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Examining Habitat Selection and Home Range Behavior at Multiple Scales in a Population of Eastern Box Turtles, (Terrapene c. carolina), With Notes on Demographic Changes After 17 Years

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Examining Habitat Selection and Home Range Behavior at Multiple Scales in a Population of Eastern Box Turtles, (*Terrapene c. carolina*), With Notes on Demographic Changes After 17 Years

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By

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ABSTRACT

The Eastern Box Turtle, *Terrapene c. carolina*, is a terrestrial species native to the eastern United States. Once considered common, it is currently declining in much of its range due to habitat destruction and disease. To conserve the species, knowledge of Eastern Box Turtle habitat selection and the factors influencing their movement is necessary. Although the home range behavior of the Eastern Box Turtle has been well studied, few studies have quantified habitat selection at the home-range scale. Therefore, I examined home-range selection and within home range habitat selection in a population of Eastern Box Turtles at Hungry Beech Nature Preserve, in Roane County, West Virginia. I tracked 10 turtles from May to October 2012 approximately twice weekly. I assigned habitat categories to each turtle's location based on field observations and aerial images. Using LoCoH, I estimated home range for each turtle. I examined habitat selection at the home-range scale and within the home range using binary logistic regression using habitat type, proximity to creek-associated habitat, slope, and aspect as predictor variables. In addition, I conducted a mark recapture study at the preserve. I opportunistically captured turtles throughout the preserve and uniquely marked them using shell notching. I estimated sex ratio, total population and population density at the preserve. I compared my results with estimates from a 1996 study. I also estimated apparent survival of individuals marked in 1996.

My results suggested that habitat type, proximity to aquatic habitat, and slope influence Eastern Box Turtle home-range selection. Specifically, turtles did not include aquatic habitats in their home ranges in proportion to their availability. Turtles selected steeper slopes in their home ranges, and avoided field habitat. However, my results suggested that turtles in areas with increased slopes may have had smaller home ranges. The inclusion of steep habitats could be

caused by turtles moving around steep areas and inadvertently including them in their home ranges. Within home ranges, turtles selected habitats associated with the creek and mixed forest habitats. Eastern Box Turtles likely used creek-associated habitats to thermoregulate in extreme temperatures, and mixed forest habitat at the preserve contained a large amount of debris that may have been used as cover. Turtles may have selected habitats that contain a large amount of cover objects. Therefore, aquatic habitats and mixed forest habitats containing a large amount of cover should be considered when protecting Eastern Box Turtle habitat.

I estimated population size and density as 332 box turtles and 6 turtles/ha, respectively. Apparent survival was 66% since 1996. Average home-range size appears to have increased since 1996, likely due to successional habitat changes. My results suggest that sex ratio has become male skewed since 1996. The skewed sex ratio could be the result of increased female mortality, as I found more male survivors than females. However, future survival studies are necessary to conclude if female mortality is high at the preserve, or if sex ratio has changed due to changes in nesting behavior. My study has increased our knowledge of Eastern Box Turtle habitat requirements and habitat selection, and has shed light on long-term demographic shifts in a population of Eastern Box Turtles. The results of my study, as well as those from continued research at the preserve, may prove useful in future conservation efforts.

Chapter 1: Species Account of The Eastern Box Turtle (*Terrapene c. carolina*)

Species Range and General Characteristics

The Eastern Box Turtle (*Terrapene carolina*) is a turtle species in the genus *Terrapene*. The genus is confined to North America and contains four species (Dodd 2001). Within the species *Terrapene carolina,* there are seven recognized subspecies (Dodd 2001). *Terrapene c. carolina,* which is the focus of this thesis, ranges throughout much of the eastern United States and is the only subspecies present in West Virginia (Figure 1). It ranges throughout the state's lower elevations and is currently considered common and a species of low concern within West Virginia (Green and Pauley 1987)

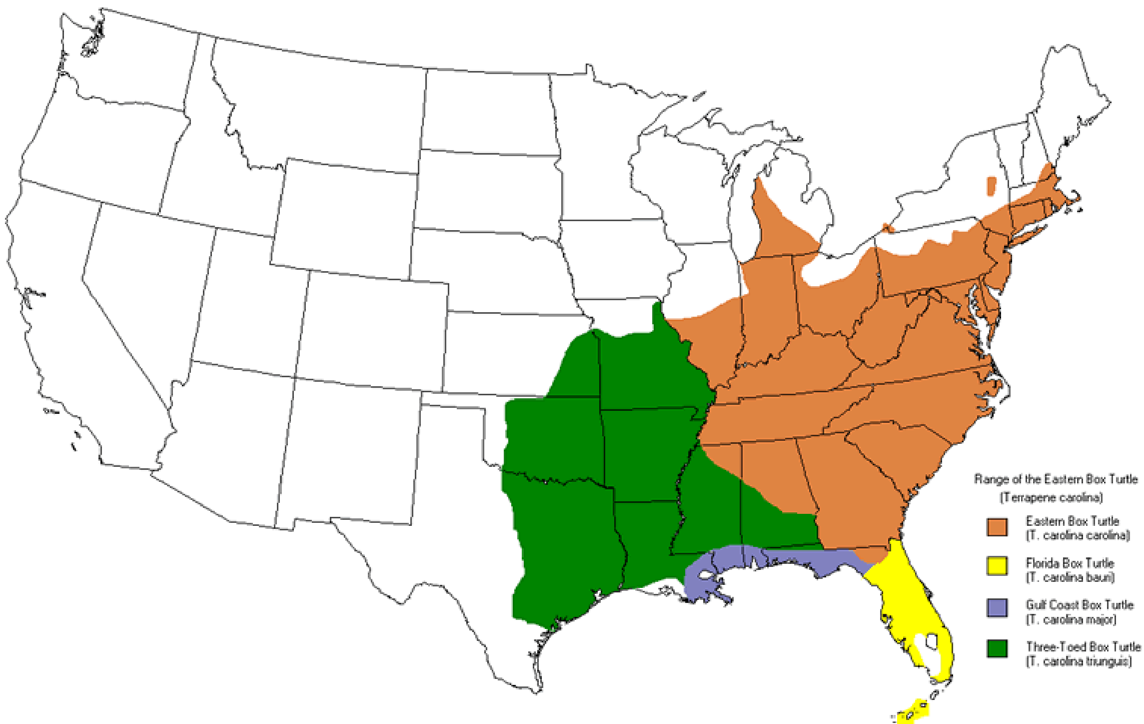

Figure 1: *Range map of the Eastern Box Turtle, showing ranges of the four subspecies occurring in the United States. Terrapene c. carolina is the only subspecies that occurs in West Virginia, and was the subject of this thesis. Adapted from bio.davidson.edu, 2012.*

The Eastern Box Turtle is the most terrestrial turtle species in West Virginia and throughout much of its range. The species inhabits mesic, or moist, deciduous forests (Dodd 2001). As with all members of the genus *Terrapene,* the plastron of Eastern Box Turtles is hinged and can be closed to allow the turtle to seal itself entirely within its shell (Dodd 2001). Additionally, the bones in a box turtle's shell are fused together, unlike those of many other turtle species (Dodd 2001). This adaptation strengthens the shell and grants box turtles added defense against predators.

Eastern Box Turtles are moderate-sized turtles, typically reaching 165 mm in carapace length (Dodd 2001). Adults are sexually dimorphic, meaning there are physical differences between males and females of the species. In *Terrapene carolina*, males are typically larger than females (Dodd 2001). Despite size differences, body mass is similar, possibly due to the presence of eggs within the females (Dodd 2001). Other characteristics that differ between sexes are iris color, carapace shape, tail length, and plastron concavity (Barron 1996; Dodd 2001). Males typically have red/orange irises, a thicker and longer tail, a more posterior cloacal opening, and a concave region on the bottom of the plastron (Figure 2). Females typically have a shorter tail with a more anterior cloacal opening on the tail, a uniform plastron with little concavity, and brown or yellow irises (Figure 3) (Barron 1996; Dodd 2001). Members of both sexes exhibit large variation in color and patterning (Dodd 2001).

Figure 2: *An adult male Eastern Box Turtle. Note the red iris and highly concave plastron.*

Figure 3: *An adult female Eastern Box Turtle. Note the brown iris.*

The Eastern Box Turtle is a generalist and omnivore (Dodd 2001). Therefore, it consumes a wide variety of food items. Box turtles will eat a variety of invertebrates, such as worms, slugs, and insects (Dodd 2001). Invertebrates appear to be the principle component of a box turtle's diet, and typically constitute the majority of stomach contents (Surface 1908; Klimstra and Newsome 1960)

A box turtle will consume whatever animal prey it can catch (Dodd 2001). However, vegetation of varying types constitutes a large part of the Eastern Box Turtle's diet (Dodd 2001). Box turtles will consume shoots and leaves of many plant species. They often feed on berries and other fruits, and they are sometimes found in large numbers under fruiting plants (Dolbeer 1969; Dodd et al.. 1994; Trail 1995). Eastern Box Tutles consume various fungi, and they can safely consume mushrooms that are poisonous to humans; potentially accumulating the toxins within their tissues to levels that are toxic to human and non- human predators (Carr 1952). Box turtles will also consume carrion when it is available (Dodd 2001).

Like many turtle species, Eastern Box Turtles are long-lived animals (Henry 2003). Their exact lifespan in the wild is unknown. However, life spans of most wild box turtles are likely 50 years or less, although individuals exceeding this age may not be uncommon (Dodd 2001). There are many reports of Eastern Box Turtles attaining very old age. A turtle found in Rhode Island with the dates 1844 and 1860 carved into its plastron was estimated to be 138 years old (Graham and Hutchinson 1979). While turtles surviving to this age are likely not a frequent occurrence, some box turtles may live exceptionally long lives in the wild (Dodd 2001).

In Eastern Box Turtle populations, adult survivorship is important for the persistence of a population (Bowen et al. 2004; Dodd 2001). Like many long-lived animals, Eastern Box Turtles reach sexual maturity at a late age (Henry 2003). They also have low reproductive potential, typically laying 1-7 eggs per clutch depending on geographic region and the size of the mother (Dodd 2001). Clutch sizes vary by subspecies as well, but maximum individual reproductive capability per year for *Terrapene c. carolina* is 11 eggs (Dodd 2001). Box turtles exhibit no parental care, and they do not defend their eggs. Therefore, predators consume many of the eggs within a 24 hour period after the eggs are laid (Dodd 2001). Eastern Box Turtle hatchlings are similarly helpless. They hatch at a very small size, roughly the size of a quarter, making them susceptible to predation from small and large predators (Madden 1975; Dodd 2001; Belzer et al. 2002). Their soft, poorly ossified shell provides little protection at this stage (Dodd 2001). However, once a turtle reaches adult size and the plastron hinge develops completely to allow full closure of the shell, a box turtle is well defended against most predators (Dodd 2001). Thus, the survival of adult box turtles that can continually reproduce is important to maintain population size, due to low recruitment and low survival of eggs and hatchlings (Dodd 2001).

Early observations of aggressive interactions among individuals suggested that the Eastern Box Turtle may be territorial (Latham 1917). In captivity, box turtles may fight during feeding (Boice 1970). There are also reports of males dominating access to females in captivity and preventing other males from mating (Tonge 1987). Although box turtles may be aggressive towards conspecifics, there is currently no evidence to support the idea that turtles engage in interspecific conflicts over living space in the wild (Dodd 2001). Interactions between box turtles in the wild are typically similar to courtship behavior, even in male-male interactions (Stickel 1989). Therefore, box turtles are considered a non-territorial species, and it is likely that early observations of what appeared to be territorial behavior were actually misinterpreted courtship behavior.

Conservation

Although once considered a common species, the Eastern Box Turtle is currently declining throughout much of its range as a result of several factors, including habitat loss, habitat fragmentation, and disease (Dodd 2001, Cook 2004). Habitat loss and fragmentation are probably the largest threats to the continued existence of box turtles (Dodd 2001). Box turtles that reside in the altered location can be directly affected by the loss of habitat. Additionally, alteration of habitats adjacent to intact box turtle habitat causes slow declines in turtle populations in adjacent habitat patches (Williams and Parker 1987). Road fragmentation, in particular, can have profoundly detrimental effects on box turtle populations because box turtles have difficulty crossing roads safely, and they spend more time on roads than other turtle species (Gooley 2010).

Disease may also cause declines in Eastern Box Turtle populations. Evidence suggests that *Ranavirus*, an iridovirus originating in amphibians, is an emerging chelonian pathogen (Johnson et.al. 2008). The disease is implicated as the cause of many mass die-offs of various chelonian species in the wild, including box turtles, and may heavily impact affected populations (Johnson et al. 2008).). *Ranavirus* is believed to have been responsible for Eastern Box Turtle mortality events in Pennsylvania, Tennessee, Maryland, Florida, and West Virginia (Johnson et al. 2008; Farnsworth and Siegel 2012; Shaver 2012; Steelhammer 2012). Although the exact method of the virus's spread is unknown, it has been hypothesized that *Ranavirus* is capable of spreading as a result of turtles ingesting infected amphibians or using infected water sources

(Johnson et al.. 2008). Regardless of the reasons for box turtle declines, it is becoming increasingly obvious that conservation action is necessary to ensure the continued existence of *Terrapene c. carolina* (Dodd 2001).

Home Range Behavior

Although they are not territorial, box turtles establish home ranges in which they spend the majority of their lives (Nichols 1939; Stickel 1950; Dodd 2001). Home ranges are not actively defended against conspecifics, therefore they differ from territories. (Burt 1943). In box turtles, home ranges often change little over time (Nichols 1939; Yahner 1974; Bernstein et al. 2007). Yahner (1974) captured individual turtles in the same locations that they were found in five years prior. At the Patuxent Wildlife Research Center in Maryland, Eastern Box Turtle home ranges were measured from 1941-1981 (Stickel 1989). Stickel (1989) found that the home ranges of many turtles did not change significantly over a 40-year study period. Turtles that did show statistically significant home range changes remained in the same general location (Stickel 1989). Thus, box turtles are fairly philopatric under most conditions.

Box turtle home-range size may vary between locations and individuals (Table 1). Home-range area of males and females is typically not significantly different (Stickel1989; Aall 2011). Home-range area may vary slightly with gender, although the variation is not consistent among populations studied and either males or females may have larger home ranges (Barron 1996; Dodd 2001). Home-range size does appear to show significant change seasonally (Aall 2011).

Table 1: *Terrapene c. carolina* home-range estimates from various locations and studies.

Author/ Year of Study	Estimation Method	Number of Turtles Tracked (n)	Location	Mean Home-range area (ha)
Aall 2011	Minimum Convex Polygon	10	Wayne County, West Virginia	1.200
Barron 1996	Minimum Convex Polygon	11	Roane County, West Virginia	0.145
Donaldson and Echternacht 2005	Minimum Convex Polygon	13	Tennessee	1.180
Madden 1975	Minimum Convex Polygon	23	New York	2.120
Stickel 1989	Bivariate Normal	M: 51, F: 52	Maryland	M: 1.20, F: 1.13
Davis 1981	Convex Polygon	4	Tennessee	0.380
Bayless 1984	Minimum Area	6	Virginia	1.250
Bayless 1984	Ornstein-Uhlenbeck	6	Virginia	2.470
Hallgren-Scaffidi 1986	Convex Polygon	11	Maryland	0.200

Many factors besides sex and season may influence home-range size of Eastern Box Turtles. Population density at a given location may influence the size of a turtle's home range, however no study has shown that there is such a relationship (Madden 1975; Dodd 2001). Physical barriers such as fences and ravines increase home-range size of Eastern Box Turtles, because the animals must navigate around such obstacles (Dodd 2001). Home-range size may also be influenced by habitat diversity (Stickel 1950). Stickel hypothesized that box turtles may utilize smaller home ranges in areas of higher habitat diversity because they may have to move less to find all of the resources they need if the habitat is more diverse (Stickel 1950). Therefore, turtles in more diverse habitats do not need to have a large home range in order to survive (Stickel 1950; Barron 1996; Dodd 2001). Although little tested, this hypothesis has been supported by studies of a similar species, the ornate box turtle (*T. ornata)* (Nieuwolt 1993;

Nieuwolt 1996). In these studies, individuals living in desert habitats had larger home ranges than those living in mesic habitats with more plentiful resources (Nieuwolt 1993; Nieuwolt 1996). Further understanding of the factors influencing Eastern Box Turtle home-range area and selection is important, not only because it will expand our knowledge of the species' natural history, but because it will allow for more informed conservation decisions.

The goal of this study was to examine home-range selection by the Eastern Box Turtle at Hungry Beech Nature Preserve in Roane County, WV. I examined the habitats that made up each home range, as well as the habitats that were used within each turtle's home range. For both the home-range scale and habitat within the home range, I performed a use vs. availability analysis using logistic regression to determine if turtles were using habitat randomly, or if they were selecting specific habitats. I also examined habitat selection in response to aspect and slope to test whether or not these geomorphic variables influenced habitat use. In order to examine factors that may influence home-range size, I examined the effect of slope on home-range area.

Eastern Box Turtles at Hungry Beech Nature Preserve were previously studied by Barron (1996). He conducted a mark-recapture survey as well as a radio telemetry study to examine home range behavior. An additional goal of my study was to examine changes in average home-range area, as well as demographic changes in the population since 1996. Therefore, I compared estimates of average home-range size and sex ratio from the current study and the 1996 study to determine if there had been a significant change in these parameters after 17 years. I also estimated the total population of Eastern Box Turtles at the preserve, and compared my estimates with those from1996.

Information from my study will be useful for conservation and management. Determining the factors that can affect home-range size and home-range selection in Eastern Box Turtles will allow for better understanding of their habitat requirements. Increased knowledge of box turtle habitat requirements will allow managers to design better preserves for Eastern Box Turtles, which may increase the success of future conservation attempts. Additionally, increased knowledge of how Eastern Box Turtle population characteristics change in protected habitats will be of use in successfully conserving the species.

