GROWTH RATES OF JUVENILE GREEN TURTLES, *CHELONIA MYDAS*, FROM THREE DEVELOPMENTAL HABITATS ALONG THE EAST CENTRAL COAST OF FLORIDA

by

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B.S. Virginia Polytechnic Institute and State University, 1997

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Biology
in the College of Arts and Sciences
at the University of Central Florida
Orlando, Florida

Summer Term
2003

ABSTRACT

Growth rates were determined for juvenile green turtles *(Chelonia mydas)* in three developmental habitats along the east central coast of Florida. Data were collected over twenty-years at the Indian River Lagoon site, thirteen years at the Sabellariid worm rock reef site and nine years at the Trident Submarine Basin site. Straight carapace length (SCL) measurements were used to calculate mean annual growth rates. Length-weight relationships were determined for each study site.

Significant differences in growth rates were observed among study sites and among size classes within sites. A nonmonotonic pattern, or single peak in growth rates, was observed at all three sites. Juvenile green turtles from the Indian River Lagoon site grew significantly faster than those from the Sabellariid worm rock reef site and the Trident Submarine Basin site. The length-weight relationships for juvenile green turtles from the Indian River Lagoon and Sabellariid worm rock reef sites were nearly identical. The length-weight relationship for the Trident Submarine Basin population was significantly different from the other two populations. Turtles from the Trident Submarine Basin increase in mass slower than turtles from the other two sites. Differences in growth rates and length-weight relationships among sites may be attributed to turtle density and food availability.

ACKNOWLEDGMENTS

I would like to thank Dr. Llewellyn Ehrhart for allowing me the privilege to work with him and experience the wonderful world of marine turtle research. I have learned more in the past four years than I ever thought possible. This project would not have been possible without the help of all former and present members of the UCF Marine Turtle Research group. I would especially like to thank Dean Bagley for her friendship and support.

Dr. James Roth helped me get through the difficult stage of data organization. His willingness to help and enthusiasm for data analysis were a source of encouragement. I would like to thank him for taking time out of his busy schedule to help me.

I would also like to thank Dr. Milani Chaloupka for offering assistance with analyzing these data.

I would like to extend a special thanks to my committee members, Dr. John Weishampel and Dr. Franklin F. Snelson, who were patient with me and encouraged me during this long endeavor.

Finally, I'd like to thank my family for their encouragement and support throughout this and all of my life experiences. They gave me the strength to become the independent person that I am. Without their support, I would not have been able to make my dreams a reality.

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LIST OF ABBREVIATIONS

ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
CL	Carapace length
FMRI	Florida Marine Research Institute
FWC	Florida Fish and Wildlife Conservation Commission
IRL	Indian River Lagoon
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCL	Over-the-curve carapace length
PL	Plastron length
SWRR	Sabellariid worm rock reef
SCL	Standard carapace length
TSB	Trident Submarine Basin
USFWS	U.S. Fish and Wildlife Service

INTRODUCTION

Most research involving sea turtles has been conducted on nesting beaches and has involved adult females and hatchlings. These stages may be the easiest and most convenient to study, but only constitute limited segments of the life history of the species. Studies on juvenile populations of sea turtles are crucial, but due to logistical difficulties they are relatively uncommon. Understanding aspects of the immature stages of naturally occurring populations of sea turtles, like growth rates and age to maturity, is an essential part in the formulation of sound management strategies (NMFS and USFWS, 1991).

Green turtles are distributed throughout tropical and subtropical waters. Breeding populations in Florida and the Pacific coast of Mexico are listed as endangered, while all others are listed as threatened (*ibid*.). In the Western Atlantic, juvenile green turtles occur in coastal habitats from Massachusetts in the north to the Caribbean in the south. Turtles inhabiting the northern extent of the range are typically present during the warm months and move south during the cold months. The Atlantic green turtle suffered severe population declines in Florida in the late 1800s due to over harvesting by commercial turtle fisheries (True, 1887; Wilcox, 1896). In 1978, Florida green turtles were afforded protection under the Endangered Species Protection Act. Current threats to the species include but are not limited to disease, loss of nesting habitat, entanglement in fishing gear, incidental capture in fisheries, and collisions with watercraft. The long-term trend in nest production for Florida green turtles is encouraging. Statewide increases in nest production have been documented over the past decade (FMRI, 2003). The relative abundance of juvenile green turtles in developmental habitats along the east central coast of Florida also appears to be increasing (Ehrhart, unpublished data).

Growth rates of wild green turtles have been studied in the Atlantic and Pacific oceans. Results from some early studies might include inflated growth rates due to small sample sizes and relatively short recapture intervals. Previous studies in the Atlantic yielded mean growth rates ranging from 2.15 – 5.32 cm/year in Mosquito Lagoon, Florida (Mendonça, 1981), 2.3 – 2.7 cm/year from the Atlantic Coastal waters off St. Lucie County, Florida (Bresette and Gorham, 2001), 3.6 – 6.0 cm/year in Puerto Rico (Collazo et al., 1992), and 1.2 – 8.8 cm/year in Great Inagua, Bahamas (Bjorndal and Bolten, 1988). Individual growth rates have been found to be highly variable within a population (Bjorndal and Bolten, 1988). Factors that contribute to individual differences in growth rates can be divided into two groups, environmental factors and intrinsic factors. Environmental factors include water temperature, salinity, food quality and availability, and population density. Size, sex, maturity status, genetic make-up and health of the individual are all intrinsic factors. Determining the sex, maturity status and genetic make-up of an individual requires advanced medical and laboratory techniques. Due to financial limitations, these techniques were not included in this study. It is difficult to determine which environmental factors directly influence growth, and to do so requires sophisticated experimental design and extensive knowledge of ecological processes. This study describes growth rates of green turtles from three ecologically distinct habitats along the east central coast of Florida. Comparisons are made between the results of this study and those of previous studies in similar habitats.

Allometry, the study of the influence of body size on form and function, also known as scaling, has become a prominent focus in ecological studies. Simple relationships, like volume being proportional to length cubed ($V \alpha L^3$), can be applied to animal models if the linear dimensions differ only by a constant multiplier. Since measuring the volume of an animal is difficult, most scaling studies assume that the density of different organisms is approximately the same and substitute mass for volume (LaBarbera, 1989). A study of sub-adult green turtles in the Southern Bahamas determined that changes in carapace length cubed (CL^3) and plastron length cubed (PL^3) can be used to estimate changes in body mass (Bjorndal and Bolten, 1988). However, CL^3 and PL^3 do not accurately estimate mass, and the relationship should be used with caution. In the case of Bahamian green turtles, the exponent that accurately converts carapace length to mass is 3.04. This value indicates that Bahamian green turtles increase in mass slightly faster than they increase in length.

Comparisons of length-weight relationships between different aggregations of juvenile green turtles provide insight into the overall condition of the animals utilizing various habitats. The condition of the turtles in each habitat is also indicative of the quality of habitat. Therefore, the length-weight relationship may indicate whether a habitat is suitable for green turtle foraging. This simple analysis can lead to more sophisticated studies on density-dependent effects on growth, quality of forage items, and health-related studies of entire aggregations.

METHODS

Study sites and methodology

Fieldwork was conducted in three geographically similar, but ecologically distinct, study sites along the east central coast of Florida (Figure 1). The Indian River Lagoon (IRL) is a shallow, brackish water estuary that extends 260 km along the east coast of Florida from Ponce de Leon Inlet in the north to St. Lucie Inlet in the south. The study site is 3 km south of Sebastian Inlet in a large embayment known by local fisherman as South Bay (Figure 1; 27°49'N, 80°26'W). Sea grass beds composed of *Syringodium filiforme*, *Halodule wrightii* and *Halophila decepiens* are found in shallow waters, and large beds of drift algae are found in the deeper waters. The drift algae beds are the primary food source for juvenile green turtles in this area (Holloway-Adkins, 2001). Data at this site were collected year round from 1982 to 2002. Two large-mesh tangle nets (455 m x 3.7 m, mesh size = 40 cm stretched) connected at the middle were deployed perpendicular to the east shore in water depths less than three meters. Nets were set during daylight hours for varying lengths of time and were monitored continuously by elevating the top line and pulling hand-over-hand along the length of the net from the bow of a boat. Turtles were brought aboard the boat where they were tagged and measured. All turtles were held until the end of the workday and released at the capture site.

