Tennessee Journal of Herpetology, Vol. 3, pp. 4-14, 2020
ISSN 2576-9340

AN ESTIMATE OF HOME RANGE SIZE AND TEMPORAL ASPECTS OF HIBERNATION FOR THE EASTERN BOX TURTLE (*TERRAPENE CAROLINA CAROLINA*) IN A SUBURBAN WETLAND HABITAT OF MIDDLE TENNESSEE

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Abstract.—Eastern Box Turtles (*Terrapene carolina carolina*) are known for spending most of their lives within a defined home range, but there is variation in home range size depending upon both biotic and abiotic factors. Our objective was to use radio-telemetry to estimate home range for Eastern Box Turtles (n = 6) in a suburban wetland habitat in Murfreesboro, Tennessee, USA. In addition, we characterized temporal aspects of hibernation, including immergence, emergence, and duration. The 95% fixed kernel (FK) home range estimates for two female turtles and one male turtle averaged 1.50 ± 1.18 ha. The 50% FK core areas for the same three turtles were small and averaged 0.19 ± 0.15 ha. The 95% minimum convex polygon (MCP) home range estimates for four female and two male box turtles averaged 1.19 ± 1.67 ha. Turtles entered their hibernacula in November and emerged in April, spending an average of 149 ± 9.44 d in hibernation. To our knowledge, this is the first study to quantify home range and describe temporal aspects of hibernation for Eastern Box Turtles in middle Tennessee, as well as one of the few studies examining these aspects in a suburban wetland habitat. This baseline information provides general aspects of box turtle ecology and can be used for identifying minimum conservation areas necessary to preserve box turtle populations considering that habitat quality and fragmentation affect home range size and regional variation affects timing of hibernation.

Key Words.—conservation, fidelity, habitat, hibernaculum, management, mark-recapture, radio-telemetry

As habitat fragmentation and loss continues, it is becoming increasingly important to understand all aspects of box turtle ecology such as home range size and timing of hibernation. Much of the remaining box turtle habitat only exists in small patches, which can lead to wandering behavior and larger home range sizes as turtles search for resources and suitable habitat (Dodd 2001). Additionally, changes in the biophysical characteristics (e.g., microclimate, landscape structure) of the habitat due to improper management or fragmentation can result in habitat that is unsuitable for box turtle populations, thus altering their behavior and ultimately affecting their overall survival (Curtin 1995, 1997; Dodd 2001). For example, Eastern Box Turtles (*Terrapene carolina carolina*) in an urbanized landscape in North Carolina exhibited lower adult survivorship and delayed maturity due to anthropogenic factors (Budischak et al. 2006). Consequently, gathering basic information on the life history and natural history of a species can be critical for proper management and conservation, especially in long-lived species such as box turtles where decline might not be apparent until years into the future (Belzer and Steisslinger 1999; Dodd 2001).

While Eastern Box Turtles are generally not territorial, they do have a home range in which they spend most of their lives (Stickel 1950, 1989). Box turtles have excellent homing abilities and have been known to orient towards their home range if they are displaced or translocated (Dodd 2001; Cook 2004). These home ranges are typically small and often overlap with the home ranges of other conspecifics in the area (Stickel 1950; Madden 1975). Within the home range, there is often a "core area" where most normal daily activities occur (Madden 1975; Dodd 2001). Box turtles generally have an average home range size between 0.25 and 5 ha (e.g., Legler 1960; Schwartz and Schwartz 1974; Stickel 1989; Fredericksen 2014; Williamson 2014), with occasional outliers having home range sizes of 10 ha or more, typically due to searching for mates, nesting sites, or hibernacula (e.g., Stickel 1950; Willey 2010; Greenspan et al. 2015). In some instances, there are seasonal shifts in home range usage but generally not yearly shifts (Madden 1975; Stickel 1989). Reported home range size tends to fall within the smaller end (0.25–2.5 ha) of the typical size range (0.25–5 ha). For example, in one of the most noted long-term studies on Eastern Box Turtle home range size, Stickel (1989) estimated home ranges of females to be 1.13 ha and males to be 1.20 ha based on multiple captures between 1944 and 1981. However, home range estimates are quite variable and are influenced by tracking technique, calculation and estimation method, displacement, and by both biotic and abiotic factors, such as habitat type, level of urbanization, or level of forest fragmentation.

