GROWTH RATES AND BODY CONDITION OF JUVENILE GREEN TURTLES (*CHELONIA MYDAS*) IN DRY TORTUGAS NATIONAL PARK AND MARINE PROTECTED AREA

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. John Baldwin, Department of Biological Sciences, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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Dry Tortugas National Park (DRTO) consists of 261.8 km^2 in the Gulf of Mexico and provides protection to marine species facing a multitude of threats. Among the many species that utilize DRTO is the green sea turtle *(Chelonia mydas*). I examined seven years of capture-recapture data to determine how the body condition (using Fulton's equation, $K = M/L^3$) and growth rate for juvenile green turtles vary within, and among size classes in DRTO, and how those rates compare to similar populations in other locations. Body conditions ranged from 0.77 to 1.71 (mean 1.3 SD ± 0.16). Growth rates ranged from 2.5 to 9.9cm/yr (mean 5.5 cm/yr SD ± 1.25), which is a high growth rate for green turtles. Establishing growth rates and body condition for a specific population can provide insight into life history and health of that population, as well as important data for comparison to populations in other areas.

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INTRODUCTION

Green sea turtles (*Chelonia mydas*) are considered an endangered species by the International World Conservation Union (IUCN), and continue to face many threats that include degraded habitat quality, direct harvest of turtles and eggs, bycatch in marine fisheries (Eguchi et al. 2012, Wallace et al. 2013), and debris ingestion and entanglement (Lazar and Gracan 2011, Sul et al. 2011). While consequences of some threats are apparent, such as drownings in debris or on long lines, others can be more subtle and slower to manifest. For example, reduced habitat quality such as lessened availability and quality of foraging options may not cause quick fatalities, but rather result in slow growth and poor body condition. This makes scientific understanding of the growth rates and patterns of a specific species imperative for effective long-term conservation management of that species.

Vertebrates have a pattern of growth that is exhibited by an S-shaped or sigmoidal curve (Gerrard and Grant 2003). This type of growth curve is characterized by different relative rates of growth during different life stages (Lee and Werning 2008). At the bottom of the curve there is a period of exponential increase representing rapid growth in early life. Growth slows again as the animal approaches its species' asymptotic size, which is the maximum size to which it will grow (Fig. 1). In general, there are multiple benefits to rapid growth in early life. When animals are at their smallest, they are consequently more vulnerable to predation (Bolten 2003). Rapid growth is therefore beneficial in outgrowing this highly vulnerable stage. Additionally, there are reproductive benefits since rapid growth in the early years allows for reaching sexual maturity sooner and contributing to the breeding population (Bjorndal et al. 2013).

Taxa vary in the stage of development at which reproduction occurs because an animal's ability to reproduce is tied to its life history strategy. Birds and small mammals reproduce after they have reached asymptotic size, which they achieve in their first year of life. Conversely, reptiles and large mammals, which typically take longer to reach their asymptotic size, reproduce while they are still growing (Lee and Werning 2008, Fig. 2). This allows reptiles and other slow growing animals to contribute to population size more quickly than if they did not breed until after asymptotic size, which for some species can take decades. Being able to contribute to the population while they are still growing allows them to be less vulnerable to population disturbances (Colman et al. 2014).

Another important life history variable associated with the growth curve is habitat and resource use. Many animals shift habitats and thus resources during different stages of ontogeny. Examples include Atlantic salmon (*Salmo salar*, Erkinaro 2011), bluegill (*Lepomis macrochirus*, Werner and Hall 1988), largemouth bass (*Micropterus salmoides*, Olsen 1996), and five of the seven species of sea turtles, excluding leatherbacks (*Dermochelys coriacea*) and flatbacks (*Natator depressus*, Chaloupka and Musick, 1997, Bjorndal et al. 2013). Smaller animals inhabit areas where they are better able to escape predation, and forage availability is sufficient to reach a less vulnerable size. This is often in estuaries or shallow waterways for fish and offshore for sea turtles (Carr and Meylan 1980). For example many young fish hide in the complex structures of mangroves (Laegdsgaard and Johnson 2001) and post hatchling loggerhead (*Caretta caretta*) sea turtles closely associate with sargassum mats (Witherington et al. 2012, Musick and Limpus 1997). To successfully shift from one habitat to another is predicated on reaching a size at which they are less vulnerable to predation.

Although sea turtles fit the long lived and slow growing pattern, there is variation in growth parameters and their associations to life stages, both among and within species. The variation within species is evident when making regional comparisons. For example some species tend to reach a larger asymptotic size in one ocean than the other (Chaloupka and Musick 1997). Green turtles reach a larger asymptotic size in the Atlantic than they do in the Pacific, and leatherbacks reach a greater asymptotic size in the Pacific. Also, green turtles, loggerheads and hawksbills (*Eretmochelys imbricata*) in the Atlantic make their habitat shift from pelagic to neritic at smaller sizes than their cohorts in the Pacific (Chaloupka and Musick 1997).

Variation in growth rates between species has been linked to a variety of physiological and dietary influences. Leatherbacks are the fastest growing sea turtles (Davenport et al. 2009). This is reflective of their classification as mesotherms, rather than ectotherms as with the other six species of sea turtles. As a group, the rate of growth for mesotherms is between those of ectotherms (slower growing) and endotherms (faster growing) (Fig. 3, Grady 2014). Green turtles are the slowest growing sea turtles (Seminoff 2004), which may be attributed to being a primarily herbivorous species (Bjorndal 1982).