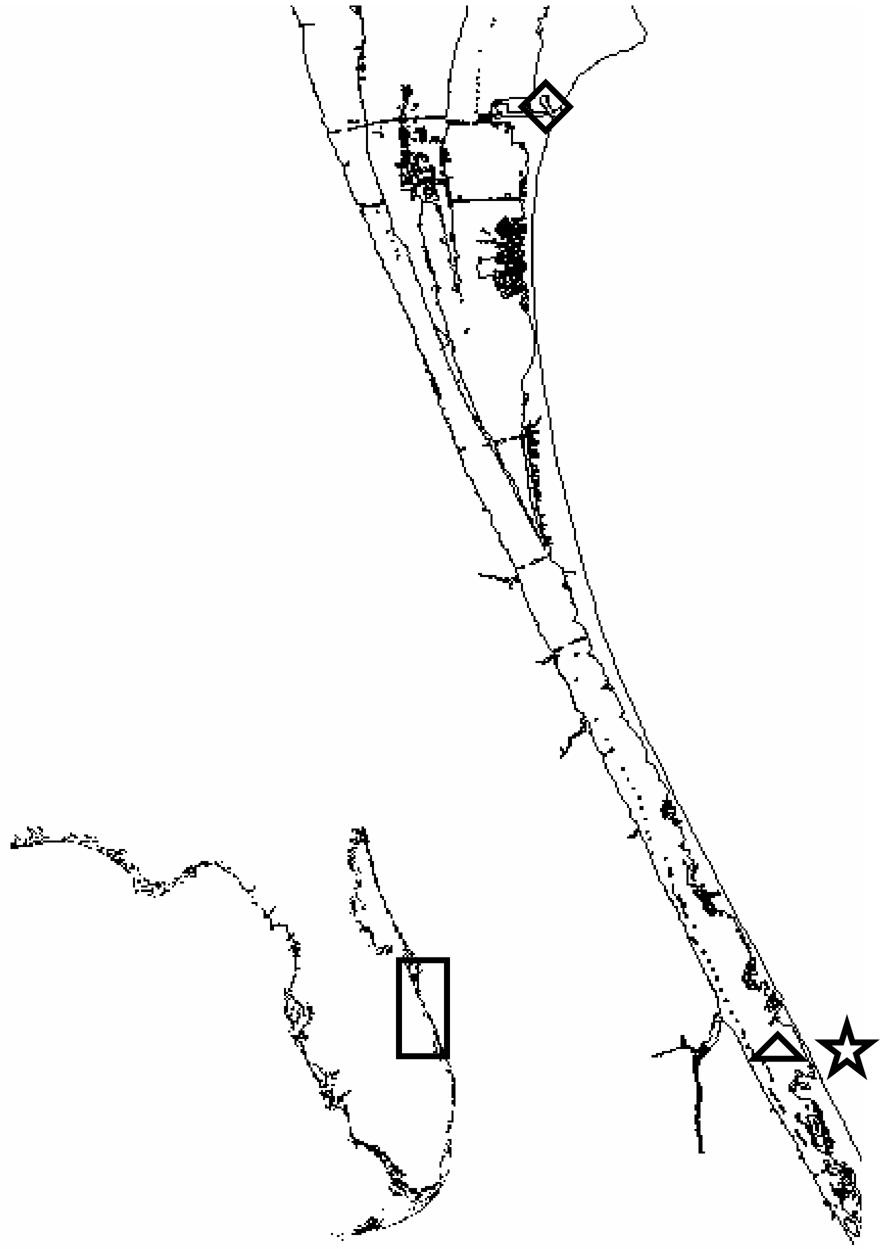

Figure 1. Study sites along the east central coast of Florida. Indian River Lagoon = △ , Sabellariid worm rock reef = ☆ , and Trident Submarine Basin = ◇ .

A comparative study was begun in 1989 over the near shore Sabellariid worm rock reefs (SWRR) in the Atlantic Ocean (Figure 1; 27°49'N, 80°25'W). This site is due east of the IRL study area, separated only by a narrow stretch of barrier island. The reefs are formed by polychaete worms, *Phragmatopoma lapidosa*, and are only found from Cape Canaveral, Florida to Biscayne Bay, Florida (Kirtley and Tanner, 1968; Main and Nelson, 1988). The reef structures extend from the intertidal zone to a depth of approximately 10 meters. This type of reef provides substrate for at least 109 species of benthic marine algae (Juett et al., 1976), upon which juvenile green turtles forage (Holloway-Adkins, 2001). Fieldwork was conducted in the summer months when ocean conditions were benign. Rough ocean conditions prevent access to the reefs during fall, winter and spring. A large-mesh tangle net (220 m x 3.7 m, mesh size = 30.5 cm stretched or 40 cm stretched) was set on sandy bottom between parallel reef structures and patrolled by relays of swimmers equipped with mask, snorkel and fins. Divers brought turtles to the surface, untangled them from the net, and placed them in a boat until net capture was completed. All turtles were transported to the UCF Marine Turtle Research field station where they were tagged and measured. Turtles were released at the capture site later the same day.

In 1993, a third study on juvenile marine turtles was begun at the Trident Submarine Basin (TSB) near the mouth of the Port Canaveral Ship Channel, Brevard County, Florida (Figure 1). The basin is a man-made embayment approximately 600 m wide by 1200 m long. A concrete seawall and large wharf extend along the east side of the basin, and the remaining perimeter is lined with rock riprap. Water depths along the edges of the basin range from 0.5 m to 2.5 m at high tide. The center of the basin is approximately 13 m deep. An algal mat covers the submerged part of the rock riprap and is the primary food source for the juvenile green turtles inhabiting the basin. Large mesh tangle nets and long-handled, large-hoop dip nets were used to capture turtles. Two separate tangle nets (220 m x 3.7 m, mesh size = 30.5 cm stretched; 220 m x 3.7 m, mesh size = 40 cm stretched) were set along the walls of the basin and monitored by elevating the top line and pulling hand-over-hand along it from the bow of a boat. Foraging turtles or those swimming in shallow water along the narrow shelf were opportunistically captured with long-handled dip nets. All turtles were taken to shore where they were tagged and measured. At the end of the day, all turtles were released back into the basin.

Over the years various types of flipper tags were applied to juvenile green turtles. Both Monel and Inconel metal tags and plastic roto-tags have been used. External flipper tags were applied to the second proximal scale of each front flipper. Flipper tag loss is a constant problem in mark-recapture studies of marine turtles and results in the loss of valuable recapture data. The use of Passive Integrated Transponders (PIT tags), a small microchip manufactured by Destron-Fearing, was begun in 1993 and has proven to be invaluable. PIT tags were inserted subcutaneously into the right front flipper near the shoulder. PIT tags provide a permanent method of identifying individuals for an indefinite period of time. During the course of this study, we documented 0% PIT tag loss.

Standard morphometric measurements were taken to the nearest 0.1 cm using forester's calipers. Standard carapace length (SCL) was measured from the nuchal notch to the posterior-most portion of the carapace. Trained research assistants performed all measurements throughout the course of this study. Measurement error (0.18 cm SCL ± 0.17 SD) was calculated from 34 turtles recaptured at intervals less than 30 days.

Juvenile green turtles in Florida range in size from approximately 22 to 70 cm SCL. The size class distribution of juvenile green turtles from the IRL site and SWRR site were nearly identical, but turtles from the TSB were skewed towards the smaller size classes (Figure 2). From the histogram of size distribution and knowledge of the various habitats, two hypotheses were devised. Since juvenile green turtles from the IRL and SWRR were essentially identical in size class distribution and food was abundant in both sites, I hypothesized that turtles from these sites would exhibit similar growth rates. I also hypothesized that turtles from the TSB would grow significantly faster than those from the IRL and SWRR sites since they were smaller in size, and previous studies showed faster growth rates in smaller individuals.

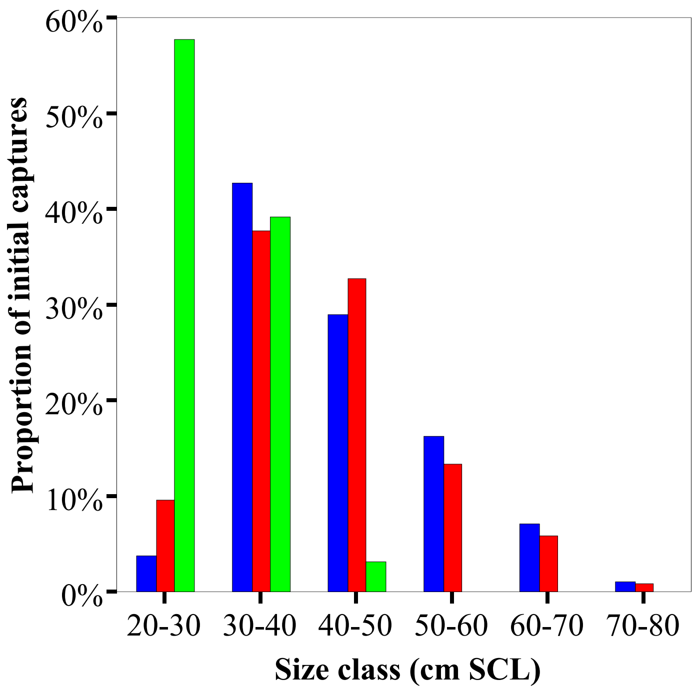

Figure 2. Size class distribution of juvenile green turtles from three developmental habitats along the east central coast of Florida. Indian River Lagoon = ■, Sabellariid worm rock reef = ■, Trident Submarine Basin = ■.

