



Factors affecting temperature variation and habitat use in free-ranging diamondback terrapins



C.D. Akins^a, C.D. Ruder^a, S.J. Price^b, L.A. Harden^{a,*}, J.W. Gibbons^c, M.E. Dorcas^a

^a Department of Biology, Davidson College, Davidson, NC 28035, USA

^b Department of Forestry, University of Kentucky, Lexington, KY 40546, USA

^c Savannah River Ecology Laboratory, University of Georgia, Aiken, SC 29802, USA

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ABSTRACT

Measuring the thermal conditions of aquatic reptiles with temperature dataloggers is a cost-effective way to study their behavior and habitat use. Temperature dataloggers are a particularly useful and informative approach to studying organisms such as the estuarine diamondback terrapin (*Malaclemys terrapin*) that inhabits a dynamic environment often inaccessible to researchers. We used carapace-mounted dataloggers to measure hourly carapace temperature (T_c) of free-ranging terrapins in South Carolina from October 2007 to 2008 to examine the effects of month, sex, creek site, and tide on T_c and to determine the effects of month, sex, and time of day on terrapin basking frequency. Simultaneous measurements of environmental temperatures (T_e : shallow mud, deep mud, water) allowed us to make inferences about terrapin microhabitat use. Terrapin T_c differed significantly among months and creek and between sexes. Terrapin microhabitat use also varied monthly, with shallow mud temperature being the best predictor of T_c November–March and water temperature being the best predictor of T_c April–October. Terrapins basked most frequently in spring and fall and males basked more frequently than females. Our study contributes to a fuller understanding of terrapin thermal biology and provides support for using dataloggers to investigate behavior and habitat use of aquatic ectotherms inhabiting dynamic environments.

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1. Introduction

Changes in temperature have profound effects on the rates of many physiological processes, particularly those of ectotherms whose body temperatures (T_b) are directly influenced by temperatures of their environment (T_e ; Beitinger and Fitzpatrick, 1979; Huey, 1982; Fitzgerald and Nelson, 2011). Ectotherms produce little metabolic heat, and must employ thermoregulatory behaviors such as basking and microhabitat selection to promote optimal physiological performance for locomotion, energy acquisition, reproduction, and other processes (Stevenson, 1985; Rowe and Dalgarn, 2009; Bulte and Blouin-Demers, 2010). Semi-aquatic ectotherms (e.g. many reptiles) rely on a combination of solar radiation and available T_e , such as water and substrate temperature, to regulate T_b . The effectiveness of a particular environment for thermoregulation may change seasonally, daily, or even hourly depending on specific properties of the microhabitats (Heatwole and Taylor, 1987). Thus, examining T_e in conjunction with temperatures of free-ranging, semi-aquatic reptiles is critical to

understanding the nuances of individual thermal variation, and may provide insights into behaviors (e.g. basking, burrowing, swimming) and habitat use (Peterson et al., 1993).

The semi-aquatic diamondback terrapin (*Malaclemys terrapin*) provides a reptilian model for investigating thermal variation and temperature-inferred habitat use because of the dynamic coastal ecosystem in which it lives. Terrapins inhabit salt marsh estuaries along the Eastern and Gulf coasts of the United States and they experience the dramatic variations in environmental factors associated with tidal and seasonal fluctuations (e.g., temperature, water level, salinity and oxygen availability; Ernst and Lovich, 2009; Largier, 2010). Salinity can change from nearly fresh to nearly marine within a single tidal cycle (NOAA, 2005) and tidal amplitude can be up to two meters (Kana et al., 1984). Furthermore, water temperatures within many coastal estuaries can range from near freezing to above 30 °C (Dame et al., 2000), depending on the season and latitude. Terrapins also experience dramatic temperature fluctuations as a result of season or time of day. Williard and Harden (2011) documented terrapins experiencing 7 °C summer temperature variations and 9 °C winter temperature variations (including sub-zero temperatures), both within 24-h time periods.

* Corresponding author. Tel.: +1 704 894 3096.

E-mail address: leharden@davidson.edu (L.A. Harden).

Environmental fluctuations within estuaries likely have strong effects on terrapin T_b and various physiological processes, and may result in subsequent changes in habitat use. Previous studies have investigated thermal biology and habitat use of other semi-aquatic turtles by recording T_b or T_c (carapace temperature) and T_e with microdataloggers (Grayson and Dorcas, 2004; Harden et al., 2007; Dubois et al., 2009; Pittman and Dorcas, 2009; Rowe and Dalgarn, 2009; Bulte and Blouin-Demers, 2010), however, few studies have used this affordable and remote monitoring technique to measure thermal variation and assess temperature-inferred habitat use of diamondback terrapins in their uniquely dynamic environment (but see Harden et al. (2007) and Williard and Harden (2011)). We used temperature microdataloggers to measure environmental temperatures (T_e ; water, deep mud, shallow mud) and terrapin carapace temperatures (T_c , used as a proxy for T_b , see Section 2.4 for more detail) for 1 year in two salt marsh tidal creeks to address the following study objectives: 1) investigate the effects of month, sex, creek site, and tide level on terrapin T_c , 2) evaluate the relationships between T_e and T_c to infer seasonal variation in habitat use, and 3) examine the effects of month, sex, and time of day on basking behavior.

