Investigation of Headstarted Blanding's Turtles (*Emydoidea blandingii*) in Shiawassee National Wildlife Refuge, Saginaw, MI.

By

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Abstract

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When implementing management decisions managers should utilize the most cost-effective strategies that also provide the most benefit for the managed species. There are many different management options to consider when the objective is conservation of long lived reptiles (e.g., turtles) with one of them being headstarting. Headstarting is when reptile eggs are collected by managers, hatched in captivity, and hatchlings are raised for a certain time before being released into their native habitat. Blanding's Turtles (*Emydoidea blandingii*) are a state species of special concern in Michigan, where this study takes place. Headstarted Blanding's Turtles were raised for one and a half years and should benefit from being released in a suitable microhabitat within a wetland. This study's aim was to investigate the success of varying release locations and the headstart program by measuring thermoregulation patterns, survival, and movements of juvenile headstarted Blanding's Turtles. During June 2014, twenty-four Blanding's Turtles were released and tracked for eighteen months using radio telemetry to measure survival and to look at the movements among microhabitats; water and carapace temperature data were used to measure thermoregulation patterns. The headstarted juvenile Blanding's Turtles had an average carapace temperature lower than adults from previous studies and used basking as a thermoregulatory behavior.

To evaluate factors that may potentially affect survival of Blanding's Turtles microhabitat factors at turtle relocation points within Shiawassee National Wildlife Refuge, Saginaw, MI, USA were recorded, including water depth, vegetation type and dominance, substrate depth, and air and water temperature. GIS and ground truth data were used to investigate microhabitat factors and map turtle locations. All of the headstarted Blanding's Turtles survived overwintering through spring 2015. Turtles were released in four different locations with different microhabitats. Minimum convex polygon home ranges and movement patterns were analyzed to see if differences occurred across release groups and age classes. Significant differences were found between turtle home range size per release group. Comparisons to studies on wild-hatched Blanding's Turtles were made and showed that these headstarted Blanding's Turtles behaved similar to their wild-hatched counterparts when comparing behaviors at relocations and home range sizes. Use versus availability showed that the juvenile headstarted Blanding's Turtles avoided open water, willows, and lowland forest while preferring muskrat dens and cattails. Geographically weighted regression modeling predicted that these turtles would move towards preferred habitats and away from release sites with avoided non-preferred habitats. This research identified an estimated survival of between 63 and 96% over the eighteen month study period with all Blanding's Turtles surviving their first winter in the refuge. This research suggests that headstarting programs for Blanding's Turtles should release the species in preferred habitats of dense cattails with plenty of muskrat dens for basking and refuge, if available.

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Introduction

Blanding's Turtles *(Emydoidea blandingii)* (Holbrook, 1838) are a long lived freshwater turtle that inhabit the Great Lakes region of the United States and Canada, going as far east as southern Nova Scotia and as far west as Nebraska (Harding, 1997). Blanding's Turtles reach sexual maturity at 14 – 20 years of age which is when they are considered adults; Blanding's Turtles are considered juveniles before secondary sexual characteristics show at the age of 14 - 20. These secondary sex characteristics are concave plastrons with the cloaca beyond the rear carapace in males and the cloaca contained by the carapace in females (Harding, 1997). The primary habitat of Blanding's Turtles is composed of lentic wetlands (non-breeding) and terrestrial uplands (breeding) (Edge et al., 2010; Congdon et al., 2011). Adult Blanding's Turtles are more likely to be found in larger wetland complexes with good quality connectivity and less human disturbance (Attum et al., 2008). Ephemeral wetlands provide protection from heat, protection from predators, and plenty of invertebrate prey for adult female Blanding's Turtles (Refsnider & Linck, 2012).

Blanding's Turtles are listed as endangered on the IUCN redlist of threatened species, special concern on the Michigan threatened and endangered species list and special concern, threatened or endangered throughout the rest of their range except Nebraska. Population surveys of Blanding's Turtles show that there is little to no recruitment to aging populations; this is in large part due to increases in nest and hatchling predation from raccoons, skunks, and coyotes which has increased due to human related factors (Congdon et al., 1993). Newly hatched Blanding's Turtles are usually more than a day away from a proper wetland and must orient themselves towards proper wetlands using environmental cues in their environment as they are dispersing from their nest site (Brecke et al., 2009). Protected wetland areas, such as wildlife refuges where human disturbance is minimal, can help declining Blanding's Turtle populations stabilize when adults and juveniles are protected from the threats of habitat loss but recruitment is needed for future generations to succeed (Congdon et al., 1993).

Nest predation is a huge factor affecting turtle survival; one study found that raccoons predate 93% of all diamond-backed terrapin nests; raccoons use visual and olfactory cues with most predation happening during the first night after eggs are laid (Burke et al., 2005). Haegen et al. (2009) show that headstarted western pond turtles have an 88% to 95% survival rate, with mammal predation being the cause of death of the turtles that did not survive. A study of Blanding's Turtles hatching from 11 natural nests showed that only 25% of the hatchlings made it to permanent wetlands with 18% dying in the first weeks and 11% of the mortality due to predation (Jones & Sievert, 2012). Avian predators can cause a decrease in survival in freshwater turtle hatchlings, but larger hatchlings have a survival advantage (Janzen et al., 2000). Age and size dependent mortality are an important variable to look at when studying wild and headstarted freshwater turtles (Heppell et al., 1996).

Headstarting is a management option to increase population numbers in threatened and endangered turtles. This is done by collecting eggs from nests or gravid females, hatching them in a protected setting, and raising the hatchlings until they are larger and the threat of predation is lessened, usually about one year (Mitrus, 2008). Blanding's Turtles nest far from the wetlands they use and hatchlings are required to make the long trek to find suitable wetland habitats for their home (Brecke et al., 2009). Similar species of freshwater turtles have been shown to walk in a straight line in search of resources when released in unfamiliar places (Caldwell & Nams, 2006). By placing headstarted Blanding's Turtles in an appropriate wetland the risk of certain types of predation should be reduced since they will not have to make the terrestrial trek to find an appropriate wetland habitat like wild born hatchlings. Previous research of headstarted Blanding's Turtles (Angela Cleary, University of Michigan-Flint, personal communication) demonstrated a high mortality rate when turtles were released at the edge of a pool with adjacent forests. These mortalities appeared to be from raccoon predation and some surviving turtles showed signs of attacks by raccoons.

The benefits of GPS data from turtle tracking have made habitat analysis possible where it wasn't before (Schofield et al., 2007). Aerial orthophotographs have been shown to be good habitat guides in conjunction with use in GIS software for habitat mapping for Blanding's Turtles and other species (Barker & King, 2012; Maktav et al., 2000). Using aerial photographs in conjunction with ground truth data can assist researchers when looking at macrohabitats or microhabitats.

Various studies have looked into microhabitat preferences of adult Blanding's Turtles. Analysis of preferred microhabitat on adult Blanding's Turtles show that in the summer active months they prefer water temperatures that are cooler and areas with floating and submerged vegetation (Millar & Blouin-Demers, 2011). Newton and Herman (2009) found that turtle movement was positively correlated with water temperature across seasons and that activity was seasonal. Hartwig & Kiviat (2010) found that in constructed wetlands Blanding's Turtles prefer abundant vegetation in shallow waters, but Wieten et al. (2012) showed no connection between vegetation type and presence of Blanding's Turtles.

While studies have reported adult habitat preferences and behavior patterns, little is known about juveniles. The goal of this study was to investigate thermoregulation patterns, survival, movement patterns, and habitat preferences of juvenile headstarted Blanding's Turtles

(Figure 1.0) at Shiawassee National Wildlife Refuge (SNWR). The results of this study can be used to improve management decisions for headstarted turtles, saving time, money and turtles.

References

Attum, O., Lee, Y. M., Roe, J. H., & Kingsbury, B. A. (2008). Wetland complexes and upland wetland linkages: Landscape effects on the distribution of rare and common wetland reptiles. *Journal of Zoology, 275*(3), 245-251.

Barker, R. & King, D. J. (2012). Blanding's turtle (*Emydoidea blandingii*) potential habitat mapping using aerial orthophotographic imagery and object based classification. *Remote Sensing (Basel, Switzerland), 4*(1), 194-219.

Brecke, B. J., Capps, J. D., Congdon, J. D., & Pappas, M. J. (2009). Orientation and dispersal of hatchling Blanding's turtles (*Emydoidea blandingii*) from experimental nests. *Canadian Journal of Zoology, 87*, 755+.

Burke, R. L., Schneider, C. M., & Dolinger, M. T. (2005). Cues used by raccoons to find turtle nests: Effects of flags, human scent, and diamond-backed terrapin sign. *Journal of Herpetology, 39*(2), 312-315.

Caldwell, I. R., & Nams, V. O. (2006). A compass without a map: Tortuosity and orientation of eastern painted turtles (*Chrysemys picta picta*) released in unfamiliar territory. *Canadian Journal of Zoology, 84*(8), 1129-1137.

Congdon, J., Dunham, A., & Sels, R. (1993). Delayed sexual maturity and demographics of Blanding turtles *(Emydoidea-blandingii*) - implications for conservation and management of long-lived organisms. *Conservation Biology, 7*(4), 826-833.

Congdon, J. D., Kinney, O. M., & Nagle, R. D. (2011). Spatial ecology and core-area protection of Blanding's turtle (*Emydoidea blandingii*). *Canadian Journal of Zoology, 89*, 1098+.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2010). Habitat selection by Blanding's turtles (*Emydoidea blandingii*) in a relatively pristine landscape. *Écoscience, 17*(1), 90-99.

Grayson, K.L. & Dorcas, M.E. (2004). Seasonal Temperature Variation in the Painted Turtle (Chrysemys picta). *Herpetologica*, 60(3):325-336.

Haegen, W. M. V., Clark, S. L., Perillo, K. M., Anderson, D. P., & Allen, H. L. (2009). Survival and causes of mortality of head-started western pond turtles on pierce national wildlife refuge, Washington. *Journal of Wildlife Management, 73*(8), 1402-1406.

Harding, J.H. (1997). Amphibians and Reptiles of the Great Lakes Region. *University of Michigan Press*, 378 pp.

Hartwig, T. S., & Kiviat, E. (2007). Microhabitat association of Blanding's turtles in natural and constructed wetlands in southeastern New York. *The Journal of Wildlife Management, 71*(2), 576; 576-582; 582.

Heppell, S. S., Crowder, L. B., & Crouse, D. T. (1996). Models to evaluate headstarting as a management tool for long-lived turtles. *Ecological Applications, 6*(2), 556-565.

Herman, T. B., & Newton, E. J. (2009). Habitat, movements, and behavior of overwintering Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia. *Canadian Journal of Zoology, 87*, 299+.

Holbrook, J.E. (1838). North American Herpetology; or, a Description of the Reptiles Inhabiting the United States. Ed. 1, Vol. 3. Philadelphia: J. Dobson, 122 pp.

Janzen, F. J., Tucker, J. K., & Paukstis, G. L. (2000). Experimental analysis of an early life-history stage: Avian predation selects for larger body size of hatchling turtles. *Journal of Evolutionary Biology, 13*(6), 947-954.

Jones, M. T., & Sievert, P.R. (2012). Elevated Mortality of Hatchling Blanding's Turtles in Residential Landscapes. *Herpetological Conservation and Biology* 7(1):89−94.

Maktav, D., Sunar, F., Yalin, D., & Aslan, E. (2000). Monitoring loggerhead sea turtle (caretta caretta) nests in turkey using GIS. *Coastal Management, 28*(2), 123; 123-132; 132.

Millar, C. S., & Blouin-Demers, G. (2011). Spatial ecology and seasonal activity of Blanding's turtles (*Emydoidea blandingii*) in Ontario, Canada. *Journal of Herpetology, 45*(3), 370-378.

Mitrus, S. (2008). The headstarting technique is an ineffective method for conservation of the European Pond turtle - elasticity analysis. *Ecological Questions, 10*(-1), 51.

Newton, E. J., & Herman, T. B. (2009). Habitat, movements, and behavior of overwintering Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia. *Canadian Journal Of Zoology, 87*(4), 299-309.

Refsnider, J., & Linck, M. (2012). Habitat use and movement patterns of Blanding's turtles (*Emydoidea blandingii*) in Minnesota, USA: A landscape approach to species conservation. *Herpetological Conservation and Biology, 7*(2), 185-195.

Schofield, G., Bishop, C. M., MacLean, G., Brown, P., Baker, M., Katselidis, K. A., Hays, G. C. (2007). Novel GPS tracking of sea turtles as a tool for conservation management. *Journal of Experimental Marine Biology and Ecology*, *347*(1–2), 58-68.

Wieten, A. C., Cooper, M. J., Parker, A. D., & Uzarski, D. G. (2012). Great lakes coastal wetland habitat use by seven turtle species: Influences of wetland type, vegetation, and abiotic conditions. *Wetlands Ecology and Management*, *20*(1), 47-58.

Figure 1.0: Photo of juvenile headstarted Blanding's Turtle with transmitter epoxied onto rear carapace in SNWR.

CHAPTER 1. Thermoregulation Patterns in Headstarted Blanding's Turtles

Abstract

As part of an ongoing conservation project, Shiawassee National Wildlife Refuge (SNWR) and the Detroit Zoological Society (DZS) started a Blanding's Turtle Headstarting program. Juvenile Blanding's Turtles were headstarted until they were eighteen months old. Starting June, 2014, Thermochron iButton data loggers were epoxied to the carapaces eight headstarted Blanding's Turtles before being released within the refuge to record carapace temperatures and basking behaviors over eighteen months. In addition, Thermochron iButtons were used to record water temperature at varying water depths from substrate to surface in the wetland where turtles were released. Data from 2014 and 2015 were analyzed and show the preferred temperature ranges and basking tendencies of juvenile headstarted Blanding's Turtles throughout active and inactive seasons. Active season carapace temperatures were above mean water temperatures and inactive season carapace temperatures were below average water temperatures. Juvenile headstarted Blanding's Turtles were shown to use basking as a thermoregulation behavior. This study provides information on thermoregulation patterns for this understudied age class to aid in future conservation and management efforts.

Introduction

Blanding's Turtles, *Emydoidea blandingii* (Holbrook, 1838), are freshwater turtles with a range spanning across Northeast and Midwest North America. They are a species of special concern in the state of Michigan, where this study took place, and are listed as threatened or endangered throughout most of their geographic range, excluding Nebraska where their population is listed as stable. Ectotherms, such as reptiles, with northern ranges face the challenge of thermoregulation where temperatures vary greatly over the course of a year, and when temperatures are below preferred ranges for four to six month periods at a time (Nutting & Graham, 1993). Many studies researching thermoregulation in Blanding's Turtles have focused on field studies of adults or laboratory studies of hatchlings (Packard et al., 1999; Dinkelacker et al., 2004; Innes et al., 2008; Edge et al., 2009; Newton & Herman, 2009; Millar & Blouin-Demers, 2011; Millar et al., 2012; Paterson et al., 2014).

Turtle body temperatures have been shown to be correlated with their environment (Ernst, 1972). Field studies on adult Painted Turtles (*Chrysemys picta*) have shown that they have a mean optimal activity temperature of 20.5 °C, with an activity range of 8.0 to 26.5 °C (Ernst, 1972). Similarly studies show that Wood Turtles (*Glyptemys insculpta*) have a mean optimal activity temperature of 21.0 °C, with an activity range of 7.5 to 30.0 °C (Ernst, 1986). Adult Blanding's Turtles showed a difference in mean preferred temperature between the sexes; during laboratory testing males had a mean preferred temperature of 22.5 $\pm$ 0.19 °C and females had a mean preferred temperature of 24.8 $\pm$ 0.19 °C. Preferred temperature ranges were 14.6 to 29.2 °C and 18.7 to 31.9 °C respectively (Nutting & Graham, 1993). The Blanding's Turtle mean preferred temperatures were the lowest of five species (*Pseudemys rubriventris, Clemmys insculpta, Graptemys geographica, Trachemys scripta elegans* & *Emydoidea blandingii*) studied in the lab (Nutting & Graham, 1993), but still higher than previous field studies on Painted Turtles (Ernst, 1972) which have a range further north than the Blanding's Turtle.

The biological rhythms of turtles can be impacted by several environmental factors. Painted Turtles have shown cyclical daily temperature patterns (Rowe et al., 2013) and have different wintering habitats based on dissolved oxygen in the environment (Rollinson et al., 2008). Edge et al. (2009) found that adult Blanding's Turtles did not select overwintering locations based on dissolved oxygen but instead selected sites by balancing freezing and predation risks as all overwintering areas were low in measured dissolved oxygen and Blanding's Turtles were anoxia tolerant.

Blanding's Turtles have been shown to have physiological and behavioral adaptations to survive prolonged dormancy through the inactive months by thermoregulating to depress metabolic processes and save energy (Ultsch, 2006; Edge et al., 2009). Blanding's Turtles show communal overwintering and fidelity to sites (Edge et al., 2009, Newton & Herman, 2009) similar to Spotted Turtles (*Clemmys guttata*; Rasmussen & Litzgus, 2010). Edge et al. (2009) found at least 10 cm of free water between ice and substrate in all Blanding's Turtle overwintering locations. Over 90% of Blanding's Turtles show less than 5 meters in distance movements during the inactive season with an additional 7% only moving 5 to 15 meters (Newton & Herman, 2009). Greaves & Litzgus (2007) only showed 8% of adults moving greater than 5 meters during the inactive months. Laboratory studies show that hatchling Blanding's Turtles can survive temperatures of -2.0 °C for up to 48 hours (Packard et al., 1999), -4.0 °C for 7 days, or -8.0 °C for 1 hour (Dinkelacker et al., 2004). One juvenile turtle in Innes et al. (2008) overwintered earlier than adults and individual adults overwintered up to 6 months in a single location.

The active season for adult Blanding's Turtles measured in Ontario and Nova Scotia have begun when movements were greater than 25 meters away from hibernacula; this began in March and April with the best predictors of emergence being temperature and ice melt (Edge et al., 2009, Newton & Herman, 2009). Millar et al. (2012) and Edge et al. (2009) described basking as any time the turtle temperature was above the water surface temperature. Grayson & Dorcas (2004) calculated basking as the highest temperature that could not be due to a change in location in the water column for a basking event. Adult turtle basking events occurred in greater numbers in June, with a slow decline throughout the rest of the months until overwintering began again (Millar et al., 2012). Ernst found that Wood Turtles, Bog Turtles (*Glyptemys muhlenbergii*), and Spotted Turtles spent 13.7 %, 37.4 %, and 36.3 % of their time respectively during the active season basking (Ernst 1986, 1977, & 1982). No studies were found describing basking behaviors of hatchling or juvenile Blanding's Turtles.

Since thermoregulation is an important factor that affects many physiological processes in turtles (Packard et al., 1999; Dinkelacker et al., 2004; Innes et al., 2008; Edge et al., 2009; Newton & Herman, 2009; Millar & Blouin-Demers, 2011; Millar et al., 2012; Paterson et al., 2014), understanding thermoregulatory and basking behaviors in Blanding's Turtles will fill an important knowledge gap in their biology. One of the objectives of this study was to describe thermoregulation during the active and inactive seasons, and basking behaviors of juvenile Blanding's Turtles in SNWR. External temperature data loggers mounted to the carapace have been shown to be an effective method for studying thermoregulation patterns in turtles (Angilletta & Krochmal, 2003). Thus to achieve our objective temperature data loggers were used to gather temperatures of the juvenile headstarted Blanding's Turtle carapace and water column temperatures in the study area. By comparing carapace and water temperatures, basking events for these juvenile turtles can be described.

Methods

Study site: This study took place at Shiawassee National Wildlife Refuge (SNWR), Saginaw, MI, U.S.A. The SNWR is a 3,885 hectare wetland complex that is a part of the national wildlife refuge system (Figure 1.1). The wetlands and marshes within the refuge are managed with conservation of all native habitat types and native species in mind. Species that reside in the refuge include many wading birds that use the refuge as a migration stop over or summer residence e.g. (Great blue heron, *Ardea herodias*), mammals e.g. (Raccoons, *Procyon lotor*), amphibians e.g. (Leopard Frogs, *Lithobates pipiens*), and many types of reptiles including the Blanding's Turtle.

