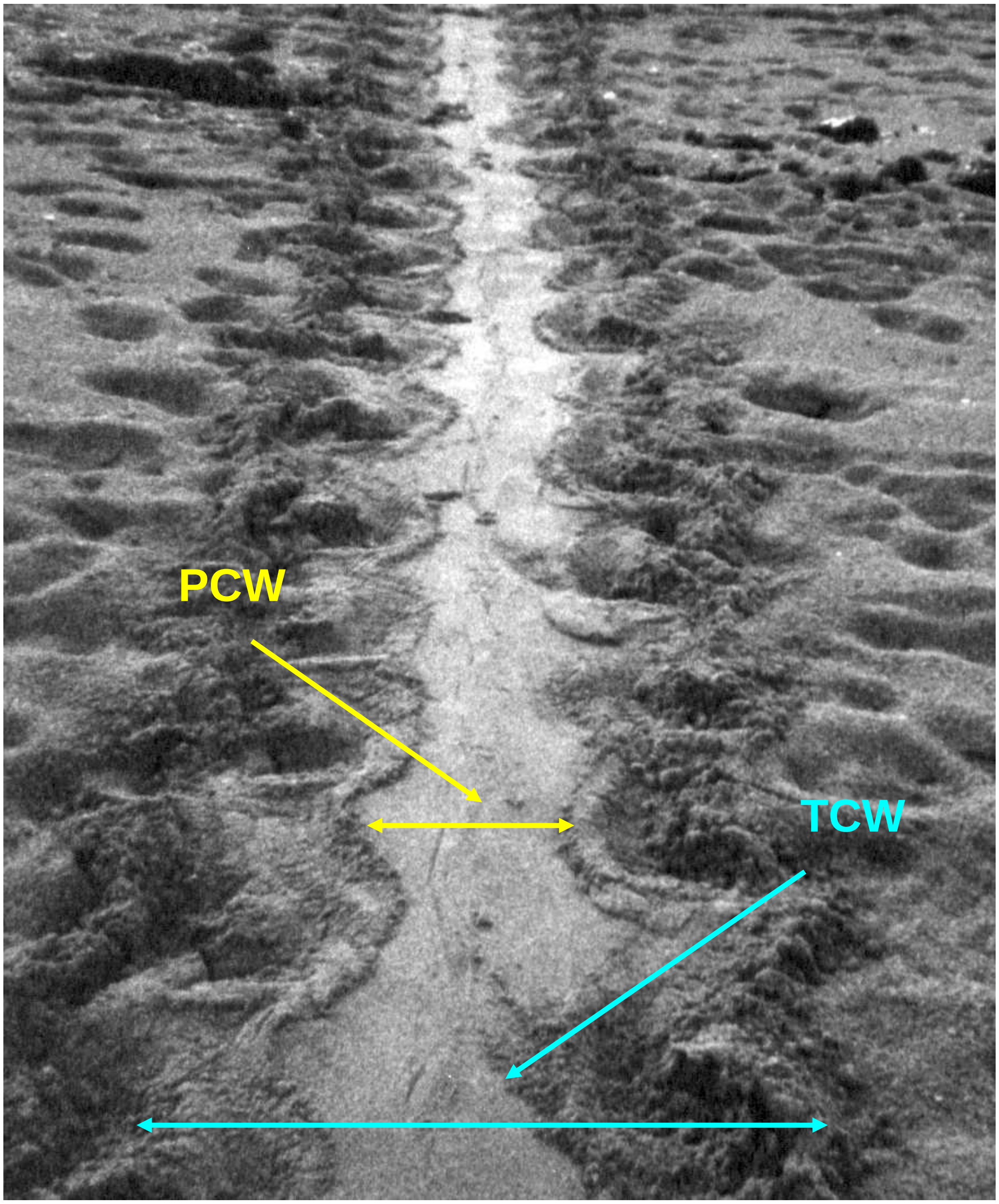
In order to obtain measurement of nesting female size, turtles must be captured and measured, causing stress and potential physical harm. How the turtles are captured defines the type of stress or harm caused to them. Handling can cause damage to the plastron and flippers, especially when conducted on hard surfaces. The researcher may also be injured due to sharp carapace edges, claws, epibionts and the awkwardness of handling a large slippery turtle.

Positioning the turtle is then difficult, which causes more handling, placing more stress on the turtle (Nielsen, I.B. 1995). Valverde et al. (1996), Morris and Owens (1982) and Gregory et al. (1996) have tested capture and handling stress in loggerheads. All have agreed that stress levels are increased by various methods of capturing and handling. An indirect and non-invasive method of determining the size of female nesting loggerheads may prove useful.

Previously Collected Data

During the past 10 years, the Broward County Sea Turtle Conservation Program has recorded beach plastron crawl width (PCW) and beach track crawl width (TCW) for over 23,000 nesting turtles (Figure 2). These measurements have yielded some indication of the size of female loggerheads in the local nesting population (Cornelisen et al. 1997 and Encalada et al. 1998). Davis and Whiting (1977) found no significant correlation between crawl width and carapace length at Cape Sable, Florida. They stated that beach slope seemed to confound the relationship, but crawls occurring on the same beach sector showed a promisingly high correlation. In Broward County, beaches are fairly uniform in slope. The beaches of Pompano and Fort Lauderdale have average slopes of 2.5 degrees and 3.7 degrees, respectively (calculated from range and elevation information provided by Sea Systems Corporation 1999, see Appendix 1). Although a t-test found a small, yet significant, difference between the two beaches ($P<0.05$), geologically the beach slopes are relatively similar and flat. In a beach topography study by Frazer (1983), beach slopes of 1.87 degrees and 3.15 degrees were considered quantitatively similar.

Figure 2. Loggerhead plastron crawl width (PCW) and track crawl width (TCW) identified and measured on the beach.



Purpose of Study

No study to date has directly compared carapace measurements and crawl widths to determine if PCW and TCW (Figure 2) data are valuable in estimating the size of females nesting or the nesting population. Broward County has a large database of crawl measurements. There was a relationship between PCW and clutch size (P =0.018), but it was not a predictive relationship (R^2 = 0.005). Since carapace length and clutch size are directly related (Buskirk and Crowder 1994), carapace measurements and crawl measurements may be as well. Direct measurements are needed to determine if the relationship will yield a predictive model. The null hypothesis (H_o) is that the slope of the least squares regression line relating crawl measurements and carapace measurements is equal to or less than zero. The alternative hypothesis (H_1) is that the slope is greater than zero.

The above information could explain past nesting patterns and provide insight into the nesting sea turtle population in Broward County. Since the Southeastern Florida region is demographically independent based on morphometric and genetic differences, other counties in this region should display similar patterns. An increase in the proportion of smaller nesting females over time suggests that the nesting and hatchling output of Broward County beaches may increase as these smaller (younger) individuals age. However, if the proportion of smaller turtles is sustained, then small clutches of eggs will be laid and not enough hatchlings will be produced to increase the population size. Sustained increases in the proportion of the larger size class might suggest to conservationists an aging population. Presently the larger senescent (aging and elderly) population may produce more eggs, but because they may be nearing the end of their reproduction years, future fecundity from this proportion of turtles will be reduced. Knowing the local size class, one can estimate the number of eggs produced and the number of hatchlings surviving to maturity (Crouse et al. 1987). The predictive model and past PCW and TCW data could then be used to predict future population size.

