THERMAL ASPECTS OF NESTING ECOLOGY OF THE TEXAS RIVER COOTER (*PSEUDEMYS TEXANA*) AND RED-EARED SLIDER (*TRACHEMYS SCRIPTA ELEGANS*) AT SPRING LAKE, HAYS COUNTY, TEXAS

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THERMAL ASPECTS OF NESTING ECOLOGY OF THE TEXAS RIVER COOTER (*PSEUDEMYS TEXANA*) AND RED-EARED SLIDER (*TRACHEMYS SCRIPTA ELEGANS*) AT SPRING LAKE, HAYS COUNTY, TEXAS

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ABSTRACT

THERMAL ASPECTS OF NESTING ECOLOGY OF THE TEXAS RIVER COOTER (*PSEUDEMYS TEXANA*) AND RED-EARED SLIDER (*TRACHEMYS SCRIPTA ELEGANS*) AT SPRING LAKE, HAYS COUNTY, TEXAS

by

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SUPERVISING PROFESSOR: THOMAS R. SIMPSON

Texas river cooters (*Pseudemys texana*) and red-eared sliders (*Trachemys scripta elegans*) are large-bodied freshwater emydid turtles common in Central Texas. Previous studies have focused on diet, growth, body size, and reproductive potential, but there is little published information on adult female thermal relationships and nesting ecology. Thermal ecology is important to turtles not only for their metabolism and growth (Thornhill, 1982) but it can be fatal if they are exposed to high temperatures (Hutchison et al., 1966). I recorded weather parameters, water temperatures, ground surface temperatures, and internal and external body temperatures of emerging Texas river cooters (n=52) and red-eared sliders (n=18). Temperatures were also recorded for 48

Texas river cooters and 16 red-eared sliders upon completion of nesting. I also examined whether an association exists between cloacal temperatures of Texas river cooters with algae and mud carapaces that might serve as a thermal buffer while they are in the process of nesting. Of those I recorded completing nests, 68.9% of Texas river cooters and 56.3% of red-eared sliders did so in May. Texas river cooters (78%) and red-eared sliders (73.3%) emerged at water temperatures between 22°C and 26°C. Texas river cooters (85%) and red-eared sliders (89%) also emerged when ground surface temperatures were between 20°C and 35°C. The majority of Texas river cooters (68.9%) and red-eared sliders (56.3%) completed nests in May. Red-eared sliders seem to incur higher internal temperatures at nest completion than Texas river cooters. There is a strong positive correlation between the cloacal temperatures at nest completion of Texas river cooters ($r = 0.7750274$, $P < 0.001$,) and red-ear sliders ($r = 0.751557$, $P < 0.001$) to ground surface temperatures. More red-eared sliders (43.8%) seem to complete nests in warmer portions of the day when the ground temperatures are between 30°C and 35°C, while Texas river cooters (37.5%) complete nests when ground temperatures are between 25°C and 30°C. This information provides valuable insight into the nesting ecology of these turtles that has not previously been documented.

CHAPTER I

INTRODUCTION

Texas river cooters (*Pseudemys texana)* and red-eared sliders (*Trachemys scripta elegans*) are large-bodied freshwater emydid turtles. Texas river cooters are endemic to five river drainages in Texas: the Brazos, Colorado, Guadalupe, Frio and San Antonio rivers (Fields et al., 2003; Linderman, 2007). Red-eared sliders are widely distributed, ranging from Indiana to New Mexico and southward through Texas to the Gulf of Mexico (Conant and Collins, 1998). In Central Texas, both species are frequently seen basking on logs, snags, stumps and rocks (Conant and Collins, 1998; Vermersch, 1992). Both can be found in habitats providing abundant vegetation and basking sites such as man-made impoundments, rivers, streams, ponds, irrigation ditches, canals, and cattle tanks (Fields et al., 2003). Red-eared sliders, however, prefer quiet waters with mud bottoms and a profusion of vegetation (Conant and Collins, 1998).

Red-eared sliders are uniquely characterized by a broad red stripe behind the eye, although, older specimens tend to become uniformly dark or black. Texas river cooters have variable yellow head markings and lateral stripes along the neck. Five or six concentric whorls with dark centers occur on the second costal scutes (Conant and Collins, 1998). Color and markings on carapaces can be obscured due to extensive algae coverage. Algae coverage on freshwater turtles has been well documented as supporting copious crustacean fauna (Allen and Neill, 1950), being a form of camouflage (Edgren et

al., 1953), and helping in seed dispersal (Burgin and Renshaw, 2008).

Females are larger than males in both species and Texas river cooters are generally larger than red-eared sliders. Adult male Texas river cooters attain carapace lengths <305 mm. Adult female carapace lengths range between 305 mm to 406 mm. Adult red-eared slider carapace length range from 127 mm to 279 mm (Garrett and Barker, 1987; Conant and Collins, 1998). Lindeman (2007) considered female Texas river cooters with a carapace length of 233 mm to be mature. In the construction of nests, females of both species will use their hind feet to dig the nest cavity (Vermersch, 1992). Both species can lay 4 to 23 eggs and nest multiple times during the breeding months of late March to July (Garrett and Barker, 1987; Vermersch, 1992; Rose, 2011).

Previous studies of Texas river cooters, along with other species of freshwater turtles have focused on food habits of Texas river cooters (Fields et al., 2003), annual frequency of clutches (Tucker, 2001; Rose, 2011), clutch sizes (Iverson, 2001), egg volume and shape of Texas river cooters (Rose et al., 1996), home ranges of Texas river cooters (Franklin, 2006) and on nest predation (Washington, 2008). There are no published results of investigations into thermal relationships of nesting ecology.

Thermal regime is an important topic of study to turtle ecology because it directly affects their growth, metabolism, and activity (Boyer, 1965; Thornhill, 1982; Grayson and Dorcas, 2004). Habitat selection for musk turtles (*Sternotherus odoratus*) in Canada is based on its thermal quality (Picard et al., 2011). The gonadal cycles are influenced by temperatures for painted turtles (*Chrysemys picta*) (Grazhorn and Licht, 1983). Sex determination is influenced by the temperature of the nest cavity in most species of turtles (Vogt and Bull, 1982; Packard et al., 1989). In extreme cases, high internal body

temperatures can be fatal (Hutchison et al., 1966). Female turtles are sometimes exposed to direct sunlight while they are constructing and finishing nests during the hottest months of the year.

My objectives were to: 1) document the temperatures (internal and external) of female turtles emerging from water to nest; 2) document the internal and external temperatures experienced by turtles during the nesting process; 3) determine if thermal regimes experienced by red-eared sliders and Texas river cooters of similar size are comparable and; 4) determine if algae, mud, or other substances covering the carapace provide a thermal buffer for Texas river cooters from potentially extreme temperatures experienced during the nesting process in full sun.

CHAPTER II

METHODS

Study Area

My study site was Aquarena Center, Hays County, Texas. Aquarena Center (29°53'N, 97°55'W) is a 36 ha segment of the Texas State University-San Marcos campus containing educational and research sites surrounding Spring Lake (a 7.89-ha reservoir at the headwaters of the San Marcos River, Fields et al., 2003), and a golf course (Fig. 1). Aquarena was formerly an amusement park with an underwater submarine theater and glass bottom boats. After acquisition by Texas State University, Aquarena Center has been dedicated to educational and research use. Spring Lake and the San Marcos River is fed by the San Marcos Springs (some 200 springs along the Balcones fault), the second largest spring system in Texas with a average annual discharge of 4,300 lps (Brune, 2002; Fields et al., 2003; Washington, 2008). Spring Lake has an abundant turtle population, including the Texas river cooter and the red-eared slider, as well as the common musk turtle (*Sternotherus odoratus*), common snapping turtle *(Chelydra serpentina)* and the spiny softshell turtle (*Apalone spinifera*).