Chapter 2: Examining Home-Range Area and Habitat Selection in a Population of Eastern Box Turtles in Roane County, West Virginia

Introduction

Throughout the world, herpetofauna have experienced large declines in recent times (Gibbons 2000). Although global amphibian declines have received the most attention, reptiles are declining as well (Gibbons 2000). Among reptiles, turtles appear to be particularly imperiled. Currently, turtles are recognized as the most highly threatened vertebrate group when considering the percentage of species that are listed as at least "vulnerable" on the IUCN Red List (Luiselli 2009). Many of the most threatened turtle species are found in Asia, where over-exploitation is the chief conservation concern (Gibbons et al.., 2000). However, North American turtles are also experiencing declines, especially species within the genera *Terrapene, Clemmys*, *Sternotherus*, *Kinosterdon*, *Malaclemys*, and *Emydoidea* (Garber and Burger 1995).

Terrapene c. carolina, the Eastern Box Turtle, is included in these genera. The Eastern Box Turtle inhabits mesic woodlands throughout eastern North America. It is an omnivore and a dietary generalist (Dodd 2001). Eastern Box Turtles occupy home ranges that can vary widely in size. Factors such as habitat and slope may influence home-range area, and the size of box turtle home ranges sometimes varies with sex (Dodd 2001).

Although once considered common; the Eastern Box Turtle is currently declining in much of its range (Stickel 1978; Dodd 2001; Cook 2004). Habitat destruction and fragmentation, as well as diseases such as *Ranavirus*, are likely the main causes of box turtle declines (Dodd 2001; Gooley 2010; Williams and Parker 1987; Johnson et al. 2008). Increased understanding of the natural history and ecology of Eastern Box Turtles will be important to conserve the species.

In particular, knowledge of what habitats and conditions are important for Eastern Box Turtles, as well as what factors may be influencing their movements and habitat selection, will be invaluable when conserving habitat for the species.

Eastern Box Turtle home range behavior has been studied often (Stickel 1950; Dolbeer 1969; Madden 1975; Halgren-Scaffidi 1986; Donaldson and Echternacht 2005; Willey 2010; Aall 2011; Currylow et al. 2012). In addition, numerous studies have examined habitat selection at different scales using several methods (Reagan 1974; Madden 1975; Dodd et al. 1994; Barron 1996; Rossell et al. 2006; Weiss 2009; Willey 2010). However, much of this research focused on selection at the microhabitat scale, and many of the studies that have examined habitat selection at larger scales used more qualitative methods (e.g. Barron 1996; Weiss 2009). Additionally, while many estimates of home- range area exist, there has been relatively little examination of Eastern Box Turtle home-range selection. Information concerning factors that could influence selection at the home-range scale, as well as within the home range, will be valuable when managing habitat for the species.

I studied habitat selection and home-range behavior in an Eastern Box Turtle population at Hungry Beech Nature Preserve, in Roane County, West Virginia. The goal of my study was to examine the influence of slope, habitat type, and aspect on home-range selection using logistic regression and Aikaike Information Criterion (AIC) model selection. The patterns observed during a given study can be affected by the scale of the investigation (Wiens 1989). Therefore, I also examined habitat selection at the within home-range scale, (third order selection (Johnson 1980)) with respect to slope, habitat type, and aspect to gain an understanding of the factors that may influence turtle movements within their home ranges. To test the hypothesis that home-range area is lower in areas of steep slopes, I examined the effect of slope on home-range size using linear regression.

Methods

Study Site

I conducted this study at Hungry Beech Nature Preserve, in Roane County, West Virginia (Figure 4). Hungry Beech Nature Preserve is approximately 53 ha, consisting of a ridge top meadow and forest on the surrounding slopes. Approximately nine ha of the preserve have never been logged and are a close approximation of the region's virgin forest (Williams 1980). The rest of the forest in the preserve is in varying stages of succession (Williams 1980). The slopes on either side of the ridge are steep in places, including a ravine on the southern slope near the oldest forest stands. The preserve is partially bound on both slopes by Green Creek, a small stream that runs along the bottom of each slope.

Figure 4: *An aerial image of Hungry Beech Nature Preserve. The white line represents the preserve boundary. The total study area included some areas outside the preserve because some radio tagged turtles left the preserve during the study.*

The forest consists mainly of mixed hardwoods, and is dominated by beech (*Fagus*), oak (*Quercus*), and hickory (*Carya*) species (Williams 1980). However, there are forest stands on the southern slope that consist of a mixture of coniferous and deciduous trees, with the largest patch being 0.8 ha (Williams 1980). Although these sections of forest contain many coniferous species, mainly pitch pine and scrub pine, many of these trees are dead or dying because of shading by faster growing hardwood trees (Williams 1980; Pers. obs.). In the time since Williams (1980) conducted vegetation surveys at the preserve, many of these trees have fallen to the forest floor (Pers. obs). Ground cover and low-lying vegetation at the preserve consists mainly of greenbrier, as well as various grasses (Barron 1996).

Historically, the preserve was the original homestead of the Paxton family (Williams 1980). Much of the preserve, aside from the nine ha of virgin forest, was logged and used for agriculture in the past (Williams 1980). Currently, the West Virginia Nature Conservancy owns and manages the property. However, the Paxton family maintains a lease on the ridge-top field and harvests it annually for hay. Aside from annual haying, the preserve is not subject to any major human disturbance, and is not near any paved roads. The surrounding land is mostly forest and farmland.

Data Collection

In May 2012, I opportunistically captured 10 Eastern Box Turtles throughout the preserve to be tracked via radio telemetry. I attempted to capture equal numbers of turtles from both slopes, as well as an approximately equal number of males and females. I determined the sex of each turtle using a combination of secondary sex characteristics, including iris color and plastron concavity. I have discussed the use of secondary sex characteristics to determine gender of box turtles in detail in Chapter 1. Tracked turtles included five males, four females, and one sub adult, whose sex I could not determine due to a lack of secondary sex characteristics. Of the turtles that were tracked, five were captured on the northern slope, and five were found on the southern slope.

Upon capture, I fitted each turtle with a 5-g SOPR-2190 radio transmitter. I attached each transmitter to the carapace using PC-7 epoxy. I attached transmitters to the rear of the carapace, towards the right side (Figure 5). I attached transmitters in this position in order to avoid hindering mating. I allowed the epoxy to dry for at least 20 minutes or until sufficiently hardened. After this period, I released each turtle at its original point of capture. I recorded the coordinates for each turtle’s capture location using a Delorme PN-20 handheld GPS unit.

Figure 5: *I attached transmitters to the right side of the carapace, towards the rear of the animal*

I tracked each turtle approximately twice a week from May through October 2012 using a Wildlife Materials TRX-1000s receiver and Yagi antenna. Poor weather and logistical issues forced me to track the turtles opportunistically, therefore there were times where I located them once weekly, and there were uneven time gaps between recaptures. Upon locating a telemetry-equipped turtle, I recorded GPS coordinates of its location. At the end of the study period, I removed transmitters from all of the turtles.

I categorized habitat at the preserve using a combination of field observations and high-resolution aerial imagery in Arc GIS. The habitat categories I used were field, deciduous forest, mixed forest (which represented the mixed coniferous/deciduous stands) and edge habitat (Figure 6). Edge habitat included areas 10 meters into the forest from the field edge, and areas five meters from the forest edge into the field.

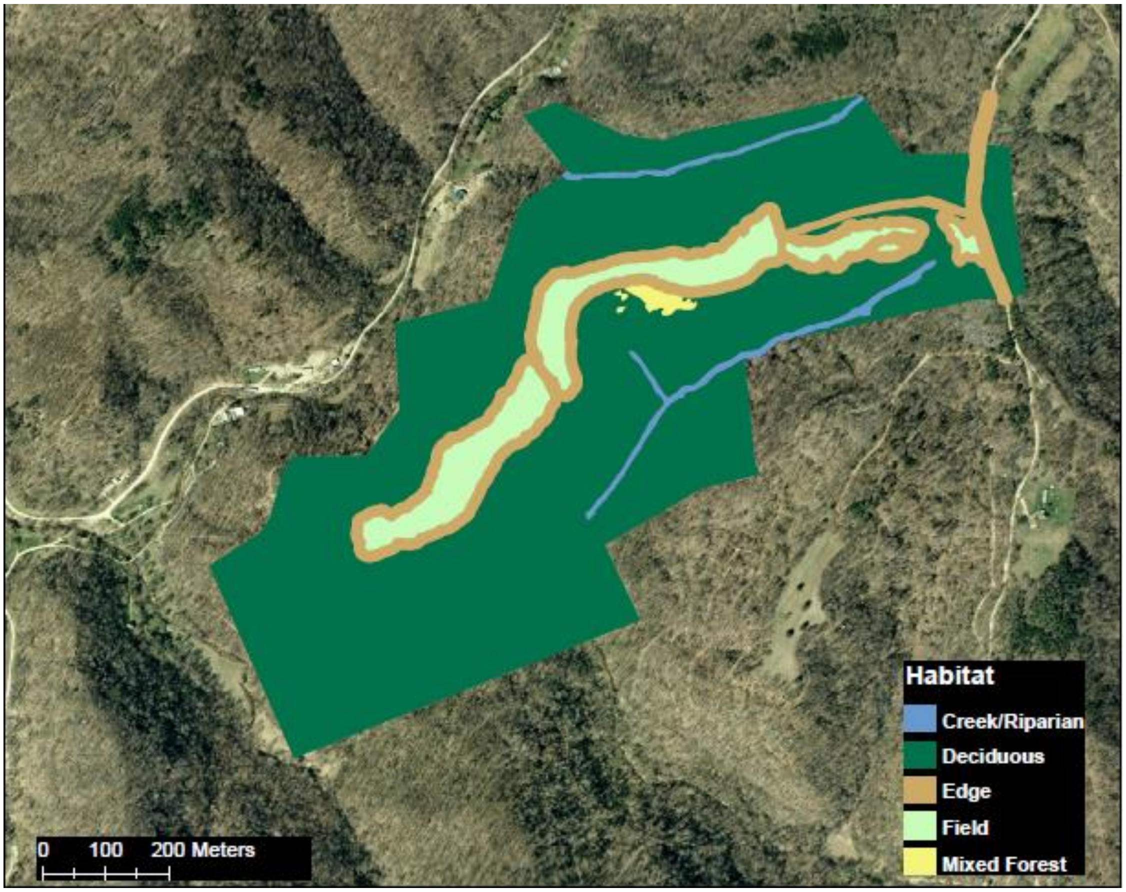

Figure 6: *A map of classified habitats at the preserve. I classified habitats using a combination of aerial photos and field observations. The creek is also visible on this map.*

I also classified habitats based on the presence or absence of aquatic associated habitats. At Hungry Beech Nature Preserve, these habitats were the creek and its riparian zone. I defined the riparian zone as areas within two meters from the creek. I based this definition on the small size of the creek, as well as field observations. I recorded the presence of creek-associated habitat at a capture location as a dummy variable. Using a GIS, I assigned capture locations that fell within creek-associated habitat a value of 1 to signify that the location was associated with the creek. If a capture location was not within the creek or riparian zone, I assigned it a value of zero.

I calculated slope across the preserve using the slope tool in the spatial analyst package of Arc Map 10. I calculated aspect in a similar way, using the aspect tool from the spatial analyst package in Arc Map 10. I standardized aspect measurements using the equation [l-cosine (aspect in degrees)] + [1-sine (aspect in degrees)], so that dry southwestern slopes had the largest values and mesic northeastern slopes had the smallest values (Ford et al. 2002).

Data Analysis

Using field-collected GPS coordinates, I estimated home-range area for each turtle using adaptive LoCoH (Localized Convex Hulls) in R. Home range was estimated using 100 and 90 percent isopleths. LoCoH is a non-parametric method for estimating an animal's home range (Getz and Wilmers 2004). This method produces isopleths that represent an animal's home range by creating local convex hulls from all points within a given radius around a root point, such that the sum of the distances between the root point and its neighboring points is less than the radius (Getz et al. 2007).

I selected LoCoH over more conventional home range estimation techniques such as Minimum Convex Polygon (MCP) and the kernel method because LoCoH gives a more accurate home-range estimate than other methods (Getz et al. 2007). MCP tends to fit data poorly for animals with home ranges that are highly non-convex (Getz and Wilmers 2004). Additionally, MCP cannot account for holes in home ranges caused by obstacles or other factors, and does not allow relative use of different parts of the home range to be determined (Getz and Wilmers 2004). While the kernel method does allow a researcher to visualize relative use of parts of the home range, it gives estimates of home-range area that are less accurate than estimates from other methods, such as LoCoH (Lawson and Rodgers 1997; Ostro et al.. 1999; Getz et al.. 2007).

After estimating home-range area for each turtle, I calculated average home-range size for all turtles, as well as for males and females separately. All analyses were performed using SAS 9.3. I tested for a significant difference between male and female home-range area using a two-sample t-test. I performed this analysis for 100% and 90% isopleths. The data were non-normally distributed; therefore I transformed them using a square root transformation prior to running the analysis.

I examined the effect of average slope on home-range area by calculating average slope within each home range using the spatial statistics tool in Arc Map. I used linear regression to examine the effect of average slope on home-range size. I performed this analysis using 90% and 100% home-range estimates. Again, home-range area was not normally distributed for either 90% or 100% estimates; therefore, I transformed these values using a square root transformation. Measurements of slope met all assumptions of normality; therefore, I did not transform them.

I imported home range isopleths and turtle capture locations into Arc Map for further analysis. I examined habitat selection at the home-range scale in response to additive and interactive effects of four predictor variables: habitat type, the presence of creek habitat, slope, and aspect (Table 2). I conducted a use versus availability analysis. Using the “create random points” tool in Arc Map, I generated 2500 random points across the preserve. I assigned habitat types, slope, creek presence/absence, and aspect values to each point based on where they fell using spatial joins in Arc Map.

Table 2: *Descriptions of predictor variables used to model habitat selection both at the home-range scale and within home ranges.*

Variable	Explanation
Habitat	The habitat type at a location. Habitat types included field, deciduous forest, mixed forest, and edge.
Creek Presence/Absence	The presence or absence of the creek and its 2 m riparian zone at a location. A value of 0 signified the absence of creek habitat at a capture location, while a value of 1 meant that the turtle was captured in habitat associated with the creek .
Slope	The angle of the ground at a location, in degrees.
Aspect	The linearized aspect at a location. Higher values indicate mesic northeast facing slopes; lower values indicate drier southwest facing slopes.

I treated use as a binary dummy variable, with a 1 indicating that a point was used by a turtle and a 0 indicating a point that was available but not used. I assigned each of the 2500 random points a value of 0 for use. I then generated 100 random points within each turtle's home range, and assigned values for habitat type, slope, creek presence/absence, and aspect to each point based on where they fell. Points generated in each home range were considered to be used, and were therefore assigned a use value of 1. I analyzed the data using binary logistic regression in SAS. I stratified the data by turtle, to account for a lack of independence from observations from the same turtle. I used five candidate models in this analysis, each representing a different *a priori* hypothesis (Table 3). I performed home-range selection analysis for 100% and 90% home range isopleths, using the same set of candidate models.

Table 3: *The list of candidate models used to examine home range and within home-range selection.*

Model	Explanation
habitat + creek	Models habitat selection in response to the additive effect of habitat type and the presence of creek-associated habitats.
habitat + creek + slope+ aspect + slope*aspect	Models habitat selection in response to the additive effect of habitat type, the presence of creek-associated habitats, slope, and linear aspect, as well as the interaction between slope and aspect.
habitat + creek + slope + aspect	Models habitat selection in response to the additive effect of habitat type, the presence of creek-associated habitats, slope, and linear aspect.
slope + aspect	Models habitat selection in response to the additive effect of slope and aspect.
slope + aspect + slope*aspect	Models habitat selection in response to the additive effect of slope and aspect, as well as the interaction between slope and aspect.

For habitat selection within the home range, I conducted a similar use versus availability analysis. Again, I examined habitat use in response to the additive and interactive effects of the four predictor variables (Table 2). For this analysis, I considered the 100 random points in each turtle’s home range to be available but not used; these points were assigned a use value of 0. Radio locations for each turtle represented points that were used by the turtles; therefore, I assigned these points a use value of 1 to signify that they were used. I analyzed the data using binary logistic regression in SAS. I stratified data by turtle to account for a lack of independence from observations of the same turtle. For this analysis, I ran the same five candidate models used to analyze home-range selection (Table 3). I performed the analysis for 100% and 90% home range isopleths. For both scales of habitat selection that I examined, I used AIC model selection to rank the models (Burnham and Anderson 2002). I evaluated all statistical tests using an alpha of 0.05.