Nesting Habits

Loggerhead turtles complete their nesting cycle in one to two hours depending on the tide and beach slope (Frazer 1984). On average, females nest two to three times a season, with an interval between nesting of about 14 days. Few females nest every year, having a reproduction interval of every two to three years (Kemf et al. 2000, Environment Associations-1 1996, U.S. Fish & Wildlife Service 2001, Frazier 1998, EuroTurtle 2001). Loggerhead sea turtles can nest in temperatures below 20 degrees Celsius, but mainly nest on continental shores of warm shallow seas (EuroTurtle 2001). They prefer sandy mainland beaches and barrier islands that are moderately steep (Pritchard et al. 1983) so as not to be inundated by high tide or soaked by ground water rising from below (Environment Associations –1 1996).

Location of Study Area

Broward County contains 38.6 kilometers of beaches (Burney and Margolis 2000). This beach length has been divided into five areas that are patrolled on a daily basis during the nesting season: Hillsboro Beach/Deerfield Beach; Pompano Beach; Fort Lauderdale Beach; John U. Lloyd Beach State

Park; and Hollywood Beach/Hallandale Beach. Each of these areas contains regions referenced by Florida Department of Environmental Protection (DEP) survey markers, R1 - R128. Individual zones (R), are 308m (1000ft) in length on average. The Broward County Sea Turtle Program patrols all areas except John U. Lloyd Beach State Recreation Area (R86-R97), which is surveyed by park rangers. From 1991-2000, Hillsboro (R1-R24) had the highest density of nests per zone, an average of 29. However, the beaches are not uniform, often eroded and with many rocky out-croppings. Hollywood/Hallandale (R98-R128) had the lowest average density of nests per zone (4), but also had sea walls that could have restricted nesting. Pompano and Fort Lauderdale beaches (R25-R84) are much more uniform in beach topography and are densely nested, averaging 28 and 20 nests per zone, respectively. Uniform beach topography is important for comparison among the beaches and carapace and plastron measurements, and the densely nested areas almost guarantee finding nesting females every night during the season (for ease of data collection). For this reason, carapace and crawl measurement surveys were conducted from June 2001 through August 2001 on the Pompano and Fort Lauderdale beaches (R25-R84).

MATERIALS AND METHODS

Data Collection

Regions of Pompano and Fort Lauderdale beaches (R39-R53) (Figure 3) were surveyed between 9 p.m. and 5 a.m. from June through August 2001. When a nesting female was encountered the turtle was allowed to begin egg deposition and enter the nesting trance (to reduce stress) before the straight and curved carapace measurements were taken using a flexible measuring tape and calipers (example of data sheet in Figure 4).

Three methods of measuring straight carapace length (SCL) were utilized: minimum SCL (SCLmin), notch-to-tip SCL (SCLn-t) and maximum SCL (SCLmax). Three methods of measuring curved carapace length (CCL) were utilized: minimum CCL (CCLmin), notch-to-tip CCL (CCLn-t) and maximum CCL (CCLmax) (Pritchard 1983) (Figure 5). The measurement of the carapace width, whether straight or curved, was taken at the widest point (Bolten 1999).

Once the turtle had returned to the water, the PCW and TCW were measured in four different places using a flexible tape measure (TM) and calipers (C) on the crawl: 1) in the wet sand emerging from the water (HT o); 2) in the dry sand emerging from the water between the high tide line and the nest (Mid o); 3) in the dry sand returning to the water between the nest and high tide line (Mid i); and 4) in the wet sand just before returning to the water (HT i). Measurements were taken at four different areas on the crawl because sand compaction is different depending on whether the sand is wet (more compact) or dry (loose and less compact), and whether the female is slowly pulling herself up the beach or quickly heading back to the surf. These factors could have caused variation in the PCW and TCW measurements. Small numbered flags were placed on the nests so that when the conservation program relocated the nests the next morning, the nest data could be obtained for further analysis and comparison.

Data Analysis

Carapace length has been used as the principal measurement for assessing turtle body size (Van Dam 1999). The straight and curved carapace measurements were compared to plastron and track width measurements by linear regression and correlation analysis to determine if there were any significant relationships. A two-way ANOVA without replication was used to test variance among the four points along each of the crawls. Carapace and crawl width measurements were compared to the clutch size data obtained from the morning nest surveyors to test for significant relationships. Frazer and Richardson (1986) found a significant correlation ($R = 0.55$, $P < 0.01$) between carapace lengths and mean clutch size. All statistics were done using Excel (Microsoft 2000).

Figure 3. Pompano and Fort Lauderdale regions (R39-R53) surveyed June through August 2001 (U.S. Fish & Wildlife Service 2001).

Figure 4. Data Collection Sheet.

Date:____________ Beach:___________ Region #:_________ Flag #:____________

Turtle #:_________ GPS Readings:___________________________________ Clutch #:_____

Distance from high tide:________________ Nester / False Crawl

Weather & Nesting Conditions:___________

Time out of surf:______________________ Time into surf:__________

Carapace Measurements

CCLmin:________________________ SCLmin:_______________

CCLn-t:_________________________ SCLn-t:________________

CCLmax:________________________ SCLmax:_______________

CCW:___________________________ SCW:__________________

Plastron Crawl Width (PCW) Measurements

TM @ T out:___________________ C @ T out:_____________

TM @ Mid out:__________________ C @ Mid out:___________

TM @ Mid in:____________________ C @ Mid in:_____________

TM @ T in:_____________________ C @ T in:_______________

Track Crawl Width (TCW) Measurements

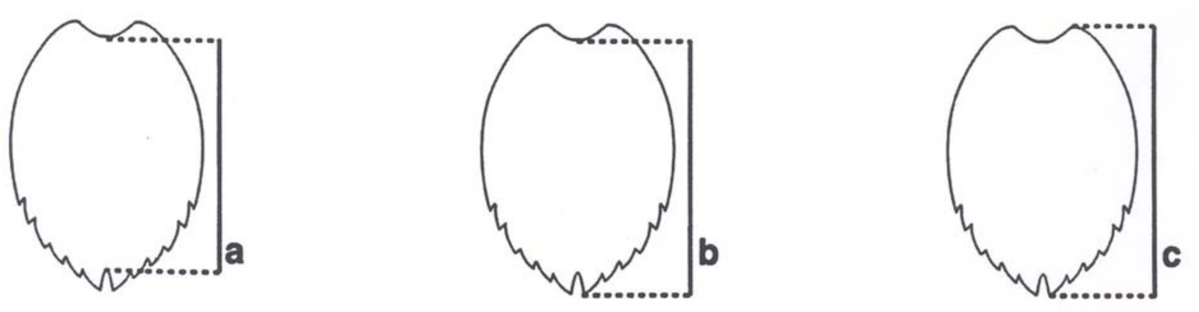
TM @ T out:___________________ C @ T out:_____________

TM @ Mid out:___________________ C @ Mid out:___________

TM @ Mid in:_____________________ C @ Mid in:_____________

TM @ T in:______________________ C @ T in:_______________

Figure 5. The anatomical points for SCL and CCL measurements. (a) Measured from the midline of the nuchal scute to the midline between the supracaudals are the SCL_{min} and CCL_{min}. (b) Measured from the midline of the nuchal scute to the posterior tip of the supracaudals are the SCL_{n-t} and CCL_{n-t}. (c) Measure SCL_{max} and CCL_{max} from the anterior edge of the carapace to the tip of the supracaudals (Pritchard 1983).



RESULTS

Forty-four turtles were encountered and measured on Pompano and Fort Lauderdale Beaches (R39 – R53) from June through August 2001. A complete data set was not taken on all 44 turtles because some turtles finished nesting and began crawling before all carapace measurements could be made. The problems that occurred are further explained in the section “Problems Encountered” (page 34). As a result, some of the correlations calculated in this study used as few as 25 data sets while others used as many as 44.

