Environmental Correlates of Hatchling Emergence in the Red-Eared Turtle, *Trachemys scripta elegans*, in Illinois

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ABSTRACT. – This study examined temperature and precipitation correlates of hatchling emergence from nests in the red-eared turtle (*Trachemys scripta elegans*) in west-central Illinois. Rising daily low temperatures were the only statistically significant environmental variable recorded during the period when naturally emerging hatchlings were caught. However, partial correlations suggested that the number of hatchlings caught increased with both increasing daily low temperatures and daily high temperatures, i.e., as the weather warmed. Most hatchlings were caught when both daily high and low temperatures were relatively high. Hatchling emergence was not directly associated with precipitation but generally occurred during periods of rising temperatures following rain events. Temperatures were also monitored in the tops and bottoms of experimental nest cavities. Emergence occurred after soil temperature gradients became warmer at the top of the nest cavity than at the bottom. Spring-time hatchling emergence in species that overwinter in the nest appears to be influenced by environmental conditions both within and outside the nest cavity.

KEY WORDS. – Reptilia; Testudines; Emydidae; *Trachemys scripta*; turtle; hatchlings; overwintering; nest emergence; Illinois; USA

The evolutionary significance of overwintering in the nest by hatchling turtles is little understood (Gibbons and Nelson, 1978; Holman and Andrews, 1994; Jackson, 1994; DePari, 1996). For turtle species such as the slider turtle (Trachemys scripta) that overwinter in the nest throughout their extensive geographic range in temperate North America (Gibbons et al., 1990; Jackson, 1994; Tucker, 1997), overwintering in the nest cavity is apparently a complex adaptive behavior. Successful overwintering requires sufficient energy stores to maintain hatchlings for the eight or so months that they remain in the nest cavity following hatching (Congdon and Gibbons, 1990), along with some means of timing emergence so that it occurs at an ecologically appropriate time. Timing of hatchling emergence in species that overwinter in the nest is also little understood but is possibly related to environmental cues transmitted to hatchlings in the nest cavity.

Information on hatchlings and their emergence from the nest in response to various environmental cues is limited, particularly for freshwater turtles. Rainfall has been advanced as a proximal cause of emergence for species that overwinter in the nest (Mitchell, 1988; DePari, 1996) and for some that do not (Moll and Legler, 1971; Alho and Pádua, 1982; Polisar, 1996).

Other factors that may be important in triggering emergence are nest integrity (DePari, 1996) and soil temperature gradients (Bleakney, 1963). DePari (1996) suggested that emergence and overwintering in hatchling *Chrysemys picta* is directly related to nest plug integrity and the factors that serve to degrade it. Thus, he believed that hatchlings are constantly in the process of emergence whenever soil temperatures are high enough but that an intact nest plug prevents emergence in the fall. Degradation of the nest plug during the winter due to freeze-thaw cycles and spring rains allows hatchlings to escape. In contrast, Bleakney (1963) suggested that soil temperature gradients in the fall and winter (i.e., October through March) encouraged hatchlings to remain in the nest because soil above the nest was relatively colder than soil near the bottom of the nest cavity; but during April and May when soil temperature gradients reverse, hatchlings would emerge in response to this reversal.

Preliminary results from soil temperatures recorded from January to April 1995 by Tucker (1997) agreed with Bleakney's hypothesis. Emergence of overwintering hatchlings of the red-eared slider (*Trachemys scripta elegans*) occurred after soil temperatures at 10 cm soil depth exceeded those at 25 cm soil depth. Hatchling emergence was also associated with daily high temperature but not with precipitation (Tucker, 1997).

The purpose of the current study is to extend the preliminary examination of environmental correlates of nest emergence in hatchlings of the red-eared slider (*Trachemys scripta elegans*) at the same nesting area in west-central Illinois studied by Tucker (1997). The association between hatchling emergence and environmental parameters for 1996 is examined and compared to data previously reported for 1995. Further, soil temperature gradients recorded from within seven experimental nest cavities constructed in the field and modeled after natural nest cavities are measured and compared to natural nests reported by Tucker (1997).