Study organism: To increase the Blanding's Turtle population within Shiawassee National Wildlife Refuge, the Detroit Zoological Society (DZS) and SNWR have implemented a headstarting program. Beginning in 2010, adult female Blanding's Turtles were found at SNWR each year from May to June while traversing terrestrial habitats, collected, and palpitated. Gravid females are transported to the DZS and x-rayed to identify and count eggs. Egg laying is hormonally induced and these adult females are then released where they were originally collected in SNWR. These Blanding's Turtle eggs are incubated and once they hatch, they are raised in captivity at the DZS for approximately eighteen months until zoo staff deem them ready for release. Zoo staff selected twenty-four turtles who were ready for release to be a part of this study. Veterinarians with the DZS implanted passive integrated transponder (PIT) tags via injection near the right rear leg and each turtle carapace was notched with both markings used for individual identification purposes. The PIT tags measured 12 mm (115 mg, 12.5 X 2.12 mm, Biomark, 134.2-kHz International Organization for Standardization Full Duplex B). The twenty-four turtles were randomly selected to be released at four different sites along a transect in Grefe pool within SNWR (Figure 1.1).

Data collection: The beginning mass range for all juvenile headstarted Blanding's Turtles (n = 24) was 91 to 150 grams; the eight turtles (referred to as Turtle 3, 4, 6, 15, 18, 19, 20, and 21) with the greatest mass were chosen to have iButtons attached. During June 2014, Thermochron iButtons (3.3 g, iButtonLink, LLC., Whitewater, WI) were attached externally using Devcon clear coat epoxy – 2 ton (ITW Polymers Adhesives North America, Danvers, MA) and PC Marine hand moldable all-purpose epoxy putty (Protective Coating Company, Allentown, PA) to eight out of twenty-four juvenile headstarted Blanding's Turtles which are part of a larger study investigating movements and habitat use. The thermochron iButtons recorded carapace temperature every 84 minutes from June, 2014 to September, 2014 and April, 2015 to September, 2015 (active seasons) and every 174 minutes from September, 2014 to April 2015 (inactive season). In addition to iButtons, these eight individuals were fitted with R1680 radio transmitters (3.6 g, Advanced Telemetry Systems, Isanti, MN) which were attached to the carapace of the headstarted Blanding's Turtles with the same two aforementioned epoxies. The total mass of iButtons, transmitters, and epoxies were <10 % turtles body weight. Turtles were recaptured in fall 2014, spring 2015, and fall 2015 in order to replace and/or remove iButtons as necessary.

To measure environmental water temperature iButtons were placed from the water surface down to the substrate (four iButtons in total) on a pole erected at the Northeast corner of Grefe pool in SNWR in July 2014. To measure temperatures inside a muskrat den, iButtons were placed from the water surface down to the substrate (four iButtons in total) on a pole erected in the center of a muskrat den in June. To determine basking temperature, the largest temperature shift that could not be a result from turtle movement within water was used (Grayson & Dorcas, 2004); this was surface temperature plus 5.5 °C in 2014 and plus 7.0 °C in 2015. Analyses and results are split between active season, April thru September, and inactive season, October thru March; these dates were chosen due to the decrease in measured movements during this time frame (Figure 1.2) and correlate with similar activity time frames as found in previous research on adult Blanding's Turtles.

Results

Data were collected on eight turtles for a total of 27,423 carapace temperature measurements. Daily average movement of juvenile Blading's Turtles decreased when surface water temperatures decreased below substrate surface temperatures (inactive; Figure 1.2). Movement increased again when surface water temperatures increased above substrate temperatures (active; Figure 1.2). These movement patterns were used to determine inactive to active seasons.

All eight iButtons were recovered from the 2014 active season, six iButtons were recovered from the inactive season, and seven iButtons were recovered from the 2015 active season. Mean active season carapace temperatures ranged from 19.6 to 22.1 °C with the minimum observed temperature being 5.5 °C and the maximum being 47.0 °C (Table 1.1). Carapace temperatures correlated with environmental temperatures. Basking was calculated for turtles in Grefe pool where the water column temperatures were known, this was five turtles in 2014 and four turtles in 2015. Turtle 21 had the most basking events and had one of the largest temperature ranges (Figure 1.3 & 1.4). Number of observed basking events were significantly different between June, July, and August in 2014 and April, May, June, July, August, and

September in 2015 (2014: χ^2 value = 14.82, df = 2, N = 5, $p < 0.05$; 2015: χ^2 value = 251.46 df = 5, N = 4, $p < 0.05$; Table 2.2). The number of juvenile headstarted Blanding's Turtle recorded basking events were 320 in 2014 and 794 in 2015. The frequency of witnessed basking events that researchers observed while tracking the juvenile headstarted Blanding's Turtles was 5.6% (Figure 1.9). Differences in mean carapace temperature per month from June 2014 – September 2014 and April 2015 – September 2015 were not found to be significant ($p > 0.05$, $F_{(7, 67)} = 1.13$; Figure 1.3 & 1.4). A one-way ANOVA compared the temperatures of water in emergent vegetation to temperatures of water inside of a muskrat den, recorded from June 2015 to October 2015 (Figure 1.5). A significant difference was found ($p < 0.05$, $F_{(1, 13132)} = 2019.815$). Habitat analysis has shown that these turtles use muskrat dens in greater proportion than any other available habitat (Szymanski, Chapter 3, unpublished data). Observed mean preferred temperature of juveniles was 21.0 °C during the active seasons (Figure 1.6).

Mean carapace temperatures ranged from -0.5 to 4.5 °C with the minimum observed temperature being -0.5 °C and the maximum being 10.0 °C (Figure 1.7) during the inactive season. Mean carapace temperature for November 2014, December 2014, January 2015, February 2015, and March 2015 were 3.8 °C, 1.6 °C , 0.9 °C , 0.3 °C , and 0.7 °C, respectively. Mean carapace temperatures were lower than mean water temperatures with lowest temperatures in February (Figure 1.7). All turtles were found alive after the inactive season in spring 2015 (Szymanski, Chapter 2, unpublished data).

Discussion

Mean carapace temperatures of Blanding's Turtles during the active season were above the mean water temperature. The average preferred temperature of juveniles (21.0 °C) during the active season was lower than that observed in adult males (22.5 °C) and adult females (24.8 °C) but was within the preferred body range measured by Nutting & Graham (1993). This study used the method from Grayson & Dorcas (2004) to calculate basking events which accounted for movements within the water column throughout all seasons. Basking events recorded for juvenile Blanding's Turtles show that this age class does use basking as a behavioral mechanism for thermoregulation similar to adult Blanding's Turtles (Edge et al., 2009; Millar et al., 2012). This suggests that captive-reared turtles in headstarting programs behave like wild-hatched turtles after release. The large increase in basking events in 2015 could be partially accounted for due to more months of temperature recordings than in 2014. Additionally turtles bask more in the spring months because water temperatures are still cooler and have not warmed up to peak summer temperatures, which were measured in 2015 but not 2014. Basking events were significantly different per month each year.

During the inactive season the mean carapace temperatures were below the mean water temperatures. Mean carapace temperature from November – March of overwintering juveniles (1.5 °C) was higher than that observed in overwintering adults (0 °C) in Brooks et al. (2009) (Figure 1.8). The lowest carapace temperature recorded was -0.5 °C which was above temperatures affecting survival in laboratory studies (Packard et al., 1999; Dinkelacker et al., 2004). All of the juvenile headstarted Blanding's Turtles survived the first inactive season. This is important considering they had no previous hibernation in captivity for eighteen months and shows that headstarting does not negatively affect their ability to hibernate.

Thermoregulation patterns in juvenile Blanding's Turtles seem to be similar to studies on adult Blanding's Turtles. The significant difference in muskrat den temperature compared to water temperature may indicate that the dens are used as thermoregulation sites within emergent wetlands. The gender of these juvenile Blanding's Turtles are unknown due to the fact that secondary sex characteristics do not show until sexual maturity. Therefore, this study could not compare differences in thermoregulation between genders. Future studies could use genetics to determine gender at hatching and look to see if differences between genders occur in juveniles as they do in adult Blanding's Turtles or if thermoregulation differences appear at the same time as secondary sex characteristics. Additionally, studies could see if other differences can be observed between juvenile Blanding's Turtles that were wild-hatched and those that were headstarted. Future research may benefit from looking at inactive season thermoregulation temperatures over multiple seasons and until sexual maturity to see if any patterns emerge since Blanding's Turtles use overwintering sites for mating (Newton & Herman, 2009).

References

Angilletta, M.J. & Krochmal, A.R. (2003). The Thermochron: A Truly Miniature and Inexpensive Temperature-logger. *Herpetological Review* 34:31–32.

Brooks, R. J., Edge, C. B., Litzgus, J. D., & Steinberg, B. D. (2009). Temperature and site selection by Blanding's Turtles (*Emydoidea blandingii*) during hibernation near the species' northern range limit. *Canadian Journal of Zoology*, 87, 825+.

Dinkelacker, S. A., Costanzo, J. P., Iverson, J. B., & Lee, R. E.,Jr. (2004). Cold-hardiness and dehydration resistance of hatchling Blanding's Turtles (*Emydoidea blandingii*): Implications for overwintering in a terrestrial habitat. *Canadian Journal of Zoology*, 82(4), 594-600.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2009). Temperature and site selection by Blandings Turtles (*Emydoidea blandingii*) during hibernation near the species northern range limit. *Canadian Journal of Zoology*, *87*(9), 825-825.

Ernst, C. H. (1972). Temperature-activity relationship in the painted turtle, *Chrysemys picta*. *Copeia*, 1972(2), 217-222.

Ernst, C. H. (1977). Biological notes on the bog turtle, *Clemmys muhlenbergii*. *Herpetologica*, 33:241-246.

Ernst, C. H. (1982). Environmental temperatures and activities in wild spotted turtles, *Clemmys guttata*. *Journal of Herpetology*, 16:112-120.

Ernst, C. H. (1986). Environmental temperatures and activities in the wood turtle, *Clemmys insculpta*. *Journal of Herpetology*, 20(2), 222-229.

Grayson, K.L. & Dorcas, M.E. (2004). Seasonal Temperature Variation in the Painted Turtle (*Chrysemys picta*). *Herpetologica*, 60(3):325-336.

Greaves, W. F., & Litzgus, J. D. (2007). Overwintering ecology of wood turtles (*Glyptemys insculpta*) at the species' northern range limit. *Journal of Herpetology*, 41(1), 32-40.

Holbrook, J.E. (1838). North American Herpetology; or, a Description of the Reptiles Inhabiting the United States. Ed. 1, Vol. 3. Philadelphia: J. Dobson, 122 pp.

Innes, R. J., Babbitt, K. J., & Kanter, J. J. (2008). Home range and movement of Blanding's Turtles (*Emydoidea blandingii*) in New Hampshire. *Northeastern Naturalist*, 15(3), 431-444.

Millar, C. S. & Blouin-Demers, G. (2011). Spatial ecology and seasonal activity of Blanding's Turtles (*Emydoidea blandingii*) in Ontario, Canada. *Journal of Herpetology*, 45(3), 370-378.

Millar, C. S., Graham, J. P., & Blouin-Demers, G. (2012). The effects of sex and season on patterns of thermoregulation in Blanding's Turtles (*Emydoidea blandingii*) in Ontario, Canada. *Chelonian Conservation and Biology,* 11(1), 24-32.

Newton, E. J., & Herman, T. B. (2009). Habitat, movements, and behavior of overwintering Blanding's Turtles (*Emydoidea blandingii*) in Nova Scotia. *Canadian Journal of Zoology*, 87(4), 299-299.

Nutting, W.L. & Graham, T.E. 1993. Preferred Body Temperatures in Five Nearctic Freshwater Turtles: A Preliminary Study. *Comp. Biochem. Physiol,* Vol. 104A (2): 243-246.

Packard, G. C., Packard, M. J., Lang, J. W., & Tucker, J. K. (1999). Tolerance for freezing in hatchling turtles. *Journal of Herpetology*, 33(4), 536.

Paterson, J. E., Steinberg, B. D., & Litzgus, J. D. (2014). Effects of body size, habitat selection and exposure on hatchling turtle survival. *Journal of Zoology*, 294(4), 278-285.

Rasmussen, M. L., & Litzgus, J. D. (2010). Habitat selection and movement patterns of spotted turtles (*clemmys guttata*): Effects of spatial and temporal scales of analyses. *Copeia, 2010*(1), 86-96.

Rollinson, N., Tattersall, G. J., & Brooks, R. J. (2008). Overwintering habitats of a northern population of painted turtles (*Chrysemys picta*): Winter temperature selection and dissolved oxygen concentrations. *Journal of Herpetology*, 42(2), 312-321.

Rowe, J.W., Converse, P.E., & Clark, D.L. (2013). Daily and Annual Patterns of Thermoregulation in Painted Turtles (Chrysemys picta marginata) Living in a Thermally Variable Marsh in Northern Michigan. *Journal of Thermal Biology*.

Ultsch, G. (2006). The ecology of overwintering among turtles: Where turtles overwinter and its consequences. *Biological Reviews of the Cambridge Philosophical Society, 81*(3), 339; 339

Table 1.1: Mean, minimum, and maximum carapace temperatures for eight juvenile headstarted Blanding's Turtles from 17 June – 30 September 2014 and 4 June – 30 September 2015 in SNWR.

TURTLE	MINIMUM CARAPACE TEMPERATURE (°C)	MAXIMUM CARAPACE TEMPERATURE (°C)	MEAN CARAPACE TEMPERATURE (°C)
3	7.0	41	19.6
4	6.5	39.5	21.3
6	10.5	40.0	22.1
15	11.5	43.0	22.1
18	5.5	42.5	21.8
19	6.5	47.0	19.8
20	6.0	39.0	19.8
21	6.5	40.0	21.7

Table 1.2: Total basking events per month for juvenile headstarted Blanding's Turtles from July 2014 – September 2014 (n = 5) and April 2015 – September 2015 (n = 4) in SNWR. Differences in basking events per month were analyzed using a Chi-squared test (2014: $\chi^2 = 14.82$, df = 2, $p < 0.05$; 2015: $\chi^2 = 251.46$, df = 5, $p < 0.05$).

Basking Events						
YEAR	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**
2014	**-**	**-**	**-**	93	88	139
2015	109	195	96	235	148	111

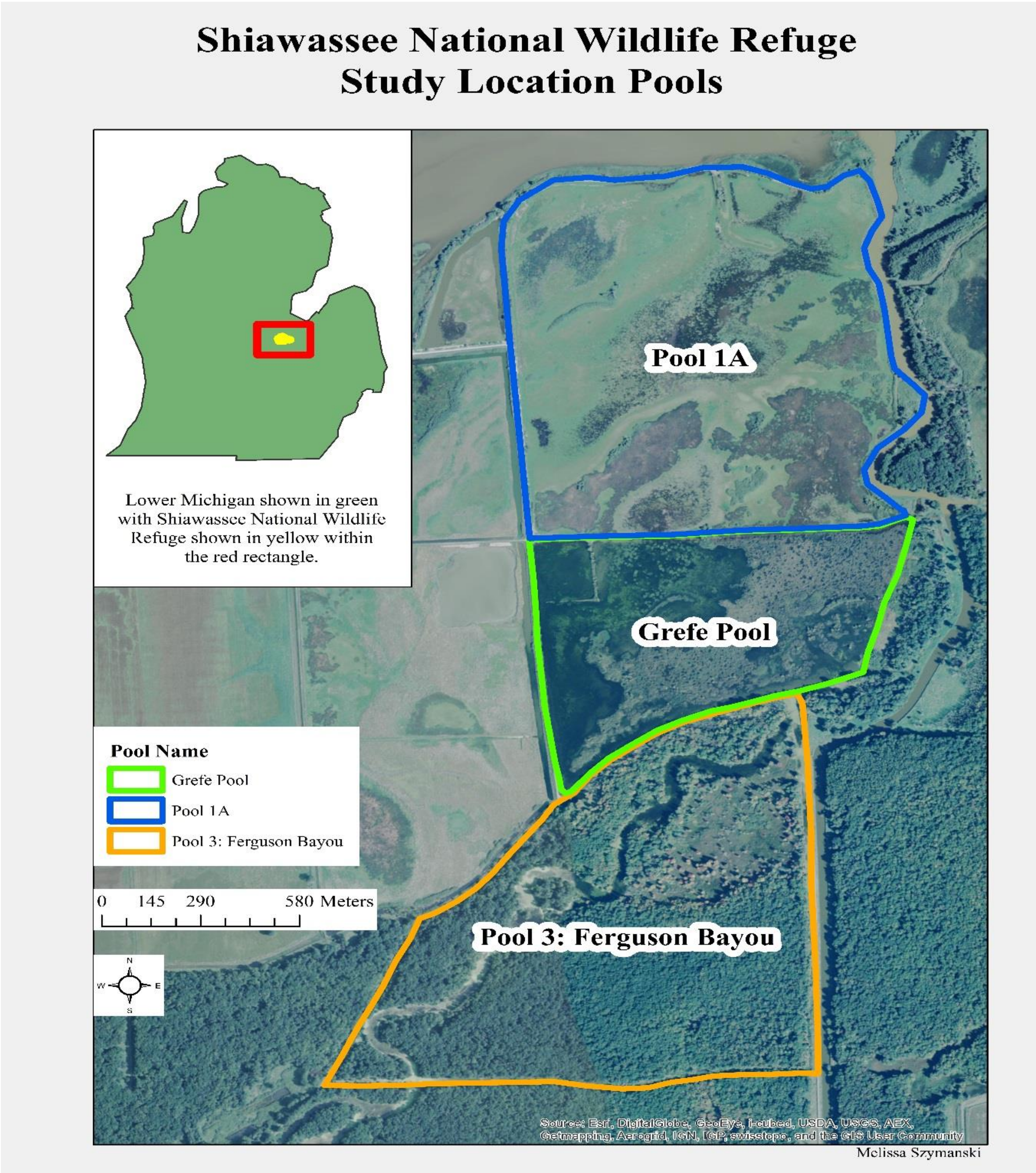

Figure 1.1: Map of study location pools within Shiawassee National Wildlife Refuge. Shiawassee National Wildlife Refuge shown in inset map in Lower Michigan within the red rectangle in yellow.

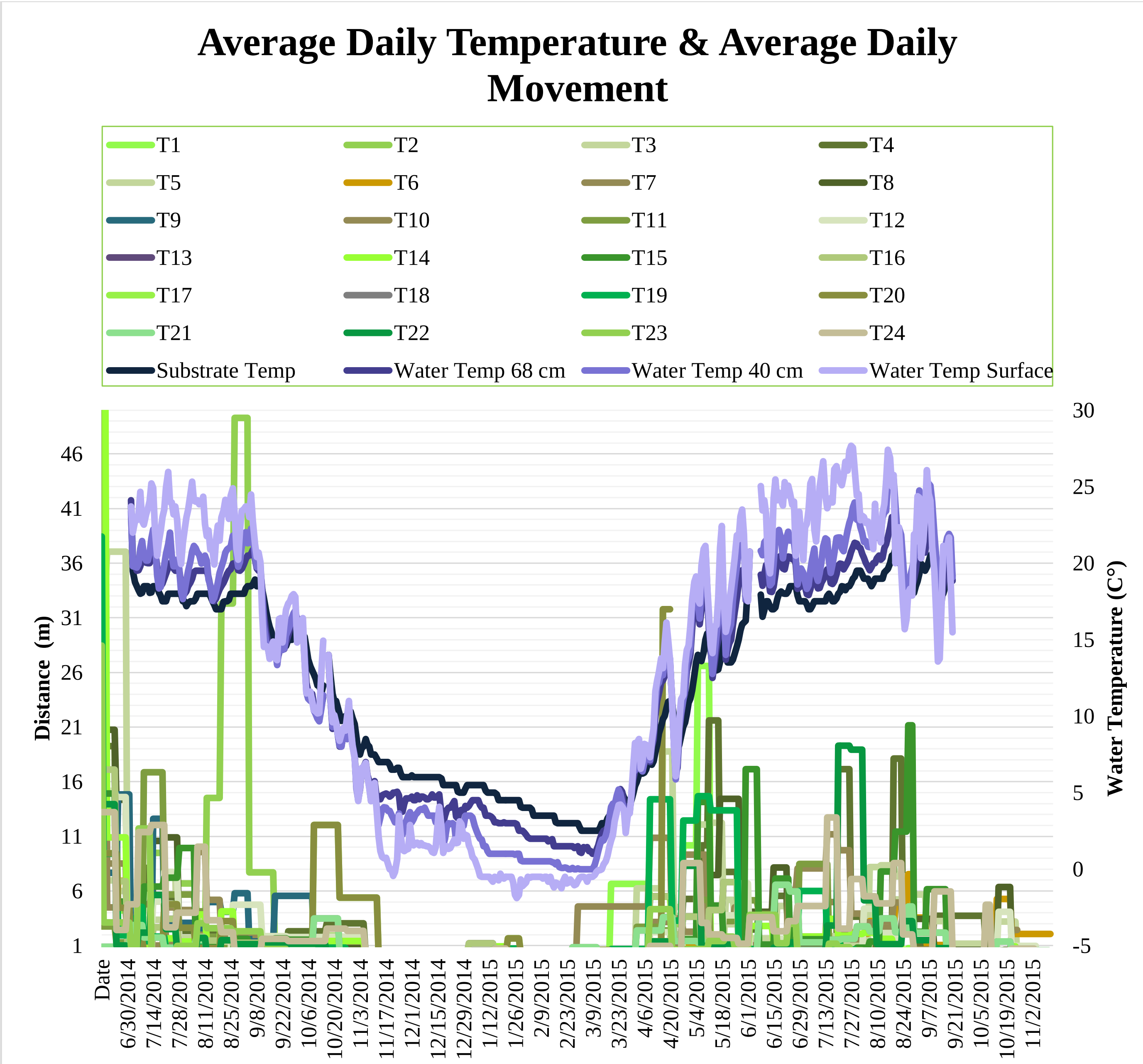

Figure 1.2: Daily average movement (meters) for 24 juvenile headstarted Blanding's Turtles (from larger study containing the eight turtles in this study) and daily average water temperatures (Celsius) from substrate to water surface in SNWR.

