

**SPATIAL ECOLOGY OF SNAPPING TURTLE (*CHELYDRA  
SERPENTINA*) WITHIN AN URBAN WETLAND COMPLEX**

by

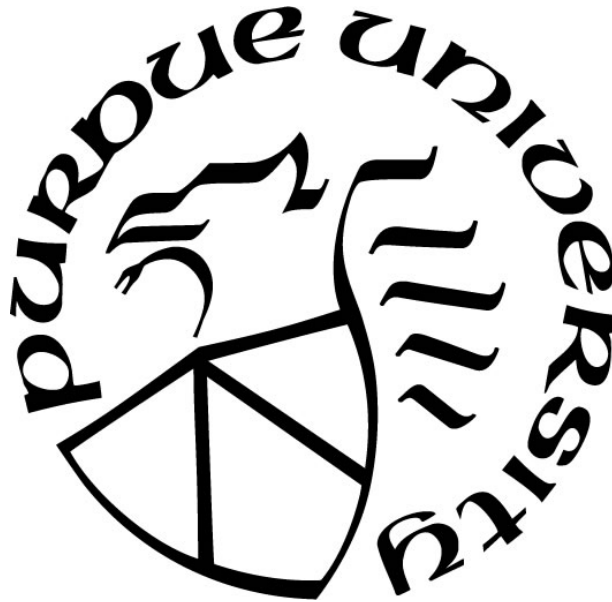
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## ABSTRACT

The conversion of natural habitat to urban areas has lasting impacts on wildlife and biodiversity. Known effects to urban wildlife include direct mortality while crossing roads, reduced species diversity, and habitat fragmentation and degradation. Among wildlife occupying urban areas, turtle populations can be particularly impacted in anthropogenic landscapes. Snapping Turtle (*Chelydra serpentina*) is one of the most common species found within urban wetlands, but populations are beginning to show declines in northern portions of their geographic range. The preservation and management of this species is aided by knowledge related to its spatial ecology. I investigated *C. serpentina* home range, movement, habitat use, and habitat selection in a midwestern USA urban wetland complex during two active seasons (May-August 2019 and 2020) using radiotelemetry. Home range sizes and movement did not differ between sex or sample year except the mean movement of males decreased from 2019 to 2020. No differences in mean monthly movement were found between sexes but mean monthly movement did differ between month and year. Habitat use was skewed during the active season and did not differ between sex or year, but there were positive habitat associations between forested wetlands and modal centers of activity (MCA). Habitat selection was tested at two spatial scales by comparing random points to home ranges and turtle locations using Euclidean Distance Analysis. Turtles appeared to select home ranges from available habitat site-wide but did not select habitat within home ranges. Home range selection included semi-permanent open water, trail, road/barrier, permanent open water, scrub-shrub, ditches, shoreline, and vegetated ponds, while upland forest, field and agriculture habitat were avoided. Home ranges appear to be constrained by available habitat and movement differences between years may be due to anthropogenic change in water levels. The use of space seems to be more affected by wetland size and connectivity than proximity to barriers, which suggests that management practices that protect turtles from accessing roads and railways will benefit populations. Additionally, habitat selection and association indicate that ditches are utilized as corridors between wetland areas. When feasible, increasing the connectivity of large wetlands containing many habitat types should have positive impacts on the persistence of populations in human dominated landscapes.

## CHAPTER 1. INTRODUCTION

The increase in human population and accelerated use of technology over the past 200 years has led to widespread and increasingly intensive urbanization. Natural areas are reduced and have become fragmented as landscapes are converted to urban and suburban land use that is dominated by anthropogenic activity and features (McDonnell & Hahs, 2008; Pimentel & Pimentel, 2003). Urbanization not only has the initial effect of the removal of habitat but also has lasting impacts on the wildlife that inhabit remaining fragments of natural areas (Grimm et al., 2008; McKinney, 2002) including direct mortality, barriers to movement such as roads (Lodé, 2000; McKinney, 2008)) that fragment home ranges, the homogenization of remaining flora and fauna (McKinney, 2006), and habitat degradation (Trombulak & Frissell, 2000; Welsh Jr & Ollivier, 1998). Additionally, wetlands are affected by changes in hydrology and increased storm-water runoff, which affects biodiversity, pollution levels and water chemistry (Grimm et al., 2008; McKinney, 2008; Paul & Meyer, 2001).

Effective management of urban wildlife requires understanding the spatial distribution of organisms in their environment (Krebs, 2012; Patrick & Gibbs, 2010; Soule, 1991). Conservation of wildlife populations, particularly those living in urban areas, involves knowledge of species' home range, and the location of critical habitat (Markle, Chow-Fraser, & Chow-Fraser, 2018). Semi-aquatic freshwater turtles are sensitive to landscape transformation from natural to urban areas. Examples of these transformations include roads, increased land use, and subsidized predators. Transformations can have changing effects on distribution, population demographics and spatial ecology of turtle communities (Marchand & Litvaitis, 2004; Steen et al., 2006; Steen & Gibbs, 2004). Thus, it is important to identify the effects habitat alteration have on spatial ecology, especially in turtles. The survival strategies of turtle species include long-lives, delayed sexual maturity, and low mortality in adulthood; characteristics which were once beneficial but now make this taxa heavily impacted by urbanization (Aresco, 2005; Ashley & Robinson, 1996). Turtles are major components of biodiversity and are keystone species in the ecosystems they reside. The loss of freshwater turtles gradually degrades ecosystems in ways that are still not fully understood (Colston, Kulkarni, Jetz, & Pyron, 2020).

Snapping Turtle (*Chelydra serpentina*), is one of the most widely distributed and well-studied freshwater turtle species in the North America (Ernst & Lovich, 2009). Although there are



numerous studies on the species' biology, relatively few have investigated spatial ecology (Obbard & Brooks, 1981; Paisley et al., 2009; Paterson, Steinberg, & Litzgus, 2012) and research in urban wetland complexes is limited (Piczak & Chow-Fraser, 2019; Ryan, Peterman, Stephens, & Sterrett, 2014). Snapping Turtle can be found in a variety of habitats consisting of still or slow-moving water with abundant vegetation, organic debris, and loose substrate. However, they have been observed making extensive overland migrations during nesting and extreme droughts (Brown & Brooks, 1994; Ernst & Lovich, 2009; Obbard & Brooks, 1981). Snapping Turtle is a species of least concern in the United States (Palacio, Negret, Velásquez-Tibatá, & Jacobson, 2020). Despite their perceived heartiness related to its abundance, ubiquity, and presence within heavily modified habitats, it is listed as a species of Special Concern in Canada (COSEWIC, 2008). This status is due in part to the species' life-history characteristics (e.g., delayed maturity, low recruitment) and increasing urbanization of habitats (COSEWIC 2008). The loss of snapping turtles is concerning due to the many roles they play as predators, scavengers, and their ability to sequester biomass (Garig, Ennen, & Davenport, 2020; Iverson, 1982). Understanding the spatial ecology of *C. serpentine* can inform management of its critical habitat, restoration strategies, and help prevent extirpation of its populations.

The spatial distribution of freshwater turtles depends on physical barriers, physiological constraints, and resource availability (Compton, Rhymer, & McCollough, 2002; Huey, 1991; Morreale, Gibbons, & Congdon, 1984). During the active season (May-August), the movement of individual turtles within the landscape is related to the search for resources needed for growth, maintenance, and reproduction. Females often have larger home ranges due to higher reproductive investment (Congdon, Breitenbach, van Loben Sels, & Tinkle, 1987; Congdon, Gibbons, & Greene, 1983). However, males may use large areas for mate-searching (Litzgus & Mousseau, 2004). Additionally, temporal stochastic changes in hydrology alter habitat quality which can cause distributional shifts (Cosentino, Schooley, & Phillips, 2010).

In this study, I examined the spatial ecology of Snapping Turtle in an urban wetland complex. I aimed to: 1) describe home ranges and movement, 2) determine habitat association and selection, and 3) evaluate interactions with transportation infrastructure at Eagle Marsh Nature Preserve. I expected spatial parameters would differ by sex and time. I also hypothesized that barriers such as roads and railroad tracks would impact movement and home range sizes. I expected that turtles would prefer aquatic habitats over upland and modified areas (e.g., roads) at the landscape level,

and that permanent, slow-flowing water with woody debris and vegetation would be preferred within home ranges.

## **CHAPTER 2. METHODS**

### **2.1 Study area**

Eagle Marsh Nature Preserve (EMNP; Figure 1), located in the southwestern border of Fort Wayne, Indiana, is the largest inland wetland restoration area in the United States. It is an Indiana State Nature Preserve managed by Little River Wetlands Project (LRWP). This 831-acre study site is a wetland complex that supports a large diversity of wildlife, including 235 kinds of birds, 16 mammals, and 18 species of herpetofauna (Ruch et al., 2016): with one endangered and one special concern frog species and one state endangered turtle species. The wetland also includes a diversity of habitat types consisting of permanent ponds, ephemeral open bodies of water, marsh, sedge meadow, wet to mesic prairie, shrubland, and mature swamp woodlands (Ruch et al., 2016). These habitats are the focus of an active ecological restoration of the property following its use for crop-based agriculture until 2005. The property is bordered by a landfill on the east, a major interstate to the west, a railroad track to the south, and businesses, apartments, and a wastewater treatment plant to the north, which empties its effluent into the Graham McCulloch Ditch that runs through the site. Lastly, a small portion on the north side of EMNP is bisected by a heavily traveled four-lane roadway, Engle Road (Figure 1-3a-c). Vehicular related turtle mortality surveys were conducted in 2018 along Engle Road by LRWP and 53 deceased turtles were found in six weeks during June and July (personal communication; Betsy Yankowiak, Little River Wetlands Project).

