

ASSESSMENT OF THE EFFECTS OF ROADS AND CRABBING PRESSURES ON  
DIAMONDBACK TERRAPIN POPULATIONS

by

ANDREW MICHAEL GROSSE

(Under the Direction of John C. Maerz)

ABSTRACT

The non-target effects of resource harvest and increasing encroachment on natural habitats due to development place increasing pressure on wildlife. The diamondback terrapin, *Malaclemys terrapin*, is a “high-priority” species for conservation in Georgia’s coastal habitats. Vehicle-induced mortality is proposed as an important factor contributing to *M. terrapin* population declines; however, bycatch in crab pots is linked to population declines in other parts of the species’ range. My thesis simultaneously examines the relationships between roads and crabbing pressures on *M. terrapin* abundance, sex ratio, and age-specific body size in Georgia. I found no relationship between terrapin abundance and road density or proximity; however, I did find a negative relationship between increasing crabbing activity and declining terrapin density among sites. Further, my research suggests crabbing activity is selecting for faster growth among terrapins. These results demonstrate that human activities such as crabbing can impact local abundance and demographics of terrapin populations.

INDEX WORDS: Bycatch mortality, Crabbing, Diamondback terrapin, *Malaclemys terrapin*, Roads, Turtle

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## DEDICATION

I would like to dedicate this thesis to my family, who showed me the wonders of nature, the significance of dreams and the love and support of a family. My mother, Peggy, the proudest parent on earth and the strongest woman I have ever met. My father, Chuck, who taught me to do what I love and love what I do. My brother, Alan, my biggest competitor and best friend. My sister, Rachel, who has inspired me “to learn how to dance in the rain”. My dog Blue, for convincing me to take the breaks necessary in order to finish this thesis. And my girlfriend Taylor, who continues to encourage, support, love and amaze me each and everyday.

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## CHAPTER 1

### INTRODUCTION

In recent years, the impacts of increased anthropogenic activities on aquatic turtle species have been given considerable attention by conservationists, research scientists and wildlife managers. Activities, such as recreation (Garber and Burger 1995; Hoyle and Gibbons 2000; Moore and Seigel 2006), commercial harvest (Seigel and Gibbons 1995), commercial fisheries (Roosenburg 2004; Cole and Helser 2001; Báez et al. 2007), development (Bowen et al. 2004) and road mortality (Steen and Gibbs 2004; Wood and Herlands 1997; Aresco 2005), have had significant impacts on turtle populations worldwide.

Since the beginning of the twentieth century, diamondback terrapin (*Malaclemys terrapin*) populations have been impacted by human activities. In the early 1900's, *M. terrapin* was considered a gourmet food item and many populations were diminished as a result of overharvest (Coker 1906). To help stabilize natural populations and supply the demand for turtle meat, the government established terrapin farms in Maryland and North Carolina (Hay 1917; Coker 1920; Barney 1922; Hildebrand and Hatsel 1926; Hildebrand 1928). By the 1930's, the demand for *M. terrapin* meat diminished and isolated populations were able to recover in many areas within their range.

However, as many *M. terrapin* populations began to rebound from past overharvesting, other coastal industries and residential development began to threaten their survival. The blue crab fishery was first recognized as a threat to terrapins in the early 1940's, when Davis (1942) expressed his concern over the incidental bycatch of turtles in crab pots. Since then, numerous

other studies have observed *M. terrapin* mortality in crab pots and have expressed concern over their impacts on the stability of *M. terrapin* populations throughout their range (Bishop 1983; Roosenburg 1991, 2000, 2004; Tucker 1993; Seigel and Gibbons 1995; Roosenburg et al. 1997; Wood 1997; Guillory 1998; Crowder et al. 2000; Hoyle and Gibbons 2000; Roosenburg and Green 2000; Cole and Helser 2001; Gibbons et al. 2001; Butler and Heinrich 2007; Dorcas et al. 2007; Wolak 2007). More recently, road mortality was proposed as a serious threat to *M. terrapin* populations. Roadways that run parallel and adjacent to the marshes and estuaries provide ideal nesting habitat for female *M. terrapin* during the spring and summer months (Brennessel 2006). However, as female *M. terrapin* search for suitable nesting sites they repeatedly come into direct contact with traffic, typically leading to injury or death (Seigel and Gibbons 1995; Wood and Herlands 1997; Roosenburg 2000; Brennessel 2006; Szerlag and McRobert 2005; Szerlag-Egger and McRobert 2007; Avissar 2006).

While both crabbing and road mortality may contribute to declines in *M. terrapin* populations, the two processes are likely to have different effects on the size and sex ratio of *M. terrapin* populations. For example, while crabbing tends to select for larger individuals by removing the smaller males and juveniles from the population, road mortality tends to remove adult female terrapins as they frequently must cross roadways in search of suitable nesting areas. The purpose of this thesis was to provide an evaluation of whether road, crabbing pressures or a combination of both, are influencing patterns of terrapin abundance in coastal Georgia, and to evaluate whether either activity is altering terrapin sex ratio, size, and age-specific size. Chapter 2 of this thesis focuses on the relationship between road density and proximity and crabbing activity levels on patterns of terrapin density along the Georgia coast. Chapter 3 focuses on the relationship between crabbing activity and patterns of terrapin age and age-specific size. This

research will help identify current anthropogenic factors influencing terrapin populations, and inform conservation priorities. The research also establishes a baseline of information about terrapin abundance at sites across the entire Georgia coast and how roads and crabbing activities currently predict terrapin densities among those sites. This will provide a contrast for future studies to track changes in terrapin demography that coincide with the rapidly increasing development of Georgia's coast.

### *Literature Cited*

- Aresco, M. J. 2005. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. *Biological Conservation* 123:37-44.
- Avissar, N. G. 2006. Changes in population structure of diamondback terrapins (*Malaclemys terrapin terrapin*) in a previously surveyed creek in southern New Jersey. *Chelonian Conservation and Biology* 5:154-159.
- Báez, J. C., R. Real, C. García-Soto, J. M. de la Serna, D. Macías and J. A. Camiñas. 2007. Loggerhead turtle by-catch depends on distance to the coast, independent of fishing effort: implications for conservation and fisheries management. *Marine Ecology Progress Series* 338:249-256.
- Barney, R. L. 1922. Further notes on the natural history and artificial propagation of the diamondback terrapin. *Bulletin of the United States Fishery Bureau* 38:91-111.
- Bishop, J. M. 1983. Incidental capture of diamondback terrapin by crab pots. *Estuaries* 6:426-430.
- Brennessel, B. 2006. *Diamonds in the Marsh: A Natural History of the Diamondback Terrapin*. Hanover and London: University Press of New England. 95 p.
- Butler, J. A. and G. L. Heinrich. 2007. The effectiveness of bycatch reduction devices on crab pots at reducing capture and mortality of diamondback terrapins. *Estuaries and Coasts* 30: 179-185.
- Bowen, K. D., Colbert, P. L., and Janzen, F. J. 2004. Survival and recruitment in a human-impacted population of ornate box turtles, *Terrapene ornata*, with recommendations for conservation and management. *Journal of Herpetology* 38:562-568.
- Coker, R. E. 1906. The natural history and cultivation of the diamond-back terrapin with notes of other forms of turtles. *North Carolina Geological Survey Bulletin* 14:1-67.
- Coker, R. E. 1920. The diamond-back terrapin: past, present, and future. *Scientific Monthly* 11:171-186.
- Cole, R. V. and T. E. Helser. 2001. Effect of three bycatch reduction devices on diamondback terrapin *Malaclemys terrapin* capture and blue crab *Callinectes sapidus* harvest in Delaware Bay. *North American Journal of Fisheries Management* 21:825-833.
- Crowder, L., K. Hart, and M. Hooper. 2000. Trying to solve a bycatch mortality problem: can we exclude diamondback terrapins (*Malaclemys terrapin*) from crab pots without

- compromising blue crab (*Callinectes sapidus*) catch? Final Report 00-FG-23. Fishery Resource Grant. pp 13.
- Davis, C. C. 1942. A study of the crab pot as a fishing gear. Publication number 53. Chesapeake Biological Laboratory, Solomons, Maryland.
- Dorcas, M. E., J. D. Willson and J. W. Gibbons. 2007. Crab trapping causes population decline and demographic changes in diamondback terrapins over two decades. *Biological Conservation* 137:334-340.
- Garber, S. D. and J. Burger. 1995. A 20-Yr study documenting the relationship between turtle decline and human recreation. *Ecological Applications* 5:1151-1162.
- Gibbons, J. W., J. E. Lovich, A. D. Tucker, N. N. Fitzsimmons and J. L. Greene. 2001. Demographic and ecological factors affecting conservation and management of diamondback terrapins (*Malaclemys terrapin*) in South Carolina. *Chelonian Conservation and Biology* 4:66-74.
- Guillory, V., A. McMillen-Jackson, L. Hartman, H. Perry, T. Floyd, T. Wagner and G. Graham. 2001. Blue crab derelict traps and trap removal programs. The Gulf States Marine Fisheries Commission No. 88:1-13.
- Hay, W. P. 1917. Artificial propagation of the diamond-back terrapin. *Bulletin of the United States Bureau of Fisheries* 24:1-20.
- Hildebrand, S. F. 1928. Review of the experiments on artificial culture on the diamond-back terrapin. *Bulletin of the United States Bureau of Fisheries* 45:25-70.
- Hildebrand, S. F. and C. Hatsel. 1926. Diamondback terrapin culture at Beaufort North Carolina. Department of Commerce, Bureau of Fisheries Economic Circular No. 60.
- Hoyle, M. E. and J. W. Gibbons. 2000. Use of a marked population of diamondback terrapins (*Malaclemys terrapin*) to determine impacts of recreational crab pots. *Chelonian Conservation and Biology* 3:735-737.
- Moore, M. J. C. and R. A. Seigel. 2006. No place to nest or bask: Effects of human disturbance on the nesting and basking habits of yellow-blotched map turtles (*Graptemys flavimaculata*). *Biological Conservation* 130:386-393.
- Roosenburg, W. M. 1991. The diamondback terrapin: Habitat requirements, population dynamics, and opportunities for conservation. Pages 237-244 *In* A. Chaney and J. Mihursky (eds). *New perspectives in the Chesapeake system: A research and management partnership. Proceedings of a conference.* Publication no. 137. Chesapeake Research Consortium, Solomons, Maryland.