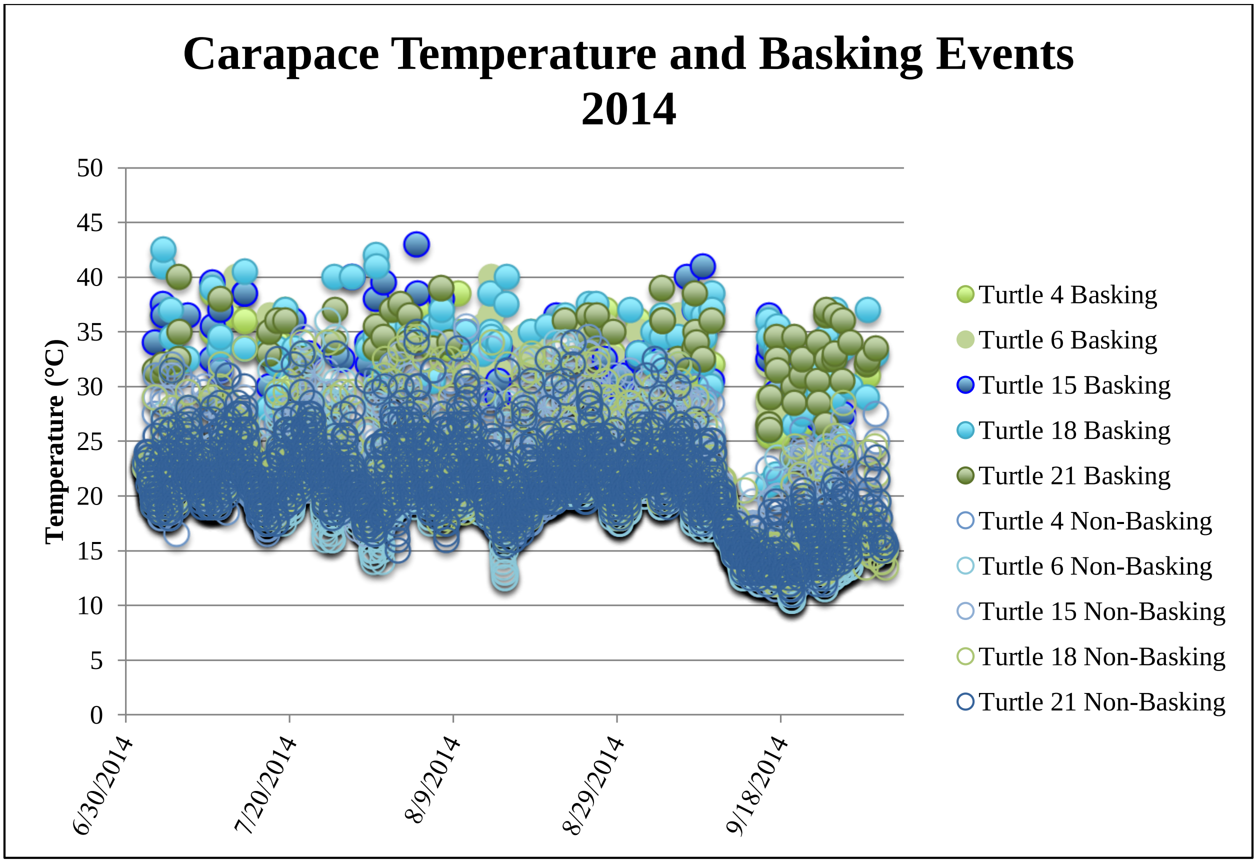

Figure 1.3: Carapace temperature and basking events for five juvenile headstarted Blanding's Turtles from 2 July – 30 September 2014 in SNWR. Basking temperature data points were carapace temperatures >5.5 °C in 2014 above the water surface temperature.

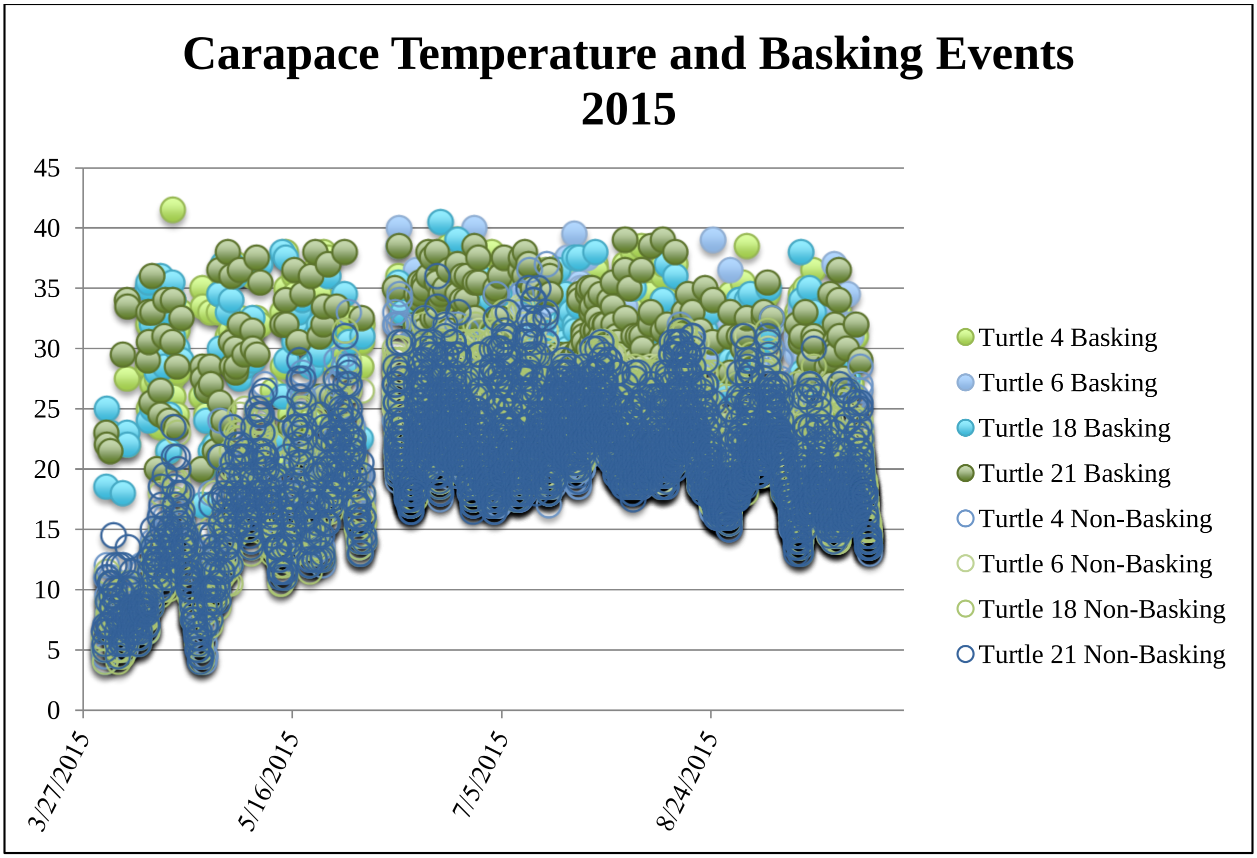

Figure 1.4: Carapace temperature and basking events for four juvenile headstarted Blanding's Turtles from 1 April – 30 September 2015. Basking temperature data points were carapace temperatures >7.0 °C in 2015 above the water surface temperature.

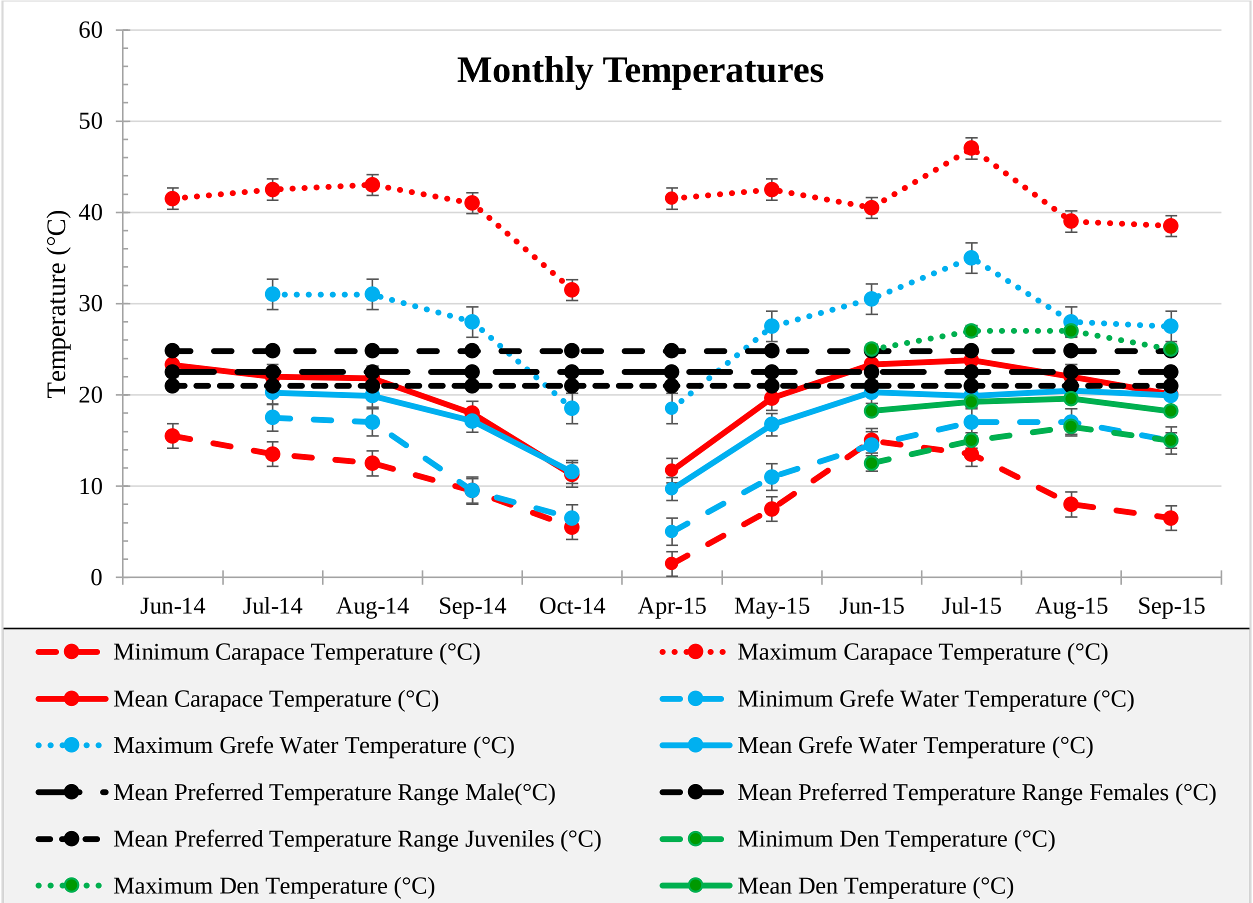

Figure 1.5: Mean, minimum, and maximum monthly (± SE) carapace temperatures for eight juvenile headstarted Blanding's Turtles from June 2014 – September 2014 and April 2015 – September 2015 in SNWR. Differences in mean carapace temperature per month were analyzed using one-way ANOVA ($p > 0.05$, $F_{(7, 67)} = 1.13$). Mean preferred temperature range of adult females and adult males from Nutting and Graham (1993) presented for comparison.

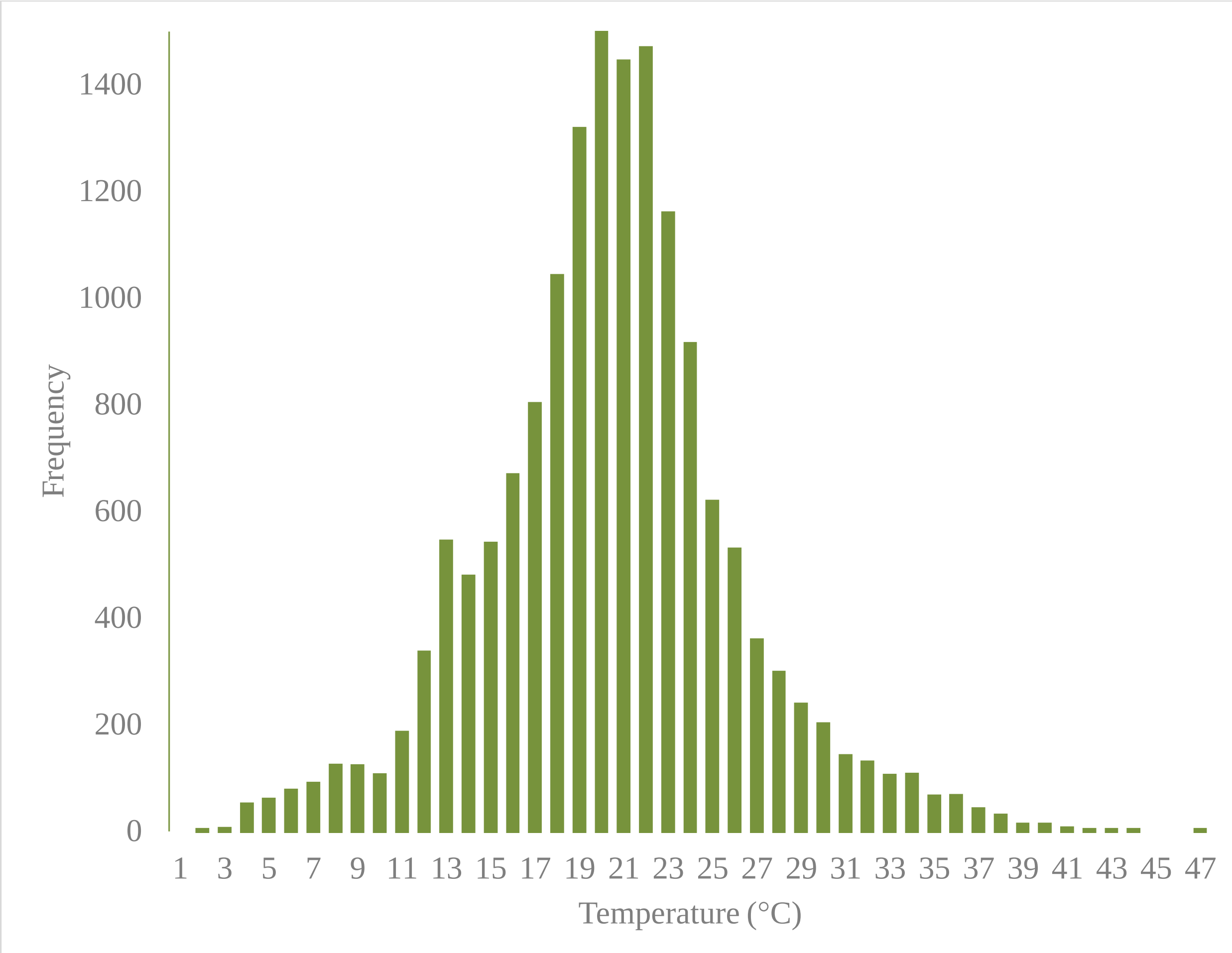

Figure 1.6: Frequency distribution of mean carapace temperature for juvenile headstarted Blanding's Turtles (n = 8) recorded daily every 84 minutes from June 2014 – September 2014 and April 2015 – September 2015 in SNWR. Mean preferred temperature of juveniles is 21.0 °C.

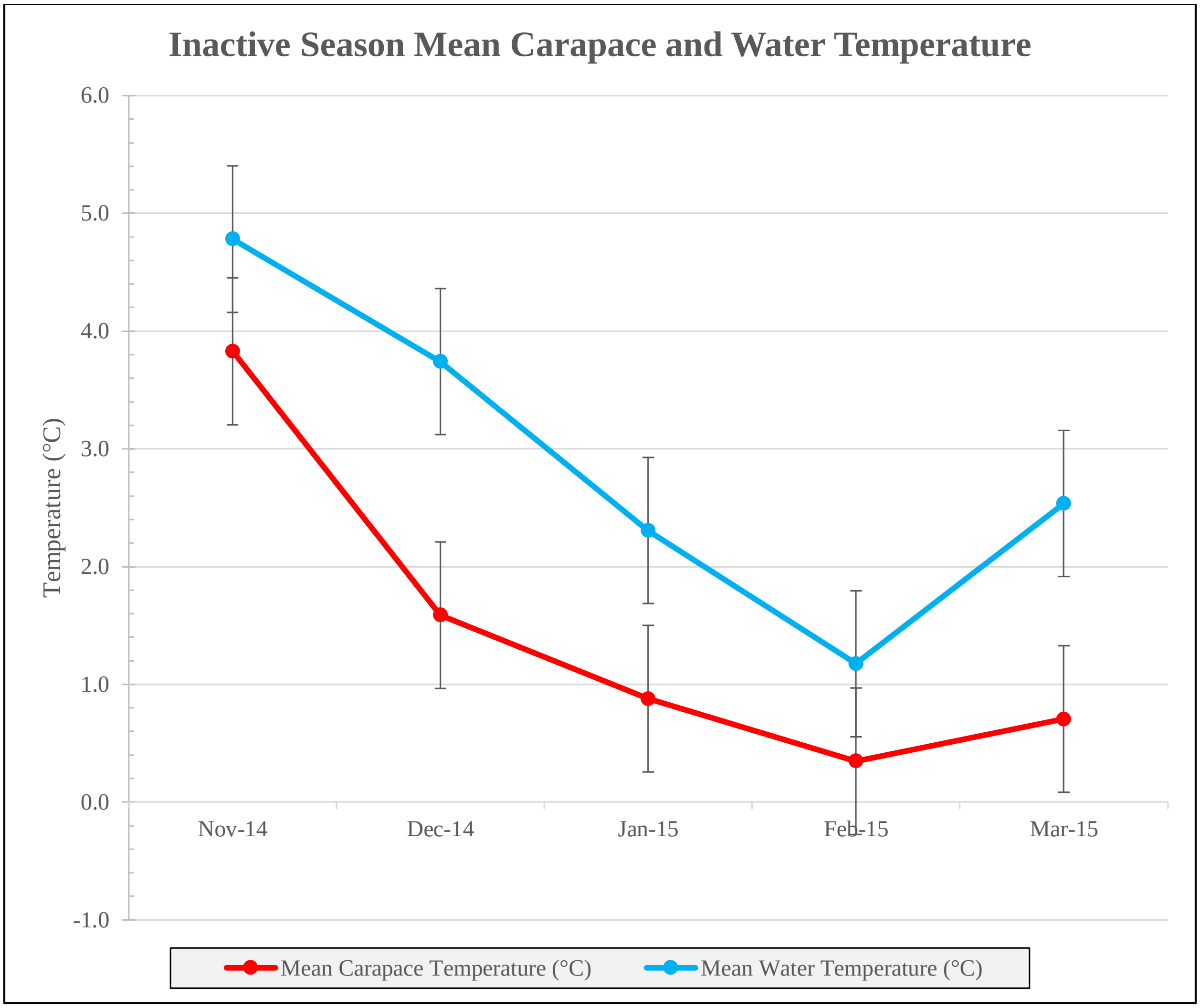

Figure 1.7: Mean carapace temperature for juvenile headstarted Blanding's Turtles (n = 6) and mean water temperature of main pool per month during inactive season, 1 November 2014 – 31 March 2015.