Spring Lake is composed of the lotic Main Lake and a lentic backwater system known as the slough. The springs discharge into the northern portion of the main lake and creates a lotic system that empties into the San Marcos River. The eastern portion of

the Main lake has high concrete walls and small amounts of floating vegetation; most of the shoreline that surrounds the lake is steep. The slough has an abundance of emergent shoreline vegetation, floating vegetation and fallen trees. Female turtles concentrate in the slough for staging and nesting, where they will bask on the shore and eventually nest in the surrounding golf course (Franklin, 2006).

My study site, which includes a 9-hole golf course is arbitrary divided into four quadrants (A,B,C, and D) by a road (Laurel Ridge) and the slough (Fig. 1). The golf course surrounds the slough and provides suitable nesting habitat for turtles (Washington, 2008). The golf course has more areas for turtles to construct nests due to little vehicular traffic, no obstructive plants, and short grass. Turtles nest in other areas of the Aquarena Center, but find fewer places to construct nests.

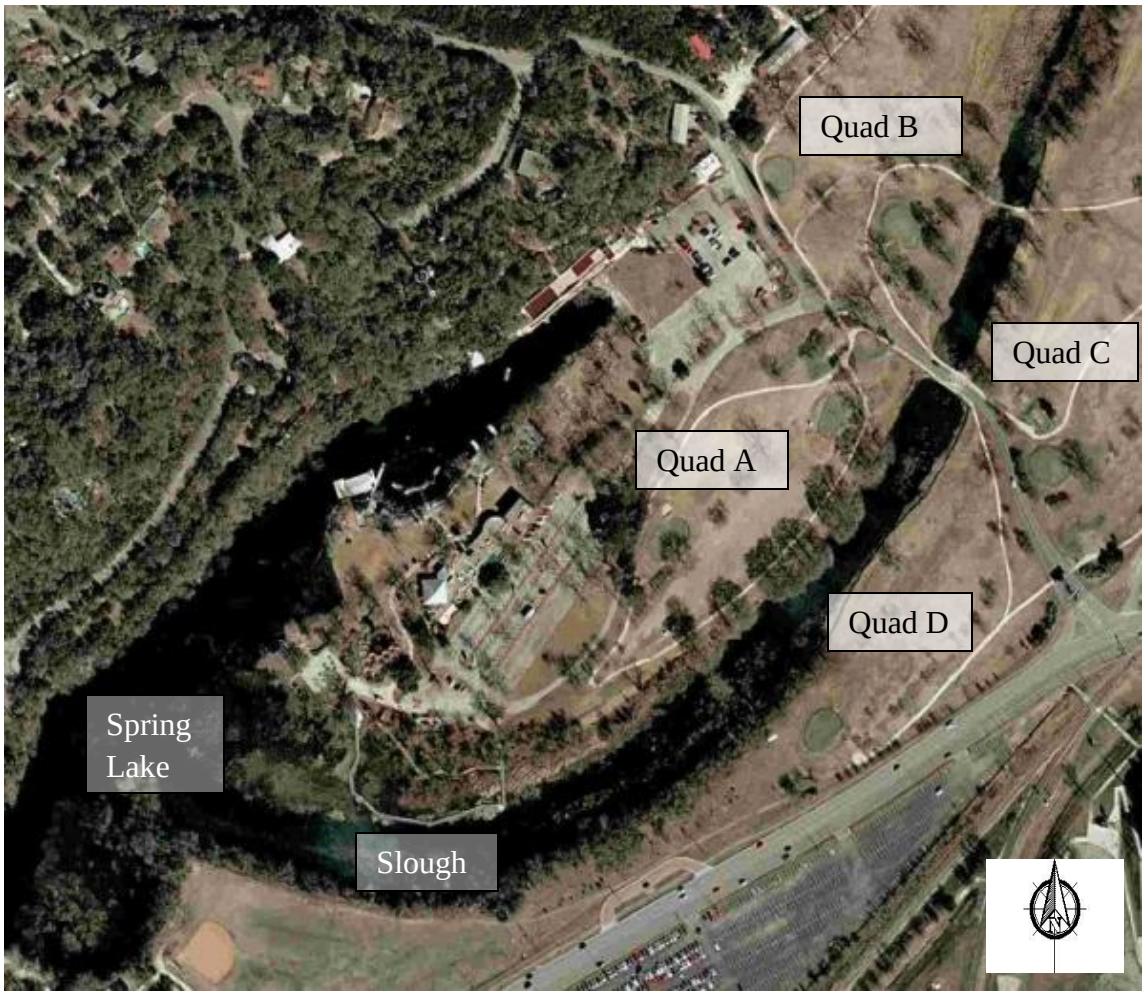

Figure 1. Aerial image of Spring Lake, Aquarena Center, golf course and slough with four quadrants (A, B, C, D).

From October 2010 to March 2011 prior to the nesting season, I captured 31 individual female Texas river cooters by opportunistically dip-netting from a canoe or by floating basking traps (Fields et al., 2003; Lindeman, 2007). I attached thermochron iButtons (Angilletta and Krochmal, 2003) (Maxim Integrated Products Inc., part no. DS1921G-F5#, Sunnyvale, CA; accuracy ± 0.5°C) to the right coastal scute of the carapace (Grayson and Dorcas, 2004; Pittman and Dorcas, 2009) to assist in thermal relationships to nesting ecology. I applied PC7 Epoxy over the thermochron for additional waterproofing.

During nesting season from 25 April 2011 through 14 July 2011, I searched for both Texas river cooters and red-eared sliders each day beginning at 0700h (Washington, 2008; Rose, 2011) as they emerged from the slough for nesting. I walked the entire lengths of the banks of Spring Lake bordering Aquarena Center and the banks of the slough of all four quadrants (Fig. 1). Upon locating an emerging turtle, I intercepted and recorded internal cloacal temperatures (YSI Model 44 Tele-thermometer) and external carapace temperatures (Fluke 62 mini IR thermometer). I also recorded the water temperature and the ground surface temperature at the emergence point for each turtle. I also scanned for a passive integrated transponder (PIT) tag in the right forelimb and recorded the PIT tag identification number. Most turtles returned to water after this disturbance.

Activities requiring the handling of turtles were performed under the Texas State University IACUC Permit # 1030_0909_21.

Emergence Analysis

I used a paired t-test to determine if there was a significant difference between mean cloacal temperatures and mean carapace temperatures of emerging Texas river cooters and red-eared sliders. I then used a Welch's t-test to determine if a significant difference exists between the mean emergent cloacal temperatures of all emergent Texas river cooters and mean cloacal temperatures of all emergent red-eared sliders. I also used a Welch's t-test to determine if a difference exists between mean cloacal temperatures of emergent Texas river cooters and mean cloacal temperatures of emergent red-eared sliders of similar size. I used an Pearson's product-moment correlation to determine if there was an association between the cloacal temperatures of emerging Texas river cooters and red-eared sliders to water temperatures at the time of emergence. All statistical tests were performed using program R (R Development Core Team, version 2.11.1).

Body Temperatures at Nest Completion

I regarded temperatures taken from turtles digging a nest, laying eggs, or covering a nest as temperatures experienced by turtles at the end of the nesting effort. I searched further from the banks to locate nesting females, this included walking through the park adjacent to Aquarena Center, the golf course (quadrants A, B, C, D), and playing fields bordering quadrant D. I recorded turtle carapace temperature and ground surface temperatures adjacent to turtles during nest construction. I took cloacal temperatures after the nest was completed in order to keep disturbances to a minimum. I monitored the study site and searched for turtles from 0700h until 1500h or when no turtles were

located.