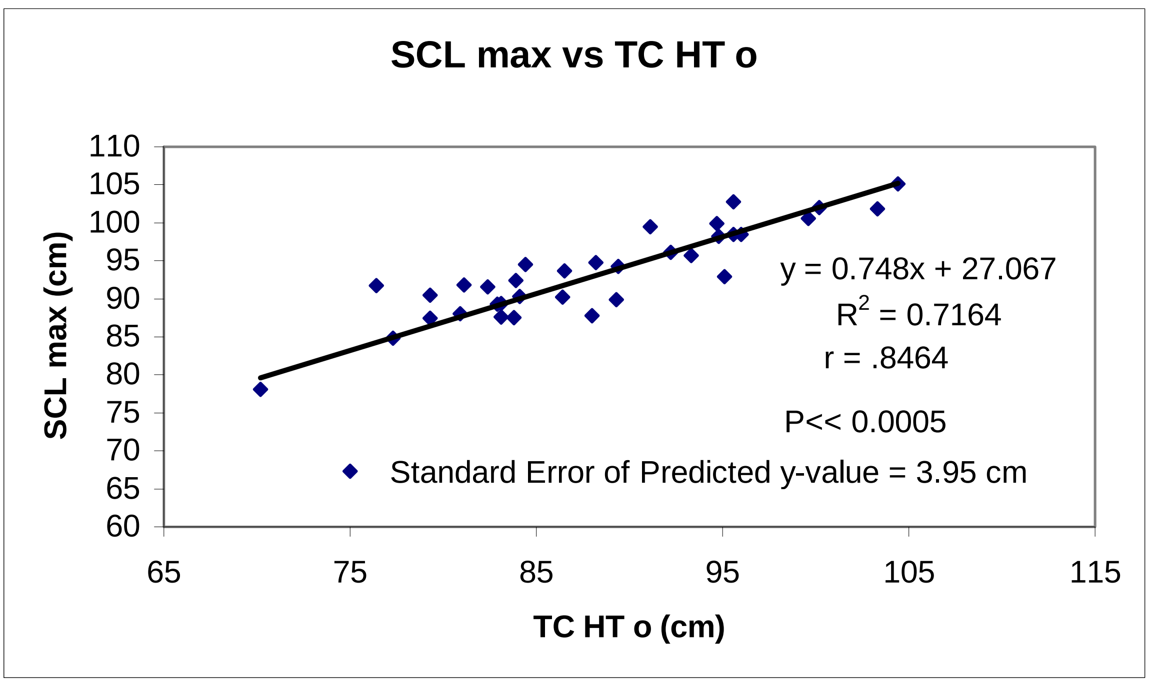
Caliper Measurements

Data obtained by calipers (Appendix 2) were valuable because of the accuracy in measuring. The most significant mathematical correlation was between maximum straight carapace length (SCLmax) and the emergent track crawl measured with calipers in the wet sand (TC HT o) (r = 0.8464, Table 1, standard error of estimate +/- 3.95 cm, Figure 6).

Table 1. Correlation of SCLmax to the various crawl width measurements taken with calipers (n=35).

	SCL max
SCL max	1.0000
PC HT o	0.4840
PC Mid o	0.5106
PC Mid i	0.4680
PC HT i	0.3236
TC HT o	0.8464
TC Mid o	0.6763
TC Mid i	0.6601
TC HT i	0.7601

Figure 6. Maximum straight carapace length (SCLmax) correlated to track crawl width measured with calipers emerging from the water in the wet sand (TC HT o) (n=35).



Flexible Tape Measurements

A flexible measuring tape was used to duplicate measurement efforts from the Broward County Sea Turtle Conservation Program. Data collected by flexible tape measure can be found in Appendix 3. Maximum curved carapace length (CCLmax) correlated to the emergent track crawl width measured with a flexible tape in the wet sand (TTM HT o) (r = 0.7186, Table 2, n=29). However, three studies used straight carapace lengths for comparisons (Pritchard et al. 1983, Hirth 1980, Van Buskirk and Crowder 1994). The highest correlation between a straight carapace measurement and a crawl measurement with a flexible tape was maximum straight carapace length (SCLmax) to emergent track crawl in the wet sand (TTM HT o) (r = 0.7456, standard error of estimate +/- 4.94 cm, Figure 7, n=35).

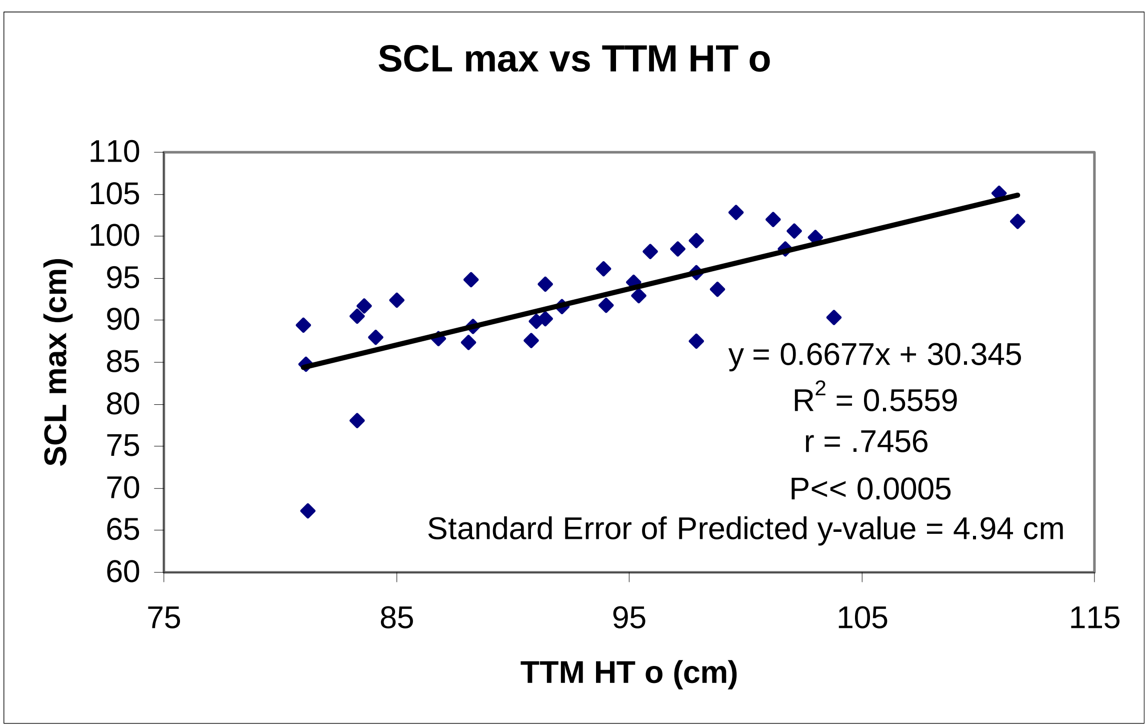
Clutch Size Measurements

Of the 44 turtles encountered in this study, 32 nested, 11 false crawled and 27 clutches were counted. Clutch size correlated to notch-to-tip straight carapace length (SCLn-t) (r = 0.6635, P<0.0005, standard error of estimate +/- 21 eggs, n=25). Clutch count correlated best to track width (TTM Mid o) (r = 0.5735, P<0.0005, a prediction error of +/- 23 eggs, n=27).

Table 2. CCLmax correlations with various crawl width measurements taken with a flexible measuring tape (n=29).