MATERIALS AND METHODS

Study Site. — Hatchling emergence was studied at a nesting area near Stump Lake, Jersey County, Illinois (39°18'N, 90°29'W) (Tucker and Moll, 1997; Tucker, 1997).

Nesting occurred here from late May to early July. The nesting habitat at this site consisted of a disked agricultural field of well-drained Worthen silt loam (Fehrenbacher, 1956) which had contained millet, sunflowers, weedy grasses, and other forbs, and was described in detail by Tucker (1997). Environmental parameters (rainfall and daily high and low temperatures) were collected within 3.1 km of the nesting area at Nutwood and Rosedale.

Natural Hatchlings. — Emerging hatchlings were collected with a drift-fence accompanied by pitfall traps (Tucker, 1997; Tucker et al., 1998). The drift-fence was deployed between 20 April and 20 June 1996, and was checked at least once per day. Some hatchlings were found before they reached the fence during daily visits; these were included with those found at the drift-fence. Hatchlings caught in the spring of 1996 came from eggs laid in the spring of 1995 because hatchlings of this species routinely overwinter in the nest (Gibbons and Nelson, 1978; Gibbons et al., 1990; Tucker et al., 1998).

Experimental Nests. — Because results from 1995 suggested that hatchling emergence might be related to soil temperatures (Tucker, 1997), eight experimental nests were constructed at a fenced area 3.1 km north of the nesting area. The soil types at the nesting area and the fenced area used for experimental nests were both Worthen silt loam. These nests were used to examine overwinter survivorship (Tucker and Packard, 1998) and the pattern of emergence in relation to soil temperatures. Methods used to construct nests and monitor nest temperatures were outlined in Tucker and Packard (1997); they are summarized here.

Nest cavities were constructed by digging a vertical tunnel of the appropriate depth with a cavity hollowed out of its side at the bottom. Eight nest cavities were constructed in a 2 x 4 grid inside a 2 x 3 m rectangular fenced area from which all surface vegetation had been removed. Neighboring nests were placed nearly equidistant from each other.

Nest cavity construction was completed on 10 October 1995. At that time, hatchlings from incubated eggs (see below) were placed in the cavities. Before sealing the nests, two temperature probes were installed in seven of the eight cavities. One probe was placed at the bottom of the cavity and the other at the top, with each attached to a HOBO-XT temperature logger. Temperature loggers were activated on 16 January 1996. Loggers recorded 15 temperature readings in each 24-hr interval. The one unmonitored nest was used to evaluate hatchling conditions.

Beginning 15 April 1997, the fenced area was checked daily for emerging hatchlings at about 0600 hrs and about 1800 hrs. Six monitored nests were left undisturbed until hatchlings emerged unassisted, the seventh monitored nest was opened 15 April after hatchlings from the other six nests had emerged. The unmonitored nest was opened on 15 April to check condition of hatchlings.

Egg Incubation and Hatchlings.—Eggs for each clutch placed in experimental nests were incubated on moist vermiculite with each clutch placed in a separate plastic box.

These boxes contained a mixture of 1.11 g water/1.0 g vermiculite (water potential = -150 kPa). All boxes had an aluminum foil covering between the box and lid to retard moisture loss.

During incubation, boxes were rotated once weekly to reduce effects of possible temperature gradients. Incubation temperature fluctuated, but all clutches were exposed to similar thermal environments during incubation.

Statistical Treatment. — The associations between hatchling emergence and environmental variables were determined with Spearman rank correlation. Comparisons of means were done with Kruskal-Wallis test (= KW). All statistical analyses were performed using SAS (SAS Institute, 1988). The sequential Bonferroni method was used for multiple correlation coefficients (Rice. 1989). To make data collected in 1995 (Tucker, 1997) and 1996 comparable, statistical analysis was limited to hatchlings collected between 30 April and 28 May in both years.

RESULTS

Natural Hatchlings – 1996. — Overall. 95 hatchlings were caught at the drift-fence between 30 April and 5 June 1996. These 95 hatchlings averaged 32.2 mm in maximum carapace length (1.48 mm SD. 28.0–35.4 mm range), 30.5 mm in maximum plastron length (0.18 mm SD. 25.2–33.4 mm range), and 7.25 g in mass (0.08 g SD. 5.10–8.77 g range). Although hatchlings were collected over a span of 37 days, most hatchlings were caught in a span of a few days in early May (Fig. 1).