Nest Completion Analysis

I compared cloacal temperatures to carapace temperatures of each species at completion of nesting using a paired t-test. I then compared cloacal temperatures of all Texas river cooters to cloacal temperatures of all red-eared sliders at nest completion and also for similar sized Texas river cooters and red-eared sliders (200mm to 250mm) using a Welch's t-test. I used Pearson-product moment correlation to determine if the surrounding ground surface temperatures are associated with cloacal internal temperatures.

Influence of Carapace Covering on Cloacal Temperatures

For this section of my study, I captured Texas river cooters by opportunistically dip-netting, setting a floating basking trap, or by picking them up after nest completion. I only used turtles with the following criteria; carapace length > 250 mm, carapaces completely covered in algae and mud, or turtles that had completely bare carapaces. I collected data under laboratory conditions to hold all variables constant with the exception of temperature. I used standard reflector light fixtures with 250-watt heat lamps. In order to duplicate observed field ground surface temperatures, I calibrated the proper height for the heat lamps by positioning the heat lamps at a starting height of 157.5 cm focused onto a black 30.5 cm x 22.9 cm piece of black paper inside a 62 L plastic container for 15 min and recorded temperatures (Fluke 62 mini IR thermometer) every 5 minutes. I then lowered the lamp to 127 cm for 15 min and recorded temperatures every 5 min, I repeated this process for heights of 96.5 cm, 66 cm, and 30.5

cm. I concluded that a height of 66 cm best represented field ground surface temperatures. Texas river cooters captured on land were placed in water of ~22°C to 24°C, which best represented slough water temperatures, for at least 8 hr to acclimate. Turtles dip netted or caught in floating basking traps did not need to be acclimated. I recorded both cloacal temperatures (YSI Model 44 Tele-thermometer) and external carapace temperatures (Fluke 62 mini IR thermometer) every 10 minutes for 150 minutes to simulate an entire nesting event. Rose (2011) recorded past nesting events for Texas river cooters and red-eared sliders to take approximately 2.5-3 hours. I took carapace and cloacal temperatures of turtles with fully covered carapaces and bare carapaces for each time frame. I used a repeated-measures ANOVA to determine significance between cloacal temperatures of turtles with algae covered carapaces to cloacal temperatures with no coverage. I also used a repeated-measures ANOVA to determine significance in carapace temperatures between algae covered carapaces and bare carapaces.

CHAPTER III

RESULTS

Emergence Analysis

I was not able to recapture any turtles equipped with thermochrons, even though multiple people assisted in searching for these turtles. Although, great care was exercised in attaching the thermochrons, scutes may have been sloughed along with the thermochrons.

I intercepted and recorded temperatures from 70 individual turtles (52 Texas river cooters and 18 red-eared sliders) emerging to nest. Ten (19.2%) Texas river cooters and two (11.1%) red-eared sliders emerged in late April. In May, 26 (50%) Texas river cooters and 13 (72.2%) red-eared sliders emerged, and 16 (30.8%) Texas river cooters and 3 (16.7%) red-eared sliders emerged to nest in June (Table 1). Cloacal temperatures at emergence from water of all Texas river cooters (mean = 25°C) did not differ ($t = 0.0221$, $df = 29.3$, $P = 0.983$) from cloacal temperatures of all red-eared sliders (mean = 24.8°C). Nor was there a difference ($t = 0.4834$, $df = 18$, $P = 0.635$) between the cloacal temperatures at emergence of Texas river cooters and red-eared sliders when only individuals of similar size were used. Carapace temperatures were significantly higher than cloacal temperatures at emergence for Texas river cooters ($t = 2.5496$, $df = 50$, $P = 0.014$) but not for emerging red-eared sliders ($t = 0.9162$, $df = 17$, $P = 0.372$).

Table 1. Total number and percent of Texas river cooters and red-eared sliders that emerged to nest throughout the breeding season.

Month	Texas river cooters (%) emerged	Red-eared sliders (%) emerged
Late April	10 (19.2)	2 (11.1)
May	26 (50.0)	13 (68.9)
June	16 (30.8)	3 (16.7)

I recorded water temperatures at emergence for 41 of 52 Texas river cooters and 15 of 18 red-eared sliders. There was a positive correlation between water temperatures recorded at emergence to cloacal temperatures of Texas river cooters at emergence ($r = 0.653067$, $P < 0.001$) (Fig. 2) and cloacal temperatures of red-eared sliders at emergence ($r = 0.6570076$, $P < 0.001$) (Fig. 3). Thirty-two (78%) Texas river cooters and 11 (73.3%) red-eared sliders emerged when water temperatures were between 22°C to 26°C (Table 2). Nine (22%) Texas river cooters and four (26.7%) red-eared sliders emerged to nest at cooler water temperatures between 18°C to 22°C (Table 2). No turtles were observed emerging at water temperatures above 26°C (Table 2).

Table 2. Total number and percentage of Texas river cooters and red-eared sliders emerging to nest at observed water temperatures.

Water temperatures (°C)	Texas river cooters (%)	Red-eared sliders (%)
18-22	9 (22)	4 (26.7)
22-26	32 (78)	11 (73.3)
26-30	0	0

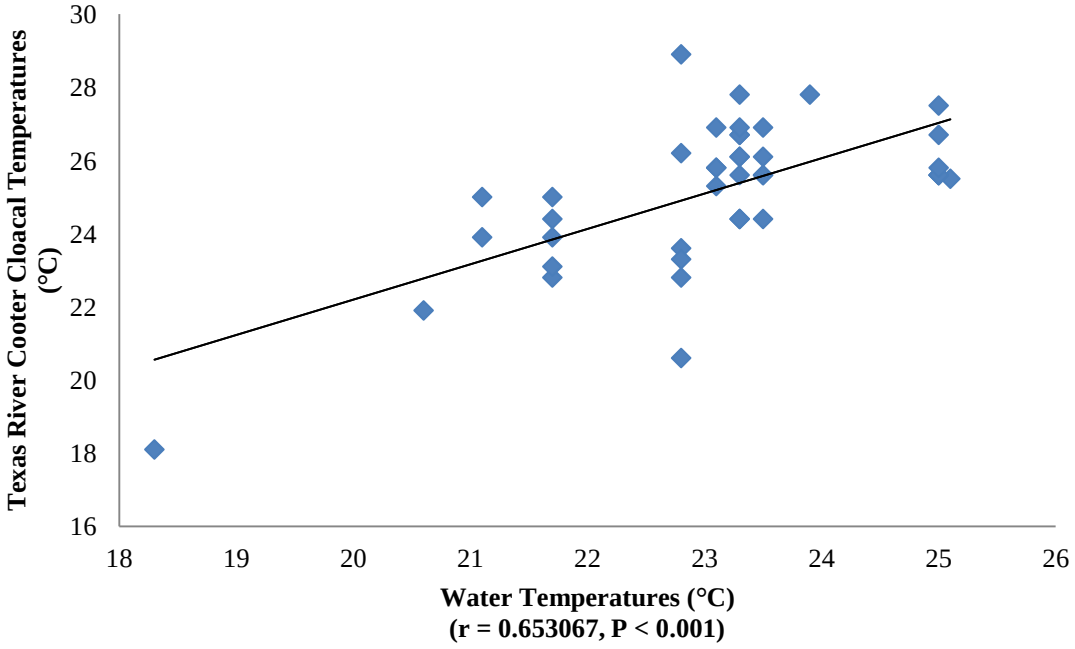

Figure 2. Cloacal temperatures of Texas river cooters at emergence from water to nest compared to water temperatures.