Results

Home ranges generated using 100% and 90% isopleths in LoCoH are shown in figure 7 and figure 8, respectively. Home ranges of individual turtles varied widely in size, and there was a large degree of overlap between many of the home ranges for both 100% and 90% home-range estimates (Figure 7; Figure 8). At the 90% scale, some turtles appeared to have two separate home ranges. At both scales, a few turtles made excursions beyond the preserve boundary (Figure 7; Figure 8)

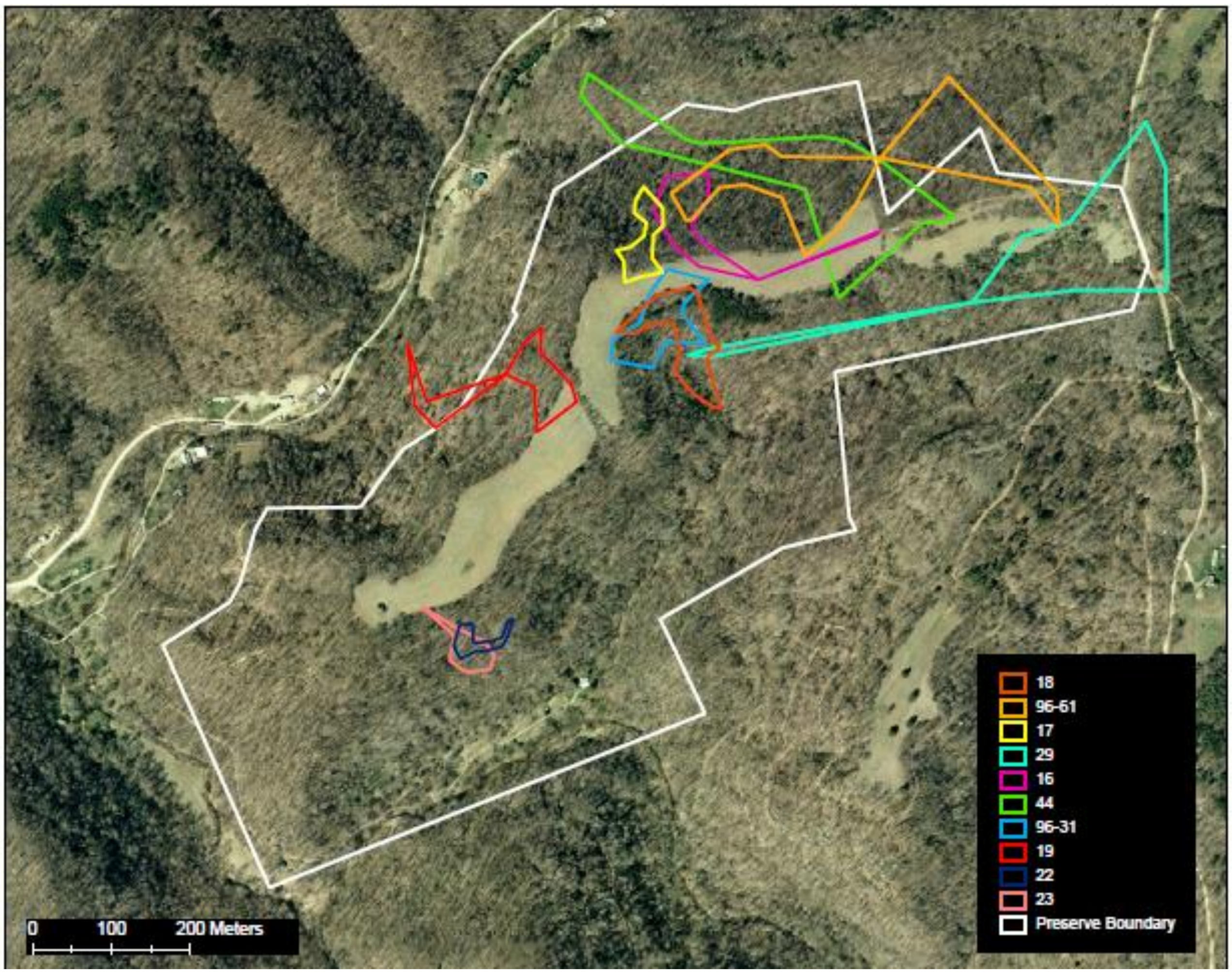

Figure 7: *100% LoCoH isopleths representing the total home ranges of the ten turtles tracked during the study. The numbers in the legend represent identification numbers that I gave to each turtle for use in a mark recapture study, which I will discuss in later chapters.*

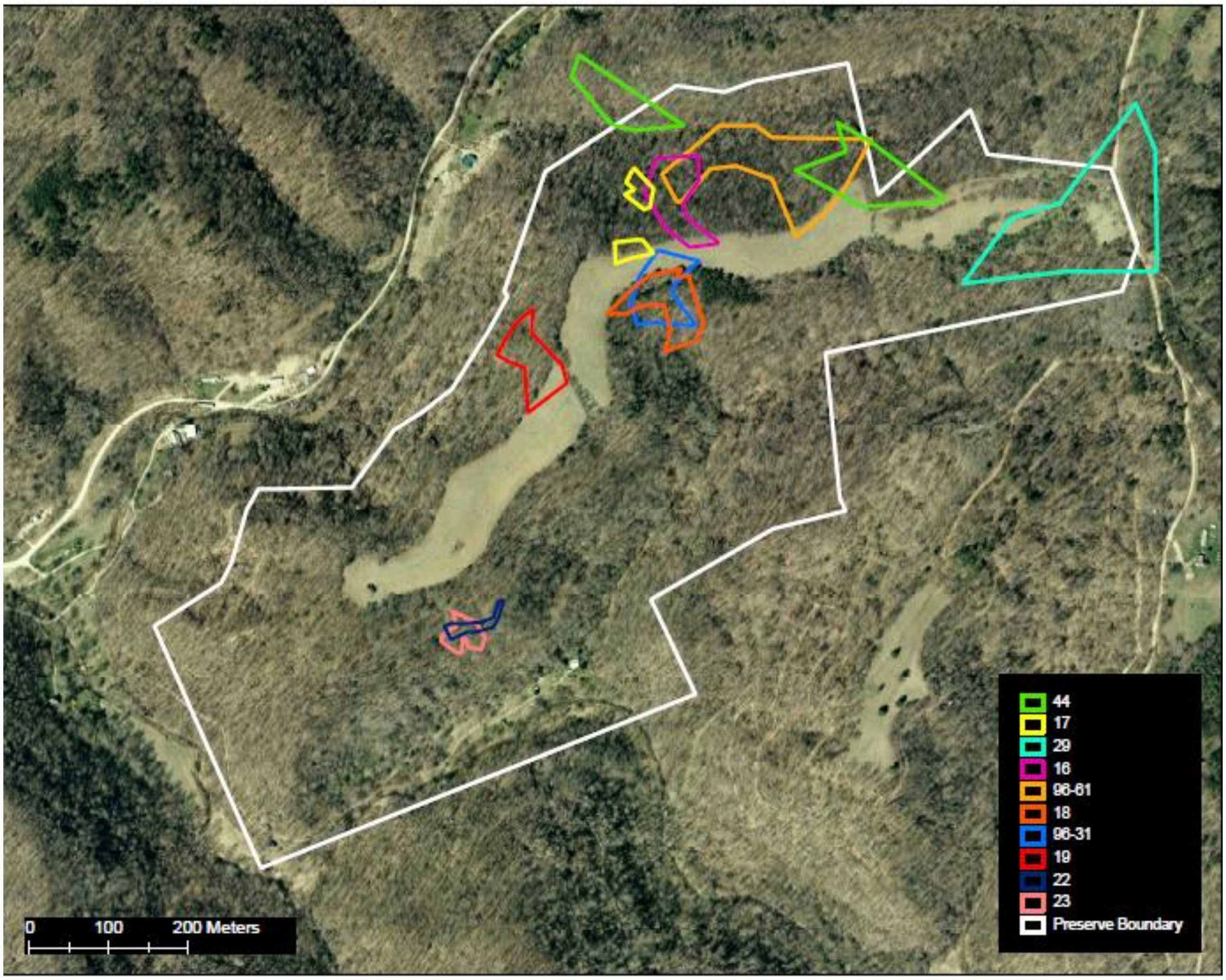

Figure 8: *A map of 90% LoCoH isopleths for 10 tracked turtles. These isopleths represent the area of the observed total home range that contained 90% of the capture locations. At this scale, it appears that individual turtles may be using multiple separate home ranges.*

The average home-range area for all ten turtles was 1.13 ± 0.34 ha at the 100% scale, and 0.83 ± 0.25 ha at the 90% scale (Table 4). Average home-range area for male turtles at the 100% scale was 1.05 ± 0.47 ha; for females, average home-range area was 1.41 ± 0.66 ha. At the 90% scale, average home-range area for male turtles was 0.86 ± 0.46 ha, and the average home-range area for female turtles was 0.95 ± 0.35 ha.

Table 4: *Home- range area (ha) for each turtle at the 100%, 90%, and 50% scale. Average home- range area and standard error are also included for each scale.*

Turtle	**Sex**	**100% HR Area**	**90% HR Area**
44	Female	3.18	1.42
17	Sub Adult	0.33	0.20
29	Male	2.85	2.65
16	Female	0.64	0.55
96-61	Female	1.61	1.66
18	Male	0.75	0.55
96-31	Male	0.74	0.51
19	Male	0.76	0.48
22	Male	0.14	0.10
23	Female	0.24	0.16
Avg. HR Area (n=10)		1.13	0.83
Std. Error		0.34	0.25

Although female turtles had a slightly larger average home-range area at the 100% scale, I failed to detect a significant difference between the average home-range areas of male and female turtles (two-sample t-test; df= 7, t=0.44, p=0.673) (Figure 9). I obtained similar results for the 90% home-range estimates. Again, females had a slightly larger average home-range size than males, but this difference was not significant (two-sample t-test; df=7, t=0.15, p=0.887) (Figure 10)

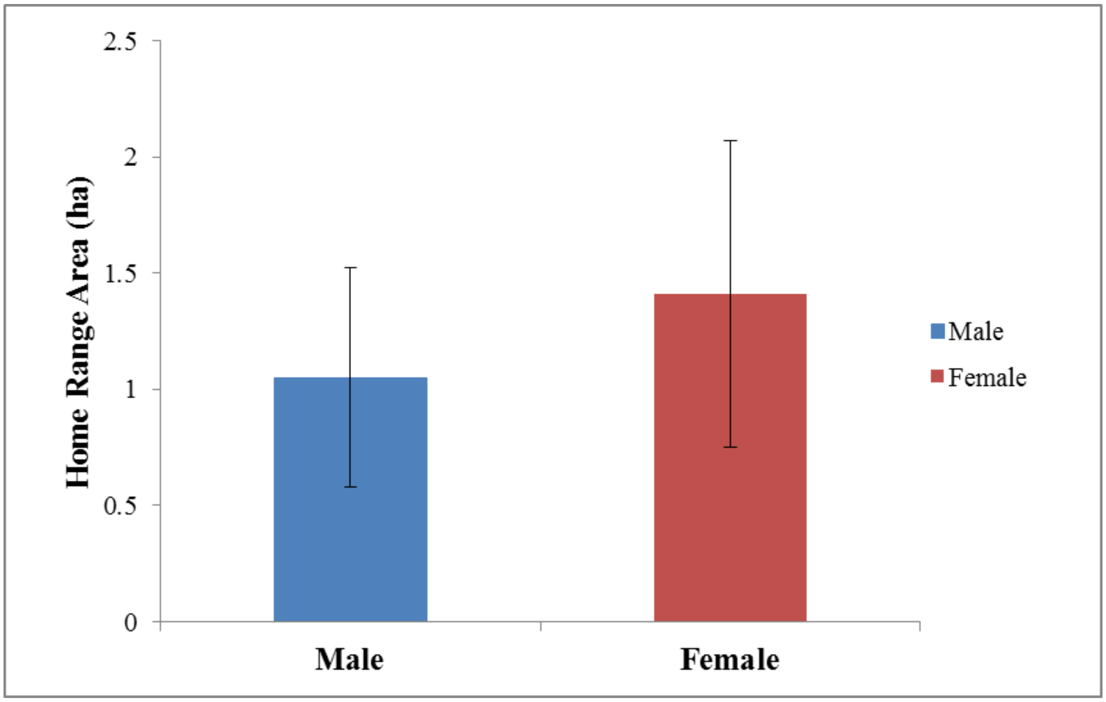

Figure 9*: Average 100% home-range estimates for male and female Eastern Box Turtles. There was no significant difference between the average estimates based on a two sample t-test (df= 7, t=0.44, p=0.673). Error bars represent standard errors around the mean.*

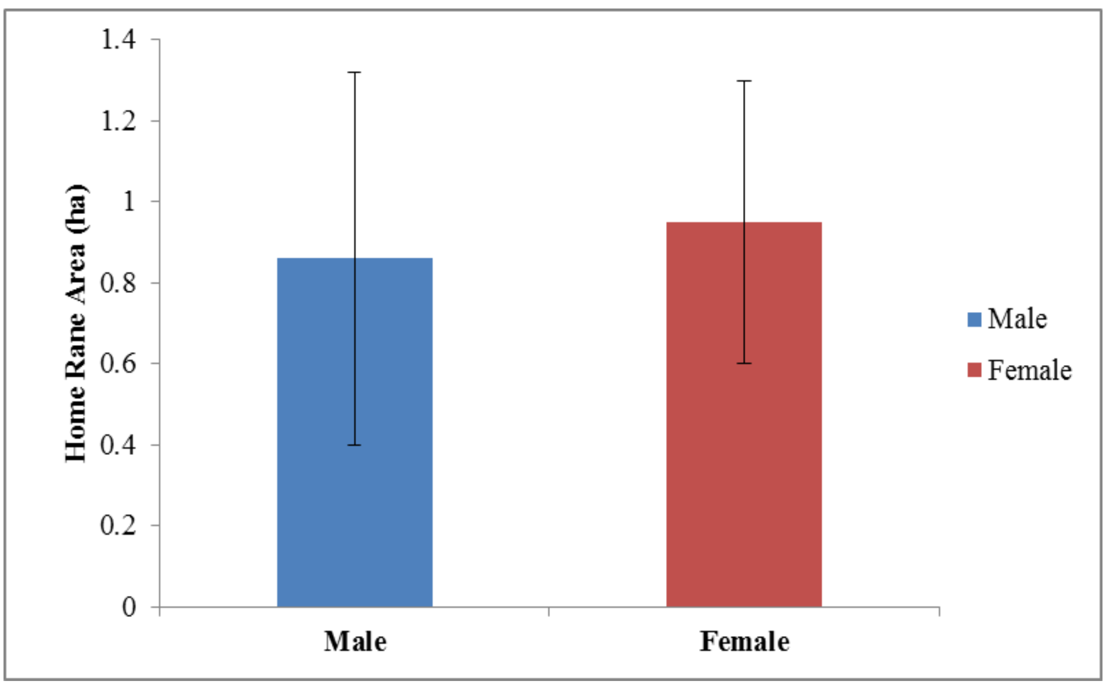

Figure 10: *Average 90% home-range estimates for male and female Eastern Box Turtles. There was no significant difference between average estimates according to a two sample t-test (df=7, t= 0.15, p=0.887). Error bars represent standard errors around the mean.*

I failed to detect a significant relationship between the average slope of turtle home ranges and home-range area using 90% estimates (DF=9, R^2=0.181, p=0.221). I detected a slight negative relationship between home-range area and average slope of the home range (Figure 11). The relationship was nearly significant (DF=9, R^2=0.345, p=0.074).

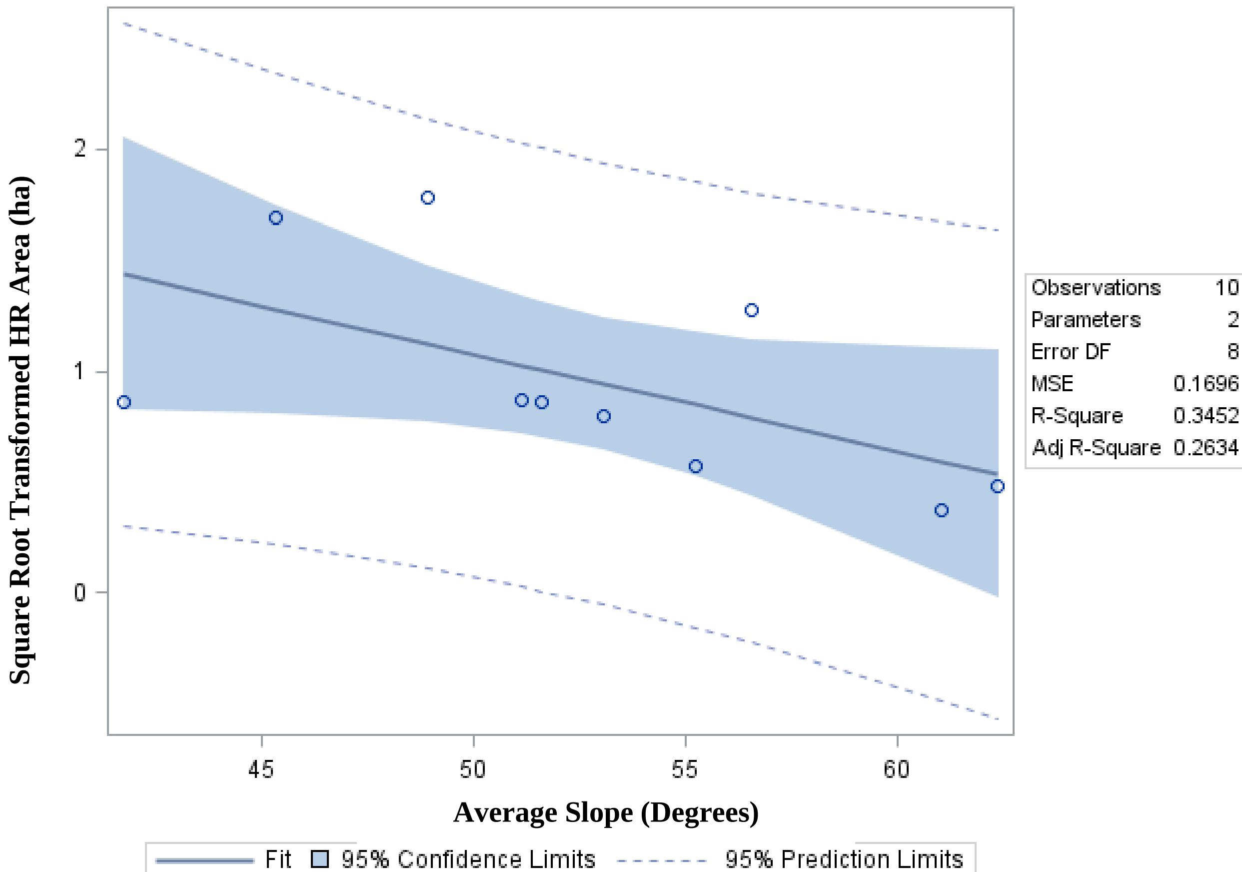

Figure 11: *The relationship between 100% home-range area (square root transformed to meet normality assumptions) and average slope of the home range. The relationship approached significance (p=0.074); it appears that home-range area may be smaller in areas of steeper slopes*

Home-Range Selection and Within Home-Range Selection - 100% Home-range estimates

The analysis of home-range selection at the 100% home-range scale indicated that one model, including habitat, creek, slope and aspect as predictors, was supported and thus used for inference (Δ AIC < 2.00) (Table 5). Models that contained only geomorphic variables (slope and aspect) were not significant and not supported.

