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Between a Rock and a Hard Place: Responses of Eastern Box Turtles (*Terrapene carolina*) When Trapped Between Railroad Tracks

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Human transportation infrastructures, such as roads, can adversely affect animal populations via fragmentation (Forman and Alexander 1998; Mader 1984) and habitat deterioration due to construction (Ritters and Wickham 2003), changes in predator/prey concentrations (Dijak and Thompson 2000) and vegetation composition (Angold 1997), and the spread of invasive species (Tyser and Worley 1992) (for summary references see Forman et al. 2003). Direct mortality has been demonstrated for many animals, including mammals (Groot Bruinderink and Hazebroek 1996; Havlín 1987), and amphibians and reptiles (e.g., Ashley and Robinson 1996; Hels and Buchwald 2001; Smith and Dodd 2003). Other land transportation networks, such as railroads, can result in direct mortality due to collisions with trains, although this has been primarily documented for mammals (see Van Der Grift 1999 for review). Although some lizards may benefit from railroad structures (Blanke 1999), the railroad bed itself may be lethal for smaller animals that can become trapped between the rails, where they may be susceptible to predation or physiological stress. Railroads can also form barriers, either physically (inability to cross) or behaviorally (avoidance), that can result in fragmented populations (Groot Bruinderink and Hazebroek 1996). For example, Van Der Grift (1999) points out that few Hedgehogs (*Erinaceus europaeus*) are killed by trains, but the structure of the railroad may act as a barrier to movement.

Eastern Box Turtles (*Terrapene carolina*) are found throughout most forests of the eastern United States. In many regions, their habitat is traversed by railroads. Points where roads intersect railroads (i.e., railroad crossings) likely increase the probability of turtles entering and becoming trapped between railroad rails. Apparent railroad-induced mortality has been documented for *T. carolina* due to individuals becoming trapped between the rails (Dodd 2001; Palmer and Braswell 1995). Anecdotal evidence of 10–15 *T. carolina* shells of varying sizes in a 5-km section of railroad in north Florida, suggests that turtles have difficulty crossing or escaping from between the rails (Pierson Hill, pers. comm.).

In this study, we examine the potential impacts of railroads on *T. carolina* by testing their ability to escape from between railroad tracks. Additionally, we estimate the temperatures that *T. carolina* experience while trapped. Finally, we use Geographic Information System (GIS) data to determine the likelihood of a turtle encountering potential entry and exit points along railroads within our study area.

Methods

We conducted our study near the town of Davidson in northern Mecklenburg and southern Iredell counties, North Carolina, USA, on a seldom-used stretch of railroad track typical of those in the region. The railroad rails are T-shaped and approximately 190 mm high and 70 mm wide at the top of the rail (Fig. 1).

We tested 12 adult *T. carolina* (8 male, 4 female) with a mean ± SE body mass of 383.1 ± 14.4 g). Mean ± SE measurements of the turtles we tested were: carapace length = 130.1 ± 1.7 mm, plastron length = 126.1 ± 1.4 mm, shell width = 103.4 ± 1.3 mm, and shell height = 62.3 ± 1.3 mm (Fig. 1). All turtles were captured by members of the Davidson College Herpetology Laboratory or the Davidson community and tested between 4 September and 2 October 2004. Turtles were maintained in the laboratory for < 2 weeks prior to experiments and were provided with food and water *ad libitum*. No animals used in the experiments were injured or displayed signs of deteriorating health while in captivity. After completion of the experimental trials, we released turtles at their original capture locations.

Experiment 1. Can box turtles climb over railroad rails?