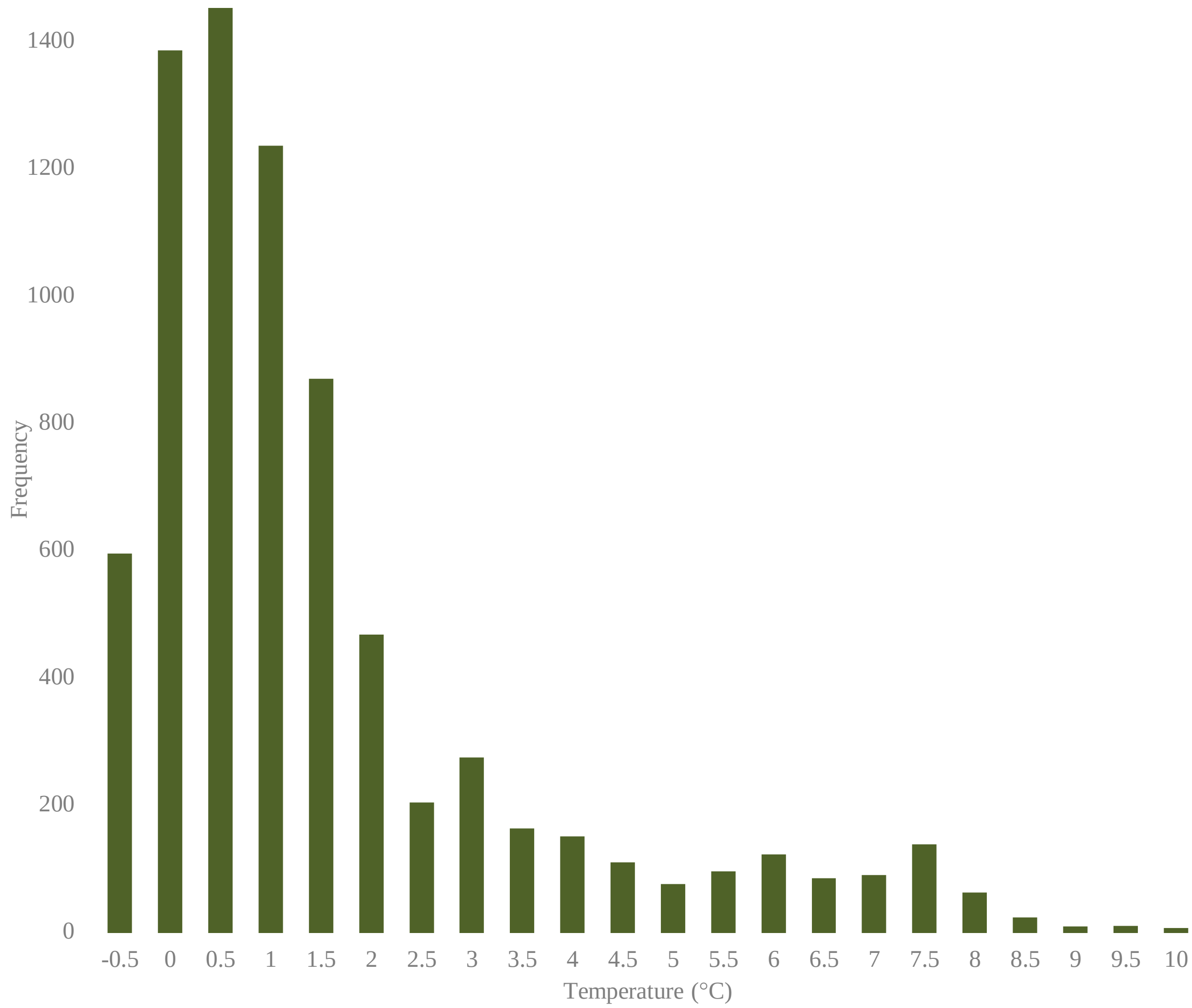

Figure 1.8: Frequency distribution of mean carapace temperature for juvenile headstarted Blanding’s Turtles (n = 6) recorded daily every 174 minutes from 1 November 2014 to 31 March 2015 in SNWR. Mean carapace temperature of juveniles is 1.5 °C, minimum -0.5 °C, maximum 10.0 °C.

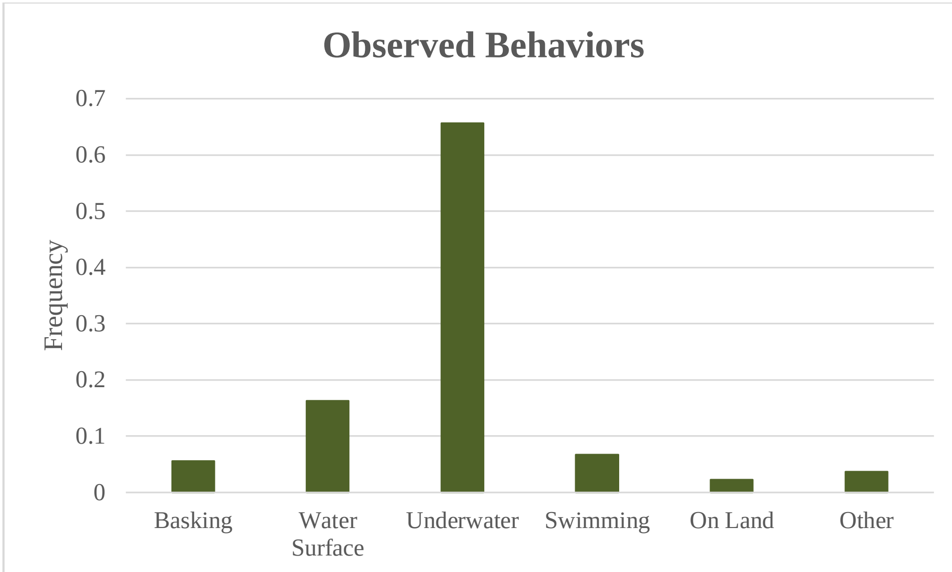

Figure 1.9: Frequency of behaviors were observed for juvenile headstarted Blanding's Turtles (n = 24) at relocation points (n = 899) during tracking. Similar patterns were found in adult Blanding's Turtles in Millar et al. 2011.

CHAPTER 2. Home Range and Movement Patterns in Headstarted Blanding's Turtles

Abstract

As a part of an ongoing conservation project with Shiawassee National Wildlife Refuge in Saginaw, MI, the Detroit Zoological Society headstarted Blanding's Turtles. One and a half year old Blanding's Turtles were fitted with radio transmitters and located weekly for eighteen months starting June 2014 and ending November 2015 following release at four different sites. Data were analyzed spatially from 2014 and 2015; straight line distance and home ranges were calculated from GPS locations of the turtles. No differences were found between distances moved between years and across release groups. Significant differences in home ranges were found across release groups but not between years. Juvenile headstarted Blanding's Turtles in this study have home range sizes similar to those measured in other studies for juvenile wild-hatched individuals, but smaller home ranges than those measured for wild-hatched adults. Future conservation and management efforts for Blanding's Turtles will benefit from information on headstarted Blanding's Turtles after release and on movement patterns for this understudied age class.

Introduction

Blanding's Turtles, *Emydoidea blandingii* (Holbrook, 1838), are freshwater turtles with a range spanning across Northeast and Midwest North America. They are a species of special concern in the state of Michigan, where this study took place, and are listed as threatened or endangered throughout most of their geographic range, excluding Nebraska where their population is listed as stable. Life history traits of the Blanding's Turtle such as delayed sexual maturity, low annual fecundity, and long life spans make conservation efforts difficult (Congdon et al., 2011). Several studies documenting the movements and home ranges of Blanding's Turtles have been done across their geographic range on adults (Congdon et al., 1993; Hamernick, 2000; Piepgras & Lang, 2000; Grgurovic & Sievert, 2005; Kasuga, 2007; Innes et al., 2008; Schuler & Thiel, 2008; Edge et al., 2010; Millar & Blouin-Demers, 2011; Fortin et al., 2012; AnthonySamy et al., 2013), with fewer documenting juvenile spatial patterns (Piepgras & Lang, 2000; Bury, 2003; Kasuga, 2007; Innes et al., 2008; Pappas et al., 2009; Anthonysamy et al., 2013). Population studies have had difficulty locating juveniles; those that do find them find the population is skewed towards large, older adults (Ruane et al., 2008).

Blanding's Turtles use a variety of wetland types that differ in preference across their range and habitat availability (Markle & Chow-Fraser, 2014). These variations could be the reason for the variations in movements and home ranges seen across studies. Adult Blanding's Turtles have minimum convex polygon (MCP) home ranges ranging from 1.5 hectares (Innes et al., 2008) to 94.9 hectares (Hamernick, 2000). Juveniles, which are measured less often and with smaller sample sizes, have been shown to have MCP home ranges of 1.27 hectares (Kasuga, 2007) to 12.8 hectares (Piepgras & Lang, 2000). Anthonysamy et al. (2014) found little movement of Blanding's Turtles between study sites for mating adults.

Some characteristics of Blanding's Turtles are that they have feeding patterns that increase in early morning and evening (Rowe & Moll, 1991). Roads create barriers for the turtles with limited movement of individuals across them (Proulx et al., 2014). Road mortality causes lower annual survivorship in adults (Raune et al., 2008). Multiple paternity has been recorded to occur in 41.6% (McGuire et al. 2013) to 81% of Blanding's Turtle clutches (Refsnider, 2009), which combined with the fact that juveniles do not always return to parents' resident wetland increases gene flow to populations (McGuire et al., 2013).

There is a lack of information on the juvenile age class for Blanding's Turtles (Pappas & Brecke, 1992). Congdon et al. (1993) reported a lack of recruitment in Blanding's Turtle populations in Michigan. Hatchlings will emerge in the fall and overwinter in water (Carroll & Ultsch, 2007). Pappas et al. (2009) measured a nonrandom dispersal of hatchlings from nests towards dark horizons. Juveniles were found to move early and late during active season and overall less than adults. Additionally four out of six of the juveniles studied by Piepgas & Lang (2000) never moved between wetlands. The mean daily distance moved by juveniles has been measured at 7.3 to 19.2 meters (Anthonysamy et al., 2013). The greatest risk to survivability over the life time of a Blanding's Turtle is at the egg/nest/hatchling stage. There may be different and competing selective pressures at these different stages (Paterson et al., 2014). This is why headstarting programs have been implemented to bolster populations of juveniles and circumvent the high predation rates that some turtle nests and hatchlings experience.

Analyzing the use of space can help determine potential success of headstarting programs (Mignet, 2014). For headstarting programs to work older juveniles and adults must be protected by protecting wetlands and terrestrial habitats from human caused habitat loss and degradation (Congdon et al., 1993; Heppel et al., 1996, Refsnider & Linck, 2012). Headstarts have a higher survival rate due to larger body size from accelerated growth in captivity (Haegen et al., 2009). Wild-born hatchlings had a higher survival rate when they were smaller. This may be due to hatching later and thus having less time exposed to the environment and potential predators (Paterson et al., 2014). The objective of this study was to analyze space use of juvenile headstarted Blanding's Turtles. To that end, straight line movements and MCP home ranges were calculated and analyses looked for patterns across age classes and release sites.

Methods

Study site: This study took place at Shiawassee National Wildlife Refuge (SNWR), Saginaw, MI, U.S.A. The SNWR is a 3,885 hectare wetland complex that is a part of the national wildlife refuge system and contains managed pools for wildlife (Figure 2.3). The wetlands and marshes within the refuge are managed with conservation of all native habitat types and native species in mind. Species that reside in the refuge include many wading birds that use the refuge as a migration stop over or summer residence e.g. (Great blue heron, *Ardea herodias*), mammals e.g. (Raccoons, *Procyon lotor*), amphibians e.g. (Leopard Frogs, *Lithobates pipiens*), and many types of reptiles including the Blanding's Turtle.

Study organism: To increase the Blanding's Turtle population within Shiawassee National Wildlife Refuge, the Detroit Zoological Society (DZS) and SNWR have implemented a headstarting program. Beginning in 2010, adult female Blanding's Turtles were found at SNWR each year from May to June while traversing terrestrial habitats, collected, and palpitated. Gravid females are transported to the DZS and x-rayed to identify and count eggs. Egg laying is hormonally induced and these adult females are then released where they were originally collected in SNWR. These Blanding's Turtle eggs are incubated and once they hatch, they are raised in captivity at the DZS for approximately eighteen months until zoo staff deem them ready for release. Sex of the headstarted Blanding's Turtles is unknown as secondary sexual characteristics do not develop until sexual maturity approximately 14-20 years of age. Zoo staff selected twenty-four turtles who were ready for release to be a part of this study. Veterinarians with the DZS implanted passive integrated transponder (PIT) tags via injection near the right rear leg and each turtle carapace was notched with both markings used for individual identification purposes. The PIT tags measured 12 mm (115 mg, 12.5 X 2.12 mm, Biomark, 134.2-kHz International Organization for Standardization Full Duplex B). The twenty-four turtles were randomly selected to be released at four different sites along a transect in Grefe pool within SNWR (Figure 2.3).

Data collection: The beginning mass range for all juvenile headstarted Blanding's Turtles (n = 24) were 91 to 150 grams, the eight turtles with the greatest mass were chosen to have iButtons attached. During June 2014, twenty-four juvenile headstarted Blanding's Turtles were fitted with R1680 radio transmitters (3.6 g, Advanced Telemetry Systems, Isanti, MN) which were attached to the carapace externally using Devcon clear coat epoxy – 2 ton (ITW Polymers Adhesives North America, Danvers, MA) and PC Marine hand moldable all-purpose epoxy putty (Protective Coating Company, Allentown, PA). In addition, eight out of the twenty-four juvenile headstarted Blanding's Turtles were fitted with Thermochron iButtons (3.3 g, iButtonLink, LLC., Whitewater, WI) with the same two previously mentioned epoxies for a study on thermoregulation (Szymanski, Chapter 1, unpublished data). The total mass of transmitters, iButtons, and epoxies were <10 % turtles body weight.

Turtles were randomly selected to be released at four different sites along a transect through Grefe pool within SNWR (Figure 2.3). Six turtles were released at each site. Each release site was in different microhabitat conditions: site 1 was in open water, site 2 was in sparse cattails with duckweed, site 3 was in willows with duckweed, and site 4 was in dense cattails. Turtles were tracked approximately once per week during the active seasons (May thru September) and twice per week during the inactive season (October thru April) to measure survivorship and record information about their immediate microhabitat conditions (detailed below). Tracking began in June 2014 and continued through November 2015, spanning eighteen months. Turtles were recaptured in fall 2014, spring 2015, and fall 2015 in order to remove and replace the transmitters and/or iButtons when necessary.

Each week when a turtle was located a 1-meter square floating plot was placed at each location with the turtle approximately in the center and the following items were recorded: water depth, ice thickness (when applicable), substrate depth; water and air temperature, above water vegetation type and dominance, and GPS coordinates using a Trimble field computer (GeoExplorer 6000 series, Trimble Navigation Limited, Sunnyvale, CA). Data were put into a database and entered into GIS software Arcmap (version 10.3, Environmental Systems Research Institute, Redlands, CA.). Additional statistics were performed in SPSS (IBM SPSS version 22.0.0.0, International Business Machines Corp. Armonk, NY).

Survival was monitored during tracking by monitoring turtle movements; if an individual had not moved between more than three tracking events then the turtle was located by hand and visually assessed to check if mortality had occurred. Survival and movements were compared between the first tracking season in 2014 and second tracking season in 2015. Analyses, which are described in detail below, compared release groups to assess release location effects on movement patterns and home ranges.

Movement patterns: Juvenile headstarted Blanding's Turtle locations were recorded and entered into GIS software Arcmap (version 10.3, Environmental Systems Research Institute, Redlands, CA.). Straight line distances were calculated between each point by sequential order to calculate the distances moved by each turtle between relocations. Average daily movement patterns were calculated by dividing the number of days between each tracking and relocation event. While this is an underestimation of movement, it has been found to be a viable way to compare distances moved between animals in previous studies (Millspargh & Marzluff, 2002; Millar et al., 2011; Jaegar et al., 2012; Anthonysamy et al., 2013). Mixed-design ANOVAs were used to check for significant differences in straight line distances between age classes and release groups. Straight line measurements were also taken from release site to the mean center of each turtle home range.

Home range analysis: GIS software Arcmap (version 10.3, Environmental Systems Research Institute, Redlands, CA.) was used to analyze juvenile Blanding's Turtle location data. X,Y coordinates were imported into ArcMap and MCP home ranges were calculated. While recent methods like Brownian bridges or Local Convex Hull (LoCoH) take into account time and space while computing animal home ranges, and are reported to be more accurate at representing animals space use (Horne et al., 2007, Getz et al., 2007), the data collected in this study were collected weekly and did not fit the criteria and assumptions for those methods which required less time between relocations. Several studies on Blanding's Turtles have reported home ranges using the MCP method (Table 2.1; Hamernick, 2000; Piepgras & Lang, 2000; Grgurovic & Sievert, 2005; Kasuga et al., 2007; Innes et al., 2008; Schuler & Thiel, 2008; Edge et al., 2010; Millar & Blouin-Demers, 2011; Fortin et al., 2012; & Anthonysamy et al., 2013) and thus to be comparable the MCP method was used. Additionally Row & Blouin-Demers (2006) found kernel home ranges to be unreliable home range estimators for herpetofauna due to the overestimation of area and subjectivity in selecting a smoothing factor. Mixed-design ANOVAs were used to check for significant differences in home range area between age classes and release groups. Time in years was the within subject factor and the four release groups were the between subject factors.

Results

In total, 899 data points were collected on 24 juvenile headstarted Blanding's Turtles. All 24 turtles survived the first winter and were found surviving through spring 2015. The overall survival of the juvenile headstarted Blanding's Turtles released in SNWR was 96% best-case survival and 63% worst-case survival (Table 2.2). Best case estimate makes the assumption that every turtle except for the one that was confirmed dead has survived and those who were not located simply lost their transmitters with their scutes that shed in the spring/summer the year after release. The worst case survival estimate makes the assumption that all the turtles that lost transmitters and that researchers lost contact with are all deceased and that only turtles that were tracked until the end of the research are still alive. The true survivability of the headstarted Blanding's Turtles is likely somewhere between the best-case and worst-case survival estimates. During the 2015 tracking season researchers were unable to locate eight turtles; five turtle transmitters were found shed with scutes, researchers lost signals for two turtle transmitters, and one transmitter signal stopped moving under a muskrat den due to either turtle mortality or shedding of the transmitter. One confirmed death occurred during the study to a turtle who was caught in a drought situation. The turtle carapace and transmitter were found with mammal teeth marks, presumed to be raccoon due to scat nearby. All twenty-four turtles were tracked 310 days; the remaining 15 turtles were tracked the entire length of the study which was 515 days.

Movement patterns: The total mean straight line movement for the headstarted Blanding's Turtles over the course of the study was 1005.01 meters (standard deviation [SD] = 511.56). The mean straight line movements for 2014 was 476.43 meters (SD=279.98) and for 2015 was 512.96 meters (SD=368.26). A mixed-design ANOVA was calculated comparing straight line distance for turtles first year (2014) and second year (2015) shown in Figure 2.1 and comparing straight line distances between release groups. The main effect for year was not significant ($p > 0.50$, $F_{(1, 40)} = 0.009$). The main effect of release group on straight line movements was not significant ($p > 0.05$, $F_{(3, 20)} = 2.091$). Additionally the interaction between year and release group showed no statistical difference in straight line movement by turtles ($p > 0.05$, $F_{(3, 20)} = 0.211$).

The distance from release site to mean center home range was 184.81 meters (SD = 129.60; Table 2.3). A one-way ANOVA was used to investigate differences between release groups and the calculated mean center of each turtle home range. No significant differences were found across release groups ($p > 0.05$, $F_{(3, 20)} = 2.540$). Mean Center home ranges are shown and color coded to release group in Figure 2.4.

Home range analysis: The total mean MCP home range area for the juvenile headstarted Blanding's Turtles over the course of the study was 2.80 hectares (SD= 0.95) (Figure 2.5). The mean home range for 2014 was 0.97 hectares (SD = 2.42) and for 2015 was 1.23 hectares (SD = 2.12). A mixed-design ANOVA was used to compare each turtles home range area to first year (2014) and second year (2015) shown in Figure 2.2 and between release groups. The main effect for year was not significant ($p > 0.05$, $F_{(1, 20)} = 0.174$). The main effect for release group on home range area was significant ($p < 0.05$, $F_{(3, 20)} = 3.59$). Turtles from release group 1 had larger home range area (mean = 2.86 ha, SD = 3.87) than turtles in release group 4 (mean = 0.43, SD = 0.56). Turtles in release group 2 (mean = 0.61, SD = 1.32) and release group 3 (mean = 0.51, SD = 0.37) were not significantly different from any other group. The interaction was not significant ($p > 0.05$, $F_{(3, 20)} = 0.181$); the effect of release group on home range area was not influenced by the year.

