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Spatial Ecology of the Striped Mud Turtle, *Kinosternon baurii*, in a Restored Florida Wetland

For many turtle species, adequate background data to formulate useful conservation, restoration, and management plans are lacking (Ernst et al. 1994; Ernst and Lovich 2009). The knowledge gap should be filled for understudied turtles, primarily because recent unforeseen population declines suggest that predicting population decline is difficult, even for relatively well-studied turtles (Gibbons et al. 2000; Christiansen et al. 2012; Lovich et al. 2018). Information on how organisms use space is an essential part of understanding their ecology (Gibbons 1970; Gregory et al. 2001; Slavenko et al. 2016). Movement data can provide insight into the actual space needed to support species by displaying where individuals use their time (Gibbons 1970; Wygoda 1979; Harden et al. 2009). This information can be valuable to land managers and conservation biologists when planning restoration and conservation projects or providing insight into turtle declines (Harden et al. 2009; Dudley et al. 2015; Marchand and Litvaitis 2004).

The Striped Mud Turtle, *Kinosternon baurii,* is a small understudied semi-aquatic turtle that resides along the Atlantic and Gulf Coastal Plains of the eastern United States from Virginia to the Florida Keys (Ernst et al. 1994; Wilson et al. 2006). The studies on *K. baurii* in Florida have been conducted in west-central Florida (Wygoda 1979; Mushinsky and Wilson 1992; Wilson et al. 1999), south Florida (Ernst et al. 1972; Meshaka and Blind 2001), and the Florida Keys (Dunson 1981), but no previous studies have taken place in central Florida.

Wygoda (1979) used thread bobbins to study *K. baurii* movement and found they spend a significant amount of time on land when aquatic areas desiccate. He concluded that terrestrial movement of *K. baurii* was bimodal and correlated with water depth, precipitation, and temperature. No studies have utilized radiotracking to examine the movement of this mud turtle species.

The major threat to *Kinosternon* in Florida is the loss of suitable habitat because they require wetlands surrounded by uplands they use for nesting (Wilson et al. 2006; Cordero et al. 2012). Hence, they are an ideal species to demonstrate how conserving wetlands, but not the land around them, is insufficient for some species (Buhlmann and Gibbons 2001; Bowne et al. 2006). These habitat requirements are also observed in *Kinosternon subrubrum* and *Kinosternon integrum* (Harden et al. 2009; Cordero et al. 2012; Pérez–Pérez et al. 2017).

Despite their wide distribution, Striped Mud Turtles have not been studied in restored habitats and do not have radiotelemetry-based home range data available. Therefore, we initiated a study in central Florida to fill knowledge gaps on the spatial ecology of *K. baurii* in a restored environment. The study contributes to an improved understanding about how *K. baurii* move in a reestablished area and provides insight for future management plans.

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Materials and Methods

Study site.—Our study area was Circle B Bar Reserve (CBR), a restored former cattle ranch adjacent to Lake Hancock in Polk County, Florida, USA. The reserve consists of 512.7 ha of land, which includes permanent marsh, semi-permanent wetlands, and upland habitat (Fig. 1). The wetland habitat where we captured most turtles (all except one) is a canal, Alligator Alley, that runs parallel to Lake Hancock approximately 2 km away from upland habitat. On the other side of the canal is a semi-permanent wetland. Areas of the marsh and wetlands dried up during the dry season (October–May), but frequently flooded during June–September. From October 2016 to June 2017 there was a drought in the area and a majority of the wetlands and canals that are ordinarily permanent dried up.

Radiotelemetry.—We tagged nine turtles with ATS radiotelemetry tags (3.5 g) starting in Sept 2016. We caught turtles using box-style minnow traps, dimensions 39 x 36 x 29 cm, with metal mesh that was 1 x 1 cm (similar to Karl and Wilson 2001). Most turtles caught were female, so we actively searched for males to tag. The tag's mass did not exceed 5 % of the turtle's body mass because we affixed transmitters only to turtles > 70 g, as measured with a Pesola scale. We attached the tags with marine epoxy (Loctite® Marine 2-hour Epoxy, Henkel Corp., Westlake, Ohio, USA) to costal scutes, on the anterior portion of the turtle on the right side of the carapace, with the antenna facing backwards and up. To minimize stress for the turtle, we

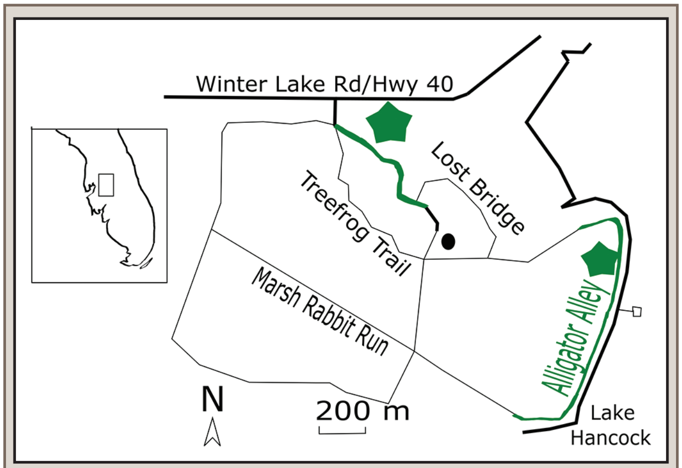

Fig. 1. Map of Circle B Bar Reserve and its location within Florida. The habitats where the turtles were caught are highlighted in green and marked with green stars. Alligator Alley is the location where 8 of the 9 turtles were caught.