To examine the ability of *T. carolina* to escape from railroad tracks, we placed turtles between the rails of a railroad at a predefined common location (i.e., starting point) and oriented them in one of three randomly chosen directions: facing away from the observer or towards the observer's left or right. After releasing the turtle, the observer sat motionless on the track at least 20 m away and remained 20–40 m away from the turtle for the duration of each experiment. The turtle's movements and behavior were followed using a spotting scope (Spacemaster, 15–45x zoom; Bushnell Corporation, Overland Park, Kansas). Trials started when the turtles emerged from their closed shells and began moving. Trials ended after 60 min or when the turtles escaped from the track. We recorded the frequency of the following behaviors during the trials: 1) Exploring – when a turtle stopped and extended its neck, apparently attempting to assess the surrounding environment and/or look over the tracks; 2) Climbing attempt – when a turtle was oriented perpendicular to and tried to climb over a rail; 3) Falling – when a turtle fell on its back after an attempt to climb; 4) Retraction – when a turtle's limbs and head were drawn inside the shell; 5) Direction change – when a turtle substantially altered its course from a straight-line movement.

Using a measuring tape, we recorded to the nearest 0.1 m, 1) the distance between the starting point and the furthest point that a turtle reached (referred to as "furthest distance"); and 2) the modal sum of the displacement vectors' lengths ("total distance"). Turtle walking speed was estimated at specified distances using predefined markers not visible to the animals.

We conducted the experiment on a 1 km section of railroad with adjacent forested land on either side of the tracks. Secondary growth mixed pine and hardwood forest on both sides of the railroad may have provided visual cues to the turtles that preferable habitat was available nearby. The forest also helped to reduce noise from nearby streets and provided shade, easing possible thermal stress to the turtles during our tests.

Experiment 2. Will box turtles escape at railroad crossings?

To test turtle behavior upon reaching a railroad crossing (i.e., intersection of a road with a railroad), we positioned all 12 subjects between railroad tracks, facing a railroad crossing 5 m away.

This site (ca. 3 km N of the location of Experiment 1) was a section of the railroad that ran between a large grass field and a two-lane road with a moderate amount of traffic running parallel to the track. A second road with low traffic levels crossed the railroad and intersected with the two-lane road. The area between the tracks at the crossing was filled to the level of the road and rail with asphalt; large wooden beams separated the track from the asphalt. The asphalt sloped at ca. 45° up to the level of the road, which allowed turtles to climb up from the railroad bed.

Observations began once the turtle started moving and lasted until one of the following events occurred: 1) the turtle turned around, walked away from the railroad crossing and passed the starting point; 2) the turtle climbed up on the asphalt, crossed the road, and continued traveling between the rails on the other side of the road; 3) the turtle moved from between the tracks towards the grass field, or 4) the turtle moved from between the tracks and traveled towards the two-lane road. The frequency of behaviors such as climbing attempts and falling (defined above) were also recorded. The observer stayed < 5 m from the turtle throughout the experiment to ensure that the turtle did not get hit by vehicles, but attempted to disturb the turtles as little as possible.

To determine the likelihood that a turtle would encounter potential entry and exit points along the railroads within our study area, we calculated the mean distance between railroad crossings using mile-marker data in a GIS for railroads passing through the towns of Davidson, Cornelius, and Huntersville, North Carolina (Mecklenburg County GIS files, Mecklenburg County Information Services and Technology).

Experiment 3. How long does it take a turtle to overheat between tracks?

We experimentally measured the changes in turtle body temperature (T_b) when placed on a railroad tie equidistant from both railroad tracks. We conducted this experiment in an area of full-sun exposure from late morning (ca.1000 h) to early evening (ca. 1900 h) on three mild days (T_{air} ca. 22°C) during late September 2004. We used two turtles in this experiment and two different turtles during preliminary trials. All were collected after being recently killed on the road but had minimal damage to the shell and body. They had similar dimensions to the living turtles used in our study, and were kept frozen until use. To estimate shell temperature, we glued a microdatalogger (Thermochron iButton, Dallas Semiconductor, Inc., Dallas, Texas, USA) to the top of each dead turtle's carapace (Grayson and Dorcas 2004). Because cloacal temperatures of *T. carolina* correlate well with core turtle temperatures (Russo 1972), we recorded core body temperature by inserting a thermistor attached to a datalogger approximately 7 cm into the cloaca (StowAway XTI Temperature Logger, Onset Computer Corp., Bourne, Massachusetts, USA). Both dataloggers were set to record every 5 min and had a resolution of ± 0.5°C (Grayson and Dorcas 2004; Onset Computer Corp.). We obtained data on air temperature from an automated weather station located ca. 2 km from the test site.