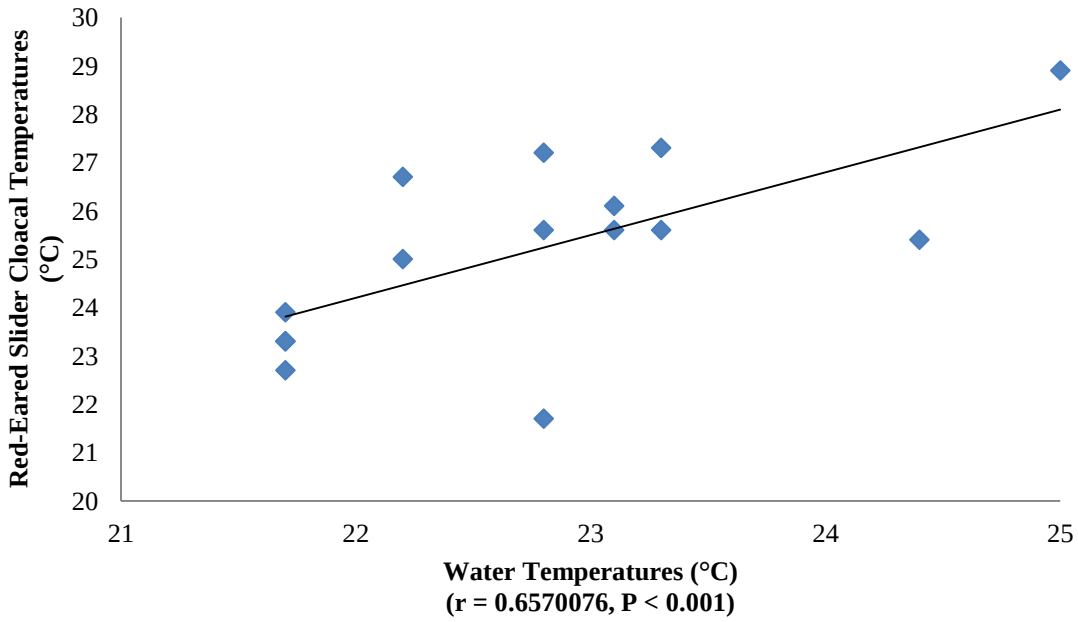

Figure 3. Cloacal temperatures of Red-eared sliders at emergence from water to nest compared to water temperatures.

I observed Texas river cooters and red-eared sliders emerging to nest as ground surface temperatures ranged from 15°C to 50°C (Table 3, Fig. 4). Of the 52 Texas river cooters that emerged to the nest, 44 (85%) emerged when ground surface temperatures were between 20°C and 35°C (Table 3, Fig. 4). Sixteen (89%) of 18 red-eared sliders emerged during the same temperatures interval (20°C to 35°C, Table 3, Fig. 4). Only, one (1.9%) Texas river cooter and one (5.6%) red-eared slider were observed to nest when ground surface temperatures were < 20°C while seven (13%) Texas river cooters and 1 (5.6%) red-eared slider emerged when ground surface temperatures were > 35°C (Table 3, Fig. 4).

Table 3. Total number and percentage of Texas river cooters and red-eared sliders emerging at observed ground surface temperatures.

Ground surface temperatures (°C)	Texas river cooters (%) emerged	Red-eared sliders (%) emerged
15-20	1 (1.9)	1 (5.6)
20-25	8 (15.4)	2 (11.1)
25-30	29 (55.8)	11 (61)
30-35	7 (13.5)	3 (16.7)
35-40	4 (7.7)	1 (5.6)
40-45	2 (3.8)	-
45-50	1 (1.9)	-

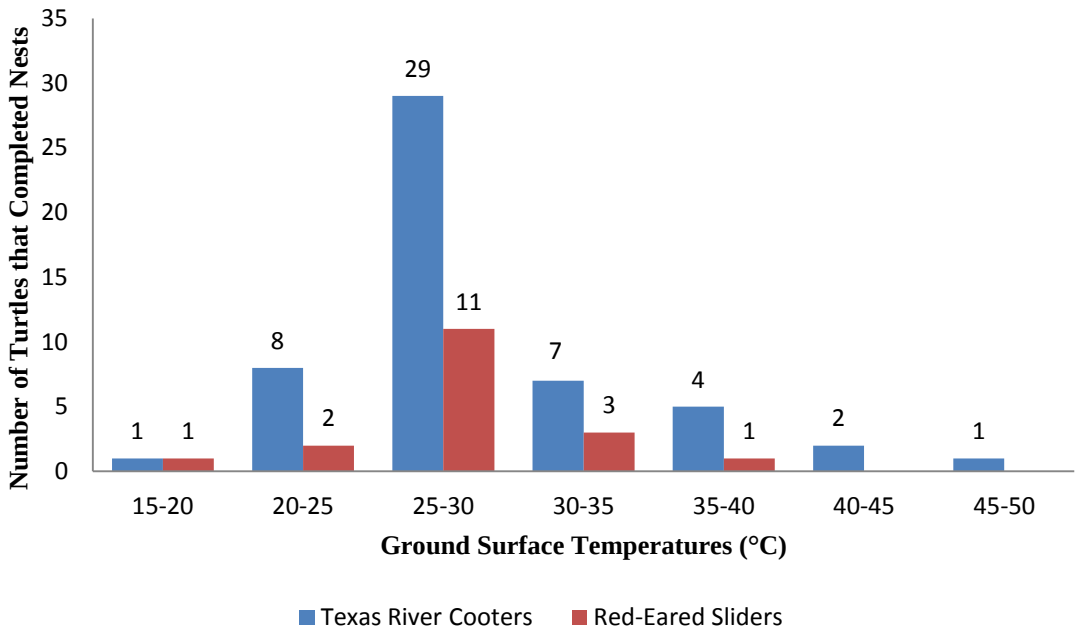

Figure 4. Total number of Texas river cooters and red-eared sliders that emerged to nest at observed ground surface temperatures.

Nest Completion Analysis

I located and recorded cloacal and carapace temperatures of 64 turtles (48 Texas river cooters and 16 red-eared sliders) that completed nesting. I did not observe any Texas river cooters and only 1 (6.25%) red-eared slider completing a nest in late April. I observed 32 (68.9%) Texas river cooters and 9 (56.3%) red-eared sliders completing nests in May, and 16 (33.3%) Texas river cooters and 6 (37.5%) red-eared sliders completing nests in June (Table 4). The cloacal temperatures at nest completion of Texas river cooters (mean = 28.2°C) (Appendix 3) and red-eared sliders (mean = 30.7°C) (Appendix 4) were significantly different ($t = 2.607$, $df = 26.546$, $P = 0.015$). Also, there was a significant difference between cloacal temperatures at nest completion of similar sized (200mm to 250mm) Texas river cooters (mean = 27.5 °C) (Appendix3) and red-eared sliders (Appendix 4) (mean = 30.3°C) ($t=2.2984$, $df = 18.83$, $P = 0.033$). Additionally, carapace temperatures were significantly higher than cloacal temperatures at nest completion for red-eared sliders (Appendix 4) ($t = 2.4336$, $df = 15$, $P = 0.028$) but not for Texas river cooters (Appendix 3) ($t = 1.3667$, $df = 46$, $P = 0.178$).

Table 4. Total number and percent completion of Texas river cooters and red-eared sliders that completed nests throughout the nesting season.

Month	Texas river cooters (%)	Red-eared sliders (%)
Late April	0	1 (6.25)
May	32 (68.9)	9 (56.3)
June	16 (31.1)	6 (37.5)

There was a strong positive correlation between ground surface temperatures ($r = .7750274$, $P < 0.001$) and cloacal temperatures of Texas river cooters (Fig. 5) upon nest completion. Also, there is a strong positive correlation between ground surface temperatures ($r = 0.751557$, $P < 0.001$) and cloacal temperatures of red-eared sliders (Fig. 6) upon nest completion.