Despite being the slowest growing sea turtle, green turtles are the largest of the six hard shelled species, growing up to 120 cm long and over 181 kg in mass (Hirth 1997). Reaching that size takes decades, but as with all sea turtles, green turtle growth rates are fast during early years. Limpus and Chaloupka (1997) found that growth after sexual maturity for green turtles is negligible. Determining growth rates and parameters is dependent on data from wild populations, however, field studies of green turtles are complicated by the fact that they migrate in subtropical and tropical oceans throughout the world, and spend different stages of ontogeny in distinct habitats. Since green turtles are pelagic in their earliest years, and exhibit relatively slow growth after reaching maturity, the most practical time to conduct long term natural growth studies is during the post-recruitment developmental stage. This is the life stage at which juvenile green turtles form near-shore resident populations ranging from 25.3 to 82.3cm (Bjorndal et al. 2000).

Capture-recapture studies are the most often used for estimates of growth rate and size at sexual maturity (SSM; see Mendoncea 1981, Frazer and Ehrhart 1985). The variability in growth rates presented in these studies demonstrates that how quickly green turtles grow, and how soon they reach sexual maturity, is associated with location. There is a general trend of green turtles having higher growth rates in the Atlantic than the Pacific (Bjorndal et al. 2000), and there is substantial variability between study sites. McMichael et al. (2009) found a mean growth of 4.7 cm yr^{-1} straight carapace length (SCL) in Northwest Florida, whereas López-Castro et al. (2012) found a mean growth of just 2.3 cm yr^{-1} SCL in Baja California. Furthermore, Seminoff et al. (2002) determined that green turtles in the East Pacific had a size at sexual maturity (SSM) of 60.0-77.3 cm as measured by straight carapace length (SCL). Conversely, in the Northwestern Atlantic, Goshe et al. (2010) found SSM of mature green turtles was 84.8 to 94.9 cm SCL for males and 99.5 to 101.5 cm SCL for females. The variation that has been revealed in previous studies show the importance of determining growth rates for specific geographic groups, rather than presuming that all individuals in a metapopulation grow at the same rate, regardless of location or time frame.

In addition to spatial variation in growth rates, temporal patterns within study sites have emerged. Although green turtles grow more slowly with age, it is not always monotonic since green turtles may have periods of faster growth at intermittent size classes. Colman et al. (2015) found that juvenile green turtles in Fernando de Noronha, Brazil had non-monotonic growth with a peak at 50-60 cm CCL. The green turtles in the Great Barrier Reef went through to go through a growth spurt at 60 to 70 cm curved carapace length (CCL; Chaloupka et al. 2004)). It is unknown whether these growth spurts were age specific or instead occurred as a consequence of habitat conditions encountered by the green turtles.

In this study I examined seven years of recapture data (including mass and straight carapace length and width), for juvenile green turtles in DRTO, Florida, USA. I focused on juvenile green turtles, which are in the rapid growth period of their life histories. I determined both growth rate and body conditions were determined for all green turtles, and then compared individual metrics to mean growth rate and body condition of juvenile populations in other areas. Additionally, I compared these parameters across size and year. Determining whether or not there are significant correlations between these variables will help establish factors that contribute to growth rate and body condition at this site.

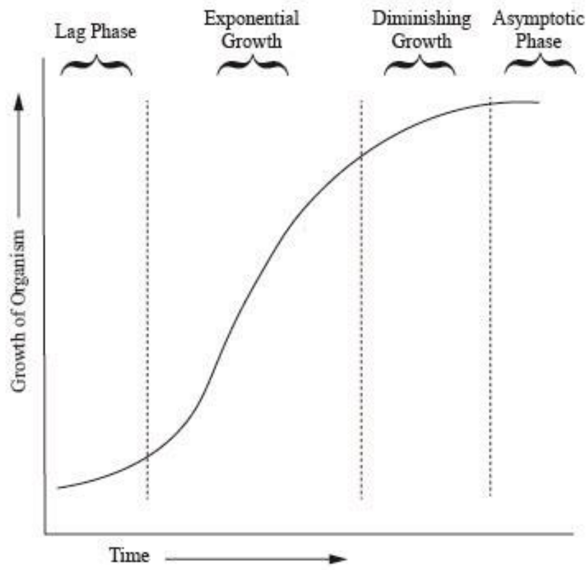

Fig. 1: A typical vertebrate growth curve demonstrates rapid growth early in life, followed by decreasing growth until asymptotic size has been reached. The green turtles in this study are still experiencing rapid growth.