#### **2.1.1 Habitat classification**

Wetlands were classified into one of eight categories based on “Classifications of Wetlands and Deepwater Habitats of the United States” (adapted from Cowardin and Golet, 1995). Class and subclass level were chosen during the habitat classification process for two major reasons: habitat types were able to be distinguished without extensive biological knowledge of various plant species and vegetation in these classes can be detected using a range of remote sensing methods (Cowardin & Golet, 1995). An additional six habitat types outside of the classification system were categorized based on water level, vegetation, substrate, and human use (e.g., trails versus roads; Table 1). Remote sensing was done by projecting orthophotographs of EMNP and the surrounding area using ArcGIS version 10.5 [Environmental Systems Research Institute (ESRI),

Inc., Redlands, California, USA]. I obtained landsat 8 images, provided by NOAA, to make a composite of 7 wavelength bands that correspond to colors refracted from satellite imagery of EMNP. I trained a supervised image classification model using combinations of 3 bands (e.g. 4,3,2 natural), Cowardin's classification system (Cowardin & Golet, 1995), and ground truth data, taken with a handheld GPS. The model then used the training to detect and categorize the physical characteristics of EMNP and the surrounding area (Figure 2).

## **2.2 Data collection**

### **2.2.1 Trapping**

I trapped turtles as part of an ongoing project to monitor the turtle assemblage at EMNP. I baited hoop nets and collapsible minnow traps (Promar TR-502) with sardines in soybean oil (C. A. Conner, Douthitt, & Ryan, 2005; Mali, Duarte, & Forstner, 2018; Sterrett, Smith, Schweitzer, & Maerz, 2010) and deployed them with my team in May of 2019 and 2020 (Figure 1; Table 2). My team and I then checked the traps daily for four consecutive days and removed on the last day (Figure 4a-d).

Once an individual was captured, I measured and marked it with a unique scute notch pattern using a steel file (Cagle, 1939). I then collected the body mass (kg) of each turtle by placing the individual into a sling suspended from a mechanical fish scale. Afterwards I measured carapace length and width (cm), and plastron length (cm) with calipers. I determined sex by using the ratio of precloacal distance to the posterior lobe of the plastron or eversion of hemipenes (Mosiman and Bider 1960), and then palpated all females to check for eggs. I then inspected individuals for ectoparasites and unique markings, deformities, or scars. Lastly, I took two photos of each turtle (carapace and plastron view) to aid in later identification.

If a turtle had previously been notched, I used the existing notch pattern for identification. I attached temperature sensitive radiotransmitters to the posterior region of the carapace (model SI-2T) on a single scute, or along the rear ridge between scutes, on the right-hand side of the carapace (Gibbons, 1986). Transmitters were adhered using epoxy (J-B WaterWeld™ epoxy putty; Figure 5a-b) (Boarman, Goodlett, & Goodlett, 1998; Bodie & Semlitsch, 2000). I attached transmitters only to adult turtles with carapaces length of  $\geq 20$ cm (Mosimann & Bider, 1960) and body mass sufficient such that transmitters and epoxy were no more than 5% total body mass. This restriction

was put in place to not interfere with normal behavior (Ryan, Conner, Douthitt, Sterrett, & Salsbury, 2008). Turtles were released at the capture location immediately after attachment of the transmitter.

### **2.2.2 Radiotelemetry**

Turtles were located every one to three days throughout the active season (May-August). This was to give individuals a chance to move between survey events and avoid auto-correlation errors in analysis. I tracked individuals (Swihart & Slade, 1985) using a handheld Yagi antenna with a R1000 Communication Specialist, Inc. Telemetry Receiver, R410 Receiver, Advanced Telemetry Systems, Inc., or a TRX 2000WR Receiver (Wildlife Materials, Inc.). Locations were recorded on handheld GPS units (Delorme Earthmate® PN-60) with three-meter to five-meter accuracy and uploaded to ArcMap version 10.5 software (ESRI, Redlands, CA, USA). Additionally, I recorded the time of locating the individual, air and water temperature (via digital thermometer), water depth (in 2020 only), macrohabitat type, behavior of the individual, body temperature via pulse frequency (amount of time per 10 pulses) and Holohil temperature graph (Holohil, 2021), and whether or not the turtle was disturbed. At the end of the second season, all turtles that could be captured were recovered for transmitter removal and were subsequently released.

Only snapping turtles with enough radiolocations to effectively estimate home range size were included in analyses. Each year of data was treated as an independent sample of for all analyses to increase sample size. Turtles which were tracked during both years were analyzed as unique individuals for each year.

## **2.3 Data analysis**

### **2.3.1 Home range**

Home ranges were determined using 95% minimum convex polygons (MCPs) in package *adehabitatHR* (Calenge, 2011; Powell, 2000) in R (version 3.6.3, The R Foundation for Statistical Computing, [www.R-project.org](http://www.R-project.org)) and 95% kernel density estimations (KDEs) in GIS implemented in ArcMap (ESRI, Redlands, CA, USA) 10.5 software (Seaman et al., 1999; Worton, 1987) using the kernel density tool. A bivariate normal kernel was used over least square cross validation as a

smoothing factor (method for choosing kernel bandwidths) due to its well-supported use in telemetry (Hemson et al., 2005). Because underestimation of home range size can occur due to inadequate sampling, I evaluated the relationship between home range size, number of unique locations per individual, and carapace length for both methods (Girard, Ouellet, Courtois, Dussault, & Breton, 2002; Kobayashi, Hasegawa, & Miyashita, 2006; Swihart & Slade, 1985) using multiple regression. This was to ensure that size of individual was not influencing home range size and to determine the threshold at which home range size could be reliably estimated. Once the minimum number of sample locations per turtle was determined, I tested for a difference between the two home range size estimation methods using a two-sampled paired *t* test. I also used two-way analysis of variance (ANOVA) on log transformed home range data, to meet normality criteria, to investigate possible differences between sex and sample year.

### **2.3.2 Interactions with roads and railroads**

To evaluate interactions with transportation infrastructure, I analyzed whether road and railroad density affects mean movement and home range size using Chi-Square tests. I calculated road and railroad density (km of road and railroads /km<sup>2</sup>) within the landscape range and home ranges of all snapping turtles at the EMNP using ArcMap (Ferronato, Roe, & Georges, 2017). Home ranges consisted of 95% MCPs created during home range analysis. Landscape range consisted of a 100% MCP of all the telemetry points, for all individuals, with a 75m buffer. I did this to include all space available to the turtles and the buffer was so the landscape range encompassed every home range. Mean movement was reused from movement assessments earlier in this study. Distance from roads to home ranges was measured using the *near* tool in ArcMap. I then categorized mean movement and home range into categories of  $\geq$  median distance to roads and railroads and  $<$  median distance to roads and railroads based on home range distances from roads and railroads. These categories were my independent variables. Mean movement and home range size were categorized into  $\geq$  median mean movement or home range size and  $<$  median mean movement and home range size, which were my dependent variables. Lastly, I ran separate Chi-Square tests for the response of each dependent variable to the independent variable.

### **2.3.3 Movement**

I measured the movement of snapping turtles using each individual's range of activity, linear distance, and mean movement. Range of activity for each turtle consisted of the distance between the two most distant locations during the active season. Linear distance was measured as the sum of straight-line distances between consecutive locations of each turtle. I did not locate each turtle an equal number of times, so I calculated mean movement using linear distance divided by the number of locations for each individual (Bodie & Semlitsch, 2000). Analysis of the effects of sex and sample year on movement (data log transformed) was performed using multivariate analysis of covariance (two-way MANCOVA) with carapace length as a covariate. This was to ensure that any differences observed were based on an independent variable and not size of the individual (McLane, 2015). If statistical significance was found for a factor, I ran Tukey's HSD (honestly significant difference) to determine the source of the difference.

I also examined how movement changes over time between sexes by calculating each individual's mean monthly movement. Mean monthly movement was calculated as total distance traveled within each month divided by the number of locations found within each month for each individual. May was excluded from analysis due to few data collected May of 2019. Analysis of the effects of sex, month, and sample year on mean monthly movement was performed using a linear-mixed effects model with carapace length as a covariate and individuals as a random effect. This was to ensure that differences observed were not due to individuals or their size but were caused by a factor. Additionally, I tested for any interactions between the fixed effects. After running the linear-mixed effects model each time I removed the non-significant fixed effect with the highest p-value and reran the model until only significant fixed effects remained. I chose this method to narrow down exactly which variables would affect mean monthly movement. If statistical significance was found for an independent variable, I ran a pairwise comparison using least-squares means test to examine the source of the difference.

### **2.3.4 Habitat selection**

I assessed habitat selection during the active season, (habitat used vs habitat available) at two different spatial scales using Johnson's (1980) hierarchical approach. Second-order (landscape level; selection of the home range) and third-order (home range level; selection of habitat within the home range) selection were analyzed using Euclidean distance analyses (L. M. Conner &

Plowman, 2001; L. M. Conner, Smith, & Burger, 2003). Selection was examined at each level to determine whether snapping turtles used habitat types differently from random (Bissonette, Harrison, Hargis, & Chapin, 1997). Habitat types included those made earlier from the remote sensing model described above (Table 1; Figure 2). I created home ranges estimated as 95% kernel densities with a smoothing factor that resulted an area that equaled each individual's 100% MCP in R (package *adehabitatHR*). Thus, home ranges would have the same areas as the 100% MCPs but their kernel density determined their shapes. This method was chosen because of previous recommendations regarding habitat selection of herpetofauna (Edge, Steinberg, Brooks, & Litzgus, 2010; Row, Blouin-Demers, & Fox, 2006) and comparability to past literature (Paterson et al., 2012). Only turtles that had home ranges >one hectare were examined in these analyses due to complications with kernel creations. Telemetry points of 28 out of 37 individuals were retained in my Euclidean distances analyses. Using this sub-sample, I created a landscape range to include all area available to the turtles with a 75m buffer. This buffer value was the minimum distance that contained all 95% kernel densities that were constructed with 100% MCP area. Random points equal to the number of telemetry points were then generated using the landscape range as an extent. Habitat availability at the second order (landscape level) was quantified as the mean distance from random points to each habitat type ( $n = 14$ ) at EMNP as described above. Habitat use was measured as the mean distance from random points within each individual's home range to each habitat type.