Hatchling activity during 1996, as measured by numbers of hatchlings caught at the drift-fence between 30 April and 28 May, was positively correlated with daily high temperature (rho = 0.40, p = 0.0322, n = 29 days), with daily low temperature (rho = 0.48, p = 0.0076), and with rainfall (rho = 0.03, p = 0.8971). However, only the association between hatchling numbers and daily low temperature was statistically significant. A p value of less than 0.0250 was needed to reduce the possibility of a type I error to 0.05 or less for the other two associations.

Because daily high and low temperatures were closely correlated, the associations between them and hatchling numbers may be affected by both variables. Therefore, partial correlations were used with the effect of daily high temperature removed for daily low temperature. Removing the effect of daily high temperature made the association between the number of hatchlings and daily low temperature statistically insignificant (rho = 0.30, p = 0.1178). Likewise, removing the effect of daily low temperature using partial correlation for daily high temperature made the association between hatchling numbers and daily high temperature even less significant (rho = -0.02, p = 0.8999). Thus the number of hatchlings caught each day increased with both increasing daily low temperatures and increasing daily high temperatures, i.e., as the weather warmed. Most hatchlings were caught when both daily high and daily low temperatures were relatively high (Fig. 1).

Nesting occurred here from late May to early July. The nesting habitat at this site consisted of a disked agricultural field of well-drained Worthen silt loam (Fehrenbacher, 1956) which had contained millet, sunflowers, weedy grasses, and other forbs, and was described in detail by Tucker (1997). Environmental parameters (rainfall and daily high and low temperatures) were collected within 3.1 km of the nesting area at Nutwood and Rosedale.

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Figure 1. Timing of hatchling emergence compared to variation in environmental parameters during 1996.

Although rainfall was not directly associated with the number of hatchlings collected each day in 1996, rainfall may be an important variable. Generally, days when numerous hatchlings were caught followed periods of rainfall (Fig. 1). The largest numbers of hatchlings were caught when a period of rising daytime temperatures followed a period of rainfall (Fig. 1).

Because small turtles may take a considerable time to traverse the distance from where most natural nests were located to the drift-fence, the comparison of hatchlings caught at the drift-fence to local environmental variables on the day that they were caught may be misleading. For instance, if hatchlings took an average of 2-3 days to reach the fence, then the number of hatchlings caught each day should be compared to conditions that existed on the day they emerged (2-3 days earlier) and not on the day that they were actually caught at the fence. I also examined the association between numbers of hatchlings caught and the weather conditions one day prior to capture and two days prior to capture. These were similar in direction but less significant than those arrived at using the conditions on the day of capture for 1996. Thus, the effect of any lag between emergence and capture was not apparent.

Natural Hatchlings – 1995 vs. 1996. — Though the total number of hatchlings collected in 1995 (n = 179) and 1996 (n = 95) varied, the pattern of hatchling emergence in relation to environmental variables was remarkably similar in both years (Figs. 1, 2). Most hatchlings were caught during periods of rising temperatures following rainfall.

Table 1. Comparison of descriptive statistics for environmental conditions between 30 April and 28 May on days when one or more hatchlings were collected in 1995 (n = 15) and 1996 (n = 20) and the number of hatchlings collected per day.

		1995		1996
	mean	(SD; range)	mean	(SD; range)
High temperature (°C)	23.6	(4.08; 15.6-30.6)	26.4	(6.50; 15.0-36.7)
Low temperature (°C)	11.7	(4.07; 3.9-18.3)	16.9	(4.82; 5.0-23.9)
Rainfall (cm)	1.6	(2.44; 0-7.50)	0.3	(0.45; 0-1.25)
Hatchlings	10.3	(15.2; 1-60)	4.6	(4.96; 1-20)



Figure 2. Timing of hatchling emergence compared to variation in environmental parameters during 1995, adapted from Tucker (1997).

