

EASTERN MASSASAUGA RATTLESNAKE POPULATION AND
HABITAT ECOLOGY IN SOUTHERN MICHIGAN

By

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ABSTRACT

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The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) is a federally Threatened species due to factors that include degradation and fragmentation of habitat and corresponding population declines throughout the species range. Further, a fungal pathogen (*Ophidiomyces ophiodiicola*) which affects snake species across North America is a potential threat to massasauga populations. The ability to identify and assess suitability of current and potential habitats, to effectively locate massasaugas, and to determine population demographic rates, are warranted for conservation of the species. In 2015 and 2016, we identified 27 20-ha study sites of varying habitat quality throughout southern Michigan where massasaugas were known to occur historically. At these sites, we applied and validated a habitat suitability index (HSI) model by quantifying the habitat attributes defined by the model (% live and dead herbaceous cover, number and DBH of trees and shrubs >3 m in height, % area in early successional deciduous upland and wetland). Habitat suitability index scores across all sites ranged from 0.21 to 0.95. We used HSI scores to predict the likelihood that a given site is occupied by massasaugas (i.e., occupancy probability). For sites approaching maximum suitability (HSI = 1), predicted occupancy was > 0.5, while for poor suitability sites (HSI scores approaching 0) predicted occupancy was < 0.2. We used resource selection probability function analysis to quantify habitat use versus availability and found a positive relationship between probability of use and % live and dead herbaceous cover, and a negative relationship between probability of use and number of stems and DBH of trees >3 m in height.

To aid researchers and managers in successfully detecting massasaugas in occupied habitat we developed and tested a visual encounter survey method. We quantified detection probability for massasaugas using this method and determined factors important in influencing detection probability (i.e., environmental conditions, surveyor conditions) at 4 study sites. In 2016, we completed 54 detection surveys with 5 surveyors; we detected ≥ 1 massasauga at 11 surveys. Our null detection probability was 0.31. We found that time spent searching and minimum air temperature were the most important correlates of detection probability of the variables we measured: detection probability approached 1.00 as searcher time exceeded 90 minutes and approached 0.80 on cooler mornings (down to 12.8°C).

At six of our 27 study sites, we obtained sufficient massasauga locations (i.e., ≥ 30) via radio telemetry or random encounters to estimate survivorship for the study region. In total, we telemetered 22 adults, 6 juveniles, and 10 neonates using both surgical implantation of transmitters and external attachment. For the 137-day study period during the active season, adult massasauga survivorship estimated using the Mayfield method was 0.767 (SE = 0.016). For juveniles and neonates, apparent survivorship was 0.65. Radiograph imagery or palpation of 17 gravid females resulted in embryo counts ranging from 5 to 18; litter counts in the field ranged from 1 to 15 ($n = 6$). We radio tracked neonate massasaugas from 2 to 26 days and found that they moved up to 551.2 m from the gestation site.

Snake fungal disease is a potential threat to massasauga populations and has been found in Michigan. To determine the presence of snake fungal disease at our study sites, we collected skin swab samples of all captured massasaugas. Out of 24 and 46 samples collected in 2015 and 2016, respectively, 3 individuals at good and optimal suitability sites tested positive for the pathogen in two counties where the pathogen had not yet been documented.

For Stella.

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PREFACE

This dissertation was formatted following general guidelines for the Journal of Wildlife Management and Chapters 1, 2, and 3 are treated as stand-alone manuscripts; therefore, some repetition of sections occurs between chapters. Chapter 4 offers overall conclusions, recommended management guidelines, and future research directions for the massasauga. Information and findings relating to this work have been presented at local, state, regional, and national conferences, as well as through various publicly-accessible outlets (Appendix A).

The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*; hereafter massasauga) is one of three massasauga subspecies in North America and ranges from central New York and southern Ontario in the east to Iowa, Minnesota, and Missouri in the west, and includes southern Wisconsin, Michigan, Illinois, Indiana, Ohio, and Pennsylvania. Massasaugas are known to be in decline rangewide due to habitat loss and degradation, human persecution, and population fragmentation due to land use change. As a result, massasaugas were designated as federally Threatened as of October 31, 2016. Massasauga populations in Michigan have been considered among the most viable rangewide due to a relatively high number of known populations, with adult survivorship estimates for the species ranging from 0.66 to 0.95 within the state (Jones et al. 2012). Still, survivorship is known to vary throughout the species' range, and little information is available regarding survival of neonate and juvenile stages.

Regarding the reduction in habitat quality through loss and degradation is the notion that natural processes, such as fires, grazing, and flooding events that historically maintained early successional vegetation communities and suitable habitat conditions for massasaugas no longer function within their historical range of variability. For example, wildfire once maintained suitable open herbaceous vegetation types (e.g., grasslands) by preventing succession, yet with

land use change and human development, wildfire has been removed from the landscape in many massasauga habitats rangewide, resulting in the loss of suitable habitats for the species (Dovčiak et al. 2013). Thus, habitat assessment and active management is necessary to identify and maintain suitable areas for remaining massasauga populations. Further, the ability to detect massasaugas in potential habitats is important for managers as they locate areas of conservation concern, warranting standardized, reproducible methods for detecting massasaugas within their habitats. Finally, the documentation of a fungal infection (*Ophidiomyces ophiodiicola*) among free-ranging snakes is a recently emerged and important potential threat to viability of massasauga populations (Allender et al. 2015). In light of these issues, objectives for this project focus on eastern massasauga rattlesnake conservation, detectability, habitat use, and demographics in southern Michigan. These objectives were:

- 1) Validate the Bailey (2010) massasauga Habitat Suitability Index (HSI) model across a range of habitat conditions in southern Michigan and explore other habitat model structures (Chapter 1).
- 2) Determine factors affecting massasauga detectability and recommend a standardized survey methodology that is effective and efficient (Chapter 2).
- 3) Estimate probability of occupancy of massasaugas for habitats classified as low, moderate, and high quality based on Bailey's (2010) HSI model (Chapter 1).
- 4) Estimate population demographic rates (survival, fecundity) for adult, juvenile, and neonate massasaugas for a range of habitat conditions in southern Michigan (Chapter 3).
- 5) Quantify presence of snake fungal disease in Michigan's massasauga populations (Appendix B).

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CHAPTER 1: ASSESSING HABITAT SUITABILITY AND PREDICTING OCCUPANCY IN POTENTIAL EASTERN MASSASAUGA RATTLESNAKE HABITAT

Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Ryan Colburn, Daniel Kennedy

ABSTRACT

Eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) are a federally Threatened species, due in part to degradation and fragmentation of habitats. Where concerns for habitat exist, the ability to identify and rank habitat suitability will inform management. Our goal was to evaluate a habitat suitability index (HSI) model for massasaugas in southern Michigan across varying habitat qualities. We *a priori* applied the HSI model to 27 20-ha sites where massasauga presence was confirmed within the past 20 years (9 were re-confirmed during this study). We used a stratified random sample to collect vegetation attributes at each site and used these attributes to calculate HSI scores. Habitat suitability index scores ranged from 0.21 (low quality) to 0.95 (high quality), and we found massasaugas at sites that represented medium to high quality scores, suggesting that the relationship between HSI score and massasauga occupancy was unreliable. However, HSI scores based on vegetation data collected at massasauga locations performed better, with HSIs ranging from 0.60 – 1.00 HSI, suggesting that the HSI model is best suited for localized scales (i.e., the 20 x 5 m sampling plot). On a subset of sites (n = 4) we mapped kernel use areas from massasauga locations collected through visual encounter and radio telemetry and used a resource selection probability function (RSPF) to verify shape of the suitability index relationships. The RSPF corroborated the importance of the habitat variables defined by the habitat suitability index model for massasaugas, illustrating positive relationships between probability of use and % live and dead herbaceous cover, and negative relationships between probability of use and DBH and number of woody stems ≥ 3 m in height. Finally, based on HSI scores and our records of confirmed occupancy by site, we

estimated occupancy for sites of varying suitability. For sites approaching maximum suitability (HSI = 1), predicted occupancy by massasaugas exceeded 0.5 (i.e., we can expect over 50% of sites at this level of suitability to be occupied). Alternately, for minimally suitable sites (HSI scores approaching 0), predicted occupancy was < 0.2 . These results link HSI scores to a population state, in this case occupancy probability, and illustrate that sites with a relatively low habitat suitability index can be occupied by massasaugas. Greatest habitat management benefits include improving these low suitability sites to facilitate population expansion. Habitat assessments using the variables described here may be used by managers as a guide to determine current and potential habitats and as a means of determining the amount and type of habitat management needed to improve habitats for conserving the massasauga.

INTRODUCTION

Populations of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*; hereafter, massasauga) are declining range wide (e.g., Szymanski 1998, Shoemaker and Gibbs 2010). In 2016, the U.S. Fish and Wildlife Service listed massasaugas as federally Threatened, partly because of habitat degradation and fragmentation (USFWS 2016). The range of massasaugas extends from central New York and southern Ontario in the east to Iowa, Minnesota, and Missouri in the west, and includes southern Wisconsin, Michigan, Illinois, Indiana, Ohio, and Pennsylvania (USFWS 2016). Considering the federal Threatened status, decline and degradation of massasauga habitat rangewide, and importance of identifying and conserving remaining habitats for massasaugas, it is imperative to understand relationships between habitats and population states. The ability to quantify quality, or suitability, of habitats is an invaluable tool for managers as they assess and manage sites occupied by massasaugas.

Massasauga habitat is generally characterized by structural attributes that include limited canopy cover and early-successional vegetation (e.g., “low or sparse vegetation”; Reinert and

Kodrich 1982:170) in upland and wetland vegetation types rangewide (e.g., Johnson 1995, Moore and Gillingham 2006, Durbian et al. 2008, McCluskey et al. 2018). Much available literature describes vegetation types where massasaugas occur as lowland bogs, peatlands, and fens (e.g., Johnson 1995, Marshall et al. 2006), and upland open, dry, herbaceous grasslands, and early successional deciduous vegetation types (e.g., Durbian et al. 2008, McCluskey et al. 2018). Although highly varied, predominant plant species include sedges (*Carex* spp.), dogwoods *Cornus* spp.), rushes (*Juncus* spp.), and cattails (*Typha* spp.; Marshall et al. 2006, Moore and Gillingham 2006, Durbian et al. 2008). Few studies quantitatively described specific structural aspects of habitat (e.g., Bissell 2006, Moore and Gillingham 2006, Bailey 2010). For a massasauga population in southeastern Michigan, Moore and Gillingham (2006:750) reported that during the active season (i.e., “summer months”), massasaugas avoided shrubs >5 m in height and primarily used areas with an open canopy and high amounts of groundcover vegetation ranging from 0.5 – 1.5 m in height. Similarly, for a southwestern Michigan population, Bissell (2006) identified optimally suitable ranges of specific habitat components for the massasauga including live herbaceous cover (optimal values ranging from 60-100% cover), dead herbaceous cover (51.5-96% cover), stem density of trees and shrubs ≥ 3 m in height (0-60 stems/ha), and basal area of trees and shrubs ≥ 3 m in height (0-0.116 m²/ha). Such vegetation structures, characteristic of open herbaceous and early successional vegetation types, are consistent with massasauga needs for thermoregulation via basking or hiding during the active season, and are important aspects of reproduction and digestion (e.g., Foster et al. 2009, Harvey and Weatherhead 2010).

Habitat suitability index (HSI) models define and evaluate suitability of a given area for species of interest to guide habitat management. These models are a tool based on quantification

of habitat structure and composition (USFWS 1981). Numerous HSI models exist for multiple taxa for game and non-game species, including barred owl (*Strix varia*; Allen 1987), eastern wild turkey (*Meleagris gallopavo sylvestris*; Schroeder 1985), American alligator (*Alligator mississippiensis*; Newsom 1987), and sea cucumber (*Apostichopus japonicus*; Zhang et al. 2017). Habitat suitability index models have been used to guide habitat management, determine habitat use by species (e.g., Dussault et al. 2006), and can be implemented without observing the species of interest within the habitat – an especially important characteristic for cryptic species such as massasaugas. To confirm multi-site applicability of these models for a range of habitat conditions, model validation is an important step (Roloff and Kernohan 2006). For example, Soniat and Brody (1988) validated an HSI model for American oyster (*Crassostrea virginica*; Cake 1983) by correlating oyster density with HSI values across multiple sites. Based on field studies and observation of environmental conditions relevant to the model (i.e., the model variables), Soniat and Brody (1988) simplified the Cake (1983) model by including negative population effects on the species. Soniat and Brody (1988) noted that while HSI models are intended for multi-site use, location-specific modifications to the model may be necessary. Further, accounting for uncertainty arising from multi-site application of HSI models will aid in interpretation and management (e.g., Zajac et al. 2015).

Previous work in southwestern Michigan quantified habitat suitability requirements for massasaugas (Bissell 2006, Bailey 2010), and resource selection in managed landscapes (Bailey et al. 2012). Bissell (2006) developed a massasauga HSI model for southwestern Michigan based on vegetation samples collected in 2004 and 2005 in areas used by telemetered massasaugas. This model was later modified by Bailey (2010) based on vegetation sampling and quantification of massasauga habitat selection patterns and movements for the same population in 2008 and

2009. This model relies on vegetation composition and structural attributes (e.g., availability of live and dead herbaceous cover, woody stem density, and basal area) at multiple spatial scales (e.g., the structure of microhabitat selected by snakes, landscape-level variables including the percent of the site made up of early successional deciduous upland or lowland vegetation types). These habitat elements related to several population fitness measures of massasaugas (e.g., survivorship, reproductive rates, home range size; Bailey 2010). The revised model was built from observations in relatively high quality habitat, so to appropriately validate this model a range of habitat conditions across southern Michigan should be assessed (e.g., Roloff and Kernohan 1999). Having a validated HSI model would aid natural resource managers in planning and implementing more effective habitat management practices to maintain or enhance massasauga habitat. Resource selection can be used to determine habitat attributes selected by massasaugas to illustrate whether specific habitat components are used disproportionately (i.e., visited more frequently than others) among what is available within a given area (Lele and Keim 2006).

Validation of HSI models involves correlating measures of population states (e.g., occupancy, abundance, use, survival) with model outputs (Roloff and Kernohan 2006). Occupancy probability is defined as the likelihood a site is occupied by a species (MacKenzie et al. 2006:26), has been used to monitor populations, and is useful for cryptic or rare species, such as massasaugas, when capture rates can be low (Durso et al. 2011). Durso et al. (2011) determined occupancy probability of 7 aquatic snake species within wetland sites based on site characteristics (e.g., wetland permanence, distance from floodplain) and availability of prey. The ability to predict occupancy based on vegetation composition and structure can allow managers to identify important sites for conservation by estimating an occupancy likelihood for a given

area. Habitat use by a species may also be used as a metric for validation of HSI models. For example, Thomasma et al. (1991) found that fishers (*Martes pennanti*) used high-suitability areas more frequently than available lower-suitability areas and stated that though improvements on the model were needed, a positive relationship was documented between fisher habitat “preference” and HSI score (Thomasma et al. 1991:295). Using home range kernel estimation and RSPF (Lele et al. 2006), we can delineate areas used by massasaugas can compare vegetation structures among use and available areas.

Our objective was to validate the Bissell (2006; as amended by Bailey 2010) massasauga HSI model using occupancy and use. We measured vegetation to populate the HSI model and surveyed for massasaugas, comparing occupancy to HSI score. On a subset of sites, we estimated massasauga use probabilities and correlated these values to HSI vegetation measures. Collectively, these methods allowed us to quantify the suitability of a given area for massasaugas based on specific habitat components, to identify and define use by massasaugas of those components, and to relate HSI score to occupancy probability at the site level.

STUDY AREA

Southern Michigan is a temperate region with moderate spring-summer (i.e., May–Aug) temperatures that ranged from approximately 10–32° C during our study (2015 to 2016 in Jackson, MI; NOAA-NWS 2017). Physiography of our research counties (Barry, Calhoun, Jackson, Lenawee, Livingston, Oakland, and Washtenaw) consists of glacially deposited outwash plains, moraines, till plains, and lacustrine plains (Striker and Harmon 1961, Engberg and Austin 1974, Engel 1977, McLeese 1981, Feenstra 1982, Thoen 1990, Tardy 1997). Soils were well drained or poorly drained and loamy with interspersed sandy-loam, loamy sand, or mucky soil types (USDA-NRCS 2017).

We identified 27 sites based on confirmed reports of massasaugas within the last 25 years (Michigan Natural Heritage Database [MNFI] 2014). These sites represented a range of vegetation types and HSI qualities for massasaugas on private and public lands (Appendix C: Table C.1). Of the 27 sites, 11 occurred on private lands owned by citizens, non-profit conservation groups, or corporations, while the remaining 16 sites occurred on public lands (Appendix C). Sites were 20 ha in size (the maximum 95% fixed kernel home range for a massasauga in southern Michigan; Bissell 2006) and ≥ 600 m apart (the maximum distance moved by an individual massasauga in a single season in southern Michigan; Bissell 2006).

METHODS

To assess massasauga habitat suitability, we used the HSI model (Bissell 2006; as modified by Bailey 2010) at our 27 20-ha study sites. We also predicted massasauga use of habitat structures defined by the HSI model using a resource selection probability function. We used a use versus available design (Lele and Keim 2006), where documented massasauga locations represented used areas and points outside the 95% fixed kernel use area represented available areas. Lastly, using the occupancy status and HSI score of each of our sites, we determined how probability of occupancy varied by HSI score.

Initial Site Assessment

We coarsely classified habitat quality a priori into low, medium, and high based on the proportion of suitable and unsuitable vegetation types for massasaugas within each 20-ha site. The purpose of this classification was to ensure inclusion of sites with varying habitat structure and composition throughout southern Michigan. We used the 2006 National Land Cover Database (hereafter NLDC; MRLC 2015; Appendix C: Table C.2) and considered grassland/herbaceous openings, woody wetlands, and emergent herbaceous wetlands as suitable types for massasaugas. We considered open water, development, deciduous forest, evergreen

forest, mixed forest, shrub/scrub, pasture/hay, and cultivated crops as non-suitable. We based these suitability groups on Bailey's (2010) vegetation types from the Integrated Forest Management Analysis Program (IFMAP; MDNR 2001) land cover data. We designated sites with <40% in suitable vegetation types as low site quality, between 40–60% suitable vegetation types as medium, and >60% suitable vegetation types as high quality (Appendix C: Table C.1).

Capture and Marking

From May through August 2015 and 2016, we located and captured massasaugas via random encounter surveys within and around study sites. We checked all captured massasaugas for a passive integrated transponder (PIT) tag (AVID; Norco, CA), and newly captured individuals were injected with a PIT tag subcutaneously into the dorsal region approximately 4–6 cm caudal to the cloaca (e.g., Bissell 2006). We transported massasaugas weighing >100 g to a veterinary clinic for surgical implantation of a radio transmitter. While in captivity under veterinary observation, massasaugas were held individually in locked glass-front reptile aquariums (model S24T; Neodesha Plastics Inc., Neodesha, KS), and provided a place to hide, a dish of water, and sheets of paper towel for additional hiding cover and to absorb liquids (e.g., spilled water, defecation).

Veterinary staff surgically implanted massasaugas with one of three radio transmitters of varying weights, depending on body mass (models R1515, 7 g, and R1680, 3.1 g, Advanced Telemetry Systems [ATS], Inc., Isanti, MN; model SB-2, 5.3 g, Holohil Systems Ltd., Ontario, Canada). A licensed veterinarian from the John Ball Zoological Park veterinary clinic in Grand Rapids, Michigan, followed transmitter implantation procedures described by Bailey (2010) and Bailey et al. (2011). The combined weight of the implanted radio transmitter and the PIT tag did not exceed 5% of body weight to minimize marking effects (Lentini et al. 2011). Following protocol with the John Ball Zoo, ≤ 3 individuals per site were implanted with a transmitter each

year (further, no more than one of these three was a gravid female). Within 7 days of capture (in most cases 3–4 days), implanted massasaugas were examined and approved for release by the veterinarian and subsequently released at their original capture location (Appendix D).

We used external transmitters attached with cyanoacrylate-based adhesive (e.g., “Super Glue”; Cobb et al. 2005, Howze et al. 2012) for adult massasaugas not receiving an implant, and for massasaugas > 100 g located after the final day of surgery (i.e., after July 31 of both years to ensure sufficient healing of the surgical site prior to hibernation). We also used external transmitters for neonate and juvenile massasaugas weighing < 100 g. These transmitters included ATS model R1635 (0.75 g), and ATS model A2414 (0.30 g), and were <5% of the body weight in combination with the PIT tag (Lentini et al. 2011).

Snake capturing, handling and housing methods were approved by Michigan State University’s Institutional Animal Care and Use Committee (IACUC), protocol 05/15-087-00, and by the Michigan Department of Natural Resources (MDNR) Fisheries Division (Scientific Collectors Permit #PR8114). Public land access was approved by the Michigan Department of Natural Resources Permit to Use State Land #PR1136-1. Private land access was arranged directly with landowners prior to the start of any research activity at that property. In accordance with the protocol and requirements outlined in our IACUC approval and MDNR Scientific Collectors Permit, boots and all gear used in the field were disinfected using a 10% bleach solution following each day in the field and before moving among field sites to reduce potential spread of pathogens (Appendix E).

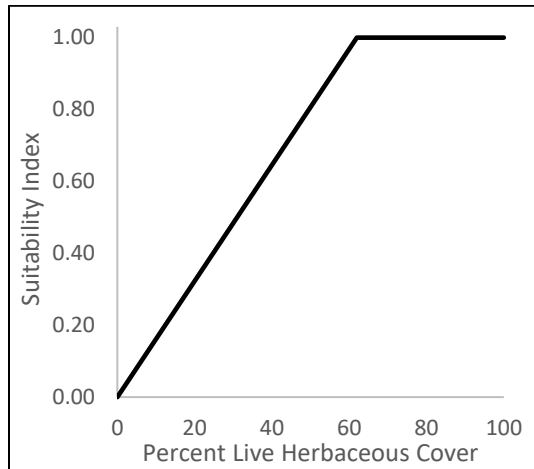
Habitat Suitability Assessment

The Bailey (2010) HSI model is based on percent live herbaceous cover (LHC; Figure 1.1a), percent dead herbaceous cover (DHC; Figure 1.1b), stem density of trees and shrubs > 3 m in height (SDTS; Figure 1.1c), and basal area of trees >3 m in height (BAT; Figure 1.1d). Each

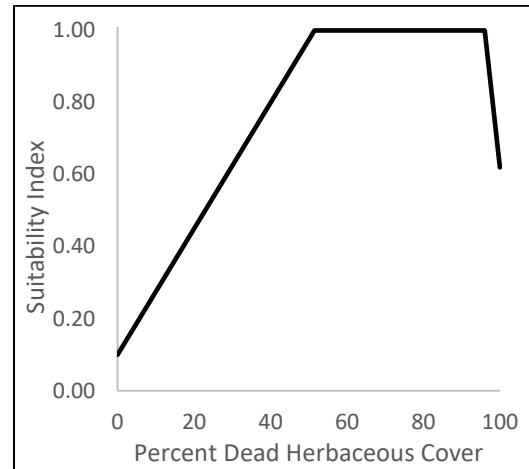
of these variables was measured in the field following vegetation sampling techniques detailed by Bailey (2010). Percent area in early successional deciduous uplands (AEDU; Figure 1.1e), and percent area in early successional deciduous wetlands (AEDW; Figure 1.1f), two additional variables, were quantified using IFMAP land cover data (MDNR 2001) in Arc GIS 10.2 for each site (Bissell 2006, Bailey 2010). The 6 variables were quantified for each 20 ha study site and used to determine a suitability index ranging from 0 to 1, with 1 being most suitable (Figure 1.1).