Results

Experiment 1. Can box turtles climb over railroad rails?—Only one of the 12 turtles tested successfully climbed over the rail and escaped from between the railroad tracks. All but three turtles made at least one attempt to climb the rails during the 1-h experiment. Of 42 climbing attempts, 11 were made at connecting brackets that joined two consecutive rails. The turtle that successfully climbed over the rail had the highest number of overall escape attempts (12) and was able to climb over the tracks at the connecting brackets. Some turtles that failed in their attempts to climb the rails tried to escape more frequently than others (mean = 3.75 ± 0.94 attempts; range = 1–8 attempts; N = 8). While attempting to climb, two turtles fell on their backs, but managed to right themselves within a few seconds.

Overall, turtles traveled primarily in straight lines. The mean furthest distance the turtles traveled while between the rails was 79.4 ± 13.2 m (range = 37.3–188.3 m). Two turtles moved more than 100 m; most moved between 45 and 70 m. Mean total distance traveled while between the rails was 89.9 ± 13.05 m (range = 37.3–188.3m) because some turtles changed directions several times. Directional changes occurred frequently, but were generally restricted to short time periods within the test (mean = 22.6 ± 4.7 direction changes per turtle; range = 3–49). Turtles walked on railroad gravel and ties at speeds ranging from 0.083 to 0.056 m/s (5 m in ca. 60–90 s) during at least part of each trial when they were not stopping or exploring the surroundings. During the testing period, turtles showed signs of exploring on average 46 ± 7.52 times per hour (range = 15–87). Three turtles retracted into their shells during the trial; one of these retractions occurred as a person walked on the tracks next to the turtle. Three other turtles buried themselves under piles of leaf litter that had accumulated on the inside of one of the rails.

Experiment 2. Will box turtles escape at railroad crossings?—Of the 12 turtles tested at the railroad crossing, five escaped and crawled towards the grass field, four escaped and moved towards the nearby moderately-trafficked road, two continued straight and remained between the tracks on the other side of the railroad crossing, and one turned back before it reached the railroad crossing.

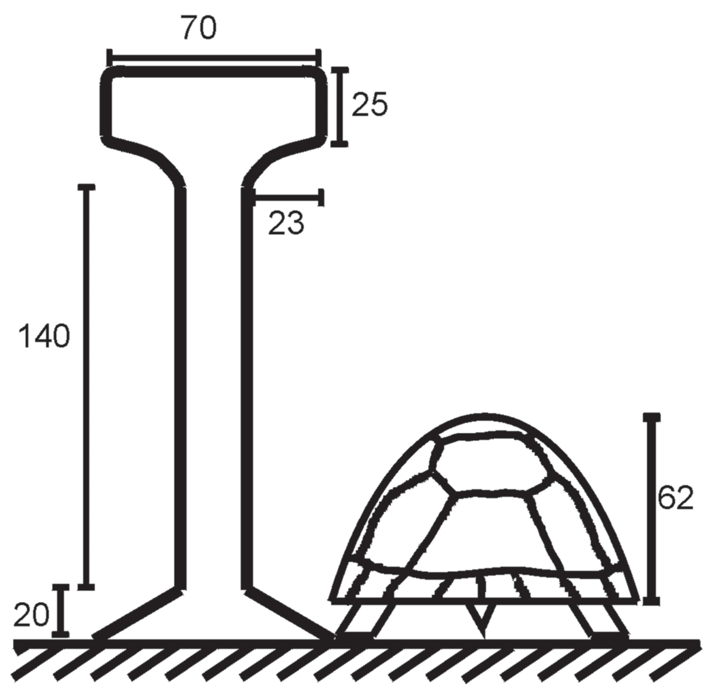

Fig. 1. Mean size of tested Eastern Box Turtle (*Terrapene carolina*; N = 12) compared to railroad track rail dimensions (in mm).

During the course of this experiment, four turtles made eight climbing attempts. The turtle successful at escaping during Experiment 1 accounted for five of the climbing attempts, although it fell over on its back and had to right itself three times.