Analysis of data

Linear growth data

Capture history profiles were constructed for each recaptured turtle. Profiles included 1) capture dates, 2) straight carapace length (SCL) at each capture, 3) time at large (months) since first capture or previous recapture, and 4) annual growth rate. To minimize potential seasonal effects on growth rate, only turtles with capture intervals greater than 11 months were included in the analysis. Annual growth rate was calculated as ($SCL_2 - SCL_1$) / recapture interval in years. Turtles were assigned to a 10 cm size class based on their mean SCL during the recapture interval. Growth rates for individuals with multiple recaptures were calculated such that an individual only contributed one growth rate per size class.

Growth rates are presented as the mean ± one standard deviation. Data were tested for normality and homogeneity of variances. Parametric procedures (One-way ANOVA and Tukey-Kramer Multiple Comparisons Test) were used when data sets met both assumptions. When parametric assumptions were not met, non-parametric procedures (Kruskal-Wallis Test and Dunn's Multiple Comparisons Test) were used. An alpha level of 0.05 was used for all statistical tests. Graphpad Instat and SPSS version 11.0 were used for all statistical tests.

Length-weight relationships

Length-weight relationships were determined for all initial capture juvenile green turtles at each study site. Turtles were weighed using spring scales. Small turtles were weighed with a 20 kg capacity scale to the nearest 0.1 kg; larger turtles were weighed on a 115 kg capacity scale to the nearest 1 kg. Body mass (kg) was plotted on length (cm SCL) to create a length-weight curve. A regression of log-transformed mass (kg) on log-transformed SCL (cm) data produced a linear relationship. The slopes of the lines were compared using ANCOVA at an alpha (α) level of 0.05.

RESULTS

Linear Growth Data – Comparisons Within Sites

Indian River Lagoon

From 1982 to 2002, 1,644 green turtles were captured at the IRL site, two of those turtles were adult males, and the rest were juveniles. The majority of turtles (87%, N = 1,427) were captured only one time, and 13% (N = 217) were recaptured a total of 253 times. Of the recaptured turtles, 85% (N = 184) were captured two times, 14% (N = 30) three times, and 1% (N = 3) on four occasions. Of the 217 recaptured turtles, only 93 were recaptured at intervals greater than 11 months. Six of those turtles were recaptured multiple times yielding a total of ninety-nine growth intervals. Initial capture juvenile green turtles ranged in size from 24.3 to 78.6 cm SCL (mean = 43.1 cm, SD = 9.99, N = 1,640). Recapture intervals ranged from 11.0 - 71.3 months, with a mean of 25.2 ± 12.8 months, and a median of 22.8 months. Growth rates were calculated for turtles ranging in size from 28.5 to 72.3 cm at initial capture. Growth rates ranged from 0.7 cm/yr (PPJ067; at large for 22.8 months with absolute growth of 1.4 cm) to 6.8 cm/yr (502D4D2D76; at large for 12.1 months with absolute growth of 6.9 cm).

Turtles were assigned to a 10 cm size class based on their mean SCL, and size specific growth rates were determined (Table 1). Growth rates increased with size and peaked at a size between 50 and 60 cm SCL (Figure 3). Growth rates differ significantly between size classes (ANOVA, $F = 4.835$, $p = 0.01$). Turtles in the 50-60 cm size class have significantly greater growth rates than turtles in the 30-40 cm size class (Tukey Kramer, $q = 4.246$; $p < 0.01$).

Table 1. Mean size-specific growth rates (cm SCL/yr ± 1 standard deviation) for juvenile green turtles from three developmental habitats along the east central coast of Florida.

	Indian River Lagoon		Sabellariid worm rock reef		Trident Submarine Basin	
Size class	Growth rate	n	Growth rate	n	Growth rate	n
20.0 - 29.9	--	--	1.3	1	2.1 ± 1.2	35
30.0 - 39.9	3.8 ± 1.1	41	2.2 ± 0.8	10	2.6 ± 1.0	82
40.0 - 49.9	4.2 ± 1.2	39	2.5 ± 0.9	8	1.6 ± 1.1	22
50.0 - 59.9	4.7 ± 0.7	17	2.7 ± 0.1	3	--	--
60.0 - 69.9	5.3	1	2.2	2	--	--
70.0 - 79.9	1.2	1	--	--	--	--

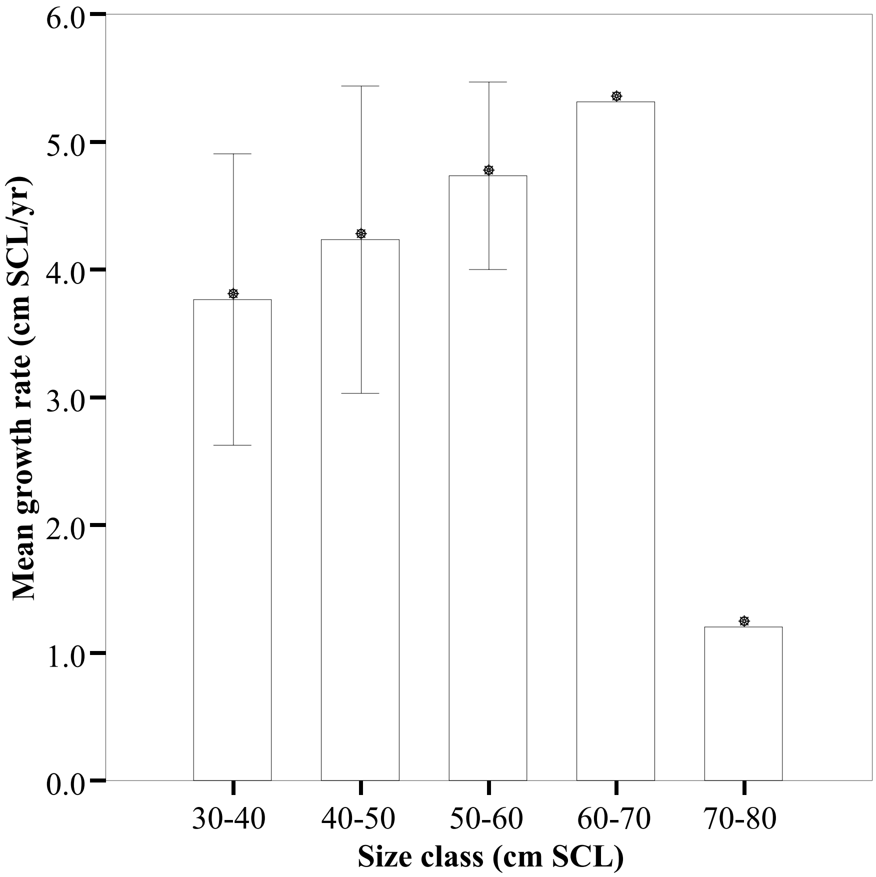

Figure 3. Mean growth rates (cm SCL/yr) ± 1 standard deviation for juvenile green turtles from the Indian River Lagoon site.

Sabellariid Worm Rock Reef

From 1989 to 2002, 759 green turtles were captured a total of 807 times at the SWRR site. Nearly 94% (N = 711) of the turtles captured were only captured one time, and 6% (N = 48) two times. Of the recaptured turtles, 25 had capture intervals greater than 11 months. One of those was a head-started turtle (raised in captivity) released one year earlier. It was excluded from the analysis due to the potential effects of the head-starting process on its growth rate. Initial capture green turtles ranged in size from 24.7 to 72.3 cm SCL (mean = 41.9 cm, SD = 9.9). Recapture intervals ranged from 11.4 to 24.7 months, with a mean of 16.7 ± 5.4 months, and a median of 13.4 months. Growth rates were calculated for turtles ranging in size from 27.4 to 61.9 cm at initial capture. Growth rates ranged from 1.1 cm/yr (122509471A; at large for 12.1 months with absolute growth of 1.1 cm) to 4.1 cm/yr (BP565; at large for 12.0 months with absolute growth of 4.1 cm).

Size specific growth rates were determined, but due to small sample sizes they should be interpreted cautiously (Table 1). There appeared to be a peak in growth rates for juveniles in the 50 to 60 cm size class (Figure 4), however, statistical tests indicated there were no significant differences in growth rates among size classes (Kruskal-Wallis = 2.889, p = 0.2).