- Roosenburg, W. M. 2000. Diamonds in the rough: diamondback terrapins in peril. *Reptilia* 23: 34-38.
- Roosenburg, W. M. 2004. The impact of crab pot fisheries on terrapin (*Malaclemys terrapin*) populations: Where are we and where do we need to go? In: Swarth, C., Roosenburg, W. M., Kiviat, E. (Eds.), *Conservation and Ecology of Turtles of the Mid-Atlantic Region: A Symposium*, Salt Lake City, UT, pp. 23-30.
- Roosenburg, W. M. and J. P. Green. 2000. Impact of a bycatch reduction device on diamondback terrapin and blue crab capture in crab pots. *Ecological Applications* 10:882-889.
- Roosenburg, W. M., W. Cresko, M. Modesitte and M. B. Robbins. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. *Conservation Biology* 11:1166-1172.
- Seigel, R. A. and J. W. Gibbons. 1995. Workshop on the ecology, status, and management of the diamondback terrapin (*Malaclemys terrapin*). Savannah River Ecology Laboratory, 2 August 1994: final results and recommendations. *Chelonian Conservation and Biology* 1:27-37.
- Steen, D. A. and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. *Conservation Biology* 18:1143-1148.
- Szerlag, S. and S. P. McRobert. 2005. Road occurrence and mortality of the northern diamondback terrapin. *Applied Herpetology* 3:27-37.
- Szerlag-Egger, S. and S. P. McRobert. 2007. Northern diamondback terrapin occurrence, movement, and nesting activity along a salt marsh access road. *Chelonian Conservation and Biology* 6:295-301.
- Tucker, T. 1993. Diamondbacks aren't forever: natural history of the diamondback terrapin. *South Carolina Wildlife* 40:6-10.
- Wolak, M. E. 2007. Ecology and Status of the Northern Diamondback Terrapin (*Malaclemys terrapin terrapin*) of the Lower Chesapeake Bay. Honor's Thesis, The College of William and Mary, Williamsburg. 71 p.
- Wood, R. C. 1997. The impact of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin*. Pages 21-27. In J. Van Abbema ed. *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles--An International Conference*. New York Turtle and Tortoise Society, New York, USA.
- Wood, R. C. and R. Herlands. 1997. Turtles and tires: the impact of road kills on northern diamondback terrapin, *Malaclemys terrapin terrapin*, populations on the Cape May peninsula, southern New Jersey. Pages 46-53. In J. Van Abbema editor. *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles--An International Conference*. New York Turtle and Tortoise Society, New York, USA

CHAPTER 2  
EFFECTS OF ROADS AND CRABBING PRESSURES ON DIAMONDBACK TERRAPIN  
POPULATIONS IN COASTAL GEORGIA

*Introduction*

Natural habitat loss and degradation within anthropogenically altered landscapes is the primary cause of wildlife population declines and species loss in the United States (Diamond, 1984; Venier and Fahrig, 1996; Mitchell and Klemens, 2000; Guthery et al., 2001). Growing urban populations also place significant pressures on exurban natural habitats through increasing land use and development (Thompson and Jones, 1999). Therefore, understanding how human activities contribute to the current and future status of wildlife is critical in developing effective, long-term wildlife conservation strategies.

In recent years, the effects of increased anthropogenic activities on aquatic turtle species have been given considerable attention. Activities such as recreation (Garber and Burger, 1995; Hoyle and Gibbons, 2000; Moore and Seigel, 2006), commercial harvest (Seigel and Gibbons, 1995), commercial fisheries (Cole and Helser, 2001; Roosenburg, 2004; Báez et al., 2007), development (Bowen et al., 2004) and vehicle-induced road mortality (Wood and Herlands, 1997; Steen and Gibbs, 2004; Aresco, 2005), have had significant impacts on turtle populations worldwide. Species such as diamondback terrapins (*Malaclemys terrapin*) have experienced declines throughout their range (Seigel and Gibbons, 1995; Dorcas et al., 2007). Anthropogenic activities in coastal ecosystems, such as crab harvesting, vehicle-induced road mortality, and habitat loss have been repeatedly identified as threats to *M. terrapin* populations (Seigel and

Gibbons, 1995; Wood, 1997; Roosenburg, 2004). In parts of the coastal southeastern U.S. that remain relatively under-developed, terrapin populations appear relatively abundant therefore, there remains the opportunity to study human impacts on *M. terrapin* populations and intervene before populations decline as they have elsewhere in the species' range.

In Georgia, *M. terrapin* is listed as a “high-priority” species for conservation efforts within coastal habitats (Georgia Department of Natural Resources, 2005). Factors proposed as contributing to *M. terrapin* population declines in Georgia include habitat conversion, fragmentation of populations, competition and predation from non-native invasive species, and vehicle-induced road mortality (Georgia Department of Natural Resources, 2005). In coastal areas, roads are often constructed on elevated land through or adjacent to marshes and the vegetation along roads is kept back by maintenance such that roadsides create attractive nesting areas for terrapins (Szerlag-Egger and McRobert, 2007). In other, more developed coastal regions within the species range, intense road mortality of terrapins is well-documented (Seigel and Gibbons, 1995). In recent years within Georgia, high numbers of female terrapins were documented killed along some causeways leading to Georgia's barrier islands. While it is inconceivable in light of extensive information on turtle life histories that documented levels of road mortality are not affecting terrapin populations, there has never been a published scientific study linking road mortality to terrapin population declines within Georgia or the larger species' range.

By contrast, crab pots are well-documented sources of terrapin mortality in other parts of the species range and have been linked to local and regional declines in terrapin abundance (Roosenburg et al., 1997, Hoyle and Gibbons, 2000, Roosenburg and Green, 2000, Dorcas et al., 2007); however, crabbing activities are not explicitly identified by Georgia's State Wildlife

Action Plan as a factor threatening terrapin populations. Roosenburg et al. (1997) demonstrated that bycatch in crab pots is biased toward male and juvenile terrapins. Mature female terrapins are generally too large to enter crab pots. The removal of males and juveniles can be detrimental to a population of turtles and other long-lived organisms by altering sex ratios and reducing recruitment of juvenile females to maturity (Dorcas et al., 2007).

Although both crabbing and vehicle-induced mortality may affect terrapin population declines, the two processes are likely to have different effects on the size and sex ratio of *M. terrapin* populations. Vehicle-induced mortality is known to disproportionately affect female turtles (Gibbs and Shriver, 2002; Gibbs and Steen, 2005; Szerlag and McRobert, 2006); so it is postulated that declines in turtle populations related to vehicle mortality should be increasingly male biased. On the other hand, if crabbing activities have a larger effect on terrapin populations, then populations impacted by crabbing activities should be increasingly female biased and have a greater proportion of larger turtles (Szerlag and McRobert, 2006; Dorcas et al., 2007). Evaluating the relative importance of these two causative factors is important to developing effective, long-term conservation strategies to protect remaining *M. terrapin* populations.

My objectives were to assess the independent and interactive effects of road density and crabbing pressures on the abundance and population structure of *M. terrapin* populations on Georgia's coast. Specifically, we tested the hypotheses that 1) *M. terrapin* density has a negative relationship with the road density or proximity and crabbing activity, 2) terrapin sex ratio (male:female) is positively related to road density or proximity and negatively related to crabbing activity.

### *Materials and Methods*

## Study Species

*Malaclemys terrapin* is the only strictly estuarine species of emydid turtle found in North America (Ernst et al., 1994). Seven sub-species inhabit the brackish tidal zones from Cape Cod, Massachusetts south around the Florida peninsula and west around the Gulf of Mexico to Texas (Ernst et al., 1994). The Carolina terrapin, *M. t. centrata*, is the species found in Georgia's brackish tidal marshes. The subspecies is sexually dimorphic with adult females growing significantly larger than adult males (Ernst et al., 1994). In Georgia, terrapins breed in April and females nest from mid-May through mid-July.

## Site Selection

Study sites were chosen using a stratified random design, using two parameters easily quantified using Geographic Information Systems data (GIS): road density and number of crab pots. Road density was determined using existing GIS data to measure kilometers of road within 0.5 km on each side of tidal creeks and standardized to a density measurement ( $\text{km}/\text{km}^2$ ). Geo-referenced crabbing activity from 2003 to 2006 (time period for which state records are available) was obtained from the Georgia Department of Natural Resources, Coastal Resources Division (Brunswick, GA). Based on observed distributions among all creeks, we considered high road densities  $>2.00$  km of roads within 500 m of each creek, and high crabbing activity  $>0.5$  crab pots/km of creek. We assigned 138 creeks into one of four treatments based on their corresponding road density and crabbing pressure: high roads-no crabbing, high roads-crabbing, low roads-crabbing, and low roads-no crabbing (Fig. 2.1). We then randomly selected six tidal creeks from each of the four classes. If, we failed to capture a terrapin during the first two capture (sampling) periods, we considered terrapins absent from the site (density = 0), and we selected another site within the same class to sample. In addition, we sampled the causeway to

Jekyll Island at the request of GA DNR. The Jekyll Causeway is a known hotspot for terrapin mortality (>250 nesting females annually; Holcomb et al. unpublished data).

Because existing GIS road density layers included all paved surfaces in Georgia (e.g. driveways, subdivisions, parking lots), and was therefore not necessarily indicative of vehicular pressure, we additionally measured the distance (km) to the closest ‘relevant’ road from each creek. Specifically, we examined each creek using digital photographs and used our best judgment as to the closest road that could sustain traffic (i.e. higher traffic volume streets, and not driveways or subdivision roads). We took into account barriers, such as sea walls, that may influence the ability of terrapins to access a road (Fig. 2.2). Once we determined the nearest relevant road, we classified all sites as being proximate (within 1.2 km of a road) or distant (> 2.3 km from the nearest road). We also attempted to generate traffic volume data for our relevant roads; however, AADT (annual average daily traffic) data were not available for many of our roads, and AADT may not reflect seasonally relevant measures such as high traffic volumes on causeways to barrier island beaches during the peak periods of terrapin nesting activity (May-July). We also verified our measure of crab pot density with direct counts of crab pots during our sampling. We used actual crab pot numbers in our analyses and based on observed patterns of crabbing activity, further refined crabbing classifications to no crabbing, low crabbing (1-2 pots per creek; only 1 creek had 2 pots), and high crabbing (3 or more pots per creek).

### Estimating Terrapin Density

We used individual mark-recapture to estimate terrapin density. We seined each creek, using two 10 m, 2.54 cm mesh seines with a bag, following the methods of Dorcas et al. (2007).

We did not use trammel nets during this study. Seining began each day immediately prior to low tide and seines were pulled from the start of each sampling area and continued until we reached the end of the creek, occasionally pulling the seines onto the mud bank to remove captured *M. terrapin* and bycatch. Depending on width and depth of creeks, seines were either pulled in tandem or side-by-side to maximize the area sampled. Each creek was seined up and back during each visit. Each creek was seined at low tide every 20 days between April 1<sup>st</sup> and June 30<sup>th</sup>, for a total of five mark-recapture periods per creek. This time period is the most effective for capturing in the study region (Gibbons et al., 2001). Following capture, all turtles were sexed based on position of the cloaca on the tail and head allometry, measured (carapace length, plastron length, shell width and depth), weighed (g), ‘aged’ by counting scute rings (Sexton, 1959), and uniquely marked using marginal scute notches (Cagle, 1939).

Because some creeks with few terrapins yielded no recaptures for one or both sexes, we could not conduct individual mark-recapture estimates for each creek. Therefore, we assumed that terrapin behavior with regard to capture and recapture probabilities were similar among creeks. We pooled all data into two data sets, one for males and one for females, and then we used each data set to estimate capture and recapture probabilities for each sex. We used Program CAPTURE (White and Burnham, 1999) to determine the most appropriate model for measuring sex-specific terrapin capture probabilities. We used sex-specific capture probabilities and the mean number of each sex captured over the 5 sampling periods to generate male and female closed population abundance estimates for each creek. We summed these estimates to generate a total density and sex ratio for each creek.

### Statistical Analysis

We conducted two sets of analyses to test our hypotheses. First, we used ANOVA to test the hypotheses that terrapin density was negatively related to crabbing activity and proximity to a road. We used road proximity (proximate or distant) and crabbing activity (none, low or high) as fixed factors. We used the same model to test the hypotheses that terrapin male:female sex ratio was positively related to road density or proximity and negatively related to crabbing activity. We also used generalized linear models combined with model selection (Akaike's Information Criterion, AIC) to examine specific linear relationships among crabbing, road density and proximity measures to terrapin densities and sex ratios. In addition to providing an additional test of hypotheses, linear models may be useful for management purposes in relating specific habitat measures to terrapin population metrics. Density estimates were square root transformed to meet the assumption of homogeneity of variance, and we used a  $\log_{10}(\text{ratio} + 1)$  transformation for sex ratio analyses. Finally, as an additional test of whether crabbing was affecting size distributions of terrapins, we used a one-way ANOVA to compare percentage of *M. terrapin* less than 107 mm plastron length among creeks with different crabbing activity classifications. All analyses were conducted in STATISTICA v8.0 (StatSoft, Inc., Tulsa, OK).