	CCL max
CCL max	1.0000
CCW	0.8968
PTM HT o	0.4597
PTM Mid o	0.4674
PTM Mid I	0.5612
PTM HT I	0.3880
TTM HT o	0.7186
TTM Mid o	0.6763
TTM Mid I	0.5149
TTM HT I	0.6038

Figure 7. Maximum straight carapace length (SCLmax) correlated to track crawl width measured with a flexible tape measure emerging from the water in the wet sand (TTM HT o) (n=35).



Crawl Width Measurements

Beach plastron and track crawl measurements were taken at four different points on the crawl. A two-factor ANOVA without replication was run on each of the different combinations of measurements. Tables 3, 4, 5 and 6 show the results of the ANOVAs (n=44).

Table 3. The P-value for the variance between each point taken along an individual plastron crawl width and between each of the 44 turtles taken with a flexible tape measure.

Source of Variation	*df*	*P-value*
Within Tracks	3	8.52E-05
Among Turtles	43	2.95E-19

Table 4. The P-value for the variance between each point along an individual plastron crawl width and between each of the 44 turtles taken with calipers.

Source of Variation	*df*	*P-value*
Within Tracks	3	0.000993
Among Turtles	43	1.97E-20

Table 5. The P-value for the variance between each point taken along an individual track crawl width and between each of the 44 turtles taken with a flexible tape measure.

Source of Variation	*df*	*P-value*
Within Tracks	3	0.001225
Among Turtles	43	1.89E-17

Table 6. The P-value for the variance between each point along an individual track crawl width and between each of the 44 turtles taken with calipers.

Source of Variation	*df*	*P-value*
Within Tracks	3	0.004203
Among Turtles	43	1.19E-24

There was a significant difference between the four measurements taken along each individual plastron and track crawl width, shown by the low P-values. As expected, there was an even greater significant difference in plastron and track crawl widths between the 44 turtles.

DISCUSSION

The null hypothesis (H_o) was rejected. The slope of the least squares regression line relating crawl measurements and carapace measurements was greater than zero. Therefore, the alternative hypothesis (H_1) was accepted. Beach track crawl widths taken with calipers (TC HTo) were predictive of straight carapace length (SCLmax) of female nesting loggerheads on Pompano and Fort Lauderdale Beaches (Figure 6).

The least squares regression line equation ($y = 0.748\ x + 28.067$, Figure 6) was used to convert track crawl width to straight carapace length (Figure 8). These data were comparable to the maximum straight carapace lengths measured from the same turtles (Figure 9). A small discrepancy was that the converted SCLmax (Figure 8) did not show the smaller nesting turtles as in the measured SCLmax (Figure 9). The length ranges and frequencies of both methods of determining SCL were within the ranges of track crawl widths converted to SCLmax in the same regions (R39 - R53) from the past decade, 1991-2000 (Figure 10). The converted SCL from the past decade were within acceptable length ranges (50 cm - 120 cm, Klinger 1995). The average maximum straight carapace length for the past decade was 90 cm and for the 2001 converted and measured SCLmax (R39 - R53) was 93 cm. Documented average carapace lengths were from 87.0 cm (Van Buskirk and Crowder 1984, EuroTurtle 2001) to 95.9 cm (Bjorndal, Meylan, and Turner 1983). It is reasonable to predict SCLmax from the track using calipers in the wet sand emerging from the water; the data fell within the normal range of turtle sizes.

Figure 8. Frequency distribution of the track crawl widths measured with calipers emerging from the water converted to maximum straight carapace lengths for the data collected in 2001 (n=35).

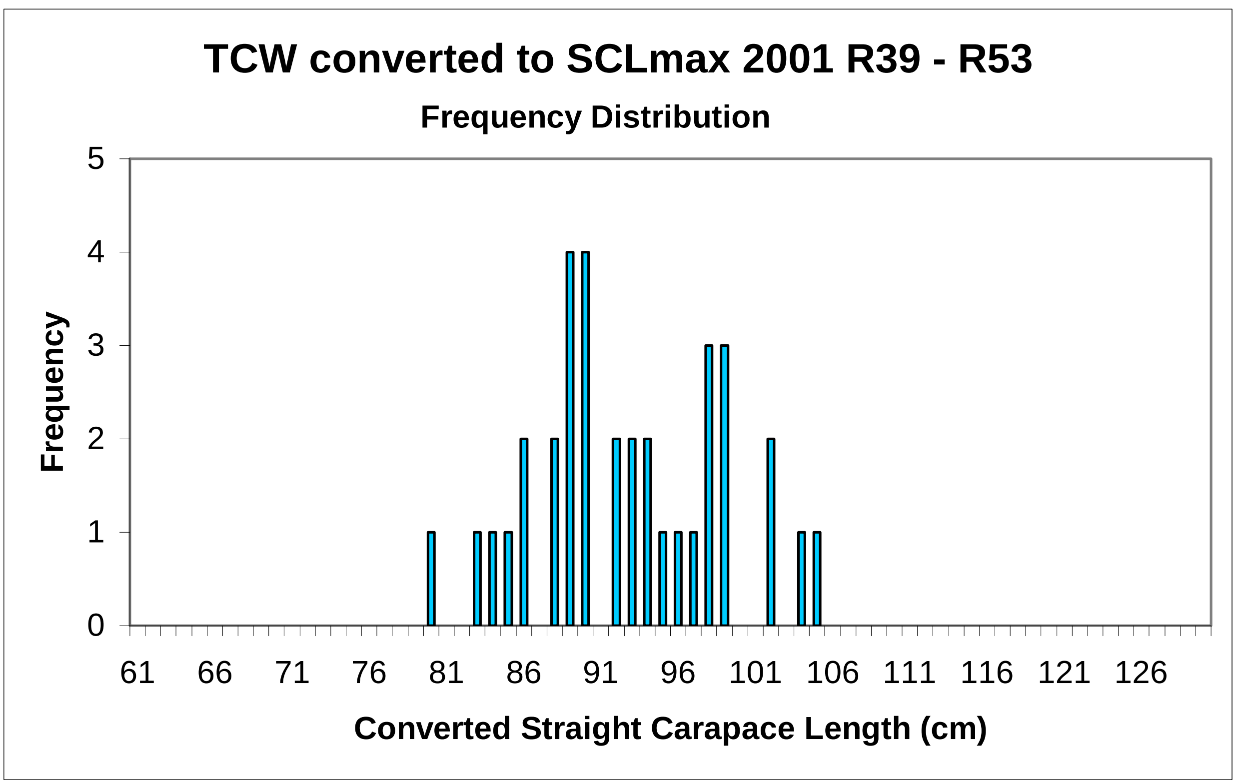


Figure 9. Frequency distribution of the measured maximum straight carapace lengths for the 2001 collected data (n=35).