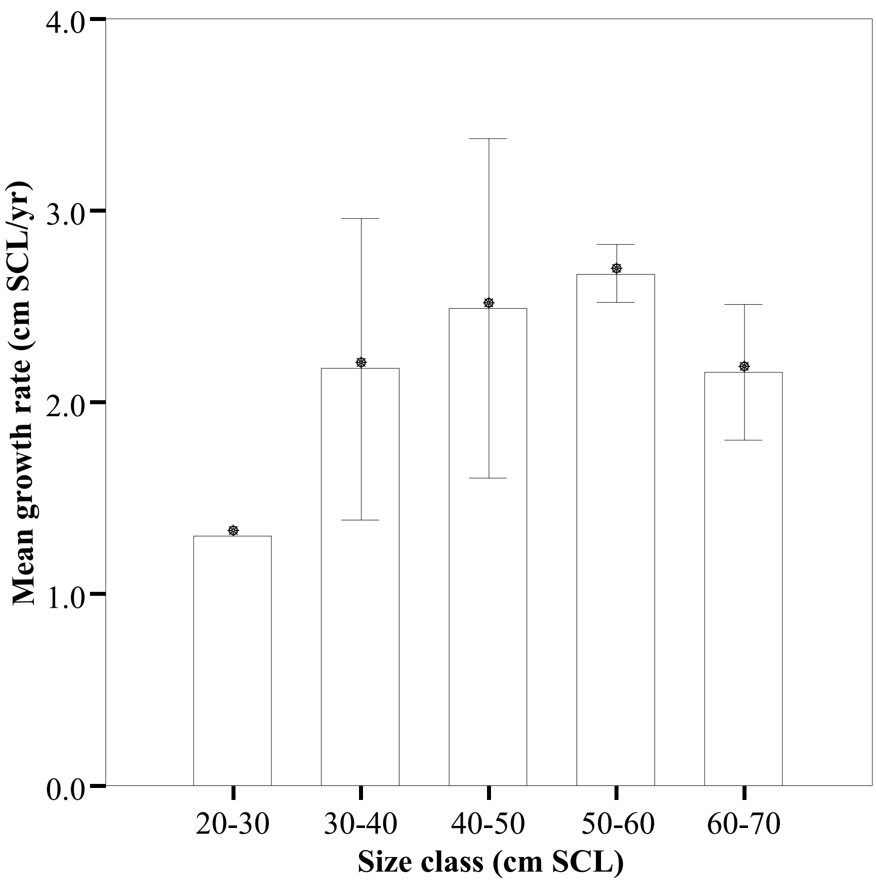

Figure 4. Mean growth rates (cm SCL/yr) ± 1 standard deviation for juvenile green turtles from the Sabellariid worm rock reef site.

Trident Submarine Basin

From 1993 to 2002, 353 juvenile green turtles were captured 982 times at the TSB site. Nearly half (52%, N = 182) of the turtles captured were only captured one time, and the remaining 48% (N = 171) were captured between 2 and 20 times. Of the recaptured turtles, 103 had capture intervals greater than 11 months. Twenty-eight turtles contributed two growth rate values, and four turtles contributed three, yielding a total of 139 growth intervals. Initial capture green turtles ranged in size from 22.8 to 48.1 cm SCL (mean = 29.9 cm, SD = 4.0). Recapture intervals ranged from 11.9 to 93.1 months, with a mean of 31.7 ± 18.0 months, and a median of 25.2 months. Growth rates were calculated for turtles ranging in size from 22.9 to 45.1 cm at initial capture. Growth rates ranged from 0.0 cm/yr (50301B662C; at large for 17.1 months with absolute growth of 0.0 cm) to 6.93 cm/yr (00-0013-BA77; at large for 17.0 months with absolute growth of 9.8 cm).

Size specific growth rates were determined for each 10 cm size class (Table 1). A peak in growth rate was observed for turtles in the 30 to 40 cm size class (Figure 5). Significant differences in growth rates were observed among size classes (ANOVA, $F = 7.658$, $p = 0.0007$). Growth rates of turtles in the 30-40 cm size class were significantly greater than those in the 40-50 cm size class (Tukey-Kramer, $q = 5.134$, $p < 0.01$).

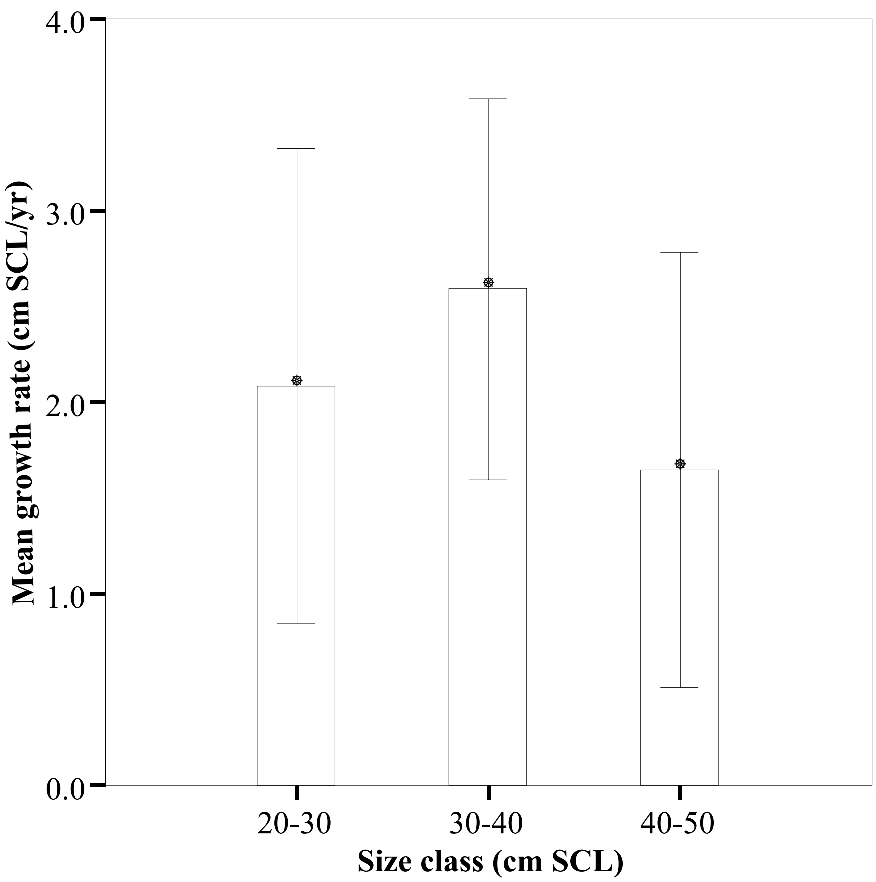

Figure 5. Mean growth rates (cm SCL/yr) ± 1 standard deviation for juvenile green turtles from the Trident Submarine Basin site.

Linear Growth Data – Comparisons Among Sites

Comparisons of growth rates were made among study sites and among size classes in the sites. Data were pooled across all size classes for each site. Significant differences in mean annual growth rates were observed among study sites (Kruskal-Wallis = 99.673, $P < 0.0001$). Green turtles from the IRL site grew significantly faster (4.1 cm/yr) than those from the Sabellariid worm rock reef site (2.3 cm/yr) and the Trident Submarine Basin site (2.3 cm/yr; Dunn's Multiple Comparisons Test, $P < 0.001$; Figure 6). No significant differences in mean annual growth rates were observed between the worm rock reef site and the Trident Submarine Basin site (Dunn's Multiple Comparisons Test, $P > 0.05$).

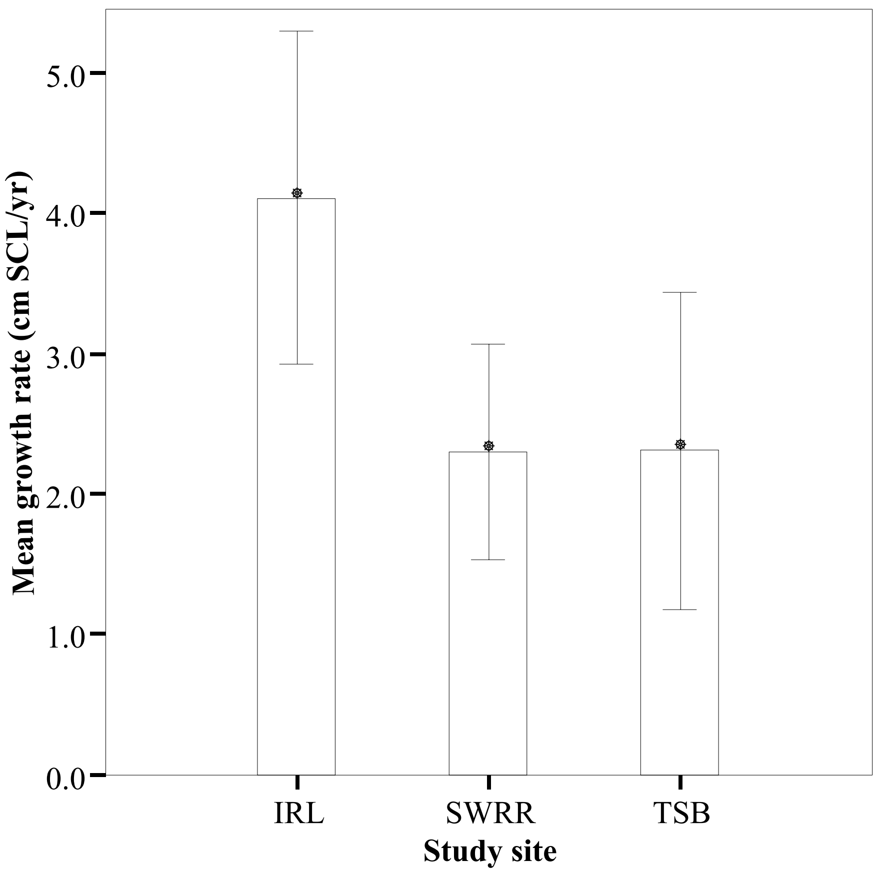

Figure 6. Mean growth rates (cm SCL/yr) ± 1 standard deviation for juvenile green turtles from three developmental habitats along the east central coast of Florida. IRL = Indian River Lagoon, SWRR = Sabellariid worm rock reef, TSB = Trident Submarine Basin.