Discussion

Blanding's Turtles have been studied across their geographic range yet little is known about the juvenile age class. The lack of juveniles found at SNWR has led to the management decision to join with the DZS and implement the headstart program for these turtles as they are a species of special concern in Michigan and threatened or endangered throughout most of their range. The survivorship of these 24 headstarted Blanding's Turtles was measured at 100% the first year and between 63 to 96% after the second active season. Congdon et al. (1993) determined that a population of Blanding's Turtles in Michigan had a cohort generation time of 37 years and that a survivorship greater than 70% for juveniles ages 1-13 years is needed for Blanding's Turtle populations to be stable. The survival estimates for the juvenile headstarted Blanding's Turtles in this study may very well be above the threshold described by Congdon et al. (1993) if at least two of the juvenile headstarted Blanding's Turtles that I lost signals for survived. The individual that was found dead from predation had moved a pool away from the release pool into a section of forested wetlands with ephemeral pools during a spring flooding event. Once the pool the turtle became established in dried, his remains and chewed transmitter were found the next week, leaving me to believe that the drought situation left the turtle more vulnerable to detection and predation. The greater the environmental exposure outside of water, similar to conditions for this turtle, was the cause for mortality in turtles from Paterson et al. (2014). Two additional turtles were last seen in drought conditions. One was next to a main pool with 30+ cm of water but the other was in a wooded lowland so this turtle has the possibility of being left vulnerable too. All other turtles with lost signals or transmitters were in main pools with plenty of vegetation and water which leaves me to believe that they were still alive when the transmitters were shed with scutes.

Straight line distances between relocations of individual turtles were used to look at movement patterns. The juvenile headstarted Blanding's Turtles in this study moved an average of 1005.01 meters total between relocations for the duration of the study. As stated before this is an underestimation of actual movements. Turtles did not move differently between their first and second active seasons. Turtles were released at four different release sites with no statistical differences, so conditions at SNWR may be ideal for the headstarted turtles and the variations observed in microhabitats were not enough to warrant one group of turtles to move any further than another. Adult Blanding's Turtles have been found to use a variety of wetland types according to different seasonal needs (Beaudry et al., 2009). Edge et al. (2010) found that preferred habitats could not be determined in a pristine landscape when no habitat type is limited. A wide variety of movement distances were seen in the turtles that were measured for the entire duration of the study, from a minimum of 568.8 meters and to a maximum of 2972.3 meters. The mean center for each home range was calculated (Figure 2.3 & 2.4) to analyze if turtles home ranges varied in distance away from the release sites. Turtle distances from release site to mean center home range were not statistically different across groups. This shows that for the first eighteen months after release there are no differences in home range distance away from the release sites per group which I believe shows the importance of release locations for headstarted turtles; turtles will remain near where they are released.

Home ranges were calculated using the minimum convex polygon method. The MCP home ranges measured for the headstarted Blanding's Turtles showed no significant difference between age classes (years) but they did show a statistical difference for release groups. Release group 1 had the largest mean group home range at 2.86 ha and release group 4 had the smallest mean group home range at 0.43 ha. I believe the differences in these home range sizes are due to microhabitat differences discussed in chapter 3. The mean MCP home range was 2.80 hectares. A table was constructed similar to Millar et al. (2011) to show the comparison of mean home range size for Blanding's Turtles from scientific literature; the table displays differences in home ranges of wild caught adults and juveniles compared to the juvenile headstarted Blanding's Turtles in this study (Table 2.1). The juvenile headstarted Blanding's Turtles in this study had similar home range sizes compared to juveniles from other studies. My study also provides the largest sample size for measuring juvenile Blanding's Turtle home ranges to date. The juvenile Blanding's Turtle home ranges in Table 2.1 are smaller on average than adult Blanding's Turtles in the comparative previous studies.

Trapping and by catch attempts at SNWR have produced no wild juveniles (M. D. Szymanski, unpublished data). I believe that thus far the beginning of the headstart program at SNWR has been a success but further monitoring and population studies are warranted. The first release of headstarts in 2012 suffered a loss of greater than 50% with 25% mortality within 2 weeks after release from raccoon predation (Angela Cleary, personal communication, University of Michigan – Flint). By changing release locations, survivability went up and can add to the known wild adult population (27 Blanding's Turtles) at SNWR. Studies have shown that where there are healthy populations of Blanding's Turtles (Valentine National Wildlife Refuge, Nebraska), a balanced percentage of males, females and juveniles can be caught (Bury et al., 2003). Straight line movements between years and release groups did not vary statistically. MCP home ranges did vary statistically between release groups but not years. This difference shows the importance of releasing headstarted turtles in appropriate microhabitats. Compared to wild-hatched juvenile Blanding's Turtles these headstarted Blanding's Turtles show a similar average home range size eighteen months after release (Table 2.1).

References

Anthonysamy, W. J. B., Dreslik, M. J., Douglas, M. R., Marioni, N. K., & Phillips, C. A. (2014). Reproductive ecology of an endangered turtle in a fragmented landscape. *Copeia,* (3), 437-446.

AnthonySamy, W. J. B., Dreslik, M. J., & Phillips, C. A. (2013). Disruptive influences of drought on the activity of a freshwater turtle. *The American Midland Naturalist, 169*(2), 322-335.

Beaudry, F., DeMaynadier, P. G., & Hunter, M. L.,Jr. (2009). Seasonally dynamic habitat use by Spotted (*Clemmys guttata*) and Blanding's turtles (*Emydoidea blandingii*) in Maine. *Journal of Herpetology, 43*(4), 636-645.

Bury, R. B., & Germano, D. J. (2003). Differences in habitat use by Blanding's turtles, *Emydoidea blandingii*, and painted turtles, *Chysemys picta*, in the Nebraska Sandhills. *American Midland Naturalist, 149*(1), 241-244.

Carroll, D. M., & Ultsch, G. R. (2007). Emergence season and survival in the nest of hatchling turtles in southcentral New Hampshire. *Northeastern Naturalist, 14*(2), 307-310.

Congdon, J., Dunham, A. & Sels, R. (1993). Delayed sexual maturity and demographics of Blanding turtles (*Emydoidea-blandingii*) - implications for conservation and management of long-lived organisms. *Conservation Biology, 7*(4), 826-833.

Congdon, J. D., Kinney, O. M., & Nagle, R. D. (2011). Spatial ecology and core-area protection of Blanding's turtle (*Emydoidea blandingii*). *Canadian Journal of Zoology, 89*, 1098+.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2010). Habitat selection by Blanding's turtles (*Emydoidea blandingii*) in a relatively pristine landscape1. *Écoscience, 17*(1), 90-99.

Fortin, G., Blouin-Demers, G., & Dubois, Y. (2012). Landscape composition weakly affects home range size in Blanding's turtles (*Emydoidea blandingii*)1. *Écoscience, 19*(3), 191-197.

Getz, W. M., Fortmann-Roe, S., Cross, P. C., Lyons, A. J., Ryan, S. J., & Wilmers, C. C. (2007). LoCoH: Nonparameteric kernel methods for constructing home ranges and utilization distributions. *Plos One, 2*(2), e207.

Grgurovic, M., & Sievert, P. R. (2005). Movement patterns of Blanding's turtles (*Emydoidea blandingii*) in the suburban landscape of eastern Massachusetts. *Urban Ecosystems, 8*(2), 203-213.

Haegen, W. M. V., Clark, S. L., Perillo, K. M., Anderson, D. P., & Allen, H. L. (2009). Survival and causes of mortality of head-started western pond turtles on pierce national wildlife refuge, Washington. *Journal of Wildlife Management, 73*(8), 1402-1406.

Hamernick, M. G. (2000). Home ranges and habitat selection of Blanding's turtles (Emydoidea blandingii) at the Weaver Dunes, Minnesota. Final report submitted to the Nongame Wildlife Program, Minnesota Department of Natural Resources

Heppell, S. S., Crowder, L. B., & Crouse, D. T. (1996). Models to evaluate headstarting as a management tool for long-lived turtles. *Ecological Applications, 6*(2), 556-565.

Holbrook, J.E. (1838). North American Herpetology; or, a Description of the Reptiles Inhabiting the United States. Ed. 1, Vol. 3. Philadelphia: J. Dobson, 122 pp.

Horne, J. S., Garton, E. O., Krone, S. M., & Lewis, J. S. (2007). Analyzing animal movements using brownian bridges. *Ecology, 88*(9), 2354-2363. doi:10.1890/06-0957.1

Innes, R. J., Babbitt, K. J., & Kanter, J. J. (2008). Home range and movement of Blanding's turtles (*Emydoidea blandingii*) in New Hampshire. *Northeastern Naturalist, 15*(3), 431-444.

Jaeger, C. P., & Cobb, V. A. (2012). Comparative spatial ecologies of female painted turtles (*Chrysemys picta*) and red-eared sliders (*Trachemys scripta*) at Reelfoot Lake, Tennessee. *Chelonian Conservation and Biology, 11*(1), 59-67.

Kasuga, L. M. C. (2007). *Small and large-scale landscape approaches for conservation of the imperiled Blanding's turtle, Emys blandingii.* (Order No. 1447539). Available from ProQuest Dissertations & Theses A&I; ProQuest Dissertations & Theses Global. (304858308).

Markle, C. E. & Patricia Chow-Fraser. (2014). Habitat selection by the Blanding's turtle (*Emydoidea blandingii*) on a protected island in Georgian Bay, Lake Huron. *Chelonian Conservation and Biology, 13*(2), 216; 216-226; 226.

McGuire, J. M., Scribner, K. T., & Congdon, J. D. (2013). Spatial aspects of movements, mating patterns, and nest distributions influence gene flow among population subunits of Blanding's turtles (*Emydoidea blandingii*). *Conservation Genetics, 14*(5), 1029-1042.

Mignet, F., Gendre, T., Reudet, D., Malgoire, F., Cheylan, M., & Besnard, A. (2014). Short-term evaluation of the success of a reintroduction program of the European Pond turtle: The contribution of space-use modeling. *Chelonian Conservation and Biology, 13*(1), 72-80.

Millar, C. S., & Blouin-Demers, G. (2011). Spatial ecology and seasonal activity of Blanding's turtles (*Emydoidea blandingii*) in Ontario, Canada. *Journal of Herpetology, 45*(3), 370-378.

Millspaugh, J.J. & Marzluff, J.M. (2001). Radio Tracking and Animal Populations. San Diego: Academic Press, 474 pp.

Pappas, M. J., Congdon, J. D., Brecke, B. J., & Capps, J. D. (2009). Orientation and dispersal of hatchling Blanding's turtles. *Canadian Journal of Zoology, 87*(9), 755.

Pappas, M.J. & Brecke, B.J. (1992). Habitat selection of juvenile Blanding's turtles, Emydoidea blandingii. *Journal of Herpetology*, 26, pp. 233–234.

Paterson, J. E., Steinberg, B. D., & Litzgus, J. D. (2014). Effects of body size, habitat selection and exposure on hatchling turtle survival. *Journal of Zoology, 294*(4), 278-285.

Piepgras, S.A. & Lang, J.W. (2000). Spatial ecology of Blanding's turtle in central Minnesota. *Chelonian Conservation and Biology*, 3:589-601.

Proulx, C. L. 1., Fortin, G., & Blouin-Demers, G. (2014). Blanding's turtles (*Emydoidea blandingii*) avoid crossing unpaved and paved roads. *Journal of Herpetology, 48*(2), 267-271.

Refsnider, J., & Linck, M. (2012). Habitat use and movement patterns of Blanding's turtles (*Emydoidea blandingii*) in Minnesota, USA: A landscape approach to species conservation. *Herpetological Conservation and Biology*, *7*(2), 185-195.

Refsnider, J. M. (2009). High frequency of multiple paternity in Blanding's turtle (*Emys blandingii*). *Journal of Herpetology, 43*(1), 74-81.

Row, J. R., & Blouin-Demers, G. (2006). Kernels are not accurate estimators of home-range size for herpetofauna. Copeia, (4), 797-802.

Rowe, J., & Moll, E. (1991). A radiotelemetric study of activity and movements of the Blanding's turtle (*Emydoidea-blandingii*) in northeastern Illinois. *Journal of Herpetology, 25*(2), 178-185.

Ruane, S., Dinkelacker, S. A., & Iverson, J. B. (2008). Demographic and reproductive traits of Blanding's turtles, *Emydoidea blandingii*, at the western edge of the species' range. *Copeia*, (4), 771-779.

Schuler, M., & Thiel, R. (2008). Annual vs. multiple-year home range sizes of individual Blanding's turtles, *Emydoidea blandingii*, in central Wisconsin. *Canadian Field-Naturalist, 122*(1), 61-64.

Table 2.1: Mean home range size for Blanding's Turtles across studies. Adult males (M), adult non-gravid females (NGF), adult gravid females (GF) and juveniles (J) shown for comparison. Reference, study location and methods are shown. Mean home range sizes with standard error (SE) are in hectares and sample size (N) is given in parentheses. In studies that did not separate sexes and/or ages home range size is centered under all applicable columns.

Reference	Location	Method	Mean home range size (ha) SE (N)			
			M	NGF	GF	J
Anthonysamy et al. 2013b	Illinios	MCP	22.9+/-0.92 (4)	17.9+/-5.2 (9)		5.4+/-0.92 (4)
Edge et al. 2010	Ontario	MCP	57.1+/-15.3 (5)	61.2+/-30.4 (16)		-
Fortin et al. 2012	Quebec	MCP	29.7+/-32.3 (44)			
Grgurovic & Sievert, 2005	Massachusetts	95 % Fixed Kernel	27.5+/-0.10 (14)	19.9+/-0.07 (27)		-
Hamernick, 2000b	Minnesota	MCP	94.92 (8)	60.75 (16)		-
Innes et al. 2008a	New Hampshire	MCP	3.7 (4)	1.5 (3) & 6.8 (3)		3.2 (1)
Kasuga et al. 2007b	Illinios	MCP	32.96 (4) & 1.85 (1)	47.96 (9) & 6.22 (2)		1.27 (1)
Millar & Blouin-Demers, 2011	Ontario	MCP	8.5+/-1.7 (20)	7.3+/-3.2 (5)	20.3 +/- (12)	-
Piepgras & Lang, 2000	Minnesota	MCP	38.4 (6)	35.4 (13)		12.8 (6)
Schuler & Thiel, 2008	**Wisconsin**	**MCP**	**26.1 (9)**	**20.7 (9)**		**-**

a. Median values used.
b. Other methods along with MCP were used in study, such a kernel density.

Table 2.2: Survival estimates of 24 juvenile headstarted Blanding’s Turtles in SNWR eighteen months after release. Shown below with total percent for the population and for each release group.

Survival Estimates	Best Case (23)	Worst Case (15)
All Release Groups Combined	96%	63%
Release Group 1	83%	33%
Release Group 2	100%	100%
Release Group 3	100%	67%
Release Group 4	100%	50%
	1 confirmed death 23 alive	1 confirmed death 8 transmitter loss/error 15 alive

Table 2.3: A one-way ANOVA analysis ($p > 0.05$, $F_{(3, 20)} = 2.540$) shows that there is no statistical difference in distance from release point to mean center home range between release groups of juvenile headstarted Blanding's Turtles with the average total distance from release point to mean center home range being 185 meters.

Release Site	Distance (m)	Standard Deviation (m)
1	371	254
2	148	133
3	213	68
4	150	141
Mean	**185**	**130**

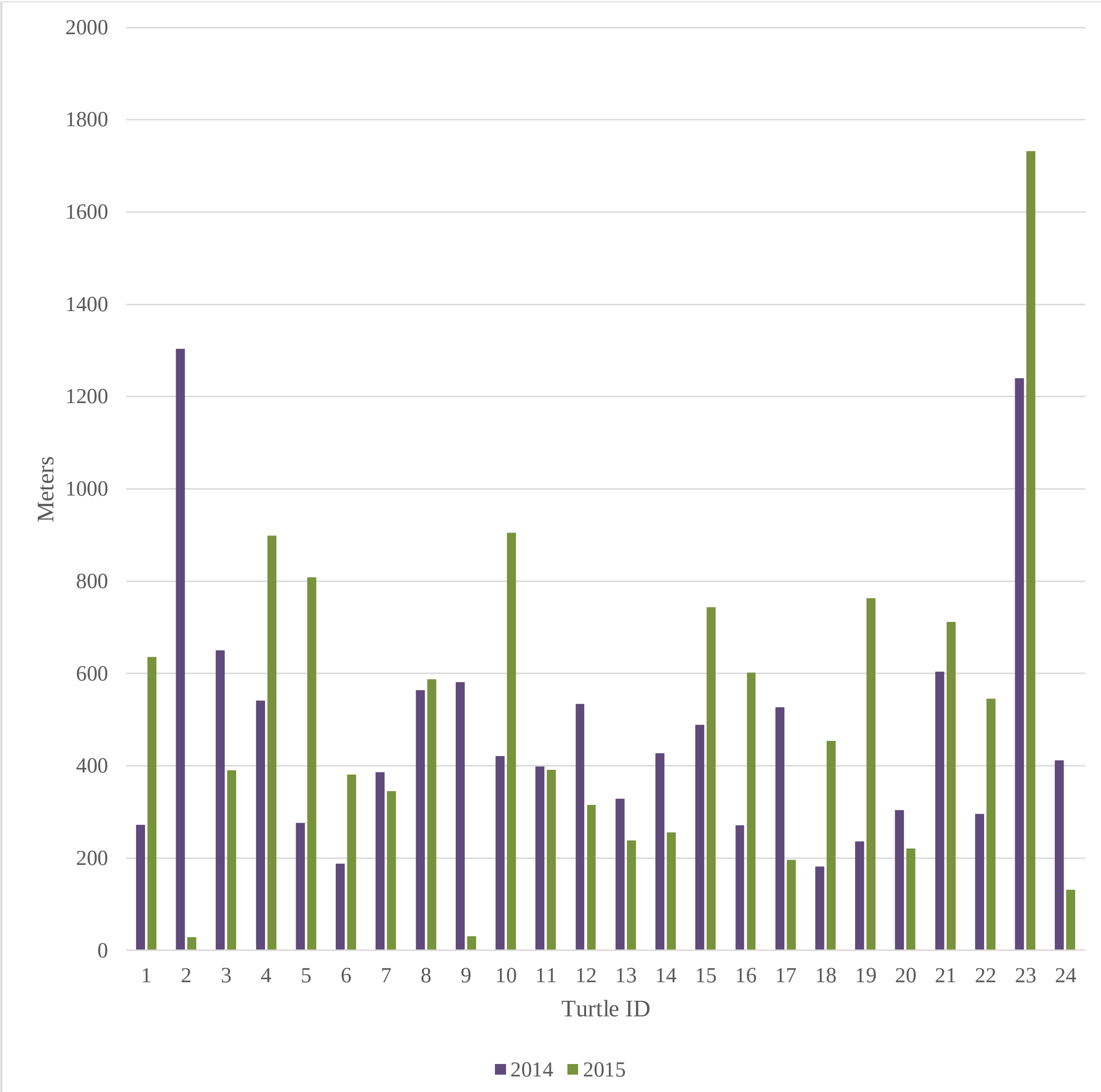

Figure 2.1: Straight line distances (meters) moved per year for each juvenile headstarted Blanding's Turtle in SNWR.