***Table 5**: AIC ranked candidate models for home-range selection (100% home-range estimates). Only one model was supported (Δ AIC < 2.00).*

Model	AIC	Δ AIC	Likelihood Chi Square	P-Value
Habitat + Creek + Slope + Aspect	2677.872	0.000	49.230	< 0.001
Habitat + Creek	2688.605	10.733	34.459	< 0.001
Slope + Aspect	2718.186	40.314	0.879	0.644

Beta coefficients from the supported model indicated that selection was positively associated with slope (0.017±0.005, 95% CI= 0.014, 0.020, p< 0.001). Specifically, areas with higher slopes showed a significantly higher probability of being included in a turtle's home range than less steep locations (Table 6). In addition, this model indicated selection was negatively associated with deciduous habitat (-0.799 ± 0.192, 95% CI = -0.897, -0.701, p=<0.001), suggesting that deciduous forest was not incorporated in home ranges as often as it was available. Furthermore, selection was positively associated with the absence of creek habitat at the home-range scale (0.584 ± 0.214, 95% CI = 0.009, 0.055, p=0.01), suggesting that turtles are not including creek habitat in their home ranges (Table 6). I failed to detect a significant effect of aspect on habitat use.

Table 6: *Beta coefficients for the 100% home-range selection model habitat + creek + slope + aspect; the only supported model. I detected significant associations of deciduous forest, creek, and slope with use.*

Parameter	Category	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
Habitat	Mixed Forest	0.671	0.504	0.414	0.928	1.776	0.183
Habitat	Deciduous Forest	-0.799	0.192	-0.897	-0.701	17.337	<0.001
Habitat	Edge	-0.038	0.198	-0.139	0.063	0.036	0.849
Habitat	Field	0.165	0.237	0.044	0.286	0.485	0.486
Creek	Creek=0	0.584	0.214	0.475	0.693	7.427	0.006
Slope	N/A	0.017	0.005	0.014	0.020	13.758	< 0.001
Aspect	N/A	0.032	0.045	0.009	0.055	0.497	0.480

At the within home-range scale of analysis (using 100% home-range estimates), two models were supported and used for inference (Table 7). The top performing model included habitat and creek as predictors, and indicated a significant negative effect of field habitat on selection, (-1.245± 0.359, 95% CI = -1.428,-1.062, $p=0.001$), meaning that within their home ranges, turtles are using field habitat proportionally less often than it is available (Table 8).

Table 7: *AIC ranked candidate models for within home-range selection (100% home-range isopleths). Two models were supported highly enough to be used for inference (Δ AIC < 2.00).*

Model	AIC	Δ AIC	Likelihood Chi Square	P-Value
Habitat + Creek	1230.650	0.000	22.732	< 0.001
Habitat + Creek + Slope + Aspect	1232.181	1.531	25.055	< 0.001
Slope + Aspect	1249.030	18.380	0.206	0.902

The analysis detected a significant positive relationship between mixed forest and selection, suggesting turtles selected mixed forest habitat within their home ranges (1.006± 0.420, CI=0.792, 1.220, p=0.017 (Table 8). Selection was negatively associated with habitats that do not contain the creek (-0.799 ± 0.267, 95% CI = -0.929, -0.657, p=0.003). This result suggests that turtles are selecting for habitats within their home ranges that are associated with the creek proportionally more often than those habitats are available (Table 8).

Table 8: *Beta coefficients for the within home-range selection model (100% estimates), habitat + creek. I detected significant associations of field, mixed forest, and creek habitat with use.*

Parameter	Category	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
Habitat	Field	-1.245	0.359	-1.428	-1.062	12.051	0.001
Habitat	Mixed Forest	1.006	0.420	0.792	1.220	5.732	0.017
Habitat	Edge	0.127	0.217	0.016	0.238	0.343	0.558
Habitat	Deciduous Forest	0.112	0.189	0.016	0.208	0.350	0.554
Creek	Creek=0	-0.793	0.267	-0.929	-0.657	8.819	0.003

The model including habitat, slope, aspect, and creek as predictors indicated a significant positive association of selection and mixed forest habitat (1.10± 0.388, 95% CI= 0.792, 1.220, p=0.010, Table 9), which suggests that turtles were selecting for mixed forest habitat within their home ranges. This model also suggests that there is a significant negative association between field habitat and selection (-1.467 ± 0.388, CI=-1.665,-1.269, p< 0.001); therefore turtles are selecting against field habitat within their home ranges (Table 8). Similar to the first model, the results from this model suggest that turtles are selecting for habitats within their home ranges that are associated with the creek (-0.760±0.268, CI= -0.897,-0.623, p=0.005). Although slope and aspect were included in this model, I failed to detect a significant effect of either variable on habitat selection within the home range (Table 9).

Table 9: *Beta coefficients for the within home-range selection (100% estimates) model, habitat + creek + slope + aspect. I detected a significant association of field, mixed forest, and presence/ absence of the creek on habitat selection.*

Parameter	Category	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
Habitat	Field	-1.467	0.388	-1.665	-1.269	14.284	< 0.001
Habitat	Mixed Forest	1.099	0.425	0.882	1.316	6.688	0.010
Habitat	Deciduous Forest	0.296	0.224	0.182	0.410	1.749	0.186
Habitat	Edge	0.072	0.221	-0.041	0.185	0.106	0.745
Creek	Creek=0	-0.760	0.268	-0.897	-0.623	8.021	0.005
Slope	N/A	-0.013	0.008	-0.017	-0.009	2.462	0.117
Aspect	N/A	0.010	0.070	-0.026	0.046	0.020	0.888

Home-range selection and Within Home-range selection- 90% Home-range estimates

Of the models used to analyze home-range selection with 90% estimates of home range, two received some degree of support (Δ AIC < 7.0). One model was highly supported and thus used for inference (Δ AIC < 2.0) (Table 9). No models containing geomorphic variables were supported, and I did not detect any significant interactive effect of slope and aspect on habitat use. As a result, I removed models containing interactive effects and re-ranked the models according to AIC.

Table 10: *AIC ranked candidate models for home-range selection (90% Isopleths). One model was supported well enough for inference (Δ AIC < 2).*

Model	**AIC**	**Δ AIC**	**Likelihood Chi Square**	**P-Value**
Habitat + Creek + Slope + Aspect	2661.162	0.000	65.902	< 0.001
Habitat + Creek	2667.596	6.434	55.468	< 0.001
Slope + Aspect	2715.915	54.753	3.150	0.207

The top model, and the only one suitable for inference, included habitat, creek, slope, and aspect as predictors (Table 10). The results from this model showed a significant positive relationship between mixed forest habitat with selection, suggesting that turtles incorporate mixed forest in their home ranges more often than it was available (1.212±0.485, 95% CI = 0.965, 1.459 , p= 0.012, Table 11). I detected a significant positive association between the absence of creek habitat and selection, suggesting that creek habitat was not selected for inclusion in turtle home ranges in proportion to its availability (0.741 ± 0.246, 95% CI = 0.615, 0.867 , p=0.003, Table 11). Deciduous habitat was negatively associated with selection -0.656 ± 0.187, 95% CI = -0.751,-0.561, (p=0.001, Table 11), and there was a significant negative association between field habitat and selection (-0.736 ± 0.251, 95% CI = -0.864, -0.608, p=0.003, Table 11). In addition, I detected a significant positive association between use and slope, suggesting that turtles were selecting steeper slopes in their home ranges (0.014 ± 0.004, 95% CI= 0.012, 0.016, p=0.002, Table 11).

Table 11: *Beta coefficient estimates for the home-range selection model habitat + creek + slope + aspect, using 90% LoCoH isopleths.*

Parameter	Category	Beta Coefficient Estimate	Standard Error	95%LCI	95%UCI	Wald Chi Square	P-Value
Habitat	Mixed Forest	1.212	0.485	0.965	1.459	6.259	0.012
Habitat	Deciduous Forest	-0.656	0.187	-0.751	-0.561	12.306	0.001
Habitat	Edge	0.180	0.193	0.082	0.278	0.862	0.353
Habitat	Field	-0.736	0.251	-0.864	-0.608	8.608	0.003
Creek	Creek=0	0.741	0.246	0.615	0.867	9.050	0.003
Slope	N/A	0.014	0.004	0.012	0.016	9.299	0.002
Aspect	N/A	0.035	0.046	0.012	0.058	0.586	0.444

For 90% home-range estimates, none of the models of habitat selection at the within home-range scale of analysis were significant (Table 12). The model including habitat type, proximity to the creek, slope and aspect was the only model supported well enough for inference (Table 12). However, none of the predictor variables showed a significant relationship with habitat selection (Table 13). As a result, I was not able to detect any effect of the predictor variables on habitat use within turtle home ranges using 90% home-range estimates.

Table 12: *Ranked models of within home-range habitat selection (90% LoCoh estimates). No models were significant, however one was supported (Δ AIC < 2).*

Model	AIC	Δ AIC	Likelihood Chi Square	P-Value
Habitat + Creek + Slope + Aspect	896.119	0.000	7.966	0.241
Habitat + Creek	1128.608	-232.489	5.560	0.235
Slope + Aspect	1130.050	-233.931	0.118	0.943

Table 13: *Beta coefficient estimates for the within home-range selection model habitat + creek + slope + aspect using 90% LoCoH isopleths.*

Parameter	Category	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
Habitat	Mixed Forest	0.721	0.418	-3.972	5.415	2.982	0.084
Habitat	Deciduous Forest	0.253	0.239	-7.945	8.450	1.116	0.291
Habitat	Edge	-0.128	0.247	-8.069	7.814	0.268	0.605
Habitat	Field	-0.846	0.494	-4.814	3.123	2.934	0.087
Creek	Creek=0	-0.457	0.381	-5.606	4.691	1.443	0.230
Slope	N/A	-0.009	0.009	-216.345	216.326	1.089	0.297
Aspect	N/A	-0.033	0.085	-23.147	23.080	0.154	0.695

Discussion

Home-Range Area Comparisons

Although there are exceptions, the average home-range area I observed at Hungry Beech Nature Preserve was not drastically different from estimates made during other studies of Eastern Box Turtles (Aall 2011; Donaldson and Echternacht 2005; Madden 1975; Stickel 1985; Bayless 1984; Barron 1996; Davis 1981; Hallgren and Scaffidi 1986). However, my study represents the first known use of LoCoH to estimate Eastern Box Turtle home ranges, therefore comparisons made between my estimate and those from previous studies may not be valid (Lawson and Rodgers 1997).

Average home-range area for turtles at Hungry Beech Nature Preserve was previously estimated by Barron (1996), who estimated average Eastern Box Turtle home-range area to be 0.145 ha (Barron 1996). This estimate is much lower than the estimate obtained in this study.

While home-range area in individual Eastern Box Turtles is quite variable, there could be other explanations for the disparity in average home-range estimates. One reason could be the methods used in estimating home-range area; Barron used Minimum Convex Polygon (MCP) to estimate home-range area; I used LoCoH (Barron 1996). However, MCP tends to over-estimate home-range area, and LoCoH has been shown to give smaller, more conservative home-range estimates than MCP (Getz and Wilmers 2004). Therefore, it seems unlikely that differences in estimates from my study and those from 1996 can be explained by differences in estimation method alone.

A second explanation could be differences in the method of transmitter attachment used. For this study, I used epoxy to attach transmitters to the carapace. In contrast, Barron (1996) attached transmitters to the carapace by tying the transmitter into place using zip ties placed through holes drilled that were in the marginal scutes. Whereas the attachment of transmitters using epoxy has not been shown to induce stress in Eastern Box Turtles (Rittenhouse et al.. 2005), it is likely that drilling holes into the carapace to attach transmitters may impact the animal more than the use of epoxy. Although I could find no studies that have been done comparing these attachment methods, it is possible that the turtles that Barron tracked moved less as a result of the more invasive attachment methods that he used.

Some other possible explanations for the disparity between average home-range estimates from 1996 and those from my study are changes in habitat quality and resource availability, as well as individual variation. Home-range area of Eastern Box Turtles may be influenced by many factors, and one of those is habitat quality (Stickel 1950; Dodd 2001). Stickel (1989) hypothesized that box turtle home ranges should be larger in areas of lower habitat quality, because required resources would be less available, forcing the turtle to move farther to find them (Dodd 2001; Nieuwolt 1996). Therefore, changes in habitat quality or resource availability at the site since 1996 could have led to larger home ranges on average. Due to the lack of human disturbance in much of the preserve, these changes would likely have occurred as a result of natural successional changes. Successional changes may lead to decreased habitat suitability, which may result in increased home-range areas because turtles must move farther to find resources that were previously readily available (Willey 2010; Erb and Jones 2011). Successional changes at the preserve may therefore have affected turtle movements since 1996.

There was large variation in home-range area among the turtles that I tracked. The largest home range was over three ha, and the smallest was less than 0.5 ha (Table 2). Interestingly, turtles that had closely associated home ranges tended to have very similar home-range areas. For example, turtle 22 and 23 had overlapping home ranges, which were both very small (Table 2; Figure 6). Similarly, turtles 96-31 and 18 both had closely associated home ranges that were very similar in size (Table 2; Figure 6). This could suggest that characteristics of these locations, such as resource availability, habitat or geomorphic characteristics, are influencing the area of turtle home ranges at these locations, resulting in similar home-range sizes for turtles living in the same area.

My results for 90% home-range estimates showed that two turtles (17 and 44) had two home ranges, separated by forested habitat that was apparently suitable for use by Eastern Box Turtles. This suggests that these turtles may have had two separate home ranges that they travelled between. If this is the case, it is likely that when I found these turtles between the two home ranges, they were moving between them. Previous studies of various box turtle species have documented individuals with multiple home ranges (Stickel 1950; Bernstein et al. 2007). These disjunct home ranges occur both when habitat between them is suitable and when they are separated by large tracts of unsuitable habitat (Dodd 2001).

The habitat between disjunct home ranges in this study appeared to be suitable; therefore, environmental factors other than habitat type, such as temperature, may have influenced use of these home ranges. For example, turtle 17 remained near the field edge in late spring/early summer, and used the forested part of its home range almost exclusively in the late summer (Figure 12). I observed a similar trend in turtle 44's behavior. Turtle 44 used the home range closer to the field from May to July, and used the home range in the forest mainly in the late summer and early fall (Figure 13). The field edge had reduced cover, and based on my observations, appeared to experience higher temperatures, particularly July and August. Other researchers have observed seasonal shifts in habitat use from open habitats in the cooler months to forested habitats in the warmer months; they have concluded that temperature may be the main driving force behind seasonal changes in habitat use (Dodd 2001; Reagan 1974; Aall 2011). Therefore, while not conclusive, it seems likely that turtles 44 and 17 may have moved into the forest in July and August to avoid extreme temperatures in the field edge.

The presence of food resources may have influenced home range use as well. I observed a high concentration of blackberry bushes near the field edge. I often found turtles in these areas, including turtle 17 and turtle 44. These turtles were found eating blackberries in the field edge on numerous occasions. I observed blackberries on these bushes from early June to early July. This time frame coincides with heavy use of home ranges near the field edge by turtle 17 and turtle 44. Therefore, while the evidence is not conclusive, food availability may be influencing home range behavior of turtles at Hungry Beech Nature Preserve.

Figure 12: *A map of the 90% home range estimate for turtle 17, showing the two disjunct home ranges that the turtle used, capture locations and capture dates. Turtle 17 used the home range closer to the field mostly in the early summer, and moved to the other home range in the late summer.*

Figure 13: *A map of the 90% home range estimate for turtle 44 showing its disjunct home range, capture points, and dates of capture. Turtle 44 used the home range closer to the field edge from May to early July, and appeared to move into the forest in the late summer.*

The Effect of Sex and Slope on Home-range area

I did not detect a significant difference between male and female home-range area at the preserve. This result is not surprising, as other studies have shown that home-range area typically is not significantly different between the sexes in Eastern Box Turtles (Stickel 1950; Aall 2011). However, females did have a slightly larger home range. The slight difference in home range is probably best explained by nesting excursions, where females temporarily leave their home range to find suitable nesting habitat if they cannot find it within their home range. These nesting excursions can involve travelling long distances, 500-774 meters in some documented cases (Stickel 1950; Flitz and Mullin 2006).

I failed to detect a significant relationship with slope and home-range area for either 100% or 90% home-range estimates. However, 100% LoCoH estimates did show a slight negative relationship between slope and home-range area. The relationship was nearly significant ($p=0.07$). This result suggests that there may be a relationship between slope of the home range and home-range area; however, I may not have had the statistical power to detect it.

The negative relationship between slope and home-range area could be a result of steep slopes limiting box turtle movements. In a laboratory study of box turtle movements on inclines , Muegel and Claussen (1994) found that turtles were unable to traverse inclinations over 60 degrees, and that speed was significantly reduced when climbing slopes of 40 degrees or more . Additionally, they found that box turtles had a higher degree of difficulty travelling downhill than uphill, and were likely to turn around when faced with steep downhill slopes (Muegel and Claussen 1994). The slopes on either side of the ridge at Hungry Beech Nature Preserve are quite steep, and inclines over 40 degrees are common. Based on my observations in the field, turtles did seem to have trouble navigating steeper areas, and I observed some individuals losing their footing or turning around to avoid steep declines (Pers. obs).

However, while slope likely influences turtle locomotion to some degree, it may not necessarily influence home-range area. Reasons for the lack of a significant effect of slope on home-range area could be that turtles are bypassing steep slopes, and moving around these areas instead of through them. Although movements to avoid steep slopes might increase home-range area (Dodd 2001), this increase might cancel out the negative effect that steep slopes may have on their movement ability, resulting in home-range sizes that appear to be similar in size regardless of slope. Obstacles such as steep slopes and ravines may influence movement in Eastern Box Turtles (Stickel 1950; Dodd 2001). Therefore it seems plausible that turtles at Hungry Beech Nature Preserve may be moving around steep areas instead of through them. Further research is necessary to examine slope as a predictor of home-range area, using a larger sample size of turtles to increase statistical power. Further study could allow us to more fully understand the effect of slope on home-range area and turtle movements.

<u>Home-range selection</u>

My analysis of home-range selection using 100% home-range estimates suggested that the most important variables for home-range selection are habitat type, the presence of aquatic associated habitat, and slope. According to the supported models for both 100% and 90% estimates, it appears turtles are incorporating areas of steeper slopes within their home ranges. At first glance, this result would suggest that turtles are selecting for steeper slopes, and this seems contradictory based on studies of the response of Eastern Box Turtles to steep slopes (Muegel and Claussen 1994), as well as my observations in the field. Therefore, it seems more likely that instead of turtles selecting for areas of steeper slopes at the home-range scale, steep inclines and declines are included in a turtle's home range incidentally as they move around obstacles. Obstacles such as steep slopes may influence the home range behavior and movements of various box turtle species. Turtles typically move around or along obstacles (Stickel 1950; Legler 1960; Dodd 2001). As a turtle moves to avoid an obstacle, such as a steep slope or drop-off, it may incidentally include the obstacle within its home range.