### *Results*

In five visits to each of 12 pre-selected tidal creeks during the summer of 2007, 977 *M. terrapin* were captured, consisting of 783 individuals. Similarly, in five visits to 14 pre-selected tidal creeks during the summer of 2008, 1028 *M. terrapin* were captured, consisting of 764 individuals. In total, during both sampling periods (2007 = April 1<sup>st</sup> to June 24<sup>th</sup> and 2008 = April 1<sup>st</sup> to June 26<sup>th</sup>), 2005 *M. terrapin* were captured, consisting of 1547 individuals. A complete summary of numbers of terrapins capture by creek as well as descriptions of the



locations of each creek are given in Appendix A. The mean number of *M. terrapin* captured in each visit was 12 (range = 0-175, SD = 22.7,  $n = 153$ ). Overall captures were male biased, with 77% males and 23% females. Over the course of this study, we had opportunity to observe 87 terrapin road mortalities, 99% of which were nesting females. We also observed 153 terrapins, 10% of all terrapins observed in study creeks, drowned in crab pots within study creeks. 83% of drowned terrapins were males, and the mean plastron length of drowned terrapins was 107 mm (median = 102 mm; 25% - 75% quartiles = 97 – 110 mm).

Terrapin density declined significantly with increasing crabbing activity (MS = 417.045,  $F_{1,25} = 9.425$ ,  $P = 0.005$ ; Fig. 2.3), but was not explained by proximity to a road (MS = 7.568,  $F_{1,25} = 0.171$ ,  $P = 0.683$ ). There was no measurable interaction between crabbing activity and road proximity (MS = 2.230,  $F_{1,25} = 0.050$ ,  $P = 0.824$ ; Fig. 2.3). Sex ratio was not measurably related to crabbing activity (MS = 0.082,  $F_{1,25} = 1.164$ ,  $P = 0.219$ ; Fig. 2.3), road proximity (MS = 0.135,  $F_{1,25} = 2.667$ ,  $P = 0.118$ ), or an interaction between the two factors (MS = 0.110,  $F_{1,25} = 2.180$ ,  $P = 0.155$ ). Generalized linear models results based on actual measures of crabbing activity and road density or distance to the nearest road were consistent with ANOVA results. The best model based on AIC included the single factor of number of crab pots in the creek. This model was statistically significant and showed a negative relationship between the number of crab pots and terrapin density (Likelihood ratio Chi-square = 9.060,  $df = 1$ ,  $P = 0.003$ ). The model including both number of crab pots and distance to the nearest road was within 2 AIC of the top model and also significant (Likelihood ratio Chi-square = 9.244,  $df = 2$ ,  $P = 0.010$ ); however, only the number of crab pots was identified as a significant factor in that model (Wald statistic = 5.625,  $P = 0.018$ ; Fig. 2.4). Distance to the nearest road was not a significant factor (Wald statistic = 0.152,  $P = 0.696$ ). The best model for predicting sex ratio only included crab

pot number; however, that model was generally indistinguishable from models including multiple factors and was not statistically significant (Likelihood ratio Chi-square = 1.823, df = 1, P = 0.177). The model that included both crab pot number and distance to nearest road was not significant (Likelihood ratio Chi-square = 2.499, df = 2, P = 0.287), and neither crab pot number (Wald statistic = 2.073, P = 0.150) or distance to nearest road (Wald statistic = 0.683, P = 0.409) was significant within the model (Fig. 2.4). Finally, the percentage of terrapins that were less than 107 mm plastron length tended to vary between creeks with and without crabbing activity (MS = 556.05;  $F_{2,21} = 2.816$ ; P = 0.083; Fig. 2.5). It is clear (Fig. 2.5) that the mean percentage of terrapins below 107 mm plastron length is lower among creeks with crabbing activity, though it does differ between creeks with high or low crabbing activity. When crabbing activity classes are combined, the difference in mean percentage of terrapins below 107 mm plastron length between creeks with and without crabbing activity is statistically significant (MS = 1110.23;  $F_{2,21} = 5.887$ ; P = 0.023).

### *Discussion*

In its State Wildlife Action Plan, Georgia identified road mortality as a significant factor impacting the conservation of diamondback terrapins in coastal Georgia. Our study showed no measureable relationship with road density or the distance to the nearest relevant road and current patterns of terrapin abundance among tidal creeks along the Georgia coast. Georgia has a relatively rural coastal region with several barrier islands with little or no vehicle traffic. Sixteen of the 29 randomly selected sites we studied were located more than 2.3 km from a biologically relevant road. Therefore, it is very possible that road mortality is not a factor affecting current population patterns across the Georgia coast. However, we caution that this does not mean that

road mortality may not be a significant factor contributing to local population declines or that road mortality will not be an increasing factor with increasing coastal development. We note that while road density or proximity are not clearly linked to the current abundance of terrapins statewide, the 3 creeks we studied within 30 m of a road all had density estimates below the median value for all sites. There is ample evidence of terrapin mortality on coastal roads that bisect or closely parallel marshes. For example, in seven years in southern New Jersey, over 4,000 terrapins were killed when attempting to cross the Garden State Parkway of the Cape May Peninsula (Wood and Herlands, 1997). Within Georgia, 405 nesting female terrapin mortalities were reported on the Tybee Island causeway between 2005 and 2007 (J. Gray, unpublished data), and 442 terrapin mortalities (99% nesting females) were documented between 2007 and 2008 (T. Norton, unpublished data). The mortality rate on the Jekyll causeway does not reflect volunteer efforts in 2008 that rescued and moved 120 females found alive on the road, of which 20 were injured. It is widely accepted that turtle populations cannot sustain significant increases in adult female mortality (Heppell, 1998); so it is likely that road mortality is having localized effects in coastal areas including along causeways within Georgia.

There are several factors that may limit the ability to measure an impact of roads on terrapin populations if one exists. It was difficult to find an available metric that adequately characterizes the potential impact of roads in a biologically meaningful way. The amount of roads in proximity to creeks can include many driveways and low traffic streets in dense residential areas that pose little risk of vehicle mortality to turtles. This is the case for the two most dense terrapin populations we documented. While these sites were among the highest for road density, the area is highly residential and most of the area that constituted roads posed no realistic risk to terrapins. Determining the distance to the most relevant road requires a

subjective criteria as to whether a road is biologically relevant, in most cases without any information about whether female terrapins nest near that road. Further, we used straight-line distances from creeks to roads. We do not know whether terrapins make straight-line, over marsh migrations to nest sites, or whether they swim along creeks until they near nesting areas. So, straight-line distances may not reflect actual migration distance. Finally, other studies show that traffic volume and speed play a large role in how roads effect wildlife populations (Rosen and Lowe, 1994; Fahrig et al. 1995; Forman, 2000; Trombulak and Frissell, 2000). We were unable to generate relevant AADT data for our study sites. AADT data was not available for some roads, and for others the data reflect an annual average. Because many of the roads are used to reach coastal beaches, traffic volume is likely high during the summer and low during the remaining 9 months. Terrapins nest from mid-May through mid-July, which coincides with peak traffic volumes. Measures of traffic levels during this period might provide a better metric for evaluating road impacts on terrapin populations.

Consistent with studies in other portions of the terrapin range, our results provide compelling evidence that crabbing activity is related to patterns of terrapin abundance along the Georgia coast. Increasing crabbing activity was negatively associated with terrapin density within a creek. That high crabbing creeks had a smaller proportion of individuals smaller than 107 mm plastron length, which was the average size of terrapins we documented drowned in crab pots, supports the inference that low density in those creeks is the result of bycatch mortality. These results are consistent with other studies in Maryland and South Carolina that report the negative effects of crab pots on terrapin populations (Seigel and Gibbons, 1995; Roosenburg et al., 1997; Wood, 1997; Hoyle and Gibbons, 2000; Roosenburg, 2004; Dorcas et al., 2007). Dorcas et al. (2007) suggest that neglected crab pots are responsible for reducing

terrapin populations by >75% over a period of 16 years, and resulting in a shift in population structure to larger, older individuals in the population. Similarly, in the upper Chesapeake Bay, Roosenburg et al. (1997) estimated that 15%-78% of isolated terrapin populations are extirpated annually as a result of the crabbing fishery. Crabbing is clearly an activity that is currently affecting the abundance of terrapins throughout a large portion of their range.

### Management Implications

Though evidence for the negative effects of crabbing on terrapin populations is documented and generally known within the wildlife management community, crabbing is not explicitly identified as a potential factor affecting the conservation of terrapins in Georgia. Our study suggests that crabbing is a significant factor influencing the abundance of the species along coastal Georgia. Commercial crabbing is an important industry to the communities of coastal Georgia, so effective management must find suitable ways to minimize the impact of this industry on terrapin populations. We know little about the factors that determine whether a particular crab pot poses a significant risk to terrapins, but anecdotal observations suggest several factors. The most obvious is that crab pots that are over-soaked, neglected, abandoned or lost pose the greatest risk. The crab pots that we observed killing large numbers of terrapins were visibly neglected as evidenced by the growth of epibenthos and partial burial. Georgia has a legal soak requirement, but it is defined as “reasonable” rather than having a specific duration, and as such we presume is not enforced. A defined and enforceable soak time for crab pots should be a legislative or regulatory priority in GA. Additionally, restriction on where crab pots may be placed could minimize mortality. We observed that pots placed in the shallowest creeks were more likely to have terrapins in them, probably because they occur in areas of high terrapin

density and because their position makes it more difficult to check reliably if the crabber does not arrive at high tide. Furthermore, efforts to clean up abandoned or lost pots, and education and enforcement about the responsible recreational use of commercial crab pots would be meritorious conservation actions. Georgia could require by-catch reduction devices on crab pots. The efficacy of such devices is an active area of research, though its efficacy in excluding small turtles is questioned. Finally, Georgia could designate areas of high conservation value for terrapins. We identified several areas such as the marsh west of Sea Island, GA where terrapin densities are in excess of 500 terrapins per kilometer. Such areas are currently free of crabbing activity, and such activity could be regulated in the future to maintain these areas for their conservation value.

Though we found no evidence that proximity to roads is related to patterns of terrapin abundance along coastal Georgia, we caution that some roads in close proximity to marsh habitats may be having localized effects that warrant management intervention. Thinking forward, it should be a priority to generate measures of local vehicle traffic volume and speeds at relevant time periods for terrapins to see whether those measures provide some evidence of an impact, and to monitor going forward whether projected increases in vehicle traffic in coastal areas correspond to changes in terrapin abundance.

