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SPATIAL AND THERMAL ECOLOGY OF DIAMONDBACK TERRAPINS (*MALACLEMYS TERRAPIN*) IN A SOUTH CAROLINA SALT MARSH

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Abstract: East coast barrier islands such as Kiawah Island, South Carolina, have experienced rapid urbanization resulting in alteration of their salt marsh ecosystems since the 1980's. These estuarine ecosystems serve as critical habitat for numerous endemic wildlife such as diamondback terrapins (*Malaclemys terrapin*) which are particularly vulnerable to anthropogenic disturbances. An intensive six-day radiotelemetric study was initiated to better understand the daily movements and habitat use of five terrapins within a tidal creek. In conjunction with radiotelemetry, we used micro-dataloggers to continuously monitor both terrapin and environmental temperatures. During high tides, low tides, and ebbing tides, terrapins spent more time in the marsh (*Spartina* sp., mud, and occasional shallow water) than in open water of the creek channel. Terrapins remained within the same tidal creek system and moved a mean total distance of 750 m with individual total distances moved ranging from 440 to 1,159 m. Carapace temperatures of two male terrapins varied from 16.0 to 41.0°C from 13 May until 1 June 2006. Comparing these temperatures to environmental temperatures allowed us to make detailed inferences about basking behavior. This short radiotelemetry study provides new insight to understanding diamondback terrapin habitat use and site fidelity, which will assist in making management decisions and in developing predictive models to estimate population sizes.

Key Words: *Malaclemys terrapin*; radiotelemetry; micro-datalogger; temperature.

INTRODUCTION

Barrier islands on the east coast of the United States provide critical habitat for many endemic species threatened with population decline. Many barrier islands have undergone rapid urban development since the 1980's (Stutz and Pilkey, 2005). Kiawah Island, South Carolina has experienced a human population growth of 62% from 1990 to 2000 (Berkeley-Charleston-Dorchester Council of Governments accessed 12-13-2006), resulting in residential and recreational development of 64% of the island (Town of Kiawah Island Comprehensive Plan Update – May 2005. Chapter 6).

Diamondback terrapins (*Malaclemys terrapin*) (Schoepff 1793) are the only estuarine turtles endemic to brackish water habitats of the eastern and Gulf coasts of the United States (Ernst et al. 1994) and have been described as a "flagship" species of barrier island salt marsh ecosystems (Hoyle and Gibbons, 2000). Terrapin populations declined during the early 1900s because of large-scale commercial harvesting (Gibbons et al. 2001). More recently, terrapin populations have been threatened by anthropogenic factors such as habitat degradation (Seigel 1993; Gibbons et al. 2001), mortality in crab traps (Seigel and Gibbons, 1995; Wood 1997; Dorcas et al. 2007), road mortality (Szerlag and McRobert, 2006) and motorized watercrafts (Gibbons et al. 2001; Tucker et al. 2001). Consequently, it is imperative to understand the activity patterns and habitat use of terrapins in salt marsh ecosystems in order to better discern how anthropogenic factors affect their populations. Radiotelemetry can be used to frequently monitor the activity and habitat use of many animals (Millspaugh and Marzluff, 2001). Combining radiotelemetry with continual animal and environmental temperature monitoring allows detailed inferences to be made about activity and habitat use (Harden and Dorcas in press; Grayson and Dorcas, 2004).

To better understand the spatial and thermal ecology of terrapins, we conducted a radiotelemetric study in the salt marshes of Kiawah Island in Charleston County, South Carolina. Specifically, we combined radiotelemetry with continual temperature monitoring to determine how environmental variables affected activity patterns, habitat use, and temperatures of free-ranging terrapins.