For third-order (home range level) selection, random points were generated within each home range equal to the turtle's recorded number of radio telemetry points. Habitat availability was calculated as the mean distance from random points within home ranges to each habitat type. Habitat use was measured as the mean distance from observed telemetry locations of each snapping turtle to each habitat type. Mean distance ratios (mean  $d$  ratio) were then created for each habitat for each turtle by dividing mean distance of habitat use by mean distance of habitat availability for second and third order. If mean  $d$  ratios equal one, turtles are selecting habitat at random, while values less than one indicate selection for that habitat and greater than one implies avoidance.

Habitat selection was tested at each order using a generalized linear model (GLM) in R (package *cran*) using mean distance ratios as the dependent variable, habitat types as the independent variables, and individual turtles as a random factor. The random factor was used to remove variation caused by individual effects on habitat use to help ensure that the differences observed are characteristic of preferences of this population and not just the preferences of



individual turtles. Multivariate analysis of variance (MANOVA) tests were used to assess whether mean distance ratios were significantly different from one. If MANOVA tests were shown to be statistically significant, I ran *t* tests or Wilcoxon sign-rank tests (if mean *d* ratios were found to be not normal) with a Bonferroni correction for multiple test ( $\alpha = 0.05/14 = 0.004$ ) to compare distances from available habitat to used habitat for each habitat type. This provided an indication of which habitat types were disproportionally used or avoided. In addition, I ranked habitats from most-selected to most-avoided using a pairwise comparison with a Tukey HSD test to determine differences between selected habitat types

### 2.3.5 Skewness and habitat association of modal centers of activity

I calculated a skewness index for each turtle by determining the distribution of each individual's locations throughout its observed range of activity (Lair, 1987). This is a relative measure of evenness of each individual's locations throughout the active season (Ryan et al., 2008) such that a value of zero indicates perfectly even use of active range while values different from zero indicate disproportionate use. This allowed for assessment of habitat selection intermediate to the second and third order scales. Skewness indices were calculated by first determining the midpoint of the range of activity (MDPT), the modal center of activity (MCA) and the standard deviation of the average distance of locations from the midpoint (SDMDPT). Skewness was then measured as:

$$\text{distance (m) between MDPT and MCA} \div \text{SDMDPT}$$

Component measures for skewness were derived from telemetry points in ArcMap. First, I calculated each turtle's MDPT from their telemetry locations using the *mean center* tool. This tool calculates a geographic center for an individual's distribution. Second, I determined the MCA using a 50% kernel density estimations which is considered an individual's core range of locations. Distances from observed locations to the MDPT were calculated using the *near* tool in ArcMap to give SDMDPT. Lastly, distances between MDPTs and MCAs were calculated using the *measure* tool. Skewness indices were examined with a one-sample *t* test. If the *t* test suggested an individual's habitat use was not even, a subsequent two-way ANOVA was used to test for differences between sex, sample year, and interaction between sex and sample year.

If skewness indices were found to be significantly different from zero, I also tested whether MCAs were distributed randomly throughout the EMNP regarding habitat type (Table 1) using a

*G*-test for goodness-of-fit. First, I determined observed values by counting habitat types from my remote sensing model (Table 1; Figure 2) within MCAs. Second, I reused the landscape range consisting of a 100% MCP of all observed telemetry points with a 75m buffer. A random distribution of MCAs equal to the number of observed MCAs was generated using the landscape range as the extent. Third, I determined expected values by generating counts of habitat types within the random MCAs. The *G*-test allowed me to determine which habitat types were associated with MCAs by testing if habitats within observed MCAs were significantly different from habitats within expected MCAs.

Table 1 Classification of habitat types at the Eagle Marsh Nature Preserve available to radio-tagged snapping turtles in spring and summer 2019 and 2020.

Habitat Type	Code	Description
Semi-permanent open water	SOW	Seasonally dependent wetlands with at least 25% cover and structure smaller than stones and less than 30% vegetative cover
Permanent open water	OW	Stable wetlands with at least 25% cover and structure smaller and less than 30% vegetative cover
Shoreline	SL	Land adjacent to bodies of water, consisting of loose substrate and minimal vegetation
Emergent wetland	EW	Shallow wetland consisting of at least 30% grasses and/or cattail areal coverage
Scrub-shrub	SS	Wetland of 30% or more areal coverage combinations of tree and shrub
Forested wetland	FW	Wetland of 50% or more areal coverage in trees over
Upland forest	UP	Mesic to dry habitat consisting of 50-100% is tree canopy
Upland field	UF	Open, natural, terrestrial area with minimum tree cover, dominated Reed Canary and other grasses
Vegetated pond	VP	Permanent wetlands where 30% or more vegetation is either on or below water's surface
Trails	TR	No canopy with no ground cover, short grass, or gravel
Ditches	DI	Altered riverine habitat that slows through the year and supports hydrophytes
Road/Barrier	RB	Open areas consisting of impermeable surfaces or railroads
Urban	UB	Heavily modified areas consisting of impermeable surfaces and buildings
Agriculture	AG	Active agricultural fields

\*Wetlands were classified using "Classifications of Wetlands and Deepwater Habitats of the United States" (adapted from Cowardin and Golet, 1995).

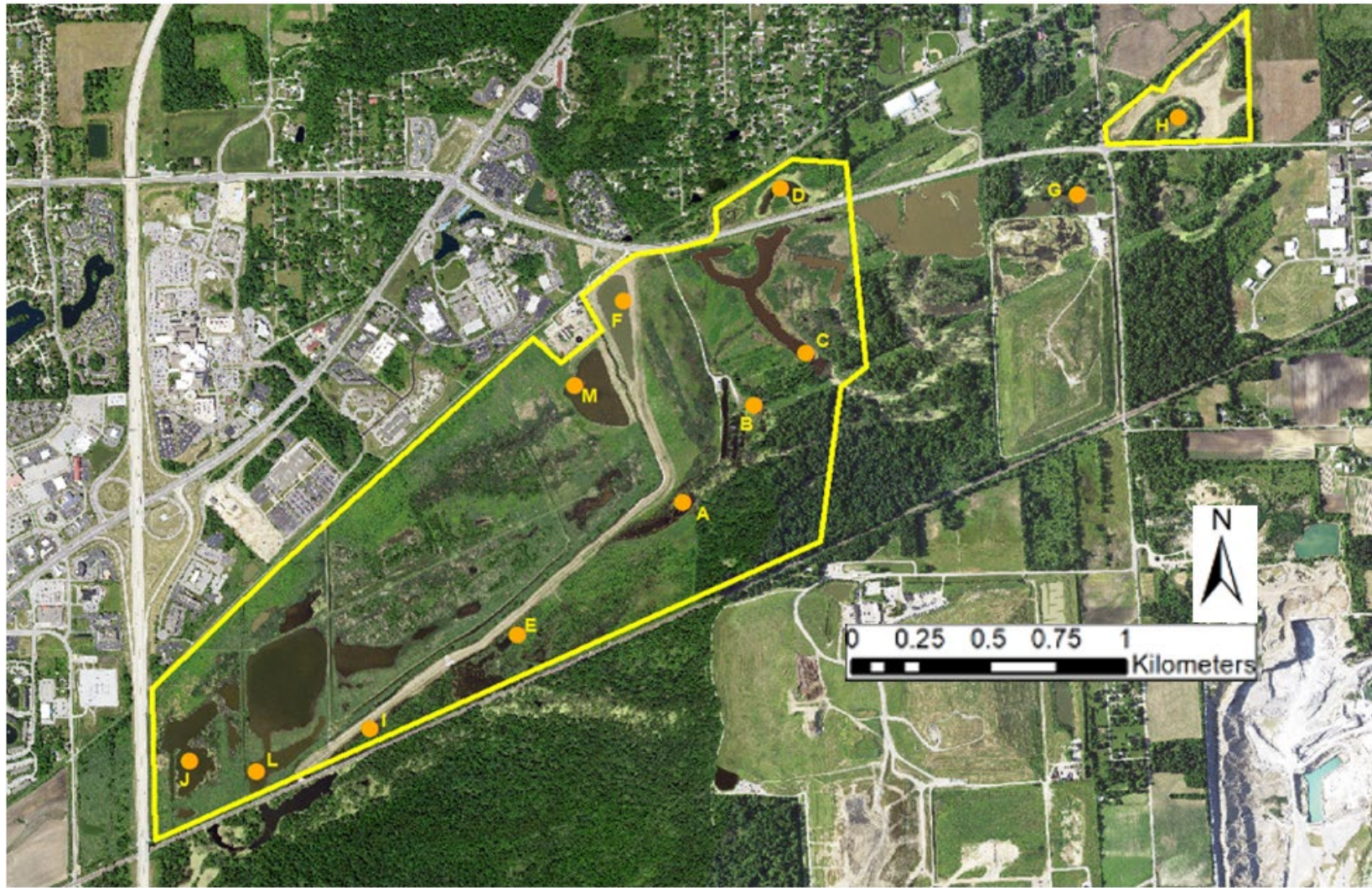


Figure 1 Eagle Marsh Nature Preserve (yellow lines) and surrounding area. Trap locations used for capture of Snapping Turtle for radio-tagging in spring and summers of 2019, and 2020 are shown with orange dots. Letters denote trap sites that were used in 2019 and 2020 (Table 1).