There are several biotic and abiotic factors that can affect home range size in box turtles, but in most cases, home ranges tend to be smaller with higher quality habitat (i.e., resource availability, mate availability, suitable nesting and hibernation sites, etc.), less habitat structure (i.e., waterways, roadways, artificial structures, etc.), decreased levels of urbanization (i.e., requiring less movement in search of suitable resources), and younger age classes (Madden 1975; Dodd 2001; Willey 2010). Habitat availability and variability have major influences on turtle movements, and turtles in high quality habitat or more diverse habitat are expected to have smaller home ranges because they presumably do not need to travel as far to find resources, such as food, mates, or nesting sites. (Madden 1975; Stickel 1989; Willey 2010). Alternatively, box turtles may be forced to exhibit smaller home range sizes in more urbanized landscapes simply because there is less habitat available, and barriers may block movement outside of urban habitat patches. However, if they are able, Eastern Box Turtles will leave their established home range on occasion if resources such as appropriate nesting sites (Stickel 1950) or a water source (Donaldson and Echternacht 2005) are not available.

Within their home range, box turtles generally have a suitable site for overwintering. However, there is regional variation in timing of immergence into and emergence from the hibernaculum, as well as duration of time spent in the hibernaculum. For example, in Ohio, Eastern Box Turtles entered their hibernacula in mid-October through mid-November and emerged in late February through early April (generally in March), with an average duration of 142 d in the hibernaculum (Claussen et al. 1991). Conversely, in Illinois, Ornate Box Turtles (*Terrapene ornata ornata*) exhibited earlier immergence and later emergence patterns than Eastern Box Turtles in Ohio, where turtles entered their hibernacula in early September to early October, emerged in early April to early May, and spent anywhere from 187 to 225 d hibernating (Milanovich et al. 2017).

Knowledge of Eastern Box Turtle home range size and timing of hibernation in Tennessee is limited to a few studies in the eastern part of the state (Dolbeer 1969; Davis 1981; Donaldson and Echternacht 2005), and

with the subspecies in decline across its distributional range (van Dijk 2011), including Tennessee (Tennessee Wildlife Resources Agency 2015), home range estimates and timing of hibernation will provide managers with important information for monitoring and conservation efforts for both turtles and their habitats. Furthermore, most movement studies have been conducted in habitats located away from urban or suburban areas, and there are no studies in Tennessee on home range or hibernation in wetlands. Therefore, the objective of this study was to estimate home range size and characterize temporal aspects of hibernation for the Eastern Box Turtle in a suburban wetland habitat of middle Tennessee. We hypothesized that turtles would have a home range size within the typical range (0.25 – 5 ha) and that timing of immergence into hibernaculum would be similar to findings of studies in east Tennessee.

METHODS AND MATERIALS

Study Species and Study Area—. The Eastern Box Turtle (*Terrapene carolina carolina*) is one of six subspecies of the common box turtle and belongs to the family Emydidae. Between 2013 and 2015, we studied Eastern Box Turtles in a 23.5 ha suburban wetland habitat known as Nickajack Trace and Black Fox Wetlands (Murfreesboro, TN, USA). Nickajack Trace is predominantly a Hardwood Forest with areas of Palustrine Emergent and Forested Wetlands (5%; U.S. Army Corps of Engineers 2000). The site is divided into two sections by a road and is surrounded by a housing community. One side of the road is 3.5 ha in size and contains a small pond fed by Black Fox Spring, whereas the area on the other side of the road is 20 ha with Lytle Creek running through the interior of the forest (U.S. Army Corps of Engineers 2000).

Field Methods—. We captured Eastern Box Turtles opportunistically by walking through the field site and visually searching for individuals. Upon initial capture, all box turtles were measured, weighed, sexed, and marked. We used digital calipers (203 mm, Neiko Tools, Homewood, Illinois, USA) to obtain shell measurements to the nearest 0.1 mm (see West and Klukowski 2016). We measured mass to the nearest 1 g using a 1,000 g spring scale (Pesola, Forestry Suppliers, Jackson, Mississippi, USA). We assigned a unique code to each individual by filing three marginal scutes (Cagle 1939; Somers et al. 2017). Additionally, we estimated age of each individual by counting annular rings on the pleural scutes (Ewing 1939). We also collected GPS coordinates (WGS 1984) and a photograph for each turtle.

Between June 2013 and October 2014, we captured and equipped six adult box turtles with VHF RI-2B radio transmitters (frequencies between 151.122 and 151.926—Holohil Systems Ltd., Carp, Ontario, Canada). We affixed the transmitters to the posterior region (pleural scutes) of the carapace using epoxy glue, and we held turtles overnight (> 8 h) to allow the glue to dry before releasing. The

TABLE 1. Tracking and demographic information for six adult Eastern Box Turtles (*Terrapene carolina carolina*) tracked with radio transmitters. M = male, F = Female.