METHODS

This study was conducted in conjunction with a long-term mark-recapture investigation of terrapins, initiated in 1983 (Lovich and Gibbons, 1990). Terrapins were captured on 13 May 2006 from an intertidal creek (Sandy Creek; UTM: E 0582068, N 3608065; Gibbons et al. 2001), which connects to the Kiawah River and is surrounded by *Spartina* sp. salt marsh vegetation. Capture methods consisted of intensive seining of the tidal creek at low tide. All terrapins were measured and marked using techniques described in Tucker et al. (2001) and then returned to their point of capture within 3 hrs. Radiotransmitters (SB-2; Holohil Systems Ltd.; 4 grams) and micro-dataloggers (Thermochron iButtons DS1922L-F51, Dallas Semiconductor, Dallas TX.) programmed to record temperature every 15 min were attached to the posterior carapace of five previously-marked terrapins (three males and two females) with epoxy putty (Loctite® Five Minute Marine Grade Epoxy). See Grayson and Dorcas (2004) for a more detailed description of micro-datalogger use in turtle studies. Five micro-dataloggers set at 15-min intervals were also used to monitor environmental temperatures including mud temperatures adjacent to the creek (at 2 cm and 60 cm deep), mud temperatures in the *Spartina* sp. marsh (at 2 cm deep) and water temperatures in the creek (at the surface and at 6 m in deep hole at low tide). Air temperatures were obtained from the National Weather Service Forecast Office, Charleston, SC (accessed 12-13-2006).

All terrapins were radiotracked from 13 May to 19 May 2006 using a Yagi antenna (Model F164-3FB, Telonics, Mesa, AZ), and a receiver (R1000, Communications Specialists, Inc., Orange, CA) while navigating the creek in a jon boat. We located animals three times a day at low tide, high tide and at ebbing or flowing tide for one week. Once located, we recorded GPS coordinates of each terrapin, tide level, approximate water depth (if in water), minimal distance from creek (if in marsh), mud depth (if found in mud), and activity (e.g., swimming, moving on land). 'Marsh' was defined as terrestrial habitat dominated by *Spartina* sp. and mud, which is usually flooded by shallow water at high tide. 'Creek' was defined as aquatic habitat including the main creek channel and the less flooded tributaries. Tide levels were recorded at the Kiawah River bridge (approximately 500 m from Sandy Creek) and ranged from 0.08 to 1.98 m during the week of radiotracking. A chi-square test was used to examine the effects of tide level on habitat use and used an α of 0.05 to determine significance.

After a week of radiotracking, we attempted to recapture all terrapins, but only captured one animal. At this time, all environmental dataloggers were removed and downloaded. We returned to Kiawah Island 7 July 2006 and recovered three additional terrapins. Upon recovery, radiotransmitters and dataloggers were removed from each turtle's carapace and dataloggers were downloaded providing temperature measurements from 13 May until 1 June 2006, at which time the datalogger memory was full. Two of the four recovered dataloggers were damaged during removal, thus only allowing data retrieval from two dataloggers. We used a geographic information system (GIS; ArcGIS ver. 9.1, ESRI, Redlands, CA) to measure the total distance moved and the straight-line distance between the two farthest points. The two male terrapins with undamaged dataloggers (code HILQ and code HJVX) were of similar size (plastron lengths = 106 and 109 mm; masses = 285 and 325 g, respectively). Using temperature data from these two terrapins, we evaluated animal microhabitat by comparing terrapin temperatures to simultaneous environmental temperatures. Basking was inferred if terrapin temperatures were at least 3°C greater than shallow water temperature (Grayson and Dorcas 2004). Because water temperature was only recorded for six days, basking events were only calculated from 13 to 19 May 2006.

RESULTS

Radiotracking of terrapins was difficult because of limited transmitter signal strength and attenuation of the signal by salt water. However, during most radiotracking sessions 3 to 5 of the terrapins were detected and located, (total number of locations = 59). Although terrapins spent more time in marsh habitat than within the creek during high tides, low tides and ebbing tides, the effect of tide level on habitat use was not statistically significant ($\chi^2 = 4.78$, df = 3, $p = 0.188$; Fig. 1). Terrapins moved a mean total distance of 750.6 m with total distances moved by individuals ranging from 440.0 to 1,159.9 m. The mean straight-line distance between the two farthest points was 642.5 m with individual straight-line distances ranging from 287.6 to 1,035.1 m (Table 1).