Table 2 Description of habitat type (Table 1) and trap year of trap locations at Eagle Marsh Nature Preserve.

Site	Habitat type	Years Trapped
A	VP	2019, 2020
B	SS/FW	2019, 2020
C	OW	2019, 2020
D	VP/OW	2019, 2020
F	OW	2020
H	SS/FW	2019, 2020
I	FW/EW	2019, 2020
J	OW	2019
L	OW	2019
M	OW	2019



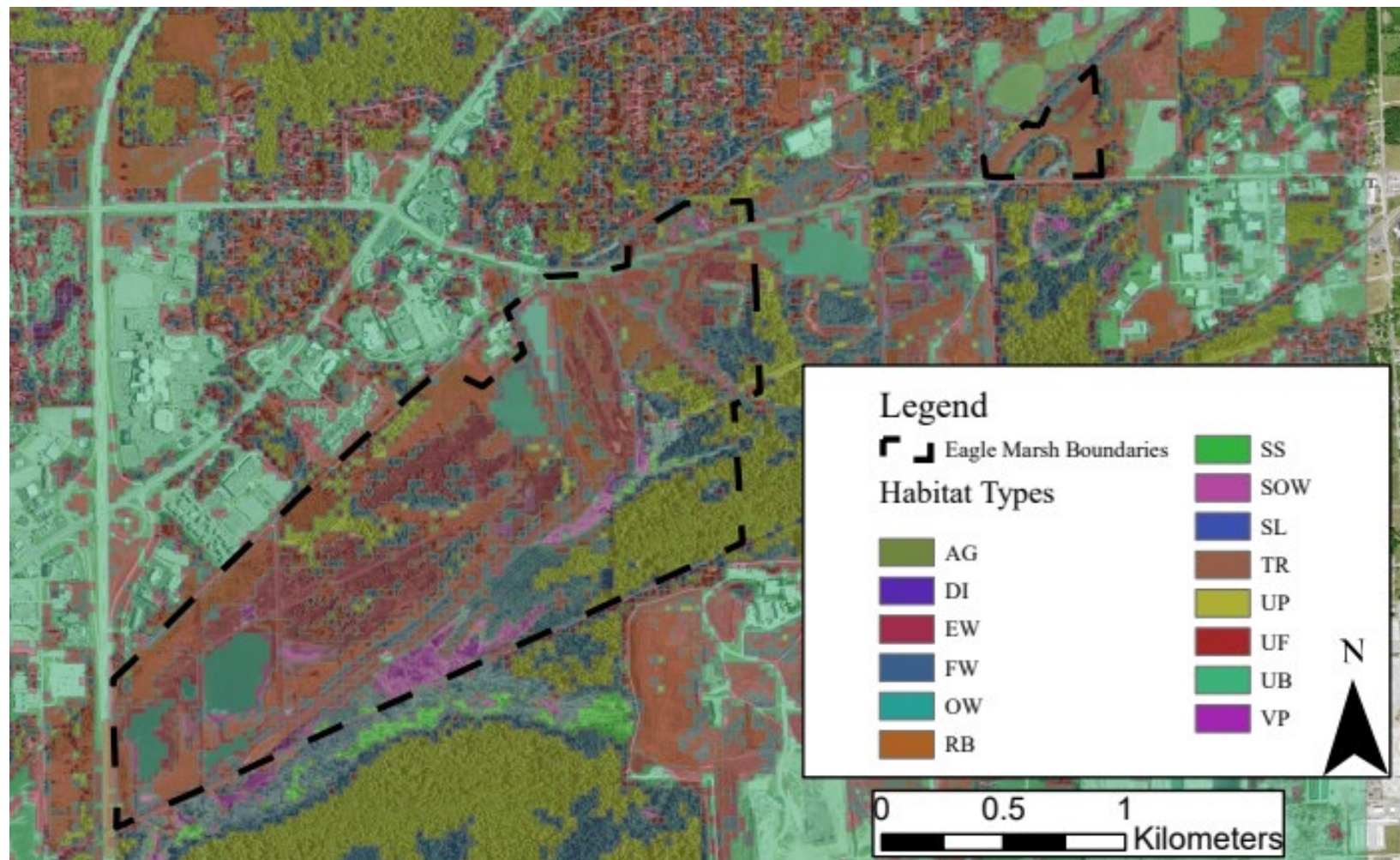


Figure 2 Distributions of categorized habitat at Eagle Marsh Nature Preserve and its surrounding area. See Table 1 for description of habitat types and codes.



Figure 3 Displays of EMNP and its proximity to human activity. a) Emergent wetlands and open water habitats with I-69 in the background. b) Open water, upland field, and trail habitat types near Engle Rd in the background. c) Open water and emergent wetland habitat types with apartments in the background. Photos collected in spring and summer of 2019 and 2020.





Figure 4 Photos of trapping methods collected during May of 2019 a) and b) baited Promar TR-502 traps c) and d) baited hoop nets.





Figure 5 a) Transmitter attachment and curing b) completion of transmitter installment.

## CHAPTER 3. RESULTS

Twenty-one turtles, 13 males and eight females, were tracked in 2019. Sixteen turtles, 10 males and six females, were tracked in 2020. Fourteen turtles were tracked in both years, but to increase sample size each year of data was treated as independent sample of for all analyses ( $n = 37$ ; 23 males and 14 females; Table 3).

### 3.1 Home ranges

At a threshold of 10 locations per individual there was no relationship between number of telemetry locations and home range size for either 95% MCP ( $F_{1, 36} = 0.59$ ,  $P = 0.447$ ), or 95% KDE ( $F_{1, 36} = 0.18$ ,  $P = 0.673$ ) using carapace length as a predictor ( $F_{1, 36} = 0.68$ ,  $P = 0.415$  95% MCP;  $F_{1, 36} = 1.76$ ,  $P = 0.194$  95% KDE). Home range sizes (log transformed data) were significantly larger using 95% MCPs ( $3.81 \pm 0.66$  ha) than 95% KDEs ( $3.60 \pm 0.86$  ha;  $t = -2.1$ ,  $P = 0.043$ ; Figure 6a-d). Average home range size using 95% MCPs increased from  $3.68 \pm 0.68$  ha to  $3.98 \pm 1.26$  ha in 2020 but decreased from  $4.12 \pm 1.31$  ha to  $2.91 \pm 1.07$  ha using 95% KDE (Figure 6c-d).

There was no statistical difference in home range size between sex ( $F_{2, 36} = 0.85$ ,  $P = 0.436$ , 95% MCP;  $F_{2, 36} = 1.51$ ,  $P = 0.236$ , 95% KDE), year ( $F_{2, 36} = 0.13$ ,  $P = 0.876$ , 95 % MCP;  $F_{2, 36} = 0.04$ ,  $P = 0.959$ , 95% KDE) and no interaction effect was found between sex and year ( $F_{2, 36} = 0.47$ ,  $P = 0.499$ , 95% MCP;  $F_{2, 36} = 0.00$ ,  $P = 0.993$ , 95% KDE) for either home range estimate (Figure 6c-d). However, there were interesting trends found between years. Male 95% MCPs decreased in 2020 ( $2.0 \pm 2.23$  ha) from 2019 ( $3.5 \pm 0.87$  ha) while there was an increase in female 95% MCPs in 2020 ( $7.24 \pm 2.96$  ha) from 2019 ( $3.91 \pm 1.18$  ha; Figure 6c). The pattern of decline between years in males was also found in 95% KDE in 2019 ( $2.87 \pm 1.07$  ha) to 2020 ( $1.71 \pm 2.23$  ha), but in females 95% KDE decreased in 2020 ( $4.90 \pm 2.53$  ha) from 2019 ( $6.18 \pm 2.97$  ha; Figure 6d). Both estimators suggested females had larger home ranges ( $5.34$  ha  $\pm 1.44$  95% MCP;  $5.63$  ha  $\pm 1.84$  95% KDE) than males ( $2.88$  ha  $\pm 0.54$  95% MCP;  $2.36$  ha  $\pm 1.61$  95% KDE) but, again, this difference was not statistically significant.

### 3.2 Interactions with roads and railroads

Road and railroad density was 3.36 km/km<sup>2</sup> within the landscape range and 1.64 km/km<sup>2</sup> within individual home ranges. Willingness to cross roads and railroads was observed in six turtles, three males and three females, whose activity range crossed at least either one of these barrier types. One male and one female activity range crossed Engle Road at different locations. The male crossed Engle Road at the northwestern end of EMNP, while the female crossed near the intersection of Engle and Smith Roads. Two males had activity ranges that crossed the railroad near the same location at the southwestern end of EMNP. Additionally, two females also had activity ranges that crossed the railroad near the same location, near the southwest corner of EMNP (Figures 6a-b). Median distance to roads and railroads was found to have no effect on mean movement ( $P = 0.873$ ) or home range size ( $P = 0.858$ ; Table 4).

### 3.3 Movement

Range of activity (distance between the two furthest points), linear distance (sum of consecutive point distances), and mean movement (linear distance divided by number of points; data log transformed) differed between sample years (two-way MANCOVA  $F_{3,36} = 21.09$ ,  $P < 0.01$ ) but not sex ( $F_{3,36} = 21.09$ ,  $P = 0.289$ ). This overall difference was due to decreased movement of males between sample years (one-way ANOVA  $F_{3,36} = 6.42$ ,  $P = 0.018$ ; Figure 9c) but not range of activity ( $F_{1,36} = 0.75$ ,  $P = 0.393$ ; Figure 7a) or linear distance ( $F_{1,36} = 0.75$ ,  $P = 0.902$ ; Figure 7b). I found that there was no interaction effect between sex and year ( $F_{3,36} = 1.33$ ,  $P = 0.284$ ) and that carapace length was not related to movement and had no effect on sex, year or interactions between any independent variable ( $F_{3,36} = 0.46$ ,  $P = 0.711$  movement,  $F_{3,36} = 0.17$ ,  $P = 0.914$  sex;  $F_{3,36} = 1$ ,  $P = 0.409$  year;  $F_{3,36} = 0.37$ ,  $P = 0.778$  sex + year).