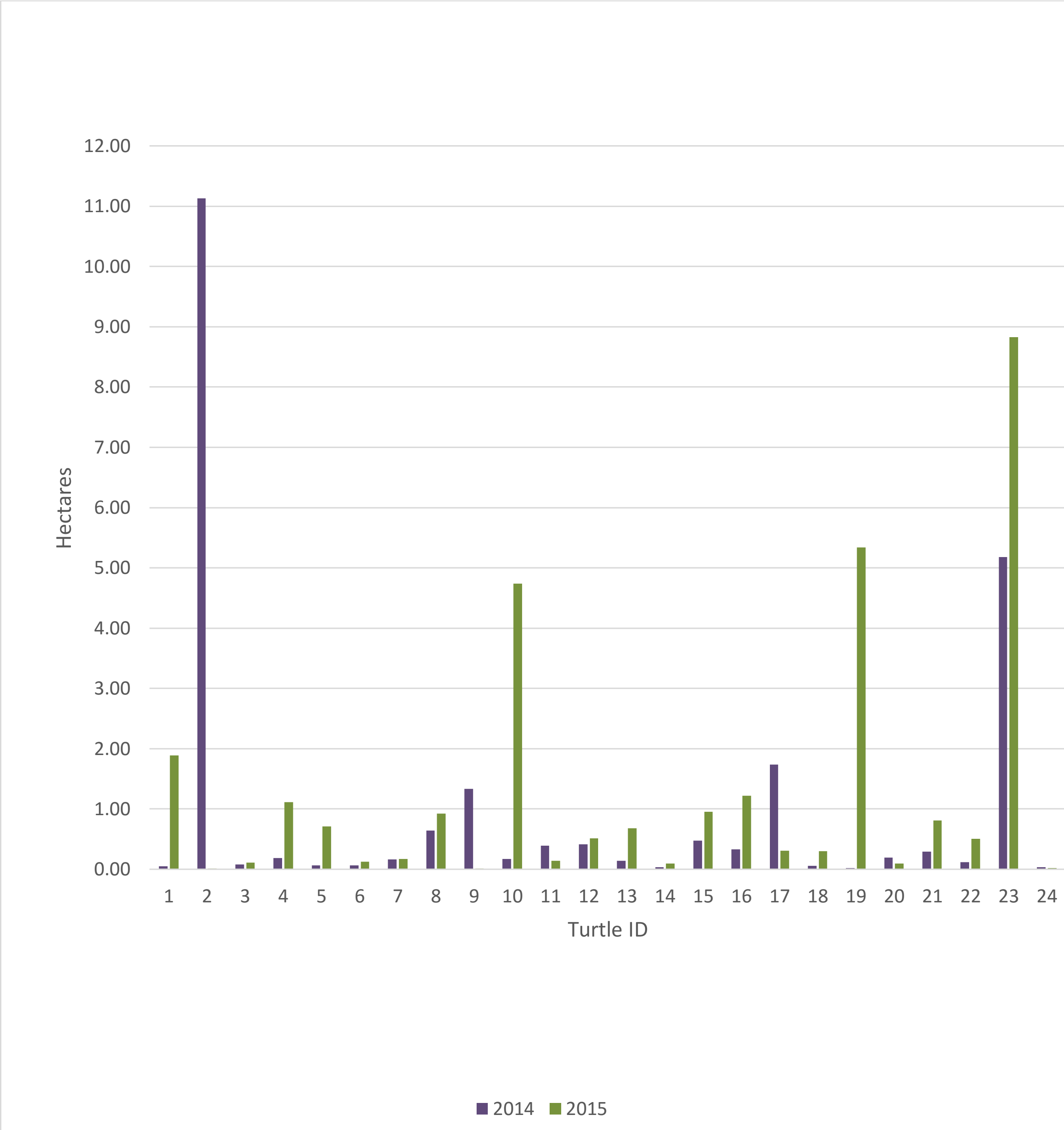

Figure 2.2: Area in hectares of home ranges per juvenile headstarted Blanding's Turtle per year in SNWR. Mean home range size 2.80 hectares.

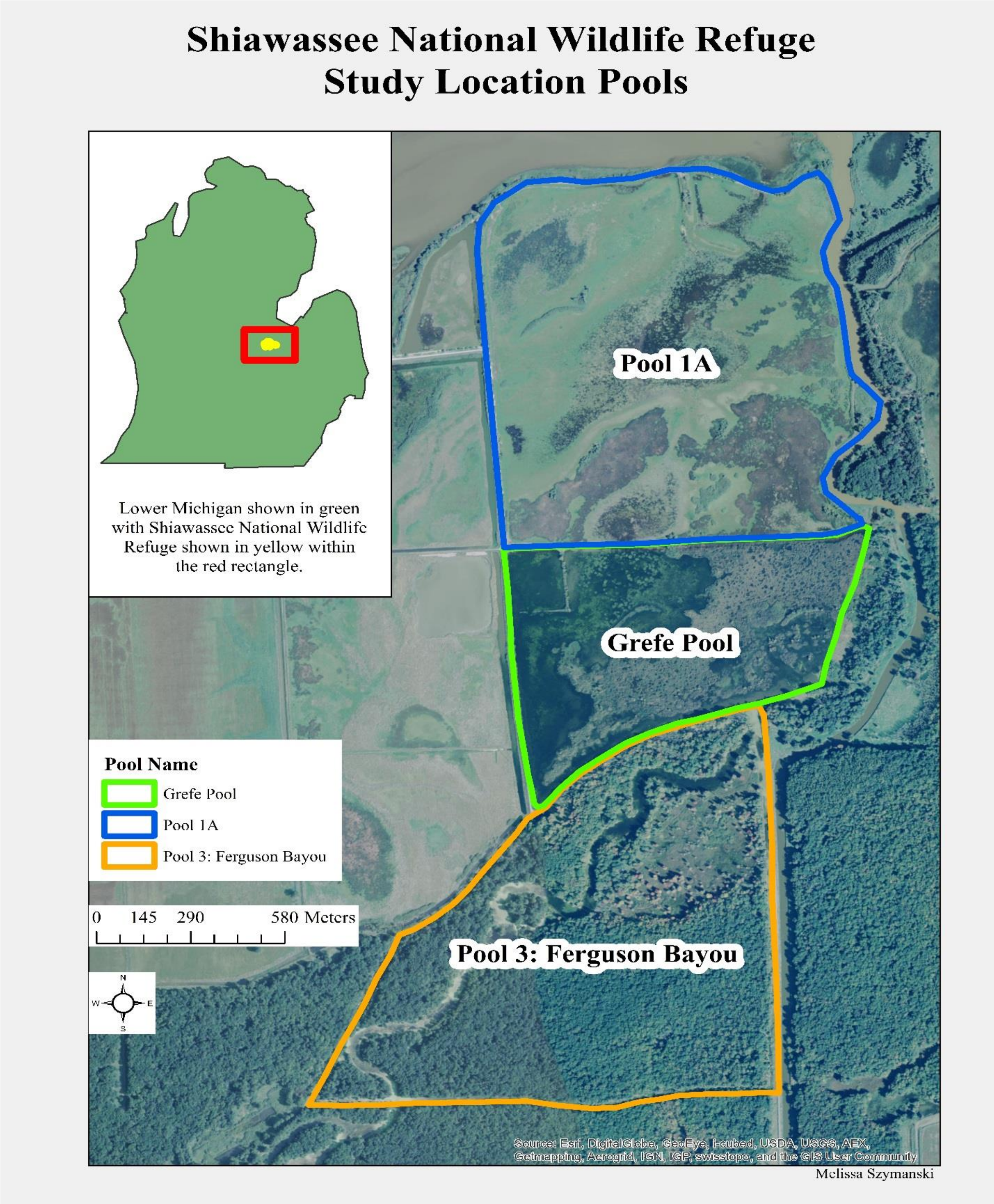

Figure 2.3: Map of study location pools within Shiawassee National Wildlife Refuge. Shiawassee National Wildlife Refuge shown in inset map in Lower Michigan in yellow within the red rectangle.

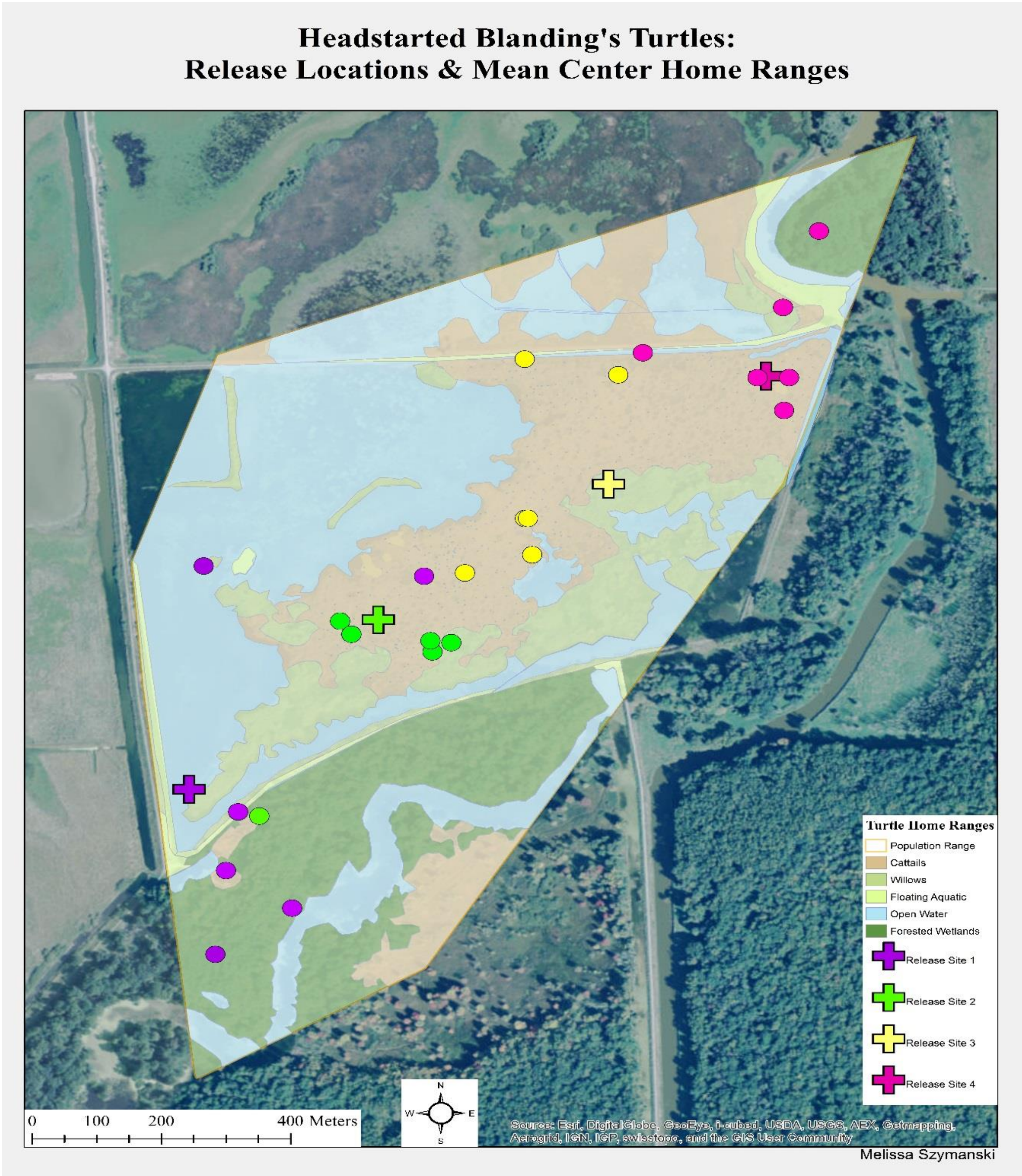

Figure 2.4: Mean center of home ranges and the release points of 24 juvenile headstarted Blanding's Turtles. Each mean center point for the home range is color coded to match the color of the release points shown as crosses. Distances were measured from the center of each home range to the corresponding the release point.

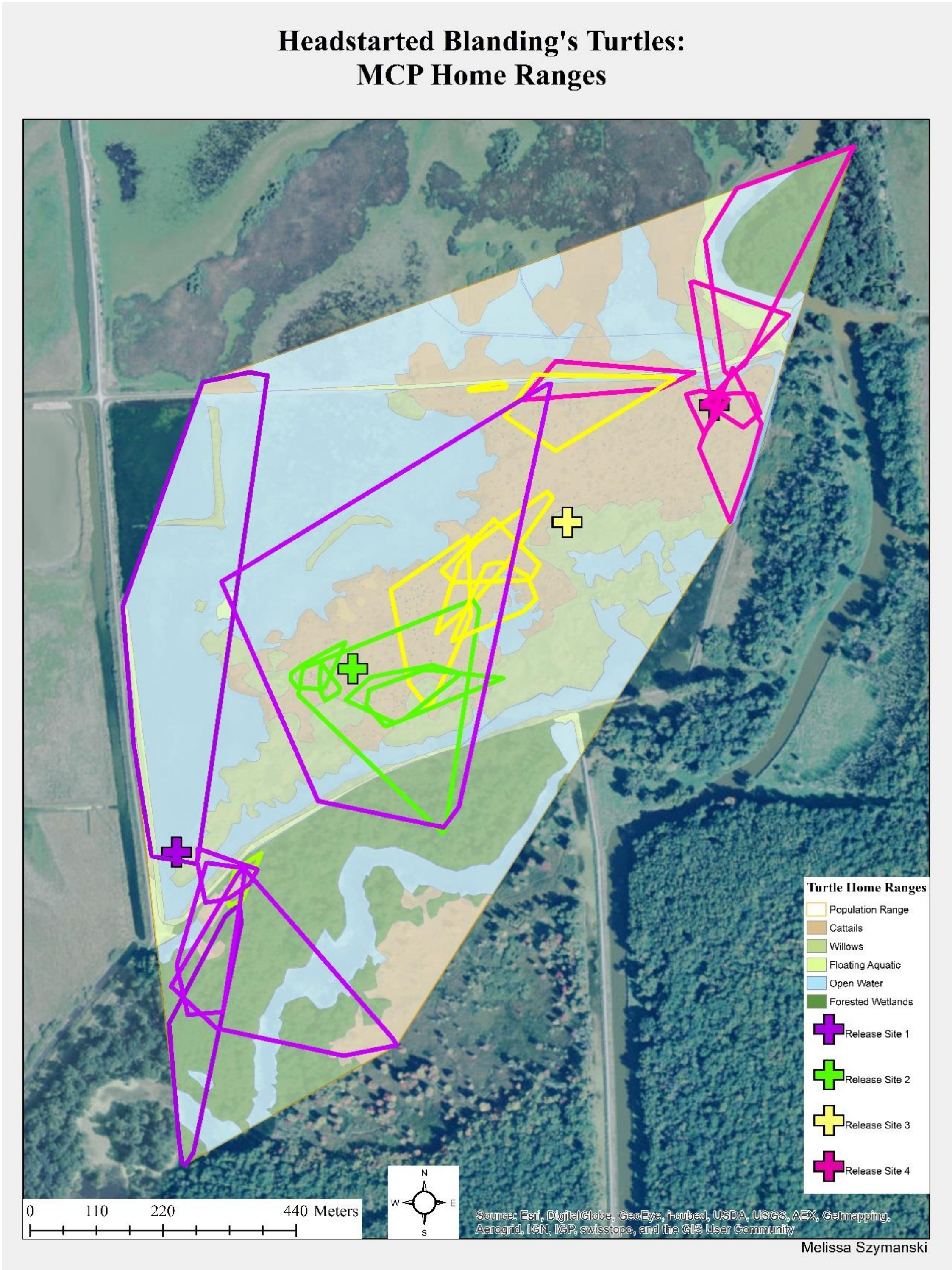

Figure 2.5: MCP home ranges of 24 juvenile headstarted Blanding's Turtles in SNWR over the eighteen month study (mean points per turtle = 38). Home ranges are color coded to match the release site of the turtle.

CHAPTER 3. Examination of Habitat Use and Release Locations of Headstarted Blanding's Turtles

Abstract

Blanding's Turtles which are a state species of special concern in the state of Michigan, were headstarted by the Detroit Zoological Society (DZS) as a part of an ongoing conservation effort with Shiawassee National Wildlife Refuge (SNWR) in Saginaw, MI. Juvenile headstarted Blanding's Turtles one and a half years in age, were fitted with radio transmitters. Turtles were located weekly during the active season and biweekly during the inactive season for eighteen months following release at four different sites within the refuge. Data collected from 2014 and 2015 were analyzed using use versus availability methods to look for habitat preference. Straight line distance away from release sites were calculated and used in a Geographically Weighted Regression (GWR) model in attempt to predict movement away from release sites with measured habitat factors. Results showed that juvenile headstarted Blanding's Turtles used habitats with muskrat dens and cattails more than proportionally available and used open water, willows, and lowland forest less than proportionally available. GWR models performed better than nonspatial models and predicted habitats that influenced movement away from the release sites. This research demonstrates how microhabitats at release locations may affect movement of headstarted Blanding's Turtles.

Introduction

Headstarting is used to bolster populations of reptiles by aiding in the survival of eggs and hatchlings, which is a time period of low survivability (Jones & Sievert, 2012). Turtle nests are predated by raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), and other mesopredators who have seen their populations rise in human dominated landscapes (Congdon et al., 1993). Headstarting cannot compensate for adult losses (Heppell et al., 1996) but in areas where adults are protected such as Shiawassee National Wildlife Refuge (SNWR), headsarting can increase recruitment where nest predation is high (Congdon et al., 1993). Headstarts have been shown to survive better due to larger body sizes (Haegen et al., 2009). Another important consideration of headstarting is the release site locations. Juvenile turtles must be released in places with habitats that benefit their survival. Death can occur if the juveniles find themselves in upland dry habitats which leave them vulnerable to predation (Hagen et al., 2009; M. Szymanski, unpublished data).

Discovering habitats used by juvenile Blanding's Turtles is important and not as well documented as habitat use by adult Blanding's Turtles (Pappas & Brecke, 1992). However, a few notable studies do exist. Juvenile Blanding's Turtles have been found to use marshes and shallow waters with lots of vegetation (Pappas & Brecke, 1992; Bury & Germano, 2003). Paterson et al. (2014) found that hatchling survival increased with more time spent in marshes and forests due to the amount of vegetation cover. Adult Blanding's Turtles were found most often in marsh, pond, and floodplain habitats in Illinois (Anthonysamy et al., 2013). Moreover, Attum et al. (2008) used logistic regression modeling and found that Blanding's Turtles occurred in larger wetlands with quality connectivity that were further away from roads. Orthophotos have been used to identify Blanding's Turtle habitat by locating wetlands with open water, vegetation, and floating logs in Quebec (Barker & King, 2012). Adult Blanding's have been found to use a variety of wetlands across seasons (Beaudry et al., 2009; Edge et al., 2009). In Ontario, field studies and habitat modeling showed Blanding's Turtles occupied habitats with higher air temperatures, lower water temperatures, floating and submerged vegetation in wetlands, and low densities of roads, open water, and croplands (Millar & Blouin-Demers, 2011; Millar et al. 2012). When comparing natural and constructed wetlands, Hartwig & Kiviat (2007) found that emergent and submergent vegetation along with basking surfaces, mucky substrate, and Buttonbushes (*Cephalanthus occidentalis*) were important microhabitat factors for Blanding's Turtles. Blanding's Turtles raised in captivity were reported to have overwintered with wild turtles (Newton & Herman, 2009), which is an indication that headstarted turtles would use the same habitats as their wild counterparts.

When managing and implementing conservation programs for species, especially ones that are listed as threatened or endangered, robust methods should be used to understand their space use and what habitats they utilize. One method that is frequently used to determine habitat utilization is the Chi-square goodness-of-fit test to discover statistically if observed values differ from expected values of habitat types (Neu et al., 1974). This approach is very good at detecting selectivity of resources by animals (Alldredge & Griswold, 2006). By comparing the observed frequencies of habitats that an animal has occurred in to the calculated expected values that an animal should occur in due to habitat availability, researchers can determine a preference for some habitats over others by then applying the Bonferroni confidence interval (Byers et al., 1984). This method can be used to determine if the headstarted juveniles released at SNWR have habitat uses and preferences similar to previous research.

The use of geographically weighted regression (GWR) analysis has rarely been applied to wildlife applications but is widely used in geography, environmental, and social sciences; GWR can be very useful for analyzing spatially autocorrelated data (McNew et al., 2013; Fotheringham et al., 1998, 2000). After reviewing methods for resource selection, Alldredge et al. (2006) found that logistic regression is beneficial to use with categorical habitat variables. Unlike this method, however, GWR has the unique ability to explain how geography affects variables which can be useful in biological modeling (Kimsey Jr. et al., 2008). GWR follows Tobler's first law of geography "Everything is related to everything, but near things are more related than distant things" (Tobler, 1970). GWR is a local regression model instead of the standard global logistic regression model; in other words, it applies an individual regression equation to each sample (Charlton & Fotheringham, 2009). Studies have used GWR to model populations and habitat features. GWR models are better able to predict deer densities (Shi et al., 2006) and also better at accounting for spatial heterogeneity when assessing habitat features for Greater Prairie-chickens (McNew et al., 2013). In this study, GWR was used to predict movement away from release site to microhabitat factors at each turtle relocation using several environmental variables and various release locations of the turtles. This method models use of space by the juvenile headstarted Blanding's Turtles in this study. Space use can be a helpful measure of headstarting program success (Mignet et al., 2014). I used Chi-square goodness-of-fit and GWR together to help wildlife biologists improve headstarting success and add to the growing body of research on juvenile Blanding's Turtles.

Methods

Study site: This study took place at Shiawassee National Wildlife Refuge (SNWR), Saginaw, MI, U.S.A. The SNWR is a 3,885 hectare wetland complex that is a part of the national wildlife refuge system (Figure 3.1). The wetlands and marshes within the refuge are managed with conservation of all native habitat types and native species in mind. Species that reside in the refuge include many wading birds that use the refuge as a migration stop over or summer residence e.g. (Great blue heron, *Ardea herodias*), mammals e.g. (Raccoons, *Procyon lotor*), amphibians e.g. (Leopard Frogs, *Lithobates pipiens*), and many types of reptiles including the Blanding's Turtle.