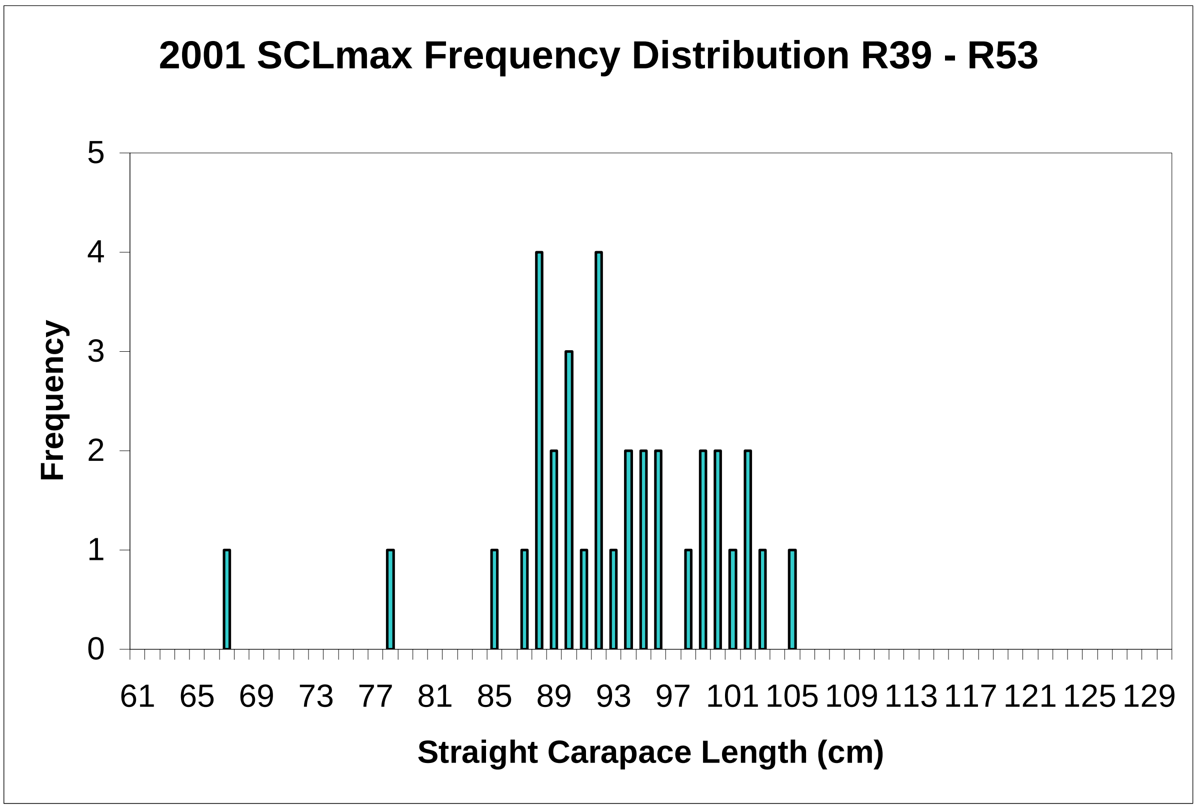
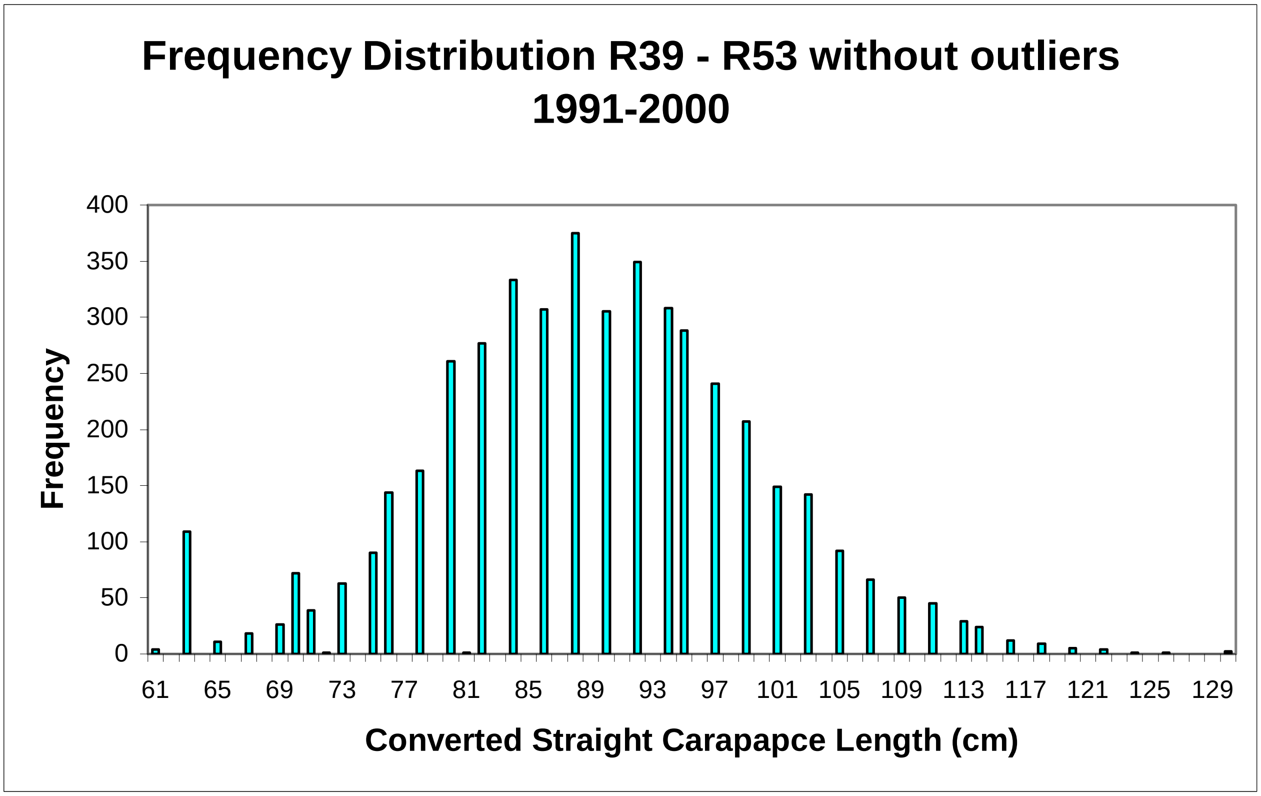


Figure 10. Frequency distribution of the track crawl width converted to maximum straight carapace length (R39 - R53) for 1991 - 2000 excluding the outliers (50, 57, and 59 cm each had 1 turtle, n = 4433).



The correlation between carapace and crawl width was influenced by the method used to measure the body and beach crawl. Straight carapace measurements provided better correlations than curved carapace measurements (Tables 1 and 2). Data taken with calipers provided more accurate measurements, while the flexible tape measurement were confounded by other factors such as barnacles, injuries and irregular areas of the sand. Plastron and track widths were measured at four different places: two measurements in the wet sand (emerging from the water and returning the surf) and two measurements in the dry sand (between the high tide line and the nest, emerging from and returning to the surf). Wet and dry sand crawl widths were measured because the wet sand is compact and sustains flipper mark and plastron depressions more distinctly. Less accurate measurements resulted in dry sand because distinct depressions are less stable in dry sand caused by looser sand grains. To maintain data continuity with the Broward County Conservation Program, crawl widths were measured in dry sand. The results in Tables 3-6 show that there were significant differences ($P < 0.005$) between each of the four points measured on the individual crawl widths. This is critical if one were going to use beach crawl widths to determine the length of a nesting female. Dry sand tends to cave in because the sand grains are loose, therefore not sustaining distinct depressions resulting in a less accurate measurement. Dry sand crawl width measurements were taken because the Broward County Sea Turtle Project usually measure crawl widths in dry sand.

Clutch size data were obtained from the Broward County Sea Turtle Program to determine if there was a predictive correlation between clutch size, turtle size and crawl width. In this study, notch-to-tip straight carapace length correlated to and was predictive of clutch size (r = 0.6635, P << 0.0005, +/- 21 eggs standard error).

There is a lack of reliable information on age-specific growth rates in marine turtles. Most researchers have used size (as measured by carapace length) as an index of age; so size-based stage classes seem appropriate (Crouse et al. 1987. According to Crouse et al. (1987), there are seven life-history stages: eggs and hatchlings, small juveniles, large juveniles, subadults, novice breeders, first year re-migrants, and mature breeders. Size classes for these life-history stages are listed in Table 7.