Eighteen (37.5%) of 48 Texas river cooters and six (37.4%) of 16 red-eared sliders completed nesting when the ground surface temperatures were between 25˚C and 30˚C (Table 5, Fig. 7). Fifteen (31.3%) Texas river cooters and seven (43.8%) red-eared sliders completed nesting when the ground surface temperatures ranged from 30˚C to 35˚C (Table 5, Fig. 9). Seven (14.6%) Texas river cooters and three (18.8%) red-eared sliders completed nests at hotter temperatures between 35˚C to 40˚C (Table 5, Fig. 7). A greater number of red-eared sliders (44%) seem to complete nests in the warmer portions of the day, with most being observed when the ground surface temperatures was between 30°C to 35°C. The greatest proportion of Texas river cooters (38%) completed nests when ground surface temperatures were between 25°C to 30°C. Only three Texas river cooters (6.3%) were observed completing a nest in temperatures > 40˚C (Table 5, Fig. 7).

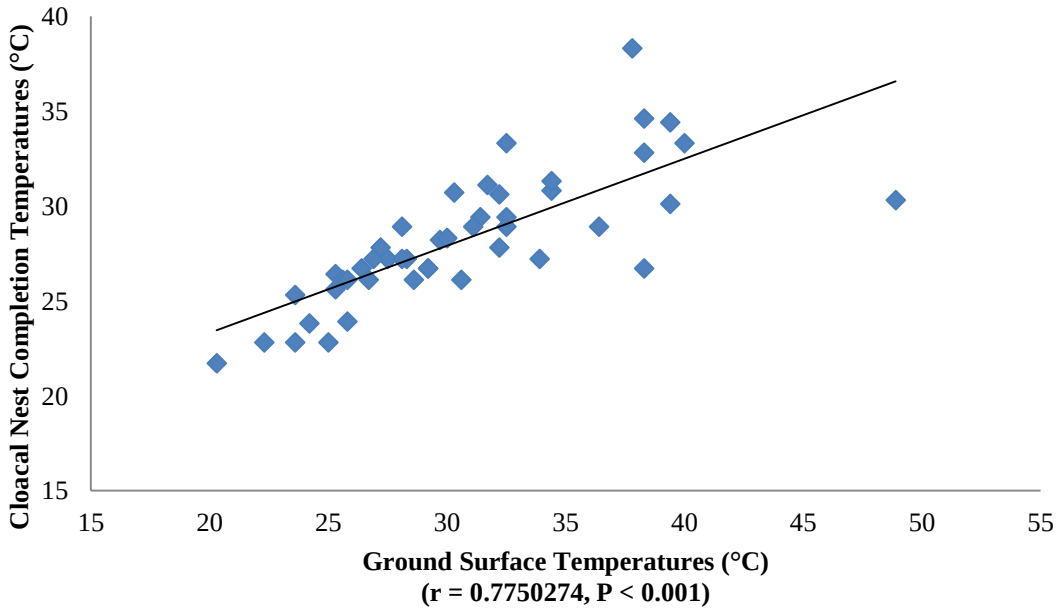

Figure 5. Cloacal temperatures of Texas river cooters at nest completion compared to ground surface temperatures.

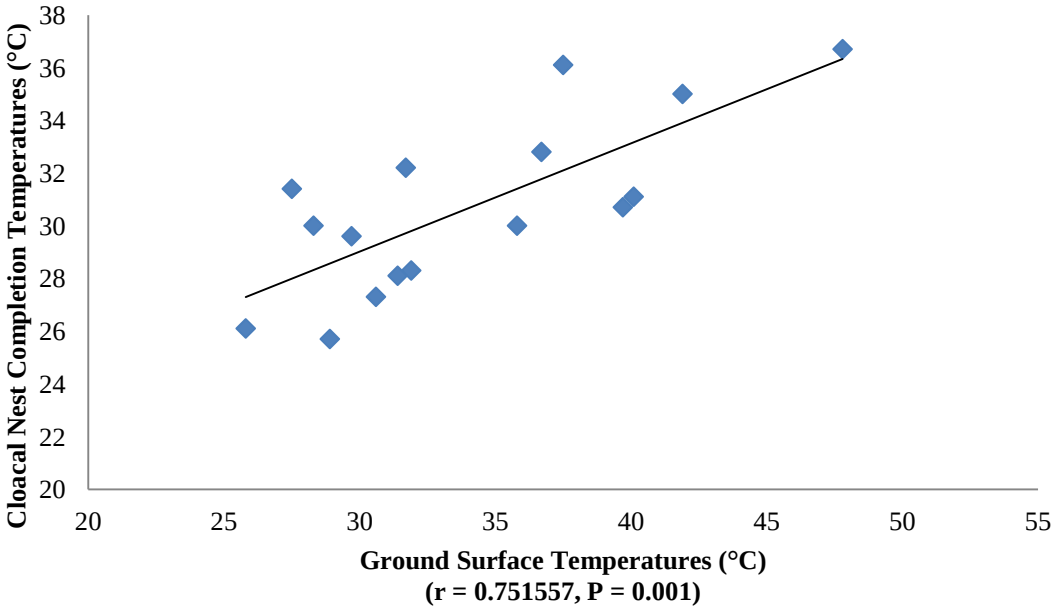

Figure 6. Cloacal temperatures of red-eared sliders at nest completion compared to ground surface temperatures.

Table 5. Ground surface temperatures at the time of nest completion for Texas river cooters and red-eared sliders.

Ground surface temperatures (°C)	Texas river cooters (%) completing nesting	Red-eared sliders (%) completing nesting
20-25	5 (10.4)	-
25-30	18 (37.5)	6 (37.4)
30-35	15 (31.3)	7 (43.8)
35-40	7 (14.6)	3 (18.8)
40-45	2 (4.2)	-
45-50	1 (2.1)	-

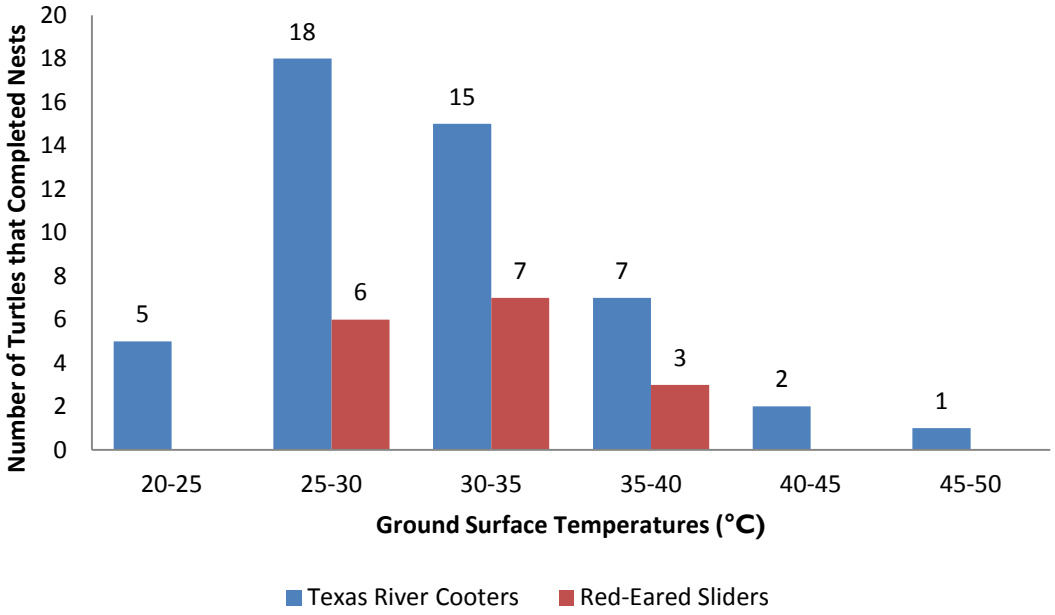

Figure 7. Ground surface temperatures at the time of nest completion for Texas river cooters and red-eared sliders.

