



## Response of juvenile diamond-backed terrapins (*Malaclemys terrapin*) to an aquatic thermal gradient



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### ABSTRACT

In many ectotherms, selection of environmental thermal niches may positively affect growth, nutrient assimilation rates, immune system function, and ultimately survival. Temperature preference in some turtle species may be influenced by environmental conditions, including acclimation temperature. We tested for effects of acclimation temperature (22 °C, 27 °C) on the selected temperature and movement patterns of 14 juvenile *Malaclemys terrapin* (Reptilia: Emydidae) in an aquatic thermal gradient of 14–34 °C and in single-temperature (22 °C, 27 °C) control tests. Among 8–10 month old terrapins, acclimation temperature influenced activity and movement patterns but did not affect temperature selection. In thermal gradient and single-temperature control tests, turtles acclimated to 27 °C used more tank chambers and relocated between chambers significantly more frequently than individuals acclimated to 22 °C. However, acclimation temperature did not affect temperature selection: both 22- and 27 °C-acclimated turtles selected the warmest temperature (34 °C), and avoided the other temperatures available, during thermal gradient tests. These results suggest that young *M. terrapin* are capable of detecting small temperature increments and prefer warm temperatures that may positively influence growth and metabolism.

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### 1. Introduction

Juveniles of many species of aquatic turtles are capable of sensing small temperature increments and thermoregulating in thermal gradients and during basking behavior in the wild (Janzen et al., 1992; Lindeman, 1993; Nebeker and Bury, 2001). Maximizing growth rates by young turtles and reaching an adult size as rapidly as possible is a critical factor that positively impacts fitness (Brooks et al., 1991; Roosenburg and Kelley, 1996). Detecting environmental temperature, and subsequently selecting thermal niches that positively affect growth rates, digestion efficiency, and immune system function, benefits young turtles at a critical life stage in which they have an abundance of potential predators (Hammond et al., 1988; O'Steen, 1998; Rhen and Lang, 1999).

Juvenile turtles placed in laboratory-based aquatic thermal gradients typically select warm (27–34 °C) temperatures, but various environmental factors impact their temperature selection. These factors include egg incubation temperature (O'Steen, 1998; Rhen and Lang, 1999; Tamplin and Cyr, 2011), ontogenetic stage (Williamson et al., 1989; Bury et al., 2000; Nebeker and Bury, 2001; Tamplin, 2009), acclimation temperature (Williamson et al., 1989; Tamplin and Cyr, 2011), and substrate type (Nebeker and

Bury, 2001; Feltz and Tamplin, 2007). To date, the responses to thermal gradients of a wide variety of taxa from several turtle families have been studied (Trionychidae: *Apalone mutica*, Nebeker and Bury, 2001; *Apalone spinifera*, Feltz and Tamplin, 2007; Chelydridae: *Chelydra serpentina*, Williamson et al., 1989, O'Steen, 1998, Bury et al., 2000; and Emydidae: *Chrysemys picta*, Tamplin and Cyr, 2011; *Glyptemys insculpta*, Tamplin, 2006, 2009; *Pseudemys nelsoni*, Nebeker and Bury, 2000; and *Trachemys scripta*, Jarling et al., 1984, 1989; Bury et al., 2000). Many of these studies have indicated that hatchlings and juveniles from these species can both sense and select particular temperatures, but that temperature preference may be modified by environmental and developmental conditions (see Tamplin and Cyr, 2011).

Acclimation temperature affects the physiology of nearly all reptiles, and several studies have suggested it may impact the thermal preferences of some juvenile turtles (Hammond et al., 1988; O'Steen, 1998; Rhen and Lang, 1999; Tamplin and Cyr, 2011). However, selected temperature was not affected by acclimation to either to 15 or 25 °C in three- and eight-month old snapping turtles (*C. serpentina*; Williamson et al., 1989) or in adult red-eared sliders (*T. scripta*) acclimated to 3, 8–11, and 19 °C (Crawshaw et al., 1980). Conclusive patterns have not yet been discerned because there is a paucity of data on the effect of acclimation temperature on temperature preference for most turtle species.