Table 7. Life-history stages, size class and age in years according to Crouse et al. (1987).

Life-history Stage	Size Class (cm)	Age in Years
Eggs, hatchlings	< 10	< 1
Small juveniles	10.1 - 58.0	1 - 7
Large juveniles	58.1 - 80.0	8 - 15
Subadults	80.1 - 87.0	16 - 21
Mature adults	> 87	
Novice breeders		22
1st yr re-migrants		23
Mature breeders		24 - 54

Future fecundity can be predicted from clutches laid during the 2001 - nesting season (n=27). The total number of eggs produced by the 27 females multiplied by the annual survival rates for each life-history stage will yield the number of mature adults that survives to reproduce. Assuming a one male to one female ratio, the number of mature adults can then be divided by two to yield the number of females to reproduce in approximately 22 years. The number of mature females can then be multiplied by the average clutch size (calculated from the n=27 data), further multiplied by the average number of clutches per season, which will yield the estimated number of eggs produced in the future. An example of this calculation is demonstrated in Table 8.

Table 8. The number of females that will survive to reproduce in 22 years can be predicted from the total number of eggs produced by the 27 females measured in 2001. The number of eggs to be produced by those females may also be predicted (calculations based on survival rates and average clutches per season by Crouse et al. 1987).

Total # Eggs Produced	**Life-history Stage**	**Annual Survival Rate**	**Years in Stage**	**Adjusted Annual Survival Rate (%^yrs)**	**# Turtles Remaining**
2926	**Eggs, hatchlings**	**0.6747**	**1**	**0.6747**	**1974**
	Small juveniles	**0.7857**	**7**	**0.1848**	**365**
	Large juveniles	**0.6758**	**8**	**0.0435**	**16**
	Subadults	**0.7425**	**6**	**0.1676**	**3**
	Mature adults	**0.8091**	**1**	**0.8091**	**2**
	Novice breeders				
	1st yr re-migrants				
	Mature breeders				

A 1 male to 1 female ratio yields 1 mature female to reproduce.

Average Clutch Size	**Mature Females**	**Avg. # of Clutches/Season**	**# of Eggs Produced**
108	**1**	**2.5**	**270**

The predicted estimate of number of eggs produced in 22 years based on Crouse et al. (1987) survival rates and size/age classes is useful in determining the number of turtles to join the population. If the number is large enough, the threatened status of *Caretta caretta* may be removed. However, the annual survival rates are based on size classes and ages that are not comparable to the 2001 or 1991-2000 data. In the last decade the smallest nesting female was 60 cm while the largest nester was 130 cm (Figure 10). According to the size classes listed by Crouse et al. (1987), large juveniles are nesting on Broward County beaches. Since juveniles cannot nest, it is possible that turtles may mature and nest at smaller sizes than previously thought. Klinger (1995) suggested that females reach sexual maturity at 6-20 years, which is approximately 50 cm. The next smallest documented nesting female was 70.5 cm by Hirth (1980).

PROBLEMS ENCOUNTERED

The timing of encountering a turtle was crucial. If it was a false crawl or the female was in the process of covering the nest, measuring the turtle was difficult. The turtle would be moving, enabling only straight carapace measurements to be taken.

It was also difficult to judge where along each crawl to take the measurements. If a female nested close to the tide line, the turtle would have a short curved crawl, which made finding a portion of the track and plastron to measure straight across difficult.

The presence of people and canines obscured measurements. Once a turtle began nesting, people would walk over to observe the action, walking through the crawl depressions. Canines would also catch the scent of a nesting female and disturb the turtle. The footprints made by people and canines over the turtle's crawl mark would bias where the measurements could be taken.

CONCLUSION

The most significant correlation between body size and crawl width was found between maximum straight carapace length (SCLmax) and the track width emerging from the water in the wet sand (TC HT o) (r = 0.8464, standard error of +/- 3.95 cm). Calipers were used on both body and crawl measurements to determine this predictive relationship. The Broward County program continues to use a flexible measuring tape, even though the correlation value for straight carapace length to beach measurements taken with a flexible measuring tape is lower (r = 0.7456) and gives a prediction error of +/- 4.94 centimeters. The correlation between body size and crawl width may be useful in determining the size of female nesting loggerheads, which may enable prediction of future fecundity and returning nesting adults (Table 8).

This non-invasive method to determine the nesting size class is important to reduce stress on nesting females. In the past decade, females have nested in the 50 cm - 70 cm range (3% of the total population). These nesting sizes are below most documented observations (except Van Buskirk and Crowder 1994 with a range of 70 cm - 100 cm and Klinger 1995 with an approximate range of 50 cm - 120 cm). Fifty-one percent nested below the average size of 90 cm.

The highest percentage of nesters was 88 cm. This may suggest that the mature breeders are divided into sub-stages as Crouse et al. (1987) stated. Van Buskirk and Crowder (1994) stated that there are geographical patterns of turtle populations based on body size. According to a map provided by Van Buskirk and Crowder (1994), Broward County may have a certain proportion of life-history stages because the counties north and south may have larger or smaller sizes of turtles. According to Van Buskirk and Crowder (1994) Broward County was approximately in the lower 20-40% (smaller) end of the size range of loggerheads, while areas north and south of Broward was in the higher 40-100% (larger) size range. The size range of loggerheads that nest on Broward Beaches (67.1-106 cm 2001 data, 50-130 cm 1991-2000 data) may be due to turtles migrating north or south as they age. This topic is beyond the scope of my study but would be interesting to investigate.

CONSERVATION EFFORT

Obtaining carapace length by way of beach crawl widths has many advantages. It is less expensive and there is less effort in locating the beach crawls in the morning rather than patrolling for females at night. A large staff would be required in order to patrol the beach at night to directly measure the turtles, while project workers can easily obtain crawl measurements in the morning. Converting track crawl widths to straight carapace length is simple and generates large amounts of data, which can be used to detect changes in distribution over the years and explain changes in the demographics of a population. The converted SCL can then be compared to reported clutch sizes to estimate future fecundity. This may then enable the prediction of re-nesters on Broward beaches. Although the r-value in predicting SCL from TCW is reasonable, it is not exact. More in-depth studies need to be done.

This comparative approach may prove useful in extending our knowledge of the turtles in Broward County and provide a non-invasive way of doing so. The research conducted may serve as a blueprint to convert the previously recorded data to data more comparable to that of other published investigations. Nesting female loggerhead sea turtles of Broward County can now be compared by physical size to other counties within the Southeastern region, the three other regions in Florida, and globally to the nine other demographic regions of the world. The size portion of morphometric variations that aid in separating the four demographic regions of Florida and the ten demographic regions in the world can be more meticulously surveyed. Using the beach crawl track widths to predict the carapace lengths of female loggerheads is a stress-free, non-invasive way to monitor changes of the physical sizes in a population.

Finally, the main goal of any conservation project is to find a method to better protect a species. Protecting species from extinction occurs in many forms. Conservation efforts may either include relocation of nests, protecting beaches, banning capture of the species, or many more. The main conservation effort of this project was to discover a non-invasive method to obtain straight carapace length. Once a predictive model was formed from TCW, the data that had been generated can be compared to other reported data, such as clutch size, size classes, and survival rates. Assuming the conservation efforts currently in practice are beneficial and increasing the population number, it is hopeful that the loggerhead be de-listed from the threatened species status in the near future.