Influence of Carapace Covering on Cloacal Temperatures

I captured and recorded in a laboratory setting the cloacal and carapace temperatures of ten Texas river cooters (six with algae and mud covered carapaces and four with no algae or mud covering). Temperatures were recorded every 10 minutes during a total time of 150 minutes. The initial mean carapace temperature for the six Texas river cooters with algae covered carapaces was 21.1°C and mean final temperature was 33.1°C, an increase of 12°C in carapace temperature (Table 6). The initial mean temperature for Texas river cooters with bare carapaces (no algae or mud cover) was 21°C and the final temperature was 36.5°C, an increase of 15.5°C in carapace temperature (Table 6).

A repeated-measures ANOVA indicated that carapace temperatures of Texas river cooters with algae covered carapaces were not significantly different from carapace temperatures of those with bare carapaces ($F_{1,8} = 4.3161$, $P = 0.071$). Because of the relatively low p-value and the divergence of carapace temperatures of cooters with algae covered carapaces from carapace temperatures of cooters with bare carapaces starting at 60 minutes, a Welch's t-test was performed on temperature readings from each 10 minute interval. No significant differences in temperatures existed between algae covered and bare carapaces until 60 minutes ($t = 2.9303$, $df = 7.834$, $P = 0.019$) (Table 6, Fig. 8). At 70 minutes, no significant difference existed between carapace temperatures ($t = 0.8462$, $df = 5.773$, $P = 0.431$). Significant differences in temperatures between algae covered and bare carapaces did exist at 80 minutes ($t = 2.3875$, $df = 7.848$, $P = 0.044$), 90 minutes ($t = 3.0128$, $df = 7.969$, $P = 0.017$), 100 minutes ($t = 2.4393$, $df = 7.892$, $P = 0.041$), 120 minutes ($t = 2.872$, $df = 7.82$, $P = 0.021$), 130 minutes ($t = 3.7964$, $df = 6.983$,

P = 0.006), 140 minutes (t = 3.574, df = 6.379, P = 0.010), and 150 minutes (t = 4.1073, df = 7.992, P = 0.003) (Table 6, Fig. 8).

In similar fashion, the mean initial cloacal temperature for Texas river cooters with algae covered carapaces temperature was 21.9°C. The mean final temperature was 28.4°C, an increase of 6.5°C in cloacal temperature (Table 6). The mean initial cloacal temperature for Texas river cooters with bare carapaces was 21°C and the mean final cloacal temperature was 30.4°C, an increase of 9.4°C in cloacal temperature (Table 6). A repeated-measures ANOVA indicated that cloacal temperatures of Texas river cooters with algae covered carapaces were not significantly different from the cloacal temperatures of Texas river cooters with bare carapaces ($F_{1,8}$ = 0.1979, P = 0.668). A Welch's t-test on cloacal temperature readings taken at 10 minute intervals also showed no significant differences between cloacal temperatures of cooters with algae covered carapaces and those with bare carapaces until 140 minutes (t = 2.5713, df = 6.761, P = 0.038) and 150 minutes (t = 2.7443, df = 7.453, P = 0.027) (Table 6, Fig. 8).

Table 6. Mean carapace and cloacal temperatures of Texas river cooters with algae covered carapaces or bare covered carapaces placed under heating lamps for 150 minutes.

	Carapace		Cloacal	
Time (min)	Algae Covered (°C)	Bare (°C)	Algae Covered (°C)	Bare (°C)
0	21.1	21	21.9	21.0
10	26.8	27.5	22.5	21.4
20	28.0	28.8	23.2	22.2
30	28.3	30.3	23.7	23.2
40	29.2	31.0	24.4	23.9
50	29.8	32.4	24.7	24.7
60	29.5	32.6	25.3	25.4
70	29.9	33.0	25.5	26.3
80	30.0	33.3	26.0	26.6
90	30.7	34.0	26.5	27.4
100	31.8	34.3	26.7	28.2
110	31.7	34.4	27.2	28.7
120	31.9	35.1	27.4	29.2
130	32.7	35.6	28.1	29.7
140	32.7	35.9	28.3	30.0
150	33.1	36.5	28.4	30.4

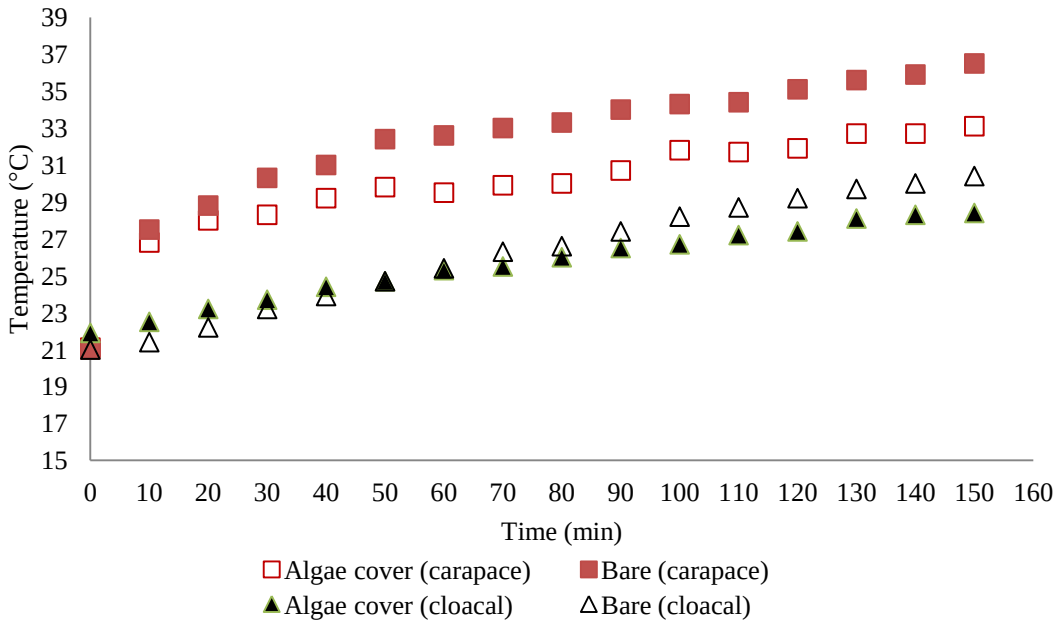

Figure 8. Comparison of mean carapace and cloacal temperatures for Texas river cooters with algae covered carapaces or bare carapaces placed under heating lamps for 150 minutes.

CHAPTER IV

DISCUSSION

Thermochrons were not recovered for my study, Texas river cooters equipped with thermochrons may have shed their coastal scutes sooner than expected or did not enter the floating basking traps. Floating basking traps were also repeatedly destroyed by resident nutria (*Myocastor coypus*) which might have allowed turtles to escape the trap. These dataloggers have been used successfully used in other temperature related studies for painted turtles (*Chrysemys picta*) and (*Chrysemys picta marginatata*) (Grayson and Dorcas, 2004; Rowe and Grace, 2010), for bog turtles (*Glyptemys muhlenbergii*) (Pittman and Dorcas, 2009), and for stripe-necked musk turtles (*Sternotherus minor peltifer*) (Ennen and Scott, 2008). Attachment of dataloggers to the carapace on the painted turtle revealed only small temperature differences from cloacal temperatures (Grayson and Dorcas, 2004).

Based on the results of my research, thermal influences are important factors in the reproductive ecology of female Texas river cooters and red-eared sliders. There is a positive correlation between water temperature and emergence by Texas river cooters and red-eared sliders to nest. Cloacal temperatures of both Texas river cooters and red-eared sliders were strongly correlated with water temperatures measured at emergence, which is expected since turtles are ectotherms. Neither species emerged in appreciable numbers until the month of May (55.7%) when the water temperatures rose above 22°C. Red-

eared sliders do not emerge when the water temperatures are 10°C or below (Garret and Baker, 1987).