Turtle home ranges also appeared to contain deciduous forest habitat less often than it was available at the preserve. These results were unexpected, because Eastern Box Turtles typically inhabit deciduous forest habitat (Dodd 2001). Therefore, it is unlikely that turtles were avoiding deciduous forest habitats. The relationship was likely a result of the large amount of deciduous forest available to turtles at the site (Figure 5). My ability to detect relationships may have been affected by low power. Therefore, the relationship would probably not have been detected if a larger sample size of turtles was used.

Based on models for both 100% and 90% home-range estimates, turtle home ranges did not include creek-associated habitats in proportion to their availability. I observed turtles using the creek most often in periods of very hot weather. Eastern Box Turtle use of the creek habitat was temporary and occurred only in certain situations; therefore, creek-associated habitats do not appear to be permanent components of turtle home ranges at the site. However, turtles at the preserve appear willing to make excursions to creek habitat in hot conditions, and return to their home ranges when conditions improve. I observed turtle 19 make a long trek to a portion of the creek outside of the preserve. When I encountered the turtle, he was returning from the creek. I observed home range extensions such as those made by turtle 19 in other turtles as well, suggesting that although the creek may be an important resource, it is not necessarily a permanent feature of a turtle's home range. Similar movements were reported by Donaldson and Echternacht (2005) in a study of Eastern Box Turtles in Tennessee.

Additionally, Green Creek is ephemeral, and I rarely found turtles in the creek when it was dry. It is possible that the dry creek bed provides conditions that are not favorable to turtles, and they avoid it during these periods. Therefore, the periodic use of the creek may have masked its importance at the home-range scale of habitat selection.

Habitat Selection Within the Home Range

Supported habitat selection models within 100% home-range estimates suggest that habitat type and the presence of creek habitat are the most important variables at this scale of habitat selection. Although slope was present in one of the top performing models, there was no significant association between slope and selection, suggesting that turtles are not selecting habitat within their home ranges in response to slope.

The supported models indicated selection was positively associated with creek habitat, meaning that turtles are selecting for creek habitats within their home range. My field observations support this finding. I often found turtles soaking in the creek on hot days in large numbers. Additionally, previous studies of Eastern Box Turtles have suggested that they may use aquatic habitats extensively (Donaldson and Echternacht 2005), and there are many anecdotal reports of large numbers of turtles gathering in and around aquatic habitat (Stickel 1950; Latham 1917). The use of aquatic habitats by Eastern Box Turtles is typically in response to hot and dry conditions, and may provide a chance to rehydrate and escape biting insects (Donaldson and Echternacht 2005; Dodd 2001; Pers. obs.). Therefore, it appears that aquatic habitats, such as streams, are habitats of importance to Eastern Box Turtles.

Field habitat was avoided by Eastern Box Turtles at the within home-range scale of analysis. This avoidance was likely a result of the warm temperatures and low relative humidity that is typically associated with open canopy habitats. Regardless, I observed box turtles in the field and the field edge early in the morning on multiple occasions. Therefore, although Eastern Box Turtles may avoid the field habitat throughout much of the day, this habitat may still be important. It is likely that the field and edge habitats are visited in the morning for thermoregulation; allowing turtles to warm up quickly. Previous study conducted at the preserve suggested that Eastern Box Turtles generally used forested habitat throughout most of the summer, and used the field only in the late spring, when conditions were milder (Barron 1996). Therefore, my results appear to support earlier findings at Hungry Beech Nature Preserve.

However, the observed avoidance of field habitat is interesting because previous studies suggest that box turtles use open canopy habitats, even if these habitats are anthropogenic in origin (Williams and Parker 1987; Flitz and Mullin 2006; Willey 2010). The size of the field at Hungry Beech Nature Preserve may have been a factor that caused it to be less appealing to turtles. The open canopy habitats that Eastern Box Turtles used in previous studies were mainly small patches of early successional habitat surrounded by forest matrix (Willey 2010). In contrast, the field at the preserve is relatively large (1.9 ha for the largest continuous meadow). Smaller openings may be preferred over larger ones because it is easier for turtles to retreat to areas of increased cover in small open patches than it is when the open habitat is larger. Although temperatures may be high in these open habitats during the summer, they have been shown to be important for nesting, foraging and thermoregulation and it has been found that males and females use them equally (Flitz and Mullin 2006; Willey 2010).Open habitats appear to be more widely used by Eastern Box Turtles during periods of moderate temperatures, including the spring and early morning (Reagan 1974; Barron 1996; Dodd 2001; Pers. obs.).

Although previous literature reports that early successional habitats may be important (Willey 2010), and I often observed groups of turtles in forest gaps, I was not able to include these habitats in my analysis due to methodological constraints. I conducted the majority of my habitat classification using a GIS and orthoimagery, and it was impossible to find images with a high enough resolution to show gaps in the forest. Additionally, many of these gaps are difficult to identify in aerial images because they maintain partial canopy cover. As a result, I did not consider these habitats in my analysis. However, previous studies, as well as my observations in the field, support the idea that early successional habitats are important to Eastern Box Turtles and that the presence of these habitats may influence home range behavior (Willey 2010). Home-range size may be decreased in areas with a high density of early successional habitats (Willey 2010). Therefore, it seems likely that early successional habitats may influence home-range selection as well. Future research should include an examination of the role early successional habitats play in home-range selection.

Eastern Box Turtles appeared to be selecting mixed forest habitat. As noted previously, the mixed forest habitat appears to contain many dead and dying trees, many of which have fallen. As a result, there is a large amount of debris on the forest floor in this habitat. Previous study of Eastern Box Turtles at Hungry Beech Nature Preserve suggested that box turtles readily use woody debris as cover (Barron 1996). I observed turtles hiding near and under woody debris in mixed forest habitat on multiple occasions. These cover objects likely provide shelter from predators and extreme temperatures. Therefore, box turtles may have selected mixed forest habitats within their home ranges due to the abundance of cover objects present in these habitats.

None of the models for 90% home-range estimates significantly explained within home-range selection. It is doubtful that turtles truly use habitats randomly at this scale of analysis. It is more likely that I was unable to detect the relationship between habitat selection and the predictor variables due to a small number of capture locations, and low statistical power. Further research with more capture locations could quantify the effect of habitat and geomorphic characteristics on within home-range selection at the 90% home-range scale.

Conclusions

My results have provided further insight into the habitat requirements of the Eastern Box Turtle. For example, few published studies have quantified aquatic habitat use by Eastern Box Turtles, and much of the literature on this subject is anecdotal (Donaldson and Echternacht 2005). Based on my results and those presented by Donaldson and Echternacht, it appears that Eastern Box Turtles use water extensively in the summer months, and that these habitats may provide important resources that influence turtle movements and habitat selection. Preserving land that does not include aquatic habitats may lead to turtles making long journeys to water sources, which may result in mortality if roads or urban centers are between the turtle and the water source. Therefore, it is important to consider including aquatic habitats when preserving land for the Eastern Box Turtle. Additionally, when managing aquatic associated habitats, such as wetlands (Donaldson and Echternacht 2005).

Furthermore, my results suggest that box turtles selected mixed forest habitats within their home ranges. Because these habitats contained a large amount of woody debris, this could suggest that the presence of cover objects influences Eastern Box Turtle habitat selection and movements within the home range. Therefore, it may be important to consider the availability of downed trees and other cover when preserving box turtle habitat.

My study represents the first application of LoCoH to home range analysis of the Eastern Box Turtle. This method is relatively easy to use, and has been shown to be superior to other home range estimators (Getz and Wilmers 2004; Getz et al. 2007). The results of this study could be a baseline for future research on Eastern Box Turtles using LoCoH. Comparing home-range estimates from different methods may not yield valid comparisons (Lawson and Rodgers 1997). Therefore, estimates from this study will be useful for comparison with results from future studies using LoCoH. The availability of previous estimates for comparison may make LoCoH a more attractive option for researchers attempting to compare their home-range estimates to those from other studies. Further research on home range behavior of the Eastern Box Turtle should employ LoCoH when possible. The use of this method may allow for a better understanding of the species' home range behavior.

In conclusion, my results suggest that Eastern Box Turtles at Hungry Beech Nature Preserve are non-randomly selecting home ranges based on habitat characteristics, and that they are non-randomly selecting habitats within the home range. Specifically, turtles appear to be avoiding field habitats at both scales and selecting for mixed forest and creek-associated habitats when they are present in the home range. In addition, slope appears to influence Eastern Box Turtle movements and home-range selection. Average slope of the home range may also slightly influence home-range area. However, future research is necessary to understand the relationship between home-range behavior and slope. Future work is also necessary to evaluate the effect of early successional habitat on home-range behavior and selection, as well as the effect of season on habitat use. Managers should consider including aquatic habitats and those with plentiful cover objects when designing preserves for Eastern Box Turtle.

Chapter 3: Morphometrics, Demographics, and Natural History Notes

Morphometrics

I measured and weighed all turtles that I found at Hungry Beech Nature Preserve during my study. I captured turtles opportunistically while walking through the preserve. For all captured turtles, I took measurements of carapace length, width, and height, as well as plastron length and width using calipers. I measured carapace width at the widest point, and plastron width at the plastral hinge. I measured carapace height from the highest point on the carapace to the bottom of the plastron. I measured plastron length from the gular scutes to the anal scutes on the plastron, and I measured carapace length from the nuchal notch to the posterior marginal scutes (Figure 14). Using Pesola hanging scales and a cloth bag, I weighed each turtle and subtracted the weight of the bag from the total weight to determine the turtle's mass .

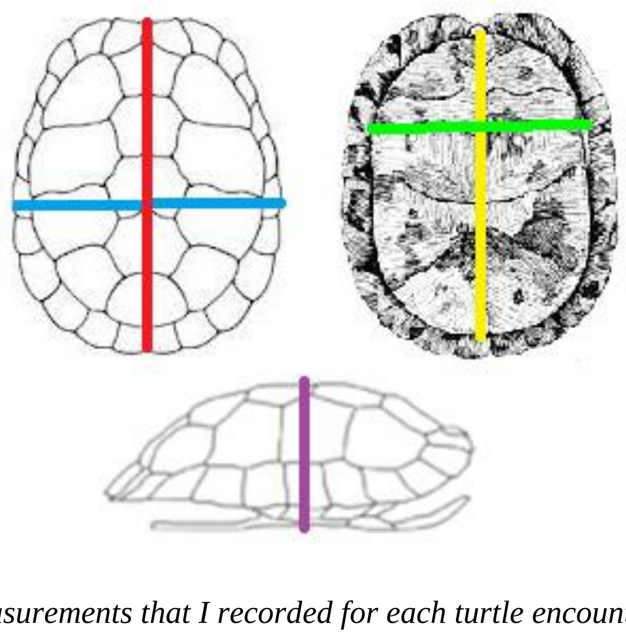

Figure 14: *Shell measurements that I recorded for each turtle encountered during the study. Blue represents carapace width, red is carapace length, purple is carapace height, green is plastron width, and yellow is plastron length.*

I marked all turtles that were encountered by filing notches into the marginal scutes of the carapace. I used a modified version of Cagle's numbering scheme (Cagle 1939) so that each turtle had a unique set of marks that could be used for identification (Figure 15). Marking the turtles allowed me to insure that I did not measure turtles a second time. In total, I captured and marked 202 individual turtles from May-October 2012.

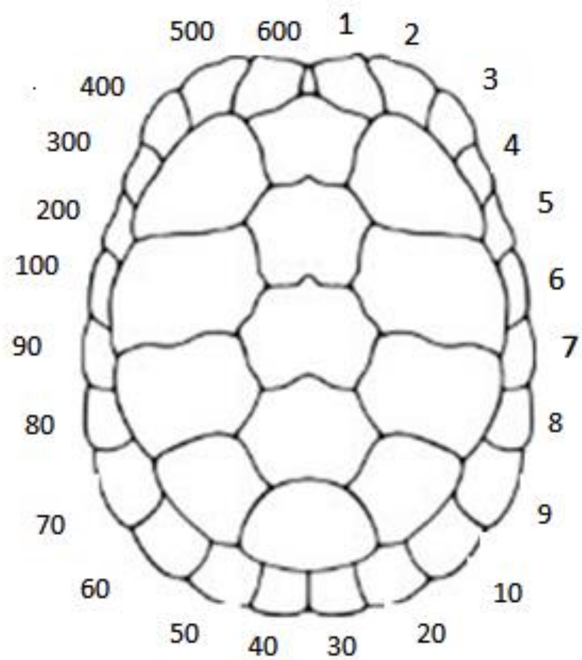

Figure 15: *The scute numbering scheme used when marking turtles at the preserve*.

I constructed size class curves using each morphometric parameter (Figures 16 through 21). I also used separate two sample t-tests for each parameter to determine if average morphometric parameters of adult turtles differed significantly between the sexes (Table 14). The results of the t-tests showed that males had a significantly larger carapace length (df=185, t=-5.82, $p < 0.0001$), carapace width (df=183, t=-5.23, $p < 0.0001$), plastron length (df=183, t=-2.97, p=0.003), and plastron width (df=185, t=-3.29, p=0.001). Females had a significantly larger average carapace height (df=180, t=2.79, p=0.006). There was no significant difference between the mass of male and female turtles (df=184, t= -0.93, p=0.352).

Table 14: *Average measurements, by sex, for each morphometric, as well as the results of two sample t-tests comparing male and female measurements.*

Parameter	**Sex**	**Mean**	**Std. Error**	**p-Value from Two Sample t-Test**
Plastron Length (cm)	M	11.273	0.721	0.0034
	F	10.9485	0.67	
Plastron Width (cm)	M	7.269	0.05	0.0012
	F	6.9906	0.0679	
Carapace Width (cm)	M	10.197	0.0499	< 0.0001
	F	9.744	0.0714	
Carapace Height (cm)	M	5.98	0.498	0.0059
	F	6.15	0.410	
Carapace Length (cm)	M	12.93	0.0723	< 0.0001
	F	12.23	0.093	
Mass (g)	M	403	4.527	0.3522
	F	395.5	6.757	

My results appear to support existing literature. Eastern Box Turtles are sexually dimorphic (Stickel and Bunck 1989; Dodd 2001). Male Eastern Box Turtles are generally larger in all respects except for carapace height, which is typically larger in females, and mass, which is similar between the sexes (Stickel and Bunck 1989; Dodd 2001). The most obvious explanation for the similarity in mass between adult male and female turtles is the presence of eggs (Dodd 2001). Although male turtles tend to be larger in other respects, the eggs of females may be heavy enough to negate any significant differences in mass between the sexes (Dodd 2001).

Reproduction could also explain the larger carapace height observed in female turtles, because the taller carapace may translate to increased room for eggs inside the body cavity (Dodd 2001). Studies have shown that there appears to be a positive correlation between carapace height and clutch size (Wilson and Ernst 2005). Therefore, a taller carapace in females may increase reproductive success. A taller carapace in females may also necessitate a larger male body size, because larger size may give males a mechanical advantage during courtship and mating (Dodd 2001).

The size class curves show a large number of medium sized turtles (Figures 16-21). The curves are skewed, with a trailing tail consisting of smaller turtles; typically juveniles and sub adults. For all of the morphometric parameters except carapace height, there are less turtles found in larger size classes. This appears to be a normal size class curve for box turtles in general; previous studies have shown similar trends in populations of various box turtle species (Legler 1960; Dodd 2001). The low number of large turtles for many of the parameters measured suggests that box turtle populations contain very few large individuals (Dodd 2001) and consist mainly of medium sized adults. However, juvenile turtles are difficult to detect (Stickel 1950; Langtimm and Dodd 1996; Dodd 2001; Forsythe et al. 2004), and I did not find many of them. Therefore, there may be more turtles in smaller size classes than my results suggest.