Comparisons of size specific growth rates were made between study sites for size classes with adequate samples. Significant differences in growth rates were observed for 30-40 cm green turtles between sites (ANOVA, $F = 20.932$, $P < 0.0001$). Green turtles in the 30-40 cm size class from the IRL site (3.8 cm/yr) grew significantly faster than those from the SWRR site (2.2 cm/yr; Tukey-Kramer Multiple Comparisons Test, $q = 6.266$, $P < 0.001$) and the TSB site (2.6 cm/yr; Tukey-Kramer Multiple Comparisons Test, $q = 8.483$, $P < 0.001$). No significant differences in growth rates were observed for this size class between the SWRR site and the TSB site (Tukey-Kramer Multiple Comparisons Test, $q = 1.754$, $P > 0.05$; Figure 7). Significant differences in growth rates were observed for 40-50 cm green turtles among sites (ANOVA, $F = 37.081$, $P < 0.0001$). Green turtles in the 40-50 cm size class from the IRL site (4.2 cm/yr) grew significantly faster than turtles from the SWRR site (2.5 cm/yr; Tukey-Kramer Multiple Comparisons Test, $q = 5.489$, $P < 0.001$) and the TSB site (1.6 cm/yr; Tukey-Kramer Multiple Comparisons Test, $q = 11.893$, $P < 0.001$). No significant differences in growth rates were observed for this size class between the SWRR site and the TSB site (Tukey-Kramer Multiple Comparisons Test, $q = 2.521$, $P > 0.05$; Figure 8).

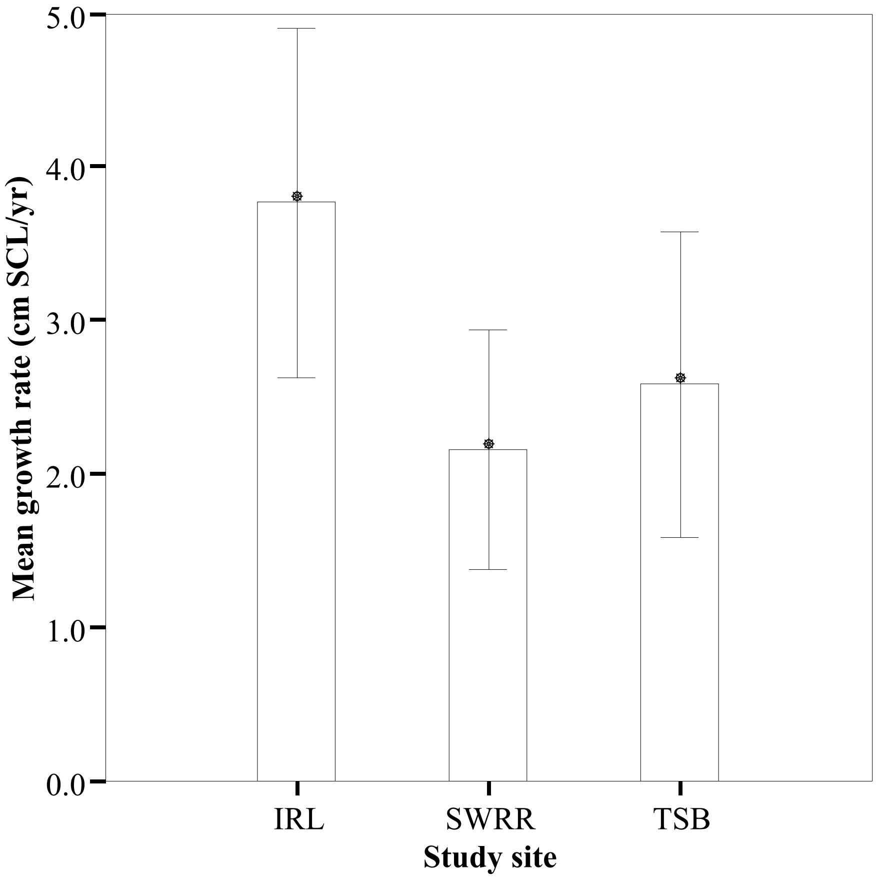

Figure 7. Mean growth rates (cm SCL/yr) ± 1 standard deviation of 30-40 cm SCL juvenile green turtles from three developmental habitats along the east central coast of Florida. IRL = Indian River Lagoon, SWRR = Sabellariid worm rock reef, TSB = Trident Submarine Basin.

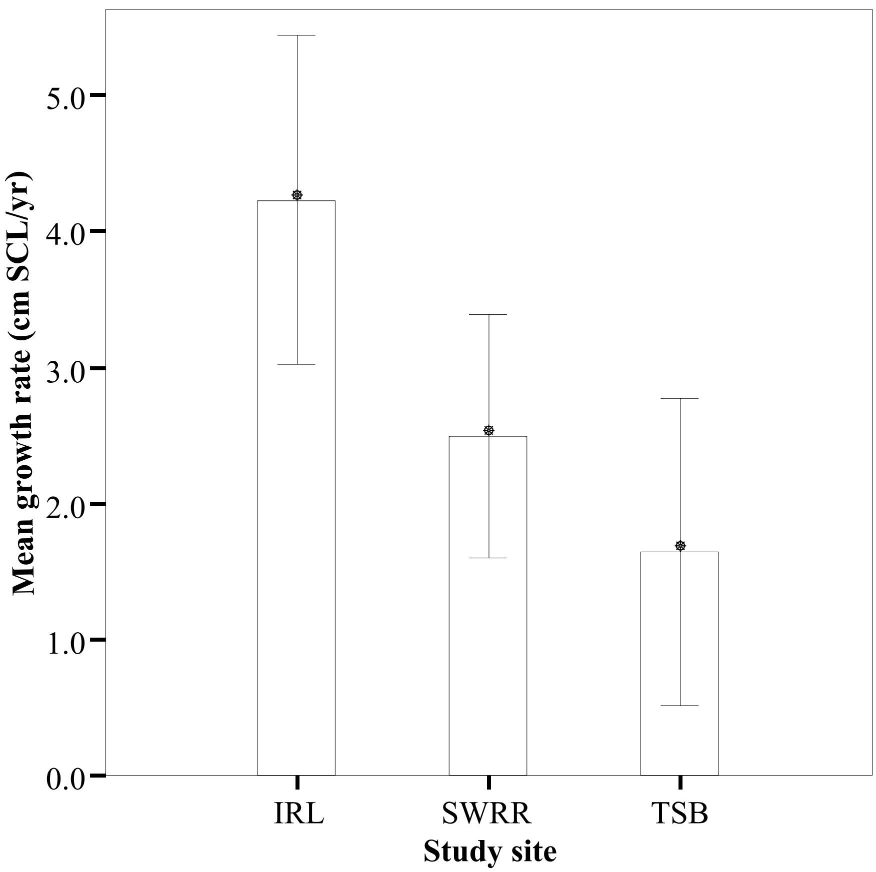

Figure 8. Mean growth rates (cm SCL/yr) ± 1 standard deviation of 40-50 cm SCL juvenile green turtles from three developmental habitats along the east central coast of Florida. IRL = Indian River Lagoon, SWRR = Sabellariid worm rock reef, TSB = Trident Submarine Basin.

Length-Weight Relationships

Length-weight relationships were determined using data from all initial capture juvenile green turtles for each study site (Figure 9). Length (cm SCL) and body mass (kg) were measured for 1599 juvenile green turtles from the IRL, 681 from the SWRR and 351 from the TSB. A regression of log-transformed mass (kg) on log-transformed length (cm SCL) yielded the following equations (Figure 10):

- IRL: Mass = 3.21·(SCL) – 4.20
  $R^2 = 0.9741$
- SWRR: Mass = 3.23·(SCL) – 4.22
  $R^2 = 0.9735$
- TSB: Mass = 2.90·(SCL) – 3.75
  $R^2 = 0.9305$

Regressions of the length-weight equations expressed logarithmically were tested for significant differences ($p < 0.05$) among study sites using an analysis of covariance (ANCOVA) test for homogeneity of slopes. There was a significant difference in the slopes of the lines among sites (ANCOVA, $F = 3.670$, $p = 0.026$). The slopes of the lines for IRL (slope = 3.21) and SWRR turtles (slope = 3.23) were nearly identical. However, the slope of the line for TSB turtles (slope = 2.90) was significantly different than the slope for Sabellariid worm rock reef turtles (slope = 3.23; LSD, $p = 0.008$). The slope of the line for Trident Submarine Basin turtles (slope = 2.90) was not significantly