Deep and surface water temperatures were similar throughout the study, however, they varied substantially with tide level. Shallow mud temperatures varied from 17.0 to 29.0°C, whereas deep mud temperature remained relatively consistent (20.0°C). From 13 May until 1 June 2006 carapace temperatures varied from 16.0 to 41.0°C for terrapin HILQ and from 18.5 to 38.5°C for terrapin HJVX (Fig. 2). During the six days in which we could determine basking events (see Methods), both terrapins exhibited basking behavior on numerous occasions (Fig. 2). During this time, terrapin HILQ basked an average of 52.5 min per day (range was 0 to 150 min per day) during which time the mean maximal carapace temperature was 25.6°C (range

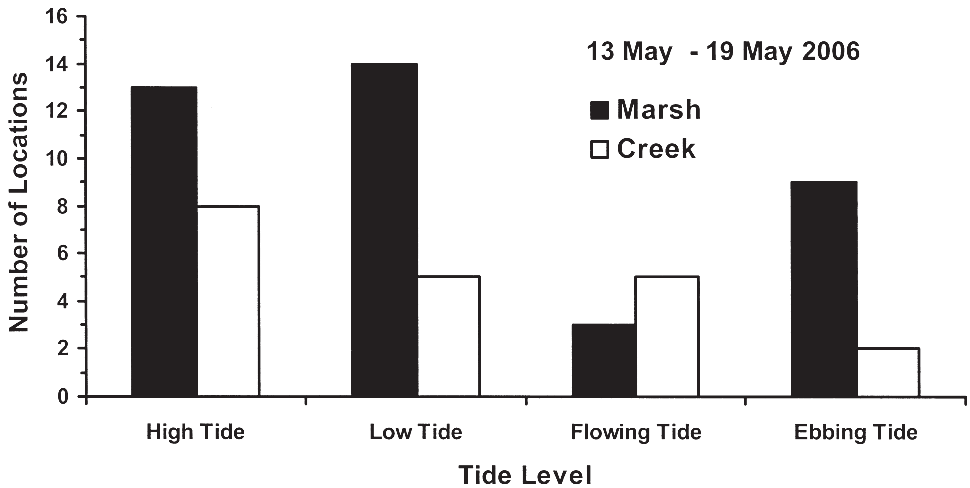

FIG. 1. Number of terrapin locations in the marsh (closed bars) and the open water of the creek (open bars) at low tides, high tides, ebbing tides, and flowing tides from 13 May to 19 May 2006. Terrapins were located three times per day using radiotelemetry; once at low tide, once at high tide and once at either ebbing or flowing tide.

16.0 to 30.5°C). Terrapin HJVX basked an average of 37.5 min per day (range was 0 to 105 min per day) at which time the mean maximal carapace temperature was 26.0°C (range 18.5 to 37.0°C). Basking behavior was inconsistent among days. No basking behavior was evident by either terrapin on 16 May 2006 (Fig. 3a), whereas both terrapins basked for at least 90 min during late morning and early afternoon on 17 May 2006 (Fig. 3b). On 16 May 2006, the high air temperature was 22.0°C and cloud cover was relatively complete throughout the day, whereas on 17 May 2006, cloud cover was partial and the high air temperature was 26.0°C.

DISCUSSION

Our radiotelemetry results on habitat use indicated that diamondback terrapins tended to spend more time in the marsh (terrestrial habitat of *Spartina* sp., mud, and shallow water at high tide) rather than in open water of the creek channel. This finding is supported by the thermal data, from which we can infer basking behavior while in marsh habitat. Similar results were reported in a radiotelemetry study conducted by Spivey (1998), who found that terrapins in a North Carolina salt

Table 1. Turtle ID code, sex, total distance moved, and furthest straight-line distance between two locations from 13 May to 19 May 2006. Distances were measured using ArcGIS.