We note that our use of variable BAT differs from variable ADT in Bailey (2010) because ADT was erroneously described in Bissell's (2006) thesis. Bissell (2006) initially reported an incorrect range of optimal suitability for ADT, and the error was not accounted for in either Bissell (2006) or Bailey (2010) but was communicated to us via Bailey (personal communication, 2017) and is detailed in the errata for Bissell's thesis (2006). Our use of BAT is based on Bissell's correction.

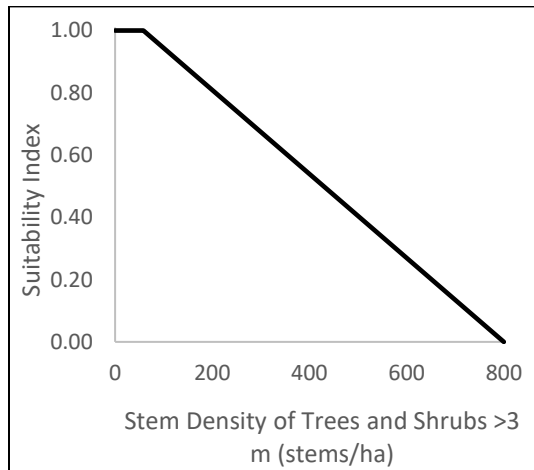
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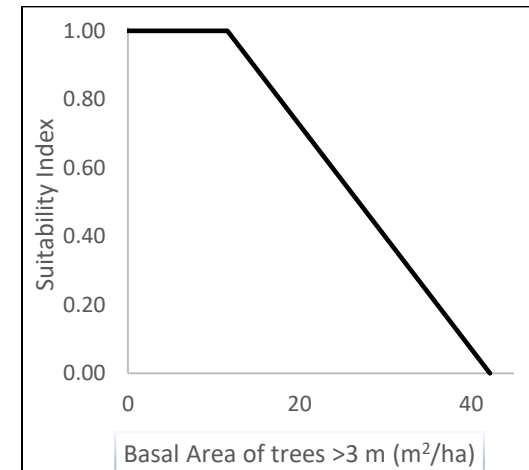
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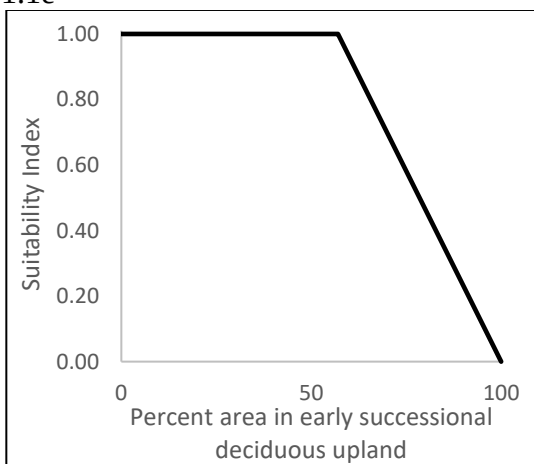
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1.1e



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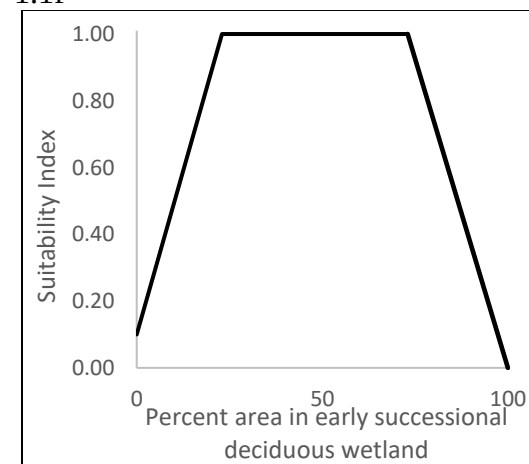


Figure 1.1. Production functions representing suitability indices for habitat components comprising the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) habitat suitability index model as defined by Bissell (2006), as amended by Bailey (2010), for southern Michigan.

Vegetation Sampling

During the 2015 and 2016 field seasons, we selected 10-12 stratified random points for vegetation sampling at each site. We stratified sample locations based on amount of each vegetation type (i.e., NLCD; MRLC 2015) to ensure proportional representation of vegetation types within a study site. For example, if 3 vegetation types occurred in equal amounts within the site, 4 vegetation samples were randomly selected within each type. If 3 vegetation types represented 0.2, 0.2, and 0.6 of the area of a site, 2, 2, and 6 vegetation sampling points were randomly selected within each type, respectively.

At each point we used a north-south 20 m line-intercept to estimate suitability indices LHC and DHC (Bailey 2010). We placed a 5 x 20 m plot eastward along each line-intercept (the line intercept being the west boundary of the plot) and counted and measured the diameter at breast height (DBH) of woody stems >3m in height. Diameter at breast height was measured for every tree within the plot up to 9 stems; if > 9 stems were present the three stems closest to the 0, 10, and 20 m marks on the line-intercept were measured. These stem measurements were used to calculate SDTS and BAT. In addition to randomly selected sampling points throughout each study site, we conducted vegetation sampling at locations of newly found massasaugas and at telemetered massasauga locations when they moved into a new vegetation type. At each site, we collected early season (i.e., May, June) and late season samples (i.e., July, August) to describe vegetation variability throughout the active season, and different random points were selected for each year. We only measured LHC and DHC during the late season sample, as we assumed that variables SDTS and BAT would remain unchanged within a span of 2-3 months (absent habitat management). To compare early season (May-June, 2015 and 2016) and late season (July-August, 2015 and 2016) samples for LHC and DHC, we used a Welch two sample t-test ($\alpha = 0.05$).

We assessed AEDU and AEDW for each site using ArcGIS (10.2) and IFMAP (MDNR 2001). Using IFMAP vegetation classes, we considered early successional deciduous upland (i.e., AEDU) as forage crop, herbaceous openland, row crop, and upland shrub, whereas early successional deciduous wetland (i.e., AEDW) included emergent wetland, floating aquatic, lowland shrub, and mixed non-forest wetland (MDNR 2001).

Habitat Suitability Index

We calculated SI scores for each habitat component (LHC, DHC, SDTS, BAT, AEDU, and AEDW) and a composite HSI for each site (Bissell 2006, Bailey (2010):

$$HSI = [(SI_{LHC} + SI_{DHC} + SI_{SDTS} + SI_{BAT}) \div 4] \times [(SI_{AEDU} + SI_{AEDW}) \div 2]$$

We calculated HSI for both early and late seasons in 2015 and 2016, and averaged scores across both years and seasons to obtain a single overall HSI for each site. Sites were subsequently ranked based on overall HSI scores as: 0.00 to 0.25 = poor suitability; 0.26 to 0.50 = marginal suitability; 0.51-0.75 = good suitability; 0.76-1.00 = optimal suitability (Bailey 2010). Our use of the term “optimal” as the highest range of suitability follows Bailey’s (2010) use of the term in the HSI model.

Resource Selection Probability Function

To assess massasauga use of vegetation structural characteristics identified as habitat components by the HSI model, we quantified use versus availability using a resource selection probability function (hereafter, “RSPF”) with package ‘ResourceSelection’ (Lele and Keim 2006, Lele et al. 2017) in R Studio. We defined use areas as a home range kernel from snake locations, compared to available samples outside the kernel. We generated home range kernels using `getverticeshr()` in package ‘adehabitatHR’ (Calenge 2006, 2015) from massasauga locations recorded in 2015 and 2016 within and around our study sites. We only used sites with ≥ 30 snake locations for this analysis (Appendix F). We delineated 25, 50, 60, 70, 80, 85, 90, and

95% contours with the default smoothing parameter “href” (the reference bandwidth), which assumes the utilization distribution is bivariate normal around each location (Calenge 2015, 2018). Because our study sites varied in the relative proportions of suitable versus unsuitable vegetation types, the range of kernel sizes allowed us to examine how these variations influenced patterns of use at sites of varying quality (i.e., what is used among what is available at these varying levels), and how vegetation structure varied among these kernels. The smallest kernels (i.e., 25, 50%) allowed us to examine core-use areas. We clipped these kernels to the extent of a 20-ha study site and overlaid the late season vegetation sampling points that represented vegetation at its structural peak during the active snake season (a majority [$>77\%$] of massasauga locations were collected during July through August or later). The resource selection probability function was implemented using `rspf()` in package ‘ResourceSelection’ (Lele et al. 2017) to quantify use versus availability (Lele and Keim 2006). Habitat variables included live herbaceous cover, dead herbaceous cover, number of woody stems >3 m in height, and DBH of woody stems >3 m in height (mean value at each sampling point). Study sites included in this analysis were those for which we obtained >30 massasauga locations throughout 2015 and 2016. These sites included: SW_H2 (Otis Audubon Sanctuary), SW_M2 (Baker Audubon Sanctuary North), SE_H3 (Ives Road Fen North), and NE_L1 (Seven Lakes State Park East; Appendix F).

Predicting Occupancy from HSI Components

To examine the relationship between components of the HSI model and massasauga occupancy, we used logistic regression in R Studio using the `glm()` function. We previously demonstrated that time spent searching (>1.5 hours for a 2 ha site) was the most important determinant of detection probability for massasaugas (Chapter 2) and, given our time spent at each site searching for massasaugas and conducting vegetation sampling, we were reasonably confident in our assessment of occupancy. We evaluated relationships between site occupancy

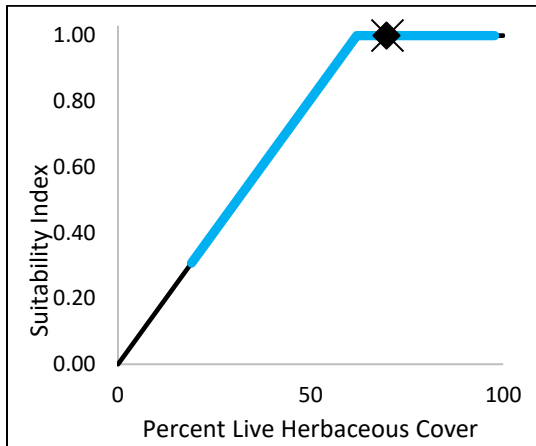
probability and three derivations of the HSI model including the full model scores, thermal subset scores (i.e., suitability indices LHC, DHC, SDTS, and BAT), and landscape-level subset scores (i.e., suitability indices AEDU and AEDW). We assessed these alternatives to the full HSI model because management context differs for each. Landscape variables can be quantified via remote imagery and require no field-based vegetation sampling, and management focuses broadly on patch types and locations. In contrast, thermal variables represent within patch vegetation structure and composition managed through prescriptions (e.g., herbicide or burn to reduce encroachment of woody stems).

RESULTS

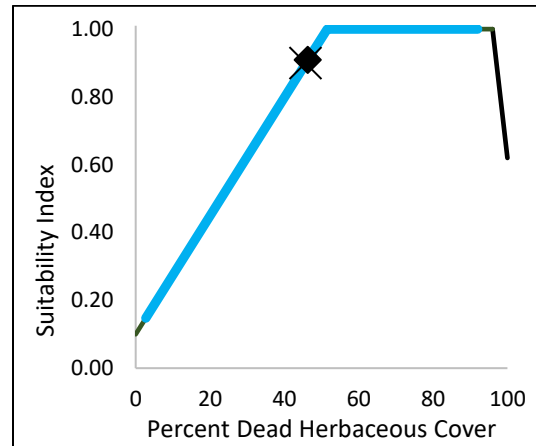
Habitat Suitability

Our measured values for each suitability index across all sites represented nearly the entire range of suitability from poor to optimal (Figure 1.2). Average conditions across sites were optimal- or good-suitability (>0.50) for most SI's (i.e., LHC, DHC, BAT, AEDU, and AEDW). Stem density of trees and shrubs ≥ 3 m in height (SDTS) was most limiting on average (i.e., SI = 0.00; Figure 1.2c), with mean counts of 1,179 stems/ha. This result indicates that woody stem encroachment currently limits average site quality for massasaugas across southern Michigan, specifically on sites that supported historical populations that are currently unoccupied.

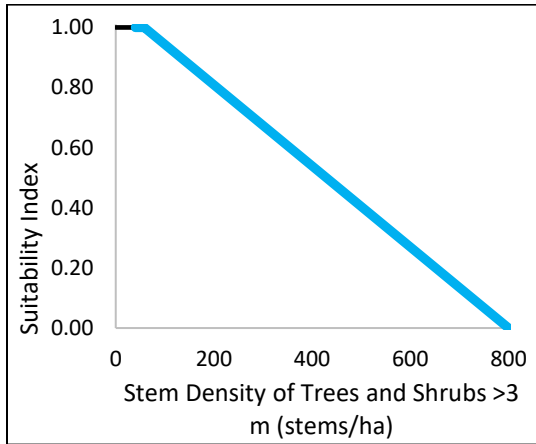
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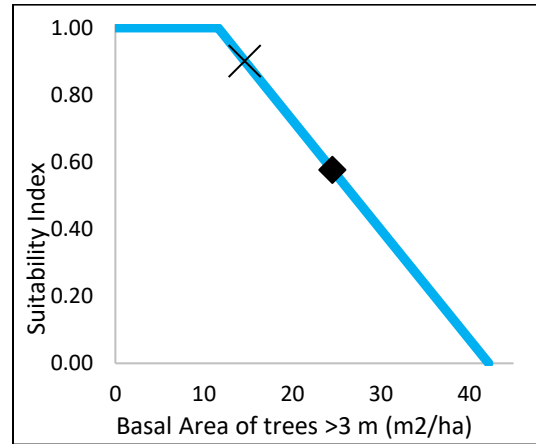
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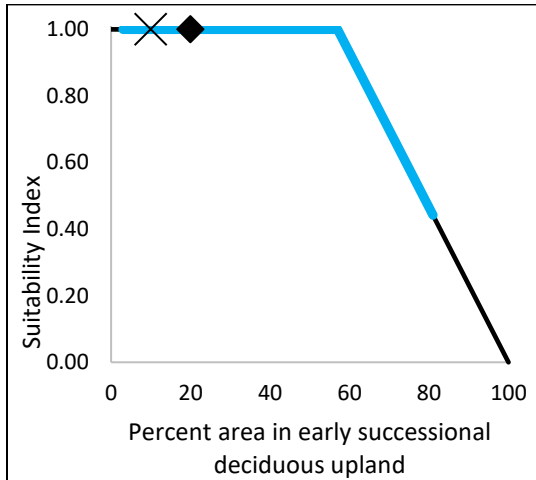
1.2c



1.2d



1.2e



1.2f

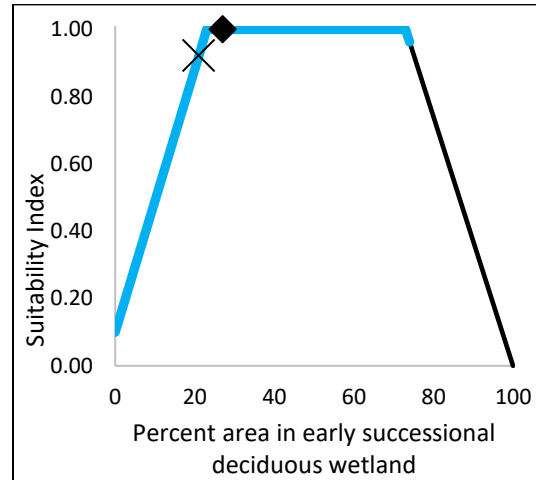


Figure 1.2. Habitat suitability production functions for components of the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) habitat suitability index model (Bissell 2006, Bailey 2010) for southern Michigan. The blue line overlaying each production function represents range of suitabilities observed across 27 field sites during the active snake season throughout southern Michigan, 2015-2016. Points marked with 'x' and '♦' represent median and mean values, respectively (for 2c, observed mean = 1179.38 stems/ha and median = 930 stems/ha).

Habitat suitability index scores (averaged across all samples within a site) ranged from 0.21 to 0.95 (mean = 0.64; Table 1.1). For sites where no massasaugas were observed during this study ($n = 18$), HSI scores ranged from 0.21-0.95 (2 “poor” sites, 6 “marginal”, 8 “good”, and 2 “optimal”). For the remaining 9 sites where one or more massasaugas were observed, suitability ranged from 0.28 to 0.89, indicating that massasaugas occurred at sites of marginal ($n = 2$; HSI range 0.26-0.50), good ($n = 5$; 0.51-0.75), and optimal ($n = 2$; 0.76-1.00) suitability (no occupied sites ranked as “poor” suitability). Hence, HSI at the site level was an unreliable predictor of massasauga occupancy, suggesting that averaging vegetation conditions at random points across a site was not a useful application of the HSI model.

Table 1.1. Habitat suitability index (HSI) scores and the associated suitability index (SI) scores for measured habitat variables^c at each study site by sampling date across southern Michigan. Scores based on Bailey (2010) HSI model for eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*). Sites where massasaugas were located during 2015 or 2016 field seasons are marked with an asterisk (*).

Study Site ^a	Date ^b	n^c	Suitability Indices ^d						HSI ^e	Overall HSI ^f
			LHC (SI1)	DHC (SI2)	STDS (SI3)	BAT (SI4)	AEDU (SI5)	AEDW (SI6)		
NE_H1	06-06-15	12	1.00	0.80	0.00	0.67	1.00	1.00	0.62	0.56
	17-07-15	12	1.00	1.00	0.00	0.67	1.00	1.00	0.67	
	29-06-16	12	1.00	0.94	0.00	0.00	1.00	1.00	0.49	
	08-08-16	12	1.00	0.96	0.00	0.00	1.00	1.00	0.49	
NE_H2	04-08-15	10	1.00	0.85	0.00	0.05	1.00	1.00	0.48	0.62
	18-08-16	10	0.98	0.99	0.00	0.76	1.00	1.00	0.68	
	02-06-16	10	1.00	0.99	0.00	0.76	1.00	1.00	0.69	
NE_H3	04-08-15	11	1.00	1.00	0.00	1.00	1.00	1.00	0.75	0.75
	02-06-16	11	1.00	1.00	0.00	1.00	1.00	1.00	0.75	
	25-08-16	11	1.00	1.00	0.00	1.00	1.00	1.00	0.75	
NE_L1 *	25-05-15	11	0.79	0.42	0.00	0.29	1.00	0.34	0.25	0.28
	09-07-15	11	0.84	0.43	0.00	0.29	1.00	0.34	0.26	
	19-05-16	11	0.51	0.53	0.00	0.73	1.00	0.34	0.30	
	21-07-16	11	0.66	0.59	0.00	0.73	1.00	0.34	0.33	
NE_L2	19-05-15	11	0.31	0.31	0.00	0.36	1.00	0.10	0.13	0.21
	16-07-15	11	0.97	0.15	0.00	0.36	1.00	0.10	0.20	
	31-05-16	11	0.81	0.23	0.00	0.65	1.00	0.10	0.23	
	15-08-16	11	0.82	0.40	0.00	0.65	1.00	0.10	0.26	

Table 1.1. (cont'd)

Study Site ^a	Date ^b	n ^c	Suitability Indices ^d						HSI ^e	Overall HSI ^f
			LHC (SI1)	DHC (SI2)	STDS (SI3)	BAT (SI4)	AEDU (SI5)	AEDW (SI6)		
NE_L3	19-05-15	12	0.47	0.29	0.00	0.00	1.00	0.56	0.15	0.21
	16-07-15	12	0.91	0.33	0.00	0.00	1.00	0.56	0.24	
	31-05-16	12	0.86	0.19	0.00	0.02	1.00	0.56	0.21	
	12-08-16	12	0.75	0.39	0.00	0.02	1.00	0.56	0.23	
NE_M1 *	25-05-15	11	0.91	0.40	0.00	0.85	1.00	0.88	0.51	0.58
	20-07-15	11	1.00	1.00	0.00	0.85	1.00	0.88	0.67	
	19-05-16	10	0.69	0.68	0.00	0.96	1.00	0.88	0.55	
	21-07-16	10	1.00	0.57	0.00	0.96	1.00	0.88	0.59	
NE_M2	20-05-15	10	1.00	0.75	0.00	0.00	1.00	1.00	0.44	0.58
	16-07-15	10	1.00	0.96	0.00	0.00	1.00	1.00	0.49	
	31-05-16	10	1.00	0.89	0.00	0.87	1.00	1.00	0.69	
	15-08-16	10	1.00	1.00	0.00	0.87	1.00	1.00	0.72	
NE_M3	17-07-15	10	1.00	1.00	0.74	1.00	0.84	1.00	0.86	0.87
	29-06-16	10	1.00	1.00	0.80	1.00	0.84	1.00	0.87	
	08-08-16	10	1.00	1.00	0.80	1.00	0.84	1.00	0.87	
SE_H1 *	28-05-15	11	0.91	0.69	0.00	0.94	1.00	1.00	0.63	0.72
	10-07-15	11	1.00	0.96	0.00	0.94	1.00	1.00	0.72	
	18-06-16	11	1.00	0.77	0.31	0.90	1.00	1.00	0.74	
	25-07-16	11	1.00	0.86	0.31	0.90	1.00	1.00	0.77	
SE_H2	19-06-15	11	1.00	0.86	0.00	0.74	1.00	1.00	0.65	0.71
	15-07-15	11	1.00	1.00	0.00	0.74	1.00	1.00	0.68	
	14-06-16	11	1.00	0.94	0.00	1.00	1.00	1.00	0.74	
	17-08-16	11	1.00	1.00	0.00	1.00	1.00	1.00	0.75	
SE_H3 *	19-05-15	11	1.00	1.00	0.39	0.94	1.00	0.63	0.68	0.66
	07-07-15	11	1.00	1.00	0.39	0.94	1.00	0.63	0.68	
	20-05-16	11	1.00	0.85	0.26	0.92	1.00	0.63	0.62	
	22-07-16	11	1.00	1.00	0.26	0.92	1.00	0.63	0.65	
SE_H4	20-05-15	11	0.84	1.00	0.65	1.00	0.43	0.24	0.29	0.31
	07-07-15	11	1.00	1.00	0.65	1.00	0.43	0.24	0.31	
	22-07-16	11	0.85	1.00	0.81	1.00	0.43	0.24	0.31	
	13-05-16	11	1.00	1.00	0.81	1.00	0.43	0.24	0.32	
SE_L1	14-05-15	24	0.69	0.40	0.00	0.91	1.00	0.39	0.35	0.42
	15-07-15	24	1.00	0.97	0.00	0.91	1.00	0.39	0.50	
	17-05-16	11	1.00	0.54	0.00	0.73	1.00	0.39	0.39	
	23-08-16	11	0.95	0.89	0.00	0.73	1.00	0.39	0.45	
SE_L2 *	18-05-15	11	0.92	0.58	0.23	1.00	1.00	0.35	0.46	0.57
	08-07-15	10	1.00	1.00	0.23	1.00	1.00	0.35	0.54	
	13-05-16	11	1.00	1.00	0.75	1.00	1.00	0.35	0.63	
	22-07-16	11	1.00	1.00	0.75	1.00	1.00	0.35	0.63	
SE_L3	20-07-15	11	1.00	0.83	0.00	0.99	1.00	0.31	0.46	0.43
	11-08-16	11	0.88	0.47	0.18	0.90	1.00	0.31	0.40	
	16-05-16	11	1.00	0.62	0.18	0.90	1.00	0.31	0.44	
SE_L4	05-08-15	10	0.97	0.66	0.00	0.87	1.00	0.75	0.55	n/a
SE_M1 *	05-08-15	12	1.00	0.67	0.00	0.18	1.00	0.89	0.44	0.40
	26-07-16	12	1.00	0.57	0.00	0.00	1.00	0.89	0.37	
	12-05-16	12	1.00	0.67	0.00	0.00	1.00	0.89	0.39	