Diamond-backed terrapins (Emydidae: *Malaclemys terrapin*) are small to medium-sized turtles [maximum carapace length=14

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(males)–29 cm (females)] that inhabit North American coastal areas ranging from Cape Cod, Massachusetts to Corpus Christi, Texas (Ernst and Lovich, 2009). A highly aquatic species, *M. terrapin* frequents coastal salt marshes, mangrove thickets, shellfish beds, estuaries, bays, and tidal creeks (Ernst and Lovich, 2009). They are diurnal and thermoregulate via aerial and aquatic basking (Ernst and Lovich, 2009). They utilize aerial basking more frequently when deprived of freshwater (Davenport and Magill, 1996) and frequently bask aquatically to maintain specific body temperatures while reducing dehydration (Brennessel, 2006). Because of their extensive latitudinal distribution, their annual activity cycle varies greatly across their range and is dictated primarily by temperature. In northern populations, they are active from April to November, when water temperatures typically range from 22 to 24 °C; they emerge from hibernation when spring water temperatures reach 13 °C (Brennessel, 2006). In southern populations, they often move in and out of dormancy and may be active on warm winter days (Ernst and Lovich, 2009). *Malaclemys terrapin* typically hibernate underwater, although some have been found brumating in moist sand or mud near the high tide line during winter (Lawler and Musick, 1972; Yearicks et al., 1981). Mortality rates during hibernation are low, indicating they can successfully acclimate to winter temperatures, but a mass die-off was reported at the northern edge of their range when a sudden drop in water temperature apparently cold-shocked a population before hibernation began (Lewis, 2000). Hatchlings may overwinter in the nest and are dormant at winter temperatures (Gibbons and Nelson, 1978; Lazell and Auger, 1981; Mitchell and Denmon, 2005; they are freeze-tolerant and survive at least 7 d at –2.5 °C (Baker et al., 2006). In captivity, juvenile terrapins become dormant at 5–7 °C (Dimond, 1987). Hatchlings maintained at 26–28 °C grow more rapidly than those maintained at lower temperatures (Brennessel, 2006).

Although thermal factors and temperature relationships impacting terrapin eggs and nests are known (Cunningham, 1939; Burger, 1976a; Roosenburg and Kelley, 1996), no studies exist on the temperature preferences and thermal activity patterns of *M. terrapin* between hatching and the attainment of sexual maturity. Adult terrapins do not feed when water temperatures are below 15 °C (Davenport and Ward, 1993). Based on feeding rate data, the thermal zone of activity of adult *M. terrapin* is between 20 and 35 °C; high  $Q_{10}$  values (20.7) between 15 and 20 °C indicate they become hypometabolic below 20 °C (Davenport and Ward, 1993).

We tested thermal responses and movement patterns of 8–10 month old juvenile *M. terrapin* in an aquatic thermal gradient of 14–34 °C and in single-temperature control tests run at the acclimation temperature of each treatment group (22 °C or 27 °C). We tested three hypotheses: (1) that hatchlings will select warm temperatures, and avoid cold temperatures, when exposed to a temperature gradient within their normal active range; (2) that acclimation temperature will affect temperature selection in an aquatic thermal gradient; and (3) that acclimation temperature will affect activity and movement patterns under both thermal gradient and single-temperature control conditions.

## 2. Materials and methods

We obtained 24 *M. terrapin* hatchlings in September 2008 from Loggerhead Acres Turtle Farm in Strafford, Missouri. Eggs were incubated in moistened vermiculite (≈ equal mass of dry vermiculite and deionized water). To produce a mixture of males and females and to mimic natural conditions, egg temperatures were allowed to fluctuate and ranged from 26.5 to 29.5 °C. Hatchlings were initially weighed and measured, and then separated into two groups with equivalent mean body size.

We maintained the hatchlings at either 22 ± 1.0 °C or 27 ± 1.0 °C in individual 14 L plastic containers that measured 35 (l) × 31 (w) × 15 (h) cm. Hatchlings had access to both wet and dry basking areas, artificial vegetative cover, and were exposed to fluorescent and UVA and UVB lamps daily (12 h light:12 h dark cycle). Hatchlings were maintained in brackish water with a specific gravity of 1.014 (=20‰); waste material was removed every 48 h and maintenance chambers were thoroughly cleaned weekly. Turtles were soaked in reverse osmosis (RO) water 3–4 times per week for 5–6 h and simultaneously fed ad libitum on a mixture of turtle pellets and dried shrimp. Exposure to freshwater maintained their hydration state and was used to acclimate them to the gradient tank conditions.