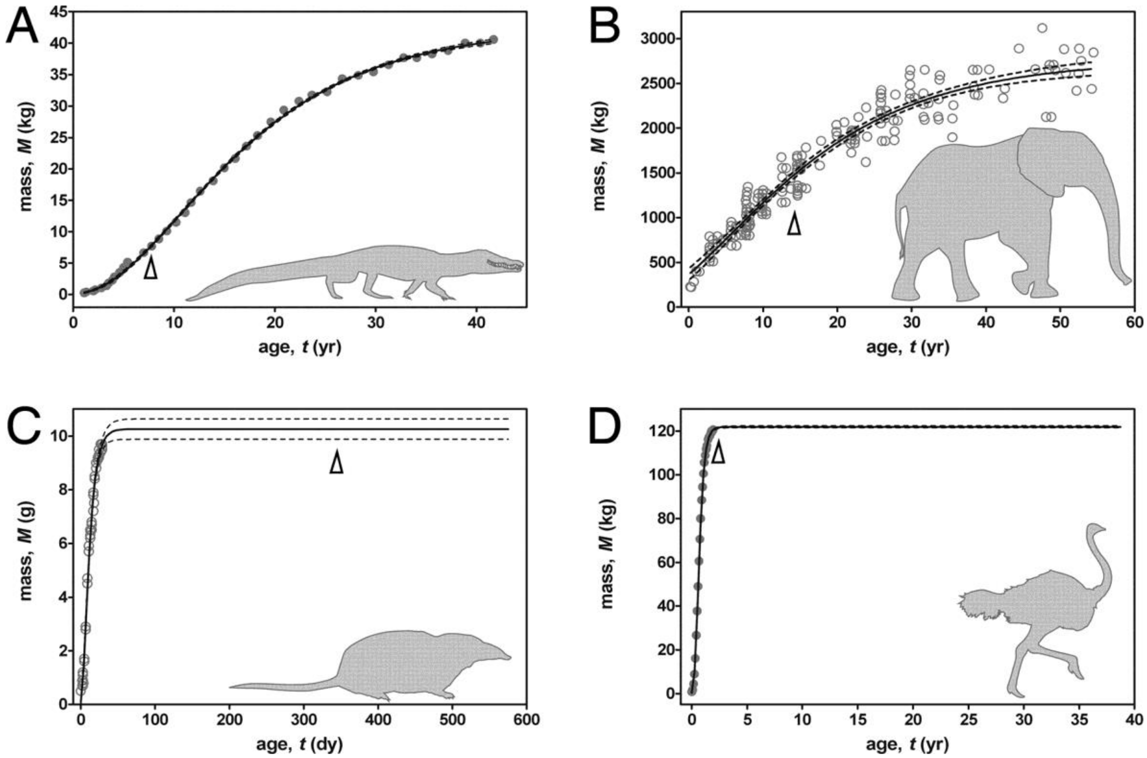

Fig. 2: Growth curves showing age at reproduction for fast growing animals, sorex and struthio, and slow growing animals, loxodonta and alligator (from Lee and Werning 2008).

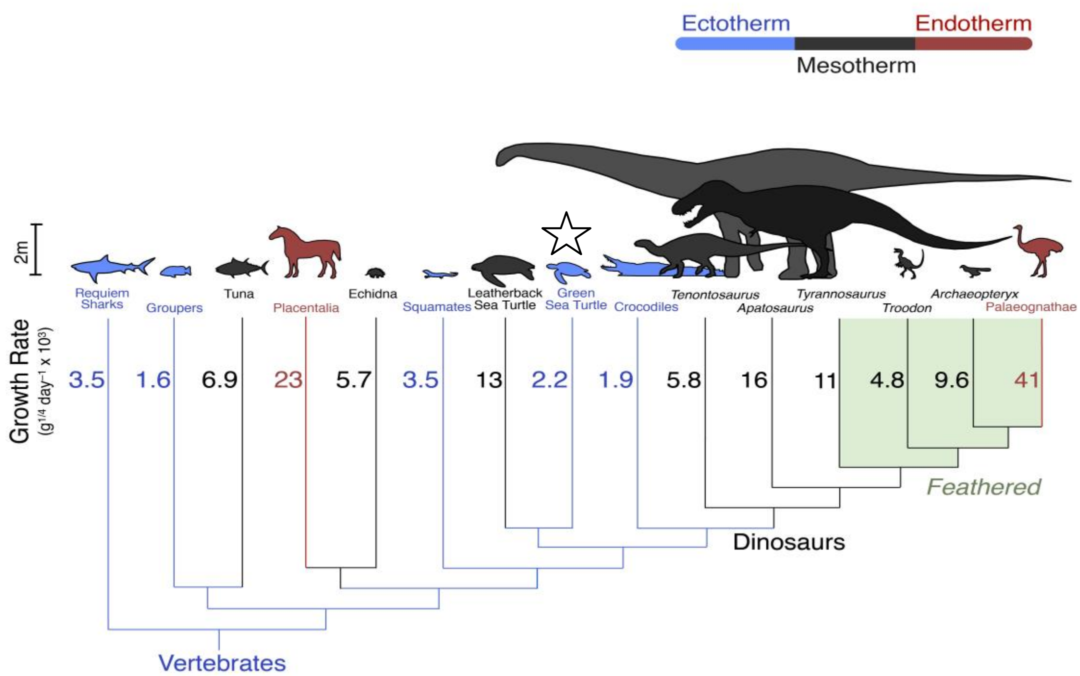

Fig. 3: Growth rates for various taxa showing differentiation between ectotherms, mesotherms, and endotherms (from Grady 2014).