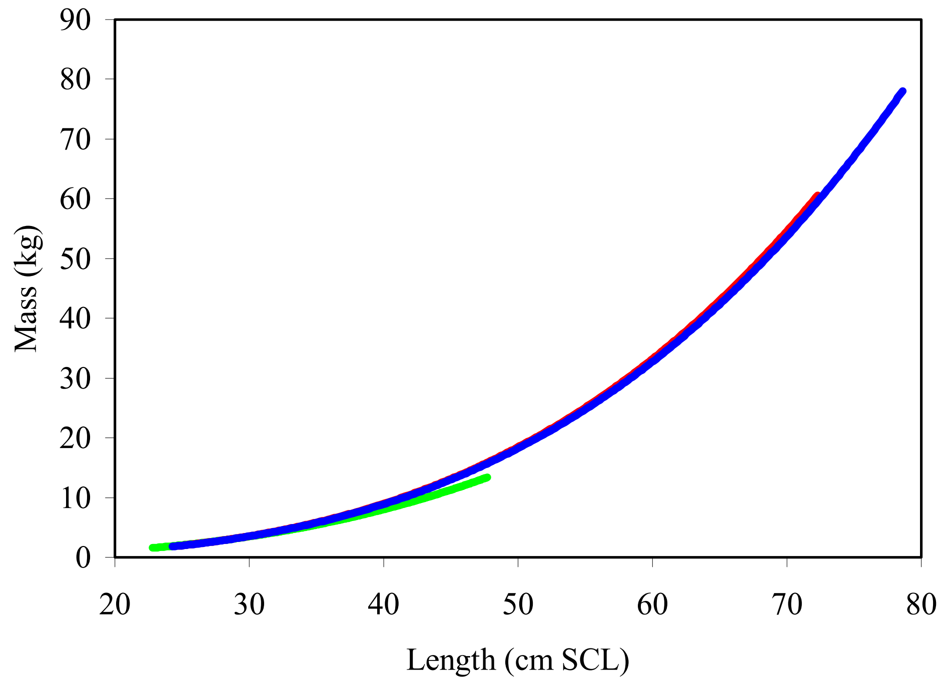

Figure 9. Length-weight relationships for all initial capture juvenile green turtles from three developmental habitats along the east central coast of Florida. Indian River Lagoon =■, Sabellariid worm rock reef =■, Trident Submarine Basin =■.

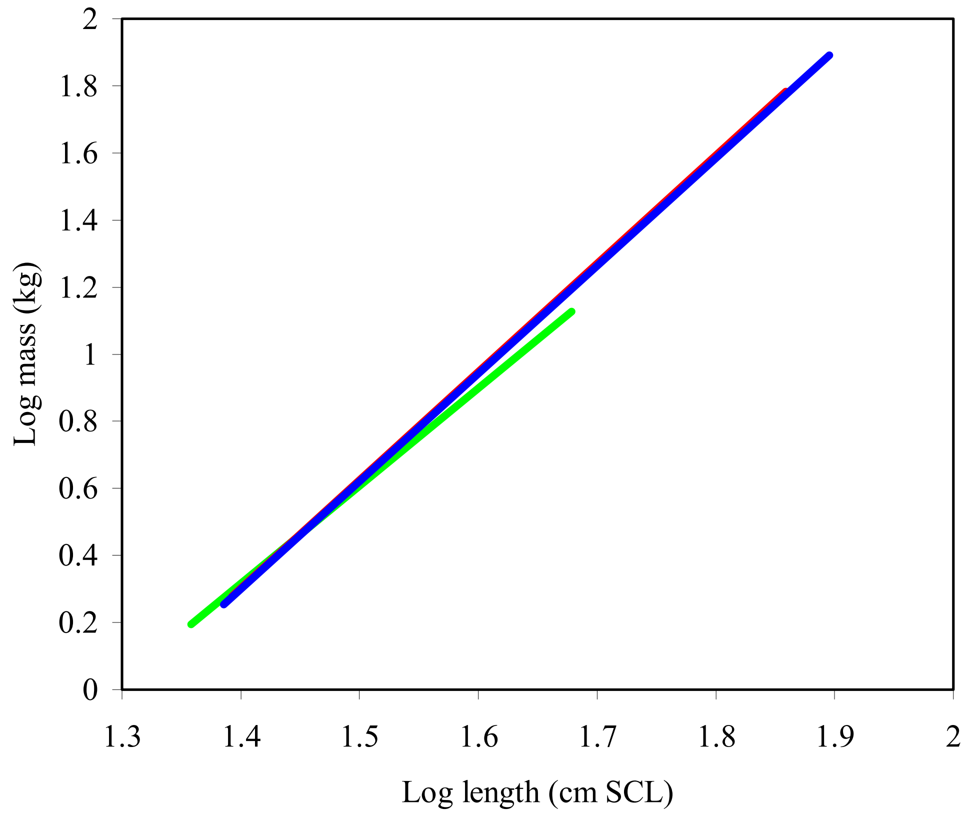

Figure 10. Log transformed length plotted on log transformed mass for all initial capture juvenile green turtles from three developmental habitats along the east central coast of Florida. Indian River Lagoon = blue, Sabellariid worm rock reef = red, Trident Submarine Basin = green.

different than the slope of the line for IRL turtles (slope = 3.21; LSD, p = 0.078), but that may be an artifact of sample size (Trident Submarine Basin, n = 351; IRL, n = 1599).

The length-weight curves were reconstructed using a sub-sample of the data. Since the size class distributions of green turtles from the IRL and SWRR sites were nearly identical, and the distribution at the TSB was skewed toward the smaller size classes (Figure 2), only SCL data for juvenile green turtles between 24 and 50 cm were used (Figure 11). SCL (cm) and body mass (kg) were measured for 1219 juvenile green turtles from the IRL site, 553 from the Sabellariid worm rock reef site and 342 from the Trident Submarine Basin site. A regression of log-transformed mass (kg) on log-transformed length (cm) yielded the following equations (Figure 12):

- IRL: Mass = 3.22·(SCL) – 4.21
  $R^2 = 0.9436$
- SWRR: Mass = 3.12·(SCL) – 4.05
  $R^2 = 0.9566$
- TSB: Mass = 2.90·(SCL) – 3.75
  $R^2 = 0.9305$

There was a significant difference in the slopes of the lines among sites (ANCOVA, F = 4.793, p = 0.008). The slopes for the IRL (slope = 3.22) and SWRR sites (slope = 3.12) were nearly identical and at $\alpha = 0.05$ the slopes were not significantly different from one another (LSD, p = 0.910). However, at $\alpha = 0.05$ the slope of the line for TSB turtles (slope = 2.90) was significantly different than the slopes of the lines for both the SWRR (slope = 3.12; LSD, $p = 0.006$) and IRL turtles (slope = 3.22; LSD, $p = 0.003$).

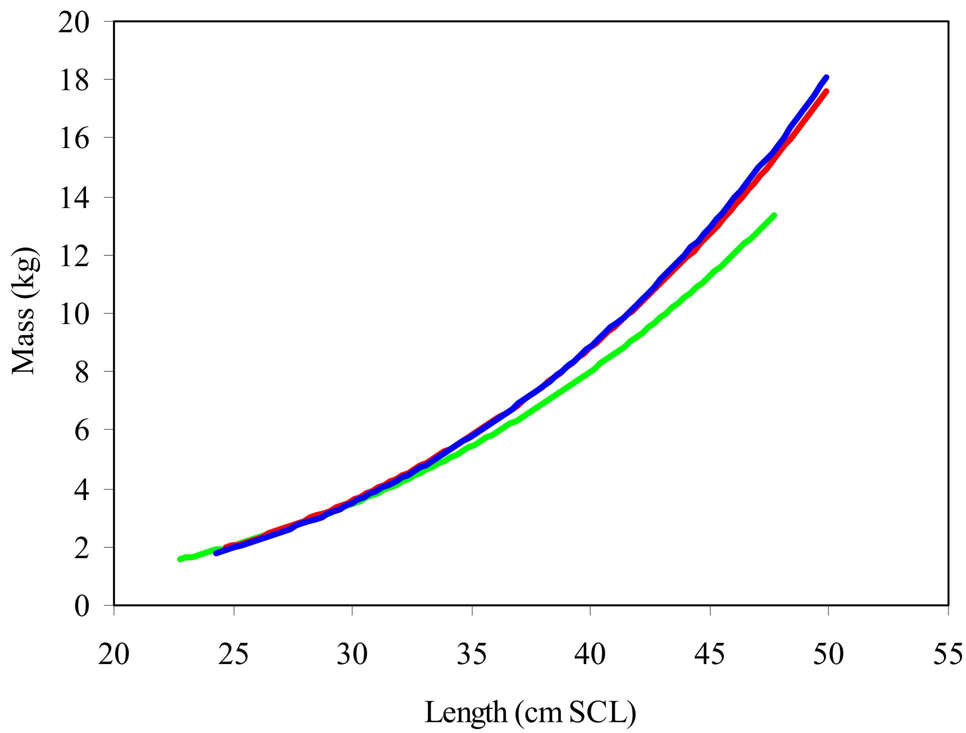

Figure 11. Length-weight relationships for initial capture juvenile green turtles ranging in size from 24 to 50 cm SCL from three developmental habitats along the east central coast of Florida. Indian River Lagoon =■, Sabellariid worm rock reef =■, Trident Submarine Basin =■.