Mean monthly movement (data log transformed) did not differ between sexes (linear-mixed effects model and Wald Chi-Square test  $df = 1$ ,  $P = 0.315$ ) or carapace length ( $df = 1$ ,  $P = 0.912$ ). Additionally, I found no interaction between carapace length, sex ( $df = 1$ ,  $P = 0.854$ ), month ( $df = 2$ ,  $P = 0.801$ ), year ( $df = 1$ ,  $P = 0.640$ ). Additionally, I found no interaction between carapace length, sex and year ( $df = 1$ ,  $P = 0.323$ ), sex and month ( $df = 2$ ,  $P = 0.716$ ), year and month ( $df = 2$ ,  $P = 0.916$ ), and sex, month and year ( $df = 2$ ,  $P = 0.384$ ). I also found no interaction between sex and year ( $df = 1$ ,  $P = 0.441$ ), sex and month ( $df = 1$ ,  $P = 0.291$ ), month and year ( $df = 1$ ,  $P = 0.935$ ) or sex, year and month ( $df = 2$ ,  $P = 0.772$ ). After removing carapace length and then sex, using

reverse variable selection from the linear-mixed effects model, I found that month ( $df = 1$ ,  $P = 0.001$ ) and year ( $df = 2$ ,  $P = 0.003$ ) individually affected mean monthly movement (Figure 8). Again, no interaction was found between month and year ( $df = 2$ ,  $P = 0.855$ ). Random effect of individual variance was high enough (0.169) to conclude that it has an effect on mean monthly movement.

Overall, differences appear to be due to decreases in movement between months and sample year. I found that differences were between 2019 and 2020 among August 2020 and June 2019 ( $P = 0.011$ ) as well as July 2019 ( $P = 0.001$ ).

### **3.4 Habitat selection**

Evidence of habitat selection was found at the second order (landscape level;  $F_{14, 26} = 8.87$ ,  $P = 0.001$ ). Mean distances ratios (mean  $d$  ratios) differ significantly from one for all habitat types ( $\alpha = 0.004$ ) except for emergent wetland ( $P = 0.931$ ), forested wetland ( $P = 0.174$ ), and urban ( $P = 0.810$ ; Table 5). Most preferred habitats (lowest mean  $d$  ratios) consisted of areas with higher water levels (e.g. open water habitats, ditches, scrub-shrub, and vegetated ponds) and as well as nearby habitats that surrounded them (e.g. shoreline, trails, and roads/railroads). Emergent wetlands, forested wetlands, and urban areas were neither selected for nor avoided in this analysis. The least preferred habitats consisted of upland field, agriculture, and upland forest. Relatively few pairwise differences in mean  $d$  ratios between habitat types were found. However, disproportionate values of mean  $d$  ratios were found between semi-permanent open water, trails, roads/railroads, open water, and scrub-shrub habitats as compared to agriculture and upland forest habitats (adjusted  $P$ -values; Table 6). Ditches, shorelines, emergent wetland, and forest wetland habitats were also different than upland forest. Lastly, vegetated ponds were found to be different from urban areas. No evidence of habitat selection was found at the third order (home range level;  $F_{13, 26} = 0.82$ ,  $P < 0.442$ ; Table 5).

### **3.5 Skewness and habitat association of modal centers of activity**

Demonstrating an unequal distribution of locations for each individual within its range of activity, the skewness values for snapping turtles at EMNP were significantly greater than 0 ( $t = 3$ ,  $P = 0.01$ ). All males and 12 out of 14 females showed skewed habitat use. However, there were

two females out of 14 whose skewness values did not differ from 0. There were no differences in skewness between sex ( $F_{1,36} = 1.60, P = 0.215$ ) or sample years  $F_{1,36} = 0.89, P = 0.352$ ).

Modal centers of activity, core ranges, (MCA) were not distributed randomly relative to the habitat types available at Eagle Marsh Nature Preserve ( $G = 30.88, df = 13, P < 0.001$ ). During the active seasons, snapping turtles were associated with forested wetland, semi-permanent open water, and vegetated pond habitats more than expected by chance and emergent wetland, upland field, upland forest and urban habitats less so (Figure 9). The MCA did not differ significantly between sample years ( $F_{1,36} = 0.685, P = 0.410$ ) or sex ( $F_{1,36} = 3.20, P = 0.083$ ).

Table 3 Average size, locations recorded, and range of snapping turtles tracked in spring and summer of 2019 and 2020 at Eagle Marsh Nature Preserve. Data are reported as mean  $\pm$  SE (range).

Parameter	Male	Female
Body Mass	7.42 $\pm$ 4.15 (1.81-14.74)	6.66 $\pm$ 1.04 (4.34-8.17)
Locations per individual	16.00 $\pm$ 4.58 (10-24)	15.79 $\pm$ 3.85 (11-22)
Turtles tracked ( <i>n</i> )	23	14

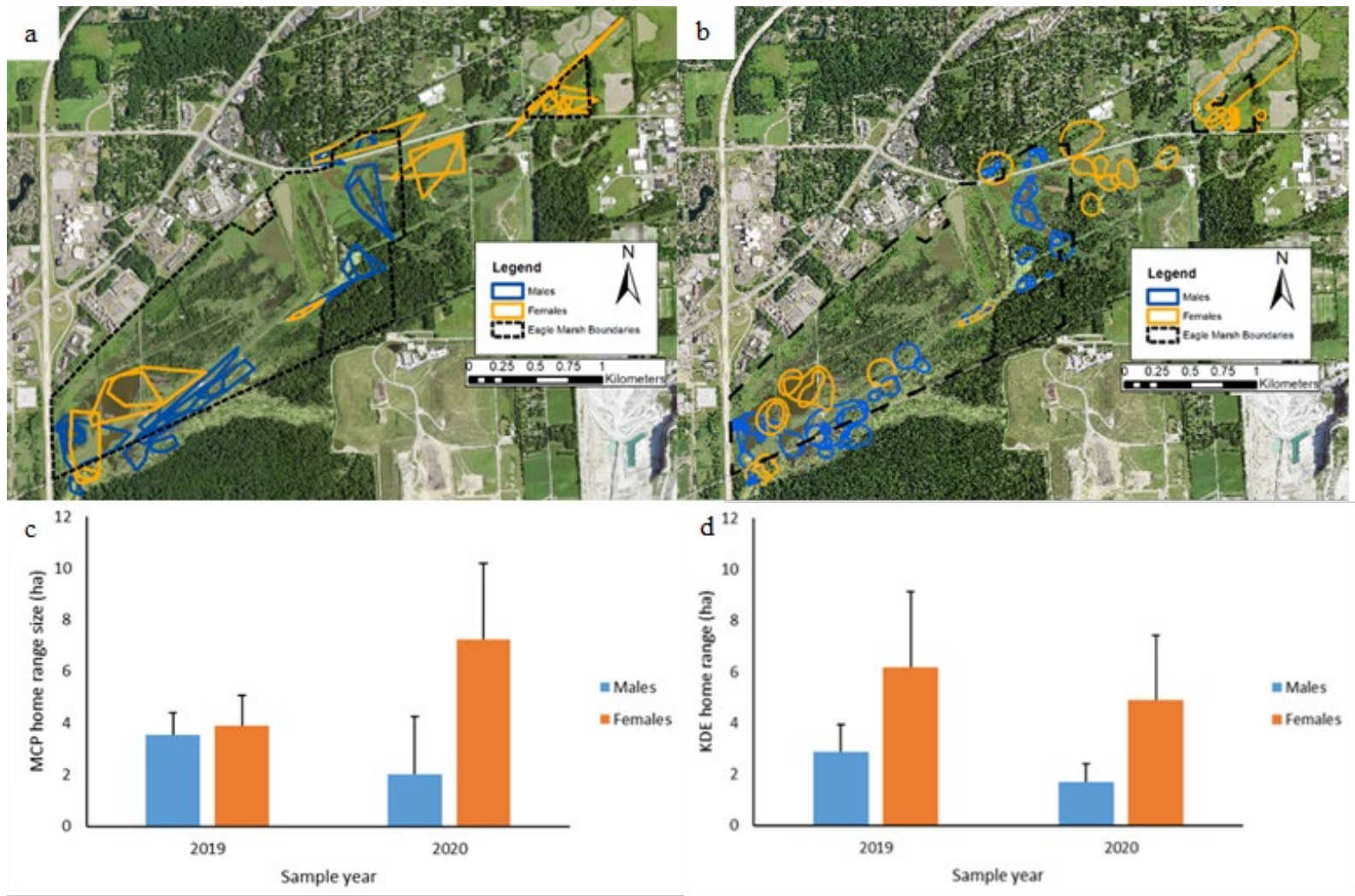


Figure 6 Visual of snapping turtle home range distribution and comparison of mean sizes among sex across both 2019 and 2020 at EMNP. a) Depicts home ranges constructed using 95% MCP. b) Depicts home ranges constructed using 95% KDE. Mean (standard error) home sizes generated using c) 95% MCP and d) 95% KDE.

Table 4 Summary of Chi-Square results of median distance to roads and/or railroads effects on mean movement and home range size.