Study organism: To increase the Blanding's Turtle population within Shiawassee National Wildlife Refuge, the Detroit Zoological Society (DZS) and SNWR have implemented a headstarting program. Beginning in 2010, adult female Blanding's Turtles were found at SNWR each year from May to June while traversing terrestrial habitats, collected, and palpitated. Gravid females are transported to the DZS and x-rayed to identify and count eggs. Egg laying is hormonally induced and these adult females are then released where they were originally collected in SNWR. These Blanding's Turtle eggs are incubated and once they hatch, they are raised in captivity at the DZS for approximately eighteen months until zoo staff deem them ready for release. Sex of the headstarted Blanding's Turtles is unknown as secondary sexual characteristics do not develop until sexual maturity approximately 14-20 years of age. Zoo staff selected twenty-four turtles who were ready for release to be a part of this study. Veterinarians with the DZS implanted passive integrated transponder (PIT) tags via injection near the right rear leg and each turtle carapace was notched with both markings used for individual identification purposes. The PIT tags measured 12 mm (115 mg, 12.5 X 2.12 mm, Biomark, 134.2-kHz

International Organization for Standardization Full Duplex B). The twenty-four turtles were randomly selected to be released at four different sites along a transect in Grefe pool within SNWR (Figure 3.1).

Data collection: The beginning mass range for all juvenile headstarted Blanding's Turtles (n = 24) were 91 to 150 grams, the eight turtles with the greatest mass were chosen to have iButtons attached. During June 2014, twenty-four juvenile headstarted Blanding's Turtles were fitted with R1680 radio transmitters (3.6 g, Advanced Telemetry Systems, Isanti, MN) which were attached to the carapace externally using Devcon clear coat epoxy – 2 ton (ITW Polymers Adhesives North America, Danvers, MA) and PC Marine hand moldable all-purpose epoxy putty (Protective Coating Company, Allentown, PA). In addition, eight out of the twenty-four juvenile headstarted Blanding's Turtles were fitted with Thermochron iButtons (3.3 g, iButtonLink, LLC., Whitewater, WI) with the same two previously mentioned epoxies for a study on thermoregulation (Szymanski, Chapter 1, unpublished data). The total mass of transmitters, iButtons, and epoxies were <10 % turtles body weight.

Turtles were randomly selected to be released at four different sites along a transect through Grefe pool within SNWR (Figure 3.1). The release pool was chosen from GIS analysis based on previous research on adult Blanding's Turtles in Michigan (Congdon et al., 1993; Congdon et al., 2011) and in agreement with U.S. Fish and Wildlife Service biologists from SNWR. Six turtles were released at each site. Each release site was in varying microhabitats (Figure 3.2) evenly spaced along the transect. The different microhabitat conditions at release were: open water (site 1), sparse cattails with duckweed (site 2), willows with duckweed (site 3), and dense cattails (site 4). Turtles were tracked approximately once per week during the active seasons (May thru September) and twice per week during the inactive season (October thru

April) to measure survivorship and record information about their immediate microhabitat conditions (detailed below). Tracking began in June 2014 and continued through November 2015, spanning eighteen months. Turtles were recaptured in fall 2014, spring 2015, and fall 2015 in order to remove and replace the transmitters and/or iButtons when necessary.

When a turtle was located via radio telemetry a 1-square meter floating quadrant was placed at each location with the turtle approximately in the center and GPS turtle location coordinates were recorded using a Trimble field computer (GeoExplorer 6000 series, Trimble Navigation Limited, Sunnyvale, CA). Several factors were collected at this location which included: water depth, ice thickness (when applicable), and substrate depth; water and air temperature; above water vegetation type and dominance. Data were put into a database and entered into GIS software Arcmap (version 10.3, Environmental Systems Research Institute, Redlands, CA.). Water depth was measured using a Keson metric tape placed in the water within the one meter plot and depth was measured to the top of the substrate. Substrate depth was measured by placing a Hayward fishing weight (6 lbs.) on the end of the Keson Metric measuring tape and measuring how far it sinks into the substrate once released. Emergent vegetation was identified and the quantity of vegetation density was estimated using similar methods outlined in Millar & Blouin-Demers, 2011: 0% vegetation, 25% vegetation, 50% vegetation, 75% vegetation, or 100% vegetation. Air and water temperature were also recorded at each turtle location. Data collected in the field were put into a database and entered into GIS software Arcmap (version 10.3, Environmental Systems Research Institute, Redlands, CA.).

Use versus Availability: Juvenile headstarted Blanding's Turtle locations and movement patterns were imported into ArcMap and used to compute MCP home ranges (Szymanski, Chapter 2, unpublished data). A population range was constructed using the MCP method similar to the home ranges by creating a MCP around all of the 24 turtle location points (N=899). Orthophotos, satellite imagery, and ground truthing were used to create habitat polygons within ArcMap and measure area of each habitat to determine availability within the population range. Area of each muskrat den was calculated using a diameter of 1 meter around each den recorded. The Chi-Square goodness-of-fit test was used to determine use versus availability of categorical habitat data by testing observed and expected values to see if habitat selection has occurred.

Spatial Testing and Global Model Development: Spatial regression analyses were used to visualize and predict which habitat variables influenced distanced traveled by turtles. Regression analyses were done in ESRI ArcMap. Variables used for the regression analyses were microhabitat factors collected at each turtle location within the 1 meter quadrant and release groups 1, 2, and 3. Thirteen different habitat factors were initially used in this model: water depth (cm), water temperature (Celsius), substrate depth (cm), air temperature (Celsius), duckweed, other floating vegetation, cattails up (*typha spp.*), cattails down (*typha spp.*, muskrat dens, push-ups, and fields), willow (*salix spp*.), grass, log, grapevine, Buttonbush, ice (mm). Dummy variables were used for the four release groups. An exploratory regression analysis was run which computes passing models, set to user defined criteria (R^2 values, VIF [variance inflation factor] values, and Ordinary Least Squares [OLS] model p values), by testing all combinations of all independent variables to the dependent variable which was the distance from each point recorded to the release point. The best passing model was chosen for an OLS regression. The OLS also computes many other statistics in a report to show model performance including the VIF which tests for redundancy among independent variables and t-tests for directionality. The OLS model showed that the variables vary spatially to the dependent variable and Global Moran's I is used to test variables for spatial autocorrelation (Rosenshein & Scott, 2011).

Geographically Weighted Regression: A Geographically Weighted Regression (GWR) model was run to account for spatial autocorrelation shown by the Global Moran's I. Using the same variables OLS and GWR models were compared using corrected Akaike information criterion (AICc). The best passing model was chosen based on lowest AICc and then highest R^2.

Results

Use versus Availability: Overall six habitat types were tested to measure the use of each variable compared to its availability within the headstarted Blanding's Turtle population MCP range (χ^2= 46854.06, N = 24, df = 5, $p < 0.05$). Out of the six habitat types three were used less than their availability: open water, lowland forested wetlands, and willows. Floating aquatic vegetation was used in proportion to its availability. Cattails and muskrat dens were used more than their availability to the turtles (Table 3.1).

Autocorrelation and Global Model: All the independent variables (IV) were found to be statistically clustered which indicates positive spatial autocorrelation as detected by Global Moran's I (Table 3.2), which is a standard means to test for spatial autocorrelation. The habitat variables that were strongest at predicting the distance traveled by turtles from release sites were: water depth, water temperature, duckweed, cattails, muskrat dens (including muskrat disturbed areas with cut down cattails termed muskrat fields), Buttonbushes, and release groups 1, 2, and 3. OLS results showed an adjusted R^2 value of 0.335 and had an AICc of 11346.682. The VIF tested for redundancy among independent variables, all VIF values were 1.145-1.791 which is well below the recommended 7.5. Additional t-statistics for each variable showing directionality on the dependent variable were significant ($p < 0.01$) except for water temperature. Water temperature was kept as an independent variable because both models performed better with it. Water depth and duckweed show a negative influence on distance traveled from release sites while cattails, muskrat/cattails, Buttonbushes, and release groups 1, 2, and 3, display a positive relationship (Table 3.3).

Geographically Weighted Regression: GWR performed better in predicting the distance turtles moved away from the release site (Table 3.3, Figure 3.3). The GWR adjusted R^2 was 0.755 which is higher than the OLS model and means that 75.5 % of the variation in the distance between each point and the release location was predicted by these independent variables. The AICc for the GWR model was lower (10449.275) than the OLS model AICc (11346.682) which shows the GWR has a better fit to the observed data than OLS.

Discussion

Juvenile headstarted Blanding’s Turtles avoided open water, which is similar to studies on adults (Hamernick et al., 2000; Millar et al., 2011), and willows and used lowland forested wetlands less than proportionally available. Millar & Blouin-Demers (2012) found a low density of open water fit in a habitat suitability model for Blanding’s Turtle. This study divided microhabitats by dominant vegetation types found at turtle locations. No other studies divided herbaceous wetland types similar to this study so it is not known whether other Blanding’s Turtles avoid willows. Lowland forested wetlands, which were used less than available, were used most by turtles from release group 1. Release group 1 turtles were released in documented non-preferred habitat types, open water. Some of the juvenile headstarted Blanding’s Turtles from release group 1 were never located in the preferred cattails with muskrat dens in Grefe pool. Hartwig et al. (2007) found Blanding’s Turtles associated with Buttonbush and I noted that the majority of areas within the lowland forest where turtles were found near Buttonbush or cattail stands.

Cattails and muskrat dens were used in greater proportion than available by the juvenile headstarted Blanding's Turtles. Release groups 2 and 4 were released in cattails and had the shortest measured straight line distance to mean center home range among release groups (See Chapter 2). Juvenile headstarted Blanding's Turtles were frequently found basking on top of muskrat dens (Szymanski, Chapter 1, unpublished data) and also located at muskrat dens where turtles seemed to be residing inside and under the dens (Figure 3.4). Previous studies indicate that Blanding's Turtles prefer emergent wetlands which contain cattails and muskrat dens within SNWR (Angela Cleary, University of Michigan-Flint, unpublished data). The results from this study are aligned with previous research regarding adult Blanding's Turtle habitat choices. Adults have been documented to prefer floating, submerged emergent vegetation habitats (Hartwig & Kiviat, 2007; Millar et al., 2011, Millar et al., 2012).

Global OLS and local GWR regression modeling was used to predict juvenile headstarted Blanding's Turtle movement away from release sites. To my knowledge this is the only attempt to use GWR methods to predict headstarted turtle movement away from release sites. The GWR model predicted that 75.5% of the variation in the movement away from release sites by headstarted Blanding's Turtles was explained by the following variables: water depth and temperature, duckweed, cattails, muskrat dens/fields, Buttonbush, and release groups. Movement by turtles from release group 1 had the lowest local R^2 values. These turtles, from group 1, moved out of the original release pool to a habitat that consisted of lowland forests with Buttonbushes, which was a different set of measured microhabitats than the other turtles in this study. Additionally release group 1 showed a statistically larger home range size than turtles from release group 4 (Chapter 2). Fortin et al. (2012) used logistic regression in an attempt to show movement and home range size differences due to categorical land use composition and found that it did not predict movement, presumably due to the low variability that occurred within turtle home ranges. I found that movement away from release groups could be predicted when microhabitat factors are teased out of wetland land type categories. Measuring the dominant vegetation within a quadrant at each turtle location gave me the ability to analyze differences in the effect of different variables on movement. Then by using a local geographic regression approach on animal space use, I was able to better predict movement. Release groups 1, 2, and 3 had the highest R^2 scores indicating that release groups had a strong relationship to movements away.

By releasing headstarted Blanding's Turtles at four different release sites with varying microhabitat features and then examining casual factors related to movement patterns, I tested for the biological importance of habitats. Alldregde et al. (2006) suggested that manipulation experiments such as those preformed in this study should be considered when testing for biological importance of habitats. Turtles from release group 1 were released into open water, a habitat that the use availability tests show they do not prefer. The only vegetation nearby was willows, another habitat type researchers found the turtles did not prefer. Five out of six turtles from release group 1 left Grefe pool where they were released and never returned. Juvenile Blanding's Turtles from another study traveled less often than adults and greater than 60% of them never moved out or between their resident wetland (Piepgrass & Lang, 2000). The juvenile headstarted Blanding's Turtles in this study had to cross the road that winds through SNWR when they left the original release pool. This outcome is in contrast to Proulx et al. (2014) who found that adult and juvenile Blanding's Turtles significantly avoided crossing roads. The high rate of movement out of the original wetland that the headstarted turtles released at site 1 experienced could be due to the habitat types at the release site. This could also help explain why release group 1 did not fit as well as the other release groups in the GWR model. Different factors seem to predict the release site 1 turtle movement away from the release site than the other three release sites which were able to locate preferred habitat types of cattails and muskrat dens. Future studies could single out Buttonbushes to test for preference, which this study did not do. Release group 1 was the only group to have a documented mortality and larger home ranges. The model does have some bias which means some of the points (with smaller R^2 values) are not as well fitted by the model and there are some independent variables missing from the model, which were not recorded, that could better explain the dependent variable. All wetland types were preferred by adult Blanding's Turtles to upland land types according to Edge et al. (2010) but fine scale habitat preference detection may not be possible in high quality landscapes. SNWR is a complex of high quality wetlands, but using the methods described I was able to detect a preference of certain habitat types. Juvenile Blanding's Turtles that were released in preferred habitat types moved the least overall, with release group 4 having significantly smaller home ranges than release group 1 (Szymanski, Chapter 2, unpublished data). The best GWR model used the preferred habitat types as independent variables for movement away from release sites along with the release sites themselves. This shows that release locations for headstarted Blanding's Turtles benefit the turtles most when they are in preferred habitats, and that it is possible to use microhabitat variables to predict turtle movement.

References

Alldredge, J. R., & Griswold, J. (2006). Design and analysis of resource selection studies for categorical resource variables. *Journal of Wildlife Management, 70*(2), 337-346.

AnthonySamy, W. J. B., Dreslik, M. J., & Phillips, C. A. (2013). Disruptive influences of drought on the activity of a freshwater turtle. *The American Midland Naturalist, 169*(2), 322-335.

Attum, O., Lee, Y. M., Roe, J. H., & Kingsbury, B. A. (2008). Wetland complexes and upland wetland linkages: Landscape effects on the distribution of rare and common wetland reptiles. *Journal of Zoology, 275*(3), 245-251. doi:10.1111/j.1469-7998.2008.00435.

Barker, R. & King, D. J. (2012). Blanding's turtle (*Emydoidea blandingii*) potential habitat mapping using aerial orthophotographic imagery and object based classification. *Remote Sensing (Basel, Switzerland), 4*(1), 194-219.

Beaudry, F., DeMaynadier, P. G., & Hunter, M. L.,Jr. (2009). Seasonally dynamic habitat use by Spotted (*Clemmys guttata*) and Blanding's turtles (*Emydoidea blandingii*) in Maine. *Journal of Herpetology, 43*(4), 636-645.

Bury, R. B., & Germano, D. J. (2003). Differences in habitat use by Blanding's turtles, *Emydoidea blandingii*, and painted turtles, *Chysemys picta*, in the Nebraska Sandhills. *American Midland Naturalist, 149*(1), 241-244.

Byers, C. R., Steinhorst, R. K., & Krausman, P. (1984). Clarification of a technique for analysis of utilization-availability data. *Journal of Wildlife Management, 48*(3), 1050-1053.

Charlton, M. and Fotheringham, M. S. (2009). Geographically Weighted Regression White Paper, *Ireland: Science Foundation*. Ireland, 2009

Congdon, J., Dunham, A. & Sels, R. (1993). Delayed sexual maturity and demographics of Blanding turtles (*Emydoidea-blandingii*) - implications for conservation and management of long-lived organisms. *Conservation Biology, 7*(4), 826-833.

Congdon, J. D., Kinney, O. M., & Nagle, R. D. (2011). Spatial ecology and core-area protection of Blanding's turtle (*Emydoidea blandingii*). *Canadian Journal of Zoology, 89*, 1098+.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2010). Habitat selection by Blanding's turtles (*Emydoidea blandingii*) in a relatively pristine landscape. *Écoscience, 17*(1), 90-99.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2009). Temperature and site selection by Blandings Turtles (*Emydoidea blandingii*) during hibernation near the species northern range limit. *Canadian Journal of Zoology, 87*(9), 825-825.

Fotheringham, A. (2009). Geographically Weighted Regression. In A. Stewart Fotheringham, & Peter A. Rogerson (Eds.), *The SAGE Handbook of Spatial Analysis.* (pp. 242-254). London, England: SAGE Publications, Ltd.

Fotheringham, A.S., Brunsdon, C., Charlton, M.E., 2000. *Quantitative Geography: Perspectives on Spatial Data Analysis.* (pp. 270) London, England: SAGE Publications, Ltd.

Fotheringham, A.S., Brunsdon, C., Charlton, M.E., 1998. Geographically weighted regression: a natural evolution of the expansion method for spatial data analysis. *Environ. Planning* A 30, 1905–1927.

Fortin, G., Blouin-Demers, G., & Dubois, Y. (2012). Landscape composition weakly affects home range size in Blanding's turtles (*Emydoidea blandingii*)1. *Écoscience, 19*(3), 191-197.

Haegen, W. M. V., Clark, S. L., Perillo, K. M., Anderson, D. P., & Allen, H. L. (2009). Survival and causes of mortality of head-started western pond turtles on pierce national wildlife refuge, Washington. *Journal of Wildlife Management, 73*(8), 1402-1406.

Hamernick, M. G. (200). Home Ranges and Habitat Selection of Blanding's Turtles (*Emydoidea blandingii*) at Weaver Dunes, Minnesota. Final Report submitted to the Nongame Wildlife Program, Minnesota Department of Natural Resources.

Hartwig, T.S. & Kiviat, E. (2007). Microhabitat association of Blanding's turtles in natural and constructed wetlands in southeastern New York. *The Journal of Wildlife Management, 71*(2), 576; 576-582; 582.

Heppell, S. S., Crowder, L. B., & Crouse, D. T. (1996). Models to evaluate headstarting as a management tool for long-lived turtles. *Ecological Applications, 6*(2), 556-565.

Jones, M. T., & Sievert, P.R. (2012). Elevated Mortality of Hatchling Blanding's Turtles in Residential Landscapes. *Herpetological Conservation and Biology* 7(1):89−94.

Kimsey Jr, M. J., Moore, J., & McDaniel, P. (2008). A geographically weighted regression analysis of Douglas-fir site index in north central Idaho. *Forest Science, 54*(3), 356-366.

Mcnew, L. B., Gregory, A. J., & Sandercock, B. K. (2013). Spatial heterogeneity in habitat selection: Nest site selection by greater prairie-chickens. *The Journal of Wildlife Management, 77*(4), 791-801.

Mignet, F., Gendre, T., Reudet, D., Malgoire, F., Cheylan, M., & Besnard, A. (2014). Short-term evaluation of the success of a reintroduction program of the European Pond turtle: The contribution of space-use modeling. *Chelonian Conservation and Biology, 13*(1), 72-80.

Millar, C. S., & Blouin-Demers, G. (2011). Spatial ecology and seasonal activity of Blanding's turtles (*Emydoidea blandingii*) in Ontario, Canada. *Journal of Herpetology, 45*(3), 370-378.

Millar, C. S., & Blouin-Demers, G. (2012). Habitat suitability modelling for species at risk is sensitive to algorithm and scale: A case study of Blanding's turtle, *Emydoidea blandingii*, in Ontario, Canada. *Journal for Nature Conservation, 20*(1), 18-29.

Neu, C. W., Byers, C. R., & Peek, J. M. (1974). A technique for analysis of utilization-availability data. *The Journal of Wildlife Management, 38*(3), 541-545.

Newton, E. J., & Herman, T. B. (2009). Habitat, movements, and behavior of overwintering Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia. *Canadian Journal of Zoology, 87*(4), 299-299.

Pappas, M.J. & Brecke, B.J. (1992). Habitat selection of juvenile Blanding's turtles, Emydoidea blandingii. Journal of Herpetology, 26, pp. 233–234

Paterson, J. E., Steinberg, B. D., & Litzgus, J. D. (2014). Effects of body size, habitat selection and exposure on hatchling turtle survival. *Journal of Zoology, 294*(4), 278-285.

Piepgras, S. A. and J. W. Lang. 2000. Spatial ecology of Blanding's turtle in central Minnesota. Chelonian Conservation and Biology 3:589–601.