The mean distance between consecutive railroad crossings in the study area was 379.6 m (range: 48.3–1223.1 m); 30% of the crossings were less than 200 m apart, 16% of the crossings were between 200 and 300 m apart, and 54% were more than 300 m apart.

Experiment 3. How long does it take a turtle to overheat between tracks?—The T_b and shell temperatures of the two dead *T. carolina* tested in late September reached temperatures considerably higher than the air temperature by about noon and remained high most of the day (10–20°C > T_{air}; Fig. 2). The two turtles' T_b and shell temperatures were nearly identical throughout the day. The turtles' core temperatures (maximum = 40.5°C; temperature increase = 0.31°C/h) did not reach mean lethal T_b for the subspecies *T. carolina triunguis* (42.98 ± 1°C; Sturbaum 1981). However, it approached critical thermal maximum (41°C for *T. ornata luteola*; Plummer et al. 2003), defined as the point at which a turtle becomes incapable of coordinated locomotion. Estimated shell temperature stayed consistently higher than core T_b throughout the day and peaked at 48.5°C (Fig. 2).

Discussion

Our results indicate that adult *T. carolina* often cannot escape when trapped between railroad tracks. Most turtles clearly have the ability to escape at railroad crossings, although they may encounter unfavorable conditions (e.g., automobile traffic) upon escaping. While between railroad tracks, turtles can quickly reach critically high body temperatures, even on relatively mild days.

The failure of turtles to climb over the railroad tracks might result both from physical and behavioral characteristics of *T. carolina*. A comparison of turtle and rail dimensions clearly illustrates that the rails represent a considerable height obstacle (Fig. 1). Although a full-grown *T. carolina* erect on its hind legs can sometimes reach the top of the rail, they generally cannot pull themselves over to escape. Willbern (1982) reported several instances of *T. carolina* climbing a 77 cm vertical wire mesh fence. In contrast, the shape and smoothness of a railroad rail, and potentially the high temperature of the rail, appear to impede successful climbing by adult turtles (Fig. 1). Although hatchling and juvenile *T. carolina* might be able to crawl under rails, especially where the gravel underneath the track has been removed, their small size makes them more prone to rapid, and potentially lethal, increases in T_b.

When faced with obstacles, *T. carolina* will often travel along the edge of habitat boundaries such as roads, forest edges, and streambeds, rather than attempting to climb (Lemkau 1970). Our data support this observation because the turtles we tested tended to spend most of their time walking rather than trying to climb over railroad rails. However, because we conducted our experiment under conditions without thermal stress (i.e., in the shade), turtles may not have been as motivated to try to escape quickly from between the railroad rails. When turtles did escape from railroads at crossings, many moved towards a nearby road rather than moving towards a grassy field, thus increasing their probability of being struck by vehicular traffic (Carr and Fahrig 2001; Hels and Buchwald 2001).

We suspect that most turtles that suffer mortality on railroad tracks enter via a railroad crossing (an intersection of a road and a railway where the pavement levels off with the rails). Even in the suburban areas of our study site, the distance between approximately 50% of the railroad crossings was greater than 300 m. The time required for turtles to travel this distance would be at least 1.5 h, assuming the turtle walked continuously at the speeds we measured (comparable to Adams et al. 1989; Lemkau 1970; Muegel and Claussen 1993; Strang 1983).

When trapped between railroad rails, *T. carolina* may quickly reach critical T_b. *Terrapene* spp. thermoregulate behaviorally primarily by varying activity periods and choosing particular microclimatic conditions (Converse 1999; Ernst and Barbour 1972; Reagan 1974). However, railroad tracks rarely provide habitats conducive to behavioral thermoregulation and once air temperature reaches 50°C, *T. carolina* are unable to maintain T_b's within their tolerance limits (Sturbaum 1981). A similar situation was documented in Madagascar, where Radiated Tortoises (*Geochelone radiata*) fell in a steep embankment on the side of an unfinished road and died of sun exposure or drowning (Goodman et al. 1994).