METHODS

Study area

This growth study focused on a resident population of juvenile green turtles inhabiting the waters surrounding DRTO, a U.S. National Park approximately 160 square kilometers in area in the Gulf of Mexico. DRTO is mostly open water with seven small islands (Fig. 1). The park provides protection to marine species facing a multitude of threats from over harvesting to habitat degradation. Among the many species that utilize this area is the green sea turtle. Adult green turtles use the sandy islands of DRTO as nesting grounds and local submerged resources as resident foraging areas (Hart et al. 2013), whereas the surrounding waters are home to subadults and the resident population of juvenile green turtles being examined in this study (Fig. 4). In addition to providing protected foraging grounds, the waters surrounding DRTO islands provide multiple beneficial habitat features for green sea turtles, such as warm subtropical temperatures. This is a rare area of limited human disturbance to green turtles and their habitat.

Green Turtle capture

We captured green turtles using boats and dip netting or turtle- jumping also known as rodeo (Eckert et al. 1999). Smaller green turtles were generally dip-netted and larger green turtles were captured using the turtle-jumping or rodeo method in which the researcher jumps from the boat and catches the green turtle by hand.

Green turtle workup

Once green turtles were captured, we took standard measurements, identified them (from PIT tags and/or flipper tags if previously captured), and tagged or retagged them if needed. We used calipers to take measurements of straight carapace length (SCL) from the nuchal notch to the posterior-most portion of the rear marginal scutes (to the nearest mm), as well as straight carapace width (SCW) and height (SCH). We measured mass using spring scales to the nearest kilograms or pounds (depending on the scale) and then converted non-metric masses to kilograms by dividing by 2.2. We marked each green turtle with temporary paint to avoid recapture during the same sampling trip, and then released each one at the site of capture.

Data analysis

Analysis for this study focused on measurement data from recaptured juvenile green turtles, but incorporated other class sizes for comparison (Fig. 5). The juvenile size range is considered to be from the size at recruitment to the lowest estimated SSM in the northwestern Atlantic (within which our study area lies), which is 84.8cm SCL (Goshe et al. 2010). We calculated annual growth rate in cm using (SCL_{final} – $SCL_{initial}$)/recapture interval in years, as used by Seminoff et al. (2002). I then examined the relationship between growth rate and size at initial capture and midpoint size using regression.

I also looked at proportional (isometric versus allometric) growth. I determined the ratio of width to length and examined whether it altered significantly within the study group, and between the larger class sizes captured in DRTO. I also compared the ratios to hatchling dimensions using raw data obtained from a previous study (Scholl and Salmon 2014).

Another variable that may contribute to growth rate is the body condition index (BCI). Evaluation of body condition incorporates mass and SCL^3, and has been used in assessments of sea turtles and a variety of other reptiles such as *Crocodylus moreletii* (Mazzotti et al. 2012), and *Anolis gundlachi* (Schall 2000). I calculated each green turtle's BCI using Fulton's equation, $K = M/L^3$. I then used regressions to compare BCI to size, annual growth rate, and width to length ratio and analysis of variance (ANOVA) to evaluate the relationship between BCI and month of capture and BCI and year of capture. I performed all statistical tests using SigmaPlot statistical software version 11.0 (Systat Software, Inc., San Jose, California).