Turtle ID Code	Sex	Total Distance (m)	Farthest Distance between Two Locations (m)
IMWX	F	1159.9	1035.1
ABJW	F	856.1	745.7
ILOQ	M	720.2	629.9
HJVX	M	576.8	514.2
HILQ	M	440.0	287.6

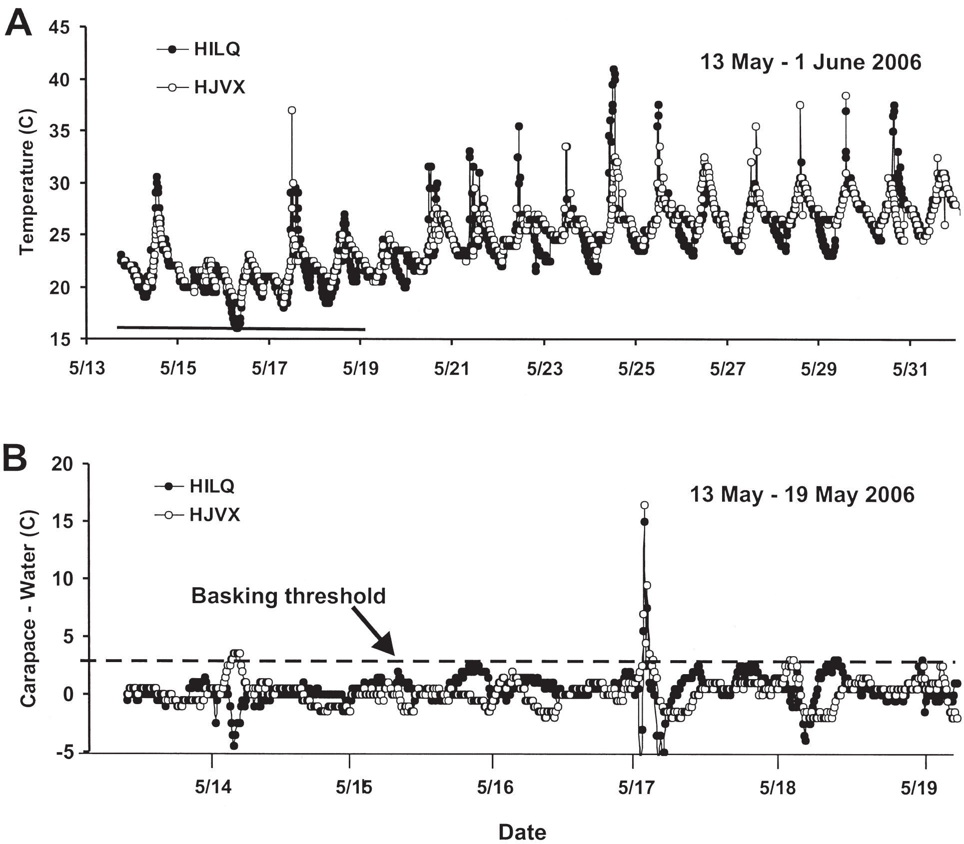

FIG. 2. (A) Carapace temperatures of two male terrapins (HILQ – closed circles and HJVX – open circles) from 13 May to 1 June 2006. Temperatures recorded at 15 min intervals by microdataloggers attached to the carapace of each individual. The horizontal line in part A represents dates displayed in part B. (B) Basking events determined by subtracting the surface water temperature from carapace temperature. Basking events were designated as times when carapace temperature exceeded water temperature by 3.0°C or more (Grayson and Dorcas, 2004).

marsh used "low marsh habitat" (defined as frequently flooded habitat containing *Spartina* sp.) more than any other habitat available.