Morphological measurements (mass, carapace length, and plastron length) were measured monthly at age 8–10 months and values were averaged to determine mean body size of the hatchlings during testing. Hatchlings acclimated to 22 °C had measurements for body mass ( $\bar{x}$  = 13.84 ± 2.27 SD g), carapace length ( $\bar{x}$  = 39.27 ± 2.43 SD mm), and plastron length ( $\bar{x}$  = 32.83 ± 1.69 SD mm). Hatchlings acclimated to 27 °C had measurements for body mass ( $\bar{x}$  = 14.33 ± 2.83 SD g), carapace length ( $\bar{x}$  = 39.43 ± 2.85 SD mm), and plastron length ( $\bar{x}$  = 33.48 ± 2.68 SD mm). Unpaired t-tests of each treatment group indicated that neither body mass (d.f. = 12; t-value = 0.357; p-value = 0.724), carapace length (d.f. = 12; t-value = 0.132; p-value = 0.897), nor plastron length (d.f. = 12; t-value = 0.267; p-value = 0.794) were different between the groups.

The gradient tank was 176 (l) × 84 (w) × 15 (h) cm and composed of 6 equal sized chambers, each 69 (l) × 27 (w) × 15 (h) cm, and a common area [15 (l) × 176 (w) × 15 (h) cm] through which turtles could easily move into and out of each chamber (see Tamplin 2006, 2009). Chamber temperature was regulated by delivering varying amounts of warm (36 °C) and cold (10 °C) water to one end of each chamber; water was mixed via aeration and then flowed to an outlet valve at the opposite end of the chamber. Water depth was 7.5 cm throughout the tank. We controlled water flow rate via needle valves and flow rates of each chamber were adjusted periodically to maintain the desired temperature; during experimental tests, flow rate varied between 1.2 and 1.8 L per min per chamber. Each chamber held two aeration stones (a 15 cm long bar at the chamber head and a 45 cm long bar along the length of the chamber), a 2 cm pea gravel substrate, and artificial plants to provide cover and resting areas.

Water temperature (± 0.1 °C) was measured continuously via 12 remote-input sensors (Fisher Scientific digital thermometer, model 14-648-46) and checked against a manual probe inserted at several locations and intervals throughout the experiments. High flow rates and vigorous aeration prevented thermal stratification and maintained temperature within 0.5 °C at any one location in each chamber; locations in the common area near the outlet valves did show some thermal mixing, but these areas did not differ more than 1.6 °C from the chamber interior. Temperature increments between chambers were maintained at approximately 4 °C intervals in gradient tests and 0 °C in control tests. Within-chamber temperatures varied slightly during experimental tests; most runs produced temperature fluctuations of less than 1 °C (e.g., 26 °C = 25.4–26.3 °C). All runs were performed during daylight, under similar lighting conditions as the maintenance chambers, and occurred between 12:00 and 19:30 h. Turtles were fed approximately 48 h before each test run.

We tested hatchlings in an aquatic thermal gradient of 14–34 °C and in single-temperature control runs at 8–10 months of age. Control tests were run at each treatment group's acclimation temperature (22 °C or 27 °C) to determine if factors other than temperature were affecting turtle distribution in the tank, to identify potential differences in activity and movement when a

thermal gradient was present or absent, and to test for effects of acclimation temperature on movement patterns. Before each test replicate, the carapace of each hatchling was marked with non-toxic white paint to identify individuals, which assured that temperature observations for each turtle were not unintentionally replicated, and that each turtle was sampled once at each time interval during test runs.