Dependent Variable	X <sup>2</sup>	df	<i>P</i> -value
Median Mean Movement (m) ( $\geq$ or $<$ )	0.03	1.00	0.87
Median Home Range Size (ha) ( $\geq$ or $<$ )	0.03	1.00	0.86



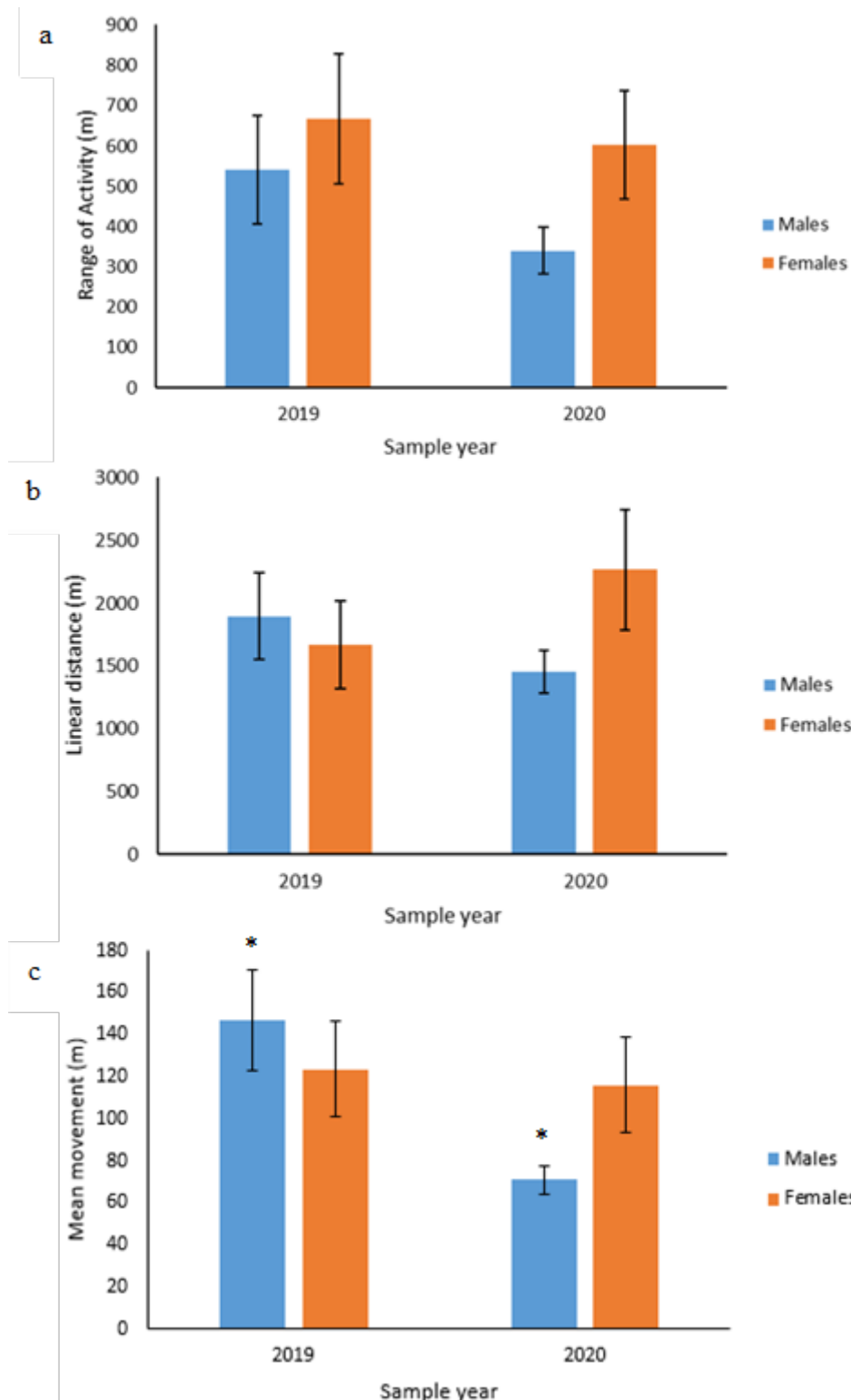


Figure 7 Comparison of mean (standard error) snapping turtle a) range of activity b) linear distance, and c) mean movement between sexes across both 2019 and 2020 at EMNP. An *asterisk* (\*) indicates statistically significant different mean values within sex between years.

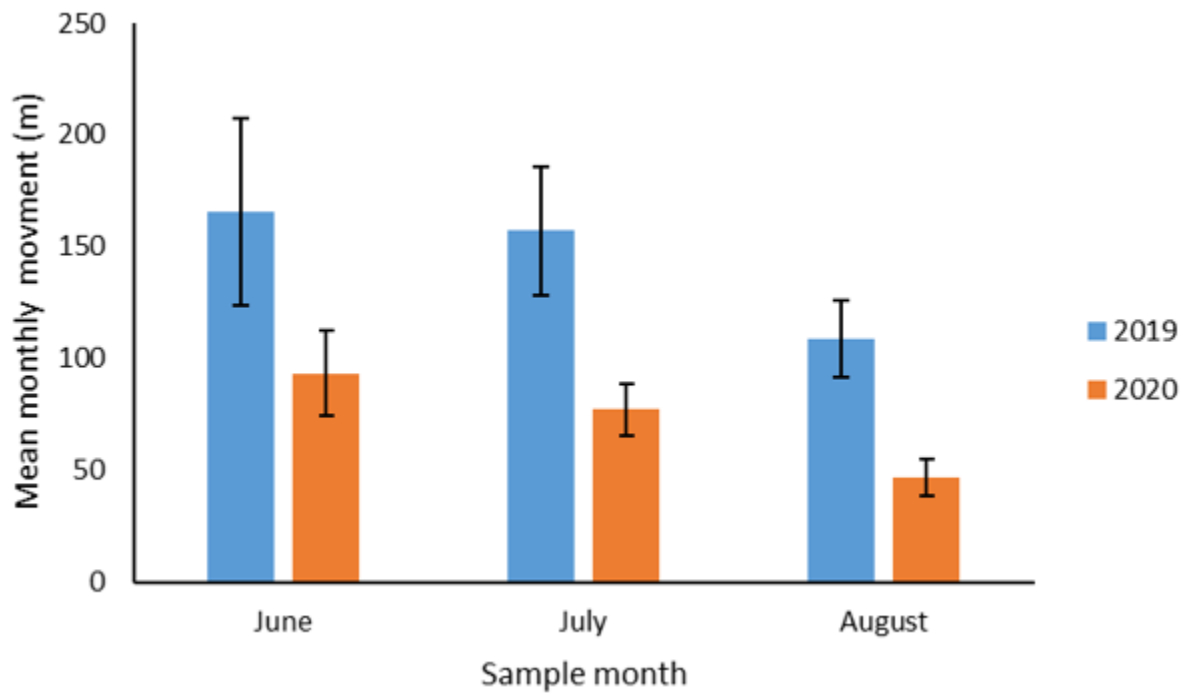


Figure 8 Comparison of mean (standard error) monthly movement during the active season of snapping turtles between sample years 2019 and 2020 at EMNP.

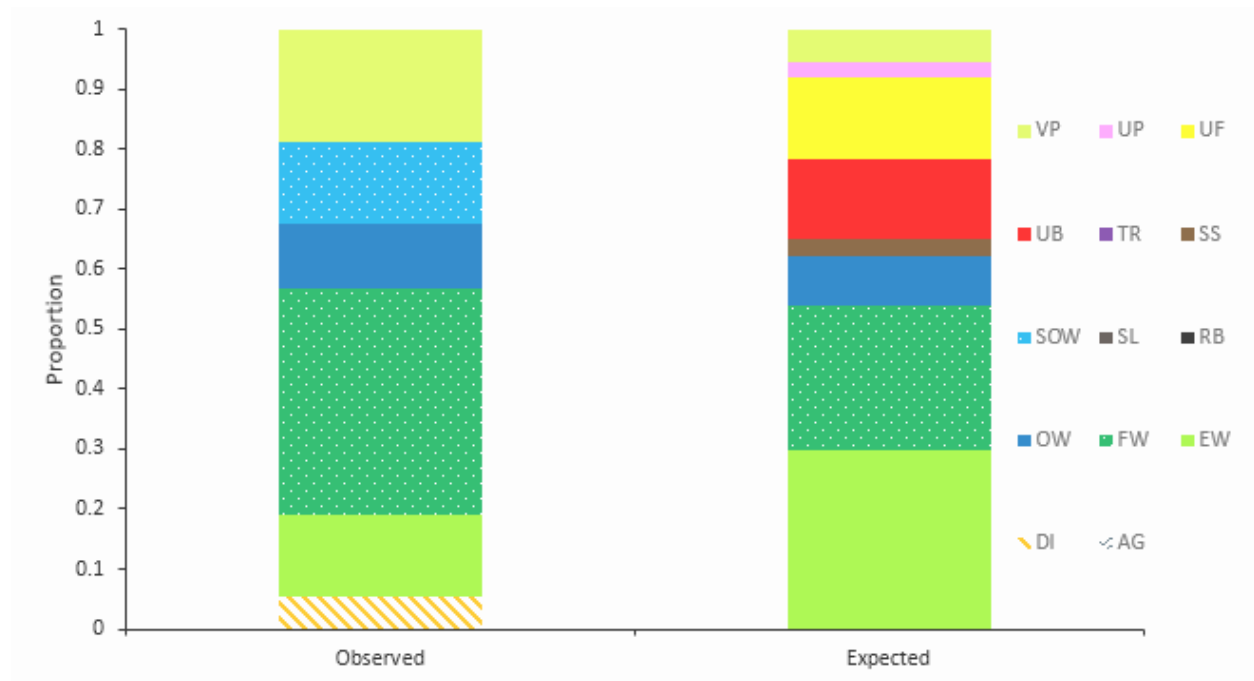


Figure 9 Habitat association of snapping turtle MCA at Eagle Marsh Nature Preserve during springs and summers of 2019 and 2020. The length of the bars represents majority of habitat within MCA during the active season compared to expected values ( $G = 30.88$ ,  $df = 13$ ,  $P < 0.01$ ). Legend refers to different habitat types from Table 1.