High levels of marsh habitat use by terrapins could be related to feeding, predator avoidance, and thermoregulation. Several of the terrapins were located in small, infrequently flooded tributaries of the main creek channel and in the marsh at high tide. Muehlbauer (1987) found that terrapins followed flowing high tides to access flooded marsh habitats where they feed. Tucker et al. (1995) found periwinkles (*Littorina irrorata*) (Say 1822), which cling to *Spartina* sp. (Spivey 1998), to be the dominant prey item of terrapins at Kiawah Island. We suspect that terrapins may also move into the shallow marsh habitat to avoid large predators (e.g., sharks) that are able to easily navigate the creek channel, especially at high tide (L. Harden, pers. obs.). Terrapins may also use the shallow marsh habitat for thermoregulatory purposes and, based on our observations, regularly bask on or just below the mud surface. Turtles may be able to remain concealed and still maintain relatively high

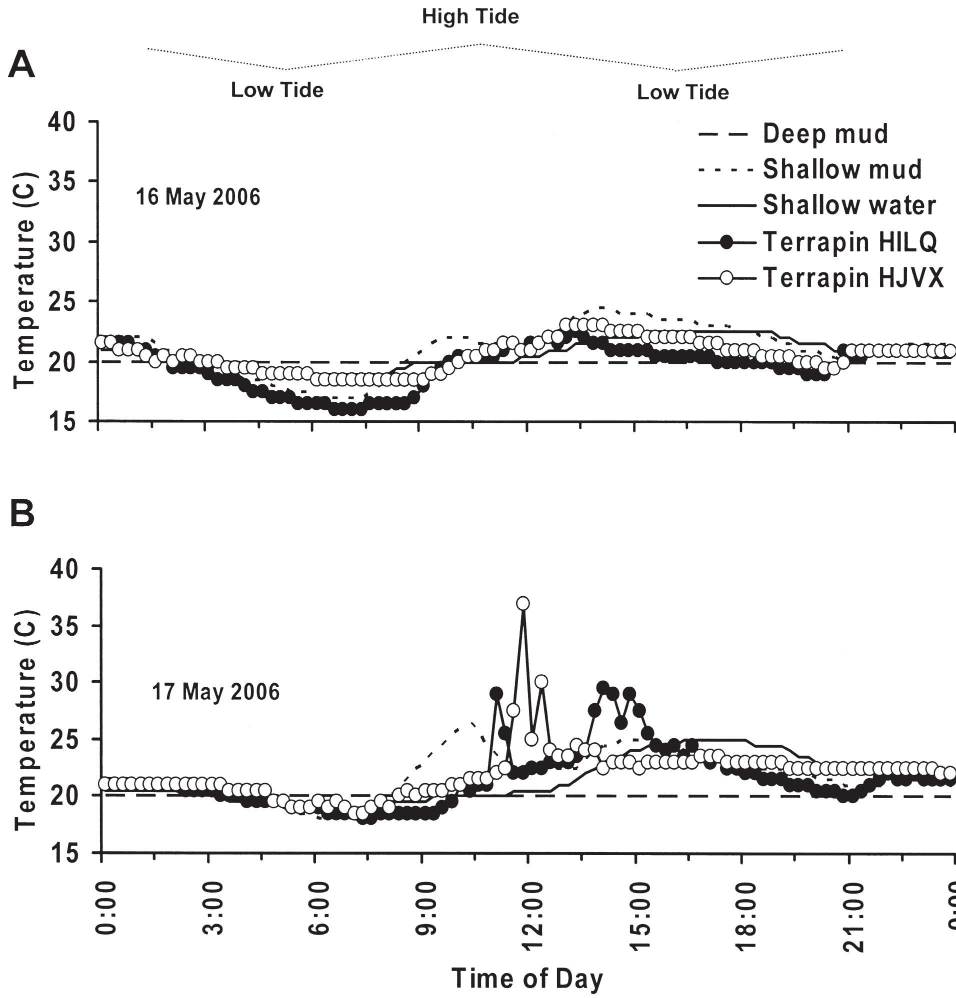

FIG. 3. Carapace temperatures and environmental temperatures recorded by micro-dataloggers at 15 min intervals for two days (16 May and 17 May 2006) within the six-day study. Times of high and low tides indicated at the top of figure vary between 16 May and 17 May by approx. 1 hr. (A) 16 May temperatures of deep mud (long-dashed line), shallow mud (short-dashed line), shallow water (solid line), terrapin HILQ (closed circles), and terrapin HJVX (open circles). Low tides: 5:11 and 17:01; high tides: 11:02 and 23:39. (B) 17 May temperatures of deep mud, shallow mud, shallow water and terrapins HILQ and HJVX. Low tides: 6:00 and 17:52; high tide: 11:55. Sudden spikes in terrapin temperatures indicate basking events.

body temperatures because shallow mud temperatures can be relatively high at times.

We recognize that when terrapins were basking, recorded carapace temperatures were only an approximation of their actual body temperature. Alternately, when terrapins were located in water or buried in mud, recorded carapace temperatures were likely very close to actual body temperature (Grayson and Dorcas, 2004).

Basking is a method of thermoregulation used to raise body temperature (Avery 1982), ultimately affecting factors such as metabolism, growth and activity

(Congdon 1989). When water temperature is cooler than air temperature, terrapins may bask in exposed areas at low tide to raise their temperatures above that of the water. This basking behavior has been observed particularly during May sampling periods when water temperatures were still cool (L. Harden and M. Dorcas, pers. obs.) We have empirical evidence of this behavior on 17 May 2006 when the carapace temperatures of terrapin HJVX and terrapin HILQ reached 16.5°C and 9.0°C above water temperature, respectively (Fig. 3b). Perhaps, as water and mud temperatures increase during the summer, frequency of basking decreases.