ID	Tracking Start	Tracking Finish	Age Class (y)	Sex	Mass (g)
AMW	04 June 2013	02 May 2014	11–14	F	508
APQ	07 August 2013	03 April 2015	11–14	F	376
CHL	18 September 2013	21 July 2014	15–19	M	415
BCX	17 August 2013	13 September 2013	11–14	F	232
AHL	11 October 2014	05 June 2015	15–19	F	466
BLX	14 October 2014	03 April 2015	15–19	M	440

transmitters had an average lifespan of 12 mo, weighed 9.7 g, and did not exceed 5% of an individuals' body mass. We used a collapsible 3-element Yagi directional antenna (Wildlife Materials, Inc., Murphysboro, IL, USA) with a R1000 handheld receiver (Communication Specialists, Inc., Orange, CA, USA) to locate turtles. We tracked different individuals between June 2013 and June 2015, but no turtle was tracked during this entire time frame (Table 1).

This project was concurrent with another larger project; consequently, turtles were located when time permitted, generally at least once or twice a week in 2013, with most data points separated by only a few days, although a small percentage (< 5%) of points (mostly from 2014 and 2015) were separated by weeks due to time constraints towards the end of the study. Once we located an individual, we used a GPS device (Garmin Etrex 30, Olathe, KS, USA) to record coordinates for home range analyses. We tracked five of the six box turtles into hibernation, but one individual lost the transmitter before the overwintering period. The dates of immergence and emergence, as well as the duration spent in the hibernaculum, are approximate, as we did not monitor turtles every single day during late fall and early spring.

Data Analyses—. We used fixed kernel (FK—Worton 1987; Seaman and Powell 1996) density estimates with least squares cross validation and minimum convex polygon (MCP—Mohr 1947) methods to estimate home ranges of box turtles. Elimination of autocorrelation among locations is required to satisfy statistical assumptions of kernel methods, so all locations were recorded at least 24 h apart (De Solla 1999; Kie et al. 2010). Repeat coordinates recorded at hibernation sites were used only once in FK analyses. Only individuals with ≥ 20 independent locations were used in FK analyses, whereas all turtles and all coordinates were included in MCP analyses (Table 1). Of the six radio-tracked individuals, sufficient location data (≥ 20 locations) for FK estimates were collected for two female box turtles and one male box turtle. All FK and MCP home range estimates were made with the default bandwidth settings and calculated in program R 3.4.0 (R Core Team 2014) using the package 'adehabitatHR' (Calenge 2006). Home ranges were plotted using 95% FK estimates and 95% MCP estimates, and core areas were delineated using 50% FK estimates. Maps were created in ArcMap 10.6 (ESRI, Redlands, CA, USA). All values are reported as mean ± standard deviation.

TABLE 2. Fixed kernel (FK) and minimum convex polygon (MCP) home range estimates (hectares) for six adult Eastern Box Turtles (*Terrapene carolina carolina*). The average home range is reported with standard deviation, and *n* indicates the number of GPS location points for each turtle. Repeat hibernation coordinates are included in MCP analyses but are not included in FK analyses.

ID	95% FK	50% FK	Core Areas	*n*	95% MCP	*n*
AMW	1.66	0.27	3	32	1.10	46
APQ	2.59	0.28	7	50	4.42	62
CHL	0.25	0.01	4	24	1.12	34
BCX	-	-	-	-	0.40	14
AHL	-	-	-	-	0.04	11
BLX	-	-	-	-	0.04	9
Average	1.50 ± 1.18	0.19 ± 0.15	4.7	35	1.19 ± 1.67	24

TABLE 3. Approximate dates of immergence into and emergence from hibernacula for five radiotracked adult Eastern Box Turtles (*Terrapene carolina carolina*) along with days spent in the hibernaculum (duration). The mean duration is reported with standard deviation.