Table 1.1. (cont'd)

Study Site ^a	Date ^b	n ^c	Suitability Indices ^d						HSI ^e	Overall HSI ^f
			LHC (SI1)	DHC (SI2)	STDS (SI3)	BAT (SI4)	AEDU (SI5)	AEDW (SI6)		
SW_H1	31-05-15	10	1.00	1.00	0.00	0.94	1.00	0.97	0.72	0.73
	22-07-15	10	1.00	1.00	0.00	0.94	1.00	0.97	0.72	
	23-05-16	10	1.00	1.00	0.00	1.00	1.00	0.97	0.74	
	02-08-16	10	1.00	1.00	0.00	1.00	1.00	0.97	0.74	
SW_H2 *	30-05-15	10	1.00	1.00	0.00	1.00	1.00	1.00	0.50	0.80
	23-07-15	10	1.00	1.00	0.00	1.00	1.00	1.00	0.75	
	01-06-16	10	1.00	1.00	0.93	1.00	1.00	1.00	0.98	
	02-08-16	10	1.00	1.00	0.93	1.00	1.00	1.00	0.98	
SW_H3 *	02-06-15	11	1.00	0.69	0.00	0.67	1.00	1.00	0.59	0.65
	23-06-15	11	1.00	0.96	0.00	0.67	1.00	1.00	0.66	
	25-05-16	11	0.89	0.81	0.04	0.80	1.00	1.00	0.64	
	03-08-16	11	1.00	1.00	0.04	0.80	1.00	1.00	0.71	
SW_L1	25-07-15	10	0.85	0.71	0.00	0.75	1.00	0.11	0.32	0.35
	25-06-16	10	0.58	0.59	0.35	1.00	1.00	0.11	0.35	
	03-08-16	10	0.73	0.59	0.35	1.00	1.00	0.11	0.37	
SW_L2	27-07-15	11	0.84	0.69	0.00	0.00	1.00	0.95	0.37	0.37
	27-05-16	11	0.78	0.51	0.00	0.00	1.00	0.95	0.32	
	04-08-16	11	1.00	0.75	0.00	0.00	1.00	0.95	0.43	
SW_L3	25-07-15	10	1.00	0.27	0.00	0.17	1.00	0.10	0.20	0.26
	25-06-16	10	0.97	0.33	0.00	0.70	1.00	0.10	0.27	
	04-08-16	10	0.94	0.68	0.00	0.70	1.00	0.10	0.32	
SW_M1	30-07-15	10	1.00	1.00	0.96	1.00	1.00	0.90	0.94	0.95
	18-05-16	10	1.00	1.00	1.00	1.00	1.00	0.90	0.95	
	01-08-16	10	1.00	1.00	1.00	1.00	1.00	0.90	0.95	
SW_M2 *	28-07-15	11	1.00	1.00	0.37	1.00	1.00	1.00	0.84	0.89
	18-05-16	11	1.00	1.00	0.64	1.00	1.00	1.00	0.91	
	01-08-16	11	1.00	1.00	0.64	1.00	1.00	1.00	0.91	
SW_M3	24-07-15	10	1.00	0.90	0.00	0.17	1.00	1.00	0.52	0.65
	24-05-16	10	1.00	0.87	0.00	0.94	1.00	1.00	0.70	
	02-08-16	10	1.00	0.92	0.00	0.94	1.00	1.00	0.72	

^a Study site represents the area (20 ha study site) within which the HSI score was assessed.

^b Date is the date (or final date) of sampling. Samples collected during the months of May and June indicate an “early season” sample, and those collected during July and August indicate a “late season” sample.

^c n = number of vegetation plots for that site.

^d Suitability indices represent the suitability (0-1) for thermal and landscape-level habitat characteristics measured within each site and are defined as follows: LHC (SI1) = live herbaceous cover, DHC (SI2) = dead herbaceous cover, STDS (SI3) = stem density of trees and shrubs >3m (stems/ha), BAT (SI4) = basal area of trees >3m (m²/ha), AEDU (SI5) = area in early successional deciduous upland, AEDW (SI6) = area in early successional deciduous wetland.

^e HSI represents the HSI score for each respective site by date.

^f Overall HSI represents the mean of the individual HSI scores for that site.

We subsequently evaluated HSI scores based on vegetation data collected at snake locations. We obtained ≥ 1 vegetation sample at massasauga locations at 8 occupied sites (Table 1.2). These HSI scores averaged 0.60 to 1.00 (1 “good”, 7 “optimal”), suggesting that massasaugas associated with vegetation structures at finer resolutions than the site. For example, the overall site HSI for NE_L1 based on randomly located vegetation measures was 0.28 (i.e., our lowest-ranking occupied site), yet HSI score based on vegetation data collected at massasauga locations was 0.60. This result indicates that the HSI model is best suited and biologically significant at the individual snake level of use (i.e., perhaps the size of the sampling plot, 20 x 5 m).

Table 1.2. Habitat suitability index (HSI) and associated suitability index (SI) scores for habitat variables^c measured at eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) locations by site throughout southern Michigan, 2015-2016.

Study Site ^a	<i>n</i> ^b	Suitability Indices ^c						HSI ^d
		LHC (SI1)	LHC (SI2)	STDS (SI3)	BAT (SI4)	AEDU (SI5)	AEDW (SI6)	
NE_L1	35	1.00	1.00	0.59	1.00	1.00	0.34	0.60
NE_M1	1	1.00	0.62	1.00	1.00	1.00	0.88	0.85
SE_H1	9	1.00	1.00	0.78	1.00	1.00	1.00	0.94
SE_H3	33	1.00	1.00	1.00	1.00	1.00	0.63	0.82
SE_M1	1	1.00	1.00	0.54	1.00	1.00	0.89	0.84
SW_H3	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SW_M2	17	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SW_H2	13	1.00	1.00	0.75	1.00	1.00	1.00	0.94

^a Study site represents the area (within 20 ha study sites) corresponding to snake locations.

^b *n* = number of massasauga locations at which vegetation sampling was conducted.

^c Suitability indices represent average suitability (0-1) for snake locations within each site and include: LHC (SI1) = live herbaceous cover, DHC (SI2) = dead herbaceous cover, STDS (SI3) = stem density of trees and shrubs >3m (stems/ha), BAT (SI4) = basal area of trees >3m (m²/ha), AEDU (SI5) = area in early successional deciduous upland, AEDW (SI6) = area in early successional deciduous wetland.

^d HSI is average from all snake locations within a site.

We found that early- and late-season vegetation samples differed (Welch two sample t-test, $\alpha < 0.05$) for LHC for 7 of 26 study sites and DHC for 4 of 26 study sites (Table 1.3). We were unable to test early and late season samples at one study site (SE_L4) because we collected a single late season sample in 2015 due to landowner availability. Hence, for most of our study sites changes in structural components of massasauga habitat were generally not significant throughout the active season. Furthermore, changes in vegetation between early and late-season samples at a site rarely shifted HSI score into a new quality category (Table 1.1). For example, at site NE_H1 in 2015, the early-and late-season HSI scores was 0.62 and 0.67, respectively, both within the “good” suitability ranking.

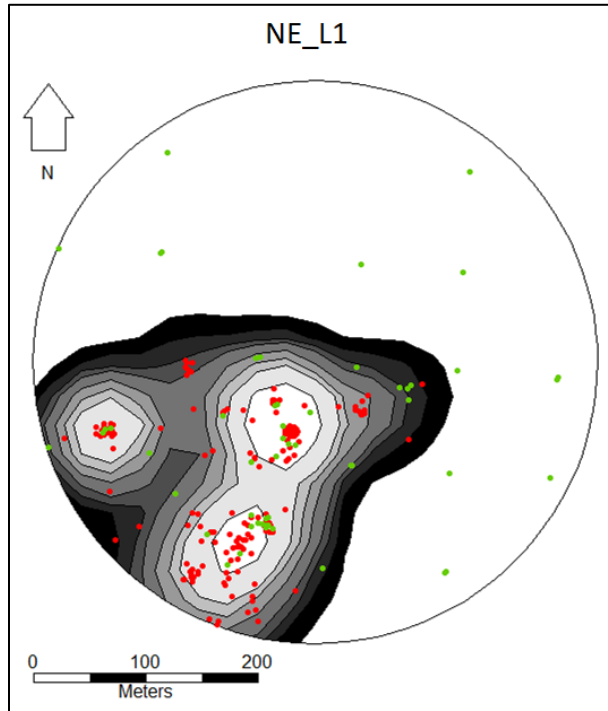
Table 1.3. Welch two sample t-test results comparing vegetation for early (May-June) and late seasons (July-August) in southern Michigan. Vegetation variables correspond to habitat components for eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*). Confidence intervals (LCI = lower 95% confidence interval, UCI = upper 95% confidence interval) portray range of values bounding the difference of early- and late-sample means. Degrees of freedom (DF) based on number of vegetation samples collected for each site. An asterisk (*) indicates significance ($\alpha \leq 0.05$).

Study Site	% Live Herbaceous Cover (LHC)							% Dead Herbaceous Cover (DHC)								
	$\bar{X}_{\text{Early}}$	$\bar{X}_{\text{Late}}$	t	p	DF	LCI	UCI	$\bar{X}_{\text{Early}}$	$\bar{X}_{\text{Late}}$	t	p	DF	LCI	UCI		
NE_H1	8.333	8.333	0.000	1.000	46	-1.183	1.183	4.417	5.292	-0.915	0.365	46	-2.800	1.050		
NE_H2	7.300	6.476	1.068	0.294	29	-0.753	2.401	5.100	4.952	0.121	0.905	20	-2.394	2.690		
NE_H3	8.091	7.545	0.666	0.511	28	-1.132	2.223	6.364	6.955	-0.490	0.630	19	-3.118	1.936		
NE_L1	4.045	4.636	-0.655	0.516	38	-2.417	1.235	2.136	2.364	-0.226	0.822	42	-2.254	1.799		
NE_L2	3.455	5.545	-2.837	0.007	*	42	-3.578	-0.604	0.955	1.000	-0.098	0.922	36	-0.984	0.893	
NE_L3	4.125	5.167	-1.236	0.223		46	-2.738	0.655	0.792	1.500	-1.387	0.174	37	-1.743	0.327	
NE_M1	5.000	6.524	-1.536	0.133		39	-3.531	0.483	2.476	4.095	-1.549	0.130	36	-3.739	0.501	
NE_M2	6.300	7.350	-1.585	0.121		38	-2.391	0.291	4.100	5.200	-0.947	0.350	38	-3.453	1.253	
NE_M3	9.400	9.700	-0.906	0.382		12	-1.020	0.420	8.000	9.100	-1.469	0.166	13	-2.721	0.521	
SE_H1	6.955	8.409	-2.342	0.024	*	40	-2.710	-0.199	3.591	4.636	-1.140	0.261	41	-2.897	0.806	
SE_H2	8.545	8.773	-0.481	0.634		35	-1.188	0.733	4.591	6.864	-2.474	0.018	*	40	-4.129	-0.416
SE_H3	7.955	9.045	-2.278	0.028	*	41	-2.058	-0.124	4.727	5.955	-1.218	0.230	42	-3.261	0.807	
SE_H4	6.000	6.682	-0.854	0.398		42	-2.294	0.930	6.727	8.455	-2.937	0.005	*	41	-2.915	-0.539
SE_L1	5.143	7.514	-3.382	0.001	*	68	-3.771	-0.972	1.971	4.829	-4.281	0.000	*	61	-4.191	-1.523
SE_L2	6.682	8.810	-3.672	0.001	*	39	-3.300	-0.955	4.227	6.190	-2.662	0.011	*	38	-3.456	-0.471
SE_L3	7.000	6.864	0.163	0.872		22	-1.596	1.869	3.000	3.136	-0.121	0.904	26	-2.448	2.175	
SE_M1	6.583	6.917	-0.476	0.638		31	-1.763	1.097	3.250	2.958	0.317	0.754	22	-1.616	2.199	
SW_H1	8.600	9.050	-0.822	0.416		37	-1.558	0.658	6.750	7.550	-1.014	0.318	35	-2.402	0.802	
SW_H2	7.300	9.400	-3.921	0.000	*	33	-3.190	-1.010	8.300	8.400	-0.161	0.873	38	-1.359	1.159	
SW_H3	6.591	6.955	-0.347	0.731		41	-2.482	1.754	3.727	5.045	-1.198	0.238	42	-3.539	0.903	
SW_L1	3.600	4.900	-0.959	0.348		22	-4.113	1.513	2.800	3.150	-0.221	0.827	18	-3.670	2.970	
SW_L2	4.818	5.682	-0.700	0.492		21	-3.432	1.705	2.364	3.545	-1.205	0.239	26	-3.196	0.833	
SW_L3	6.000	6.400	-0.484	0.636		14	-2.170	1.370	1.300	2.150	-1.235	0.227	28	-2.260	0.560	
SW_M1	7.800	9.050	-1.508	0.158		12	-3.059	0.559	6.500	7.400	-0.869	0.397	17	-3.082	1.282	
SW_M2	7.000	9.318	-3.455	0.005	*	12	-3.786	-0.850	5.909	6.864	-0.919	0.370	19	-3.131	1.221	
SW_M3	7.700	6.900	0.846	0.407		23	-1.158	2.758	4.400	4.650	-0.199	0.845	15	-2.924	2.424	

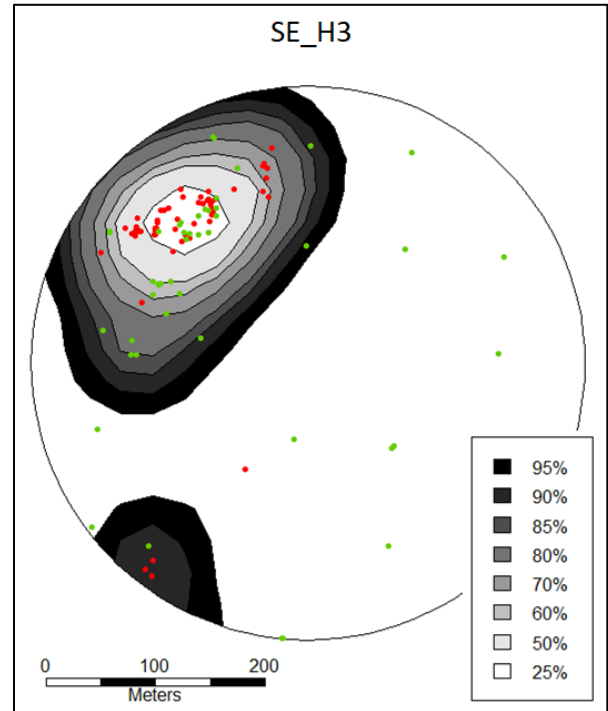
Kernel Density Estimation

We collected ≥ 30 snake locations for kernel use calculation at four sites (Figure 1.3), and at least one RSPF converged for these sites (Table 1.4). Model convergence depended on: 1) spatial extent of the utilization distribution (e.g., 95% kernel for SW_H2 covered 98% of the site [Table 1.5], limiting the number of available plots), and 2) amount of variation in vegetation measurements within kernels (e.g., available LHC within 50% kernel for SW_M2 only ranged from 80-100%, used LHC from 70-90%, thereby limiting differentiation space for the RSPF). Number of snake locations ranged from 49-262, and number of vegetation plots ranged from 30-56 within a site (Table 1.5). The 95% kernels covered 30-98% of a site, whereas 25% core use areas covered 2-12% (Table 1.5).

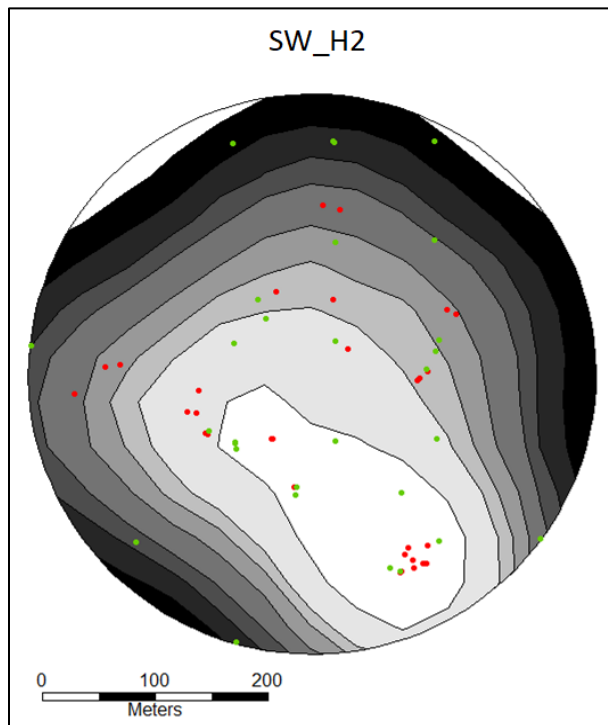
1.3a



1.3b



1.3c



1.3d

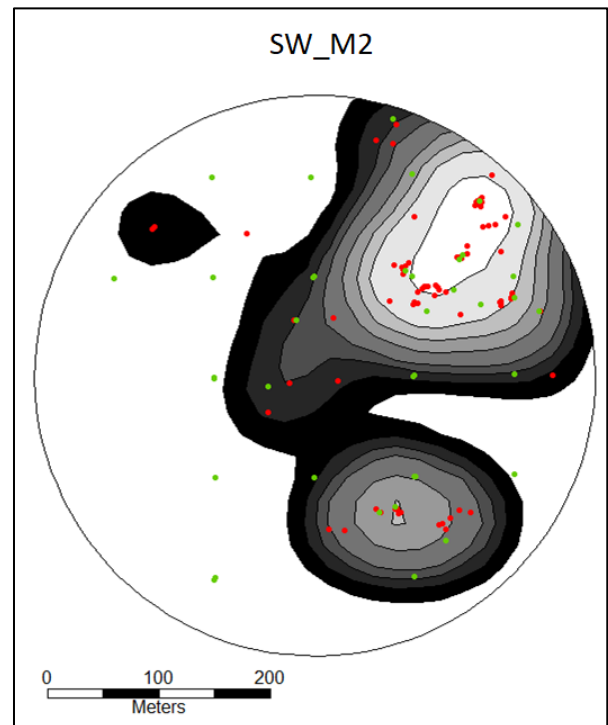


Figure 1.3. Eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) % home range kernels (50-95%), snake locations (red dots), and vegetation sampling locations (green dots) for study sites NE_L1 (1.5a), SE_H3 (1.5b), SW_H2 (1.5c), and SW_M2 (1.5d), in southern Michigan in 2015 and 2016.

Table 1.4. Consistent AIC (CAIC) tables ranking the resource selection probability functions for each % kernel home range at 4 study sites in southern Michigan, 2015 and 2016. Only models that converged are included.

Site	% Kernel	CAIC^a	dCAIC^b	wCAIC^c
NE_L1	60	81.007	0.000	0.410
	95	82.094	1.087	0.238
	90	82.094	1.087	0.238
	50	83.621	2.614	0.111
	70	92.352	11.345	0.001
	25	92.487	11.480	0.001
	85	108.551	27.544	0.000
SE_H3	85	29.122	0.000	1.000
	95	54.500	25.378	0.000
	70	116.060	86.939	0.000
SW_H2	90	13.331	0.000	1.000
	60	54.108	40.778	0.000
SW_M2	80	99.466	0.000	1.000

^a CAIC = the consistent Akaike information criterion.

^b dCAIC = change in CAIC between univariate models.

^c wCAIC = the CAIC weights.

Table 1.5. Number of snake locations ($n_{s,\text{total}}$) and vegetation sampling plots ($n_{v,\text{total}}$) in each 20 ha study site, and corresponding kernel home range with the number of snake locations ($n_{s,\text{hr}}$) and vegetation sampling plots ($n_{v,\text{hr}}$) within, southern Michigan, 2015-2016.

Study Site (20 ha)	$n_{s,\text{total}}$	$n_{v,\text{total}}$	% Kernel Home Range	Area (ha)	% Area	$n_{s,\text{hr}}$	$n_{v,\text{hr}}$
NE_L1	262	56	95	7.45	37%	262	41
			90	6.25	31%	259	41
			85	5.42	27%	255	37
			80	4.7	24%	246	32
			70	3.42	17%	241	31
			60	2.53	13%	220	28
			50	1.87	9%	208	27
			25	0.57	3%	115	14
SE_H3	98	50	95	6.02	30%	97	37
			90	4.65	23%	97	36
			85	3.57	18%	93	33
			80	2.96	15%	90	29
			70	2.01	10%	88	26
			60	1.43	7%	79	25
			50	1.01	5%	70	16
			25	0.32	2%	56	16
SW_H2	49	30	95	19.53	98%	49	30
			90	17.32	87%	49	28
			85	15.01	75%	49	24
			80	13.11	66%	49	23
			70	10.13	51%	46	21
			60	7.97	40%	42	19
			50	6.05	30%	34	16
			25	2.47	12%	26	14
SW_M2	133	38	95	9.71	49%	132	28
			90	7.15	36%	129	27
			85	5.61	28%	123	20
			80	4.52	23%	119	18
			70	3.15	16%	115	15
			60	2.67	13%	106	12
			50	1.64	8%	98	10
			25	0.62	3%	57	4

Resource Selection Probability Function

For RSPFs that converged, kernel contours of top-ranking models varied by site. Massasauga use was best described by site vegetation at the 60% kernel scale ($CAIC_{wt} = 0.41$) for site NE_L1, and at the >80% kernel scale for the other sites (Table 1.4). Site NE_L1 was low-marginal quality ($HSI = 0.28$; Table 1.1) with massasauga habitat patchily distributed (HSI at snake locations was 0.60; Table 1.2), whereas the other sites were medium and high quality with more uniform distribution of suitable habitat, particularly within the different kernel bands.

Relationships between fitted values (i.e., the absolute probability of use) and habitat variables corresponded to relationships portrayed in the HSI model for LHC and DHC. Our top-ranking RSPF functions (Table 1.4) showed increases in snake use when LHC and DHC >50% for site NE_L1 and when DHC >30% at site SW_M2 (Figures 1.4, 1.5). This relationship was not well illustrated at sites SE_H3 and SW_H2 for LHC and DHC, and at SW_M2 for LHC, likely due to the homogenous distribution of highly suitable habitat at these sites and within all home range kernels. For example, observed LHC ranged from 90-100% at SW_HW and 80-100% at SW_M2 (Figure 1.4), while DHC ranged from 80-100% at SE_H3 and 70-100% at SW_H2 (Figure 1.5), and due to the homogeneity of these variables throughout these sites, there was little difference in structure between used and available (yet unused) areas (Table 1.6); thus, the consistency of high-quality habitat limited our ability to illustrate any difference in massasauga use based on these habitat variables at these sites.