Table 5 Comparison of mean distance from random and actual snapping turtle locations to each of 14 habitat types (Table 1). Data were collected in the EMNP, Indiana, during springs and summers of 2019 and 2020. Adjusted  $t$  and  $P$  values (boldface typed indicates significant different) are from post hoc tests of disproportion for multivariate analyses of variance (MANOVAs; landscape-level habitat selection:  $F_{13, 26} = 8.87$ ,  $P = 0.001$ ; home-range-level habitat selection:  $F_{13, 26} = 0.82$ ,  $P = 0.442$ ). AG = Agriculture, DI = Ditch, EW = Emergent wetland, FW = Forested wetland, OW = Permanent open water, RB = Road/Barrier, SL = Shoreline SOW = Semi-permanent open water, SS = Scrub-shrub, TR = trails, UB = Urban, UF = Upland field, UP = Upland forest VP = Vegetated pond.

Habitat Type	Distance from random points (m)	Distance from actual points (m)	Mead $d$	Test statistic	
	$\bar{X} \pm SE$ (range)	$\bar{X} \pm SE$ (range)		$t$	$P$ -value
Landscape-level habitat selection					
AG	2143 $\pm$ 61 (0-4760)	2688 $\pm$ 69 (0-4542)	<b>1.25</b>	-5.89	>0.01
DI	170 $\pm$ 6 (0-619)	131 $\pm$ 5 (0-515)	<b>0.77</b>	5.03	>0.01
EW	28 $\pm$ 2 (0-215)	27 $\pm$ 2 (0-181)	0.96	-	0.93
FW	35 $\pm$ 2 (0-259)	36 $\pm$ 2 (0-0-250)	1.00	-	0.17
OW	210 $\pm$ 8 (0-731)	146 $\pm$ 7 (0-623)	<b>0.69</b>	6.24	>0.01
RB	248 $\pm$ 9 (0-796)	165 $\pm$ 6 (0-528)	<b>0.67</b>	7.48	>0.01
SL	930 $\pm$ 36 (10-3189)	734 $\pm$ 33 (20-2694)	<b>0.79</b>	-	>0.01
SOW	219 $\pm$ 7 (0-640)	137 $\pm$ 5 (0-509)	<b>0.63</b>	9.31	>0.01
SS	338 $\pm$ 10 (0-855)	242 $\pm$ 9 (0-740)	<b>0.71</b>	7.14	>0.01
TR	193 $\pm$ 8 (0-790)	122 $\pm$ 5 (0-519)	<b>0.63</b>	-	>0.01
UB	189 $\pm$ 7 (0-657)	187 $\pm$ 6 (0-605)	0.99	0.24	0.81
UF	54 $\pm$ 3 (0-293)	61 $\pm$ 3 (0-248)	<b>1.13</b>	-	>0.01
UP	96 $\pm$ 4 (0-423)	143 $\pm$ 5 (0-463)	<b>1.50</b>	-7.46	>0.01
VP	191 $\pm$ 6 (0-532)	150 $\pm$ 6 (0-463)	<b>0.79</b>	4.98	>0.01
Home-range-level habitat selection <sup>a</sup>					
AG	2688 $\pm$ 69 (0-4542)	2575 $\pm$ 54 (11-4748)	0.96		
DI	131 $\pm$ 5 (0-515)	124 $\pm$ 4 (0-494)	0.95		
EW	27 $\pm$ 2 (0-181)	24 $\pm$ 1 (0-157)	0.90		
FW	36 $\pm$ 2 (0-0-250)	29 $\pm$ 2 (0-266)	0.83		
OW	146 $\pm$ 7 (0-623)	156 $\pm$ 5 (0-653)	1.07		
RB	165 $\pm$ 6 (0-528)	164 $\pm$ 5 (3-734)	0.99		
SL	734 $\pm$ 33 (20-2694)	805 $\pm$ 27 (35-3137)	1.10		
SOW	137 $\pm$ 5 (0-509)	149 $\pm$ 4 (0-593)	1.09		
SS	242 $\pm$ 9 (0-740)	234 $\pm$ 7 (0-7620)	0.97		
TR	122 $\pm$ 5 (0-519)	116 $\pm$ 4 (5-630)	0.95		
UB	187 $\pm$ 6 (0-605)	184 $\pm$ 4 (0-591)	0.99		
UF	61 $\pm$ 3 (0-248)	58 $\pm$ 2 (0-241)	0.95		
UP	143 $\pm$ 5 (0-463)	141 $\pm$ 4 (0-452)	0.98		
VP	150 $\pm$ 6 (0-463)	144 $\pm$ 4 (0-467)	0.96		

<sup>a</sup> Snapping turtles were found to not select habitat at the third-order of selection. Post hoc tests were not run to determine differences between random and actual distances.

Table 6 Tukey HSD test of mean distance ratios (mean  $d$ ) of each of 14 habitat types (Table 1). Habitats are ranked from most preferred (low mean  $d$  values) to least preferred (high mean  $d$  values). Pairwise adjusted  $P$  values (significantly different comparisons are in boldface type) for habitat selection of home ranges from the population range are given on the diagonal. SOW = Semi-permanent open water, TR = trails, RB = Road/Barrier, OW = Permanent open water, SS = Scrub-shrub, DI = Ditch, SL = Shoreline, VP = Vegetated pond, EW = Emergent Wetland, UB = Urban, FW = Forested Wetland. UF = Upland field, AG = Agriculture, UP = Upland forest

	Mean $d$	SOW	TR	RB	OW	SS	DI	SL	VP	EW	UB	FW	UF	AG
SOW	0.63													
TR	0.63	1.00												
RB	0.67	1.00	1.00											
OW	0.69	1.00	1.00	1.00										
SS	0.71	1.00	1.00	1.00	1.00									
DI	0.77	1.00	1.00	1.00	1.00	1.00								
SL	0.79	1.00	1.00	1.00	1.00	1.00	1.00							
VP	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00						
EW	0.96	0.82	0.88	0.92	0.98	0.99	1.00	1.00	1.00					
UB	0.99	0.43	0.51	0.60	0.78	0.82	0.95	0.89	<b>&lt;0.01</b>	1.00				
FW	1.00	0.82	0.87	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00			
UF	1.13	0.08	0.11	0.15	0.27	0.31	0.54	0.41	0.70	0.99	1.00	0.99		
AG	1.25	<b>&lt;0.01</b>	<b>0.01</b>	<b>0.01</b>	<b>0.02</b>	<b>0.03</b>	0.09	0.05	0.16	0.65	0.94	0.65	1.00	
UP	1.50	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	0.99	<b>0.04</b>	0.20	<b>0.04</b>	0.69	0.99

## CHAPTER 4. DISCUSSION

Assessment of movement data, home range sizes and population-scale distributions of habitat showed that adult snapping turtles at EMNP have relatively stable home range sizes and that males and females utilize relatively the same amount of space during the active season. Movement data also suggests male and female snapping turtles travel similar distances within the property. However, there is some indication that movement patterns could be subject to change temporally due to habitat changes. Meanwhile, I found no effect of roads and railroads on home range size or movement.

### 4.1 Spatial use

Home range sizes were on average smaller than those found in previous studies along the coast of Lake Ontario within five areas comprising more natural habitat [Broadwing Lake, Lake Sasjewun, Cootes Paradise, Lynde Creek Marsh northeast side Algonquin Provincial Park; average area = 667.1 ha; average home range size = 38.94 ha; (Brown, Bishop, & Brooks, 1994; Galbraith, Chandler, & Brooks, 1987; Paterson et al., 2012) and one urban wetland, Cootes Paradise Marsh; area = 250 ha, average home range size = 40.1ha; (Piczak & Chow-Fraser, 2019)]. Home range sizes were similar to those found in a recent study (Lake Inbanuma; area = 1,155 ha; home range size = 4.98 ha) conducted along a human altered landscape within an introduced range of this species (Kobayashi et al., 2006). Movement of the snapping turtles at EMNP was found to be less than that of individuals in large natural areas along Lake Ontario (Brown et al., 1994) and in heavily modified riverine habitats in Indiana (McLane, 2015; Ryan et al., 2014). An explanation of these differences in movement could be due to the natural sites offering larger areas of quality habitat and riverine habitats offering more pathways for dispersal and migration when compared to EMNP (Burridge, Craw, & Waters, 2006; Galbraith et al., 1987). The above studies show snapping turtles have larger home ranges and movements within larger landscapes. The study performed in the introduced range of *C. serpentine* showed altered landscapes have similar home range sizes despite having a larger study area. These comparisons imply that home ranges and movement are constrained by habitat availability and fragmentation. Overall, these results suggest

that minimizing fragmentation and maximizing habitat availability will be beneficial in the wetland complex at EMNP.

Home range sizes were approximately twice as large in females than males for both methods of estimation but did not differ statistically between sex or year. Many studies of Snapping Turtle spatial ecology suggest males have smaller home ranges than females (Galbraith et al., 1987; Kobayashi et al., 2006; Obbard & Brooks, 1981; Pettit, Bishop, & Brooks, 1995). Males commonly travel long distances in April and May to forage and in search for mates. The fact that female home ranges were larger than males in these studies is often attributed to the need to search longer distances to find nesting habitat (Brown et al., 1994; Congdon et al., 1983; Marlen & Fischer, 1999). Females may have had to travel further due to scarcity of quality nesting habitat at EMNP.