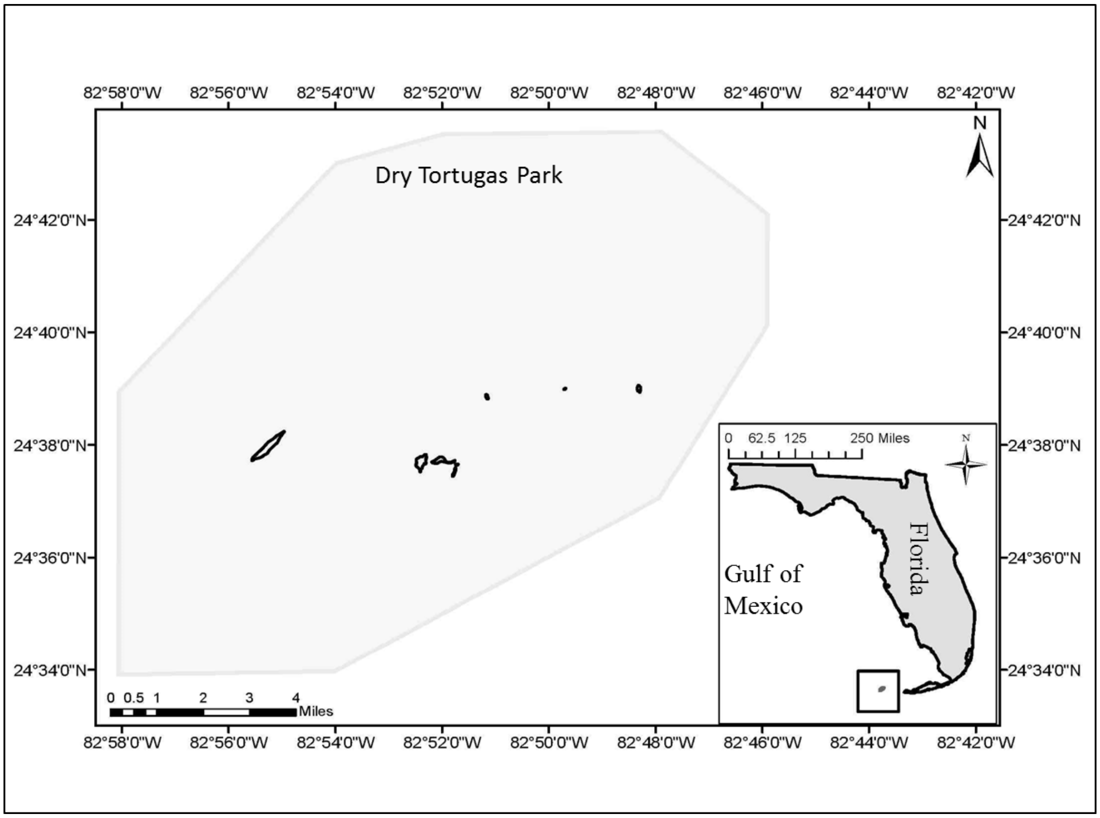

Fig. 4: Dry Tortugas National Park consists of 160 km^2, and lies in the Gulf of Mexico approximately 270 km west of Key West. The shaded area surrounding the islands represents the marine border of the park.

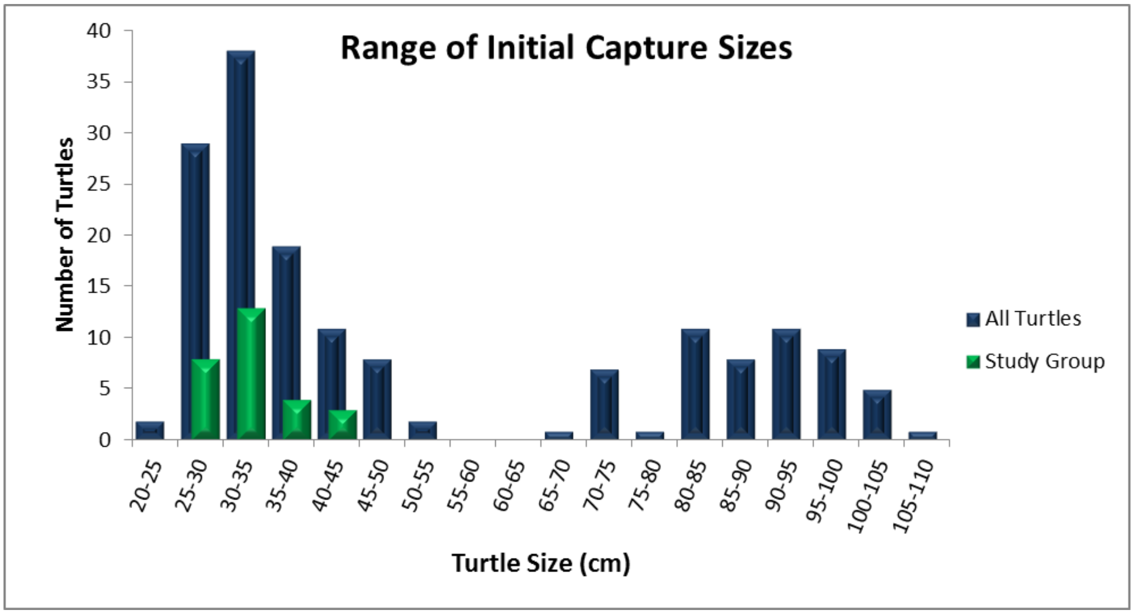

Fig. 5: Size histogram for Dry Tortugas green turtles captured in USGS study (range 22.3 to 111.7 cm). The turtles in this study ranged in size from 28.3 to 42.6 cm SCL at initial capture**.**

RESULTS

The record for analysis included 29 unique individuals, captured two to seven times (mean 4.5), with 128 total capture events. The mean annual growth rate in SCL for recaptured juvenile green turtles in DRTO ranged from 2.5 cm yr^{-1} to 9.9 cm yr^{-1} (mean 5.5 cm yr^{-1}, SD ± 1.25); this is a higher rate of growth than previously reported in other sampled populations both regionally and internationally (Table 1).

Green turtle size at initial capture ranged from 28.3 to 42.6 cm SCL (mean 33.2 cm, SD± 4.5). Size at initial capture was not significantly correlated with rate of growth (p=0.15; Fig. 6) or BCI (p=0.6623; Fig. 6). The midpoint size ranged from 30.1 to 51.2 cm (mean 38.6 cm, SD± 5.1). Midpoint size was correlated with growth rate (p=0.03; Fig. 6). Size at final capture ranged from 33.5 to 61.3 cm (mean 44.8 cm, SD± 6.5). The annual growth rate in mass ranged from 2.9 kg yr^{-1} to 10.5 kg yr^{-1} (mean 4.4 kg yr^{-1}, SD± 1.8).

BCI for the juvenile study group at initial capture varied from 0.8 to 1.7 (mean 1.3 SD ± 0.16). BCI was not significantly correlated with increased growth rate (p=0.544; Fig. 6). BCI at initial capture varied in all months and did not show a strong trend towards green turtles with higher BCI being caught in warmer months (p=0.119; Fig. 7). Mean BCI in May was 1.4, mean BCI in June was 1.3, mean BCI in July was 1.4, and mean BCI in August was 1.3. Body condition was significantly correlated with year (p=0.001), with the highest values in recent years, but it was not a continuous trend.