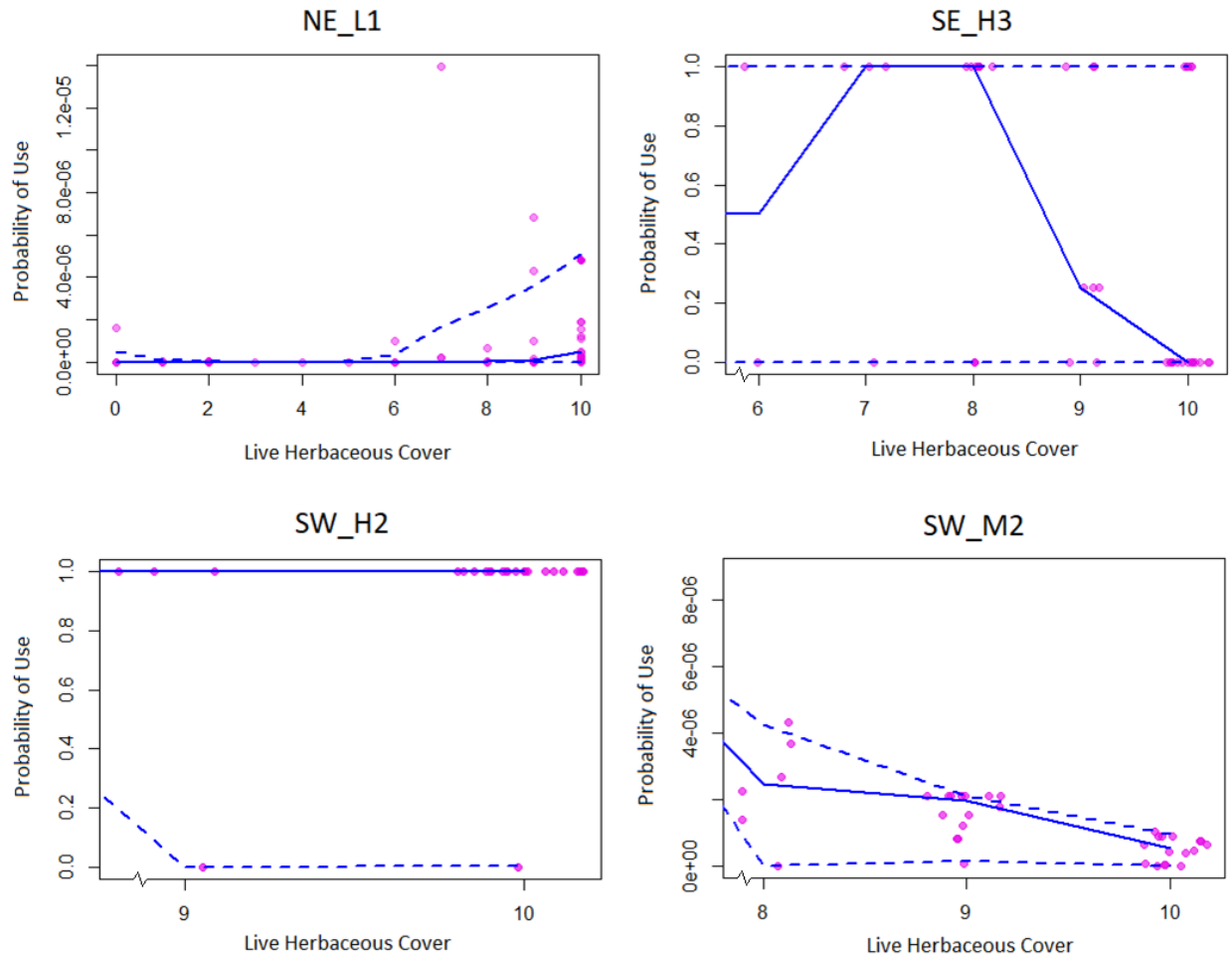


Figure 1.4. Marginal effects plots showing the relationship between availability of live herbaceous cover (0-100% transect coverage out of 0-10 meters as displayed in the x-axis, covering the range of values observed within the site) and absolute probability of use by eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) for the top-ranking home range kernels for sites NE_L1 (60% kernel), SE_H3 (85% kernel), SW_H2 (90% kernel), and SW_M2 (80% kernel) in southern Michigan (Table 1.4).

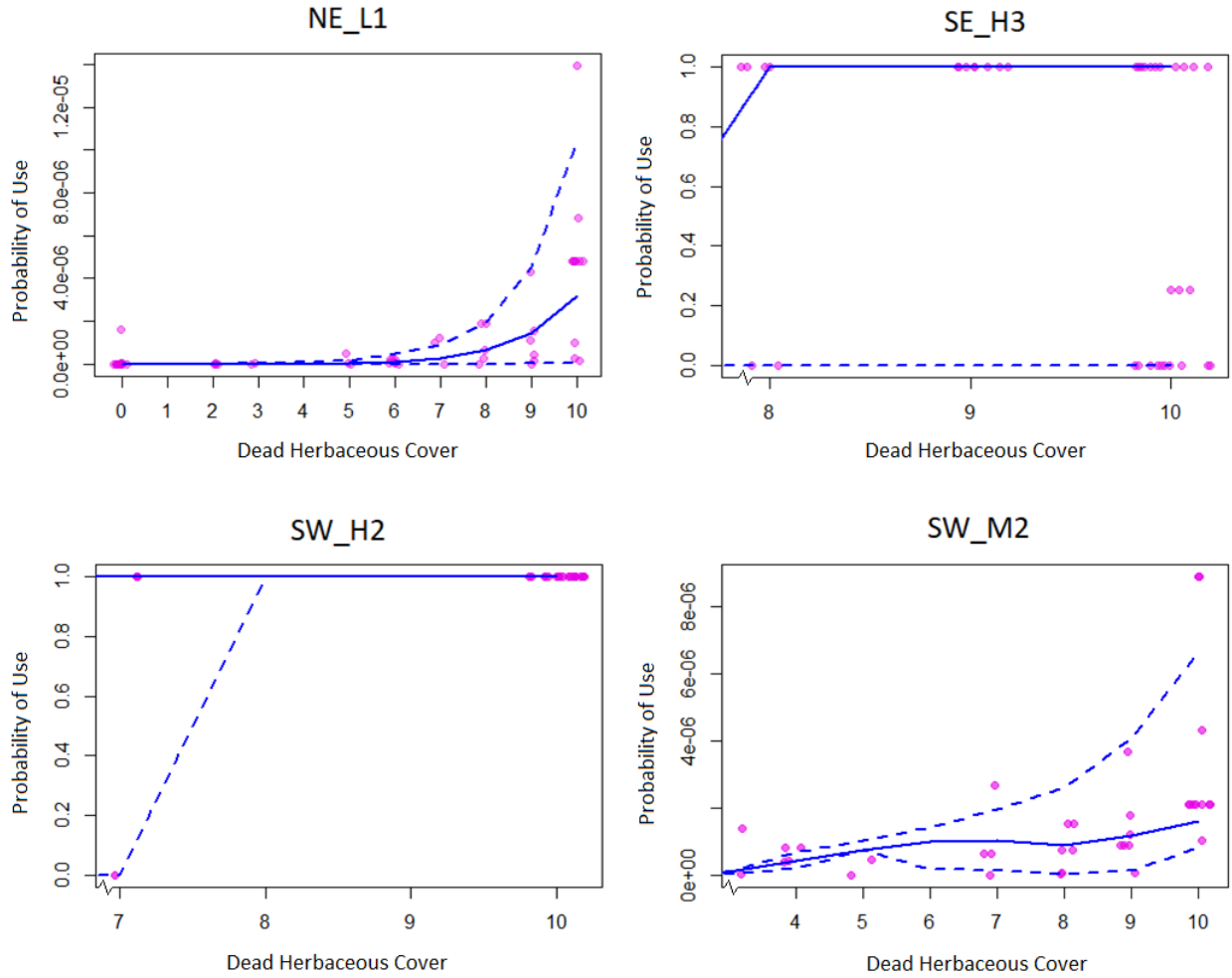


Figure 1.5. Marginal effects plots showing the relationship between availability of dead herbaceous cover (0-100% transect coverage out of 0-10 meters as displayed in the x-axis, covering the range of values observed within the site) and absolute probability of use by eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) for the top-ranking home range kernels for sites NE_L1 (60% kernel), SE_H3 (85% kernel), SW_H2 (90% kernel), and SW_M2 (80% kernel) in southern Michigan (Table 1.4).

Table 1.6. Comparative summary of vegetation structure (mean, minimum, maximum observed within the 5 x 20 m vegetation sampling plot) in used versus unused (i.e., available) areas based on the top-ranking resource selection probability function home range kernels (Table 1.4) for eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) at 4 20-ha sites throughout southern Michigan in 2015 and 2016. Sample size (*n*) indicates the number of vegetation samples that the values are based on within use or available areas.

Vegetation Structure	Site	Kernel	Use				Available			
			Mean	Min	Max	<i>n</i>	Mean	Min	Max	<i>n</i>
Percent Live Herbaceous Cover ^a	NE_L1	60%	87.5	0.0	100.0	28	50.4	0.0	100.0	28
	SE_H3	85%	84.9	30.0	100.0	33	88.2	50.0	100.0	17
	SW_H2	90%	93.9	50.0	100.0	28	95.0	90.0	100.0	2
	SW_M2	80%	88.3	70.0	100.0	18	94.5	80.0	100.0	20
Percent Dead Herbaceous Cover ^b	NE_L1	60%	81.4	0.0	100.0	28	24.6	0.0	100.0	28
	SE_H3	85%	95.2	80.0	100.0	33	50.6	10.0	100.0	17
	SW_H2	90%	90.4	40.0	100.0	28	65.0	60.0	70.0	2
	SW_M2	80%	83.3	30.0	100.0	18	68.5	0.0	100.0	20
No. Woody Stems ^c	NE_L1	60%	2.7	0.0	19.0	28	13.9	2.0	34.0	28
	SE_H3	85%	0.0	0.0	0.0	33	7.2	0.0	11.0	17
	SW_H2	90%	2.0	0.0	33.0	28	62.5	45.0	80.0	2
	SW_M2	80%	0.1	0.0	1.0	18	5.0	0.0	48.0	20
Average DBH (cm) ^d	NE_L1	60%	6.4	0.0	29.0	28	12.2	5.1	48.5	28
	SE_H3	85%	0.0	0.0	0.0	33	13.4	0.0	25.1	17
	SW_H2	90%	3.1	0.0	56.0	28	6.3	3.5	9.0	2
	SW_M2	80%	0.9	0.0	16.8	18	5.8	0.0	37.4	20

^a Percentage of the 20 m transect covered by live herbaceous vegetation.

^b Percentage of the 20 m transect covered by dead herbaceous vegetation.

^c Number of woody stems ≥ 3 m in height within the 20 by 5 m plot.

^d Diameter at breast height for trees and shrubs ≥ 3 m in height within the 20 by 5 m plot.

Snake use declined with woody stems $>500/\text{ha}$ (5 stems/ 100m^2 ; Fig. 1.5) at site NE_L1, suggesting that massasaugas were more tolerant of higher woody stem densities than predicted by the HSI model at this site. Similarly, at site SW_M2, massasauga use decreased with woody stems $>100/\text{ha}$ (Figure 1.6). At all sites, areas used by massasaugas contained lower stem densities than measured in the available areas, though at sites SE_H3 and SW_M2 these differences were less pronounced (Table 1.6) due to the highly suitable vegetation structure throughout the site. As with LHC and DHC, structural homogeneity in use areas likely limited our ability to illustrate any relationship between probability of use and stem density, particularly for site SE_H3 (Figure 1.6), where 0 woody stems occurred within areas of use (Table 1.6).

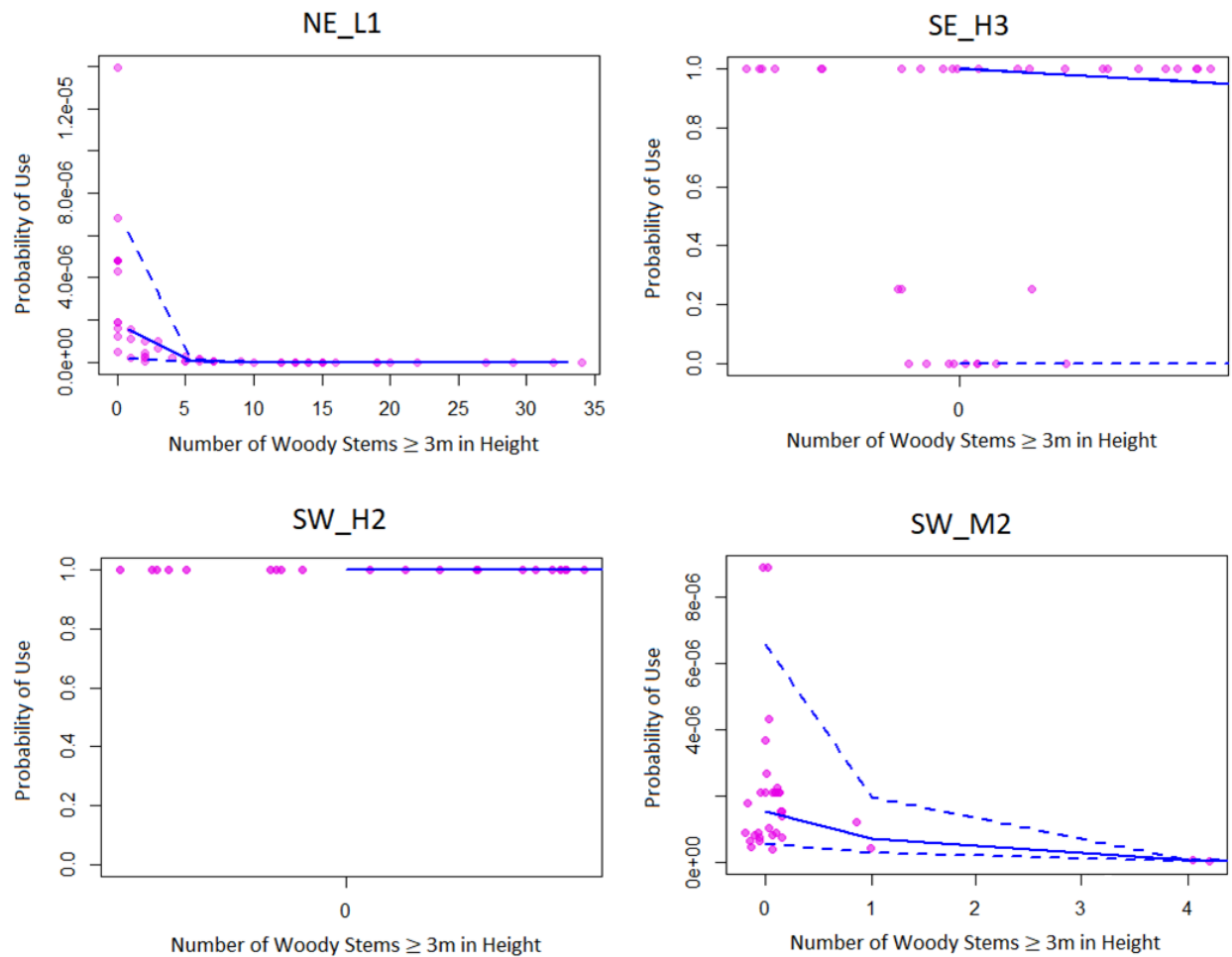


Figure 1.6. Marginal effects plots showing the relationship between the number of woody stems ≥ 3 m in height within the 20 x 5 m plot (covering the range of values observed within the site) and absolute probability of use by eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) for the top-ranking home range kernels for sites NE_L1 (60% kernel), SE_H3 (85% kernel), SW_H2 (90% kernel), and SW_M2 (80% kernel) in southern Michigan (Table 1.4).

At both sites NE_L1 and SE_H3, probability of use by massasaugas declined to 0 when average DBH exceeded approximately 5 cm (Figure 1.7) indicating massasauga use of areas with fewer overall trees, though this result should be interpreted cautiously as the relationship between average DBH and use does not account for the number of stems contributing to the DBH estimation. This fact likely contributed to our inability to detect a consistent pattern between the RSPF analysis for this variable (Figure 1.7) and the comparison of average DBH measurements among use versus available areas (Table 1.6).

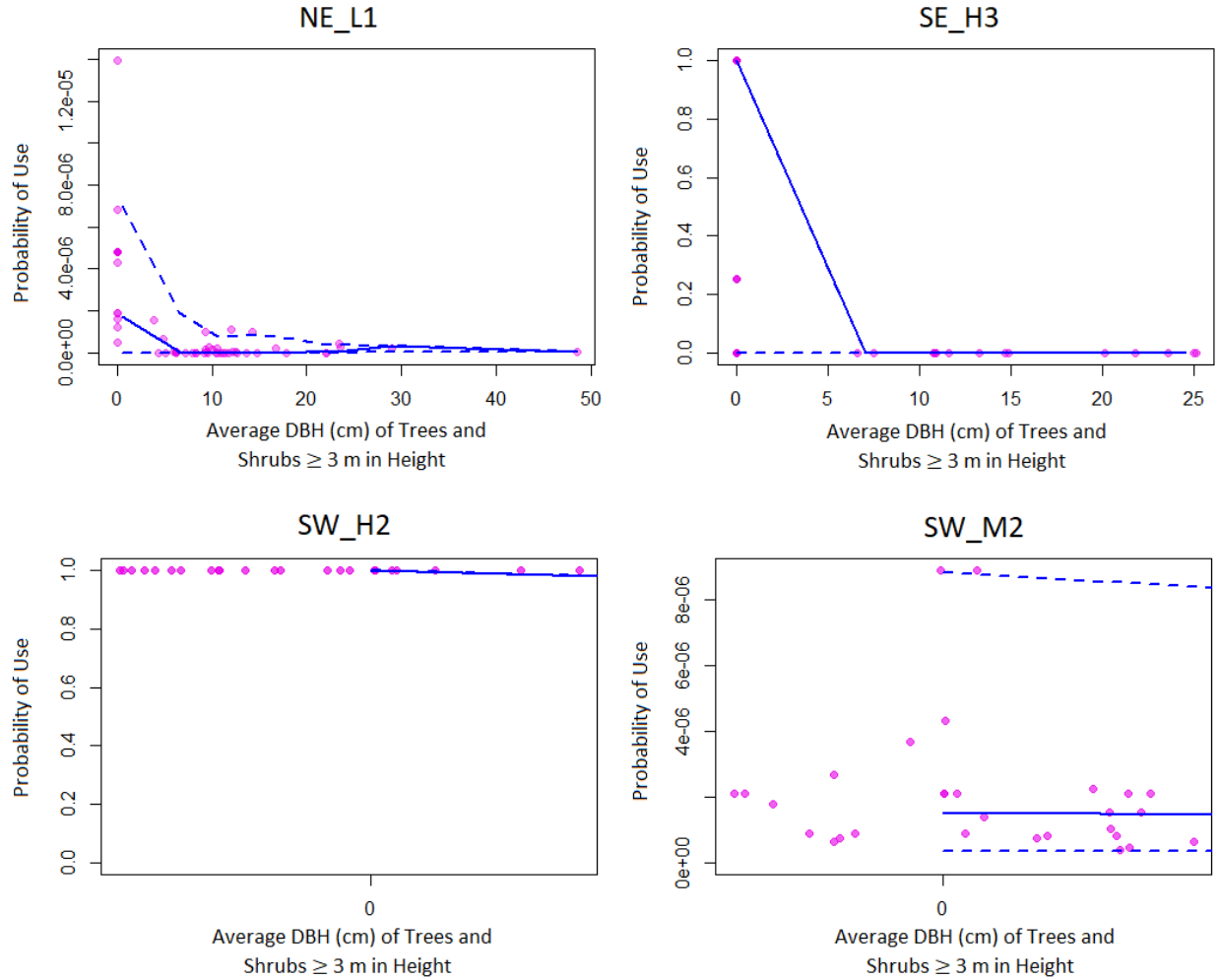


Figure 1.7. Marginal effects plots showing the relationship between the average diameter at breast height (cm) of trees and shrubs ≥ 3 m in height within the 20 x 5 m plot (covering the range of values observed within the site) and absolute probability of use by eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) for the top-ranking home range kernels for sites NE_L1 (60% kernel), SE_H3 (85% kernel), SW_H2 (90% kernel), and SW_M2 (80% kernel) in southern Michigan (Table 1.4).

Predicted Occupancy

The HSI score from the full model as a predictor variable resulted in the greatest range of occupancy probabilities, ranging from 0.18 to 0.53 for sites with HSI scores ranging from 0.21 to 0.95 (Figure 1.8), and had a greater rate of change (i.e., slope of 2.161; Table 1.7) than the thermal or landscape-level models (slopes of 1.716 and 2.136, respectively). Alternately, when using the thermal variables (LHC, DHC, SDTS, BAT) predicted occupancy ranged from 0.20 to 0.47 (HSI scores ranging from 0.27 to 1.00), and using the landscape-level variables (AEDU, AEDW) predicted occupancy ranged from 0.14 to 0.40 (HSI scores ranging from 0.34 to 1.00). This finding indicates that use of the full model (i.e., including all 6 habitat variables) offers more biologically meaningful occupancy prediction resulting in a greater range of occupancy values.

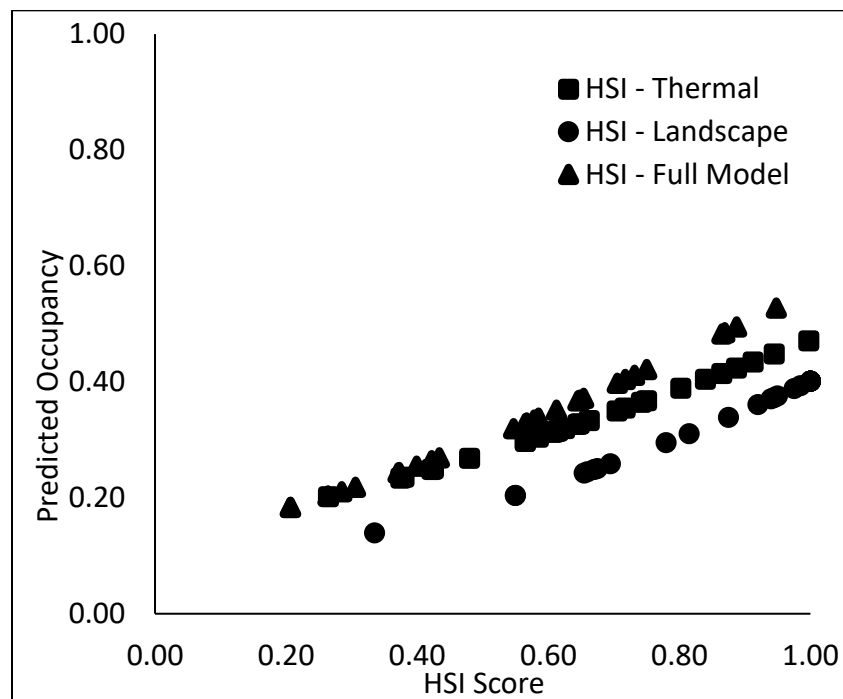


Figure 1.8. Predicted occupancy probabilities for eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) habitat suitability index (HSI) scores (Bissell 2006, Bailey 2010). Includes full model, thermal variables (LHC, DHC, STDS, and BAT), and the landscape-level variables (AEDU and AEDW).

Table 1.7. Generalized linear model parameter estimates and associated standard errors (SE), *z* scores, and *p* values for relationships between occupancy probabilities and eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) habitat suitability index (HSI) scores (Bissell 2006, Bailey 2010). Includes full model, thermal variables (LHC, DHC, STDS, and BAT), and the landscape-level variables (AEDU and AEDW).