### *Literature Cited*

- Aresco, M. J. 2005. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. *Biological Conservation* 123:37-44.
- Báez, J. C., R. Real, C. García-Soto, J. M. de la Serna, D. Macías and J. A. Camiñas. 2007. Loggerhead turtle by-catch depends on distance to the coast, independent of fishing effort: implications for conservation and fisheries management. *Marine Ecology Progress Series* 338:249-256.
- Bowen, K. D., P. L. Colbert, and F. J. Janzen. 2004. Survival and recruitment in a human-impacted population of ornate box turtles, *Terrapene ornata*, with recommendations for conservation and management. *Journal of Herpetology* 38:562-568.
- Cagle, F. R. 1939. A system of marking turtles for future identification. *Copeia* 1939:170-173.
- Cole, R. V., and T. E. Helser. 2001. Effect of three bycatch reduction devices on diamondback terrapin *Malaclemys terrapin* capture and blue crab *Callinectes sapidus* harvest in Delaware Bay. *North American Journal of Fisheries Management* 21:825-833.
- Diamond, J. M. 1984. Historic extinctions: A Rosetta stone for understanding prehistoric extinctions. *In*: Martin, P. S., Klein, R. G. (Eds.), *Quaternary extinctions: A prehistoric evolution*. University of Arizona Press, Tucson, pp. 824-862.
- Dorcas, M. E., J. D. Willson, and J. W. Gibbons. 2007. Crab trapping causes population decline and demographic changes in diamondback terrapins over two decades. *Biological Conservation* 137:334-340.
- Ernst, C. H., J. E. Lovich, and R. W. Barbour. 1994. *Turtles of the United States and Canada*. Smithsonian Institution Press, Washington and London, USA.
- Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wenger. 1995. Effect of road traffic on amphibian density. *Biological Conservation* 73:177-182.
- Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Biological Conservation* 14:31-35.
- Garber, S. D., and J. Burger. 1995. A 20-Yr study documenting the relationship between turtle decline and human recreation. *Ecological Applications* 5:1151-1162.
- Georgia's Comprehensive Wildlife Conservation Strategy. 2005. Georgia Department of Natural Resources, Wildlife Resources Division, 116 Rum Creek Drive, Forsyth, GA, 31029. <http://www.gadnr.org/cwcs/Documents/strategy.html>.

- Gibbons, J. W., J. E. Lovich, A. D. Tucker, N. N. Fitzsimmons, and J. L. Greene. 2001. Demographic and ecological factors affecting conservation and management of diamondback terrapins (*Malaclemys terrapin*) in South Carolina. *Chelonian Conservation and Biology* 4:66-74.
- Gibbs, J. P., and W. G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. *Conservation Biology* 16:1647-1652.
- Gibbs, J. P., and D. A. Steen. 2005. Trends in sex ratios of turtles in the United States: Implications of road mortality. *Conservation Biology* 19:552-556.
- Guthery, F. S., M. C. Green, R. E. Masters, S. J. DeMaso, H. M. Wilson, and F. B. Steubing. 2001. Land cover and bobwhite abundance on Oklahoma farms and ranches. *Journal of Wildlife Management* 65:838-849.
- Heppell, S. S. 1998. Application of life-history theory and population model analysis to turtle conservation. *Copeia* 1998:367-375.
- Hoyle, M. E., and J. W. Gibbons. 2000. Use of a marked population of diamondback terrapins (*Malaclemys terrapin*) to determine impacts of recreational crab pots. *Chelonian Conservation and Biology* 3:735-737.
- Mitchell, J. C., and M. W. Klemens. 2000. Primary and secondary effects of habitat alteration. In: Klemens, M. W. (Ed), *Turtle Conservation*. Smithsonian Institution Press, Washington and London, USA, pp. 5-32.
- Moore, M. J. C., and R. A. Seigel. 2006. No place to nest or bask: Effects of human disturbance on the nesting and basking habits of yellow-blotched map turtles (*Graptemys flavimaculata*). *Biological Conservation* 130:386-393.
- Roosenburg, W. M., W. Cresko, M. Modesitte, and M. B. Robbins. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. *Conservation Biology* 11:1166-1172.
- Roosenburg, W. M., and J. P. Green. 2000. Impact of a bycatch reduction device on diamondback terrapin and blue crab capture in crab pots. *Ecological Applications* 10:882-889.
- Roosenburg, W. M. 2004. The impact of crab pot fisheries on terrapin (*Malaclemys terrapin*) populations: Where are we and where do we need to go? In: Swarth, C., Roosenburg, W. M., Kiviat, E. (Eds.), *Conservation and Ecology of Turtles of the Mid-Atlantic Region: A Symposium*, Salt Lake City, UT, pp. 23-30.
- Rosen, P. C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran desert of southern Arizona. *Biological Conservation* 68:143-148.



- Seigel, R. A., and J. W. Gibbons. 1995. Workshop on the ecology, status, and management of the diamondback terrapin (*Malaclemys terrapin*). Savannah River Ecology Laboratory, 2 August 1994: final results and recommendations. *Chelonian Conservation and Biology* 1:27-37.
- Sexton, O. J. 1959. A method of estimating the age of painted turtles for use in demographic studies. *Ecology* 40:716-718.
- Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. *Conservation Biology* 18:1143-1148.
- Szerlag-Egger, S., and S. P. McRobert. 2007. Northern diamondback terrapin occurrence, movement, and nesting activity along a salt marsh access road. *Chelonian Conservation and Biology* 6:295-301.
- Szerlag, S., and S. P. McRobert. 2006. Road occurrence and mortality of the northern diamondback terrapin. *Applied Herpetology* 3:27-37.
- Thompson, K., and A. Jones. 1999. Human population density and prediction of local plant extinction in Britain. *Conservation Biology* 13:185-189.
- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.
- Venier, L., and L. Fahrig. 1996. Habitat availability causes the species abundance-distribution relationship. *Oikos* 76:564-570.
- White, G.C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46:120-138.
- Wood, R. C. 1997. The impact of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin*. In: Van Abbema, J. (Ed.), *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles--An International Conference*. New York Turtle and Tortoise Society, New York, USA. Pp. 21-27.
- Wood, R. C., and Herlands, R. 1997. Turtles and tires: the impact of road kills on northern diamondback terrapin, *Malaclemys terrapin terrapin*, populations on the Cape May Peninsula, southern New Jersey, USA. In: Van Abbema, J. (Ed.), *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles--An International Conference*, Purchase, NY, pp. 46-53.

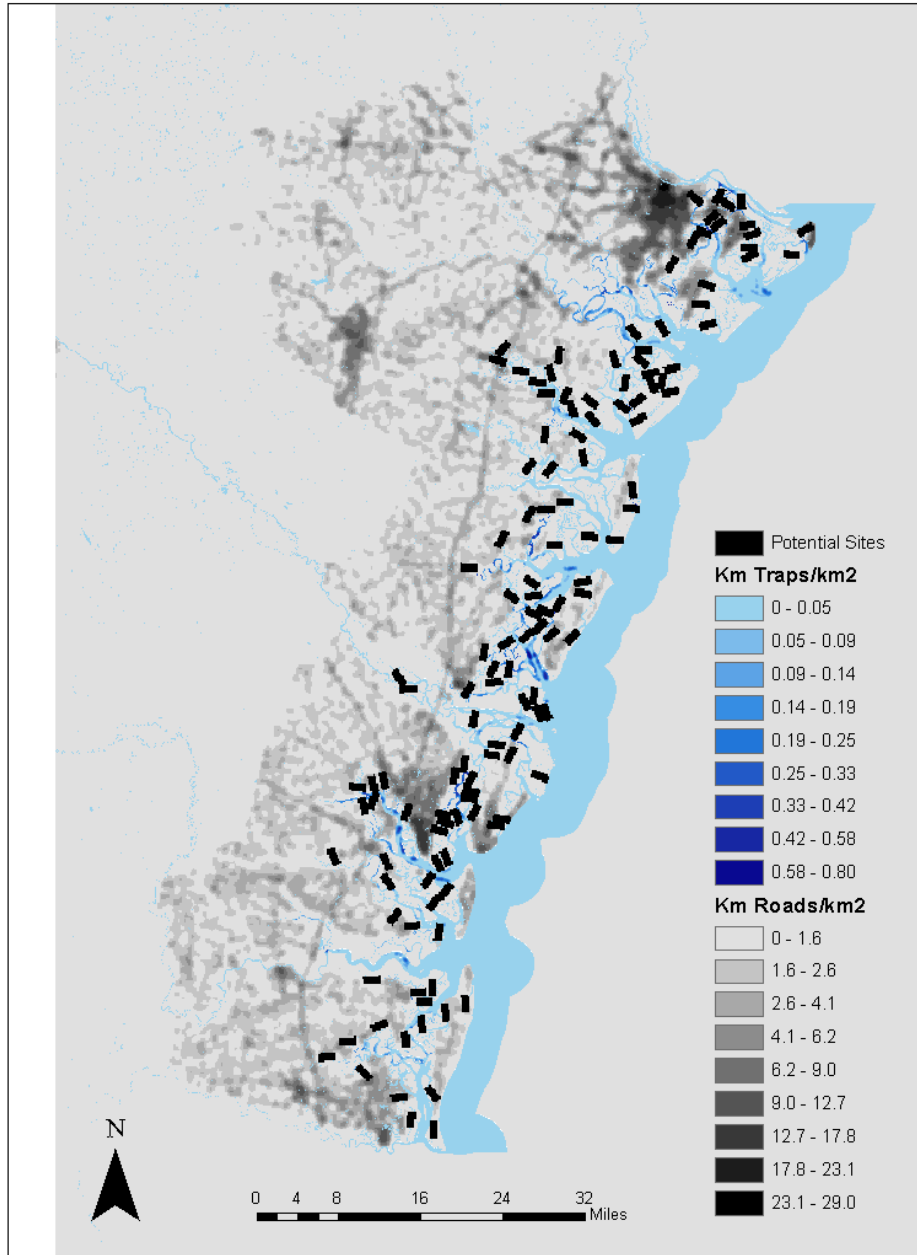


Figure 2.1: Possible sites for sampling derived from site selection database including road densities of Georgia from existing GIS, and crab pot densities obtained from Georgia Department of Natural Resources, Coastal Resources Division.



Figure 2.2: Examples of determination of distance to nearest relevant road (represented by the dotted line) for two study creeks in coastal Georgia, taking into account potential barriers (sea wall) and low traffic roads.