We numbered chambers for control runs and assigned a temperature for gradient runs. Turtles ( $n=7$  per group) were tested by acclimation temperature, and each turtle was tested in 8 replicates of gradients and controls. For each treatment group in gradient replicates, we arranged temperatures sequentially (the high temperature opposite the low temperature) for two runs and non-sequentially (mixed temperatures among the six chambers) for six runs, so that each chamber was assigned each temperature for one replicate. Sequential temperature arrangements were reversed on alternating gradient replicates so that the warm and the cold end were switched on successive runs. Control and gradient replicates were alternated, and usually performed on successive days, so that each turtle in each treatment group was tested approximately once or twice per week. In gradient replicates, turtles were placed into the common area, at a location with the temperature nearest their acclimation temperature (22 °C or 27 °C). In control replicates, turtles were placed in the corresponding location. Turtles were allowed 1 h for habituation, then observations of individual location were recorded every 10 min for 3 h (18 total observations per individual per test run, 1008 total observations per treatment group). Because the temperatures were similar, turtles located in the common area during gradient replicates were assigned to the closest chamber. We recorded the location of each turtle, and calculated the total number of observations per individual turtle at each temperature or chamber across the eight gradient or control replicates, respectively. Turtles that switched chambers between 10 min observations were noted as relocated. Mean number of chamber relocations per test, percentage of observations involving a relocation, and mean number of chambers visited per turtle were calculated for control and gradient tests and analyzed by acclimation temperature. Because the first observation was not considered a potential relocation, the maximum number of chamber relocations per individual per test was 17.

We used repeated measures ANOVA (Abacus Concepts, 1994) to determine whether the number of observations of turtles in each

temperature or chamber varied due to the effects of temperature (in the gradient runs) or chamber number (in control runs), individual turtle ID, acclimation temperature, or replicate number, and if the interactions between these factors were significant ( $\alpha=0.05$ ). Because each chamber number of the control replicates did not correspond to a specific temperature in the gradient replicates, we ran separate repeated measures ANOVAs for control and gradient tests with chamber number (for control runs), or temperature (for gradient runs), turtle ID, replicate number, and acclimation temperature as predictors. Because relocation and chamber usage data for each turtle were independent (one value per turtle per replicate), we used one-way ANOVAs (SPSS Inc., Chicago, IL) to test for significant effects of acclimation temperature on movement and activity. If significant effects were identified by the ANOVAs, we used Tukey B multiple comparisons tests to determine if acclimation temperature affected temperature (or chamber) selection, the mean number of relocations, and the mean numbers of chambers used.

### 3. Results

#### 3.1. Chamber selection (control tests)

Repeated measures ANOVA indicated that chamber number and replicate number, and the interaction between chamber number and turtle ID, affected chamber selection, suggesting that individual turtles were not evenly distributed across the chambers during control runs, and that these distributions were different between the replicates (Table 1). However, individual turtle ID and acclimation temperature did not affect distribution, indicating that the treatment effect of acclimation temperature did not affect chamber selection among individual turtles during single-temperature control runs. Some turtles chose specific chambers differentially across the replicates during control runs, as evidenced by the significant interaction between chamber number and turtle ID. However, the interaction between chamber number and replicate number, and chamber number and acclimation temperature, as well as the interaction between chamber number, replicate number, and acclimation temperature did not affect turtle distribution, further supporting that acclimation temperature did not influence chamber selection during the control replicates. In single-temperature control tests, turtles from both

**Table 1**  
Repeated measures ANOVA table of factors influencing temperature or chamber selection of 14 diamond-backed terrapin (*M. terrapin*) hatchlings. (A) Single-temperature control tests (8 replicates) run at each treatment group's acclimation temperature (22 °C or 27 °C); (B) aquatic thermal gradient (14–34 °C) tests (8 replicates). Significant  $p$ -values are indicated by bold numbers.