	Estimate	SE	z value	Pr(> z)
Intercept	-1.831	1.593	-1.150	0.250
HSI – thermal	1.716	2.287	0.750	0.453
Intercept	-2.539	2.521	-1.128	0.259
HSI – landscape-level	2.136	2.520	0.848	0.397
Intercept	-1.939	1.280	-1.514	0.130
HSI – full model	2.161	2.046	1.056	0.291

DISCUSSION

We found that eastern massasauga rattlesnakes occupied sites (20 ha) with a wide range of suitability scores, ranging from marginal to high quality (i.e., HSI = 0.28-0.89). Generally, massasaugas were located within patches of greater suitability (i.e., HSI = 0.60-1.00) within our sites, consistent with the non-uniform distribution of higher quality habitats. Generally, RSPF indicated that massasaugas used vegetation structures consistent with relationships portrayed in the HSI model (Bailey 2010) for LHC and DHC but deviated for density of woody stems. Our results indicated that massasaugas in southern Michigan were using habitats with higher woody stem densities than proposed by the HSI model (e.g., approximately 360 stems/ha, SI = 0.59, at site NE_L1). Massasaugas in southeastern Michigan tend to avoid overstory tree cover and used herbaceous vegetation 0.5-1.5 m in height (e.g., Moore and Gillingham 2006, Bailey et al. 2010, Johnson et al. 2016). Our observations of massasaugas using areas with higher woody stem densities than observed by others (e.g., Bissell 2006, Bailey 2010) could be explained by lack of effective management at occupied sites (resulting in woody stem encroachment over time), or

greater plasticity in habitat use by massasaugas than originally thought. Our results lend support for using the HSI model to portray areas likely used by massasaugas across a range of habitat conditions in southern Michigan, but we caution that the relationship between use and woody stem density warrants further evaluation, and spatial extent is highly relevant.

At lower quality sites occupied by massasaugas in southern Michigan, use of patchy habitats is best quantified at localized scales (e.g., 60% kernel). For these types of sites (e.g., NE_L1 in our study), small high-quality patches of habitat were interspersed in a matrix of unsuitable vegetation types or structures. In other situations, sites contained larger, distinct regions of high quality used and unsuitable vegetation types (e.g., sites SE_H3 and SW_M2), and use was best portrayed at larger scales (i.e., >80% kernel). Both SE_H3 and SW_M2 have been actively managed (e.g., invasive species control via herbicide, burning, or mowing) to maintain early successional herbaceous vegetation, resulting in large areas of consistently high-quality massasauga habitat. Lastly, massasauga use at sites with homogenous high quality vegetation (e.g., SW_H2) was also best described at a large kernel (90%) because snakes were located throughout the site. The power of RSPF relies on used versus available (yet unused) locations and associated habitat variables (i.e., Lele and Keim 2006), hence models for sites with homogenous vegetation (e.g., few unused plots) will struggle to converge. The relationship between probability of use and average DBH was likely confounded by our inability to account for number of stems contributing to the DBH variable for this RSPF. For example, within an area used by massasaugas a single small-diameter tree would result in a low average DBH and a low stem density estimate (i.e., optimal suitability), while numerous small-diameter trees densely distributed throughout an unused site would still indicate low average DBH yet would result in high stem density estimates (i.e., poor suitability), thus confounding any relationship between

massasauga use and average DBH. As such, we do not recommend using average DBH with RSPF as a predictor of massasauga use. Our findings highlight the importance of including heterogeneity when using RSPF to understand animal habitat use (i.e., the Modifiable Areal Unit Problem; Jelinski and Wu 1996). In our analysis, 20 ha sites (corresponding to massasauga home range size) were too small to rigorously apply RSPF, especially when locations for individual snakes are pooled to represent a population-level response. We recommend doubling this size for future RSPF analyses in southern Michigan habitats.

Spatial extent of the modeling area can significantly affect results and interpretations. For example, one of our sites (NE_L1) was scored on the low end of marginal (HSI = 0.28). Yet, this site had relatively high massasauga abundance (Appendix D), and we documented successful parturitions and litters in 2015 and 2016 (Chapter 3). Although the HSI scores for this site suggested marginal suitability, patches ranging in size from 0.12 – 0.38 ha of highly suitable habitat occurred within. These low HSI score areas may hold the greatest potential for management in that the population seems poised to occupy new habitats as they become available. Habitat degradation due to succession is a threat to massasauga populations throughout the range (e.g., Dovčiak et al. 2013), and identifying priority areas for control of woody vegetation encroachment are a conservation priority.

The HSI model offers a means to assess and define current massasauga habitats, can be used in lieu of species distribution models for species such as the massasauga where presence data are limited (e.g., Zajac et al. 2015), and can indicate amount of management effort necessary to improve lower-quality habitat. For example, massasauga occupancy probability for study site NE_L1 (HSI = 0.28) was estimated to be 0.21. According to the HSI model, this site was limited by woody stem densities (i.e., average stem density of 1573 stems per ha, resulting

in $SI = 0$). If we decrease stem density by 75% (to 393 stems per ha), the SI value for woody stem density becomes 0.55 and HSI for the site increases to 0.48 with predicted massasauga occupancy increases to 0.29. If we further reduce stem density by 90% (i.e., 157 stems per ha), the resulting SI score is 0.87, resulting in HSI score of 0.56 and predicted massasauga occupancy of 0.33. This example illustrates how HSI model relationships, when supported by validation data, can portray localized effects on massasauga occupancy. Furthermore, manipulation of stem density can directly affect basal area SI, and indirectly affect live and dead herbaceous cover, resulting from decrease in canopy cover.

Habitat management can increase habitat use by massasaugas (e.g., Dovčiak et al. 2013) and positively influence individual fitness (Johnson et al. 2016) if implemented appropriately (e.g., properly timing prescribed burns or mowing; Durbian 2006, Bailey et al. 2012). Woody stem density (SI_3) was the most limiting factor among all our sites. Thus, in many situations, management of woody stem density alone via tree and shrub removal will likely improve HSI score and occupancy probability. For a New York population of massasaugas, Johnson et al. (2016) observed increased use of basking areas that had been managed (i.e., shrub removal) compared to unmanaged areas. They suggested that shrubs be cut to <0.25 m in height to limit regrowth and recommended shrub removal in habitats threatened by succession (Johnson et al. 2016).

The full HSI model (i.e., considering all habitat attributes described by Bailey 2010) predicted the widest range of occupancy probabilities, demonstrating the importance of considering thermal (LHC, DHC, STDS, BAT) and landscape-level variables (AEDU, AEDW). Still, only considering a subset of HSI variables may be useful where time or resources for habitat assessments may be limited. For example, for interests in assessing occupancy probability

of new sites, landscape-level variables (AEDU and AEDW) are quantifiable using GIS software and a landcover database that do not require field work (save for confirmation of vegetation types). Likewise, where GIS and landcover database information is not available (e.g., some private lands), thermal variables may be used for habitat assessment and occupancy prediction. Such partial assessments may not be ideal in that they do not illustrate each aspect of massasauga habitat as defined by the HSI model but can be a useful starting point when identifying potentially occupied areas.

MANAGEMENT IMPLICATIONS

Based on the application of the Bailey (2010) HSI model at our study sites throughout southern Michigan, we determined that stem density is most often the primary habitat variable resulting in reduced habitat suitability for massasaugas. As such, we recommend managers consider tree and shrub removal as a first step in improving massasauga habitats. Furthermore, with the manipulation of stem density, it follows that basal area and the herbaceous variables (LHC, DHC) will improve as well. Our validation of the Bailey (2010) HSI model, along with results of our RSPF analysis, indicate that the HSI model can be used when determining areas of conservation value both for massasauga populations that are already identified and in need of management (e.g., site NE_L1), and for delineating new areas that may potentially be occupied. These methods can be implemented within areas where massasauga occupancy is unknown using straightforward field methods such as the vegetation sampling techniques described here, and in turn, can offer predicted occupancies for managers as they focus on sites that have potential for supporting massasaugas. Additionally, implementing our detection survey methods (Chapter 2) can then be used within these areas to further inform researchers of habitat use by massasaugas.

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CHAPTER 2: SURVEY METHODOLOGY FOR EASTERN MASSASAUGA RATTLESNAKES AND FACTORS INFLUENCING DETECTION

Stephanie A. Shaffer, Henry Campa, III, Gary Roloff

ABSTRACT

The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) was listed as Threatened in 2016 by the U.S. Fish and Wildlife Service under the Endangered Species Act. To aid researchers and managers in successfully detecting massasaugas in occupied habitat for conservation efforts we developed a visual encounter survey method in southern Michigan to quantify the detection probability for massasaugas and to determine which factors are most important in influencing our ability to detect them (i.e., environmental conditions, surveyor conditions). In 2015, we developed and implemented the detection survey methodology at sites throughout southern Michigan as a pilot study. In 2016, using the finalized detection survey methods, we conducted 54 surveys (paired, independent searchers) in 2 ha areas on 4 sites that were occupied by telemetered massasaugas. To parameterize the detection process, we collected data on environmental conditions (air temperature, humidity, solar radiation, surface temperature, precipitation) and included searcher characteristics (e.g., experience, time spent searching). We detected massasaugas on 11 of the 54 surveys. Detection probability from the null model was 0.31, but we found that time spent searching and minimum air temperature were important correlates of detection probability. Detection probability approached 1.00 as searcher time exceeded 90 minutes and approached 0.80 on cooler mornings (12.8°C). Our findings offer a means to understand the reliability of visual encounter surveys for massasaugas.

INTRODUCTION

The range of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*; hereafter, massasaugas) extends from central New York and southern Ontario in the east to Iowa, Minnesota, and Missouri in the west, and includes southern Wisconsin, Michigan, Illinois, Indiana, Ohio, and Pennsylvania (USFWS 2016). Massasaugas were designated as federally Threatened throughout this range as of October 31, 2016, because of threats that included habitat degradation and fragmentation, land use change, human persecution, and road mortality (USFWS 2016). Considering that all projects with the potential to impact massasaugas are now subjected to federal review, the ability to implement standardized field survey techniques that reliably denote occupancy status is imperative for conservation efforts.

Detection probability is an important component of occupancy surveys and is defined as the likelihood of detecting an organism given that it occurs in a location (MacKenzie et al 2006). For elusive, cryptic species such as massasaugas, knowing the factors affecting detection probability is crucial for surveying (Harvey 2005), and ultimately for informing population and habitat management or monitoring (Christy et al. 2010). Estimating detection probability for snakes is challenging (Mazerolle et al. 2007, Durso et al. 2011, Willson et al. 2011), often because space use is poorly understood, capture and observation can be difficult, and movement of individuals can vary across landscapes (Steen 2010).

Detectability of snakes can be influenced by numerous factors including habitat composition and structure, availability of micro-habitat features (e.g., burrows, basking areas), and weather conditions such as cloud cover, temperature, and wind speed (Mazerolle et al. 2007, Moreno-Rueda and Pleguezuelos 2007, Foster et al. 2009, Christy et al. 2010). Characteristics of individual snakes may also influence detection probability (Christy et al. 2010), particularly because thermoregulatory needs of individuals vary by age, sex, and reproductive status (Foster

et al. 2009). Indeed, the effects of thermal environments on space use have been documented for numerous species (Elmore et al. 2017). For snakes, thermoregulatory behaviors frequently determine whether the individual is readily observable for detection by researchers (e.g., openly basking), or hidden. Additionally, detection probability may vary by observer (e.g., Harvey 2005).

The goal of this part of our study was to quantify factors affecting massasauga detection probability during the active season (i.e., following emergence from hibernation and settling in summer habitats; Siegel 1986). Habitats used by massasaugas from June through August (approximately) are where snakes bask, forage, find mates, and in the case of reproductive females, have their young and brood (e.g., Reinert 1981, Johnson 2000), and can differ from habitats used in early spring and fall around hibernacula (Reinert and Kodrich 1982). Given that habitat management projects such as mowing, invasive plant species treatment, and prescribed fire may occur during the massasauga active season (e.g., Durbian 2006), and that prevalence of construction projects (e.g., road work, urban developments) increases during summer, insights into active season surveys for massasaugas are critical to species conservation. Our aim was to quantify detection probability with respect to environmental and searcher variables for sites known to be occupied by massasaugas, and to offer a standardized survey protocol supported by empirical estimates of uncertainty.

STUDY AREA

Southern Michigan is a temperate region with moderate spring-summer (i.e., May–Aug) temperatures that ranged from approximately 10–32° C during our study (2015 to 2016 in Jackson, MI; NOAA-NWS 2017). Physiography of the counties within which this research was conducted (Barry, Calhoun, Jackson, Lenawee, Livingston, Oakland, and Washtenaw) consists of glacially deposited outwash plains, moraines, till plains, and lacustrine plains (Striker and

Harmon 1961, Engberg and Austin 1974, Engel 1977, McLeese 1981, Feenstra 1982, Thoen 1990, Tardy 1997). Soils within our study areas were well drained or poorly drained and loamy with interspersed sandy-loam, loamy sand, or mucky soil types (USDA-NRCS 2017).

We identified 27 study sites based on confirmed reports of massasaugas within the last 25 years (Michigan Natural Heritage Database [MNFI] 2014). These 27 sites represented a range of vegetation types and habitat qualities for massasaugas on private and public lands (Appendix C: Table C.1). Of the 27 sites, 11 occurred on private lands owned by citizens, non-profit conservation groups, or corporations, while the remaining 16 sites occurred on public lands (Appendix C). Sites were 20 ha in size (the maximum home range for a massasauga in southern Michigan; Bissell 2006) and ≥ 600 m apart (the maximum distance moved by an individual massasauga in a single season in southern Michigan; Bissell 2006).

METHODS

Initial Site Assessment

When selecting sites, we coarsely classified habitat quality *a priori* into low, medium, and high based on proportion of suitable and unsuitable vegetation types for massasaugas within each 20-ha site. The purpose of this classification was to ensure inclusion of sites of varying habitat structure and composition throughout southern Michigan. We used the 2006 National Land Cover Database (hereafter NLDC; MRLC 2015; Appendix C: Table C.2) to identify vegetation types within our study sites. The NLCD includes: open water, developed (open space), developed (low intensity), developed (medium intensity), barren land (rock/sand/clay), deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, and emergent herbaceous wetlands (MRLC 2015). We considered grassland/herbaceous openings, woody wetlands, and emergent herbaceous wetlands as suitable types for massasaugas. We considered open water, development, deciduous forest,

evergreen forest, mixed forest, shrub/scrub, pasture/hay, and cultivated crops as non-suitable. We based these suitability groups on Bailey's (2010) selection of suitable vegetation types from the Integrated Forest Management Analysis Program (IFMAP; MDNR 2001) land cover data. We designated sites with <40% in suitable vegetation types as low site quality, between 40–60% suitable vegetation types as medium, and >60% suitable vegetation types as high quality (Appendix C: Table C.1).

Capture and Marking

Radio telemetering massasaugas helped us determine the location of massasaugas within our study sites and to quantify the vegetation structures used by individual massasaugas. From May through August 2015 and 2016, we located and captured massasaugas via random encounter surveys within and around study sites. We checked all captured massasaugas for a passive integrated transponder (PIT) tag (12 mm in length; AVID; Norco, CA), and newly captured individuals were injected with a PIT tag subcutaneously into the dorsal region approximately 4–6 cm caudal to the cloaca (e.g., Bissell 2006). We transported massasaugas weighing >100 g to a veterinary clinic for surgical implantation of a radio transmitter. While in captivity under veterinary observation, massasaugas were held individually in locked glass-front reptile aquariums (model S24T; Neodesha Plastics Inc., Neodesha, KS), and provided a place to hide, a dish of water, and sheets of paper towel for additional hiding cover and to absorb liquids (e.g., spilled water, defecation).

Veterinary staff surgically implanted massasaugas with one of three radio transmitters of varying weights, depending on body mass (models R1515, 7 g, and R1680, 3.1 g, Advanced Telemetry Systems [ATS], Inc., Isanti, MN; model SB-2, 5.3 g, Holohil Systems Ltd., Ontario, Canada). A licensed veterinarian from the John Ball Zoological Park veterinary clinic in Grand Rapids, Michigan, followed transmitter implantation procedures described by Bailey (2010) and

Bailey et al. (2011). The combined weight of the implanted radio transmitter and the PIT tag did not exceed 5% of body weight to minimize marking effects (Lentini et al. 2011). Following protocol with the John Ball Zoo, ≤ 3 individuals per site were implanted with a transmitter each year (further, no more than one of these three was a gravid female). Within 7 days of capture (in most cases 3–4 days), implanted massasaugas were examined and approved for release by the veterinarian and subsequently released at their original capture location (Appendix D).

Detection Surveys

During the 2015 pilot season, detection survey methods were developed and carried out at 12 2-ha survey subsites within 11 of the 27 study sites. In 2016, using the finalized detection survey methods, surveys were carried out at 2 2-ha survey subsites within or adjacent to each of 4 study sites. Survey subsites were non-overlapping. The survey subsite size of 2 ha represents the minimum annual home range size for massasaugas in southern Michigan (Bissell 2006). In 2016, prior to and after each detection survey we visually confirmed that the respective subsite was occupied by a telemetered massasauga by locating the snake with a Yagi antenna and receiver (model R-1000, Communications Specialists, Inc., Orange, CA). Searchers had no knowledge of where the massasauga(s) was located. Although searchers crossed paths in the approximate center of the subsites, they were not allowed to discuss their results during the survey.

For the detection surveys, to produce the survey replication needed to estimate detection probability, we paired two searchers that simultaneously started at opposite ends of the same subsite (Figure 2.1). Using a compass and global positioning system (GPS) unit (Garmin™ International Inc., Olathe, KS), searchers walked in general north-south and south-north transects simultaneously, resulting in 7 transects with 20 m separation (Figure 2.1). We did not require searchers to walk in straight lines along transects. Rather, they meandered along transects

offering the opportunity to more thoroughly search the habitat. Searchers recorded the location of detected massasaugas, but to reduce their influence on snake detectability (i.e., for the other searcher as they walked through the site), they were not allowed to scan for a PIT tag or to determine if it was implanted with a radio transmitter. We conducted surveys between 0800 and 1800. Because of the limited number of telemetered snakes (Table 2.1), we conducted surveys at the same subsites over multiple days. These surveys were at least 24 hours apart and we alternated searchers, searcher pairs, and start locations to reduce searcher bias.

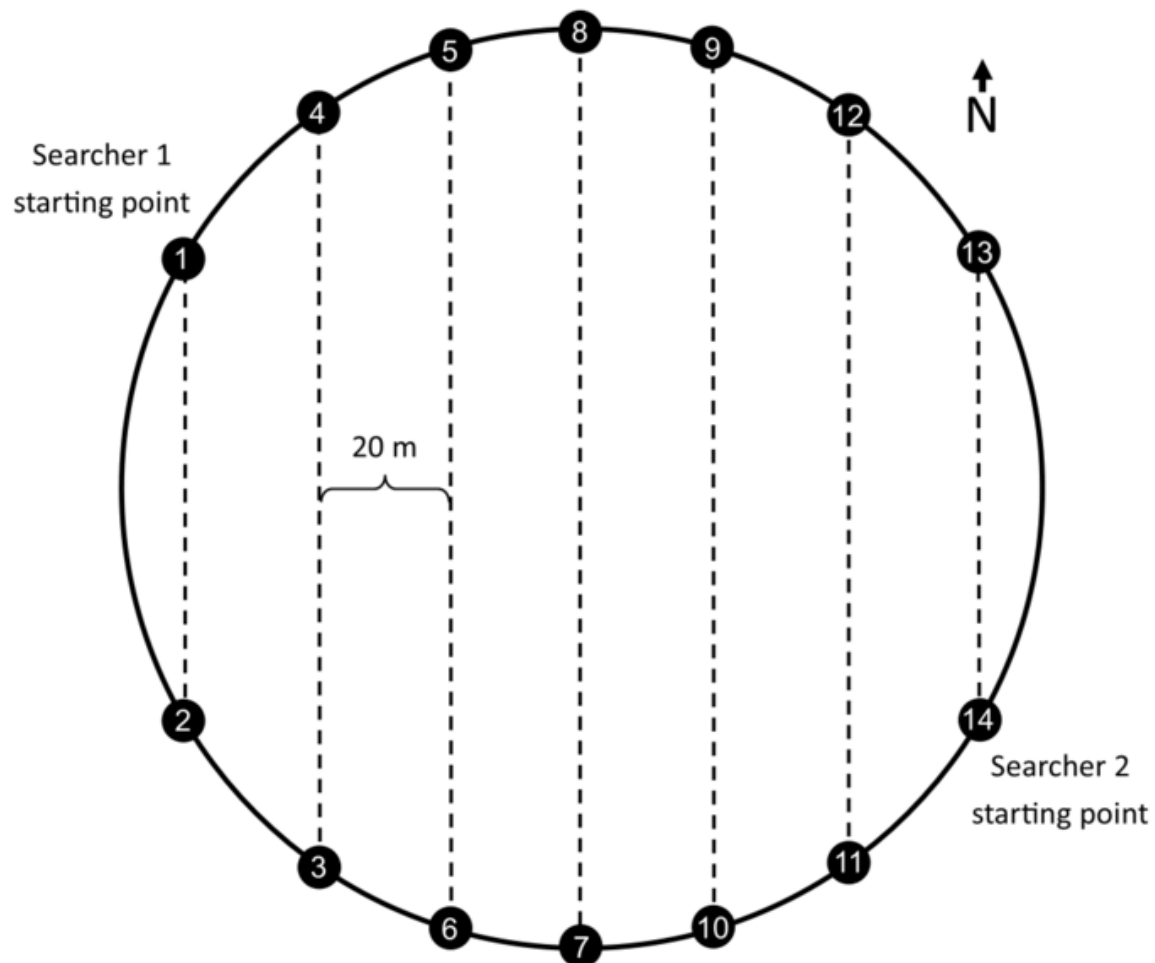


Figure 2.1. Schematic of eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) detection survey methodology conducted at 2 ha subsites ($n=4$) in southern Michigan. Filled-in numbered points indicate the pre-determined GPS locations along the subsite boundary used for navigation. Searchers simultaneously started at opposite ends (i.e., searcher 1: points 1 to 14; searcher 2: points 14 to 1) and loosely traversed each transect searching for massasaugas.

Table 2.1. Administrative information, habitat quality, and number of telemetered eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) by stage (adult, juvenile) and sex (male, female) for 20 ha sites in southern Michigan, USA, for the sites where detection surveys were carried out in 2016.

Site Code	Ownership	County	Quality Ranking ^a	Habitat Amount (% 20 ha) ^b		Telemetered Massasaugas	Age, Sex
				Suitable	Unsuitable		
NE_L1	State park	Oakland	Low	18%	82%	2	Adult ♀, adult ♂
SE_H1	Conservation group	Jackson	High	64%	36%	2	Adult ♂, juvenile ♂
SE_H3	Conservation group	Lenawee	High	64%	36%	1	Adult ♀
SW_M2	Conservation group	Calhoun	Medium	47%	53%	2	Adult ♀♂, adult ♂

^a We designated sites with <40% suitable vegetation types as low site quality, between 40–60% suitable vegetation types as medium, and >60% suitable vegetation types as high quality.

^b From the 2006 National Land Cover Data layer (MRLC 2015), suitable vegetation types included: grassland/herbaceous openings, woody wetlands, and emergent herbaceous wetlands; non-suitable included: open water, development, deciduous forest, evergreen forest, mixed forest, shrub/scrub, pasture/hay, and cultivated crops.