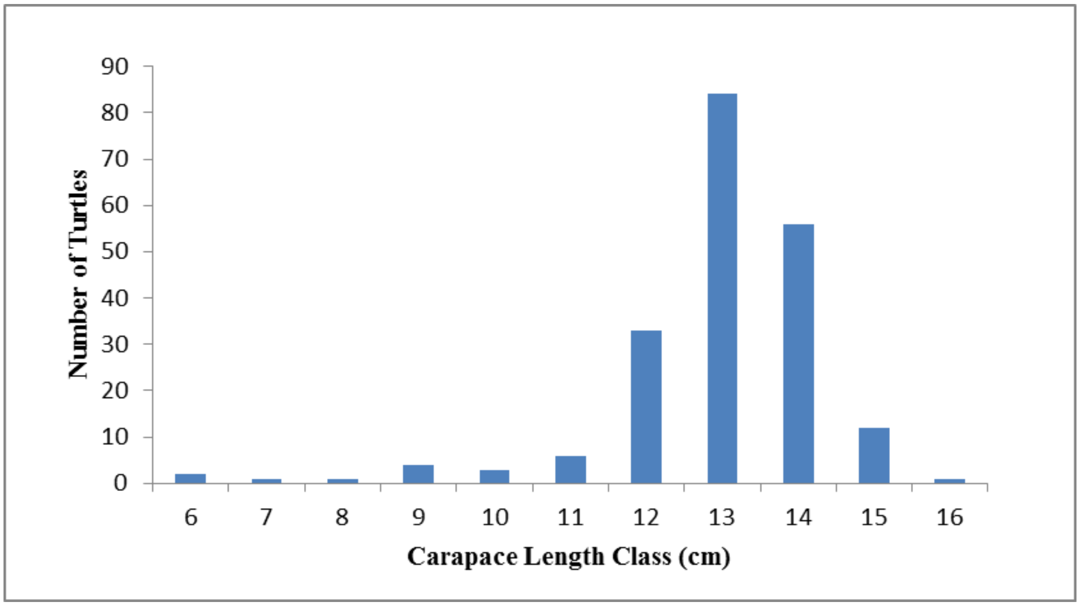

Figure 16: *A size class curve of carapace length for all turtles I captured at the preserve.*

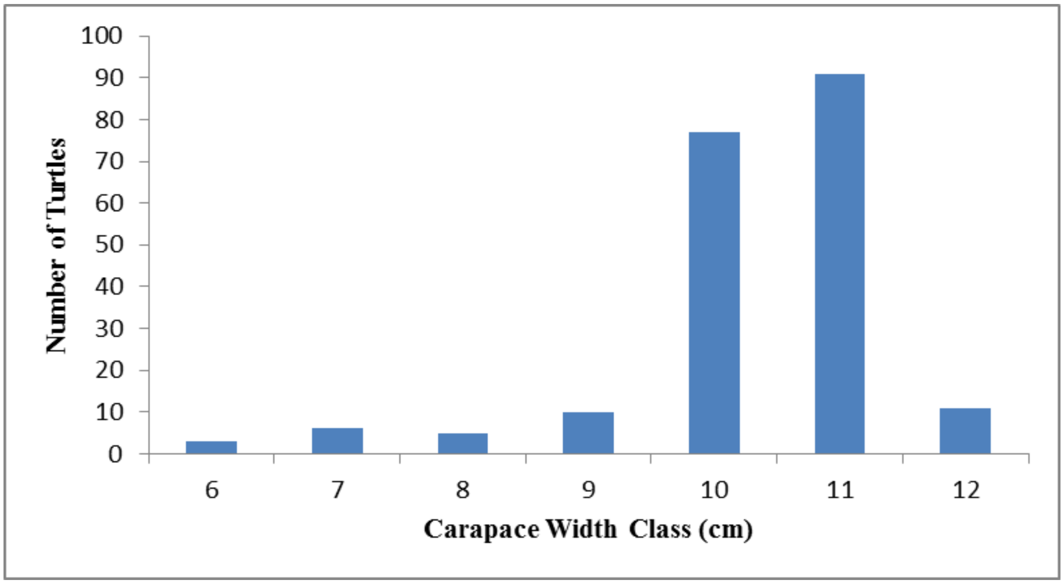

Figure 17: *A size class curve of carapace width for all turtles I captured at the preserve.*

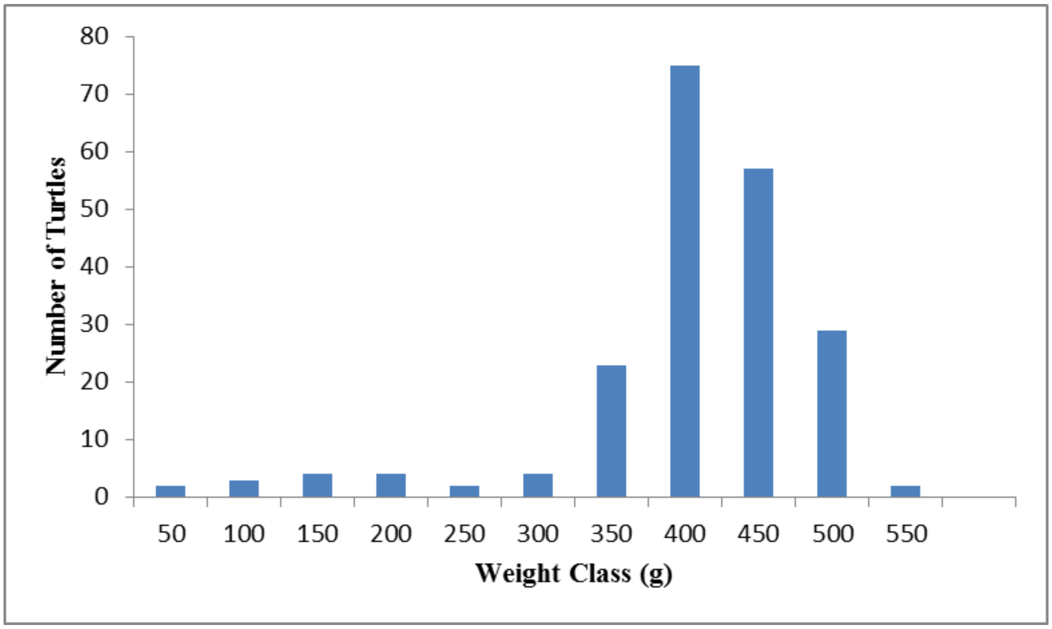

Figure 18: *A weight class curve for all turtles I captured at the preserve.*

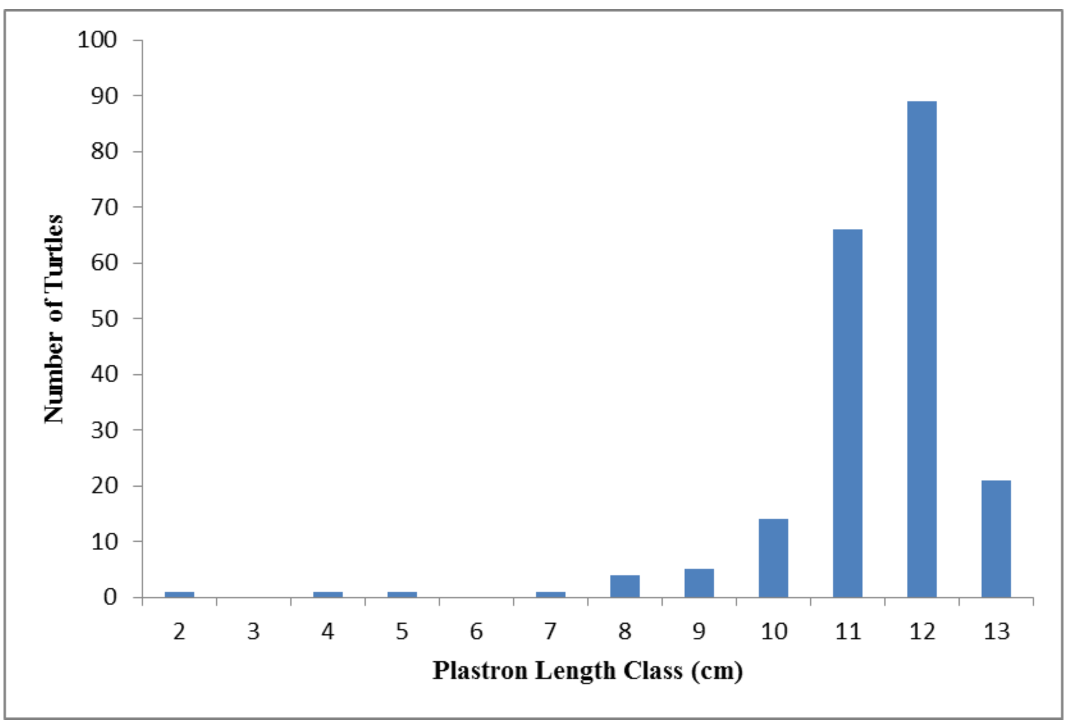

Figure 19: *A size class curve of plastron length for all turtles I captured at the preserve.*

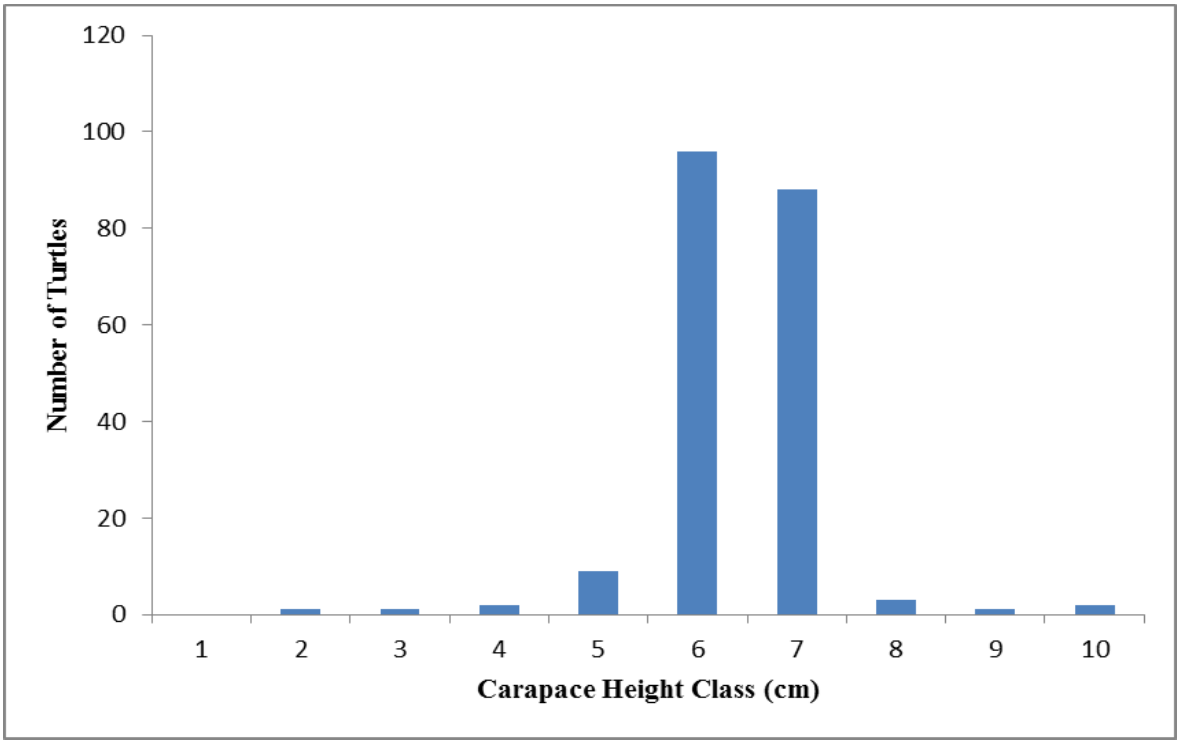

Figure 20: *A size class curve of carapace height for all turtles I captured at the preserve.*

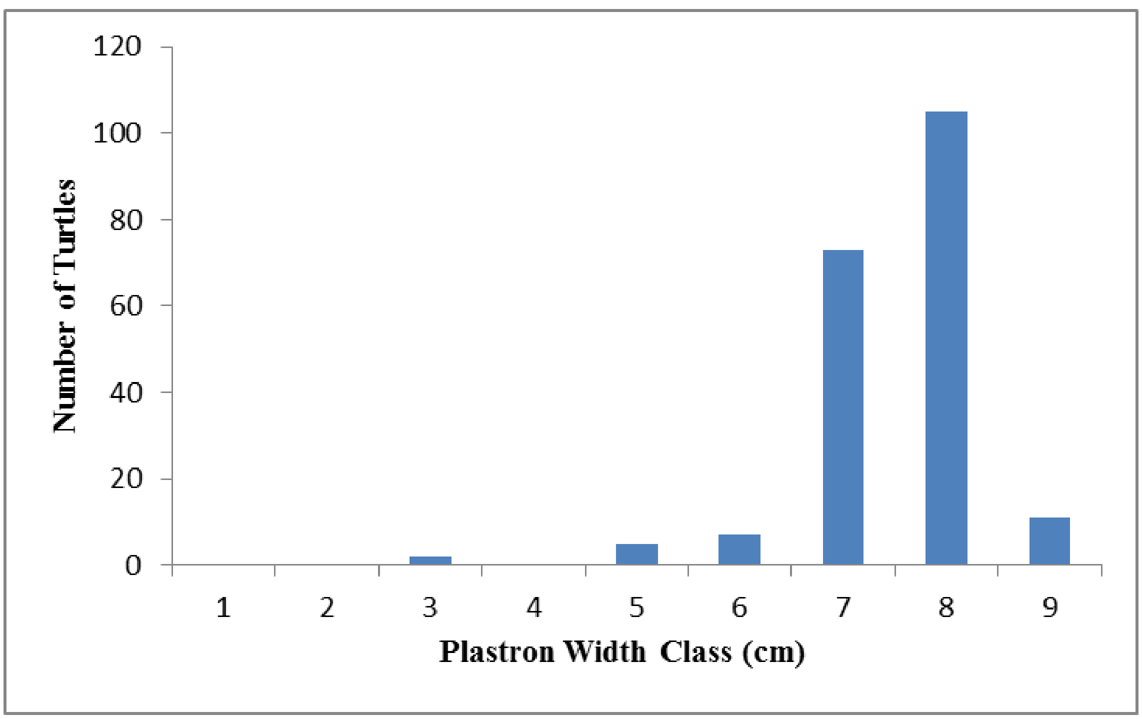

Figure 21: *A size class curve of plastron width for all turtles captured at the preserve.*

These results for morphometric analysis support those of Barron (1996), who found that male Eastern Box Turtles at Hungry Beech Nature Preserve were significantly larger than females when examining carapace length, carapace width, plastron width, and plastron length. He also found that carapace height was significantly larger in females than in males, and that mass was not significantly different between the sexes (Barron 1996). Therefore, my overall findings support those from previous studies at the preserve.

Changes in Average Home-range area

Barron (1996) estimated average home-range area of Eastern Box Turtles at Hungry Beech Nature Preserve using minimum convex polygon. To compare the average home-range area that I observed with estimates from 1996, I estimated home-range area for the ten turtles that I tracked during this study using minimum convex polygon (Jennrich and Turner 1969).

Barron (1996) estimated an average home-range area of 0.448 ha . However, I observed an average MCP home-range area of 1.445 ha in 2012. According to a one sample t-test, my estimate is significantly larger than the 1996 estimate (df= 19, t= 3.89, p= 0.001) (Figure 22). It was not possible to track the same turtles that were used in the 1996 study; therefore, my results are not conclusive. However, my findings suggest that, on average, turtles used significantly larger home ranges at the preserve in 2012 than in 1996.

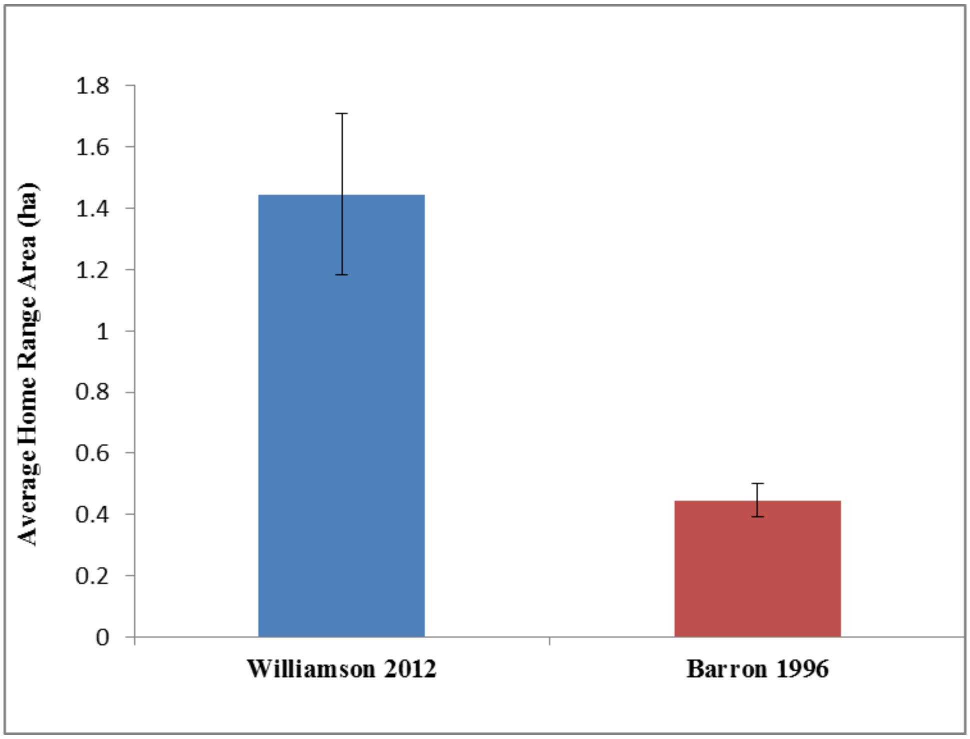

Figure 22: *A comparison of average MCP home-range area estimates. Home-range area was significantly larger in 2012. Error bars represent standard errors.*

Changes in habitat structure may be contributing to the increase in average home-range area. Home-range area in Eastern Box Turtles may be influenced by habitat diversity, and resources will likely be more available in more diverse habitats (Stickel 1950; Madden 1975). Therefore, in more diverse habitats home ranges would be expected to be smaller, because box turtles will need to move less in order to obtain resources that they require (Stickel 1950; Dodd 2001). Previous studies have found that home-range area is reduced in areas with a large amount of early successional habitat (Willey 2010). This habitat appears to be an important resource for Eastern Box Turtles in other locations (Willey 2010). As habitats proceed towards later periods of succession, forest gaps will undoubtedly decrease in abundance (Willey 2010), and the diversity of available habitats may decrease. These successional changes may therefore cause turtles to move farther in search of resources and extend their home ranges as a result (Willey

2010). The forested portion of Hungry Beech Nature Preserve is largely undisturbed and unmanaged, so it is likely that forest succession has occurred in the 17 years since 1996, and there has likely been a reduction in the availability of early successional habitat. As a result, it seems likely that forest succession may be one factor contributing to changes in home range behavior at the preserve.

Sex Ratio

During the study period (May-October 2012), I encountered 204 individual turtles. Of these 13 were juveniles, and 191 were adults. I classified juveniles as individuals less than 10 cm in carapace length that were lacking secondary sex characteristics. I based this classification on methods from previous studies (Langtimm and Dodd 1996). I did not capture many juveniles; however, this is typical for studies of Eastern Box Turtles, because juveniles are difficult to detect due to their small size and tendency to spend a significant time concealed in leaf litter (Stickel 1950; Langtimm and Dodd 1996; Dodd 2001; Forsythe et al. 2004). Therefore, it is likely that the turtle population consists of many more juveniles than my observations suggest.

Of the adults that I captured during my study, 122 were male and 65 were female. I was unable to determine sex for the remaining four adult turtles. From these data, I calculated a sex ratio of 1.88:1. Using a Chi Square in SAS, I determined that the observed sex ratio was significantly different from an expected ratio of 1:1 (x^2 =17.37, $p< 0.0001$). Therefore, the population of Eastern Box Turtles at Hungry Beech Nature Preserve appears to be significantly male skewed.