Effect (source of variation)	Sum of squares	d.f.	Mean square	F-value	$p$ -value
<b>(A) Control tests (22 °C or 27 °C)</b>					
Chamber number	2915.121	5	583.024	43.663	< <b>0.0001</b>
Turtle ID	453.034	13	34.849	1.245	0.2601
Acclimation temperature	37.786	1	37.786	1.531	0.2189
Replicate number	425.087	7	60.727	2.461	<b>0.0229</b>
Chamber number × Turtle ID	843.734	221	3.818	1.305	<b>0.0030</b>
Chamber number × Acclimation temperature	28.696	17	1.688	0.540	0.9289
Chamber number × Replicate number	339.359	119	2.852	0.927	0.6985
Chamber number × Replicate number × Acclimation temp.	327.827	119	2.755	0.895	0.7795
<b>(B) Thermal gradient tests (14–34 °C)</b>					
Temperature	6501.786	5	1300.357	67.706	< <b>0.0001</b>
Turtle ID	8650.802	13	665.446	1.499	0.1312
Acclimation temperature	1380.071	1	1380.071	3.232	0.0754
Replicate number	6745.897	7	963.700	2.257	<b>0.0360</b>
Temperature × Turtle ID	4071.913	221	18.425	1.099	0.1655
Temperature × Acclimation temperature	97.500	17	5.735	0.334	0.9950
Temperature × Replicate number	2111.389	119	17.743	1.032	0.3911
Temperature × Replicate number × Acclimation temperature	1735.833	119	14.587	0.849	0.8757

acclimation temperature treatment groups cumulatively chose the end chambers (27.4%, 37.4% of observations) (Fig. 1), and generally avoided the middle chambers (5.7–10.7% of observations) (Table 2).

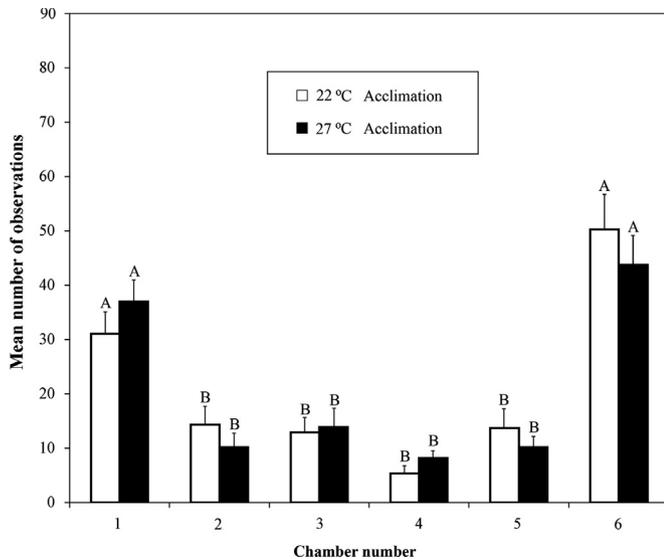
### 3.2. Temperature selection (gradient tests)

Repeated measures ANOVA indicated that only chamber temperature and replicate number affected turtle distribution during gradient runs (see Table 1). Because different temperatures were assigned to each chamber across the replicates, both of these results support specific temperature selection by turtles during the gradient tests. Because turtles acclimated to both 22 °C and 27 °C selected the same temperature (34 °C), neither acclimation temperature nor individual turtle ID affected turtle distribution during the gradient runs. Similarly, the interactions between chamber temperature and acclimation temperature, turtle ID, and replicate number, did not affect turtle distribution. In addition, the interaction between chamber temperature, replicate number, and acclimation temperature also did not affect turtle distribution (i.e., temperature selection during the gradient tests).

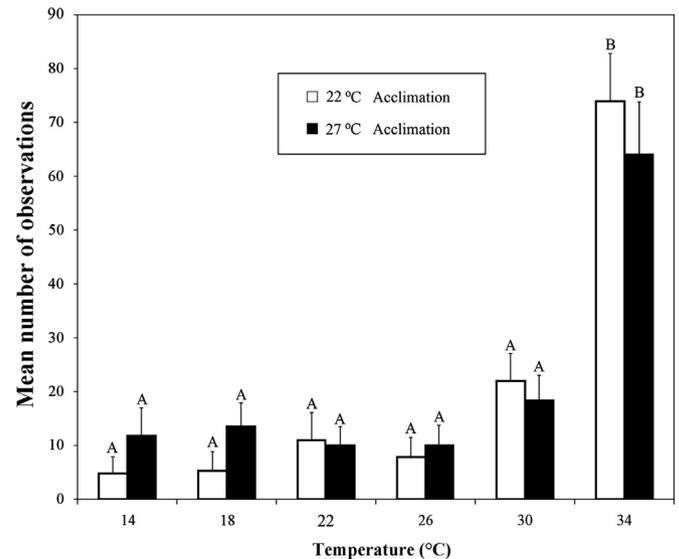
Acclimation temperature did not influence temperature selection among 14 *M. terrapin* juveniles. Turtles from both acclimation temperatures selected the warmest temperature available (34 °C) during gradient runs (Fig. 2). Turtles acclimated to 22 °C showed higher mean observations at 34 °C than did animals acclimated to 27 °C, but homogenous subsets of temperature selection (produced by Tukey B analysis) indicated that these values were not different. Turtles acclimated to 22 °C selected the warmest temperature (34 °C=58.7% of observations) more frequently than the remaining temperatures. Selection of the remaining available temperatures did not exceed 17.3% of observations, and observations in the two coldest temperatures (14 and 18 °C) represented only 4.3% and 4.6% of observations, respectively (see Table 2). Turtles acclimated to 27 °C also selected the warmest temperature (34 °C=50.7% of observations) more frequently than the remaining temperatures and avoided the remaining temperatures (range=7.9–14.9%).