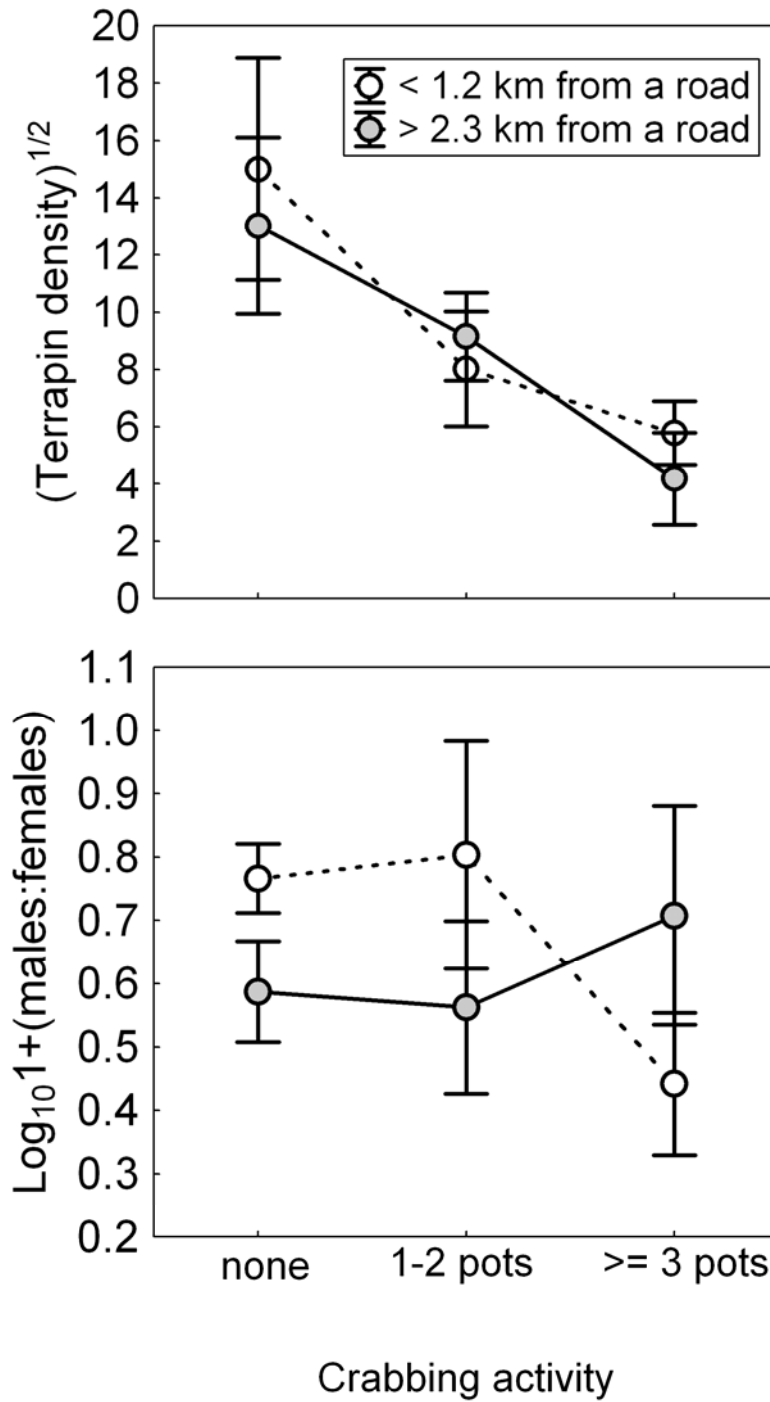


Figure 2.3: Mean terrapin density (upper panel) and sex ratio (lower panel) as a function of crabbing activity and proximity to a road. Density values are square root transformed, and sex ratio values are  $\log_{10}(\text{ratio} + 1)$  transformed. Error bars represent  $\pm 1$  SE.

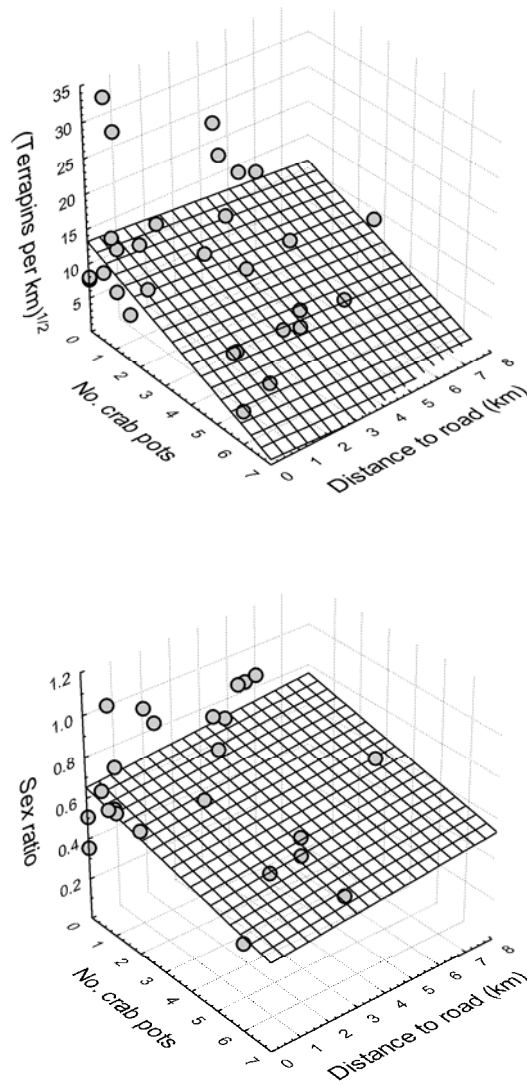


Figure 2.4: Multiple linear regression relationships between the number of crab pots in a creek and the distance to the nearest relevant road and terrapin density (upper panel) or sex ratio (lower panel). The model for terrapin density was significant (Likelihood ratio Chi-square = 9.244,  $df = 2$ ,  $P = 0.010$ ) with only the number of crab pots as a significant factor (Wald statistic = 5.625,  $P = 0.018$ ). The model for sex ratio was not significant (Likelihood ratio Chi-square = 2.499,  $df = 2$ ,  $P = 0.287$ ). Plane represents multiple linear regression.

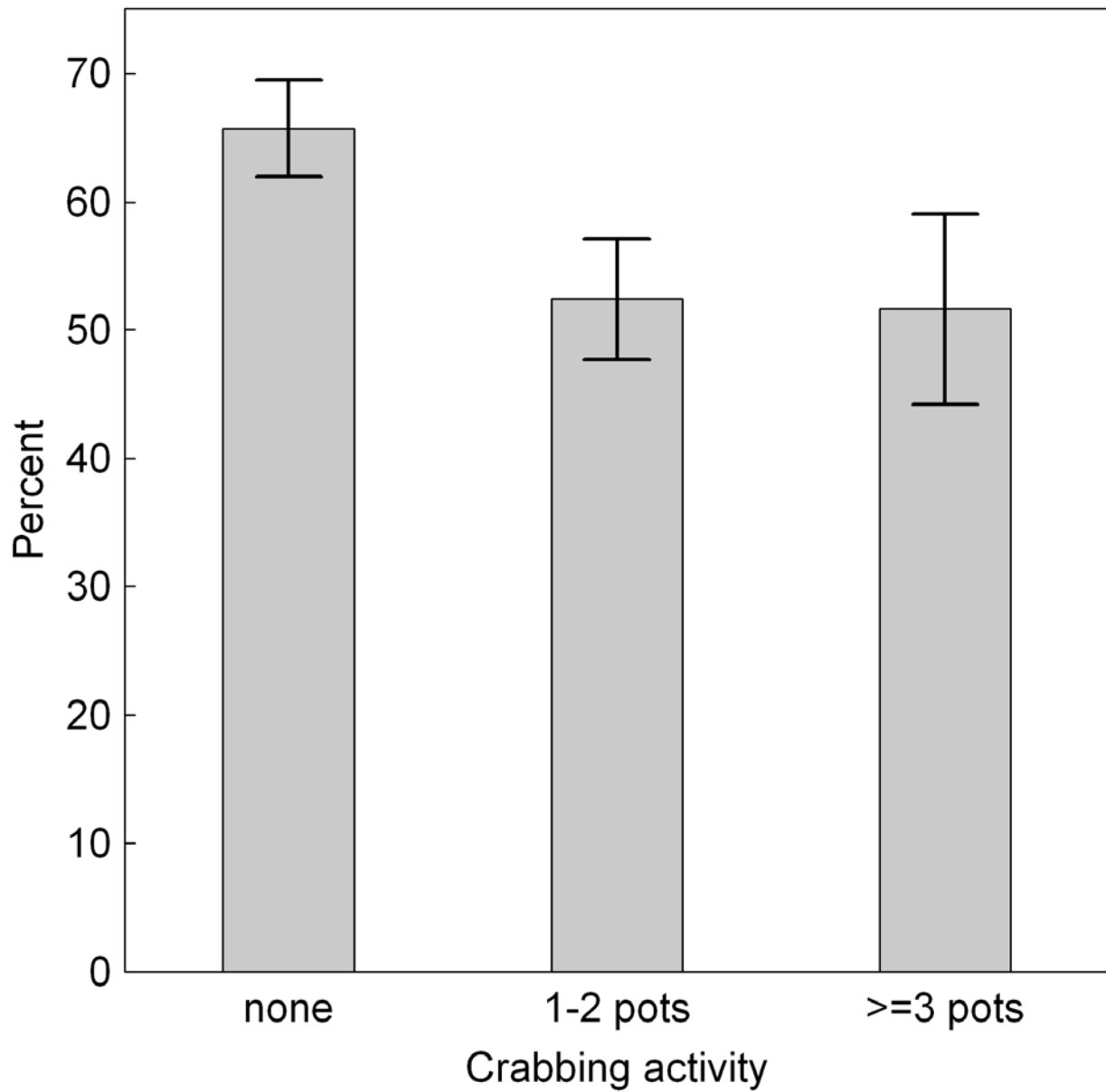


Figure 2.5: Mean ( $\pm 1$  SE) percent of *M. terrapin* captured that were smaller than 107 mm plastron length as a function of crabbing activity level within the creek (107 mm represents the mean plastron length for terrapins found dead in crab pots).

CHAPTER 3  
CRABBING ALTERS DIAMONDBACK TERRAPIN POPULATION SIZE STRUCTURE  
AND GROWTH RATES

*Introduction*

The impacts of human activities on wildlife are now a major focus of applied ecology. The overwhelming majority of studies focus on human impacts on diversity, abundances, and shifting distributions of species. Far less appreciated are the impacts human activities have on organismal phenotypes. Human alterations to landscapes and activities within natural areas are known to alter the behavior, morphology, and life history traits of species, in some cases in ways that may be relevant to a species' conservation (Moore and Seigel, 2006; Hendry, 2008). In that regard, human activities have been characterized as the greatest contemporary selective pressure affecting other species (Palumbi 2001; Smith and Bernatchez 2008).

While the attention to species losses and population declines is understandable, it may be far less intuitive why understanding human-driven changes in animal phenotypes is important. It is often the case that a shift in one set of traits comes at change in performance associated with changes in other traits. For example, studies have shown tradeoffs between growth and swimming performance (Arendt 2003), immune function (Gervasi and Foufopoulos, 2008), and muscle development (Arendt 2000) in amphibian species. Within turtles, it has been shown that smaller female turtles increase egg size at the expense of clutch size (Rowe, 1994; Roosenburg and Dunham 1997). It is thought that larger egg size increases survivorship of hatchling turtles (Allman, 2006). Examples of such trade-offs are wide spread and well documented among

animal species. In some cases, human activities alter the distribution of animal phenotypes by selecting intentionally or unintentionally against certain phenotypes. For example, there are well-documented cases of commercial fisheries harvests, which targeted the largest fish, selected against fish that matured at older ages. This led to shifts in life history traits including smaller size and earlier age at first reproduction (Darimont et al. 2009; Hutchings 2004; Trippel 1995; Conover and Munch 2002; Olsen et al. 2004). Because traits often trade-off among each other, the inadvertent selection of animal phenotypes by human activities can have unanticipated but important consequences for wildlife populations.

The objective of this study was to use available data on age-specific body size distributions to determine whether crabbing activities may be affecting diamondback terrapin (*Malaclemys terrapin*) age and age-specific body size distributions. Commercial crab pots act as gape limited predators (Roosenburg et al., 1997). In cases of natural predation, it is often observed that prey populations show larger age-specific body size distributions, and in some cases the evolution of faster intrinsic growth rates in habitats with gape limited predators (Crowl and Covich 1990; Spitze 1991; Belk and Hales 1993; Arendt 1997). Therefore, it is reasonable to assume that if crab pot mortality represents a sufficient, chronic selective pressure on terrapin populations, then shifts in animal phenotypes should be evident in areas of intense crabbing activity. We hypothesize that mean terrapin size and age-specific size will be greater in tidal creeks with high crabbing activity compared to creeks with no crabbing activity.