Our results further strengthen previous documentation of high site fidelity and low migration rates (Seigel 1993; Gibbons et al. 2001; Tucker et al. 2001). Although our study duration was short and we only radiotracked during the spring season, high site fidelity of terrapins occurred not only to the creek's general vicinity, but in some cases (e.g., terrapin HILQ), to a specific region within the creek. Such high site fidelity supports the contention that localized anthropogenic factors (e.g., urbanization, road construction, crab trapping) can result in substantial detrimental impacts to terrapin populations and even local extinctions (Gibbons et al. 2001). For example, construction of a boat dock in the 1980s coincides with the initiation of a long-term decline in a subpopulation of terrapins (Gibbons et al. 2001). Because of the frequent marsh habitat use and high site fidelity exhibited by terrapins, protection of the salt marsh from anthropogenic disturbances is critical to ensuring continued terrapin presence at Kiawah Island.

More effective monitoring is critical because of documented or apparent declines of terrapin populations throughout their range (Seigel and Gibbons, 1995). However, frequent, intensive sampling like that conducted at Kiawah Island (Lovich and Gibbons, 1990) is often not possible. Consequently, development of less intensive, but effective, monitoring programs (e.g., head-count surveys) is needed but requires a detailed understanding of terrapin activity patterns and habitat use and how they affect terrapin detectability. This study indicates that terrapins spend a considerable amount of time in marsh habitat, thus making them undetectable using traditional aquatic sampling techniques (e.g., seining; Tucker et al. 2001). Therefore, monitoring programs designed to estimate population sizes and/or track changes in populations over time, must account for low detectability and how it is affected by factors such as tide level, season, and other environmental variables.

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LITERATURE CITED

AVERY, B. A. 1982. Field studies of body temperatures. Pp. 25–91 in C. Gans and F. H. Pough (eds.), Biology of the Reptilia, Vol. 12. Academic Press, New York, New York.

BERKELEY-CHARLESTON-DORCHESTER COUNCIL OF GOVERNMENTS. Charleston County. http://www.bcdcog.com/publications/census_data_planarea_census_tract/charlestonco/chas_co_pop_inc_areas.PDF. Accessed 12-13-2006.