### 3.3. Movement and activity

One-way ANOVAs of relocation data indicated that acclimation temperature affected the number of relocations in both control



**Fig. 1.** The mean (+SE) number of observations of 14 juvenile diamond-backed terrapins (*Maclemys terrapin*) acclimated to either 22 °C or 27 °C in each chamber in single temperature control tests run at each group's acclimation temperature. Observations were made every 10 min for 3 h (18 observations • turtle<sup>-1</sup> • test run<sup>-1</sup>; n<sub>control</sub>=1008). Each treatment group (22 °C or 27 °C acclimation temperature) consisted of 7 turtles, with 144 observations recorded per turtle. Letters indicate within-treatment homogenous subsets as indicated by Tukey B multiple comparisons tests (p < 0.05).



**Fig. 2.** The mean (+SE) number of observations of 14 juvenile diamond-backed terrapins (*M. terrapin*) acclimated to either 22 °C or 27 °C at each temperature in an aquatic thermal gradient (14–34 °C). Observations were made every 10 min for 3 h (18 observations • turtle<sup>-1</sup> • test run<sup>-1</sup>; n<sub>gradient</sub>=1008). Each treatment group (22 °C or 27 °C acclimation temperature) consisted of 7 turtles, with 144 observations recorded per turtle. Letters indicate within-treatment homogenous subsets as indicated by Tukey B multiple comparisons tests (p < 0.05).

**Table 2**

Number of observations of 14 diamond-backed terrapin (*M. terrapin*) hatchlings, acclimated to 22 °C or 27 °C (AT), at 10 min intervals for 3 h, at each temperature in aquatic thermal gradient (14–34 °C) and single-temperature control tests that were run at each treatment group's acclimation temperature (22 °C or 27 °C). Seven turtles were included in each AT treatment group.

Test conditions	Acclimation temp. (AT)	# Replicates	Chamber 1	Chamber 2	Chamber 3	Chamber 4	Chamber 5	Chamber 6	Control total
Control									
(22 °C)	22 °C	8	247 (24.5%)	110 (10.9%)	97 (9.6%)	45 (4.5%)	103 (10.2%)	406 (40.3%)	1008 (100.0%)
(27 °C)	27 °C	8	305 (30.3%)	83 (8.2%)	118 (11.7%)	70 (6.9%)	83 (8.2%)	349 (34.6%)	1008 (99.9%)
<b>Total (%)</b>	–	<b>16</b>	<b>552 (27.4%)</b>	<b>193 (9.6%)</b>	<b>215 (10.7%)</b>	<b>115 (5.7%)</b>	<b>186 (9.2%)</b>	<b>755 (37.4%)</b>	<b>2016 (100.0%)</b>
<b>Test conditions</b>	<b>Acclimation temp. (AT)</b>		<b>14 °C</b>	<b>18 °C</b>	<b>22 °C</b>	<b>26 °C</b>	<b>30 °C</b>	<b>34 °C</b>	<b>Gradient Total</b>
Gradient	22 °C	8	43 (4.3%)	46 (4.6%)	89 (8.8%)	64 (6.3%)	174 (17.3%)	592 (58.7%)	1008 (100.0%)
(14–34 °C)	27 °C	8	89 (8.8%)	97 (9.6%)	80 (7.9%)	81 (8.0%)	150 (14.9%)	511 (50.7%)	1008 (99.9%)
<b>Total (%)</b>	–	<b>16</b>	<b>132 (6.5%)</b>	<b>143 (7.1%)</b>	<b>169 (8.4%)</b>	<b>145 (7.2%)</b>	<b>324 (16.1%)</b>	<b>1103 (54.7%)</b>	<b>2016 (100.0%)</b>