## *Materials and Methods*

### Sampling



Study sites in this study represent a subset of a larger set of sites selected using a stratified random design to measure the relationship between proximity to roads and crabbing activity levels on terrapin density. Sites were initially selected using a stratified random design based on GIS data on road density and crab pot density. Crabbing activity data was provided by Georgia Department of Natural Resources, Coastal Resources Division (Brunswick, GA) and represented all of coastal Georgia from 2003 to 2006. Crabbing activity was subsequently verified by direct measurements during terrapin population sampling. For this study, we restrict our analysis to 22 creeks for which there was no historic or current evidence of crabbing activity or where we documented significant crabbing activity (> 3 crab pots) within the portion of the creek sampled. Our initial study found no measurable relationship between road proximity and terrapin density (Grosse et al. unpublished data), so we do not consider that factor in this study.

Each creek was seined on 5 occasions between April 1 and June 30, the time period most effective for capturing terrapins in the study region (Gibbons et al., 2001), using two 10 m, 2.54 cm mesh seines with a bag. Seining began each day immediately prior to low tide and seines were pulled from the start of each sampling area and continued until we reached the end of the creek, occasionally pulling the seines onto the mud bank to remove captured *M. terrapin* and bycatch. Depending on width and depth of creeks, seines were either pulled in tandem or side-by-side to maximize the area sampled. Each creek was seined up and back during each visit. Following capture, all turtles were sexed based on position of the cloaca on the tail and head allometry, measured (carapace length, plastron length, shell width and depth), weighed (g), 'aged' by counting scute rings (Sexton, 1959), and uniquely marked using marginal scute notches (Cagle, 1939).

## Statistical analysis

Within each crabbing classification, data were pooled on turtles from all creeks. Because high crabbing activity dramatically reduced the density of terrapins (Grosse et al., unpublished data), we had insufficient captures to adequately represent the range of turtle ages separately for each creek, which prevented us from generating reliable growth curves for each creek. That said, each creek's crabbing activity was relatively evenly represented in the data set such that the pattern in any one creek could not have a disproportionate influence on the results (126 turtles were captured in high crabbing creeks representing 10% of turtles used in the analysis). We used two-way ANOVA to test the hypothesis that mean terrapin size (plastron length) and estimated age differed as a function of crabbing activity. We included sex as a factor in the model because terrapins are highly sexually dimorphic. To test the hypothesis that terrapin growth rates were faster in creeks with high crabbing activity, we used a general linear model of plastron length with creek crabbing class and sex as fixed factors and age as a continuous factor. We used a  $\log_{10}$  (plastron length + 1) transformation for size analyses. All analyses were conducted using STATISTICA v8.0. (StatSoft, Inc., Tulsa, OK).

## *Results*

In total, 1736 *M. terrapin* were captured, consisting of 1301 individuals. Overall captures were male biased, with 78% males and 22% females. Crabbing activity was restricted to either no historic or current evidence of crabbing activity or where we documented significant crabbing activity (> 3 crab pots) within the portion of the creek sampled. We found no relationship between crabbing activity and mean estimated terrapin age ( $MS = 0.388$ ,  $F_{1,556} = 0.212$ ,  $P =$

0.645), though mean estimated age did differ between sexes ( $MS = 38.453$ ,  $F_{1,556} = 21.012$ ,  $P = <0.001$ ). Mean estimated age was older for female terrapins compared to male terrapins (Fig. 3.1a). Mean terrapin size (plastron length) varied significantly as a function of terrapin sex ( $MS = 105277$ ,  $F_{1,1170} = 541.36$ ,  $P = <0.001$ ) and creek crabbing classification ( $MS = 3868$ ,  $F_{1,1170} = 19.89$ ,  $P = <0.001$ ; Fig. 3.1b). Mean terrapin growth (size x age) varied significantly as a function of terrapin sex and creek crabbing classification (Table 3.1; Fig. 3.2). For both males and females, terrapin age specific size (growth) was larger in creeks with high crabbing activity (Fig. 3.2).

### *Discussion*

Our data suggest that high crabbing activity drives a shift in mean body size but not age within diamondback terrapin populations. Dorcas et al. (2007) also observed a shift in mean terrapin size concurrent with a 75% decline in terrapin abundance over a 16 year period in South Carolina, and hypothesized that the pattern implicated bycatch mortality in crab pots as the causative agent of decline. Roosenburg et al. (1997) linked increasing terrapin size to crabbing activity in the upper Chesapeake Bay, MD. Dorcas et al. (2007) found an increase in mean terrapin age through time, so inferred that the increase in mean terrapin size was the result of the differential survival of older, larger female terrapins. In contrast, we found no shift in mean age associated with increased size among creeks that differ in crabbing activity. Therefore, our results suggest that high crabbing activity results in larger terrapins by selecting for more rapidly growing individuals. We also note that results are consistent with that of Wolak (unpublished

data, pers. comm.), who reports documenting more rapid growth among terrapins in high crabbing areas within the lower Chesapeake Bay, VA.

There are a number of ecological and evolutionary hypotheses that may explain larger age-specific size among terrapins from high crabbing creeks. The simplest explanation is that because crabbing selectively removes only smaller individuals, age-specific mortality in crab pots is higher for smaller individuals, and they are progressively removed from populations. While we cannot rule out this hypothesis, we believe that this is unlikely. We observed larger, age-specific body sizes among male terrapins from high crabbing creeks; however, even the largest male terrapin is still sufficiently small that he can fit into a crab pot. In other words, we would not expect male size distributions to differ between crabbing and no crabbing creeks if crab pots were simply removing the smallest individuals. If we assume that our age-specific size distributions are indicative of mean growth rates of individual terrapins, our results suggest that male terrapins grow faster in high crabbing creeks, even though they cannot outgrow the gape of crab pots. This suggests that high crabbing creeks either support more rapid terrapin growth, or have selected for faster intrinsic growth rates in females, which is inherited by males.

It is possible that high-crabbing creeks support more rapid terrapin growth either because they support greater prey production or because high crabbing creeks have lower densities of terrapins. We cannot reject the possibility that creeks that support high crab production, and thus high crabbing activity, also support more rapid terrapin growth; however, we think it is unlikely that reductions in terrapin density from crabbing results in competitive release. Little is known about the importance of intraspecific competition to terrapins or more generally all turtles. Among freshwater turtles, a few studies have demonstrated potential competition for basking sites. The one study to address resource partitioning failed to find support for interspecific

competition (Flaherty and Bider 1984, Lindeman, 2000), and Spencer et al. (2006) reported that turtle species show reduced (not accelerated) growth in populations in habitats where densities were reduced. Marshes are extremely productive ecosystems that support high densities of prey for terrapins (Beck et al. 2001). Montague et al. (1981) described that typical populations of fiddler crabs (*Uca pugnax*), periwinkle snails (*Littorina irrorata*) and mud snails (*Ilyanassa obsoleta*), which constitute the bulk of terrapin diets in Georgia (M. Erickson, unpublished data), ranged from 80 to 200, 400 to 700 and 500 to 1600 individuals/m<sup>2</sup>, respectively. Such densities are not likely to be limiting for terrapins.

We must also consider the possibility that the increase in age-specific size among terrapins from high crabbing creeks is the result of an evolutionary shift towards more rapid growth in high crabbing environments. Until relatively recently, evidence of rapid human evolutionary influence on other species was generally ignored because it was presumed that the rate of evolutionary change was too slow to have manifested in contemporary species. However, many studies have revealed rapid microevolutionary changes in species that operate at scales equal to ecological influences (e.g., shifts in beak morphology in Darwin's finches and size selection in fish; Grant and Grant, 2002; Conover and Munch, 2002; Conover et al. 2009). In order for selection to drive evolution in terrapin growth rates, there needs to be sufficient and relatively stable selection pressure, limited gene flow among high crabbing and no crabbing creeks, and heritable variation in growth rates. Below we address each of these issues as it relates to current knowledge on diamondback terrapins.

Based on our earlier results that show high crabbing is associated with a significant reduction in terrapin density, and similar results throughout the species range (Roosenburg et al., 1997; Wood, 1997; Dorcas et al., 2007), we believe that the assumption that high crabbing

activity can provide strong selection for large size is valid. The question is whether high crabbing activity within creeks is stable long-term. During our study, the numbers of crab pots within creeks were stable within a season, and follow-up visits to our study sites showed crab pots were present in creeks between our two study years. Longer-term, all of the study creeks identified by GA DNR as having crab pots from 2003-2006 were still crabbed commercially in 2007 and 2008. These observations suggest short-term stability in crabbing activity. Additionally, the culture of commercial crabbing in Georgia is similar to that of other commercial fisheries (Durrenberger and Palsson 1987; Acheson 1975; D. Karwacki Pers. Comm.) such that individual crabbers operate with assumed rights to fish in specific locations, and these locations are fished regularly by the same crabber (D. Karwacki Pers. Comm.). We feel that it is likely that some areas of high crabbing activity present consistent selective pressure on terrapin populations.

At this time, we cannot adequately address the issue of gene flow between creeks with and without high crabbing activity. Hauswaldt and Glenn (2005) report a lack of genetic structuring among terrapin populations over relatively large geographic areas. This suggests genetic homogenization, though does not preclude local evolution of specific traits. The results remain in conflict with data from long-term studies demonstrating extremely high site fidelity among sub-adult and adult terrapins. It is not known whether juvenile terrapins return to their parent's creeks, or whether they disperse among creeks. If there is sufficient gene flow among adjacent creeks, then local adaptation to crabbing activity may be limited to areas where crabbing activity is relatively uniform over adjacent creeks.

The last element required for crabbing activity to drive evolution of terrapin growth rates would be heritable variation in growth rates. Individual variation in growth rates are common

among most organisms including turtles (Hildebrand, 1932; Wilbur, 1975; Fraser et al., 1993; Arendt, 1997). Variation in intrinsic growth rates can be adaptive and reflect trade-offs between the benefits of larger size (e.g., ability to eat larger prey or escape gape limited predators) and other aspects of performance (e.g., immune function, muscle development and performance) (Cole 1954; Wilbur 1975; Stearns 1976; Sinervo and Adolph 1994; Arendt 1997, 2003; Arendt and Wilson 1997; Morgan and Metcalfe 2001; Crowl and Covich 1990; Spitze 1991; Belk and Hales 1993). One possible trade off for rapid growth in turtle species may be shell thickness. Among North American emydid turtles, which includes the terrapin, the species with the fastest growth rate, the chicken turtle (*Deirochelys reticularia*), has a significantly thinner shell than slower growing confamilial species. The thinner shell is hypothesized to increase vulnerability to large predators that crush prey. We expect that there is natural heritable variation in growth rate among individual terrapins upon which selection can act. Additionally, terrapin populations in Georgia are likely hybrids descended from historic interbreeding of various subspecies in commercial farms during the terrapin soup era and subsequently in efforts to restore wild populations (Hay 1917; Coker 1920; Hildebrand 1929; Hauswaldt and Glenn, 2005). The most common subspecies interbred were from the Chesapeake Bay (then called *Malaclemys centrata concentrata*) and the Carolinas (then called *Malaclemys centrata centrata*; Hildebrand 1929). The Chesapeake subspecies is known to grow faster and to a larger body size. The Bureau of Fisheries released 1,000-3,000 hybrid offspring annually in South Carolina throughout the 1930s and 1940s (Lunz 1944), and after the demand for terrapin soup diminished, tens of thousands of adults from Atlantic coast farms were released into marshes including Georgia (B. Barbee, Pers. comm.). Hybrid genotypes may have been disproportionately released into areas where crabbing

activities were concentrated, or could provide additional genetic variation in growth rate upon which local selection pressures including high crabbing activity could act.