2. Materials and methods

2.1. Study area

This study was conducted in conjunction with long-term mark-recapture sampling of terrapins, initiated in 1983 (Lovich and Gibbons, 1990). We executed this study in two tidal creek tributaries, known as Fiddler creek and Oyster creek, of the Kiawah River adjacent to Kiawah Island, Charleston County, South Carolina, USA. Both tidal creeks were bordered by salt marsh dominated by *Spartina alterniflora* (for more information on the study site see Materials and Methods of Dorcas et al. (2007) and citations within).

2.2. Turtle capture and datalogger attachment

During 2007 and 2008, we captured terrapins using trammel nets and seines, primarily during low tides (Lovich and Gibbons, 1990) within the two aforementioned tributaries. Upon capture, any unmarked terrapins were uniquely marked by filing notches into their marginal scutes (Sexton, 1959). Measurements taken on each turtle included straight-line carapace length (SCL), plastron length, width, depth and mass (Tucker et al., 2001). Body mass was measured to the nearest gram using a digital scale. We determined sex via tail length and other secondary sex characteristics (Dorcas et al., 2007). All terrapins were returned to their location of capture within three days.

Prior to release, we attached temperature microdataloggers (iButton Thermochrons, Dallas Semiconductor, Dallas, TX; accuracy ± 0.5 °C; Grayson and Dorcas, 2004; Pittman and Dorcas, 2009) to the posterior carapace of each terrapin using marine-grade epoxy (Loctite Five Minute Marine Grade Epoxy, Avon, OH). We selected individuals for datalogger attachment based on previous capture frequency, which we believed would increase the probability of retrieving the dataloggers at the next sampling period. Before attachment, dataloggers were programmed following the protocols of Grayson and Dorcas (2004) to record T_c at 60-min intervals and were then covered in plastic tool dip (Plasti-Dip International, Circle Pines, MN) to prevent water damage. The amount of epoxy used for attachment was limited to reduce the weight carried by the turtle ($\leq 6\%$ of the smallest turtle's mass). Previous investigations have shown that carapace temperature is strongly correlated with body temperature (Grayson and Dorcas,

2004; Chen and Lue, 2008). However, we did not directly compare body temperature and carapace temperature of terrapins in this study. Consequently, carapace temperatures may differ slightly from actual body temperature, especially during basking. Dataloggers recorded temperatures hourly from 16 October 2007 through 12 October 2008 with the exception of 17–23 May 2008 while they were being replaced. Overall, we recovered dataloggers and were able to evaluate T_c from 17 individual terrapins (males=12, females=5) during 2007 and 2008, although the duration of data collection varied among individual terrapins: 16 Oct. 2007–17 May 2008 ($n=4$), 16 Oct. 2007–29 May 2008 ($n=5$), 16 Oct. 2007–15 Sept. 2008 ($n=2$), 12 May 2008–10 Oct. 2008 ($n=4$), and 28 June 2008–12 Oct. 2008 ($n=2$).

2.3. Environmental data collection

We measured environmental temperatures (T_e) by placing the same model of microdataloggers used to measure T_c in each of three possible microhabitats used by terrapins: water (15 cm below the water surface; $n=2$), shallow mud (10 cm mud depth; $n=2$) and deep mud (45 cm mud depth; $n=2$). The water habitat microdatalogger was secured 15 cm below a buoy tied to a rope and weighted by a small anchor. The two mud habitat microdataloggers were secured to a wooden stake using duct tape at the two designated mud depths (10 and 45 cm) and placed in the intertidal creekbank marsh of their respective creek site. One water datalogger and one wooden stake with two mud dataloggers were deployed at each field site, Fiddler and Oyster creek. Because tide level may influence both T_e and T_c , we obtained 2007–2008 tide information from a National Oceanic and Atmospheric Administration tidal station ~ 45 km from Kiawah Island in Charleston, SC (NOAA National Data Buoy Center, Station CHTS1-8665530).

2.4. Data analysis

To evaluate the effects of month ($n=12$), sex ($n=2$), and creek ($n=2$) on terrapin T_c , we performed a generalized linear model (GLM; SAS v. 9.2). To avoid auto-correlation among our T_c data, we randomly selected 30 daytime time-stamped T_c (decided by examining the average time of sunrise and set within each month) from both tidal creeks for each week, resulting in a total of 1560 data points over the course of the year-long study. To evaluate the effects of tide level (low, high; $n=2$) on male and female terrapin T_c , we matched the available tide data to our time-stamped T_c data in order to identify the time points closest to both high and low tides for each day. Because each high or low tide time point was roughly 12 h removed from the previous tide time point, auto-correlation within this dataset was not an issue. Prior to analysis, all T_c data were separated by sex and log transformed to conform to the assumptions of parametric statistical analysis and then analyzed using a GLM to examine month, sex, creek, and tide as predictors of terrapin T_c . Significance of these independent variables was assessed using an $\alpha=0.05$. Finally, we used a Duncan's multiple-range test to investigate significant differences in mean terrapin T_c among our independent variables, which allowed us to determine if monthly differences in mean T_c differed, and whether mean T_c was different between sites, between sexes, and between high and low tide.

To evaluate the relationships between T_e and T_c and infer monthly habitat use, we used a corresponding subset of 30 weekly, daytime, time-stamped T_c from both tidal creeks and corresponding T_e (water, shallow mud, deep mud). All T_c and T_e data were log transformed to conform to the assumptions of parametric statistical analysis. We used linear regression to assess the effectiveness of each environmental predictor on terrapin T_c . We used an

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