Environmental measurements from the 15 days in 1995 when one or more hatchlings were collected were compared to those for the 20 days in 1996 when one or more hatchlings were collected (Table 1). Although this period in 1995 seemed cooler and wetter than the same period in 1996, means for daily high temperature (KW = 1.78, DF 1, p = 0.1820) and rainfall (KW = 2.44, DF 1, p = 0.1184) did not differ significantly. However, daily low temperature (KW = 9.73, DF 1, p = 0.0018) was significantly warmer in 1996 than it was in 1995. Importantly, the number of hatchlings caught per day, though overall higher in 1995 than 1996 (Table 1), was not statistically different (KW = 2.15, DF 1, p = 0.1430).

Experimental Nests. — Hatchlings from the six experimental nests that emerged unaided did so from 2–4 May in 1996 (Table 2). The first natural hatchling caught in 1996 was found on 30 April, two days prior to emergence from the first experimental nest. Thus, emergence from experimental nests occurred when hatchlings from natural nests were emerging, suggesting that conclusions drawn from experimental nests have ecological relevance.

The time that the nest cavity was breached was apparent from temperature records for the six nests where hatchlings emerged unaided. For both the bottom and top temperature sensors, breaching of the nest cavity was followed by a temperature reading that greatly exceeded the penultimate temperature measurement while the nest was closed. The sudden change in temperature reflected the entry of relatively warm air from outside the nest cavity (Table 2).

Table 2. Comparison of nest temperatures before and after breaching of nest cavity.

		Last closed nest reading		First open nest reading	
Nest	Date	Time	°C	Time	°C
1	4 May	0951	11.96	1127	20.11
2	4 May	0948	12.24	1124	26.81
3	2 May	1617	12.54	1753	18.76
5	3 May	1311	12.24	1447	17.12
6	2 May	1628	12.24	1804	19.09
7	2 May	1632	12.84	1808	19.09

Two nests (nests 1 and 2) were breached during the late morning. In both of these instances, hatchlings were found at the fence the same evening suggesting that they emerged shortly after the nest was opened. In contrast, the remaining four nests (nests 3, 5–7) were breached in the afternoon. Hatchlings from these nests were found not during the morning but instead during the evening fence check on the following day. Apparently, hatchlings remained in the nest cavity overnight and emerged the next day rather than emerging as soon as the nest was breached. Because the fence was placed very close to the array of experimental nests and all vegetation had been removed, it is unlikely that hatchlings could have emerged without being detected.

Temperature gradients within nest cavities overall varied systematically. Temperatures in the bottom of the nests were significantly warmer than temperatures in the top of the nests from January through March (Table 3). The gradients reversed in April and May when temperatures were higher in the top of the nests (Table 3, Figs. 3 and 4). Emergence occurred after nest temperature gradients reversed (and overall temperatures increased).

Temperature profiles of individual nests were quite variable (Table 4). In most nests, temperatures in the bottom of the nest were distinctly warmer than those in the top of the nest in January and February. However, temperatures in the bottom and top of nests were statistically equivalent in March for five of seven nests monitored, despite a statistical difference for combined nest temperatures for that month as noted above. In contrast, four of seven nests in April were warmer at the top of the nest than at the bottom and three others did not differ significantly. In May, rising temperatures in the bottom of nests resulted in four of seven nests having temperatures in the top and bottom that were statistically equivalent and two other nests that had warmer temperatures in the top than at the bottom. The most important result was the degree to which potential thermal gradients varied. Despite this variation, hatchlings in six of the nests emerged within 48 hrs of each other.

The weather for the time period that emergence from experimental nests occurred (2–4 May) was relatively dry with rain restricted to the evening of 4 May when 2.4 cm fell. If a rain event triggered emergence from these nests, then it would have had to have been associated with the 1.2 cm of rain that fell on 30 April, a delay of 2 to 4 days after the event.



Figure 3. Mean and ranges for temperatures recorded in the top (T) and bottom (B) of nest cavities by month for all nests combined.

Importantly, temperatures during the period between 1 and 5 May showed a distinct increase with highs approaching 26°C (Fig. 1).