There is ample evidence showing that anthropogenic activities are having substantial impacts on our wildlife species world-wide. While the bulk of that attention is focused on changes to diversity and abundance, we should not lose sight of the potential for human activities to drive shifts in species' phenotypes. Several possible explanations for the variation in growth rates of terrapins have been presented here and may provide a framework for future studies focusing on specific aspects of fluctuating growth in wildlife populations. We urge that determination of the costs of rapid growth in terrapins or other turtle species may be of biological and conservation importance. Our ability to acknowledge and understand the complete impacts of human activities on wildlife is essential to their continued survival and the conservation of the biodiversity in our remaining natural areas.



### *Literature Cited*

- Acheson, J. M. 1975. The lobster fiefs: Economic and ecological effects of territoriality in the Maine lobster industry. *Human Ecology* 3:183-207.
- Allman, P. A. 2006. Consequences of egg size on hatchling energetics in the diamondback terrapin, *Malaclemys terrapin*. Dissertation. Ohio University, Athens, Ohio, USA.
- Arendt, J. D. 1997. Adaptive intrinsic growth rates: An integration across taxa. *The Quarterly Review of Biology* 72:149-177.
- Arendt, J. D. 2000. Allocation of cells to proliferation vs. differentiation and its consequences for growth and development. *Journal of Experimental Zoology* 288:219-234.
- Arendt, J. D. 2003. Reduced burst speed is a cost of rapid growth in anuran tadpoles: problems of autocorrelation and inferences about growth rates. *Functional Ecology* 17:328-334.
- Arendt, J. D. and D. S. Wilson. 1997. Optimistic growth: competition and an ontogenetic niche-shift select for rapid growth in pumpkinseed sunfish (*Lepomis gibbosus*). *Evolution* 51:1946-1954.
- Beck, M. W., K. L. Heck, Jr., K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan and M. P. Weinstein. 2001. The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. *Bioscience* 51:633-641.
- Belk, M. C. and L. S. Hales, Jr. 1993. Predation-induced differences in growth and reproduction of blue-gills (*Lepomis macrochirus*). *Copeia* 4:1034-1044.
- Cagle, F. R. 1939. A system of marking turtles for future identification. *Copeia* 1939:170-173.
- Coker, R. E. 1920. The diamond-back terrapin: past, present, and future. *Scientific Monthly* 11:171-186.
- Cole, L. C. 1954. The population consequences of life history phenomena. *The Quarterly Review of Biology* 29:103-137.
- Conover, D. O. and S. B. Munch. 2002. Sustaining fisheries yields over evolutionary time scales. *Science* 297:94-96.
- Conover, D. O., S. B. Munch, and S. A. Arnott. 2009. Reversal of evolutionary downsizing caused by selective harvest of large fish. *Proceedings of the Royal Society B*. doi:10.1098/rspb.2009.0003

- Crowl, T. A. and A. P. Covich. 1990. Predator induced life-history shifts in a freshwater snail. *Science* 247:949-951.
- Darimont, C. T., S. M. Carlson, M. T. Kinnison, P. C. Paquet, T. E. Reimchen and C. C. Wilmers. 2009. Human predators outpace other agents of trait change in the wild. *Proceedings of the National Academy of Sciences* 106:952-954.
- Dorcas, M. E., J. D. Willson and J. W. Gibbons. 2007. Crab trapping causes population decline and demographic changes in diamondback terrapins over two decades. *Biological Conservation* 137:334-340.
- Durrenberger, E. P. and G. Palsson. 1987. Ownership at sea: fishing territories and access to sea resources. *American Ethnologist* 14:508-522.
- Flaherty, N., and J. R. Bider. 1984. Physical structures and the social factor as determinants of habitat use by *Graptemys geographica* in southwestern Quebec. *American Midland Naturalist* 111:259-266.
- Fraser, N. B., J. L. Greene, and J. W. Gibbons. 1993. Temporal variation in growth rate and age at maturity of male painted turtles, *Chrysemys picta*. *American Midland Naturalist* 130:314-324.
- Gervasi, S. S., and J. Foufopoulos. 2008. Costs of plasticity: responses to desiccation decrease post-metamorphic immune function in a pond-breeding amphibian. *Functional Ecology* 22:100-108.
- Gibbons, J. W., J. E. Lovich, A. D. Tucker, N. N. Fitzsimmons and J. L. Greene. 2001. Demographic and ecological factors affecting conservation and management of diamondback terrapins (*Malaclemys terrapin*) in South Carolina. *Chelonian Conservation and Biology* 4:66-74.
- Grant, P. R., and B. R. Grant. 2002. Unpredictable evolution in a 30-year study of Darwin's finches. *Science* 296:707-711.
- Hauswaldt, J. S., and T. C. Glenn. 2005. Population genetics of the diamondback terrapin (*Malaclemys terrapin*). *Molecular Ecology* 14:723-732.
- Hay, W. P. 1917. Artificial propagation of the diamond-back terrapin. *Bulletin of the United States Bureau of Fisheries* 24:1-20.
- Hendry, A. P., T. J. Farrugia, and M. T. Kinnison. 2008. Human influences on rates of phenotypic change in wild animal populations. *Molecular Ecology* 17:20-29.
- Hildebrand, S. F. 1929. Review of the experiments on artificial culture of the diamond-back terrapin. *Bulletin of the United States Bureau of Fisheries* 45:25-70.

- Hildebrand, S. F. 1932. Growth of diamond-back terrapins size attained, sex ratio and longevity. *Zoologica* 9:231-238.
- Hutchings, J. A. 2004. The cod that got away. *Nature* 428:899-900.
- Lindeman, P. V. 2000. Resource use of five sympatric turtles species: effects of competition, phylogeny, and morphology. *Canadian Journal of Zoology* 78:992-1008.
- Lunz, Jr., G. R., J. T. Penny and T. P. Lesesne. 1944. Special study of the marine fishery resources of South Carolina. South Carolina State Planning Board. Bulletin No. 14. Columbia, SC.
- Montague, C. L., S. M. Bunker, E. B. Haines, M. L. Pace, and R. L. Wetzel. 1981. Aquatic macroconsumers. Pp. 69–85, *In* L.R. Pomeroy and R.G. Wiegert (Eds.). *The Ecology of the Salt Marsh*. Springer-Verlag, New York, NY.
- Moore, M. J. C., and R. A. Seigel. 2006. No place to nest or bask: effects of human disturbance on the nesting and basking habits of yellow-blotched map turtles (*Graptemys flavimaculata*). *Biological Conservation* 130:386-393.
- Morgan, I. J. and N. B. Metcalfe. 2001. Deferred costs of compensatory growth after autumnal food shortage in juvenile salmon. *Proceedings of the Royal Society of London B* 268:295-301.
- Olsen, E. M., M. Heino, G. R. Lilly, M. J. Morgan, J. Brattey, B. Ernande, and U. Dieckmann. 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. *Nature* 428:932-935.
- Palumbi, S. R. 2001. Humans as the world's greatest evolutionary force. *Science* 293:1786-1790.
- Roosenburg, W. M., and A. E. Dunham. 1997. Allocation of reproductive output: Egg- and clutch-size variation in the diamondback terrapin. *Copeia* 1997:290-297.
- Roosenburg, W. M., W. Cresko, M. Modesitte and M. B. Robbins. 1997. Diamondback terrapin (*Malaclemys terrapin*) mortality in crab pots. *Conservation Biology* 11:1166-1172.
- Rowe, J. W. 1994. Reproductive variation and the egg size-clutch size tradeoff within and among populations of painted turtles (*Chrysemys picta bellii*). *Oecologia* 99:35-44.
- Sexton, O. J. 1959. A method of estimating the age of painted turtles for use in demographic studies. *Ecology* 40:716-718.
- Sinervo, B. and S. C. Adolph. 1994. Growth plasticity and thermal opportunity in *Sceloporus* lizards. *Ecology* 75:776-790.

- Smith, T. B. and L. Bernatchez. 2008. Evolutionary change in human-altered environments. *Molecular Ecology* 17:1-8.
- Spencer, R. J., F. J. Janzen, and M. B. Thompsom. 2006. Counterintuitive density-dependent growth in a long-lived vertebrate after removal of nest predators. *Ecology* 87:3109-3118.
- Spitze, K. 1991. *Chaoborus* predation and life-history evolution in *Daphnia pulex*: temporal pattern of population diversity, fitness, and mean life history. *Evolution* 45:82-92.
- Stearns, S. C. 1976. Life-history tactics: a review of the ideas. *The Quarterly Review of Biology* 51:3-47.
- Trippel, E. A. 1995. Age at maturity as a stress indicator in fisheries. *Bioscience* 45:759-771.
- Wilbur, H. M. 1975. A growth model for the turtle *Chrysemys picta*. *Copeia* 1975:337-343.
- Wood, R. C. 1997. The impact of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin*. Pages 21-27. In J. Van Abbema editor. *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles--An International Conference*. New York Turtle and Tortoise Society, New York, USA.

Table 3.1. Results of general linear model examining the effects of crabbing pressures, sex and age on *M. terrapin* plastron length.

Source	df	MS	F	P-value
Crabbing	1	0.012	6.23	0.002
Sex	1	0.128	65.85	<0.001
Age	1	0.182	93.86	<0.001
Crabbing * Sex * Age	2	0.065	33.55	<0.001
Error	635	0.002		

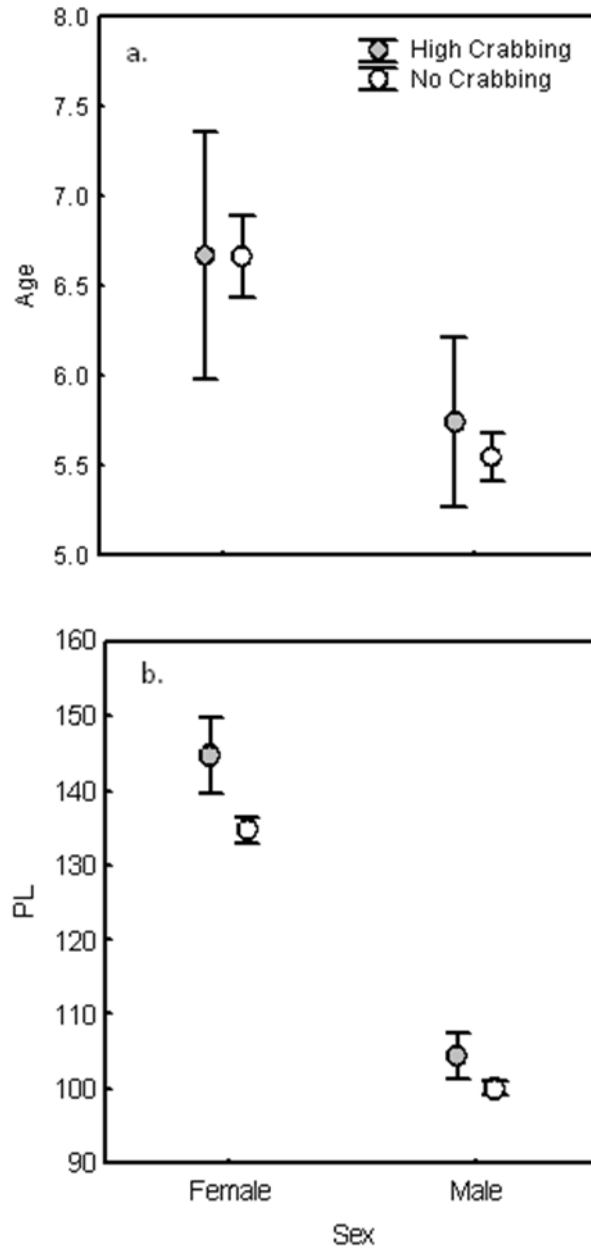


Figure 3.1. Estimated age (a) and Plastron length (b) as a function of crabbing activity and sex.