ID	Immergence	Emergence	Duration
AMW	01 November 2013	02 April 2014	152
APQ	24 November 2013	05 April 2014	132
CHL	15 November 2013	16 April 2014	152
AHL	07 November 2014	03 April 2015	154
BLX	07 November 2014	03 April 2015	154
Average			149 ± 9.44

RESULTS

We successfully tracked six adult box turtles using radio transmitters (Table 1). The 95% fixed kernel (FK) home ranges for two female turtles and one male turtle averaged 1.50 ± 1.18 ha (min.: 0.25 ha, max.: 2.59 ha; Table 2; Fig. 1). The 50% FK core areas for the same three turtles were small and averaged 0.19 ± 0.15 ha (min.: 0.01, max.: 0.28), with an average of 4.7 core areas per turtle (Table 2; Fig. 1). Similar to the FK estimates, the 95% minimum convex polygon (MCP) home range estimates for four female and two male box turtles averaged 1.19 ± 1.67 ha (min.: 0.04 ha, max.: 4.42 ha; Table 2; Fig. 2).

For the five turtles monitored during winter dormancy, approximate immergence was in November and approximate emergence was in April (Table 3). Turtles spent an average of 149 ± 9.44 d (132–154 d) in their hibernaculum, and we did not witness any turtles emerging from their hibernaculum and moving during this period. We also observed hibernation site fidelity at our field site, with two turtles each using their exact same hibernaculum for two consecutive years. All turtles used hibernacula that were well within (at least 50 m from edge) the forest (i.e., not in any open fields, along edges, etc.). One turtle (BLX) hibernated in a tree root complex that was flooded with water throughout the entire winter dormancy period.

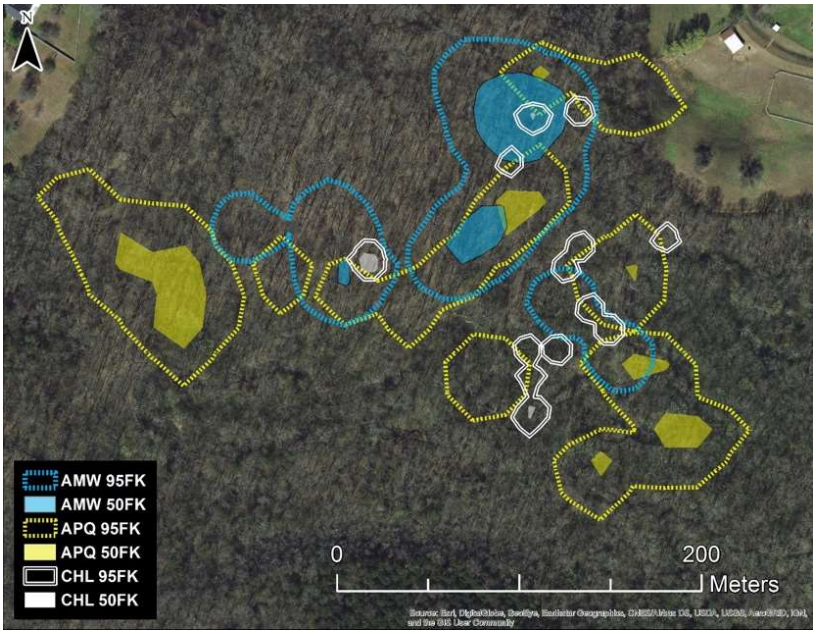

FIG. 1. 95% fixed kernel (FK) home range estimates and 50% FK core areas (shaded areas) for three Eastern Box Turtles (*Terrapene carolina carolina*).