DISCUSSION

The observations made on *Trachemys scripta elegans* in 1995 (Tucker, 1997) and 1996 suggest that spring-time hatchling emergence is closely tied to air and soil temperatures. The results largely agree with Bleakney (1963) in finding that soil temperature gradients during the winter months would encourage hatchlings to remain in the nest if they constantly attempted to stay in the warmest part of the nest. However, Bleakney's (1963) hypothesis cannot account for hatchlings remaining in nests during August and September when soil temperatures are likely warmer in upper layers of the soil column than they are in the lower portion. Consequently, some other developmental process or factor appears to exist that prevents fall emergence.

In an experimental study of the painted turtle (*Chrysemys picta*), DePari (1996) found that fall emergence occurred from nests whose plug had lost its integrity. DePari's (1996) hypothesis was that an intact nest plug would physically prevent hatchlings from leaving the nest cavity during late summer to early fall when temperature gradients would

Table 3. Comparison of temperatures ($^{\circ}$ C) recorded in the top and bottom of seven experimental nests combined from mid-January to early May; KW = Kruskal-Wallis test.

Sensor	January Mean (SD)	February Mean (SD)	March Mean (SD)	April Mean (SD)	May Mean (SD)
Тор	1.45(2.02)	1.39(2.96)	3.97(2.35)	10.07(2.56)	12.40(1.72)
Bottom	2.24(1.66)	1.62(2.41)	4.10(1.78)	9.74(2.12)	12.10(1.34)
Bottom - Top =	0.79	0.23	0.13	-0.33	-0.30
KW result	T < B	T < B	T < B	T > B	T > B
D	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001
n	215	435	465	450	259 top. 279 bottom



Figure 4. Temperature profiles for the top and bottom of nest 1 showing the variation in temperature gradients from mid-January to early May. The sudden rise in nest temperatures following day 118 represents nest breach. The period of constant temperatures recorded by the top sensor during late February was due to snow cover being present.

otherwise encourage them to emerge. While the current study does not experimentally examine the importance of the nest plug, observations made during this study suggest that the hypothesis is not sufficient by itself to account for these hatchling *T. s. elegans* to remain in their nests during the fall.

First, all of the experimental nests that I employed had no nest plugs at all because each nest cavity was constructed as a lateral tunnel off of a larger vertical tunnel. It may be that the never-dug soil above the cavities acted as the functional equivalent of the nest plug. Nonetheless, turtles did not emerge in October but had no difficulty in digging exit tunnels through the never-dug soil to emerge in May. Second, the nesting area where naturally emerging hatchlings were collected is an agricultural field. Each fall and spring prior to the time that hatchlings generally emerge the field was disked with individual disk blades set to a depth of 75 to 100 mm. Thus at this site, the top 100 mm or so of the soil is completely disturbed and there is little chance that nest plugs survive this operation. Yet hatchlings remained in the nest cavities in both years until late April and May. Hatchling turtles are able to burrow and hatchlings of some species actually dig deeply into the soil after hatching. Hatchling yellow mud turtles (Kinosternon flavescens) were found to burrow to depths of 41-66 cm below the ground surface in Nebraska to overwinter, whereas hatchling ornate box turtles (Terrapene ornata) were also found buried to depths of 68 cm (Costanzo et al., 1995). Further experimental study of the importance and persistence of nest plugs is needed before nest integrity can be positively associated with hatchling emergence.

The degree to which intranest soil temperatures varied among individual nests is an important finding of this study. Although combined results support Bleakney's (1963) temperature gradient hypothesis, temperature gradients are variable among nests. This variation occurred despite the close proximity of nests and the relatively uniform substrate for the experimental nests. Despite the internest variation in

Table 4. Comparison of temperatures (°C) recorded in the top and bottom of seven experimental nests demonstrating the amount of internest variability along with depth from soil surface to the top and bottom of each nest.