Detection Factors

We *a priori* identified weather factors thought to be important to massasauga detection (Table 2.2) that included variables related to air temperature, ground surface temperature, solar radiation, precipitation, and humidity (Mazerolle et al. 2007, Moreno-Rueda and Pleguezuelos 2007, Foster et al. 2009, Christy et al. 2010). We measured these variables at the start and end of each survey, and every 10 minutes during each survey as searchers conducted their walks through the subsites. Air temperature, ground surface temperature, and humidity were measured using an Extech® Hygro-Thermometer with Infrared Thermometer (model RH101, Extech Instruments, Waltham, MA). Solar radiation was measured using an Extech® Foot Candle/Lux Meter (model 401025). We examined the influence of minimum, mean, maximum, and change in these variables during the survey on massasauga detection probability. We also included same day and previous day minimum air temperature (data collected *a posteriori* using the Climate Data Online Data Tools from the National Oceanic and Atmospheric Administration National Centers for Environmental Information; NOAA-NCEI 2017).

Other potential massasauga detection factors that we analyzed included start and end time of each survey, Julian date, and the proportion of canopy cover of woody vegetation and herbaceous vegetation types in the 2-ha subsites, estimated using aerial imagery in ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA, USA). The proportion of woody and herbaceous vegetation types was explored as this would be a simple and repeatable way for researchers to assess sites potentially supporting massasauga populations. Searcher covariates included an individual identifier, searcher skill (a relative index among all searchers based on the amount of previous field experience with the species ranging from 0–3; 0 = no previous work with massasaugas, 1 = 1 year [spring-summer field season] previous work with massasaugas, 2 =

Table 2.2. All detection covariates (environmental, habitat, searcher, and survey) considered and measured during 2015 and 2016, quantified to evaluate their importance when detecting eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) in their habitats throughout southern Michigan.

Category	Covariate Name	Comments
Environmental	AirAvg	Air temperature average during survey
	AirDif	Air temperature change during survey
	AirMax	Air temperature maximum during survey
	AirMin	Air temperature minimum during survey
	difNOAAminAirmax	SameDayMinNOAA minus AirMax
	difNOAAminAirmin	SameDayMinNOAA minus AirMin
	difNOAAminSurfmin	SameDayMinNOAA minus SurfMin
	HumAvg	Humidity average during survey
	HumMax	Humidity maximum during survey
	HumMin	Humidity minimum during survey
	Prec	Precipitation during survey (0 for no rain, 1 for rain)
	PrevDayMinNOAA	Previous day air temperature minimum (NOAA)
	SameDayMinNOAA	Same day air temperature minimum (NOAA)
	SoilAvg	Soil temperature average during survey ^a
	SoilMax	Soil temperature maximum during survey ^a
	SoilMin	Soil temperature minimum during survey ^a
	SolRadAvg	Solar radiation average during survey
	SolRadMax	Solar radiation maximum during survey
	SolRadMin	Solar radiation minimum during survey
	SolRadSD	Solar radiation standard deviation during survey
	SolRadSE	Solar radiation standard error during survey
	SurfAvg	Soil surface temperature average during survey ^b
	SurfMax	Soil surface temperature maximum during survey ^b
	SurfMin	Soil surface temperature minimum during survey ^b
Habitat	herbtowood	Herbaceous:woody vegetation type
	PropHerb	Proportion herbaceous vegetation type
	PropWood	Proportion woody vegetation type
	SqmHerb	Square meters of herbaceous vegetation type
	SqmWood	Square meters of herbaceous vegetation type
Searcher	MMTs	Number of times searcher stopped to take measurements
	OverallRank	Rank of surveyor skill ^c
	RankSnake	Index of surveyor success ^d
	RankSnakePerSite	Proportion of successful surveys for each surveyor
	SearchMins	Time spent actively searching ^e
	SrchrCode	Individual searcher identification code (1 – 6)
	TotalMins	Total survey time ^f
Survey	DaysSince	Days since last survey
	EndMins	End time of survey
	Julian	Julian date of survey
	SiteOccu	Subsite occupancy status ^g

Table 2.2. (cont'd)

Category	Covariate Name	Comments
	StartMins	Start time of survey
	SubsiteCode	Individual identification for each survey subsite
	SurveyOrder	Number of times subsite had been surveyed

^a Soil temperature was measured in 2015 but not in 2016. Soil temperature covariates were excluded from the final analysis.

^b Soil surface temperature was measured in 2016 but not in 2015.

^c Rank of searcher skill from 1 (Low) to 6 (High), partially informed by the index of searcher success covariate.

^d Index of searcher success based on number of massasaugas located during field season (0–3).

^e Does not include time spent measuring detection covariates during the survey.

^f Includes time spent searching for massasaugas and measuring detection covariates.

^g Covariate SiteOccu excluded from final analysis which included only 2016 data since the occupancy = 1 for all survey subsites in 2016.

2 years previous work with massasaugas, 3 = >2 years previous work with massasaugas), proportion of successful detections by each searcher (i.e., the proportion of total surveys which resulted in a positive detection), and total minutes spent actively searching during a survey (i.e., not including time spent measuring environmental variables; Table 2.2).

We did not include a study site's habitat suitability index (HSI) score (i.e., Chapter 1) because the methods discussed here were developed as a potential tool for researchers and managers to use, and such vegetation information would not be readily available for any given site. The general habitat quality ranking that was assessed as a detection variable for this analysis (i.e., the NLCD habitat score used to qualify sites as low, medium, or high quality) is a broader representation of quality and is both accessible and easily applied without requiring on-site vegetation sampling efforts.

All snake capturing, handling and housing methods were approved by Michigan State University's Institutional Animal Care and Use Committee (IACUC), protocol 05/15-087-00, and by the Michigan Department of Natural Resources (MDNR) Fisheries Division (Scientific Collectors Permit #PR8114). Public land access was approved by the Michigan Department of Natural Resources Permit to Use State Land #PR1136-1. Private land access was arranged directly with landowners prior to the start of any research activity at that property. In accordance with the protocol and requirements outlined in our IACUC approval and MDNR Scientific Collectors Permit, boots and all gear used in the field were disinfected using a 10% bleach solution following each day in the field and before moving among field sites to reduce the potential spread of pathogens (Appendix E).

Analysis

We standardized model covariates using the `scale()` function in R. Given the large set of *a priori* detection covariates that measured similar things (e.g., 4 measures of air temperature; Table 2.2), we built univariate logistic regression models (predicting detection probability) to help identify those with statistical support for inclusion in the final model set (Table 2.2). We subsequently used AIC_c to rank all logistic models (Table 2.2) and removed redundant variables by selecting only the variable among those with the highest AIC_c score. Single season occupancy models (with occupancy fixed at 1.00), based on various combinations of these covariates, were subsequently ranked using AIC using the R program Unmarked (Fiske et al. 2011, Fiske and Chandler 2011, 2015). We calculated pairwise Pearson *r* correlation coefficients for the final 6 covariates to ensure that no correlated variables ($|r| \geq 0.5$) occurred in the same model.

RESULTS

In 2015, 24 pilot detection survey pairs were conducted at 11 sites (5 occupied, 6 unoccupied) to develop our survey methods (Table 2.3); 5 total massasaugas were observed at 3 of sites. Data from the 2015 detection surveys were omitted from further analysis due to sparsity of data and the fact that these were pilot surveys to develop and test our methods. Final survey methods were carried out in 2016. In 2016, we captured 7 massasaugas at 4 of our 27 study sites from 12 May to 14 October in 2016 that were PIT tagged and telemetered (Table 2.1, Table 2.3; Appendix D). From 8 June to 17 August, we surveyed 8 occupied 2-ha subsites at the 4 sites (2 subsites per site) from 5-9 times, omitting one subsite (subsite SE_H3_s2) because we never had any telemetered massasaugas within that subsite, resulting in 54 survey pairs (Table 2.4). We detected at least one massasauga on 11 of those surveys (Table 2.4). Our null model estimated massasauga detection probability at 0.31 (SE = 0.167). All analyses and results are based on the data collected during the 2016 detections surveys.

Table 2.3. The 27 20-ha study sites where detection surveys were carried out for detection of the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) in 2015 and 2016 throughout southern Michigan.

Year	Site Code ^a	Property Name	Survey Subsite Code ^b	# Individual Surveys ^c	Massasaugas Detected ^d	Site Occupancy ^e
2015 ^f	NE_H1	Indian Springs Metropark	NE_H1_s1	4	0	0
	NE_L1	Seven Lakes State Park	NE_L1_s1	4	0	1
	NE_M1	Seven Lakes State Park	NE_M1_s1	4	0	1
	NE_M3	Indian Springs Metropark	NE_M3_s1	4	0	0
	SE_H1	Liberty Fen	SE_H1_s1	4	0	1
	SE_L4	Fay Lake	SE_L4_s1	4	0	0
	SE_H3	Ives Road Fen	SE_H3_s1	4	3	1
			SE_H3_s2	4	1	1
	SE_L3	Sharonville State Game Area	SE_L3_s1	4	0	0
	SW_H2	Otis Audubon Sanctuary	SW_H2_s1	4	0	1
	SW_M1	Baker Audubon Sanctuary	SW_M1_s1	4	0	0
	SW_M2	Baker Audubon Sanctuary	SW_M2_s1	4	1	1
2016	NE_L1	Seven Lakes State Park	NE_L1_s1	18	3	1
			NE_L1_s2	18	3	1
	SE_H1	Liberty Fen	SE_H1_s1	12	0	1
			SE_H1_s2	12	1	1
	SE_H3	Ives Road Fen	SE_H3_s1	20	8	1
			SE_H3_s2 ^g	20	0	1
	SW_M2	Baker Audubon Sanctuary	SW_M2_s1	10	2	1
			SW_M2_s2	10	1	1

^a Site Code indicates focal region (NE = North-East, SE = South-East, SW = South-West), site suitability (L = Low, M = Medium, and H = High, based on our preliminary analysis of the proportions of available vegetation types using the NLCD land cover data [MRLC 2015]).

^b Survey Subsite Code indicates the Site Code of the 20-ha site and the number of surveys carried out within that site (e.g., s1, s2).

^c # Individual Surveys indicates the number of individual surveys carried out within that survey subsite (e.g., “4 surveys” equates to “2 pairs of surveyors” as discussed in the detection survey methods).

^d Massasaugas Detected indicates the total number of massasaugas observed by surveyors within that survey subsite.

^e Site Occupancy indicates whether the survey subsite was known to be occupied at any point in time during the study via radio telemetry or observation (1 = occupied, 0 = unoccupied).

^f Year 2015 pilot detection data were omitted from our final analysis due to sparsity of data, unconfirmed occupancy status for many of the subsites, and because of the limited amount of time we had for surveys resulting from the time it took to develop the final survey methodology.

^g This subsite was omitted from our final analysis because no massasauga was detected within this subsite at any time during the extent of this research.

Table 2.4. Survey count and massasauga detection for occupied subsites (2 ha) in the 4 sites (20 ha) where the final detection surveys were conducted for eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*), southern Michigan, USA, in 2016.

Site (20 ha)	Subsite (2 ha)	Survey Pairs	Paired Surveys with Detected Massasaugas
NE_L1	1	9	3
	2	9	1
SE_H1	1	6	1
SE_H3	1	10	3
	2	10	0
SW_M2	1	5	2
	2	5	1

The top-ranking univariate models estimating detection probability included time spent searching ($w_i = 0.94$), followed by minimum air temperature (AIC $w_i = 0.04$) and the number of times a subsite was surveyed (AIC $w_i = 0.01$; Table 2.5; Table 2.6 shows AIC results for all 39 covariates evaluated; Appendix G). Parameter coefficients from the top-ranking model indicated that massasauga detection probability increased nearly to 1 as search minutes approached 95 minutes ($\beta = 2.46$, $SE = 0.767$, $p = 0.001$; Figure 2.2) and decreased to below 0.25 as minimum air temperature increased to 21.1°C ($\beta = -1.13$, $SE = 0.384$, $p = 0.003$; Figure 2.3). As subsites were repeatedly surveyed (i.e., number of times a subsite was surveyed) detection probability increased ($\beta = -1.11$, $SE = 0.443$), although this model was likely uninformative ($\Delta_{aic} = 9.39$; Burnham and Anderson 2002). Our results indicated that the likelihood of detecting massasaugas was high (i.e. detection probability >0.9) if searchers spent >90 min in our 2-ha subsites, and almost undetectable if they spent <60 min (Figure 2.2). We also found that detection probability was highest when minimum air temperatures ranged between 12.8 and 21.1° C (resulting in average detection probabilities >0.20), but those results were highly variable. (Figure 2.3). On hot days (i.e., $>25^\circ$ C) massasaugas were almost undetectable on average (Figure 2.3).

Table 2.5. AIC table for models found to have the greatest influence on detectability of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) at 2 ha survey subsites in southern Michigan, USA. All models are statistically supported ($p \leq 0.05$).

Univariate Model	K^a	AIC^b	Δ_i^c	w_i^d
Minutes spent searching	3	67.01	0.00	0.94
Minimum air temperature	3	73.14	6.12	0.04
Number of times subsite was surveyed	3	76.40	9.39	0.01
Same day minimum temperature (NOAA)	3	77.95	10.93	0.00
Julian date	3	78.67	11.66	0.00
Minimum surface temperature	3	79.06	12.05	0.00
Null model ^e	3	81.50	14.49	0.00

^a K = the number of estimated parameters for each model.

^b AIC = the Akaike information criterion.

^c Δ_i = change in AIC between univariate models.

^d w_i = the Akaike weights.

^e The null model, which includes no observation covariates.

Table 2.6. AICc table for all 39 covariates considered (plus the null model) to have a potential influence on detection probability for eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*), southern Michigan, USA, 2016.

Covariate	Covariate Name	K ^a	AIC ^b	Δ_i ^c	w_i ^d
Time spent actively searching ^e	SearchMins	3	67.01	0.00	0.64
Total survey time ^f	TotalMins	3	69.30	2.29	0.20
Number of times surveyor stopped to take measurements	MMTs	3	70.69	3.68	0.10
Air temperature - minimum during survey	AirMin	3	73.14	6.12	0.03
Number of times subsite had been surveyed	SurveyOrder	3	76.40	9.39	0.01
Air temperature - average during survey	AirAvg	3	77.61	10.60	0.00
Same day air temperature minimum (NOAA)	SameDayMinNOAA	3	77.95	10.93	0.00
Julian date of survey	Julian	3	78.67	11.66	0.00
Soil surface temperature minimum during survey	SurfMin	3	79.06	12.05	0.00
Start time of survey	StertMins	3	79.84	12.83	0.00
Air temperature - maximum during survey	AirMax	3	80.01	13.00	0.00
Air temperature - change during survey	AirDif	3	80.01	13.00	0.00
Solar radiation standard error during survey	SolRadSE	3	81.47	14.46	0.00
Null model	EMRfm1	2	81.50	14.49	0.00
End time of survey	EndMins	3	81.75	14.73	0.00
Soil surface temperature maximum during survey	SurfMax	3	82.25	15.23	0.00
Humidity - average during survey	HumAvg	3	82.35	15.34	0.00
Solar radiation standard deviation during survey	SolRadSD	3	82.39	15.38	0.00
Herbaceous:woody vegetation type	herbtowood	3	82.47	15.45	0.00
Humidity - minimum during survey	HumMin	3	82.57	15.55	0.00
Humidity - maximum during survey	HumMax	3	82.57	15.55	0.00
Solar radiation average during survey	SolRadAvg	3	82.59	15.57	0.00
Proportion of successful surveys for each surveyor	RankSnakePerSite	3	82.81	15.80	0.00
SameDayMinNOAA minus AirMax	difNOAAminAirmax	3	82.89	15.87	0.00
Solar radiation maximum during survey	SolRadMax	3	83.04	16.03	0.00
Precipitation during survey (0 for no rain, 1 for rain)	Prec	3	83.04	16.03	0.00
Same day minimum (NOAA) minus surface temperature minimum	difNOAAminSurfmin	3	83.14	16.13	0.00
Index of surveyor success ^g	RankSnake	3	83.23	16.22	0.00
Solar radiation minimum during survey	SolRadMin	3	83.28	16.27	0.00
Individual identification for each survey subsite	SubsiteCode	3	83.36	16.35	0.00

Table 2.6. (cont'd)

Covariate	Covariate Name	K^a	AIC^b	Δ_i^c	w_i^d
SameDayMinNOAA minus AirMin	difNOAAminAirmin	3	83.41	16.39	0.00
Individual searcher identification code (1 - 6)	SrchrCode	3	83.41	16.40	0.00
Rank of surveyor skill ^h	OverallRank	3	83.43	16.42	0.00
Previous day air temperature minimum (NOAA)	PrevDayMinNOAA	3	83.43	16.42	0.00
Proportion woody vegetation type	PropWood	3	83.44	16.43	0.00
Square meters of woody vegetation type	SqmHerb	3	83.44	16.43	0.00
Square meters of herbaceous vegetation type	SqmWood	3	83.44	16.43	0.00
Proportion herbaceous vegetation type	PropHerb	3	83.44	16.43	0.00
Soil surface temperature average during survey	SurfAvg	3	83.49	16.47	0.00
Days since last survey	DaysSince	3	83.50	16.49	0.00

^a K = the number of estimated parameters for each model.

^b AIC = the Akaike information criterion.

^c Δ_i = change in AIC between univariate models.

^d w_i = the Akaike weights.

^a Does not include time spent measuring detection covariates during the survey.

^b Includes time spent searching for massasaugas and measuring detection covariates.

^c Index of searcher success based on number of massasaugas located during field season (0–3).

^d Rank of searcher skill from 1 (Low) to 6 (High), partially informed by the index of searcher success covariate.

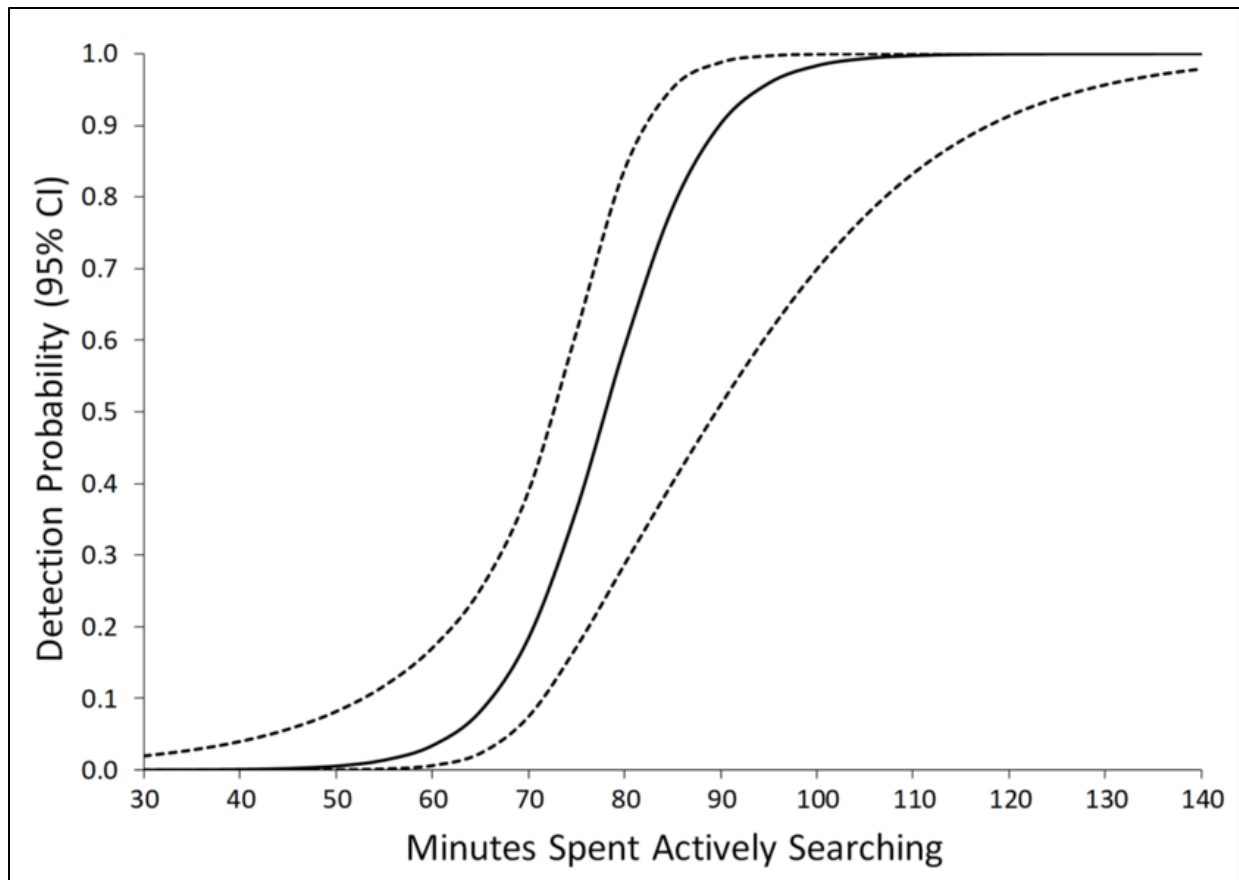


Figure 2.2. Predicted detection probabilities for eastern massasauga rattlesnakes by minutes spent actively searching (i.e., total length of search time in minutes for a given survey), at 2 ha survey sites, southern Michigan, USA, during the active season 2016. Detection probability is indicated by the solid line; 95% confidence intervals are indicated by the dotted lines.

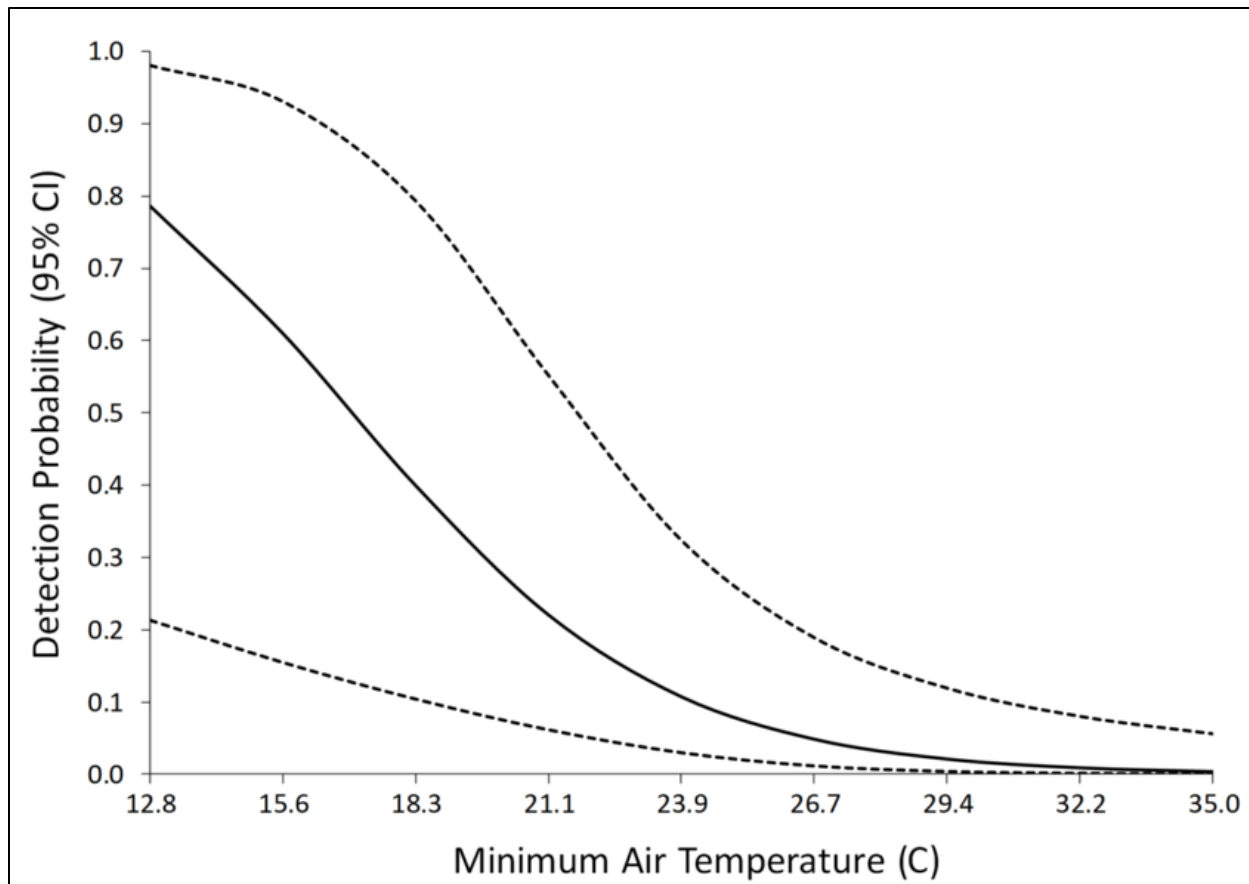


Figure 2.3. Predicted detection probabilities for massasauga rattlesnakes across a range of minimum air temperatures (C) at 2 ha survey sites, southern Michigan, USA, during the active season 2016. Detection probability is indicated by the solid line; 95% confidence intervals are indicated by the dotted lines.