RECOMMENDATIONS

Measuring sea turtles while nesting was not difficult, but it was time consuming and can disturb the nesting female, causing unnecessary stress. Measuring beach crawls can be done at a more convenient time (crowd and beach use permitting) and only takes a few minutes. However, by using a flexible tape measure to collect data, accuracy is reduced and prediction error of carapace length by crawl width increases (by 0.99 cm). Also, the predictability and correlation between crawl width and body size can be altered by where on the crawl measurements are taken. Using calipers, measuring in cm, and measuring in the wet sand emerging out of the water would benefit the Broward County Program. Finally, Broward County contributes 5.1% of the loggerhead nesting population in the Florida Southeastern Region (Florida Fish & Wildlife Conservation Commission 2001). More studies need to be done on other beaches in this region to see if crawl width to body size comparison is true to this particular population as a whole and not just on a particular beach with a particular slope. If crawl widths are predictive measures to body size on the other beaches in the Florida Southeastern Region, then the other three Florida regions should be researched to determine if this could then be a global conservation method to reduce stress on nesting female turtles (possibly of all species).

Recommended future studies include: determining if the predictive model can be applied to other beaches and species; determining if there is a significant difference in the size of clutches laid based on the size of the female; determining survival rates for turtles at different sizes/ages; determining if different size females lay significantly different amounts of clutches per season; and if there is a significant difference in the size of females nesting North or South of a given county.

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LIST OF ABBREVIATIONS

R = Region number

CCLmin = Curved Carapace Length minimum

CCLn-t = Curved Carapace Length notch to tip

CCLmax = Curved Carapace Length maximum

SCLmin = Straight Carapace Length minimum

SCLn-t = Straight Carapace Length notch to tip

SCLmax = Straight Carapace Length maximum

CCW = Curved Carapace Width

SCW = Straight Carapace Width

PCW = Plastron Crawl Width

TCW = Track Crawl Width

TM = Tape measure

C = Calipers

HT = Tide mark

Mid = Middle of beach crawl

T= Track

P= Plastron

APPENDIX 1 --- Slope Measurements

Range and elevation information was taken from Sea Systems Corporation 1999. Slope (x/y) of each region was calculated from the range (y) of where the water meets the beach to the elevation of the DEP marker (x). The slope was then converted into degrees by taking the arctangent of the slope.

Region	Range (y)	Elevation (x)	Slope (x/y)	Slope (Degrees)	Region	Range (y)	Elevation (x)	Slope (x/y)	Slope (Degrees)
25	175	9.5	0.05	3.11	55	100	12.7	0.13	7.28
26	282	7.1	0.03	1.44	56	150	13.2	0.09	5.04
27	285	10.1	0.04	2.03	57	150	12.6	0.08	4.81
28	350	9.9	0.03	1.62	58	125	13.3	0.11	6.10
29	400	11.2	0.03	1.60	59	86	8.6	0.10	5.73
30	395	13.2	0.03	1.91	60	120	15	0.13	7.16
31	375	14.5	0.04	2.22	61	150	11.8	0.08	4.51
32	414	14.5	0.04	2.01	62	250	11.2	0.04	2.57
33	420	14	0.03	1.91	63	136	9.8	0.07	4.13
34	411	12.8	0.03	1.78	64	100	10.4	0.10	5.96
35	325	12.1	0.04	2.13	65	107	7.3	0.07	3.91
36	275	12.5	0.05	2.60	66	125	7	0.06	3.21
37	275	12.5	0.05	2.60	67	125	7.4	0.06	3.39
38	225	10.5	0.05	2.67	68	260	12.5	0.05	2.75
39	175	9.9	0.06	3.24	69	237	11.8	0.05	2.85
40	225	12.7	0.06	3.23	70	147	7.5	0.05	2.92
41	225	13.8	0.06	3.51	71	210	8.4	0.04	2.29
42	200	11.6	0.06	3.32	72	190	8.3	0.04	2.50
43	250	10.7	0.04	2.45	73	157	8.8	0.06	3.21
44	275	13	0.05	2.71	74	175	11.7	0.07	3.83
45	323	11	0.03	1.95	75	225	11.4	0.05	2.90
46	200	8.6	0.04	2.46	76	225	11.4	0.05	2.90
47	300	12.2	0.04	2.33	77	250	11.4	0.05	2.61
48	275	12.5	0.05	2.60	78	240	13.7	0.06	3.27
49	250	9.8	0.04	2.25	79	400	14.9	0.04	2.13
50	175	12.4	0.07	4.06	80	350	11.5	0.03	1.88
51	150	13	0.09	4.97	81	332	15	0.05	2.59
52	150	9.9	0.07	3.78	82	400	10.4	0.03	1.49
53	125	10.6	0.08	4.86	83	500	10.7	0.02	1.23
54	100	11.2	0.11	6.42	84	350	10.9	0.03	1.78

APPENDIX 2 --- Caliper Measurements

Turtle #	*SCL min*	*SCL n-t*	*SCL max*	*SCW*	*PC HT o*	*PC Mid o*	*PC Mid I*	*PC HT I*	*TC HT o*	*TC Mid o*	*TC Mid I*	*TC HT I*
1	96.3				25.4	21.2	28.3	27	82.7	75.4	82.1	78
2	95.6	99.2	99.5	73.6	30.6	27.2	16.8	16.2	91.1	83.7	79.3	86.4
3	93.9			74.3	26.3	31.2	22.2	28.4	95.1	87.5	94.8	95.6
4	85.3	86	87.4	64.3	18.2	20.3	14.2	18.8	79.3	77	84.7	74.7
5	87.2	87.3	88	68.1	10.7	12.6	11.5	12.8	80.9	77.1	72.2	70.3
6	99.6	101.5	102	80.3	19	17.9	20.8	17.6	100.2	89.2	85.7	85.9
7	92.4	93.3	94.8	69.3	22.2	20.5	21.8	22	88.2	82.6	83.7	87
8	85.2	85.7	87.6	65.2	22.3	23.7	19.7	19.2	83.1	89	76.2	75.4
9	91.4			69.8	22.3	23.1	23.5	24.7	87.4	94.2	84.3	85
10	104			75.4	22.7	23.7	30.2	25.5	93.1	93.2	88.1	98.7
11	88.9	91.6	92.4	68.6	20.3	21.5	24.9	20.7	83.9	81.6	82.4	84.1
12	75.6	76.9	78.1	59.2	18.5	19.8	19.3	18.9	70.2	70.4	65.9	67.5
13	82				28.1	23.2	27.4	23.9	82.4	80.8	77.4	78.2
14	89.7	91.2	91.7	71.4	14.1	16.8	13.2	15.4	76.4	78.2	77.9	77.1
15	94.1	95.9	98.5	74.6	18.4	16	21.8	21.2	95.6	86.9	91.1	95.6
16	92.8	92.5	94.3	71.4	20.2	20.7	20.4	20.4	89.4	87.6	80.6	90.4
17	88.8	89.4	90.2	69.2	22.5	24.2	24.8	21.4	86.4	74.7	80.9	87.3
18	86.4				17.1	17	17	13.7	87.9	85.1	81.2	86.7
19	98.4	98.6	99.9	77.3	22.1	20.5	26.6	21.2	94.7	88.1	86.9	100.4
20	89.7			73.2	20.8	17.7	23.9	25.6	78.2	84.2	78.5	77.5
21	90.9	92	93.7	71.7	25.8	23.7	29.4	30.6	86.5	92.2	82.7	94.4
22	91	91.3	91.6	69	24.2	19.9	21.1	25.5	82.4	87.4	70.7	77.3
23	94.2			74.3	20	8.8	19.2	22.8	80.7	71.1	73.9	76.7
24	87.6	88.8	89.4	67.6	18.4	13.4	20.9	23.2	83.1	74.2	86.3	81.8
25	85.1	86.1	87.5	61.2	18.7	16.9	14.4	23	83.8	75.3	81.9	87.5
26	87.7	88.7	89.9	68.8	17.4	11.3	15.3	16.8	89.3	101.8	83.7	85.6
27	88.4	89.8	91.8	69.9	15.6	13.3	13.4	16.2	81.1	71.9	85.2	86.7
28	85.2	87.3	87.8	64.8	14	13.3	12.8	15.2	88	72.7	65	83.4
29	90.4	92.2	92.9	68.8	19.3	14.7	20.2	22.1	95.1	94.8	92.8	91
30	95.6	98.9		69.4	17.8	22.4	19.3	26.4	94.2	86.1	86.2	92.9
31	98.7	98.7	101.8	75.1	19.9	24.3	27	27.3	103.3	117	91.8	89.9
32	86.8	87.7	89.3	68.8	16.3	17	16.2	17.4	82.9	77.6	85.7	80.3
33	65.2	65.5	67.3	53.3	18.5	13.1	16.4	22.8	75	68.9	74.4	73
34	82.8	84.2	84.8	63.7	15	13.4	25.4	26.8	77.3	76.3	72.3	77.9
35	87.9	89.4	90.3	68.3	21.3	23.7	18.4	25.6	84.1	90	81.2	80.8
36	102.7	103.7	105.1	75.2	26	27.8	24.8	25.2	104.4	100.3	101.6	102.2
37	95.6	101.6	98.2	75	23	25	34.8	30.7	94.8	105.8	104.3	89.8
38	93.6	94.4	95.7	70.4	21.3	18.8	21.9	25.8	93.3	78.4	91.7	84.2
39	94.2	94.9	96.1	72.6	20.1	18.9	21.8	30	92.2	101.3	91.7	94.5
40	93.7	94	98.5	74.4	30.9	26.9	22.3	33.9	96	91.4	94.2	92.7
41	92.2	93.2	94.5	71.9	21.6	24.6	22.2	19.9	84.4	83.2	78.2	76.4
42	101.9	101.7	102.8	80.9	23.1	20.3	22.1	28.2	95.6	103.8	85.2	99
43	88.8	89.5	90.5	69.3	20.4	22.4	16.7	22.5	79.3	79.8	82.7	83.2
44	96.7	97	100.6	75.2	35.1	36.2	30.2	35.1	99.6	94.6	101.6	95.6
# data sets	44	36	35	41	44	44	44	44	44	44	44	44