Nest	Sensor	Soil Depth (mm)	January (n = 215) Mean (SD)	February (n = 435) Mean (SD)	March (n = 465) Mean (SD)	April (n = 450) Mean (SD)	n	May (n varies) Mean (SD)
1	Top Bottom KW result:	52 133	0.76(2.17) 2.43(1.65) T < B***	1.15(3.44) 1.88(2.50) T < B***	3.64(2.83) 4.29(1.82) T < B***	9.98(3.07) 9.91(2.17) $T \approx B$	53 53	$12.65(2.06) \\ 12.50(1.42) \\ T \approx B$
2	Top Bottom KW result:	87 160	1.62(1.94) 2.40(1.65) T < B***	1.48(2.71) 1.73(2.36) T < B***	4.02(2.19) 4.25(1.75) T < B*	$\begin{array}{c} 10.08(2.38) \\ 9.87(2.07) \\ T \approx B \end{array}$	53 53	$\begin{array}{c} 12.77(2.14) \\ 12.39(1.24) \\ T \approx B \end{array}$
3	Top Bottom KW result:	65 142	1.27(2.07) 2.24(1.63) T < B***	1.29(3.03) 1.54(2.35) T < B***	3.98(2.40) 4.04(1.71) $T \approx B$	10.09(2.58) 9.54(2.06) T > B***	27 27	$\begin{array}{c} 12.38(1.96) \\ 11.77(1.51) \\ T \approx B \end{array}$
4	Top Bottom KW result:	81 148	1.92(1.89) 2.28(1.69) T < B***	1.51(2.68) 1.59(2.43) T < B***	4.00(2.07) 4.05(1.81) $T \approx B$	9.93(2.31) 9.74(2.15) T > B*	52 52	$\begin{array}{c} 12.18(0.70) \\ 12.01(0.54) \\ T > B^{**} \end{array}$
5	Top Bottom KW result:	77 165	1.93(1.79) 2.38(1.58) T < B***	1.58(2.61) 1.73(2.27) T < B***	4.03(1.96) 4.03(1.65) T = B	9.93(2.22) 9.56(2.01) T > B***	40 40	12.21(1.08) 11.87(1.38) T > B***
6	Top Bottom KW result:	55 137	$\begin{array}{l} 1.17(2.04) \\ 1.88(1.74) \\ T < B^{***} \end{array}$	1.30(3.08) 1.42(2.54) T < B*	4.03(2.49) 4.07(1.94) $T \approx B$	$\begin{array}{c} 10.22(2.75) \\ 9.85(2.20) \\ T \approx B \end{array}$	7 27	10.63(0.35) 11.91(1.67) T < B**
7	Top Bottom KW result:	51 125	1.49(1.99) 2.07(1.63) T < B***	1.45(2.99) 1.42(2.42) $T \approx B$	$\begin{array}{c} 4.07(2.40) \\ 3.98(1.79) \\ T \approx B \end{array}$	10.28(2.53) 9.70(2.11) T > B***	27 27	$\begin{array}{c} 12.38(1.91) \\ 11.76(1.67) \\ T \approx B \end{array}$

* p < 0.05; ** p < 0.01; *** p < 0.001; KW = Kruskal-Wallis test.

intranest temperature gradients, turtles that emerged unaided did so within a 48-hr period. The narrow window of emergence from experimental nests in contrast with the degree of internest variation in soil temperature gradients further underscores the importance of external environmental effects and developmental components involved in nest emergence in this species.

Field results (Figs. 1 and 2) suggest that hatchling emergence from natural nests also mostly occurs over a short time span. Moreover, periods of maximal hatchling emergence as reflected by captures at drift-fences occurred at about the same time in May for both 1995 and 1996 (Tucker, 1997, and herein). Experiments designed to examine the developmental components involved in timing nest emergence would yield interesting insights into the biology of turtles whose hatchlings overwinter in the nest.

ACKNOWLEDGMENTS

I thank Jason Uttley and Moynell M. Tucker for assistance in the field. Neil Booth and Kim Postlewait (Illinois Department of Natural Resources) at the Mississippi River State Fish and Wildlife Area in Rosedale, Illinois, allowed free access to the Stump Lake nesting area. Gary L. Paukstis assisted with drift fence construction. This work was partially supported by the Illinois Natural History Survey and the Upper Mississippi River System Long Term Resource Monitoring Program.

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Received: 24 January 1997 Reviewed: 28 February 1998 Revised and Accepted: 23 March 1999