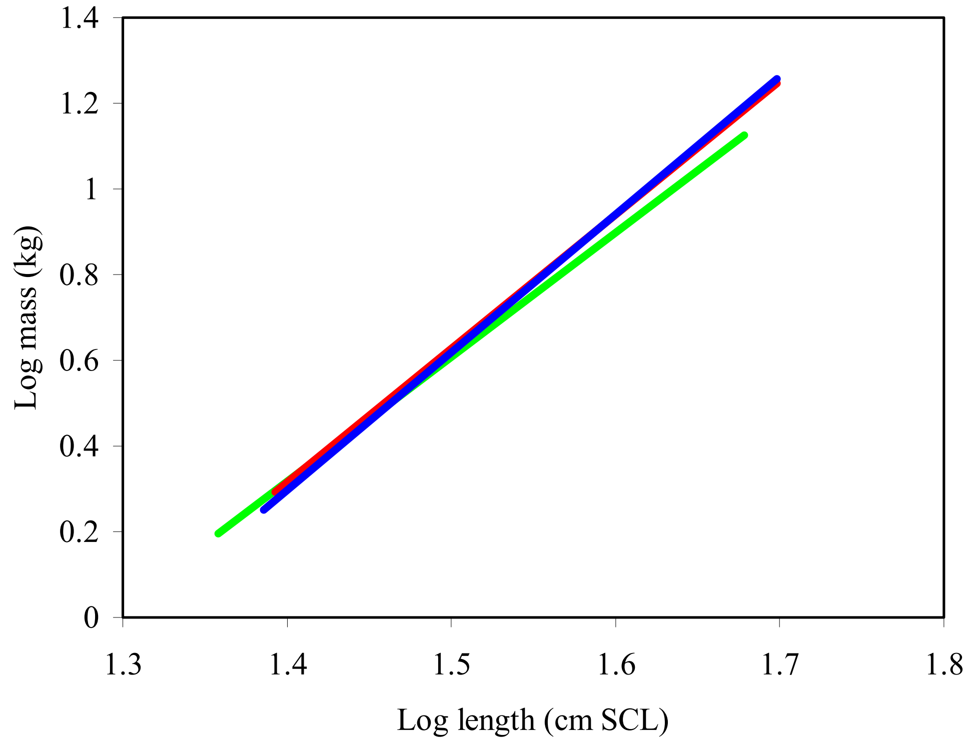

Figure 12. Log-transformed length (cm SCL) plotted on log-transformed mass (kg) for initial capture juvenile green turtles ranging in size from 24 to 50 cm SCL from three developmental habitats along the east central coast of Florida. Indian River Lagoon = ■, Sabellariid worm rock reef = ■, Trident Submarine Basin = ■.

DISCUSSION

The size-specific growth rates described for IRL, SWRR and TSB turtles are part of the first comparative study on growth rates of juvenile green turtles in the Atlantic Ocean. The comparative nature of this study offers insight into variability in growth rates in a small geographic region and among habitat types. Increased nest production and increased relative abundance of juvenile turtles (Ehrhart et al., 1996) may indicate that the Florida green turtle is recovering. As relative abundance of juveniles in coastal waters increases, further study of those growing aggregations will add to our understanding of immature stages.

Size-specific growth rates of juvenile green turtles have previously been described for populations along the east central coast of Florida (Mendonça, 1981; Zug and Glor, 1998; Bresette and Gorham, 2001). Early studies on growth were often hindered by small sample sizes and short recapture intervals (Mendonça, 1981; Shaver, 1994). The results from these early studies often led to inflated growth rates and unrealistic estimations of age at maturity. Determining growth rates of a long-lived species requires large data sets collected over a long period of time. This has become the trend in more recent studies on growth rates of green turtles (Limpus and Chaloupka, 1997; Bjorndal et al., 2000). Following that trend, this study provided long-term data and relatively large sample sizes for each study site. The results are compared to those from previous studies in the same location or a similar habitat.

Variability in growth rates of juvenile green turtles has been observed worldwide. Pacific green turtles tend to grow much slower than their Atlantic counterparts (Balazs, 1982; Limpus and Chaloupka, 1997; Zug and Glor, 1998). A comparative study of growth rates of immature green turtles at seven sites in the Hawaiian Archipelago showed that turtles in different locations within the region grow at different rates (Balazs, 1982). Differences in growth rates between populations and among individual turtles can be attributed to a variety of intrinsic and external factors. Sex, genotype, habitat type and quality, food type and quality, size, year, water temperature, density of turtles and other such factors may affect how turtles grow.

Differences Within Sites

Size-Specific Growth Rates

The effect of body size on growth rates has been determined for green turtles in Florida (Mendonça, 1981; Zug and Glor, 1998; Bresette and Gorham, 2001), the Bahamas (Bjorndal and Bolten, 1988), and Mexico (Seminoff et al., 2002). Juvenile green turtles from the IRL and Trident Submarine Basin also exhibited significant differences in size-specific growth rates. There were not enough samples from the Sabellariid worm rock reef to determine if significant differences were present.

In the Bahamas, small juveniles (30-40 cm SCL) grew faster than large juveniles (70-80 cm SCL; Bjorndal and Bolten, 1988). Accelerated growth in small juveniles (30-40 cm SCL) was also observed in Mendonça's study (1981) of IRL green turtles. Interestingly, the larger data sets used in this study and Zug and Glor's skeletochronology study (1998) yielded different results. Faster growth rates were documented for turtles between 50 and 60 cm SCL in both studies. Differences in growth rates between this study and Mendonça's (1981) study are mainly attributed to differences in sample size.

Fewer size classes were represented at the TSB. Turtles in the 30 – 40 cm size class grew faster than those in the 20 – 30 and 40 – 50 cm size classes. The smallest turtles (20 – 30 cm SCL) entering the TSB come from a pelagic environment and have to switch from an omnivorous to an herbivorous diet. The switch from omnivory to herbivory may take several weeks or months and result in slower growth rates for this size class. The 30 to 40 cm turtles have made the switch to herbivory and forage on the available resources (Redfoot, 1997). These turtles can ingest sufficient amounts of algae to grow faster. The largest turtles may not be able to ingest enough algae to sustain optimal growth and exhibit slower growth rates. This explanation is speculative and is not supported or refuted by scientific data.

Differences Among Sites

Forage Items

The three study sites along the east central coast of Florida, the IRL, SWRR and TSB, are ecologically distinct habitats. They primarily differ with respect to food type and abundance. Esophageal lavage was performed on hundreds of turtles for a study on diets of juvenile green turtles.

Diet analysis showed that IRL turtles primarily feed on red algae and more specifically drift algae (Holloway-Adkins, 2001). Sea grasses and drift algae are the predominant types of vegetation available for green turtles at the IRL site. Ten species of red algae made up 83.3% of the vegetation consumed by IRL green turtles (*ibid*.).

Over one hundred species of algae grow on Sabellariid worm rock reefs (Juett, 1976), but only a few species were consumed in large quantities by juvenile green turtles. Red algae made up the greatest proportion of the green turtles' diet on the reef, but the species were different from those in the IRL. Twenty-two species of red algae made up 81.2% of the vegetation consumed by these turtles (Holloway-Adkins, 2001).

The TSB is a man-made embayment and food is a limited resource. An algal mat, varying in density, covers the submerged portion of rock rip-rap lining the basin and is kept cropped short by foraging turtles. These turtles were often observed foraging on other food items like jellyfish, fish carcasses, floating vegetation, and green algae on floating docking stations. Seven species of red algae made up 82.4% of the vegetation consumed by TSB turtles (Redfoot, 1997; Holloway-Adkins, 2001).

Even though red algae are the main dietary component for juvenile green turtles in all three sites, the species of algae they consume and the availability of those species vary. The nutritional quality of the algal species has yet to be determined and may further explain differences in growth rates between sites.

Relative Abundance

Observed differences in growth rates could be attributed to the quality and quantity of food, combined with the effect of relative density of turtles at each site. Relative density was measured as catch per unit effort (CPUE). The mean CPUE for the IRL site was approximately five turtles per km/hour (Ehrhart, unpublished data). The mean CPUE for the SWRR site was approximately 12, but has reached as high as 148 turtles per km/hour (Holloway-Adkins et at., 2002). CPUE at the TSB could not be calculated since multiple methods of capture were employed. Instead, mark-recapture data were used to estimate population size after each netting session. Population estimates ranged between 35 and 121 with a mean of 61 ± 10 turtles (Ehrhart, unpublished data).

Differences in growth rates between the IRL site and SWRR site could be attributed to the density of turtles in each habitat. The first neritic habitat pelagic turtles encounter along the east central coast of Florida is Sabellariid worm rock reef. Both habitats provide an abundance of forage material for juvenile green turtles. The higher density of turtles at the SWRR site compared to the IRL site could be due to the fact that turtles have to find their way into the IRL through an inlet, one being Sebastian Inlet. As the population of juvenile green turtles continues to increase, and more growth data are collected, a study on density-dependent effects on growth rates would be possible. A study in the Bahamas showed that as the density of turtles increased over time, growth rates decreased, indicating density-dependent effects on growth rates (Bjorndal et al., 2000).