In vertebrates with overlapping generations, such as the Eastern Box Turtle, a sex ratio of 1:1 is expected assuming factors such as recruitment and survival are equal for both sexes (Dodd

2001). Sex ratios not significantly different from 1:1 have been reported in several studies (Williams and Parker 1987; Barron 1996; Nazdrowicz et al. 2008). However, other studies have reported significantly male skewed sex ratios in box turtle populations (Dodd 1997; Dolbeer 1969; Strass et al. 1982, Ferebee et al. 2008).

Eastern Box Turtle sex ratios fluctuate naturally over time (Dodd 2001). Sex ratio does appear to have changed at Hungry Beech Nature Preserve since 1996. Barron (1996)concluded that the sex ratio of the population at Hungry Beech Nature Preserve was 1.12:1, which is not significantly different from an expected ratio of 1:1 (x^2 =0.195, p=0.68). However, I observed a significantly male skewed sex ratio. Therefore it appears that the sex ratio is currently more heavily male skewed than it was in the past.

Various factors may have played a role in the apparent sex ratio changes at Hungry Beech Nature Preserve. One factor could be natural changes in habitat due to successional processes, and the resulting changes in the availability of nesting habitat. Eastern Box Turtles exhibit temperature dependent sex determination (Dodd 2001). Warmer nest temperatures produce females, and cooler nest temperatures produce males (Dodd 2001). Therefore, nest site selection is one potential cause for skewed sex ratios turtle populations (Dodd 1997). Eastern Box Turtles typically select nest sites in open canopy habitats with low amounts of vegetative cover (Flitz and Mullin 2006; Willey and Sievert 2012). Therefore, forest gaps may be important nesting habitat for Eastern Box Turtles (Willey 2010). As previously discussed, succession may decrease the amount of open nesting habitats available (Willey 2010). Open canopy habitats are likely to be warmer due to the increased intensity of sunlight reaching the forest floor (Flitz and Mullin 2006).As open habitats decrease in abundance; more turtles would nest in environments with higher canopy cover and cooler temperatures, which would result in the production of a higher number of male hatchlings. Over time, a higher number of male hatchlings could cause the population to become male skewed. Therefore, succession may have influenced sex ratios in this population.

In the absence of open habitat within the forested areas of the preserve, turtles are still able to nest in the field. I observed two nests in the field habitat during the study period, and both were depredated (Pers. obs.). Temperatures of nests in the field are likely relatively high, thus these nests probably produce higher numbers of female hatchlings. However, their position in a large anthropogenic clearing may leave these nests more vulnerable to predators, because they are probably more accessible and easier to find than nests in more sheltered locations (Flitz and Mullin 2006). Therefore, nests that contain mostly females may be depredated more often than those that contain males, resulting in a skewed sex ratio.

Changes in sex ratio can be indicative of differential mortality in the sexes (Gibbs and Steen 2005).Male skewed sex ratios can be a result of increased female mortality, and have been associated with population declines (Stickel 1978; Hall et al. 1999; Gibbs and Steen 2005). Further research is necessary, but my observations suggest that female mortality may be high at Hungry Beech Nature Preserve. I encountered more male survivors from the 1996 study than female survivors. I recaptured 31 of the marked turtles from 1996, and of these 31 turtles, 8 were female and 21 were male. According to Chi-Square analysis, the ratio of recaptured male survivors to females is significantly more male skewed than the 1.12 : 1 sex ratio reported by Barron in 1996 (x^2=4.972, p=0.026) , which suggests that females from the 1996 study may have had lower survivorship than males. However, there are likely other surviving individuals from 1996 that I could not detect, so there may be more female survivors than I observed.

Therefore, future research that accounts for capture probability is necessary in order to reach a conclusion regarding different mortality rates in male and female box turtles at the preserve.

There are a variety of possible causes of female mortality in turtle populations. In some cases, female mortality may be higher than male mortality in turtle populations because females may travel across roads more often than males to find nesting sites (Steen et al. 2006). However, roads are an unlikely cause of increased female mortality at Hungry Beech Nature Preserve, because there are few well-travelled roads near the site, and turtle mortality on roads is likely not very high.

Alternatively, it is possible that female mortality is occurring when females nest in the field at the preserve. Barron (1996) observed dead turtles in the field following haying events, and I observed turtle nests in the field habitat (Pers. obs). I also observed turtles with shell injuries that could have resulted from agricultural machinery (Pers. obs.). Additionally, I captured females in field habitat more often than male turtles (Table 13). Therefore, it is possible that females nesting in the field are killed more often during haying than males, and because haying occurs annually, over time this may result in a male skewed sex ratio. Studies have shown that agricultural practices may cause turtle mortality, and in some cases the scale of this mortality exceeds that caused by automobiles (Saumure et al. 2007; Nazdrowicz et al. 2008; Tingsley et al. 2009; Erb and Jones 2011). In addition, the haying of fields has been known to have a negative impact on the survival probability of turtles (Saumure et al. 2007), therefore haying practices could have a significant impact on turtle populations over time. However, there is no conclusive evidence that hay harvests are causing high female mortality at Hungry Beech Nature Preserve. Future studies should be conducted in order to evaluate the impacts of hay harvests at the preserve.

Table 15: *Percent captures in each habitat type. I captured female turtles in field habitats more often than male turtles. No mixed forest habitat was available to females, therefore I captured no females in this habitat type.*

Sex	Deciduous	Mixed Forest	Edge	Field	Creek
Male	75.44%	2.11%	15.09%	0.35%	6.67%
Female	76.34%	0%	13.84%	4.02%	5.80%

The Effect of Sex on Habitat Selection

I captured female turtles in the field more often than males (Table 15). If females are nesting in the field, then they may be selecting field habitat more often than males. To test this hypothesis, I constructed binary logistic regression models similar to those discussed in chapter 2. These models tested the interactive effect of sex and habitat type on habitat selection. For these models, I removed turtle 17 from analysis because it was a sub adult and its sex could not be determined. In addition, I condensed my habitat classifications by removing mixed forest habitat from analysis, because it was not available to any of the female turtles tracked during my study. To do this, I merged deciduous and mixed forest into a single category, termed forested habitat. I then ran the model Habitat + Sex+ Habitat x Sex for home-range selection using 90% and 100% LoCoH isopleths. I carried out this analysis using SAS statistical software. I explain the process of fitting logistic regression models fully in Chapter 2. I did not have enough statistical power to analyze habitat selection within home ranges due to decreased sample size, and as a result, the models did not fit my data. Therefore, I was unable to draw conclusions regarding habitat selection within home ranges in males and females.

My results showed that there was a significant interactive effect of sex and habitat type on home-range selection at both the 100% and 90% scale ($p < 0.001$). For home-range selection using 100% LoCoH isopleths, there appears to be a significant positive interaction between female turtles and field habitat, suggesting that females include field habitat in their home ranges more often than males (0.932 ± 0.178, 95% CI= 0.841, 1.023, $p<0.001$, Table 16). This result was reversed at the 90% home-range scale; males had a significant positive association with field habitat, suggesting that male turtles use field habitat more than females at this scale (0.617 ± 0.233, 95% CI= -0.736, -0.498, $p=0.008$, Table 17).

Table 16*: Results for the home-range selection model Habitat + Sex + Habitat*Sex (100% HR estimates)*

Sex	Habitat	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
M	Field	-0.932	0.178	-1.023	-0.841	27.49	< 0.001
F	Field	0.932	0.178	0.841	1.023	27.49	< 0.001
M	Forest	0.206	0.104	0.153	0.259	3.92	0.048
F	Forest	-0.206	0.104	-0.259	-0.153	3.92	0.048
M	Edge	0.725	0.128	0.660	0.790	32.362	< 0.001
F	Edge	-0.725	0.128	-0.790	-0.660	32.362	< 0.001

Table 17*: Results for the home-range selection model Habitat + Sex + Habitat*Sex (90% HR estimates)*

Sex	Habitat	Beta Coefficient Estimate	Standard Error	95% LCI	95% UCI	Wald Chi Square	P-Value
M	Field	0.617	0.233	0.498	0.736	7.013	0.008
F	Field	-0.617	0.233	-0.736	-0.498	7.013	0.008
M	Forest	-0.553	0.128	-0.618	-0.488	18.823	< 0.001
F	Forest	0.553	0.128	0.488	0.618	18.823	< 0.001
M	Edge	-0.064	0.145	-0.138	0.010	0.192	0.661
F	Edge	0.064	0.145	-0.010	0.138	0.192	0.661

The results of the 90% and 100% home-range selection models may seem contradictory, but they can be explained by considering differences between 100% LoCoH home-range estimates and 90% estimates. The 100% isopleths include all turtle locations, including possible nesting excursions undertaken by females. Brief extensions of the home range, such as nesting excursions, are not included at the 90% scale, and their absence may account for the difference in my results for 90% and 100% estimates. Therefore, while not conclusive, my results seem to suggest that female turtles are including field habitat in their home ranges more often than male turtles, and that this difference may be a result of nesting excursions. My results suggest that female turtles could be using field habitats more often than males. Future study at the preserve should include an analysis of the effect of sex on habitat selection within home ranges, to determine if females are selecting field habitats more often at this scale.

Estimation of Total Population and Population Density

From the mark- recapture data that I collected, I estimated total population of Eastern Box Turtles at the preserve, as well as population density. To estimate the total population, I used the Schnabel method (Schnabel 1938). I captured and marked turtles on 64 occasions. During these 64 occasions, I captured and marked 202 turtles according to the marking protocol in figure 15. I recaptured 66 individuals 104 times (Table 18). My resulting population estimate was 332 ± 33 box turtles at the preserve (Table 19).

To estimate population density, I could not simply divide this estimate by the size of the preserve, because my results suggested that turtles are not using habitats throughout the preserve equally. Therefore, the density of turtles throughout the preserve is likely not the same. To account for this, I used all the capture locations at the preserve, including telemetry captures, to determine the total area of the preserve that turtles were known to use during this study. I adopted this method from a previous study estimating population density in wood turtles and spotted turtles (Breisch 2006). Using a GIS, I estimated the size of the activity area to be 51.3 ha. I divided my total population estimate of 332 turtles by the size of the activity area, which gave me an estimate of 6.46 turtles per ha (Table 19)

Table 18: *Mark and recapture data used to estimate population size using the Schnabel method.*

Sampling Occasion	(C_t) Captures/Occasion	Newly Marked Individuals	(R_t) Recaptures/ Occasion	(M_t) Total Marked at Start of Sampling Occasion
1	5	5	0	0
2	6	6	0	5
3	10	8	2	11
4	9	9	0	19
5	3	3	0	28
6	5	5	0	31
7	4	4	0	36
8	2	2	0	40
9	8	6	2	42
10	13	12	1	48
11	5	2	3	60
12	3	3	0	62
13	4	4	0	65
14	16	14	2	69
15	10	7	3	83
16	6	4	2	90
17	3	0	3	94
18	11	9	2	94
19	4	4	0	103
20	2	0	2	107
21	3	2	1	107
22	6	6	0	109
23	1	0	1	115
24	2	1	1	115
25	3	1	2	116
26	7	4	3	117
27	2	0	2	121
28	3	3	0	121
29	5	5	0	124
30	2	1	1	129
31	3	2	1	130
32	3	3	0	132
33	4	3	1	135
34	13	8	5	138
35	7	7	0	146
36	8	0	8	153
37	4	2	2	153
38	2	2	0	155
39	4	2	2	157
40	10	4	6	159
41	4	1	3	163
42	2	1	1	164
43	7	4	3	165
44	5	2	3	169
45	4	3	1	171
46	6	3	3	174
47	1	1	0	177
48	6	2	4	178
49	7	4	3	180
50	4	0	4	184
51	3	2	1	184
52	8	4	4	186
53	1	0	1	190
54	5	2	3	190
55	2	0	2	192
56	1	1	0	192
57	1	0	1	193
58	5	4	1	193
59	2	1	1	197
60	1	0	1	198
61	3	1	2	198
62	2	1	1	199
63	5	2	3	200
64	0	0	0	202

Table 19: *Estimate of total population and population density.*	
Total Population	332
Variance	1057.355
Standard Error	32.517
Population Density (Turtles / ha)	6.460

My estimates of population size and density are both lower than those calculated in 1996 (Barron 1996). Barron (1996) estimated that there was a total population of 61 ± 46 box turtles within a 2 ha study plot at the preserve. After including a buffer zone of half the average home-range area to account for turtles that may have had home ranges that were not entirely within the plot, he estimated that there were 14 box turtles per ha (Barron 1996). He extrapolated his estimate to the scale of the entire preserve, assuming equal density of turtles throughout the preserve, and calculated a total population of 682 box turtles.

Although my estimates for total population and population density are lower than those from the 1996 study, there are some problems with Barron's estimates that prevent me from confidently stating that the turtle population has declined. First, he assumed that turtle densities are equal throughout the preserve, which is very unlikely. Eastern Box Turtles are known to use habitat unequally (Dodd 2001); this is further supported by my results, which suggest turtles are selecting certain habitats at the preserve while avoiding others. Furthermore, Barron conducted his study in a small part of the preserve, and mine was conducted throughout its entirety. Therefore, because turtle density is not likely to be the same throughout the preserve, it is possible that the 2 ha study plot used in 1996 was an area of higher density that is not representative of the population density of the entire preserve. In addition, the Schnabel method assumes a closed population (Schnabel 1938). As a result of the small size of the study plots used in 1996, Barron's study may have violated the assumption of a closed population. The violation of this assumption could have resulted in an inaccurate population estimate in 1996.

When comparing my estimate of population density to other studies of *Terrapene c. carolina* in various locations, my results appear to indicate that population density at the preserve is fairly typical. Results of studies I reviewed gave density estimates ranging from 3.7-9.2 turtles per ha (Stickel 1950; Madden 1975; Williams and Parker 1987; Dolbeer 1969). My population density estimate falls within that range; however, it is higher than estimates from three of the studies (Stickel 1950; Madden 1975; Williams and Parker 1987).

A more accurate population estimate would be possible if I had used data from the 1996 study in my estimate. However, if I were to use this data I would not be able to use the Schnabel method, because during the time between the two studies there is likely to have been significant emigration, death and recruitment. This would violate the Schnabel method's assumption of a closed population. To perform such an analysis, the Jolly-Seber method, or a similar model, would be more appropriate. I did not use these methods because they are very time intensive, and this estimate is a minor part of my thesis. However, I recommend that any future estimates be done using data from all mark-recapture studies at the preserve using more powerful estimation techniques.

Apparent Survival of Marked Turtles from 1996

Of the 202 turtles encountered during my study, 31 were individuals that James Barron marked in 1996. Of these 31 individuals, 8 were female, 21 were male, and 2 were unable to be sexed. Barron (1996) used a drill to mark 47 turtles by drilling holes in the marginal scutes; therefore, the marks are permanent and easy to recognize. In addition to the 31 survivors that I recaptured, I found the shells of three dead turtles that were marked during the previous study. Therefore, I can account for 34 of the 47 turtles originally marked in 1996, and at least 66% of the turtles marked in 1996 have survived. I was unable to obtain survival probability estimates because the capture data from 1996 were not available. However, the fact that I encountered 66% of the turtles from the 1996 study alive suggests that survival probability of adults in this population may be high; because it is likely there were additional survivors that I did not detect.

High survival rates do not appear to be uncommon in box turtle populations. Studies have documented high probabilities (80-96% depending on the study) of adult survival in populations of various box turtle species (Bowen et al. 2004; Converse et al. 2005; Dodd et al. 2006; Currylow et al. 2012). Therefore, it is likely that adult survival rates are high at Hungry Beech Nature Preserve. Future research should estimate annual survival rates at the preserve using techniques that can account for capture probability. In addition, future studies should examine male and female survival rates separately, because my results suggest that females may have a lower survival probability. I have already collected mark and recapture data for this population, therefore a survival study would not be difficult, and would provide valuable knowledge about the box turtle population at Hungry Beech Nature Preserve.

Natural History Notes

I found many turtles with scars or injuries at the Hungry Beech Nature Preserve. Turtles with missing limbs, dents in the carapace and along the marginal scutes, as well as missing scutes, were common. Agricultural machinery could have caused some of these injuries. For example, I observed a turtle with a misaligned spine due to a previously healed crack in the carapace (Figure 23). Machinery used in hay harvests may have caused this injury. Most of the injuries appeared to be the result of predator attacks, and I often found bite marks on the shells of turtles. It is not uncommon to find box turtles at other locations with scars similar to the ones that I observed (Dodd 2001).

Figure 23: *Examples of turtle injuries that I observed at the preserve, including a healed cracked carapace and misaligned spine (left), damaged scutes and a dent in the carapace (center), and a large dent in the carapace (right).*

Additionally, it appears that turtles 11 and 19 may have been injured in a fire at the preserve. The carapace of these turtles appeared to be burned, although the turtle appeared to be otherwise unharmed. According to Robin Paxton, a local who has agricultural rights to the property, there was at least one fire at the preserve in the past (Pers. comm. R.Paxton). A past fire event was also suggested by the presence of charred trees that I observed at the site (Pers. obs.). Therefore, it is possible that these turtles were burned during that event.

Deformities were also common. I found many turtles with anomalous scute patterns; some turtles had extra scutes (Figure 24), and others were missing one or more scutes. I typically found these anomalies on the carapace, and they often occurred in the marginal scutes. I also found an adult male (turtle 48) who appeared to have severely stunted growth. He displayed all of the secondary sex characteristics; however his carapace was 10.7 cm, which is below average size for an adult male (Table 11). The shell appeared deformed, which may suggest that this was a result of nutrient deficiency or disease.

Figure 24: *An adult box turtle found at the preserve with additional scutes on the carapace.*

I observed sick turtles on a few occasions as well. Turtle 96-61, one of the females in my radio telemetry study and a survivor from 1996, developed a large growth on her side during the study period. Toward the end of my study, the growth ruptured and began to leak brown, foul smelling pus. After searching the literature, I have been unable to determine what this lesion was, and I have been unable to find anything that fits its description. However, her condition did not appear to affect her behavior, even after the lesion ruptured. It did not appear to reduce her activity; turtle 96-61 was one of the most active turtles in my radio-telemetry sample, with one of the largest home ranges (Table 2).