DISCUSSION

We identified factors that can influence detection probability of massasauga rattlesnakes during visual encounter surveys on 2 ha subsites during the active season. Time spent actively searching and minimum air temperature were most influential; incorporating these factors into survey planning can improve the probability of detecting massasaugas in occupied habitat of varying quality. Detection probability can be relatively low for cryptic species, particularly snakes (e.g., Durso et al. 2011), but our work illustrated that detection probability can be substantially improved during optimal survey conditions. For example, we estimated that massasauga detection probability (i.e., detecting at least 1 massasauga within the 2 ha detection survey area) approached 1.0 with the proper combination of search time and minimum temperature (e.g., 90 min search time at $\sim 13^{\circ}\text{C}$). Hence, our results indicated that massasaugas can be detected on occupied sites with a relatively easy to implement visual encounter survey protocol, provided that search time and temperatures are considered.

Other studies reporting on factors influencing the ability to find massasaugas also found that temperature was important (Casper et al. 2001, Shoemaker and Gibbs 2010). For example, in a consensus of expert opinion from massasauga researchers throughout the species range, Casper et al. (2001) suggested that surveys for massasaugas be conducted preferably in the “morning and evening”, though specific times were not given due to the variability of conditions across the species’ range, and at “temperatures between 50 and 80 degrees Fahrenheit [10 to 27°C]” (Casper et al., 2001:3); Casper et al. (2001) state that their survey methods may not be applicable south and west of the Missouri River. For a northeastern New York population, Shoemaker and Gibbs (2010:508) found that most massasauga observations occurred during times of day when temperatures were increasing. Collectively, these results confirm that thermoregulatory behaviors are important considerations when surveying for massasaugas. Thermoregulatory behaviors

influence how massasaugas use vegetation and other micro-site features (e.g., basking sites). For example, Harvey and Weatherhead (2010:414) found that massasaugas at the edge of their northern range in Ontario, Canada, thermoregulated primarily by microhabitat selection based on favorable thermal ranges (as opposed to macrohabitat selection), becoming more visible as forest cover declined, resulting in more efficient thermoregulatory behaviors. Such behavior was exhibited by massasaugas at our study sites, generally basking either partially or completely out in the open in herbaceous vegetation types with little to no overstory cover.

For ectotherms like snakes, the relationship between individual body temperature and ambient temperatures within a given site is an important determinant of behavior and space use (e.g., Elmore et al. 2017). Studies to date have focused on snake body temperature and microsite (in close proximity to the snake) ambient temperature (e.g., Harvey and Weatherhead 2010), recognizing that microsite temperatures are confounded by thermoregulatory behaviors of individual animals. Indeed, massasauga basking sites tend to be warmer than temperatures observed at random locations (Shoemaker and Gibbs 2010). During 20 min time-limited detection trials within 0.25 ha for massasaugas using temperature-logging implanted radio transmitters, Harvey (2005) found that detection probability of massasaugas on the Bruce Peninsula in Ontario, Canada, was greatest when body temperatures ranged from 20–30° C. Furthermore, Shoemaker and Gibbs (2010:508) reported average massasauga body and average environmental temperatures of 29.3° C and 29.1° C, respectively, at time of capture for a population near Syracuse, New York. In their description of suitable conditions for effective massasauga surveys, Casper et al. (2001:3) recommended surveying between 10 and 27° C. Our results are generally consistent with these previous observations, indicating that detection probability is highest during cooler days (e.g., approaching 0.80 at 12.8°C) when massasaugas

apparently seek microsites that expose them to direct sunlight. Hence, training crews to look for these microsites (e.g., exposed mats of dead vegetation, grass tussocks) during cooler mornings or afternoons improves detection probability. Our results also indicated that as temperatures exceed 24° C massasauga detection probability was <0.1, suggesting that surveys during warmer days will be considerably less effective, or that searchers should aim to begin surveys earlier in the day during ideal temperature conditions. For researchers locating massasaugas in other parts of the species range (i.e., northern or southern limits) optimal temperatures for detection may need to be adjusted. For example, for southern populations, massasauga basking habits may differ from massasaugas in the north because of differences in daily and seasonal temperature variability across the species range.

Given optimal search time and temperature conditions, our results indicated that massasauga surveys could be conducted throughout the day (i.e., survey start time was not an important covariate). We also failed to find a searcher or habitat quality effect (similar to Harvey 2005), indicating that basic training of field staff in snake and microsite identification, field navigation (e.g., use of GPS, compass), and training on the survey protocol prior to data collection, can result in reliable surveys for massasaugas during the active season throughout a range of habitat conditions. Finally, though survey fatigue was not a factor accounted for in this study, anecdotally we found that two surveys per searcher per day was optimal for maintaining searcher alertness and interest. Further, to maintain optimal searcher performance, we recommend taking a break between surveys. Three surveys were attempted on multiple occasions and in these instances the third survey always proved to not be worth the effort for the searchers involved due to fatigue and decreased interest and alertness.

Conservation concerns impacting massasaugas (e.g., federally Threatened status, habitat degradation and fragmentation), combined with a cryptic life history in dense vegetation types, highlights the need for reliable, standardized survey methodologies as described here. A standardized method would ensure that researchers are following reproducible methods with comparable effort when detecting the species rangewide. Our results can be used to increase the effectiveness of conducting eastern massasauga rattlesnake surveys and to quantify survey reliability. We encourage biologists to use standardized survey methodologies to detect massasaugas throughout their range and across a range of habitat conditions, providing additional avenues for conservation planning.

MANAGEMENT IMPLICATIONS

We offer a standardized survey technique for determining occupancy status of sites potentially supporting massasaugas. During the active season, we recommend that 2-ha areas be surveyed for 90 min using coordinated transect walks during days or at a time of day with cooler temperatures ($\sim 13^{\circ}\text{C}$). These temperatures tend to occur early in the morning during spring or summer in southern Michigan, though this pattern can vary daily and annually; e.g., NOAA-NWS 2017). For larger areas we recommend distributing 2-ha survey subsites throughout as opposed to conducting a long, single survey to avoid searcher fatigue. The 2-ha area of our survey subsites represented minimum annual home range size for massasaugas in southern Michigan (Bissell 2006), so we recommend that researchers use subsite sizes that align with region-specific massasauga home ranges.

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CHAPTER 3: EASTERN MASSASAUGA RATTLESNAKE SURVIVORSHIP, MOVEMENTS, AND REPRODUCTION

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ABSTRACT

The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) was listed as Threatened in 2016 by the U.S. Fish and Wildlife Service under the Endangered Species Act in part due to a documented population decline rangewide. While some life history and demographic data are available for large, well-studied populations occurring in high quality habitats, little is known about massasauga populations occurring outside of these areas. To quantify survivorship and obtain life history data for massasaugas throughout southern Michigan, we surveyed for massasaugas at 27 20-ha study sites in areas known to have been historically occupied by massasaugas. From May through September (i.e., the active season) in 2015 and 2016, telemetry was used to relocate snakes. Six of the 27 study sites resulted in sufficient massasauga locations to estimate survivorship rates across the study region. For each 137-day study period in the 2015 and 2016 active season, adult massasauga survivorship using a modified version of the Mayfield method was 0.767 (SE = 0.016). For juveniles and neonates ($n = 10$), apparent survivorship was ≥ 0.65 . Using radiograph imagery or palpation, embryo counts for gravid females ($n = 17$) across all sites ranged from 5 to 18, and litter counts ($n = 6$) in the field ranged from 1 to 15. Neonate massasaugas were radio tracked from 2 to 26 days, moving up to 551.2 m from the gestation site within this period. Our active season survivorship rates fall within the range of estimates from other massasauga populations and add to the current literature which is relatively lacking in life history data for neonate and juvenile massasaugas. Because demographic rates can be used to infer population viability, such information may be used by

managers to assess small and fragmented populations in lower-quality habitats throughout the species range.

INTRODUCTION

The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*; hereafter, massasauga) was designated as federally Threatened rangewide as of October 31, 2016, due to threats that included habitat degradation and fragmentation, land use change, human persecution, and road mortality (USFWS 2016). Massasauga range extends from central New York and southern Ontario in the east to Iowa, Minnesota, and Missouri in the west, and includes southern Wisconsin, Michigan, Illinois, Indiana, Ohio, and Pennsylvania (USFWS 2016). Research has suggested that demographic rates for massasaugas can vary greatly among populations throughout this range (e.g., adult survivorship; Bissell 2006, Bailey 2010, Bailey et al. 2011, Jones et al. 2012), yet few studies estimate neonate or juvenile survivorship rates (e.g., Hileman et al. 2018), or recruitment rates, fecundity, or movements (e.g., Jellen and Kowalski 2007). Further, though demographic information is available for specific populations, little is understood regarding demographic rates for populations occurring throughout a range of habitat conditions. This, along with population fragmentation (i.e., USFWS 2016), creates difficulty for managers interested in monitoring and evaluating trends and shifts in local populations and modeling population viability. Because massasauga populations in Michigan are considered among the most viable (e.g., Szymanski 1998), Michigan offers an opportunity to research life history traits pertaining to all life stages. It is imperative that demographic rates are estimated across a range of habitat conditions so that natural resources managers can predict population viability and implement appropriate habitat management to help conserve populations. Such information can be used as performance measures to indicate fitness of the population (e.g.,

Haufler et al. 2002). Adding information on these vitality rates to currently available literature would assist managers attempting to assess population viability for a range of habitat qualities.

Further, little information is available on dispersal and movements of snake neonates following parturition. Such information is relevant for managers as they assess habitat use by massasaugas; however, it is difficult to obtain due to difficulties associated with locating and successfully radio tracking snakes of small body mass. Still, some researchers have successfully collected such data via radio telemetry for neonate rattlesnakes (e.g., Cobb et al. 2005, Jellen and Kowalski 2007). Movement of animals throughout their habitat is related to the availability of habitat components and quality (i.e., suitability). Examining movements of individual massasaugas combined with habitat assessment tools (e.g., see Chapter 2), can indicate habitat suitability and areas of high use within an area. This information can be used to inform habitat management.

When assessing demographic parameters, radio telemetry has been successfully used across multiple taxa including snakes and other relatively small-bodied animals (e.g., timber rattlesnake neonates [*Crotalus horridus*; Cobb et al. 2005, Howze et al. 2012], various bat species [O'Mara et al. 2014]). Telemetry studies involving snakes have mainly resulted in estimates of adult demographic data (e.g., Plummer and Mills 2000, Bailey et al. 2011), though Jellen and Kowalski (2007) successfully telemetered neonate massasaugas in Pennsylvania by attaching transmitters to the snake's skin using 3M[®] Vetbond Tissue Adhesive. Similarly, Cobb et al. (2005) reported that following external attachment of transmitters using a similar adhesive to neonate timber rattlesnakes (*Crotalus horridus*), 4 individuals were successfully tracked from 39-42 days in Tennessee.

The purpose of our work was to estimate survival rates for massasaugas in southern Michigan. Further, in the interest of supplementing available literature on life history of neonate massasaugas, we report on individual movements of radio telemetered neonate massasaugas and reproductive information (embryo counts of gravid females, litter sizes).

STUDY AREA

Southern Michigan is a temperate region with moderate spring-summer (i.e., May–Aug) temperatures that ranged from approximately 10–32° C during our study (2015 to 2016 in Jackson, MI; NOAA-NWS 2017). Physiography of the counties within which this research was conducted (Barry, Calhoun, Jackson, Lenawee, Livingston, Oakland, and Washtenaw) consists of glacially deposited outwash plains, moraines, till plains, and lacustrine plains (Striker and Harmon 1961, Engberg and Austin 1974, Engel 1977, McLeese 1981, Feenstra 1982, Thoen 1990, Tardy 1997). Soils within our study areas were well drained or poorly drained and loamy with interspersed sandy-loam, loamy sand, or mucky soil types (USDA-NRCS 2017).

We identified 27 study sites based on confirmed reports of massasaugas within the last 25 years (Michigan Natural Heritage Database [MNFI] 2014). These 27 sites represented a range of vegetation types and habitat qualities for massasaugas on private and public lands (Appendix C: Table C.1). Of the 27 sites, 11 occurred on private lands owned by citizens, non-profit conservation groups, or corporations, while the remaining 16 sites occurred on public lands (Appendix C). Sites were 20 ha in size (the maximum home range for a massasauga in southern Michigan; Bissell 2006) and ≥ 600 m apart (the maximum distance moved by an individual massasauga in a single season in southern Michigan; Bissell 2006).

METHODS

Initial Site Assessment

When selecting sites, we coarsely classified habitat quality *a priori* into low, medium, and high based on proportion of suitable and unsuitable vegetation types for massasaugas within each 20-ha site. The purpose of this classification was to ensure inclusion of sites of varying habitat structure and composition throughout southern Michigan. We used the 2006 National Land Cover Database (hereafter NLDC; MRLC 2015; Appendix C: Table C.2) to identify vegetation types within our study sites. The NLCD includes: open water, developed (open space), developed (low intensity), developed (medium intensity), barren land (rock/sand/clay), deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, and emergent herbaceous wetlands (MRLC 2015). We considered grassland/herbaceous openings, woody wetlands, and emergent herbaceous wetlands as suitable types for massasaugas. We considered open water, development, deciduous forest, evergreen forest, mixed forest, shrub/scrub, pasture/hay, and cultivated crops as non-suitable. We based these suitability groups on Bailey's (2010) selection of suitable vegetation types from the Integrated Forest Management Analysis Program (IFMAP; MDNR 2001) land cover data. We designated sites with <40% in suitable vegetation types as low site quality, between 40–60% suitable vegetation types as medium, and >60% suitable vegetation types as high quality (Appendix C: Table C.2).

Capture and Marking

From May through August 2015 and 2016, we located and captured massasaugas via random encounter surveys within and around study sites. We checked all captured massasaugas for a passive integrated transponder (PIT) tag (12 mm in length; AVID; Norco, CA), and newly captured individuals were injected with a PIT tag subcutaneously into the dorsal region

approximately 4–6 cm caudal to the cloaca (e.g., Bissell 2006). We transported massasaugas weighing >100 g to a veterinary clinic for surgical implantation of a radio transmitter. While in captivity under veterinary observation, massasaugas were held individually in locked glass-front reptile aquariums (model S24T; Neodesha Plastics Inc., Neodesha, KS), and provided a place to hide, a dish of water, and sheets of paper towel for additional hiding cover and to absorb liquids (e.g., spilled water, defecation).

Veterinary staff surgically implanted massasaugas with one of three radio transmitters of varying weights, depending on body mass (models R1515, 7 g, and R1680, 3.1 g, Advanced Telemetry Systems [ATS], Inc., Isanti, MN; model SB-2, 5.3 g, Holohil Systems Ltd., Ontario, Canada). A licensed veterinarian from the John Ball Zoological Park veterinary clinic in Grand Rapids, Michigan, followed transmitter implantation procedures described by Bailey (2010) and Bailey et al. (2011). The combined weight of the implanted radio transmitter and the PIT tag did not exceed 5% of body weight to minimize marking effects (Lentini et al. 2011). Following protocol with the John Ball Zoo, ≤ 3 individuals per site were implanted with a transmitter each year (further, no more than one of these three was a gravid female). Within 7 days of capture (in most cases 3–4 days), implanted massasaugas were examined and approved for release by the veterinarian and subsequently released at their original capture location (Appendix D). While in captivity, all female snakes were examined for presence of embryos via palpation and ultrasound or radiograph, and embryo counts were recorded. To determine dates (or a range of dates) of parturition, we noted when the adult female was last observed while gravid and related it to the first observation of a neonate in close proximity to her.

We also conducted telemetry external transmitters attached with cyanoacrylate-based adhesive (e.g., “Super Glue”; Cobb et al. 2005, Howze et al. 2012) for adult massasaugas that

could not be implanted due to our protocol limiting the number of surgeries per site (≤ 3), or for massasaugas > 100 g that were located after the final day of surgery (i.e., after July 31 of both years to ensure sufficient healing of the surgical site prior to hibernation), and for neonate and juvenile individuals weighing < 100 g. These transmitters included ATS model R1635 (0.75 g), and ATS model A2414 (0.30 g), and again did not exceed 5% of the body weight in combination with the PIT tag (Lentini et al. 2011).

All snake capturing, handling and housing methods were approved by Michigan State University's Institutional Animal Care and Use Committee (IACUC), protocol 05/15-087-00, and by the Michigan Department of Natural Resources (MDNR) Fisheries Division (Scientific Collectors Permit #PR8114). Public land access was approved by the Michigan Department of Natural Resources Permit to Use State Land #PR1136-1. Private land access was arranged directly with landowners prior to the start of any research activity at that property. In accordance with the protocol and requirements outlined in our IACUC approval and MDNR Scientific Collectors Permit, boots and all gear were disinfected using a 10% bleach solution following each day in the field and before moving among field sites to reduce the potential spread of pathogens (Appendix E).

Survivorship Estimates

To estimate survival of massasaugas, we used the Mayfield method (Mayfield 1961) as modified by Bart and Robson (1982). The Mayfield method has been used for massasauga survival estimates (e.g., Bailey et al. 2011), and is recommended for smaller sample sizes, and it allows for staggered entry assuming constant survival throughout the study period (Winterstein et al. 2001). Due to the large number of field sites and logistical limitations, visits to sites for tracking massasaugas were not regular (e.g., intervals between visits ranged from 1 to 57 days). The modification to the Mayfield estimator introduced by Bart and Robson (1982) allows for

irregular intervals between visits. Bart and Robson (1982) do not explicitly account for censored individuals and therefore we modified the calculation for censoring (e.g., Bunck and Pollock 1993, Winterstein et al. 2001) and calculated a daily survival rate ($\hat{p}_m$):

$$\hat{p}_m = (1 - n_d) / \left(\sum_l^L l(n_{ls} + hn_{lf} - n_{lc}) \right)$$

where n_d is the number of mortalities observed during the study, L is the maximum interval between visits, l is the interval length, n_{ls} is the number of intervals of length l during which a mortality did not occur, h is a fraction of the days during which mortality did not occur ($h = 0.4$ for long intervals, as recommended by Bart and Robson [1982] and Miller and Johnson [1978], representing the presumed number of days after which death occurred between the second-to-final and final locations), and n_{lf} is the number of intervals of length l during which a mortality did occur (Bart and Robson 1982). Variable n_{lc} , the number of intervals of length l during which an individual was censored, is our modification to the original formula presented by Bart and Robson (1982). A massasauga was censored when we could no longer locate the individual, the radio transmitter, or both, and the fate of the individual was unknown. A mortality event was documented when a carcass was located and identified via telemetry or PIT tag, or when we located a transmitter that had been surgically implanted with no sign of the snake (presuming the snake had been depredated and the transmitter discarded). Using this method to estimate survival, we included massasaugas where ≥ 2 locations were collected following release from initial capture or surgery. We pooled data across all field sites and years due to small sample sizes, treating any massasaugas observed in both years independently.

RESULTS

Estimated Daily and Period Survivorship

Massasaugas were located at 9 of the 27 study sites, 3 of which only resulted in a single massasauga sighting (study sites SE_L2, SE_M1, and SW_H3). These massasaugas were omitted from further analysis. For the remaining 6 study sites (NE_L1, NE_M1, SW_M2, SE_H1, SE_H3, and SW_H2) at least one massasauga with 2 or more locations was found (Appendix D). Site NE_L1 was a marginal quality site (HSI = 0.28, Chapter 1) and was where we found a majority of massasaugas included in this analysis (Table 3.1).

Table 3.1. Number of adult, juvenile, and neonate eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) used to estimate survivorship throughout southern Michigan in 2015 and 2016. The habitat suitability index (HSI) represents a suitability score assigned to each site based on the vegetation composition and structure within the site (Chapter 1).

Site	HSI	Adults	Juveniles	Neonates
NE_M1	0.28	10 ^a	1	3
SW_M2	0.89	5	0	3
SE_H1	0.72	3	2 ^a	0
SE_H3	0.66	4	2	0
SW_H2	0.8	2	0	0

^a 1 individual tracked in both years, treated independently for this analysis

Three adult massasauga mortalities occurred in 2015 and 2016 (Appendix H). Years and massasaugas were treated independently and the study period was 137 days in length (26 May to 10 Oct for each year). Among all massasaugas including adults, juveniles, and neonates both telemetered and untelemetered ($n = 36$; 19 censored, 3 mortalities), daily survivorship was 0.998 (SE = 0.001, UCI = 1.000, LCI = 0.996; Table 3.2), and period survivorship (i.e., 137 days) was

0.785 (SE = 0.014, UCI = 0.811, LCI = 0.755; Table 3.3). Results differed slightly when only adult massasaugas (including both telemetered and untelemetered; $n = 25$; 9 censored, 3 mortalities) were included. Daily survivorship was 0.998 (SE = 0.001, UCI = 1.000, LCI = 0.995; Table 3.2) and period survivorship was 0.767 (SE = 0.016, UCI = 0.796, LCI = 0.732; Table 3.3).

Table 3.2. Daily survivorship estimates for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) at 6 20-ha study sites throughout southern Michigan in 2015 and 2016.

Groups Included ^a	Survival ^b	LCI ^c	UCI ^c	<i>n</i>	Censored	Mortalities ^d
All Adult, Juvenile, Neonate	0.998 (0.001)	0.996	1.000	36	19	3
All Adult	0.998 (0.001)	0.995	1.000	25	9	3
Telemetered Adult, Juvenile, Neonate	0.998 (0.001)	0.995	1.000	30	13	3
Telemetered Adult	0.998 (0.001)	0.995	1.000	20	4	3

^a Group Included indicates massasaugas of which stage were included in the analysis and whether telemetered and untelemetered individuals were combined and included (i.e., “All”), or only telemetered individuals were included (i.e., “Telemetered”).

^b Survival Rate estimates (and standard error) made using Bart and Robson’s (1982) modified Mayfield method.

^c LCI, lower 95% confidence interval, and UCI, upper 95% confidence interval.