The TSB would be an ideal site for such a study. The combined effects of large number of turtles inhabiting the basin and the limited amount of food could explain why these turtles grew so slowly.

Length-Weight Relationships

Body mass is not usually included in growth rate studies of marine turtles because it is difficult to obtain accurate measurements in the field. However, the relationship between body mass and SCL can provide valuable information regarding the condition of turtles in a given habitat.

Linear growth analysis indicated that IRL turtles grew significantly faster than SWRR turtles. The length-weight curves however, were nearly identical. According to these results, a juvenile green turtle in the IRL will grow to a given SCL faster than a juvenile green turtle from the SWRR, but the two will obtain a similar mass at a given size. Turtles in these two sites are similar in proportion and body condition.

The overall condition of TSB turtles, with respect to body mass, is inferior to that of IRL and SWRR turtles. The IRL and SWRR reef appear to be high quality foraging grounds, whereas the TSB does not appear to be a high quality foraging area. TSB turtles do not increase in mass to the same degree as IRL and SWRR turtles. TSB turtles are underweight for their size. They are not gaining weight as quickly as turtles from the IRL or SWRR.

Comparisons with Previous Studies

The first published study on growth rates of IRL green turtles was by Mendonça (1981). Size-specific growth rates were calculated using the available data (Table 2). The pattern was a monotonic decline in growth rate as carapace length increased (Mendonça, 1981). The monotonic pattern has also been observed in juvenile green turtles in the Bahamas (Bjorndal et al., 2000), Caribbean (Boulon and Frazer, 1990) and Texas (Shaver, 1994). Interestingly, with a larger data set and greater time frame, the results from this study are different. A nonmonotonic growth rate pattern, a single peak in growth between 50 and 60 cm SCL, was observed. Nonmonotonic patterns in growth rates have been reported in Pacific green turtles in Mexico (Seminoff et al., 2002), Hawaii (Balazs et al., 1994), and Australia (Limpus and Chaloupka, 1997). This study is the first time a nonmonotonic pattern has been documented in Atlantic green turtles.

Another study of IRL green turtles used skeletochronology to estimate growth rates. Skeletochronology is an indirect method of growth analysis in which the periosteal layers in the humerus are examined to estimate past growth rates (Zug, 1990). A cold-stunning event in the northern reach of the IRL, Mosquito Lagoon, in 1989 provided carcasses of juvenile green turtles for this type of analysis. Growth rates and estimates of age were calculated for juvenile green turtles from the IRL system (Table 2; Zug and Glor, 1998). To validate the results of the skeletochronology study, growth rate estimates must be compared with direct growth measurements. In this case, both studies yielded a nonmonotonic pattern in growth and similar estimates of size-specific growth rates (Table 2).

A long-term study of juvenile green turtles from the Atlantic coastal waters off St. Lucie County, Florida was begun in 1976 at the St. Lucie Power Plant on Hutchinson Island. Turtles become entrained in the power plant's intake canal system and are captured in tangle nets within the canal (Bresette et al., 1998). Analysis of recapture data between 1994 and 1999 yielded growth rates for 80 juvenile green turtles (Table 3). The green turtles at the Hutchinson Island site utilize Sabellariid worm rock reef habitat that is part of the same reef system found off Sebastian Inlet, Florida. Growth rates reported for Hutchinson Island turtles (Bresette and Gorham, 2001) were nearly identical to growth rates reported in this study. Additionally, the larger number of growth increments per size class help validate the results of my study in which fewer growth increments were available.

Table 2. Mean growth rates (cm SCL/yr ± 1 standard deviation) of juvenile green turtles from the Indian River Lagoon using direct (mark-recapture) and indirect (skeletochronology) methods of analysis.

	Mark-recapture				Skeletochronology	
	This Study		Mendonça, 1981		Zug and Glor, 1998	
Size Class	Growth rate	n	Growth rate	n	Growth rate	n
20.0-29.9	--	--	--	--	3.1 ± 1.4	23
30.0-39.9	3.8 ± 1.1	41	5.3 ± 2.8	4	4.4 ± 2.5	70
40.0-49.9	4.2 ± 1.2	39	--	--	4.8 ± 2.1	68
50.0-59.9	4.7 ± 0.7	17	3.1 ± 1.8	2	5.3 ± 1.9	40
60.0-69.9	5.3	1	2.8 ± 1.2	3	4.1 ± 2.3	11
70.0-79.9	1.2	1	2.1 ± 1.1	3	1.3	1

Table 3. Mean growth rates (cm SCL/yr ± 1 standard deviation) of juvenile green turtles from Sabellariid worm rock reef habitats at Sebastian Inlet, Florida and Hutchinson Island, Florida (Bresette and Gorham, 2001).

	This Study Sebastian Inlet, Florida		Hutchinson Island, Florida	
Size Class	Growth rate	n	Growth rate	n
20.0-29.9	1.3	1	--	--
30.0-39.9	2.2 ± 0.8	10	2.3 ± 1.1	48
40.0-49.9	2.5 ± 0.9	8	2.6 ± 0.9	25
50.0-59.9	2.7 ± 0.1	3	2.7 ± 0.7	7
60.0-69.9	2.1	2	--	--

The Trident Submarine Basin provided an interesting setting to study juvenile green turtles. The animals present in this area were smaller than those studied in most sites around the world. In addition, the majority of turtles were long-term residents, which allowed for multiple recaptures of individuals over time. The only other published study with the size class distribution skewed towards the smaller size classes is from the Mansfield Channel, Texas (Shaver, 1994). Growth rates reported for those turtles were nearly four times greater than those of the TSB turtles (Table 4). Shaver (1994) acknowledged that growth rate values might have been inflated. Sixteen of the 18 recaptured turtles were captured at intervals less than one year and the time interval was during the warmest part of the year when growth rates may have been higher. Another possibility is that juvenile green turtles at the Mansfield Channel, Texas do grow extremely fast. As previously noted, the density of green turtles on a foraging ground plays an important role with respect to growth rates (Bjorndal et al., 2000). Only 43 juvenile green turtles were captured during three and half years and 435 hours of netting effort at the Texas site, a CPUE of 1.38 turtles/km-hr. The low relative density of turtles may enable those inhabiting the Mansfield Channel to grow faster since competition for resources would be reduced. The TSB supports a higher density of turtles and food appears to be a limiting resource, possibly leading to reduced growth rates.

Table 4. Mean growth rates (cm SCL/yr ± 1 standard deviation) of juvenile green turtles from the Trident Submarine Basin, Port Canaveral, Florida and Mansfield Channel, Texas (Shaver, 1994).

	Trident Submarine Basin, Port Canaveral, Florida		Mansfield Channel, Texas	
Size Class	Growth rate	n	Growth rate	n
20.0-29.9	2.1 ± 1.2	35	9.0 ± 3.2	4
30.0-39.9	2.6 ± 1.0	82	8.9 ± 2.7	13
40.0-49.9	1.6 ± 1.1	22	--	--
50.0-59.9	--	--	6.6	1

CONCLUSIONS

The results of this study were different from my initial hypotheses. Based on previous studies on growth in Atlantic green turtles, I hypothesized that small turtles (20-30 cm SCL) would grow faster than large turtles (> 30 cm SCL). This study showed that IRL and SWRR turtles in the 50-60 cm size class grew faster than turtles in the smaller size classes. At the TSB, growth rates peaked in the 30-40 cm size class, with smaller and larger turtles growing at slower rates.

I also predicted that juvenile green turtles from the IRL and SWRR would exhibit similar growth rates since both habitats have an abundance of algal food resources and the size class distributions are similar. In addition, I hypothesized that the mean growth rate at the TSB site would be greater than those at the IRL and SWRR sites since TSB turtles were smaller overall. IRL turtles grew at nearly twice the rate of those from the SWRR and TSB sites. Differences in size-specific growth rates among sites followed the same pattern. IRL turtles in the 30-40 and 40-50 cm size classes grew faster than their counterparts from the SWRR and TSB. Even though the linear growth analysis showed that IRL and SWRR turtles grew at different rates, the length-weight relationships for the two populations were nearly identical. Turtles in these two ecologically distinct habitats were in similar body condition. The TSB turtles, however, increased in mass slower than they increased in length. These turtles were essentially underweight and had poor body condition. It appears that the IRL and SWRR provide good foraging habitat for juvenile green turtles, whereas the TSB is a developmental habitat of poorer quality.

The results of this study have implications for the long-term management of the species. Variability in growth rates within and among sites indicates that generalizations about life history traits in one location should not be based on results from studies in another. Additional comparative studies on wild populations are needed to advance our understanding of growth in green turtles. Future studies on density effects and quality of food will further our understanding of the manner in which these factors affect growth rates. There is still much to learn about the influence of environmental and intrinsic factors on growth in juvenile green turtles.

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