tests ( $F$ -value<sub>1, 110</sub>=9.986;  $p$ =0.002) and gradient tests ( $F$ -value<sub>1, 110</sub>=6.275;  $p$ =0.014). In both control and gradient tests, turtles acclimated to 27 °C relocated more frequently than animals acclimated to 22 °C (Table 3). In control tests, acclimation temperature affected movement patterns in hatchlings; animals acclimated at 27 °C used more of the experimental tank ( $\bar{x}$ =4.04 ± 0.10 SE chambers) than turtles acclimated to 22 °C ( $\bar{x}$ =3.52 ± 0.11 SE chambers). In gradient tests, acclimation temperature affected the mean number of relocations; turtles acclimated to 27 °C relocated more frequently ( $\bar{x}$ =3.04 ± 0.44 SE) than individuals acclimated to 22 °C ( $\bar{x}$ =1.89 ± 0.21 SE). Across both treatment groups, the number of chamber relocations was greater for control tests ( $\bar{x}$ =5.84 ± 0.37 SE) than for gradient tests ( $\bar{x}$ =2.46 ± 0.38 SE). In control tests, 98.0% of hatchlings changed chambers at least once; in gradient runs, 74.5% of hatchlings relocated (i.e., changed temperatures) at least once.

ANOVA indicated that chamber usage (mean number of chambers used during each test run) was different between treatment groups during single-temperature control tests ( $F$ -value<sub>1, 110</sub>=4.980;  $p$ =0.0277), and during gradient tests ( $F$ -value<sub>1, 110</sub>=7.351;  $p$ =0.0078). Thus, acclimation temperature affected the mean number of chambers used whether the temperature gradient was present or absent. Across all treatment groups, hatchlings visited more chambers in control tests ( $\bar{x}$ =3.78 ± 0.11 SE) than in gradient tests ( $\bar{x}$ =2.58 ± 0.17 SE).

#### 4. Discussion

The ability to effectively sense small temperature increments may be particularly important for *M. terrapin*. They occur across a great latitudinal range (26–40°N) and often occupy shallow water near coastal areas, where they are exposed to a wide variety of seasonal and diurnal temperature shifts. Aquatic habitats are typically more thermally stable than terrestrial habitats, but due to tidal flow, fluctuating water levels, and a constant mixing of fresh and salt water, coastal estuaries and salt marshes often experience greater fluctuations in temperature than many other aquatic habitats. *M. terrapin* selects habitats differentially; juveniles and small adult males utilize shallower water while larger adult females may be found farther offshore in deeper water (Roosenburg et al., 1999). Although Roosenburg et al. (1999) could not correlate these differences in habitat selection with a variation in water temperature, this outcome may have been a function of homogenous water temperatures during the middle of the summer. During periods of varying diurnal water temperatures, juveniles and other smaller terrapins may utilize shallower habitats to optimize aquatic thermoregulation.

Our results suggest that juvenile *M. terrapin* are adept at sensing and selecting preferred water temperatures. Further, acclimation to different temperatures within their normal active range does not significantly alter the ability and efficacy of

selecting warm temperatures. Young *M. terrapin* can alter behavioral patterns based on their thermal environment (Burger 1976a, 1976b). Our hypothesis (1) that hatchlings will select warm temperatures and avoid cold temperatures when exposed to a temperature gradient within their normal active range, was supported.

We found that selection of warm temperatures by 8–10 month old juvenile *M. terrapin* was not influenced by acclimation temperature because turtles acclimated to 22 °C and 27 °C both chose the warmest temperature available (34 °C). Our hypothesis (2) that acclimation temperature will affect temperature selection in an aquatic thermal gradient was rejected.