Proulx, C. L. 1., Fortin, G., & Blouin-Demers, G. (2014). Blanding's turtles (*Emydoidea blandingii*) avoid crossing unpaved and paved roads. *Journal of Herpetology, 48*(2), 267-271.

Rosenshein, L. & Scott. L. (2011). Spatial statistics: Best practices. http://video.esri.com/watch/903/spatialstatistics-best-practices. ESRI Users Conference 2011. San Diego, CA.

Shi, H., Laurent, E. J., LeBouton, J., Racevskis, L., Hall, K. R., Donovan, M., Doepker, R.V., Walters, M.B., Lupi, F., Liu, J. (2006). Local spatial modeling of white-tailed deer distribution. *Ecological Modelling*, 190(1), 171-189.

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography*, *46*, 234–240.

Table 3.1: Habitat availability versus use Chi-square goodness-of-fit test results with Bonferroni z-stat confidence intervals. Results showed that open water, lowland forested wetlands, and willows were used less in proportion to their availability, floating aquatic vegetation was used in proportion to its availability, and cattails and muskrat dens were used more in proportion to availability

Habitat Variable	Area Available	Number of Turtles Observed	Lower Critical Value	Upper Critical Value
Open water	39.5%	4	-0.001	0.010
Cattails	27.0%	490	0.501	0.587
Lowland Forest	19.0%	133	0.117	0.178
Willows	11.9%	20	0.009	0.035
Floating Aquatic	2.5%	16	0.006	0.029
Muskrat Dens	0.1%	238	0.226	0.302
χ^2 = 46854.06, N = 24, df=5, p<0.05				

Table 3.2: Below the variables used in the OLS regression model. Moran's I analysis showed significant clustering.

Variable	Morans I	Pattern	p- value
Dependent Variable			
Distance to Release Site (meters)	0.534	clustered	0.00
Independent Variables			
Water Depth (cm)	0.601	clustered	0.00
Water Temperature (C°)	0.216	clustered	0.00
Duckweed (%)	0.388	clustered	0.00
Cattails (%)	0.311	clustered	0.00
Muskrat down Cattails **(%)**	0.456	clustered	0.00
Buttonbush	0.473	clustered	0.00
Release Group 3	0.663	clustered	0.00
Release Group 2	0.446	clustered	0.00
Release Group 1	0.647	clustered	0.00

Table 3.3: Regression analysis comparing OLS and GWR models. Adjusted R^2 and AICc show that GWR performed better in predicting the distance turtles moved away from the release site. Water depth, water temperature, and duckweed show a negative relationship with movement of juvenile headstarted Blanding's Turtles away from release sites while cattails, muskrat/cattails, buttonbush, and release groups 1, 2, and 3, have a positive relationship with movement of juvenile headstarted Blanding's Turtles moving away from the release sites in SNWR.
a. Water temperature was not significant for directionality but both the OLS and GWR models performed better with water temperature as an IV. Lack of directionality is presumably due to seasonally changes between temperature and movement seen in turtles.

	OLS (Ordinary Least Squares)	**GWR (Geographically Weighted Regression)**		
R^2	0.335	0.764		
Adjusted R^2	0.329	0.755		
AIC_c	11346.682	10449.275		
Habitat Variables	**VIF (Variance Inflation Factor)**	**T-Statistic**	**StdError**	***p***
Water Depth	1.791	-3.671	0.263	<0.05
Water Temperature	1.330	-1.617	0.572	>0.05a
Duckweed	1.531	-2.474	0.153	<0.05
Cattails	1.398	2.558	0.161	<0.05
Muskrat down Cattails	1.723	5.104	0.134	<0.05
Buttonbush	1.145	2.668	0.288	<0.05
Release Group 3	1.233	9.384	9.384	<0.05
Release Group 2	1.339	12.809	12.809	<0.05
Release Group 1	1.742	14.646	13.588	<0.05

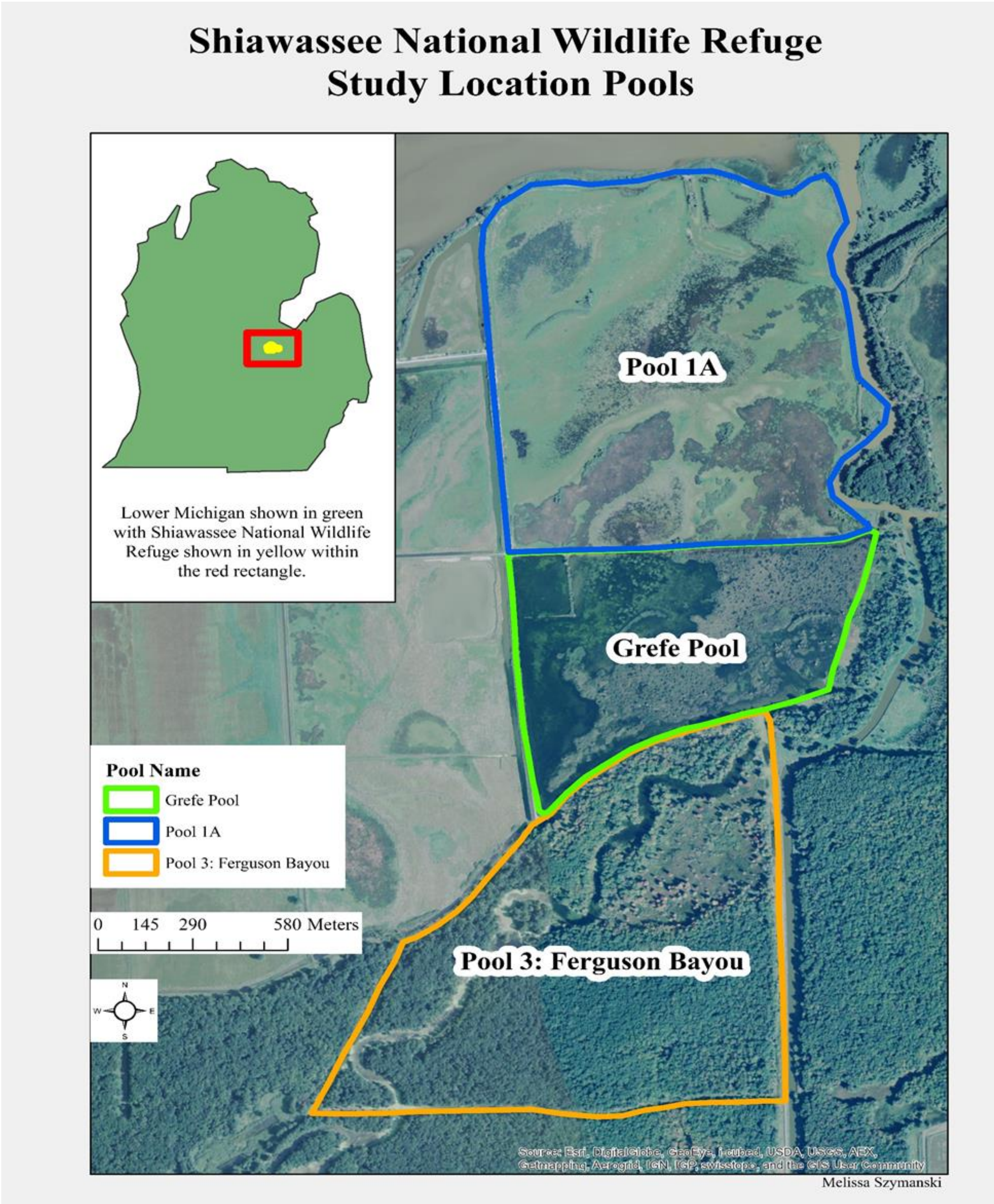

Figure 3.1: Map of study location pools within Shiawassee National Wildlife Refuge. Shiawassee National Wildlife Refuge shown in inset map in Lower Michigan in yellow within the red rectangle.

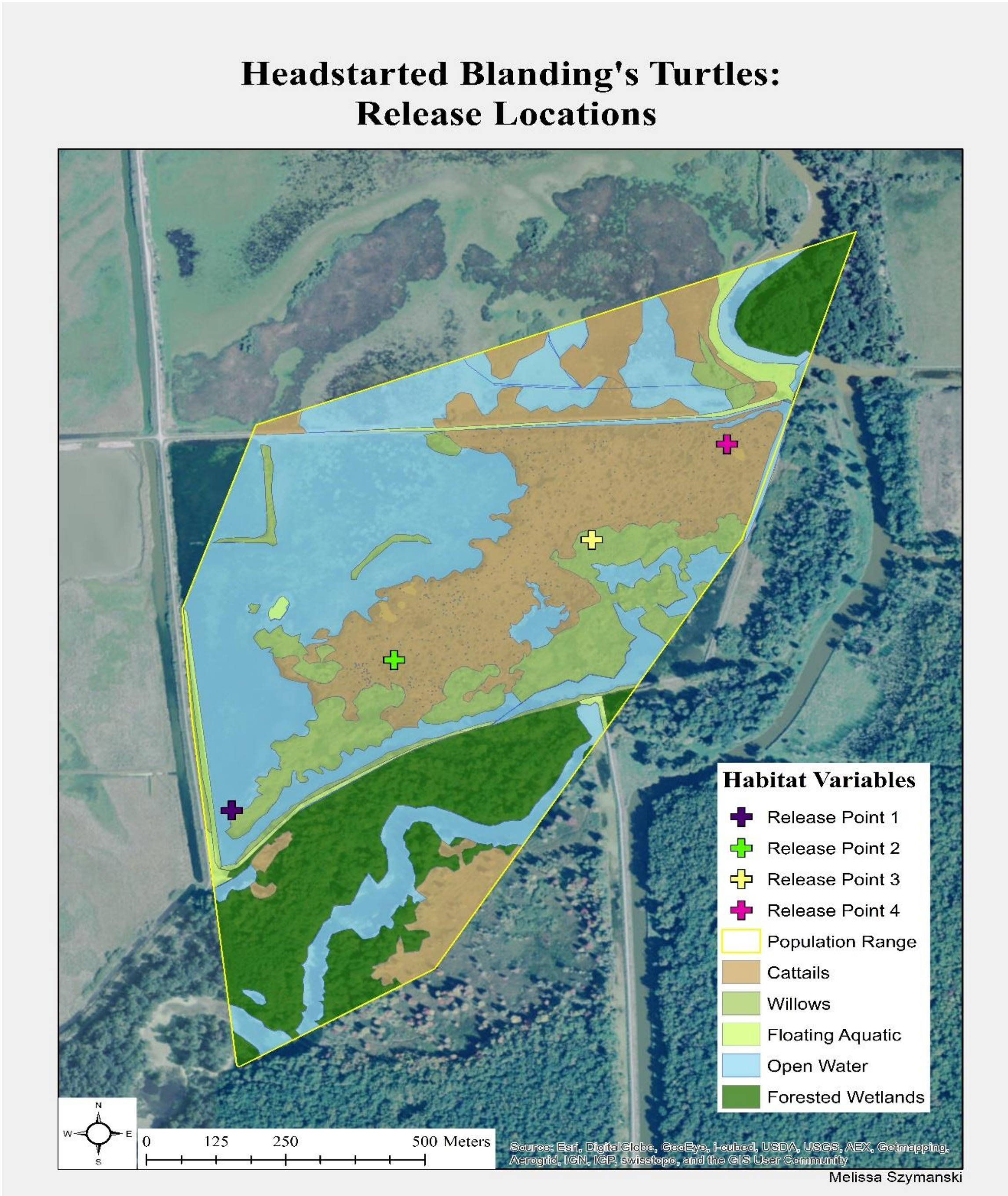

Figure 3.2: Map showing the four release sites for the 24 juvenile headstarted Blanding's Turtles in SNWR. Six turtles were randomly chosen to be released at the four different sites. Each site has varying microhabitats available to turtles; 1: open water, 2: sparse cattails, duckweed, mixed with muskrat disturbance, 3: willows and duckweed, 4: dense cattails.

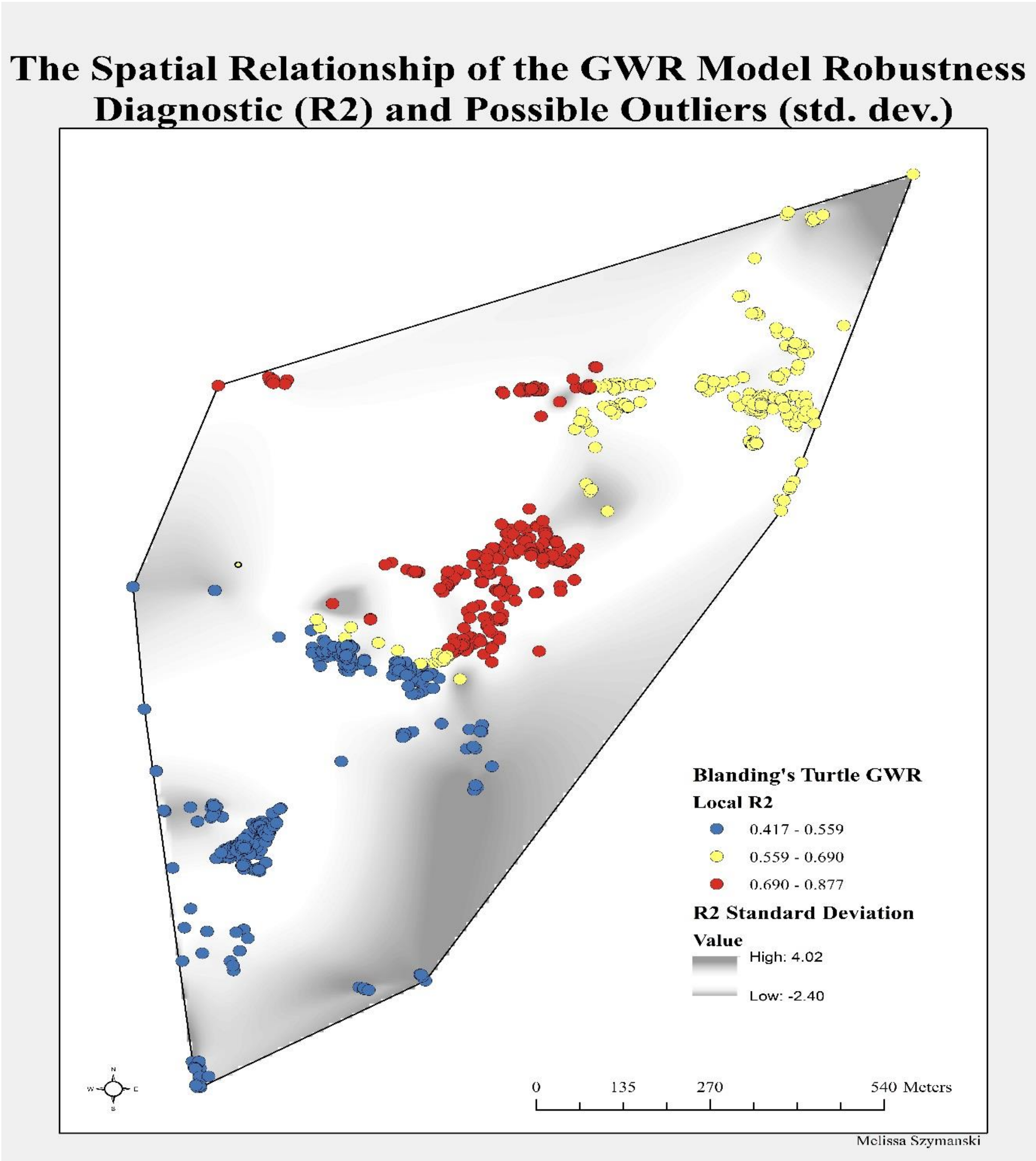

Figure 3.3: A map showing the GWR adjusted local R^2 values at each turtle point. The independent variables (IV) used are: water depth, water temperature, cattails, muskrat downed/disturbed cattails, buttonbush, and release groups 1, 2, and 3. Local R^2 values are represented by points. Red points are areas where the IV predict the dependent variable (DV) well (higher R^2 value) with the highest R^2 value at 0.877; blue points are less explained by the IV (lower R^2 value) with the lowest R^2 at 0.417. Additional factors may be responsible for juvenile headstarted Blanding's Turtle movement at locations with lower values within SNWR. R^2 standard deviation shown from high to low within the turtle population range.

Figure 3.4: Photograph of a juvenile headstarted Blanding's Turtle in SNWR basking near a muskrat den in a "muskrat field " surrounded by preferred habitat: cattails and muskrat den.

Management Recommendations

Data provided here on release sites and thermoregulation patterns, movement patterns, and habitat preferences by juvenile headstarted Blanding's Turtles adds to the growing body of research attempting to aid management and conservation decisions on an imperiled species. Thermoregulation patterns in these turtles show similarities to previous research on adult thermoregulation. This study showed that these juvenile Blanding's Turtles do indeed bask regularly and were often seen basking during tracking events. Summer temperatures measured on the turtles indicated that they keep themselves warmer than the surrounding water in the summer and cooler in the winter. Temperatures reached -0.5 °C during the winter months and turtles survived at that temperature for over a month. Some of the turtles were documented within 5 meters of one another at overwintering sites, which indicates group hibernation. Others were observed moving under the ice. Active seasons and inactive seasons where determined by turtle movements similar to previous research (Newton & Herman, 2009; Edge et al., 2010). Changes in the temperature of the water column seemed to dictate a change in movements in the turtles. When the surface water temperatures were warmer than the substrate temperatures, juvenile headstarted Blanding's Turtle movements are farther and turtles were active. When the substrate temperatures were warmer than the water surface temperatures, juvenile headstarted Blanding's Turtles decreased their movements and gathered in hibernacula sites. Headstarted turtles survived through their first year after release showing that headstarts released in the spring can acclimate to their surroundings and find suitable overwintering sites even after being raised in captivity for eighteen months.

Movement patterns match previous research in that the juveniles in this study, on average, had smaller movements than studies on adults (Table 2.1). Home range sizes varied across the 24 juvenile headstarted Blanding's Turtles showing that individual variation is wide. Although movements were not statistically different, home range sizes were significantly different between release groups 1 and release group 4. Release group 1 was released in non-preferred habitat while release group 4 was released in preferred habitat. GWR modeling showed that different independent variables may account for movements away from release sites depending on the composition of habitat types in those release sites. Using GIS techniques from other fields of study has merit and is applicable to wildlife biology. For example, the GWR technique used in this study takes into account the fact that everything is not uniform across space, which could not be truer than in ecological studies (Alldredge & Griswold, 2006). Habitat preferences demonstrated that juvenile Blanding's Turtles use and prefer muskrat dens and cattails over other available habitat in SNWR, and that they avoided open water and willows. By subdividing habitat types and using dominant vegetation as a categorical habitat type instead, I was able to determine important factors that vary in broader category types.

Further studies will need to be done to determine if the headstart program is a success given the longevity of Blanding's Turtles. Future trapping studies could use environmental temperatures to determine when turtles begin to move from overwintering sites. Additionally, locating overwintering sites will have an advantage if turtles are communally overwintering. Researchers could benefit from this knowledge and may be able to increase success rates of locating wild juveniles for population assessments. A more in-depth study could be done on home ranges using newer techniques such as Brownian bridges that take into account space and time of animal movements. Satellite tracking devices could be used to enable researchers to obtain more data points more frequently to do such analyses on juvenile turtles.

Headstarted Blanding's Turtles should be released in their preferred habitat of dense cattails with plenty of muskrat dens for basking and refuge, if available. By releasing turtles in a location suited to their needs, biologists can limit the dangers from predation and improve management techniques which increase and stabilize populations of the most threatened vertebrate group in the world, turtles (Buhlmann et al., 2009).

References

Alldredge, J. R., & Griswold, J. (2006). Design and analysis of resource selection studies for categorical resource variables. *Journal of Wildlife Management*, 70(2), 337-346.

Buhlmann, K. A., Akre, T. S. B., Iverson, J. B., Karapatakis, D. Mittermeier, R.A., Georges, A., Rhodin, A.G. J., Van Dijk, P. P. & Gibbons, J. W (2009). A global analysis of tortoise and freshwater turtle distributions with identification of priority conservation areas. *Chelonian Conservation and Biology*, 8(2), 116-149.

Edge, C. B., Steinberg, B. D., Brooks, R. J., & Litzgus, J. D. (2010). Habitat selection by Blanding's turtles (*Emydoidea blandingii*) in a relatively pristine landscape. *Écoscience, 17*(1), 90-99.

Newton, E. J., & Herman, T. B. (2009). Habitat, movements, and behavior of overwintering Blanding's turtles (*Emydoidea blandingii*) in Nova Scotia. *Canadian Journal of Zoology*, *87*(4), 299-309.