Most research on thermoregulation in *Terrapene* spp. has been conducted with *T. ornata*. do Amaral et al. (2002) failed to conclude whether *T. ornata* has a higher thermal tolerance, more precise physiological methods of thermoregulating, and a potentially higher critical thermal maximum and lethal T_b than the forest-inhabiting *T. carolina*. However, *T. ornata* selected for higher tem-

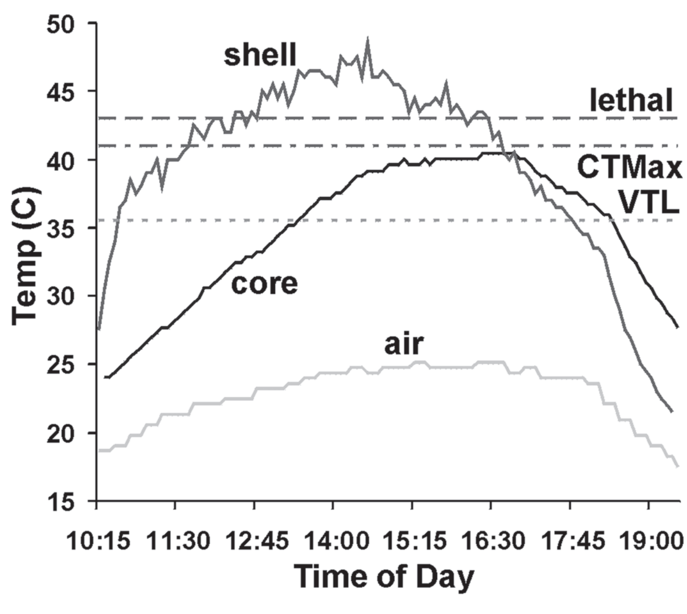

FIG. 2. Core and shell temperatures of a freshly dead Eastern Box Turtles (*T. carolina*) between railroad tracks on 25 September 2004, southern Iredell County, North Carolina. Shell and core temperatures peaked respectively at 48.5°C and 40.5°C; both were consistently higher than the air temperature by 10–20°C. Measured T_b approached estimated lethal T_b for *T. carolina triunguis* (42.98 ± 1°C; Sturbaum 1981). The critical thermal maximum (CTMax) of 41°C and maximum voluntary tolerated level (VTL) of 35.5°C (Plummer et al. 2003) for *T. ornata luteola* may be higher than those of *T. carolina* (Sturbaum 1981) because they tend to choose higher T_b (do Amaral et al. 2002).

peratures than *T. carolina*. Therefore, even though core temperatures in Experiment 3 (Fig. 2) did not quite reach critical levels for *T. ornata*, the highest temperatures recorded might represent critical T_b for *T. carolina*. Two preliminary shorter trials on slightly warmer days (T_{air} approximately 28.5°C at 1500 h) resulted in faster temperature increase (0.61°C/h and 0.42°C/h, similar to Bethea 1972) than the rate of 0.31°C/h for our trial on a relatively mild day (Fig. 2). On these warmer days, it would have taken approximately 4.5 h for a turtle with an initial T_b of 20°C to reach lethal T_b. During all of our temperature tests, the dead turtles' T_b surpassed the maximum preferred voluntary locomotory temperature of 32°C (Adams et al. 1989).

We stipulate that the presence of railroad tracks is detrimental to the health of *T. carolina* populations. Even in the suburban areas of Davidson, approximately one-half of the railroad crossings are separated by what are likely lethal distances for *T. carolina*. Even though a higher number of crossings may increase the chance for escape, individuals whose home ranges border the infrastructure would also be more prone to get trapped between the tracks. Furthermore, railroads in forested regions with fewer railroad crossings may act as physical barriers for exchange of genetic material and decrease the long-term survivability of *T. carolina* populations.

Several investigators have suggested structures such as road tunnels to reduce road mortality (Langton 1989; Messmer and West 2000); structures that reduce the possibility of turtles becoming trapped within railroad rails should be investigated. Additionally, formal studies are needed to evaluate the long-term effects of railroads on *T. carolina* populations.

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