APPENDIX 3 --- Flexible Tape Measurements

Turtle #	*CCL min*	*CCL n-t*	*CCL max*	*CCW*	*PTM HT o*	*PTM Mid o*	*PTM Mid I*	*PTM HT I*	*TTM HT o*	*TTM Mid o*	*TTM Mid I*	*TTM HT I*
1					23.9	22	22.6	27.8	83.6	82.2	75.9	83.4
2	107.9				25.9	26.9	17.1	17.1	97.9	100.1	100.4	91
3					20.9	21.7	22.7	23.7	93.4	103.2	91.5	89.4
4	95.2	96.5	97.8	89.6	15.2	18.6	17	20.1	88.1	90.8	95.5	86.2
5	98.3	97.9	98.8	88.8	12.8	14.8	15.8	12.4	84.1	76	74.9	74.5
6	108.9	108.6	112.3	103.9	20	21.4	20.3	19.8	101.2	108.2	95.4	81.7
7	100.3	101.6	102.9	90.2	22.6	20.8	20.5	20.8	88.2	84	91.5	81.7
8	94.2	94.6	96.9	86.1	24.1	24.2	20.4	23.3	90.8	88	80.4	79.5
9					24	21.3	23.2	30.5	89.8	110.7	106.5	104.4
10					21	24.4	29.4	30.2	96.2	96.7	98.9	97.8
11	97.2	99.6	102.4	89.3	23.9	20.8	24.2	23.1	85	85.4	87.5	81.4
12					21	18.1	19.3	19	83.3	85.2	78.3	75.1
13					30.5	24	28.3	25.1	87.5	81.4	78.4	70.4
14	99.2	101.1	100.6	92.6	14.5	16	16.6	14.2	83.6	84.4	80.2	79.4
15	103.4	104.1	106.3	97	20.3	18.2	22.1	23.9	97.1	98.6	84.7	98.7
16	99.6	102.2	102.1	96.6	18.4	14.4	20.8	21.9	91.4	90	85.6	99.9
17	98.3	98.7	100.2	90.2	20.9	19.3	17.3	20.4	91.4	71.2	81.1	88.8
18					15.8	15.5	15.9	19.9	88.2	87.5	88.8	89.8
19	109.9	109.3	113.5	96.3	20.1	24.4	26.8	24	103	91.6	84.5	100.1
20					22.9	16.6	21.5	26.3	90.4	88.4	74.1	88.5
21	97.6	97.9	101.8	91.8	26.8	23.3	26.9	24.6	98.8	97.6	76.3	86.9
22					23.8	17.7	23.9	25.1	92.1	93.9	81.5	92.4
23					19.8	12.1	13.7	18.6	80.5	90.1	78.8	92.1
24					16.5	16.8	16.9	28	81	86.8	89.3	85.4
25	92.9	93.1	95.9	86	21.9	19.4	14.6	19.8	97.9	88	83.2	86.9
26	95.4	96.3	98.9	88	17.2	14.7	21	20.4	91	102.7	87.7	83.9
27	98.3	98.8	100	89.9	13.9	16	13.7	16.7	94	76.7	91.3	93.4
28	95.4	95.7	98.4	89.3	13.9	12.9	13.3	18.7	86.8	84.1	83.6	79.3
29	99.2	102.1	102.4	94.6	22.2	17.3	15.7	20.1	95.4	102.9	100.7	88.9
30					24.8	21.5	18.4	27.9	90.1	91.8	99	94.5
31	109.1	109.1	113.2	102.7	26.4	22.9	22.9	22.4	111.7	126.6	102.4	98.5
32	94.7	95	96	85.1	16.6	15.8	15.8	19.1	88.3	82.3	87.4	86
33					17.4	15.9	18	18.8	81.2	68.6	77.8	80
34	90.7	91.1			16.1	17.3	25.3	23.6	81.1	88.4	81	80.7
35	96.6	98	100	87.6	25.5	23.4	23.9	23.2	103.8	99.6	85.5	101.1
36	115.4	116.5	118.6	102.3	28.5	28.2	27.3	25.4	110.9	106	105.1	109.3
37	102.7	103.4	104.7	96.9	17.6	27.1	30.6	28.8	95.9	108.8	108.4	91.3
38	100.5	101.1	103.4	90.4	18.4	19.5	18.3	26.6	97.9	96.5	97.6	93.1
39	103.1	104.8	106.7	101.4	22.4	20.2	24	33.2	93.9	97.2	80.1	98.9
40	101	101.6	106.4	95.4	32.5	25.5	19.9	35.4	101.7	90.6	97.2	99.2
41	100.6	100.9	103.2	94.2	22.2	22.2	23.7	18.5	95.2	89.1	76.3	76.5
42	113	112.2	116.6	103.6	22.4	17.4	20.3	21	99.6	117	95.5	96.1
43	97.6	98.3	100.2	92.9	21.3	23.4	15.9	20.7	83.3	80.3	83.6	87.6
44	106.3	106.8	109.3	100.3	36	34	29.5	35.4	102.1	101.2	100.3	101.9
# data sets	31	30	29	29	44	44	44	44	44	44	44	44