Juvenile green turtles in DRTO did not demonstrate allometric growth (Fig. 8); all green turtles were between 20% and 22% longer than they were wide. However, when plotted against the length to width ratios of green turtles in larger class sizes (from USGS data on DRTO sub-adults) and hatchlings (from Scholl and Salmon, 2014), it was demonstrated that green turtles do grow allometrically, resulting in different dimensions corresponding to life stages (Fig. 8).

Table 1: Growth rates in Atlantic basin studies of juvenile green turtles.

Study Site	Growth Rate (cm/yr)	Sample Size	Size Range	In/Near MPA	Citation
Northwest Florida	4.7 4.3	n=25 n=17	30-40 40-50	No	McMichael et al. 2008
Dry Tortugas	5.5	n=29	28-43	Yes	*Present study*
Culebra, Puerto Rico	5.1 6	n=6 n=9	30-40 40-50	Near	Collazo et al. 1992
US Virgin Islands	5 4.7	n=26 n=12	30-40 40-50	Near	Boulon and Frazer 1990
Brazil	2.6	n=542	Juveniles	No	Colman 2014

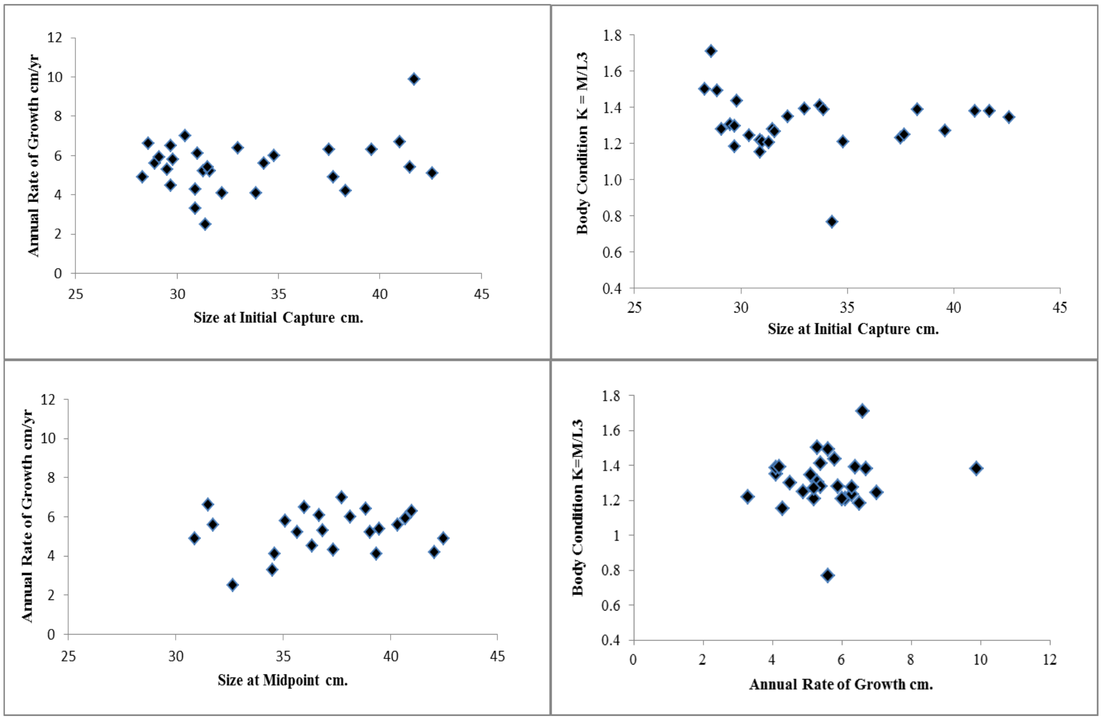

Fig. 6: Correlations of different metrics of captured green turtles: (top left) The initial sizes of recaptured juvenile green turtles ranged from 28.3 to 42.6 cm. The growth rates ranged from 3.3 to 9.9 cm/yr, and do not show an increase with size at initial capture. (top right) Size at initial capture was not significantly correlated with BCI. (bottom left) The midpoint size of recaptured juvenile green turtles ranged from 30.1 to 51.2cm. The growth rates in cm/yr do show an increase with larger midpoint sizes. (bottom right) The Dry Tortugas green turtles did not demonstrate a strong correlation between body condition and rate of growth.