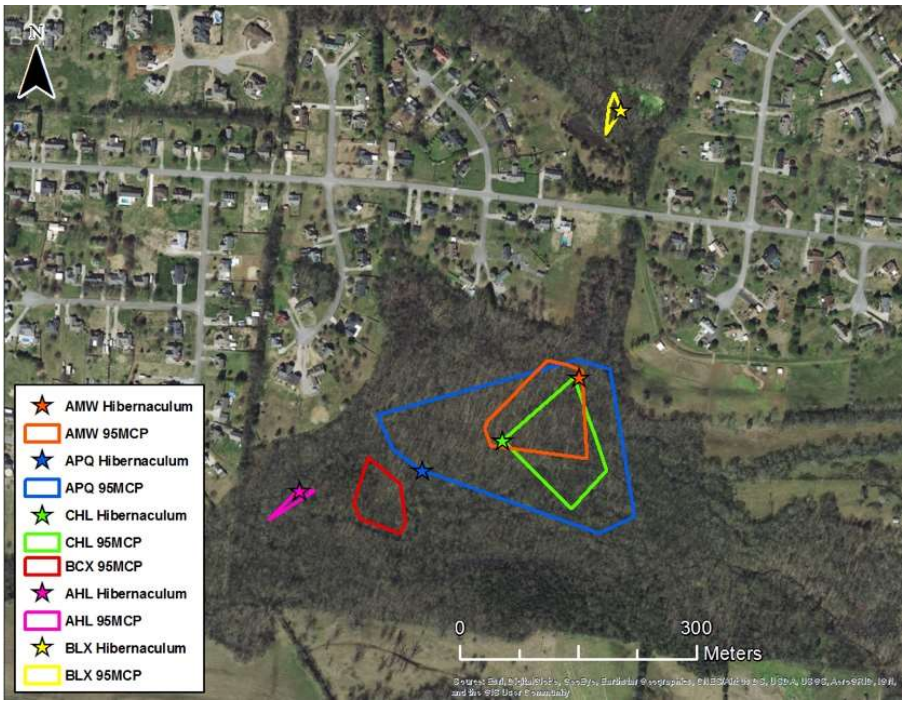

FIG. 2. 95% minimum convex polygon (MCP) home range estimates for all six radiotracked Eastern Box Turtles (*Terrapene carolina carolina*). Stars indicate hibernaculum location for each of the five turtles tracked into hibernation (i.e., all except individual BCX whose transmitter fell off before hibernation).

DISCUSSION

The average home range estimates of 1.50 ha (FK) and 1.19 ha (MCP) fell within the range of what is typically reported for adult Eastern Box Turtles (Table 4). These small home ranges had multiple core areas that likely served different purposes (e.g., resource availability) for box turtles at this site. Several of the turtles had overlapping home ranges, so conservation areas can ideally support multiple individuals. Conservation areas should seek to provide a large enough area of suitable habitat to support core areas with a surrounding buffer up to at least 5 ha to accommodate the typical home ranges of most box turtles throughout their range, keeping in mind that there may be different requirements in different habitat types and even for different individuals. However, 5 ha of suitable habitat is ideally enough for most box turtles as long as it contains the appropriate resources.

Although our home range estimates were on the smaller side, two east Tennessee studies calculated home ranges much smaller than ours (i.e., 0.45 ha—Dolbeer 1969; 0.38 ha—Davis 1981), which may be the result of differences in habitat, tracking methods, and computation and estimation methods. Based on a tracking period of four months, Marchand et al. (2004) calculated an average MCP home range of 1.19 ha for three radiotracked Eastern Box Turtles in a sanctuary with both wetland and upland habitats, which mirrors our MCP estimate. In comparison, Donaldson and Echtnernacht (2005) used thread-trailers and radio-transmitters to track Eastern Box Turtles in east Tennessee and calculated an average home range of 1.88 ha (MCP) and 2.26 ha (95% FK), which is also comparable to the findings in our study. By removing two outliers, Greenspan et al. (2015) found that the average MCP home range for box turtles went from 10.33 ha to 5.87 ha in a Longleaf Pine forest, which is still rather large but emphasizes the importance of spatial variation as well differences in individuals and differences due to habitat type and quality.

Not only is habitat a factor in determining home range size, but box turtles may exhibit seasonal differences in home range usage,

TABLE 4. Comparison of tracking methodology, home range computational methods, and home range size estimates from other Eastern Box Turtle (*Terrapene carolina carolina*) home range studies. FK = fixed kernel, MCP = minimum convex polygon, M = male, F = female.

Study	Location	Tracking Method	Estimation/ Computation Method	Home Range Size (ha)
Dolbeer (1969)	east Tennessee	mark-recapture	diameter	0.45
Davis (1981)	east Tennessee	radio-telemetry	convex polygon	0.38
Stickel (1989)	Maryland	mark-recapture	ellipse	M: 1.20, F: 1,13
Cook (2004)	New York	translocation and radio-telemetry	95% bivariate normal and 95% harmonic mean	bivariate: 9.77, harmonic: 4.82
Marchand et al. (2004)	Maryland	radio-telemetry	100 % MCP	1.19
Donaldson and Echternacht (2005)	east Tennessee	thread-trailer and radio-telemetry	MCP and 95% FK	MCP: 1.88, FK: 2.26
Greenspan et al. (2015)	Georgia	radio-telemetry	MCP and 50% FK	MCP: 10.33, FK: 2.08