Table 1. Frequency, sex, home range, straight-line distance, days radio tracked, and number of relocation points.

Turtle frequency	Sex	Home range area (m^2)	Straight-line distance (m)	Number of days tracked	Total relocation points
209	F	9200	247	369	66
171, 151	F	5791	154	245	50
310	M	1111	170	230	31
131	F	5184	175	120	16
110	M	14,396	283	152	31
250	F	3146	88	203	31
228	F	2083	123	110	18
290	F	4435	218	66	11
191	F	5716	67	72	16

contained them for < 3 days during the tagging process. We affixed nine turtles with transmitters, seven females and two males, with one turtle having the first tag replaced when the transmitter battery malfunctioned, for a total of 10 transmitters. We located the nine turtles one to three times every week (less during winter months) and took a GPS point. When visual confirmation of a turtle's location was not feasible, we triangulated a bearing and approximated the location. We estimated location by using the geofunction library of Microsoft Excel and the NewPostLat/NewPostLong equation. We continued tracking until the end of the battery life, approximately 260 days, or until we could not obtain the signal. If the signal vanished, we searched for it in numerous locations at least once every three weeks until the end of the study. We entered the GPS points into ArcGIS Explorer version 10.1 (ESRI 2012) to view the movements and home ranges of each turtle. To estimate home range, we used the polygon and then area feature of ArcGIS. This involved including all the outermost GPS points as the edge of the home range and then recording the area of the formed polygon.

Statistical analysis.—We took the area of each home range and obtained the means and standard deviation (SD) for all turtles and by sex. We measured straight-line distance (SLD) to show the greatest distance between two GPS locations within the home range and calculated the mean and SD of the SLD. We performed a Mann-Whitney *U*-test to compare male and female home range sizes. We used MiniTab -18 and Microsoft Excel for statistical analyses ($\alpha = 0.05$).

Results

Home ranges.—We tracked turtles between 66 and 369 days (mean = 174 ± 97.9; N = 9; Table 1). Home range polygons are shown in Figs. 2 and 3. A male turtle had the largest home range (14,396 m^2) and SLD (281 m; Table 1). The other male turtle had the smallest home range, 1111.2 m^2. The second largest home range was a female who was gravid during the last segment of the tracking period (9200 m^2). The mean SLD for the turtles was 169.3 m and went through mostly shallow, lentic wetlands and canals, with the occasional trail or road. We confirmed two females to be gravid during their tracking period (frequencies 209 and 131; Table 1). Females had a mean home range of 5079.0 m^2 ± 2274.0 (N = 7) and males had a mean home range of 7753.4 m^2 ± 9393 (N = 2). The mean home range difference between the sexes was not statistically significant (P = 0.76; N = 9).

Fig. 2. Home range polygons of the two male turtles, frequencies 310 and 110, mapped together to show overlap.

Movement patterns.—During a drought in 2017, three tracked turtles were together in a very shallow pool of water, which was once the canal, for a few days. One turtle retreated to the nearby lake, which had abundant water, when its normal pool dried. After tracking her twice in the lake, her signal was lost and not located after extensive searching. A male estivated when the water in his home range disappeared. Nesting activities continued during the drought, as a gravid female was found while crossing a road. She became sedentary after laying her eggs near the roadway. Unfortunately, we lost her signal soon after her nesting event.

Discussion

Our study is the first to investigate *K. baurii* movement with radiotelemetry and provides the first accurate home ranges for Striped Mud Turtles. Overall, the mud turtles in our study moved a considerable amount and their home range sizes fell near the middle of the variability found for other species of Kinosternidae (Harden et al. 2009; Cordero et al. 2012; Pérez–Pérez et al. 2017). The lowest reported mean home range found in Kinosternidae was 80 m^2 for *Sternotherus depressus* and the upper extreme was 657,000 m^2 for *Sternotherus odoratus* (Dodd et al. 1988; Bennett et al. 2015). In comparison to other freshwater turtles, kinosternids have relatively small home ranges (Slavenko et al. 2016).

FIG. 3. Home range polygons of the seven female turtles, mapped together to show overlap.