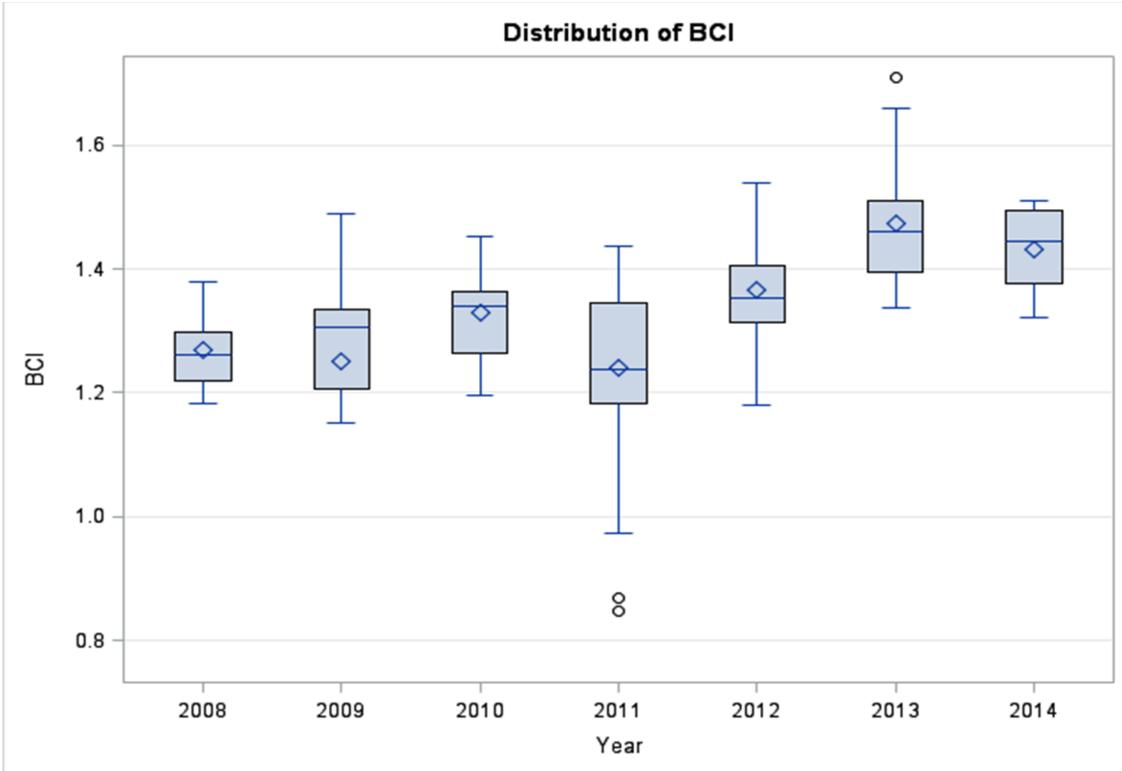

Fig. 7: Body condition index (BCI) at initial capture from 2008 to 2014. There was significant variation between years, and BCI was highest in more recent years, but it was not a continuous trend.

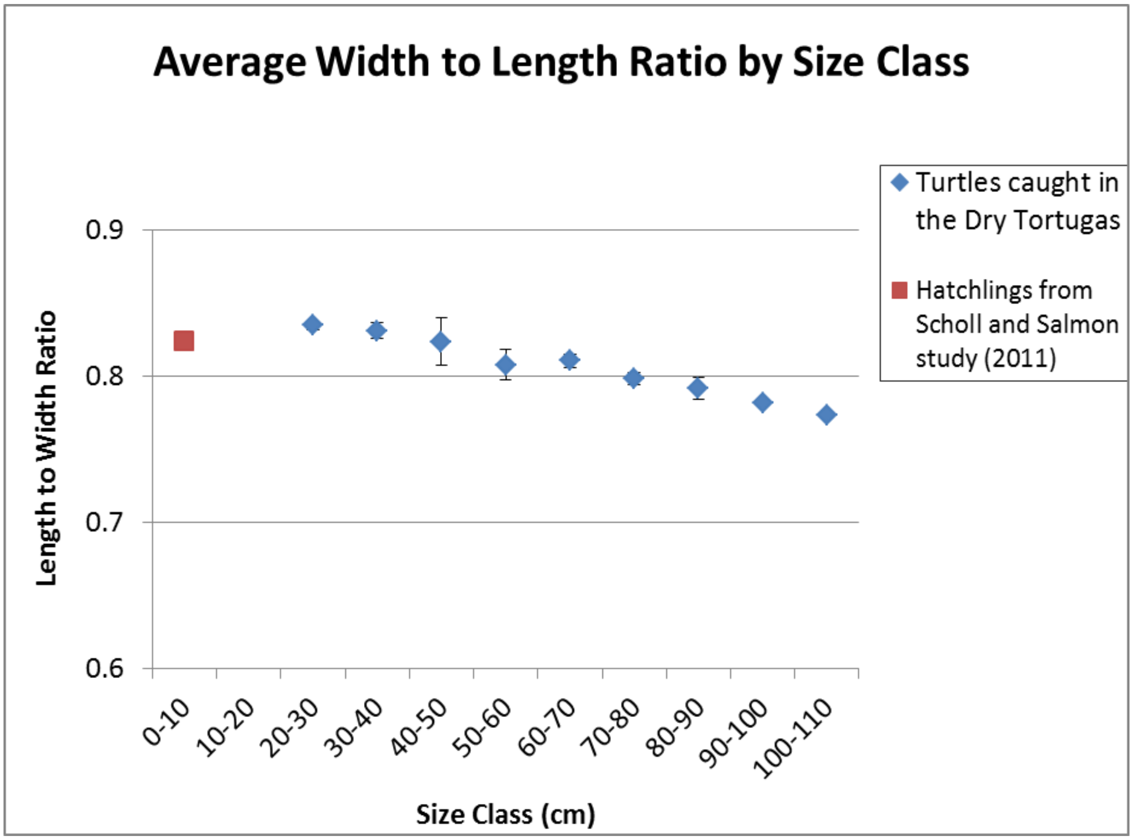

Fig. 8: Average length to width ratio by size class. Green turtles showed allometric growth, resulting in different dimensions corresponding to life stages.