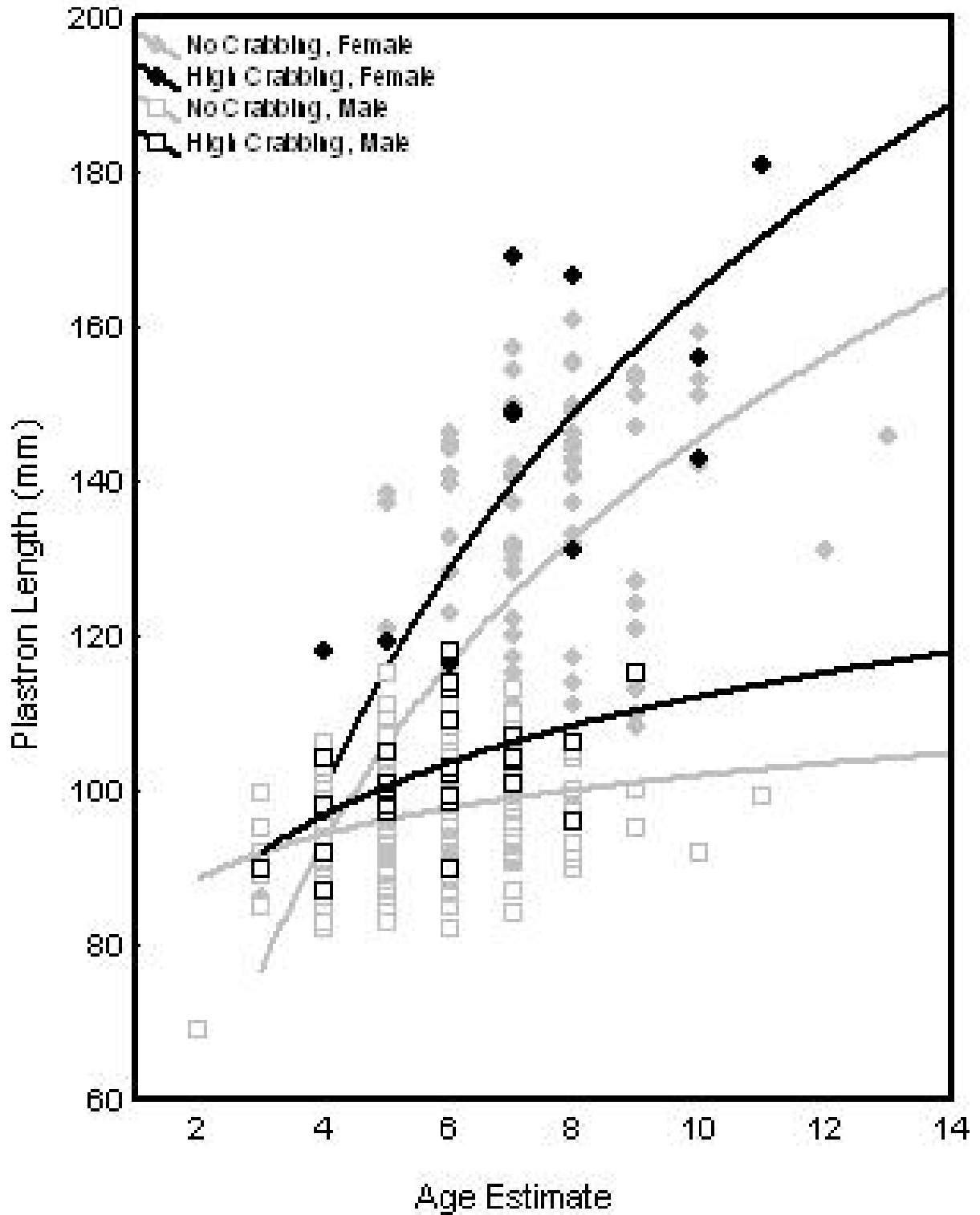


Figure 3.2. Patterns of age-specific size for male and female *M. terrapin* in tidal creeks with no crabbing pressure and high crabbing pressure.

## CHAPTER 4

### CONCLUSION

Historically, diamondback terrapin (*Malaclemys terrapin*) populations were decimated as a result of the high demand for turtle soup. As the demand for turtle soup ebbed, *M. terrapin* populations began to rebound only to be negatively impacted again by new anthropogenic threats; mortality from vehicles and crab traps. The purpose of this thesis was to determine if anthropogenic pressures, specifically roads and crabbing activity, are associated with patterns of terrapin abundance along coastal Georgia.

In my first chapter we reported no measurable association between terrapin density and road density or proximity; however, we observed that crabbing activities were negatively associated with terrapin density. We suggest that the relatively rural state of the Georgia coast may mean that roads currently have little impact on terrapins state wide, though road mortality may still have significant local effects such as along high volume causeways connecting barrier islands. We also suggest that better metrics be developed to improve the evaluation of road impacts on terrapin populations. The clear negative association between crabbing activity and terrapin density is consistent with other studies across the species' range that show population declines or local extirpations are directly related to bycatch mortality. Collectively, these studies demonstrate a widespread negative association between crabbing activity and terrapin abundance. Commercial crabbing is an important industry to many coastal communities, so effective management must find suitable ways to minimize the impact of this industry on terrapin populations. Defined and enforceable soak time requirements, designation of conservation areas



that prohibit crabbing, restrictions on crabbing far up in the shallow portions of tidal creeks, requirement of by-catch reduction devices on crab pots, efforts to clean up abandoned or lost pots, and education and enforcement about the responsible recreational use of commercial crab pots are all actions that could minimize the impact of crabbing on terrapin populations without negatively impacting the industry.

In my second chapter we evaluated mean terrapin age and age-specific size patterns of terrapins as it relates to crabbing activity. We found no difference in mean estimated terrapin age between creeks without crabbing and those with high crabbing activity; however, we did observe that terrapins were larger in high crabbing creeks. This result is consistent with other studies; however, unlike those studies that imply the increase in terrapin size is the result of higher survival among larger, adult females, our results suggest that larger age-specific size may be related to faster growth among terrapins from high crabbing creeks. We provide both ecological and evolutionary processes that could lead to increased growth rates among terrapins in creeks with high crabbing activity. We proposed that the possibility of crabbing has driven an evolutionary shift in terrapin growth rates and that this shift may have come at an unknown cost to terrapin performance. This will be an interesting and important area for future research.

It seems clear that human activities, specifically crabbing, are currently influencing the density of terrapins along coastal Georgia. This research should inform management actions to insure the conservation of terrapin populations, namely the need to establish conservation areas free from crabbing and to develop programs to mitigate the impacts of crabbing in other areas. The research also establishes a baseline of information about terrapin abundance at sites across the entire Georgia coast and how roads and crabbing activities currently predict terrapin densities

among those sites. This will provide a contrast for future studies to track changes in terrapin demography that coincide with the rapidly increasing development of Georgia's coast.

Future research should continue to monitor and examine the effects of anthropogenic interactions on diamondback terrapin populations. Continuous monitoring of diamondback terrapin populations is a valuable tool to monitor and detect long term variability and changes in demography resulting from interactions with natural or artificial modifications that may need attention in order to ensure preservation of the species. The negative impacts of crab pots have been well documented, and future efforts should be made to mitigate the impacts of crabbing on terrapin populations, through education, increased regulations and preventative fishing techniques. Past research has shown that, during the nesting season, diamondback terrapin mortality is high on roads that bisect or run parallel to the marsh ecosystem; however, the direct impacts of this mortality to populations are currently unknown. Future research should focus on the impacts of road mortality to diamondback terrapin populations in Georgia. Additional efforts to determine and preserve nesting areas for various terrapin populations in Georgia should be a priority. By providing further insight into terrapin natural history and habitat use and by establishing collaborations with the general public, research scientists and wildlife organizations, we can expand upon present conservation and management techniques and develop effective strategies for future preservation of diamondback terrapins.

## APPENDIX

APPENDIX A. Summary data including latitude/longitude for each tidal creek, total captures by sex and corresponding Mean Plastron Length (PL), Standard Deviation (SD) and Range.

Creek	Coordinates		Total Males	Mean PL	SD	Range	Total Females	Mean PL	SD	Range
4	32° 0'36.51"N	80°56'26.56"W	40	105.8	4.95	92-116	7	149.5	26.54	98-167
6	31°59'32.79"N	80°56'22.74"W	47	103.9	4.01	94-112	8	143.6	16.74	117-166
7	32° 2'37.88"N	80°57'53.74"W	21	95.7	5.10	85-103	11	136.7	26.69	94-169
9	32° 2'32.93"N	80°59'15.15"W	36	99.2	6.83	83-116	4	112.3	31.49	87-157
11	32° 1'9.96"N	81° 1'7.53"W	17	99.9	5.16	90-108	4	127.4	34.91	95-170
12	32° 0'55.05"N	81° 0'47.85"W	14	104.4	4.45	98-111	4	167.0	8.12	159-174
16	31°57'7.26"N	81° 5'2.61"W	5	105.2	2.28	103-108	3	170.3	3.06	167-173
21	31°50'33.16"N	81° 8'46.23"W	8	104.6	6.86	90-111	4	150.5	45.56	89-187
37	31°47'47.84"N	81°17'3.51"W	16	102.8	5.10	96-116	6	133.6	29.23	95-161
39	31°46'24.38"N	81°15'56.15"W	19	103.3	5.69	92-116	6	157.7	6.62	148-166
45	31°42'49.11"N	81°13'53.50"W	6	109.1	7.63	100-117	0	-	-	-
52	31°33'40.62"N	81°13'1.93"W	24	105.2	4.25	97-113	8	144.2	34.89	88-182
60	31°29'31.86"N	81°20'13.30"W	20	104.7	7.58	90-115	2	159.5	7.78	154-165
66	31°28'6.61"N	81°18'2.70"W	15	105.4	6.69	90-119	5	144.2	20.02	119-165
70	31°27'9.46"N	81°19'44.15"W	23	106.1	7.42	91-120	2	154.0	9.90	147-161
91	31°13'34.07"N	81°24'57.00"W	37	103.5	6.83	86-113	6	144.5	28.77	95-170
93	31°11'46.44"N	81°25'45.29"W	163	98.7	5.99	83-114	41	122.6	23.45	86-179
97	31°11'16.78"N	81°21'0.61"W	156	101.1	8.36	82-176	40	142.0	22.12	101-175
98	31°10'31.27"N	81°22'9.07"W	223	97.3	5.34	72-111	103	135.1	22.61	82-166
100	31°10'33.01"N	81°26'36.56"W	42	99.5	7.12	81-115	21	136.6	28.39	95-190
102	31°10'4.86"N	81°27'2.36"W	10	104.1	4.98	97-111	8	145.8	27.87	106-172
109	31° 7'5.27"N	81°26'40.16"W	116	98.2	5.65	86-115	36	120.3	23.62	86-157
122	30°58'0.52"N	81°27'5.89"W	66	106.1	6.50	89-119	11	148.7	24.65	111-184
123	30°54'40.69"N	81°29'32.54"W	14	104.8	4.56	98-113	7	136.6	24.09	107-166
JC	31° 3'51.64"N	81°27'11.89"W	22	99.6	5.36	87-109	10	144.0	22.26	90-165