Likewise, emergence for nesting was well defined by ground surface temperatures, with 86% of Texas river cooters and 89% of red-eared sliders emerging to nest when the ground surface temperatures were between 20°C and 35°C. Other studies show that temperatures influence nesting behavior in other species of turtles. Warming ambient temperatures and the spring water temperature was found to trigger nesting behavior in snapping turtles (*Chelydra serpentina*) in Quebec (Obbard and Brooks, 1987). Mud turtles (*Kinosternon subrubrum*) nest on days when the temperatures range from 30.6°C to 35.6°C (Burke et al., 1994).

Texas river cooters and red-eared sliders nest in the hottest months of the year and can experience both high internal and external temperatures during the nesting process. Both species (64%) completed nests in May while 34.4% of both species completed nests in June. There was a strong positive correlation between the ground surface temperatures to the cloacal temperatures for both species. Most of the observed Texas river cooters (68.8%) and red-eared sliders (81.3%) completed nests on days when the ground surface temperatures were between 25°C to 35°C. Painted turtles in Southwestern Quebec nest in the later evening when temperatures are warmer but there is a late completion of nests with a rapid drop in temperature (Christens and Bider, 1987).

Red-eared sliders seem to experience higher internal temperatures at the completion of nesting than do Texas river cooters. Mean internal cloacal temperature at nest completion for red-eared sliders was 30.7°C while the mean internal cloacal temperature at nest completion for Texas river cooters was 28.2°C. Similar size Texas

river cooters and red-eared sliders (200mm to 250mm) also showed a significant difference in cloacal temperatures with a mean internal cloacal temperature for red-eared sliders of 30.3°C and for Texas river cooters of 27.5°C. Red-eared sliders typically have smaller carapace dimensions than Texas river cooters, so it is possible that their carapace temperature correlates more closely with their internal temperatures. In smaller species of turtles such as bog turtles (*Glyptemys muhlenbergii*), carapace temperature correlates strongly with internal body temperatures (Pittman and Dorcas, 2009). Even though red-eared sliders seem to incur higher mean cloacal temperatures, some Texas river cooters experienced higher cloacal temperatures at nest completion. The highest recorded temperature for a Texas river cooter upon nest completion was 38.3°C while the highest recorded temperature for a red-eared slider was 36.7°C. The observed cloacal temperatures of Texas river cooters and red-eared sliders at nest completion and their correlation to the surrounding ground surface temperatures of the summer nesting months are to be expected of ectotherms. Turtles in my research have been documented with high internal temperatures at nest completion and possibly could reach an internal temperature which could produce disorientation or be fatal.

Previous research has shown that for emydid turtles, the range of temperatures for the loss of righting response (locomotory ability is lost) is 37.8°C to 41.3°C and the range of critical thermal maximum (violent spasms) is 38.4°C to 42.8°C (Hutchison et. al., 1966). Even though I observed some high cloacal temperatures, none of the turtles showed signs of loss of righting response or of thermal distress. Turtles reaching these extreme temperatures would no doubt try and find cooler temperatures or return to water. I observed 21 Texas river cooters and nine red-eared sliders that abandoned nests, but not

due to high temperatures. The highest cloacal temperature recorded for a Texas river cooter that abandoned nesting was 31.4°C and 28.9°C for a red-eared slider. The most common reason for nest abandonment in this study was either observer disruption, interference by golfers, or fire ant (*Solenopsis invicta*) activity.

A carapace completely covered by algae and mud did keep the carapace of Texas river cooters significantly cooler than a bare carapace (at 60 minutes to 150 minutes). The cloacal temperatures of algae covered turtles were significantly cooler than cloacal temperatures of turtles with bare carapaces in the later portions of the simulated nesting event (at 140 minutes to 150 minutes). I only recorded temperatures up to 150 minutes to not risk stress on the turtles. This would suggest that a carapace covering of algae and mud could act as a thermal buffer. Even though carapacial covering might act as a thermal buffer, little information is available on the subject. Most turtles I observed seemed to chose random sites for nesting, either in the open under direct sun light or in the shade. However, further research might reveal whether or not a carapace covering of algae allows turtles to endure high temperatures experienced during nesting events.

My data show that temperatures are important to the nesting ecology of Texas river cooters and red-eared sliders. Emergence from water to nest for both species was restricted to warmer water temperatures (> 20°C) and ground surface temperatures (>20°C and < 35°C). Red-eared sliders incur higher mean cloacal temperatures at nest completion than Texas river cooters but both are subjected to the hot summer ground temperatures while they are nesting. Nesting turtles can reach high internal temperatures but no turtles were observed to reach temperatures high enough to show signs of distress. Algae covering on carapaces may help to create a thermal buffer from high external

temperatures while turtles are nesting. Temperatures are not only important to turtle metabolism, activity, and growth, but also temperatures appear to be an important factor in the reproductive ecology of turtles.

Appendix 1. All Texas river cooter emergence data for the nesting season of April 2011 to July 2011.

Carapace temperature (°C)	Cloacal temperature (°C)	Water temperature (°C)	Ground surface temperature (°C)
23.3	24.4	-	25.0
22.8	24.4	-	26.7
23.6	23.3	-	24.7
22.8	23.6	-	23.1
23.1	24.7	-	23.3
23.9	25.0	-	33.6
25.6	24.4	-	35.0
25.3	25.6	-	43.3
20.6	21.7	-	33.6
25.0	24.4	-	41.1
16.4	18.1	18.3	18.3
26.7	21.9	20.6	21.9
28.9	25.0	21.1	50.0
25.3	23.9	21.1	27.2
23.1	23.9	21.7	22.5
22.5	22.8	21.7	25.6
27.2	26.7	23.3	30.8
27.2	27.8	23.9	33.6
26.1	26.1	23.3	28.3
26.9	25.6	23.3	27.8
26.1	26.1	23.3	28.3
25.0	26.7	23.3	27.5
19.9	20.6	22.8	20.2
22.6	22.8	22.8	22.0
29.2	25.0	21.7	23.6
23.6	23.1	21.7	29.4

Appendix 1, continued. All Texas river cooter emergence data for the nesting season of April 2011 to July 2011.

31.7	28.9	22.8	38.3
25.8	24.4	21.7	31.1
24.2	23.6	22.8	26.4
27.2	26.2	22.8	29.7
24.4	23.3	22.8	26.9
24.4	25.8	23.1	25.6
25.6	26.9	23.1	26.9
24.2	25.3	23.1	27.2
27.2	25.8	23.1	29.7
25.3	24.4	23.5	26.7
26.4	26.9	23.5	26.4
26.4	26.1	23.5	29.2
26.4	25.6	23.5	28.3
25.8	25.6	23.5	26.4
29.2	27.8	23.3	39.2
31.4	26.9	23.3	37.5
25.0	24.4	23.3	27.8
24.4	24.4	23.3	28.3
26.1	25.5	25.1	30.6
27.5	25.6	25.0	26.7
27.2	25.6	25.0	26.1
29.4	25.6	25.0	28.3
28.1	26.7	25.0	26.9
26.2	25.8	25.0	29.4
29.7	27.5	25.0	35.6

Appendix 2. All red-eared sliders emergent data during the nesting season of April 2011 to July 2011.

Carapace temperature (˚C)	Cloacal temperature (˚C)	Water temperature (˚C)	Ground surface temperature (˚C)
20.0	22.2	-	15.6
22.8	23.3	-	29.4
31.1	25.0	-	33.6
26.7	25.6	23.1	25.8
25.0	26.1	23.1	27.2
25.8	25.6	22.8	26.9
24.7	25.6	23.3	27.5
21.7	21.7	22.8	22.5
26.9	23.9	21.7	35.6
20.8	23.3	21.7	25.6
22.5	23.3	21.7	24.4
24.2	22.7	21.7	26.7
26.9	27.2	22.8	28.3
25.8	25.0	22.2	27.5
28.9	26.7	22.2	33.6
30.3	27.3	23.3	33.1
25.8	25.4	24.4	29.2
27.2	28.9	25.0	25.3

Appendix 3. All nest completion data for Texas river cooters during the nesting season of April 2011 to July 2011.