DISCUSSION

Juvenile green turtles in DRTO exhibit high rates of growth. This is the case for both growth in SCL and growth in mass. The high rate of growth, and the small sizes at which some of the green turtles were first caught (indicating neritic recruitment at smaller sizes), are characteristic of Atlantic green turtles, but is relatively high even in comparison to other Caribbean studies. The high growth rate is also reflective of the presence of multiple favorable habitat features. In DRTO subtropical temperatures provide warm waters favorable to reptile growth. Additionally there is limited human disturbance to the sea grass beds that surround the islands and provide foraging for green turtles.

Unlike growth rate, mean body condition for juvenile green turtles in DRTO was not particularly high, but this may reflect the use of energy stores for growth. Saalfeld et al. (2008) found that growth could come at the expense of body condition in alligators. Body condition was correlated with year, however, indicating that variation in biological or physical features between years may affect the energy stores of the green turtles.

The high growth rates in comparison to other studies and the yearly variability in body condition show the importance of carrying out growth studies of green turtles in different locations with varied habitat parameters, as well as long term studies in locations where habitat quality has varied over time. This has particular current relevance because in March of 2015 the Fish and Wildlife Service (FWS) and the National Oceanic and Atmospheric Administration (NOAA) proposed that green turtles no longer have a single species-wide listing, but that 11 distinct population segments (DPS) be listed individually as either threatened or endangered. This proposal followed a petition from the Association of Hawaiian Civic Clubs to classify the Hawaiian green turtle as a DPS, and for delisting from the Endangered Species Act (ESA). The FWS and NOAA recognize the Hawaiian green turtle as the Central North Pacific DPS but denied the petitioned to delist it. Green turtles in North Atlantic would be listed in the ESA as threatened, not endangered, under the proposed rule (FWS and NOAA 2015).

Growth rate is an integral factor in determining a given population's vital rates, since it provides insight into population size projections by elucidating the time it takes individuals of the population to reach sexual maturity (and begin contributing to population size). Multiple studies have associated growth rates with reproduction such as with plaice (*Hippoglossoides platessoides*, Pitt 1975), Arctic char (*Salvelinus alpinus*, Grainger 1953), and both rainbow (*Oncorhynchus mykiss*, Scott 1962) and brown trout (*Salmo trutta*, Bagenal 1969). This is particularly important for green turtles due to their life history strategies. There are synergistic negative effects of unnaturally high mortality (whether from intentional or unintentional anthropogenic causes) for species like green turtles which exhibit slow growth and maturation, since these species consequently have slow recovery rates. Attaining a larger size at maturity may also increase fecundity in females and reproductive competitiveness in males.

Effective conservation of green turtles will reach beyond protecting a single species. Protecting this species is contingent upon protecting their habitat, which will consequently protect numerous species from multiple taxa since green turtles inhabit areas which are high in biodiversity. Furthermore, green turtles have high ecological importance in their ecosystems (Bjorndal and Jackson 2003). As large marine herbivores, they significantly affect the areas in which they are grazing (Thayer et al. 1984). As seas warm, green turtles may be particularly important in controlling the increases in algal growth in many areas which threatens reef health.

The physical and biological features of a habitat can influence green turtle growth rates (Avens and Snover 2013). Although resident juvenile green turtle populations are consistently in near-shore habitats where they can feed on sea grass and algae (Bjorndal 1980, Mortimer 1981) their foraging grounds can vary in the availability and quality of food, as well as other physical features such as temperature (Musick and Limpus 1997). The variation in intraspecies growth rate can be associated with food stress and temperature stress (Stearns and Koella 1986). Additionally, foraging grounds also vary in population density and which can have an inverse relationship with growth rate (Bjorndal et al. 2000). Comparisons between sites may clarify the relative importance of these factors.

Determining growth rates of resident green turtles in specific locations allows for comparison to other areas with different physical and biological features, and long term studies can help detect increases or decreases in the quality of that habitat. Establishing which habitat variables correlate to rapid growth may help elucidate the most important habitat features to manage for when compared to growth in areas with varying environmental and biological features. Future studies that elucidate the habitat features, such as abundance and quality of foraging material would be beneficial in determining why juvenile green turtles in DRTO exhibit high growth rates. Furthermore, a study of specifically what they are selectively consuming may be useful in determining why these green turtles are growing quickly. Herbivory in green turtles limits their productivity (Bjorndal 1982, 1985), and Bjorndal et al. (2013) found that a higher quality diet shortened the amount of time it took green turtles to reach size at maturity. Since researchers have found that juvenile green turtles in some areas consume significant amounts of non-plant items, such as jellyfish (Burkholder et al. 2011), it would be useful to know if the rapidly growing green turtles in this study exhibit this type of foraging behavior.

The allometric growth of green turtles over time should also be considered in future growth and body condition studies. Growth studies considering only carapace length, but comparing different size class may be less accurate if they do not account for differences in proportional width to length growth. Furthermore, the calculation of body condition using Fulton's K assumes isometric growth. Therefore, body condition analysis may also be less accurate if they do not considering changes in the width to length ratio in relationship to mass. Adjusting analysis of growth rate and body condition by considering allometric growth may improve the accuracy of these parameters and the information they provide about current, and future population dynamics.

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