Turtle 23, another female tracked during my radio telemetry study, appeared to be sick from June 16 to July 11. Her eyes were swollen shut and leaking pus (Figure 25). She was mostly immobile during the time that she was sick. After July 11, she recovered and was apparently healthy for the rest of the study period. She did not display any of the respiratory symptoms associated with *Ranavirus*. Eastern Box Turtles will sometimes exhibit swollen eyes as a result of bacterial infection (Pers. comm. R. Seigel). Therefore, a bacterial eye infection seems like the most plausible explanation.

Figure 25: *Turtle 23, showing symptoms of what was most likely a bacterial eye infection.*

I observed box turtles engaging in a number of interesting behaviors during my research. As I have previously discussed, the preserve contains many rock outcrops, and there are many small rock crevices, some of which are deep. I often found box turtles hiding in these crevices. On one occasion, I observed three box turtles using the same rock crevice (Figure 26). The weather on that day was particularly warm (33.1°C in the forest). These crevices probably serve as refuge from hot conditions, and there may be plentiful invertebrates in the crevices, which could serve as a potential food source. I can find no documentation in the literature of Eastern

Box Turtles using rock crevices or caves as cover, therefore this may be the first documented case of this behavior.

Figure 26: *I observed three male box turtles together in this crevice, likely trying to escape the heat. Only two are visible in this picture; the second individual's front limb is visible behind the first turtle. The crevice went back into the rock about one meter.*

I often found box turtle footprints around a small vernal pool on the dirt trail leading into the preserve (Figure 27). While it is likely that turtles used this pool as a water source, they may have been attracted to the pool as a food source as well. Over the course of my study, I observed various amphibian species and life stages in the pool. I observed *Lithobates sylvaticus* eggs and froglets in the pool, as well as the tadpoles and toadlets of an *Anaxyrus* species. Eastern Box Turtles may have been moving to this pool in order to consume amphibian eggs, metamorphs and larvae.

Figure 27: *Turtle footprints near the vernal pool.*

Additionally, the field edge contained a large number of blackberry bushes (Pers. obs.). Although I was unable to detect that turtles were selecting edge habitats at either scale of habitat selection that I examined, these habitats are likely important as a food source, at least when blackberries are present. I often found turtles eating blackberries in the edge habitat. Turtles appeared to use edge habitats more often in the morning. Results of a study by Reagan (1974) support this observation. Furthermore, previous studies have suggested that edge habitat is preferred by Eastern Box Turtles (Willey 2010). Although I was unable to detect any significant association of edge habitat and habitat use, the field edge may still be important habitat for box turtles at the preserve. My inability to detect an effect of edge on habitat use may be a result of a lack of capture occasions, resulting in low statistical power.

Chapter 4: Conclusions, Future Work and Management Recommendations

In summary, my results suggest that Eastern Box Turtles at Hungry Beech Nature Preserve are selecting home ranges based on habitat type. Specifically, turtles are not including field habitats in their home ranges in proportion to their availability, and their home ranges mainly included other habitat types (Table 5; Table 9; Table 10). Within home ranges, turtles were avoiding field habitats and selecting mixed forest and habitats associated with the creek (Table 7; Table 8). Although turtles of both sexes are avoiding field habitats at the home-range scale of selection, it appears that females may be including more field habitat in their home range than males (Table 14; Table 15); this trend is likely the result of nesting activity. Additionally, my observations suggest that while turtles appear to be avoiding field habitats, turtles may use these habitats more often in the morning when temperatures and humidity levels are more favorable. My results also suggest that slope may influence home-range selection and home-range area, but this subject should be studied further. In addition, my sample size of location points was probably not sufficient in order to observe significant effects of any predictors of within home-range selection using 90% home-range estimates. Future studies of habitat selection should use a higher number of captures and a larger sample size of turtles for telemetry. Future habitat selection studies should also include early successional habitat as a covariate, and examine habitat selection at the core home range (50% LoCoH isopleth) scale.

Although box turtles appear to remain plentiful at Hungry Beech Nature Preserve, my results suggest that there have been changes in population structure and home range behavior since 1996. The sex ratio of box turtles at the preserve appears to have become significantly male skewed, and box turtles appear to have larger home ranges on average than they did in 1996. The skewed sex ratio and increased average home-range size of turtles at Hungry Beech Nature preserve could indicate successional changes in habitat. As succession occurs, open habitats that box turtles have been known to prefer will become more rare, requiring turtles to move farther to find them (Willey 2010). Additionally, because Eastern Box Turtles have temperature dependent sex determination, the lack of warmer, open canopy nesting habitats could result in nests that produce a higher number of male hatchlings.

However, male skewed sex ratios can also indicate increased female mortality. Of the 31 turtles from 1996 that I recaptured, 8 were female. Barron (1996) had originally marked 22 females. Therefore, it is possible that female box turtles are experiencing higher mortality than males at Hungry Beech Nature Preserve. While the evidence is not conclusive, it is possible that increased female mortality could be the result of haying activity at the preserve. My results suggest that females may be using field habitats more often than males. I found nests in the field habitat, which could suggest that females are using this habitat for nesting.

Barron (1996) found a turtle that had been crushed by agricultural machinery at the preserve following haying, and some turtles that I captured appear to show signs of injuries that might have been caused by agricultural machinery (Pers. obs). Therefore, I recommend that future studies examine the survival of male and female Eastern Box Turtles at the preserve. A survival study would allow us to examine if female survival probability is less than that of male turtles. The results of such a study would allow us to more conclusively say whether high female mortality may be the cause of skewed sex ratios at Hungry Beech Nature Preserve.

Based on my results, I cannot conclude that hay harvests are responsible for increased female mortality at the preserve. It is necessary to conduct future research to examine the impacts of hay harvests. However, until further studies are performed I recommend that changes in the timing of hay harvests are considered. Changes in the timing of hay harvests could minimize possible impacts to the box turtle population. Previous studies have indicated that harvesting when box turtles are least active may be the best method of reducing mortality (Erb and Jones 2011). Eastern Box Turtles use open habitats more often in the morning and in cooler conditions (Reagan 1974; Dodd 2001). Previous studies, as well as my own observations, suggest that Eastern Box Turtles use open habitats more often in the late spring and early summer (Barron 1996; Willey et al. 2010; Pers. obs.). Therefore, hay should be harvested on warm afternoons in late July or August, since turtles will be less likely to be in the field at these times.

The equipment and methods used in harvesting hay at the preserve could also be changed in order to reduce the potential for turtle mortality. A study in 2011 examined methods to reduce turtle mortality in managed fields (Erb and Jones 2011). They conducted an experiment using model turtles, and concluded that sickle bar mowers were the least likely to cause mortality when compared to flail, rotary and mulch head mowers (Erb and Jones 2011). In addition, raising blade heights to 15 cm for all mowers aside from the flail mower, which always resulted in 100% mortality, resulted in decreased mortality (Erb and Jones 2011). However, the tires of haying equipment caused a large amount of mortality regardless of the type of mower used (Erb and Jones 2011). Additionally, studies have shown that turtles may learn to avoid mowers during haying, and may flee mowers as they approach (Saumure et al. 2007). Mowing the field from the center out may allow turtles enough time to retreat to safety, and may reduce mortality (Saumure et al. 2007). Therefore, although avoiding harvesting in the active season is the best method of reducing mortality (Erb and Jones 2011), changing haying methods slightly may reduce mortality further. I recommend that future hay harvests be conducted using sickle bar mowers if possible, using a 15 cm blade height, and starting in the center of the field. Although further evidence is needed to determine if there are any significant impacts of hay harvests on turtle populations at this site, small changes in harvest practices could reduce the chances that turtles will be killed during hay harvests.

In conclusion, my research has granted increased understanding of Eastern Box Turtle habitat selection and home range behavior. Furthermore, my study may serve as a basis for continued research at Hungry Beech Nature Preserve. Future studies will be necessary to ensure the long-term persistence of this population. Although the population appears to remain large based on the number of turtles captured (203), the population may decline if female mortality is higher than male mortality. Studies that examine the effect of sex on survival probability will provide increased understanding of the situation at Hungry Beech Nature Preserve, and will allow for appropriate management decisions. Until these studies are completed, I recommend steps be taken to reduce the potential for turtle mortality at the preserve.

Future studies of habitat selection should use a large sample size, account for early successional habitats, and examine the effect of sex on habitat selection. Eastern Box Turtle populations are declining in much of the species' range (Dodd 2001; Cook 2004). Studies of Eastern Box Turtle habitat selection, such as the one I have presented here, can provide information about habitat requirements that can be useful for conserving the species. Continued research on Eastern Box Turtles is necessary to increase our understanding of their ecology and successfully conserve populations of this species.

APPENDIX

A: Core Home Ranges

I was unable to obtain core home-range estimates (50% LoCoH isopleths) for all ten turtles that were equipped with radio transmitters because two of them were not located on enough occasions. Therefore, I did not investigate habitat selection at this scale. However, I have included a table of core home-range areas for the turtles whose core home ranges could be estimated (Table 20). In addition, I have included a map showing the core home ranges at the preserve (Figure 28).

Table 20: *Core home-range area (ha) of each turtle for which 50% LoCoH isopleth estimates were possible. Average area and standard error are also included.*

Turtle	Sex	50% HR Area (ha)
44	Female	0.534
17	Sub Adult	0.069
29	Male	N/A
16	Female	0.228
96-61	Female	0.460
18	Male	0.242
96-31	Male	0.108
19	Male	N/A
22	Male	0.038
23	Female	0.063
Sample Size (n)		8
Average HR Area		0.173
Standard Error		0.031

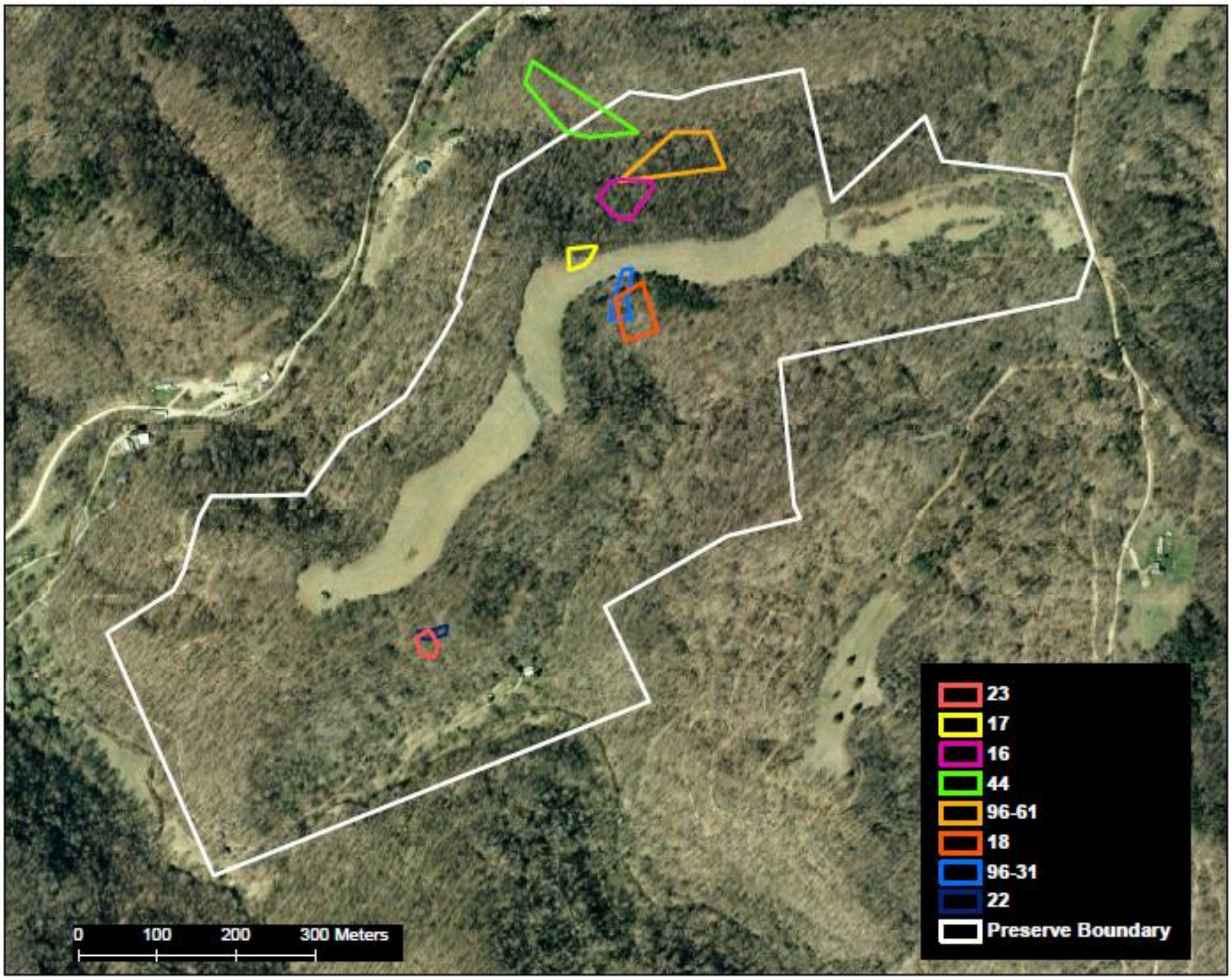

Figure 28: *Core home ranges (50% LoCoH) for 8 of the ten tracked turtles at the preserve. I could not estimate core home ranges for the other two due to a lack of location points.*

B: Activity Area

The activity area is a polygon constructed from all turtle locations from my study. I used the area of this polygon in my calculation of population density (Chapter 3, pg 60). I have included a map showing this polygon (Figure 29).

Figure 29: *Activity area at Hungry Beech Nature Preserve. This area is a MCP encompassing all turtle locations from my study, and represents the area of the preserve that I observed Eastern Box Turtle within.*

C: IRB Approval Letter

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Office of Research Integrity

May 7, 2013

Brian A. Williamson
1919 Maple Avenue, Apartment 2
Huntington, WV 25703

Dear Mr. Williamson:

This letter is in response to the submitted thesis abstract titled "The Effect of Habitat Diversity on Home Range Area of the Eastern Box Turtle." After assessing the abstract it has been deemed not to be human subject research and therefore exempt from oversight of the Marshall University Institutional Review Board (IRB). The Institutional Animal Care and Use Committee (IACUC) has reviewed and approved the study under protocol #500. The applicable human and animal federal regulations have set forth the criteria utilized in making this determination. If there are any changes to the abstract you provided then you would need to resubmit that information to the Office of Research Integrity for review and a determination.

I appreciate your willingness to submit the abstract for determination. Please feel free to contact the Office of Research Integrity if you have any questions regarding future protocols that may require IRB review.

Sincerely,

Bruce F. Day, ThD, CIP
Director

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Vita

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EDUCATION

Marshall University, Huntington, WV

Biology (MS) Completed: 7/2013

Thesis Topic: Examining habitat selection and home range behavior of the Eastern Box Turtle (*Terrapene c. carolina*) at multiple scales, with notes on demographic changes after 17 years

Advisor: Dr. Thomas K. Pauley

GPA: 4.0/4.0

Roger Williams University, Bristol RI.

Biology (BS) and Environmental Science (BS) Completed: 5/2011

GPA: 3.78/4.0

RESEARCH EXPERIENCE

MS Thesis Research: Examining habitat selection and home range behavior of the Eastern Box Turtle (Terrapene c. carolina) at multiple scales, with notes on demographic changes after 17 years, summer 2012-2013;

- Performed a mark-recapture and radio telemetry study of Eastern Box Turtles.
- Tracked 10 box turtles twice a week from May to October 2012.
- Estimated population size, population density, and sex ratio.
- Estimated home range area using LoCoH and Minimum Convex Polygon.
- Used ArcGIS extensively to map turtle capture locations and home ranges.
- Examined habitat selection at the home range scale and within the home range using binary logistic regression and AIC model selection.
- Examined changes in population demographics since 1996
- **Advisor**: Dr. Thomas K. Pauley

Snake Mark/Recapture and Amphibian Surveys in South Carolina, spring 2013;

- Assisted Dr. Shane Welch and Dr. Jayme Waldron with a mark/recapture population study of various non-venomous and venomous snake species.
- Conducted presence/absence call surveys of anurans in accordance with NAAMP protocol.
- Deployed and checked minnow traps to capture amphibians and reptiles.
- Performed cover board surveys to capture snakes in the field as part of a small team, and handled and measured them upon capture.
- Marked snakes using cauterization techniques.

Woodland Salamanders Surveys in Monongahela National Forest, West Virginia, fall 2011;

- Assisted Dr. Thomas Pauley and a small team examining the distribution of woodland salamanders in the national forest, with special focus on the federally threatened Cheat Mountain Salamander.
- Identified and captured various plethodontid salamander species during opportunistic surveys.

Undergraduate Senior Thesis Research: Examining nest site distribution in a population of northern diamondback terrapins (Malaclemys terrapin terrapin), summer 2010- 2011; Roger Williams University.

- Collected GPS coordinates of nests to determine terrapin nest distribution and abundance.
- Examined characteristics responsible for nest site selection.
- Mapped nest locations.
  Advisor: Dr. Scott Rutherford

Diamondback Terrapin Research Internship, Barrington, RI, summer 2009-2011;

- Monitored nesting activity.
- Captured, measured, identified, and marked female terrapins.
- Installed predator excluders around selected nests and released hatchlings from excluders.
- Assisted in planning research and management activity for future field seasons.

SCIENTIFIC MEETING PRESENTATIONS

ASB 2013

12 Minute Talk: "Examining habitat selection and home range behavior in the Eastern Box Turtle (*Terrapene c. carolina*)".

B.I.O.N.E.S. 2010

Poster presentation: "Examining nest site distribution and abundance in a population of northern diamondback terrapins (*Malaclemys terrapin terrapin)"*

PROFESSIONAL SOCIETY MEMBERSHIPS

Tri Beta Biological Honors Society (Inducted: 2008)

Alpha Chi Honors Society (Inducted: 2009)

Phi Kappa Phi Honors Society (Inducted: 2013)

TECHNICAL EXPERIENCE

- Mark and recapture techniques
- Radiotelemetry
- ArcGIS 10
- SAS Statistical Software
- Microsoft Office (Word, Excel, Powerpoint, Access)
- Use of handheld GPS units
- Experience with MARK and PRESENCE