Carapace temperature (˚C)	Ground surface temperature (˚C)	Cloacal temperature (˚C)
27.8	30.6	26.1
19.9	20.3	21.7
23.6	24.2	23.8
23.7	23.6	25.3
23.6	25.8	23.9
21.1	22.3	22.8
25.8	32.2	27.8
22.5	23.6	22.8
23.3	25.0	22.8
29.4	38.3	26.7
31.9	30.3	30.7
31.9	31.4	29.4
26.9	31.1	28.9
25.8	25.3	26.4
26.1	25.6	26.1
27.2	29.2	26.7
28.1	30	28.3
35.6	38.3	34.6
29.7	32.5	28.9
31.1	38.3	32.8
30.8	27.5	27.2
25.8	26.9	27.2
32.8	39.4	30.1
32.8	39.4	34.4
26.7	26.4	26.7
25.8	28.3	27.2
26.7	29.7	28.2
31.4	31.7	31.1
25.8	26.7	26.1
25.6	28.6	26.1

Appendix 3, continued. All nest completion data for Texas river cooters during the nesting season of April 2011 to July 2011.

32.2	48.9	30.3
30.6	32.5	29.4
25.3	25.8	26.1
28.3	29.2	26.7
25.6	33.9	27.2
33.1	34.4	30.8
34.2	40.0	33.3
29.7	36.4	28.9
33.1	34.4	31.3
28.6	30.0	28.3
24.4	25.3	25.6
28.6	27.2	27.8
34.2	32.5	33.3
29.2	28.1	28.9
26.7	28.1	27.2
33.1	32.2	30.6
45.0	37.8	38.3

Appendix 4. All nest completion data for Red-eared sliders during the nesting season of April 2011 to July 2011.

Carapace temperature (°C)	Cloacal temperature (°C)	Ground surface temperature (°C)
25.8	25.7	28.9
29.2	28.3	31.9
40.0	36.1	37.5
32.5	29.6	29.7
40.0	32.8	36.7
31.7	31.1	40.8
34.7	32.2	31.7
28.1	30.0	28.3
31.9	31.4	27.5
32.2	30.1	39.7
24.7	26.1	25.8
26.9	30.0	35.8
31.4	27.3	30.6
38.3	35.0	41.9
43.3	36.7	47.8
28.3	28.1	31.4

Appendix 5. Recorded temperatures of algae and mud covered carapaces for Texas river cooters.

Algae Covered Texas River Cooters						
PIT Number # time (min)	**051*366*047 (A)** Carapace Temperature (°C)	**051*865*588 (B)** Carapace Temperature (°C)	**042*289*883 (C)** Carapace Temperature (°C)	**051*806*770 (D)** Carapace Temperature (°C)	**000*787*062 (E)** Carapace Temperature (°C)	**025*808*382 (F)** Carapace Temperature (°C)
0	15.3	21.7	18.3	26.4	25.3	19.7
10	23.1	27.5	24.2	30.8	29.7	25.3
20	23.6	29.2	25.8	32.5	30	26.7
30	25.6	29.4	25.3	32.5	30.3	26.9
40	27.2	30.3	25.3	34.2	31.1	26.9
50	29.2	30.8	26.4	33.9	30.3	28.1
60	26.9	30.8	27.5	33.3	29.7	28.6
70	27.2	30.8	27.8	34.2	30.8	28.3
80	26.7	31.7	28.3	33.3	31.4	28.6
90	28.6	31.4	29.2	33.9	31.9	29.2
100	30.6	31.9	29.4	34.4	33.6	30.6
110	31.4	32.2	29.7	33.1	31.9	31.7
120	30.6	31.1	28.9	34.2	32.5	33.9
130	33.1	31.7	30.8	33.6	32.8	34.2
140	32.2	31.9	30.6	33.6	33.3	34.4
150	33.9	31.1	31.1	33.3	33.6	35.3

Appendix 6. Recorded temperatures of cloacal temperatures of Texas river cooters with algae and mud covered carapaces.

Algae Covered Texas River Cooters						
Time (min)	Cloacal temperature (°C)	Cloacal temperature (°C)	Cloacal temperature (°C)	Cloacal temperature (°C)	Cloacal temperature (°C)	Cloacal temperature (°C)
0	16.7	22.3	19.6	26.1	26.2	20.3
10	18.1	22.8	20.1	26.4	26.4	21.1
20	19.2	23.3	21.1	26.9	26.7	21.7
30	19.7	23.3	22.2	27.3	27.2	22.5
40	20.6	23.9	23.3	27.8	27.5	23.1
50	20.8	24.4	23.1	28.3	27.5	24.2
60	21.9	25.1	23.9	28.3	27.8	24.5
70	22.5	25.3	23.9	28.9	27.2	24.9
80	23.3	25.6	24.4	29.0	28.3	25.1
90	24.4	26.1	25.0	29.4	28.3	25.6
100	24.9	26.1	25.3	29.7	28.3	26.1
110	25.6	26.7	25.7	30.0	28.3	26.7
120	25.6	26.7	26.1	30.0	28.9	27.2
130	26.7	28.3	26.4	30.6	29.4	27.2
140	27.2	28.8	26.6	30.6	28.6	28.1
150	27.2	27.8	26.7	30.8	29.7	28.3

Appendix 7. Recorded temperatures of uncovered carapaces for Texas river cooters.

Texas River Cooters with Uncovered Carapaces				
PIT Number	**102*589*608**	**051*895*063**	**017*883*023**	**055*008*046**
	(G)	**(H)**	**(I)**	**(J)**
time (min)	Carapace Temperature (°C)	Carapace Temperature (°C)	Carapace Temperature (°C)	Carapace Temperature (°C)
0	21.4	20.8	20.0	21.9
10	29.7	27.5	25.6	27.2
20	29.7	28.1	28.1	29.4
30	31.4	30.3	28.6	30.8
40	32.2	29.7	29.7	32.5
50	33.9	32.2	30.8	32.5
60	34.4	32.2	31.4	32.5
70	34.7	30.8	31.4	35.0
80	34.2	30.8	33.1	35.0
90	35.0	32.5	33.1	35.3
100	34.2	32.5	34.7	35.8
110	35.8	31.1	34.7	35.8
120	36.7	33.1	35.0	35.6
130	36.1	34.2	35.3	36.9
140	36.7	34.7	34.7	37.5
150	37.2	35.3	36.1	37.5

Appendix 8. Recorded cloacal temperatures of Texas river cooters with bare carapaces.

Texas river cooters with bare carapaces				
time (min)	Cloacal Temperature (°C)	Cloacal Temperature (°C)	Cloacal Temperature (°C)	Cloacal Temperature (°C)
0	21.1	21.2	20.3	21.1
10	21.7	21.7	21.1	21.1
20	22.2	22.5	22.3	21.7
30	23.3	23.3	23.1	23.1
40	24.4	23.9	23.9	23.3
50	25.0	25.0	25.0	23.9
60	25.8	25.0	25.6	25.0
70	26.7	26.7	26.1	25.6
80	26.9	27.2	26.7	25.6
90	28.6	27.8	27.2	26.1
100	28.9	28.3	28.1	27.5
110	28.6	28.9	28.9	28.2
120	29.4	28.9	29.4	28.9
130	30.0	29.4	30.0	29.4
140	30.6	30.0	29.7	29.4
150	31.1	30.6	30.6	29.4

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VITA

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