generally with a larger average home range in the summer than in the spring and fall (Aall 2011). We only tracked most turtles over the course of one (or part of one and part of another) active season and sometimes only during certain seasons (i.e., spring, summer, and/or fall), and our tracking schedule was not structured due to time constraints from a simultaneous project. While our small home range sizes could be indicative of high-quality habitat, our MCP estimates were inherently smaller due to a lack of data points collected for most individuals (especially BCX, AHL, and BLX), and the average FK home range estimate was likely biased by individual CHL. Individual CHL was tracked only between the months of September through November (i.e., fall season) just prior to hibernation and a few times in July. When CHL's home range was removed, the average 95% FK home range value increased from 1.50 ha to 2.13 ha and the average 50% FK estimates shifted from 0.19 ha to 0.28 ha. Comparatively, when individuals BCX, AHL, and BLX are removed from MCP home range estimates, the average increased from 1.19 ha to 2.21 ha. A home range study for a longer time-period over multiple seasons with a more rigorous tracking protocol is warranted for valid comparison to other studies. However, the presented data can serve as a baseline comparison and a starting point for future studies.

In general, turtles entered their hibernaculum in November and emerged in April, with an average of 149 d spent in the hibernaculum, which is similar to other Eastern Box Turtle studies. For example, in Ohio, Eastern Box Turtles immerged in mid-October through mid-November and generally emerged in March, with an average of 142 d spent in the hibernaculum (Claussen et al. 1991). In east Tennessee, no study has reported hibernaculum emergence dates for Eastern Box Turtles, but

turtles generally entered their hibernaculum in late October through November with movements recorded up until mid-December (Dolbeer 1969). In Virginia, Eastern Box Turtles immerged in late November through late December and emerged in mid-March through early April; however, some turtles emerged early and relocated during this time frame, with an average of 82.2 d between entry and relocation (Boucher 1999). During our study, we recorded no movements of turtles to other locations between November and April, so we believe turtles were sedentary during that entire time frame.

Hibernation site fidelity has been documented in Eastern Box Turtles (e.g., Claussen et al. 1991; Seibert and Belzer 2015; Vannatta and Klukowski 2015), but it is more common to find turtles hibernating in the same general area rather than in the exact same hibernaculum. At our study site, two individuals exhibited hibernation site fidelity (Vannatta and Klukowski 2015 and this study). In both instances, each turtle was found in the exact same hibernaculum two winters in a row, and these two hibernacula were within ~15 cm of one another, indicating that it might be an optimal hibernation location. All five turtles hibernated well within (at least 50 m from the edge) the forest (i.e., not in an open area or close to the edge) where they were buried under leaf litter. However, one individual in our study chose to hibernate in an area under tree roots that was flooded throughout the winter dormancy period. This has been documented on several other occasions, indicating the resiliency of box turtles and their ability to hibernate in water (e.g., Cahn 1933; Madden 1975; Boucher 1999; Koester 2011).

Overall, as urbanization, fragmentation, and general decline of box turtle habitat continues, we can use this information on home range size and hibernation ecology to better understand the way box turtles utilize their habitat to move and overwinter and to infer best management and conservation strategies for turtles and their habitats. We first recommend a better standardization of methods because of the wide variety of tracking and home range estimation techniques (Table 4) makes comparisons difficult. Across the range, we recommend maintaining a conservation area of suitable habitat that is at least 5 ha to support box turtle home ranges, knowing that home ranges often overlap, and multiple turtles can use a given area, but there may be slight differences in home range needs in different habitat types or for different individuals. Curtin (1995) discussed how habitat fragmentation and degradation can negatively affect habitat characteristics, such as microclimate and landscape structure, which can lead to changes in turtle movements (i.e., increasing their home range size to find proper habitat), lower their overall survival, and influence their activity patterns (i.e., growth and reproduction). Therefore, understanding how box turtles utilize their habitats and which habitat variables are necessary can aid in determining the best course of long-term management for this declining species and their vanishing habitat.

As there are no known home range studies on Eastern Box Turtles in middle Tennessee, there are no data on timing of hibernation events in middle Tennessee, and very few studies have been conducted in suburban or wetland habitats, this study can act as a baseline for future studies. However, future studies should seek to employ long-term monitoring efforts in different habitat types with an increased sample size over all seasons for home range size estimation and for describing hibernation activity in Eastern Box Turtles.

Acknowledgements.—We would like to extend our gratitude to Rachel Singer of Murfreesboro Parks and Recreation for allowing us to conduct this study on city property. We also thank the Chicago Herpetological Society and the Biology Department of Middle Tennessee State University for funding and support for this project. This study was completed with IACUC

approval protocol #13-014 at Middle Tennessee State University and with Tennessee Wildlife Resources Agency permission under permits 3740 and 1902.

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