However, movement and activity patterns were affected by acclimation temperature whether a thermal gradient was present or absent. Acclimation temperature was directly related to movement: turtles acclimated to 27 °C moved more frequently in both control and gradient tests than turtles acclimated to 22 °C. Our hypothesis (3) that acclimation temperature will affect activity and movement patterns under both thermal gradient and single-temperature control conditions was supported. In both control and gradient tests, individuals acclimated to 27 °C relocated more frequently, and utilized more of the experimental tank, than turtles acclimated to 22 °C. Although those at 22 °C were efficient in identifying and selecting the warmest temperature available, juveniles acclimated to 27 °C were more active, particularly when a thermal gradient was absent.

In single-temperature control tests run at 22 °C or 27 °C, turtles demonstrated a cumulative preference for the chambers at the ends of the tank. Many individual control runs produced no pattern in distribution and no chamber during single-temperature control runs was selected as frequently as the most frequently selected temperature during thermal gradient runs. We attribute selection of the end chambers during control tests to high levels of turtle activity rather than a preference for a specific chamber over another when the temperature gradient was absent. As turtles explored the tank, they would often swim through the common area and frequently pause when reaching the end of the tank, then subsequently enter the end chambers. To eliminate any potential bias of a preference for the end chambers, we performed two sequential gradient runs (with the temperature pattern reversed) and six runs in which the temperatures were randomly assigned and the extremes located in the interior chambers (such that each chamber was assigned each temperature once) for each treatment group. This enabled detection of temperature selection patterns, as those turtles that selected warm temperatures in the thermal gradient were frequently located in the same interior chambers that were chosen less frequently during single-temperature control runs.

Previous studies have documented a complex variation in young turtles between thermoregulatory behavior and a variety of ontogenetic and environmental factors (see Tamplin and Cyr, 2011). However, our data suggests that acclimation to different temperatures within the normal active range of *M. terrapin* may not alter their preference for and ability to select warm

**Table 3**  
Number of chamber relocations, percentage of observations that involved a relocation, percentage of turtles with at least one relocation, and number and percentage of chambers visited for aquatic thermal gradient (14–34 °C) and control tests with 14 diamond-backed terrapin (*M. terrapin*) juveniles acclimated to 22 °C or 27 °C (AT). Observations were made at 10 min intervals for 3 h. Single-temperature control tests were run at each treatment group's acclimation temperature (22 °C or 27 °C). Seven turtles were included in each AT treatment group. Values are means ± standard error.

Test Conditions	Acclimation Temp (AT) (°C)	# Replicates (Obs.)	# Relocations	% Obs. Relocations	% Turtles Relocated	# Chambers	% Chambers
Control (22 °C)	22	8 (1008)	4.86 ± 0.35	28.6	96.4	3.52 ± 0.11	58.6
Control (27 °C)	27	8 (1008)	6.82 ± 0.39	40.1	100.0	4.04 ± 0.10	67.3
<b>Total</b>	–	<b>16 (2016)</b>	<b>5.84 ± 0.37</b>	<b>34.2</b>	<b>98.0</b>	<b>3.78 ± 0.11</b>	<b>62.9</b>
Gradient (14–34 °C)	22	8 (1008)	1.89 ± 0.21	11.2	71.4	2.27 ± 0.12	37.8
Gradient (14–34 °C)	27	8 (1008)	3.04 ± 0.44	17.9	82.1	2.89 ± 0.22	48.2
<b>Total</b>	–	<b>16 (2016)</b>	<b>2.46 ± 0.38</b>	<b>14.5</b>	<b>74.5</b>	<b>2.58 ± 0.17</b>	<b>43.0</b>

temperatures. This conclusion may be related to selective forces that dictate that young terrapins exploit the benefits of warm thermal niches under a variety of conditions, or given the wide distribution of this species, it may be that the two acclimation temperatures utilized in this study were both within an optimal zone that promotes similar behavioral responses. Because the ontological and environmental factors that influence thermal preferences in turtles vary widely and are still poorly understood, further studies should be performed to reveal possible phylogenetic or geographic patterns in temperature selection.

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