Home ranges.—On average, female home ranges were smaller than male home ranges, but the difference was not statistically significant, which could have been impacted by the small sample size (N = 9). Sex-specific differences in home range are seen in *K. subrubrum*, so this difference might be observed with a larger sample size of *K. baurii* (Cordero et al. 2012). Although we only confirmed two gravid females, both appeared to move outside their standard home range to nest, which is consistent with reports that nesting forays can expand a turtle's home range (Stickel 1989; Cook 2004). A male had the largest home range, but the second largest was a gravid female. Interestingly, the two male home ranges barely overlapped, while many female ranges overlapped extensively (Figs. 2 and 3). Male *K. baurii* can be aggressive to each other, as observed in the field by Carr (1952) and Lardie (1975) as well as in captivity (Wygoda 1979). Females may be able to tolerate overlap in ranges, whereas males may be pushed out of established territories of other males. Wygoda (1979) also questioned whether males are territorial or have dominance hierarchies, but further investigation is needed to determine if male avoidance is commonplace and caused by underlying male behavior.

Movement patterns.—The mean SLD for the turtles in this study was 169.3 m, which was slightly larger than what is observed in Eastern Mud Turtles in suburban environments (mean = 119.2 m; Harden et al. 2009). However, this SLD is considerably smaller than what Cordero et al. (2012) found for *K. subrubrum* in the mid-Atlantic region of the United States (mean maximum distance traveled 903 and 887 m). Additionally, these movements are more substantial than represented in *K. integrum* (mean distance = 51.44 m; Pérez–Pérez et al. 2017). The variability of the movement in the three species that have similar habitat requirements is peculiar. However, Wilson et al. (1999) found that the average movement for *K. baurii* from wetland to nest site was 137 m, which was comparable to our overall SLD found during tracking.

Through the drought in 2017, tracked turtles exhibited interesting behaviors. As we tracked one female's signal, it was lost when she moved from the shallow wetland to the adjacent lake. After her movement into Lake Hancock, we lost her signal, which may indicate that she travelled a substantial distance to establish a new home range (we made extensive efforts to locate her). Alternatively, she may have been depredated. During the drought, a male turtle (frequency 310) estivated when his wetland in his home range dried, which suggests turtles in this population respond differently to drying ponds, i.e., estivation vs. relocation. Given his extended period of inactivity, it seems estivation likely contributed to his relatively small home range. Wygoda (1979) found that many *K. baurii* in west-central Florida estivated, whereas Ernst et al. (1972) found that in southern Florida they did not estivate because the water was permanent. The apparent variation in estivation behavior is interesting but perhaps attributed to the morphometric evidence found by Iverson (1978) indicating a cline in mud turtle aquatic specialization throughout varying geography within Florida. However, our study supports the findings by Wygoda (1979) that *K. baurii* have seasonal shifts in movement that are related to water depth, precipitation, and temperature.

One gravid female's signal was lost 66 days after she was tagged. Just before her signal was lost, she was buried while resting after depositing her eggs, similar to what was seen by Wilson et al. (1999). It is not known whether she disappeared due to depredation, tag malfunction, or a long foray. However, increased vulnerability of nesting females has been observed in other turtle species and conservation planning should assess this threat to increase survival rates (Aresco 2005; Iglay et al. 2007).

When tracked turtle 209 was gravid, she stayed near the sandy levee trail, presumably to nest, during fall 2018, behavior which also has been observed in *K. subrubrum* (Cordero et al. 2012). The trail is the primary elevated area apart from the upland habitat (approximately two km) from the study site; thus, given the distance to the natural upland habitat, the levee trail is the only confirmed nesting area and is presumed to be the main nesting area for these turtles. It seems possible that the man-made levee serves as an ecological trap for these turtles (see Aresco 2005), as egg predators seem to be drawn to the trail by human activity. Because current nesting habitat is limited and might reduce egg and hatchling survival, managers of restored areas may consider constructing additional nesting habitat closer to the mud turtle home ranges to bolster recruitment (Reid et al. 2016). If anthropogenically altered areas are to be managed for both people and fauna, such as these levee trails, land managers should reflect upon the behavioral patterns and spatial ecology of wildlife (Bowne et al. 2006; Harden et al. 2009).

Our data show many home ranges encompassing large portions of land, reinforcing the evidence that *K. baurii* is a highly terrestrial species. Setting aside or restoring uplands that are close to wetlands would benefit numerous species and would help to conserve wildlife that depend on land and water within fragmented and disturbed habitats (Williams and Dodd 1978; Bowne et al. 2006; Harden et al. 2009; Reid et al. 2016). We suggest future studies on *K. baurii* nesting and terrestrial movement, especially in restored areas, to provide a more comprehensive picture of what they require (see Slavenko et al. 2016).

In increasingly human-dominated landscapes, which are progressively more common in Florida, restored habitats and reserves will serve as critical habitat for turtles and other wildlife. As even "wild" habitats in Florida become gradually more disturbed, knowledge of mud turtle movement, as well as how they respond to perturbed habitats, will be key to establishing comprehensive management plans.

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