CONGDON, J. D. 1989. Proximate and evolutionary constraints on every relation of reptiles. Physiol. Zool. 62:256–273.

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. Biol. Conserv. 137:334–340.

ERNST, C. H., J. E. LOVICH, AND R. W. BARBOUR. 1994. Turtles of the United States and Canada. Smiths. Inst. Press, Washington DC. 578 pp.

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 the diamondback terrapin (*Malaclemys terrapin*) in South Carolina. Chelonian Conserv. Biol. 4:66–74.

GRAYSON, K. L., AND M. E. DORCAS. 2004. Seasonal temperature variation in the painted turtle (*Chrysemys picta*). Herpetologica 60:325–336.

HARDEN, L. A., AND M. E. DORCAS. in press. Using thermal biology to investigate habitat use and activity of eastern mud turtles (*Kinosternon subrubrum subrubrum*) on a golf course. in R. Jung and J. Mitchell (eds.), Urban Herpetology. Herpetological Conservation Vol. 3, Society for the Study of Amphibians and Reptiles. Salt Lake City, UT.

HOYLE, M. E., AND J. W. GIBBONS. 2000. Use of marked population of diamondback terrapins (*Malaclemys terrapin*) to determine impacts of recreational crab pots. Chelonian Conserv. Biol. 3:735–737.

LOVICH, J. E., AND J. W. GIBBONS. 1990. Age at maturity influences adult sex ratio in the turtle *Malaclemys terrapin*. Oikos 59:126–134.

MILLSPAUGH, J. J., AND J. M. MARZLUFF. 2001. Radio Tracking and Animal Populations. Academic Press, California. 474 pp.

MUEHLBAUER, E. I. 1987. Field and laboratory studies of tidal activity in the turtle *Malaclemys terrapin terrapin*. Unpubl. Ph.D. Diss., New York Univ, New York.

NATIONAL WEATHER SERVICE FORECAST OFFICE. Charleston, SC. http://www.weather.gov/climate/index.php?wfo=chs. Accessed 12-13-2006.

SEIGEL, R. A. 1993. Apparent long-term decline in diamondback terrapin populations at the Kennedy Space Center, Florida. Herpetol Rev. 24:102–103.

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 Conserv.Biol. 1:240–243.

SPIVEY, P. B. 1998. Home range, habitat selection, and diet of the diamondback terrapin (*Malaclemys terrapin*) in a North Carolina estuary. Unpubl. M. S. Thesis, University of Georgia, Athens. 80 pp.

STUTZ, M. L., AND O. H. PILKEY. 2005. The relative influence of humans on barrier islands: humans versus geomorphology. Pp. 137–147 in I. Ehlen, W. C. Haneberg, and R. A. Larson (eds.), Humans as Geologic Agents: Geol. Soc. of Amer. Rev. Engineering Geology, Vol. 16. Boulder, Colorado.

SZERLAG, S., AND S. P. MCROBERT. 2006. Road occurrence and mortality of the northern diamondback terrapin. Applied Herpetol. 3:27–37.

TOWN OF KIAWAH ISLAND COMPREHENSIVE PLAN UPDATE – May 2005 Introduction. www.kiawahisland.org/uploads/introduction.pdf. Accessed 12-13-2006.

TUCKER, A. D., N. FITZSIMMONS, AND J. W. GIBBONS. 1995. Resource partitioning by the estuarine turtle, *Malaclemys terrapin*: trophic, spatial, and temporal foraging constraints. Herpetologica 51:167–181.

TUCKER, A. D., J. W. GIBBONS, AND J. L. GREENE. 2001. Estimates of adult survival and migration for diamondback terrapins: conservation insight from local extirpation within a metapopulation. Can. J. Zool. 79:2199–2209.

WOOD, R. C. 1997. The impacts of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin*. Pp. 46–53 in J. Van Abbema (ed.). Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles - An Internat. Conf.

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