Mean female home range increased from 2019 to 2020 based on MCPs but decreased based on KDEs, while mean male home range decreased between years based on both MCPs and KDEs. The difference in home range size estimates calculated using these two estimators is possibly due to differences in the inherent properties of the estimators. Female movement between consecutive locations increased in 2020 from 2019 which could increase MCP sizes. However, KDE is subject to variation with small sample size (Kazmaier, Hellgren, & Ruthven, 2002; Rettie & McLoughlin, 1999). More radiolocations were recorded in 2020 than 2019, which may have increased the precision of estimation via KDE (De Solla, Bonduriansky, & Brooks, 1999), resulting in a decrease in mean female home range size in 2020. This may also have increased the confidence in my estimate of male home range ranges in 2020 and explain why they were smaller than initially estimated in 2019. However, I cannot account for all movements of the turtles throughout the active season due to gaps in radiolocation dates. The inherent properties of the estimators must be considered when drawing conclusions about home range size over time.

The density of roads and railroads within the population's landscape and individual's home range had no significant effect on the size of individual home ranges or mean movement. Six home ranges included roads, the railroad, or both. Even though mean movement values were smaller (116 m) than those from previous studies (~150 m) and road and railroad density levels at ENMP are moderate (3.36 km/km<sup>2</sup>), both these results and previous studies (McLane, 2015; Ryan et al., 2014) suggest that roads and railroads do not impede movement (Piczak & Chow-Fraser, 2019; Piczak, Markle, & Chow-Fraser, 2019). Because barriers do not seem to prevent movement, roads and railroads may be a source of mortality for snapping turtles at EMNP.

Overall, I did not find evidence for sex-based differences in snapping turtle movement at EMNP, although mean movement of males decreased significantly from 2019 to 2020. I also found mean monthly movement differed between sample years and months. Movement in August was especially lower as compared to other months. Other studies regarding individual movement have found similar temporal changes of increased movement related to habitat augmentation (Aresco, 2005; Ryan et al., 2014). Water levels at EMNP in 2019 were high in May to June but exceedingly low in July and August following a modification to drainage at the site. This decrease in water level may have reduced wetland ability and connectivity, which would impede movement. This corroborates prior work suggesting snapping turtles are sensitive to water level (Piczak & Chow-Fraser, 2019; Ryan et al., 2014). Additionally, my study suggests males may be more sensitive to aquatic habitat change than females.

## **4.2 Habitat use**

I met my objective to determine what habitat types *C. serpentina* primarily utilize within an urban wetland complex by assessment of skewness of distributions, modal center of activity (MCA) habitat associations, and habitat selection. I found snapping turtles at EMNP have non-random use of habitat during the active season. Habitat selection and use data indicates snapping turtles in this population are aquatic generalists that utilize trails and road/barriers as nesting sites. Additionally, my habitat data suggest the use of ditches for travel from one wetland to another.

Habitat selection corroborated habitat association analysis in that turtles chose home ranges (second-order selection) closer to open water habitats, ditches, scrub-shrub wetlands, and vegetated ponds, shoreline, trails, and roads/barriers. However, there was no selection or avoidance of forested wetland, despite habitat association of MCAs to this habitat type. No aquatic habitat type was preferred over another, but aquatic habitats were selected over agriculture and upland forest. Trails and roads/barriers were chosen over agriculture and upland forest as well as vegetated ponds over urban areas. Previous research suggests females utilize roads and barriers as nesting sites (DeCatanzaro & Chow-Fraser, 2010; Piczak et al., 2019), and males position themselves close to these areas to increase mating opportunities (Brown & Brooks, 1993). Snapping turtles at ENMP may be using roads/barriers and trails as nesting sites. However, it is important to note that roads/barriers and trails are in close proximity to a majority of wetlands at EMNP which can also give a selection result.



Selection of ditch habitat type provides evidence of the utilization of ditches to disperse to other wetland areas within the property (Smit, Grant, & Devereux, 2007). The selection of all aquatic habitat types, other than forested and emergent wetland, over upland habitats and agriculture suggests the species is an aquatic habitat generalist, which aligns with previous research (Iverson, 1982; Paterson et al., 2012). Additionally, the selected aquatic habitat types, corroborate with previous literature noting Snapping Turtle preference for stagnant eutrophic habitats (Galbraith et al., 1987), with plenty of submergent-emergent structure and loose substrates (Brown & Brooks, 1994; Pell, 1941). This means the aquatic niche width for this population is large (Roughgarden, 1972) and individuals have adequate resources within their home ranges. Lastly, I found no evidence of selection of habitats at locations from those available within home ranges (third-order selection), further supporting this conclusion.

Lack of selection at the third order (home range level) may be explained by individual habitat specialization (Paterson et al., 2012). This may mean that variables important to adult snapping turtles at this level were not measured here (e.g., water level) and that there could still be selection at a finer scale, such as the fourth order (selection of specific resources within a habitat type). A long-term study focusing on individual specialization on different habitats and how they may change within an individual's lifetime, would help us understand which resources are important to *C. serpentina* within urban wetlands. This could also help determine whether individuals need to select for habitat within their home range because they already orient their home ranges to include all necessary resources.

Skewness data indicate that the distribution of snapping turtle home ranges at EMNP is largely non-random with no differences between sex or sample year. I found that individuals did not use wetland space evenly during the active seasons. Only two females deviated from this pattern by having an even spread of locations through their total range, suggesting equal use of habitat within their active range. These two females primarily used ditches during the active season, which could explain this behavioral difference.

The MCAs were also not distributed randomly relative to available habitat types and did not differ significantly between sex or year. MCAs were more associated with forested wetland, vegetated pond, semi-permanent open water and ditches than expected, and less associated with upland habitats, and emergent wetland than expected by chance, respectively. 37.8% of MCA associations were with forested wetlands, emphasizing the importance of this habitat type within

those individuals home range. Previous studies assessing habitat preferences of snapping turtles found associations with abundant vegetation, submerged logs, slow moving water and muddy substrates (Ernst & Lovich, 2009; Galbraith et al., 1987; Pell, 1941). The positive association of slow flowing, structured, soft bottom ditches at EMNP indicates the use of this habitat facilitates movement among wetlands within the complex (Smit et al., 2007).

### **4.3 Conclusions and management implications**

From the perspective of Snapping Turtle spatial use, Eagle Marsh Nature Preserve seems to have aspects of natural, urban, and riverine habitats. Home range size is impacted by wetland size and connectivity. Smaller, isolated habitats result in reduced spatial use (Smith & Cherry, 2016) and larger/more connected habitats result in greater spatial use (McLane, 2015; Paterson et al., 2012; Pettit et al., 1995; Ryan et al., 2014). Larger, more connected wetlands in natural areas give turtles more opportunity to move throughout the landscape to forage, search for mates, and find nesting sites (Congdon et al., 1983; Marlen & Fischer, 1999). Snapping turtles at ENMP do not appear to be deterred by roads/barriers and trails, but these obstacles do offer some difficulty and risk associated with crossing them. However, road and trail sides may provide some nesting sites for females (DeCatanzaro & Chow-Fraser, 2010; Marchand & Litvaitis, 2004). Male turtles will also occupy these areas when seeking potential mating encounters (Brown & Brooks, 1993).

Studies in riverine habitats have shown individuals can travel large distances in a relatively short amount of time and suggest turtles must do so to meet normal active season needs due to resource spacing (Kobayashi et al., 2006; McLane, 2015; Ryan et al., 2014). This is due to the linear nature of riverine habitats which limits the directions turtles are able to move, but does not limit the length of those movements (Ryan et al., 2014). At EMNP, individuals with home ranges in larger, connected wetlands or ditch habitats made larger movements on average than individuals found in smaller, more isolated wetlands.

Turtles that reside in smaller, isolated wetlands are more sensitive to resource change and hydrology, which could cause changes in movement patterns (Smith & Cherry, 2016). Variability in EMNP of water levels were observed in 2019. Both my findings and previous research suggest turtle populations are sensitive to low water levels (Galbraith et al., 1987) and urban habitats are susceptible to changes in hydrology, weather patterns, and alteration of surrounding land use

(Cosentino et al., 2010). This information emphasizes the importance of mitigating and studying the stochastic change in water levels at EMNP.

The findings from my study, along with the knowledge that turtles and semi-aquatic species will utilize ditches and drainage pipes (Burridge et al., 2006; Smit et al., 2007), highlights the need for managers to maintain connectivity within large wetland systems containing a variety of aquatic habitats with high turtle density, instead of focusing on specific habitat types (Pringle, 2001; Roe & Georges, 2007). Additionally, mitigation focus on deterring individuals from transportation thoroughways could be useful given turtles do not appear to avoid these features, despite their increased mortality risk. For snapping turtles to persist at EMNP, I recommend culverts (at least 24in height and width) be installed under roadways and railways to increase connectivity and avoid transportation related mortality (Roe & Georges, 2007; Roe, Gibson, & Kingsbury, 2006). Short concrete fencing construction along Engle Road and railroads could reduce possible vehicular based mortality (Langen, 2011; Piczak & Chow-Fraser, 2019). The protection of nesting mounds along trails and roads could increase recruitment. Lastly, I recommend creation of riparian buffer zones consisting of trees, shrubs and perennial plants. These buffer zones will assist in with reducing rapid changes in water levels associated with storm water runoff, provide habitat stability (Bodie, 2001; Roe & Georges, 2007; Semlitsch & Bodie, 2003) and reduce overland pollutants. Buffer zones trap excess water and pollutants from excess discharge within the sediment and plant roots (Grimm et al., 2008). Implementation of these recommendations can reduce the need for responding to flood events and minimize the movement of turtles to avoid unnecessary mortality risks.

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