^d Observed mortalities.

Table 3.3. Period (137 days) survivorship estimates for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) at 6 20-ha study sites throughout southern Michigan in 2015 and 2016.

Groups Included ^a	Survival ^b	LCI ^c	UCI ^c	<i>n</i>	Censored	Mortalities ^e
All Adult, Juvenile, Neonate	0.785 (0.014)	0.755	0.811	36	19	3
All Adult	0.767 (0.016)	0.732	0.796	25	9	3
All Juvenile, Neonate	0.650 ^d	<i>n/a</i>	<i>n/a</i>	11	<i>n/a</i>	0
Telemetered Adult, Juvenile, Neonate	0.761 (0.015)	0.728	0.789	30	13	3
Telemetered Adult	0.739 (0.017)	0.701	0.770	20	4	3
Telemetered Juvenile, Neonate	≥0.650 ^d	<i>n/a</i>	<i>n/a</i>	10	<i>n/a</i>	0

^a Group Included indicates massasaugas of which stage were included in the analysis and whether telemetered and untelemetered individuals were combined and included (i.e., “All”), or only telemetered individuals were included (i.e., “Telemetered”).

^b Survival Rate estimates (and standard error) made using Bart and Robson’s (1982) modified Mayfield method.

^c LCI, lower 95% confidence interval, and UCI, upper 95% confidence interval.

^d Estimated using apparent survival due to no observed mortalities among the neonate and juvenile stages.

^e Total number of observed mortalities.

We observed no mortalities among juvenile or neonate stages of the massasauga populations we encountered, likely due to their small size and because radio transmitters could only be attached externally. Therefore, survival could not be estimated using the Mayfield method. Instead, we estimated survival for these groups using apparent survival (i.e., length of the period during which neonates were observed [89 days; 5 Jun to 2 Sept] divided by the total length of the study [137 days; 26 May to 10 Oct]); juveniles and neonates were pooled due to small sample size ($n = 11$). Apparent survivorship for the 137-day period was 0.65 for all neonates and juveniles for 2015 and 2016 (Table 3.3) and represents a minimum survival rate within this timeframe.

Embryo Counts, Litter Size, and Dates of Parturition

Embryo counts for gravid female massasaugas ranged from 5 to 18 (mean = 8.5; Table 3.4). Observed litters in the field following parturition ranged from 1 to ≥ 15 neonates (mean = 7.5; Table 3.4). In 2015, we attempted to locate litters from known gravid females at 4 study sites. That year, a litter was first observed at site SW_M2 on 13 August and the telemetered female associated with this litter was last observed the day before on 12 August with no neonates nearby. At site NE_L1 the first litter was observed on 2 September and the telemetered female (PIT tag # 836560350; Figure 3.1) was last observed with no neonates on 28 August. No neonates were observed at site NE_M1 although the telemetered female was observed periodically into October. Likewise, no litters were observed at site SE_H3, though we were unable to closely monitor any females due to mortality of the sole telemetered gravid female at that site (Table 3.4; Appendix H).

Table 3.4. Number of embryos, the method by which the count was obtained, and observed neonates following parturition for all gravid female eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) found to be gravid during the 2015 and 2016 field seasons at our study sites throughout southern Michigan. This table does not include litter counts for instances where we were unable to obtain an embryo count for the female and does not include litters found with no associated adult female as this limited our ability to make comparisons between pre- and post-parturition litter size estimates.

Year	Site Code ^a	PIT I.D. ^b	# of Embryos	Method	Date of Observation ^c	Post-Parturition Comments	Parturition Date	# Neonates Observed ^d
2015	NE_L1	836560332	8	palpate	July 9	Female observed	Unknown	0
		836560350	≥16	radiograph	June 30	Female observed with litter	28 Aug – 2 Sept	≥15
		836568071	9	palpate	July 9	n/a	Unknown	n/a
		836580078	8	radiograph	June 30	Female observed with litter	Prior to 4 Sept	4
	NE_M1	836550298	~5	radiograph	July 14	Female observed	Unknown	0
	SW_M2	836561814	^e	radiograph	July 29	Female observed with litter	12 – 13 Aug	6-7
	SE_H3	75578601	8-9	radiograph	May 22	n/a	Unknown	n/a
		100075839	^e	palpate	July 8	n/a	Unknown	n/a
		836546351	8	radiograph	May 22	mortality	n/a	n/a
		836550585	^e	palpate	July 12	n/a	Unknown	n/a
		836559770	6	radiograph	June 8	n/a	Unknown	n/a
		836567798	~5	palpate	July 8	n/a	Unknown	n/a
		836570859	7	palpate	July 8	n/a	Unknown	n/a
		840533265	5	palpate	June 9	n/a	Unknown	n/a
			18	radiograph	July 29	Female observed with litter	7 – 15 Aug	≥15
			^e	palpate	June 15	n/a	Unknown	n/a
2016	SW_M2	840533081	8-9	palpate	June 21	Female observed with litter	9 – 11 Aug	1
		75567567	8	palpate	June 1	n/a	Unknown	n/a
	SE_H3	99874823	11	palpate	June 1	n/a	Unknown	n/a
		840520549	6	palpate	June 1	n/a	Unknown	n/a
		840527780	8-10	palpate	June 1	Female observed	Unknown	0
		840544608	^e	palpate	June 30	n/a	Unknown	n/a
	SE_M1	836551889	^e	palpate	May 12	n/a	Unknown	n/a
	SW_H2	840515348	^e	radiograph	June 24	Female observed with litter	16 – 24 Aug	4

^a Study site code.

^b PIT (passive integrated transponder) tag identification.

^c Date that embryo count was obtained.

^d Number of neonates per litter observed following parturition.

^e No embryo count obtained.



Figure 3.1. Film radiograph image (photographed) taken on 30 Jun 2015 showing 16 embryos (R. Colburn, personal communication) in female eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) from site NE_L1 (PIT tag # 836560350; Appendix D) in southern Michigan during the 2015 field season. Parturition for this female occurred between 28 August and 2 September 2015. On 2 September 2015, 15 neonates were observed in close proximity to this female. Lateral view. Image credits: John Ball Zoo, Grand Rapids, MI; R. Colburn.

3.2a



Figure 3.2. Digital radiographs taken on 29 July 2016 showing 18 embryos (R. Colburn, personal communication, 2016) in female eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) from site NE_L1 (lateral view [2a], dorsal view [2b]; PIT tag # 840543607; Appendix D) in southern Michigan during the 2016 field season. Parturition for this female occurred between 7 and 15 August 2016. On 15 August 2016, 15 neonates were observed in close proximity to this female. Image credits: John Ball Zoo, Grand Rapids, MI; R. Colburn, B. Flanagan.

Figure 3.2. (cont'd)

3.2b



In 2016, we attempted to locate litters from known gravid females at 5 study sites (Table 3.4). At site NE_L1, the first neonate was observed on 10 August (the telemetered female thought to be associated with this neonate due to close proximity was last observed with no neonates on 7 August and was again observed with 7 neonates on 15 August; Figure 3.2). At site SW_M2, the first litter was observed on 12 August, though no adult female was located in close proximity; 3 neonates observed on 16 August at this site exhibited unusual physical characteristics including 2 possible cases of hypo-melanism (J. Harding, personal communication, 2018), and one case of apparent congenital deformity (see Appendix D: Figures D.1 and D.2). At site SW_H2 the first litter was observed in close proximity to the associated telemetered female on 24 August (the female, PIT tag # 840515348, was last observed on 16 August and was still gravid at that time). At site SE_H3 no gravid females were implanted with transmitters, limiting our ability to monitor and detect any parturition events, and none of the females we had PIT tagged at that site were observed with litters, though neonates (a litter of ≥ 2) were observed on 9 August; the female attending this litter was unmarked. Likewise, at site SE_M1, no female massasaugas were telemetered and no neonates were observed.

Post-parturition Radiotelemetry of Neonates

In 2016, we tracked neonate massasaugas from litters located via telemetered adult females. We successfully attached transmitters externally to 4 neonates at site NE_L1 and to 6 neonates at site SW_M2. All neonates at site NE_L1 were from the same litter while 3 neonates each from two litters were telemetered at site SW_M2. The number of locations collected among all neonates ranged from 2 to 7 over a span of 2 to 26 days (Table 3.5). For 4 of the 10 neonates, at some unknown time following the initial transmitter attachment and release, the transmitter fell off prior to our next return to the site and the second location is based on the location of the transmitter.

Table 3.5. Radiotracking information for all telemetered neonate eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) obtained during the 2016 field season in southern Michigan. All neonates were fitted with external transmitters weighing less than 5% of their body weight (Lentini et al. 2011). Exact date of parturition is unknown for all neonates. Horizontal lines within the table delineate three different litters based on proximity and date of location (i.e., one litter at NE_L1, and two litters at SW_M2).

Site Code ^a	Snake ID	Dates Tracked ^b	# of Locations ^c	Parturition Distance (m) ^d	Total Distance (m) ^e	Comments
NE_L1	N_NEL1_2016_10	15 – 17 Aug ^f	2	4.5	4.5	<i>n/a</i>
	N_NEL1_2016_11	15 Aug – 10 Sept ^g	7	170.2	368.4	Last observed with transmitter on 2 Sept.
	N_NEL1_2016_12	15 – 25 Aug	5	445.9	551.2	No visual observation at final location but thought to be moving while being tracked.
	N_NEL1_2016_13	17 – 25 Aug	4	259.8	275.1	Observed with transmitter at final location.
SW_M2	N_SWM2_2016_1	12 – 16 Aug ^f	2	1	1	<i>n/a</i>
	N_SWM2_2016_2	12 – 18 Aug ^f	3	95.6	96.2	No visual observation following initial release, thought to be burrowed.
	N_SWM2_2016_3	12 – 16 Aug ^f	2	93.2	93.2	<i>n/a</i>
	N_SWM2_2016_4	16 – 18 Aug ^f	2	11.2	11.2	<i>n/a</i>
	N_SWM2_2016_6	16 – 24 Aug	3	41.1	62.7	Observed with transmitter at final location.
	N_SWM2_2016_7	16 – 24 Aug ^g	3	158.7	165.8	Last observed with transmitter on 18 August.

^a Study site code.

^b Range of dates that the neonate was tracked. First date indicates the date of capture, transmitter attachment, and release. Second date indicates the date that the final location was collected, based on the location of a dropped transmitter or the telemetered neonate.

^c Number of locations collected, including the initial capture location and the final location, whether the neonate was observed or not.

^d Total linear distance from gestation site to the final telemetry location.

^e Total linear distance between successive telemetry locations, representing the minimum distance moved by the individual during the timeframe within which it was tracked.

^f Only transmitter found at final location (i.e., had fallen off neonate); neonate not located.

^g No neonate or transmitter observed at final location (i.e., transmitter signal was heard but underground and unrecoverable)

At site NE_L1 on 15 August, a litter of ≥ 15 neonates was located in close proximity to a telemetered female (PIT tag # 840543607; Table 3.4; Figure 3.2; Appendix D); parturition had likely occurred at some point since 7 August. This female's radiograph image indicated at least 18 embryos (R. Colburn, personal communication, 2016), the greatest number of embryos counted during this study. Three neonates from this litter were fitted with external radio transmitters on 15 August; one transmitter fell off and was recovered within two days, and on 17 August another neonate from this litter was fitted with a transmitter. For one neonate from this litter, we obtained 7 total locations spanning a linear traveled distance of 368.4 m over 26 days (the last telemetry location of this neonate was 170.2 meters from the gestation site; Table 3.5) but the fate of this neonate is unknown as it was not observed at the final location and the transmitter was not recovered. The transmitter remained attached to this individual for at least 18-26 days and was the longest span of time during which a neonate was telemetered in our study. Another telemetered neonate from this litter traveled a linear distance of 551.2 m within 10 days of tracking, the furthest distance moved following parturition recorded among all neonates telemetered in our study. The directionality of movement differed among these three neonates; while neonate N_NEL1_2016_11 generally trailed after the mother (i.e., southeastward of the gestation site), neonates N_NEL1_2016_12 and N_NEL1_2016_13 moved eastward.

At study site SW_M2, no adult female massasauga was located in close proximity to the litter of ≥ 3 locate on 12 August 2016. For the second litter of ≥ 3 located on 16 Aug 2016, an unmarked female had been located, PIT tagged, and fitted with an external radiotransmitter on 12 Aug within 2 meters of that location (PIT tag # 840543057; Appendix D). On 16 Aug, the transmitter that had been attached to the female was found in close proximity to the neonates, but no adult massasauga was found. Interestingly, neonates N_SWM2_2016_2 and N_SWM2_2016_3 moved east and slightly north of their gestation site and were relocated

among the neonates from the second litter at this site. For the second litter, neonate N_SWM2_2016_7 moved northward and slightly east at a considerable distance compared to its littermates, while neonate N_SWM2_2016_6 moved southeast from the gestation site.

DISCUSSION

Our estimates of adult period survival (0.767) and minimum apparent survival for the neonate and juvenile group (0.65) are comparable to estimates for other massasauga populations. Hileman et al. (2018) reported that for a massasauga population in southwestern Michigan, rate of survivorship increased with age, which corroborates our findings and is reported for other reptile species (e.g., Congdon et al. 1994). Hileman et al. (2018) estimated annual adult survivorship at 0.66 for males and 0.71 for females. Apparent survival for ages 0, 1, and 2 was 0.38, 0.65, and 0.67, respectively (Hileman et al. 2018). Likewise, Jones et al. (2012) reported that active season (comparable to our study period of May through October) survivorship was 0.77 rangewide. Our estimates of period adult survival were considerably lower than adult active season survival estimate of 0.947 reported by Bailey et al. (2011) for massasaugas in southern Michigan using the Mayfield method. Bailey et al. (2011) suggested that their relatively high estimate may be because the study area is managed specifically for massasaugas, due to a lack of human development in the area, or potentially a result of low sample size. Further, our estimate was obtained at sites ranging from marginal to optimal suitability (Chapter 1).

The 6 study sites from which we obtained survivorship estimates ranged from marginal to optimal suitability (1 marginal, 3 good, 2 optimal) based on the Bailey (2010) habitat suitability index model for the massasauga in southern Michigan (Chapter 1), yet suitability ranking for these 20-ha study sites does not necessarily correlate with population viability. Thus, we note the importance of considering scale when relating habitat suitability to population fitness (e.g., Wiens 1989, Gaillard et al. 2010). For example, while one site, NE_L1, was ranked as

marginally suitable for the massasauga, patches of optimally suitable habitat occurred within a matrix of unsuitable vegetation types and this site is where we observed the two largest litter sizes documented during this study. This finding suggests that massasaugas are more strongly influenced by micro-habitat quality (i.e., vegetation structure and composition) as opposed to macro-habitat attributes (e.g., predominant vegetation type within a defined area). Habitat quality has been identified as a driving factor for population viability including increased survival (e.g., Bailey et al. 2011), though Johnson et al. (2016) found no change in massasauga reproductive rates or survival when basking site quality was improved for a New York population.

Embryo counts obtained during our study ranged from 5 – 18. Bailey (2010, unpublished data), observed an average embryo count of 6.6 (ranging from 1-10) for a massasauga population in southwestern Michigan using counts from radiograph and palpation. Our largest counts (based on radiograph imagery) were 16 (Figure 3.1) and 18 (Figure 3.2), both in massasaugas from the same study site (NE_L1) in 2015 and 2016 respectively. Following parturition for both females, we documented 15 neonates for each litter.

For massasauga parturitions monitored during our study, litter sizes ranged from 1 to 15 (mean = 7.5) neonates based on field observations. Our findings are consistent with previously reported litter sizes, for example, Bissell (2006) reported a litter size range of 4 - 12 (mean = 9) for a southern Michigan population, though these counts included both the number of observed neonates at a gestation site and the number of viable embryos counted via ultrasounds. Additional reports range from 2 - 16 (mean = 7.6, captive-born litters in Michigan; Hileman et al. 2018), 5 – 7 for a Wisconsin population (Reinert 1981), and 4 – 10 for a Missouri population (mean = 6.35; Seigel 1986). These authors did not report whether litter counts (both pre- and post-parturition) included non-viable offspring which may be due to the difficulty associated with identifying non-viable individuals using any method of counting, though Baker (2016)

observed total litter sizes for captive massasaugas ranging from 2-15 (mean = 7.74) and viable offspring ranging from 1 – 15 (mean = 6.67). We did not observe any non-viable offspring in the field and were unable to confirm whether all neonates were accounted for when we located litters in the field. Our two observations of 15 viable neonates is on the upper end of litter sizes that have been reported (e.g., Reinert 1981, Bissell 2006, Hileman 2018) and considering the number of embryos counted for these females (i.e., 16 and 18), is similar to overall embryo viability rate of 85% reported by Baker (2016). In Baker's (2016) study, 15% of embryos were found to be nonviable across all massasaugas examined in the study.

It is important to note that litter counts can vary depending on the method with which they were obtained. For example, in a study comparing effectiveness of ultrasound, radiography, palpation, and post-parturition litter observation, Bissell (2006, unpublished data) found that for massasaugas, radiography, palpation, and post-parturition litter counts consistently underestimated litter size compared to ultrasound which was found to be the most accurate. Likewise, in a study by Donini et al. (2017), accuracy of egg or follicle counts for Diamondback Terrapins (*Malaclemys terrapin*) was greater with ultrasound than with radiography. In the current study, we did not use ultrasound for litter counts and always relied on palpation in the field or on film radiograph or digital radiograph imagery when massasaugas were transported to the veterinary clinic for surgical implantation of transmitters. Thus, it is likely that for female massasaugas that were not selected for transmitter implantation, palpation counts resulted in underestimated litter size (Table 3.4); Bissell et al. (2006, unpublished data) reported that the mean difference between litter counts obtained via palpation and ultrasound was 2.5. In the current study all radiographs were produced using film-based radiographic techniques in 2015; after 2016, our collaborators upgraded to a digital radiography system (e.g., Figure 3.1, Figure

3.2). In a medical study, researchers found no significant differences between diagnostic readings of film versus digital radiograph imagery (e.g., Franzblau et al. 2018).

Parturitions for massasaugas monitored in our study occurred during August, with one instance possibly occurring the first two days of September. Likewise, Jellen and Kowalski (2007) report that for a western Pennsylvania massasauga population, parturition occurred between 5 and 27 August 2015. Foster et al. (2009) found that the mean date of parturition in 2004 and 2005 was 17 August for a southern Michigan population. Further, parturition date may vary based upon environmental conditions (e.g., Lourdais et al. 2004).

Jellen and Kowalski (2007) found that for telemetered massasauga neonates in western Pennsylvania, average total distance moved within 42 days was 257.3 m ($\pm$ 88.6 m), and at the end of the period average distance from gestation site was 83.3 m ($\pm$ 44.5 m). Our distances traveled by neonate massasaugas exceed these numbers (i.e., site NE_L1 in 2016), but such movements may be influenced by environmental factors such as temperature (e.g., Eskew and Todd 2017) and habitat quality or vegetation structure and its distribution throughout a site (e.g., Kernohan et al. 2001, Durbian et al. 2008). In 2015 and 2016, site NE_L1 was classified as a poor-marginal quality site for massasaugas (see Chapter 1) comprised of a patchy matrix of suitable and unsuitable vegetation types, and this is where we observed the greatest neonate movements observed during this study (i.e., 551.2 m moved within 10 days). Conversely, at site SW_M2, a good-optimal suitability site containing homogenous suitable habitat, neonate movements never exceeded 165.8 m within 8 days.

Our results offer demographic rates and life history information for massasaugas at multiple sites ranging in habitat quality from marginal to optimal throughout southern Michigan. We offer this analysis as a contribution to the knowledge base for massasaugas within this part of the range, for populations within areas identified as poor-marginal quality for the species (e.g.,

site NE_L1), and to add information for previously unstudied and undocumented populations. The reproductive success of massasauga populations occurring in geographically small and threatened areas (e.g., due to late successional encroachment) highlights the importance of identifying and conserving such seemingly insignificant populations. The application of appropriate habitat management (e.g., the creation of corridors, reversing succession) can promote genetic exchange among such populations, thereby improving population viability and ensuring the long-term success of the species throughout the state.

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CHAPTER 4: CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

DISSERTATION OVERVIEW

In Chapter 1 of this dissertation, I presented a validation of the Bailey (2010) habitat suitability index (HSI) model for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) at 27 20-ha study sites of varying quality throughout southern Michigan on private and public lands. Disproportionate use by massasaugas of the habitat elements defined as important by Bissell (2006) and Bailey (2010) was illustrated via resource selection probability function analysis, showing a positive relationship between probability of use and the amount of live and dead herbaceous cover and a negative relationship between probability of use and DBH and number of woody stems ≥ 3 m in height. Further, I reported predicted occupancy rates based on a site's HSI score. Using the full HSI model, occupancy probability exceeded 0.50 at sites where suitability was most optimal (i.e., HSI = 1), suggesting that I can expect 50% of the sites at that level of suitability to be occupied by massasaugas within southern Michigan. This work describes methods that may be used by managers in habitat assessments for the massasauga, and a way to identify habitats with the greatest conservation value (i.e., habitats where HSI scores indicate a high probability of occupancy).

Chapter 2 identifies environmental and searcher variables that should be considered when attempting to detect massasaugas in their habitats; specifically, minimum temperature should be considered (detection probability approaches 0.8 when minimum temperatures reach 12.8 °C), and time spent searching should exceed an hour (detection probability approaches 1 at occupied sites when 1.5 hours are spent searching within a 2-ha area). Further, I offer a standardized survey methodology that can be applied at sites where massasaugas may exist

throughout a range of habitat suitabilities. This work offers a method for detecting massasaugas within their habitats and can aid managers attempting to maximize their detection probability.

Chapter 3 describes my findings on the demographic and life history characteristics for massasaugas throughout my study sites in southern Michigan in sites ranging in suitability from marginal to optimal based on the HSI modeling in Chapter 1. Survivorship estimates are available for adult massasaugas rangewide (e.g., Jones et al. 2010) yet little is available in the literature regarding neonate or juvenile survivorship or movements. Further, little is understood regarding demographic rates for populations occurring throughout a range of habitat conditions. The aim of this work was to address some of these data gaps at sites of varying suitability. I reported daily adult survivorship (0.998), active-season adult survivorship (0.767), and minimum active season survivorship of juveniles and neonates (≥ 0.65). I reported average litter sizes (mean = 7.5, ranging from 1-15), embryo counts (mean = 8.5; ranging from 5-18), and summarized neonate movements following parturition based on radio tracking. Ten neonates were tracked for 2-26 days, moving distances up to over 551 m.

As a federally Threatened species (USFWS 2016), conservation of massasauga populations and both known and potential habitats are imperative for the future of the species. Knowledge of habitat use, habitat composition and structure, and life history information including movements, demographic rates, and reproduction in habitats of varying quality is necessary for understanding and defining massasauga populations. Based on the findings of this work and my evaluation of massasauga population and habitat ecology, I offer management recommendations for conservation of the massasauga and its habitat throughout southern Michigan on public- and privately-owned lands.

RECOMMENDATIONS FOR HABITAT MANAGEMENT AND POPULATION ASSESSMENT

Identifying Potential Massasauga Sites

For natural resource managers interested in locating potential massasauga sites throughout southern Michigan, I recommend first referring to recent and historical reports of observations of the species within and around the region of interest. When identifying specific locations for further investigation, I recommend remotely using a landcover database (e.g., National Land Cover Database [“NLCD”; MRLC 2015], Integrated Forest Management Analysis Program [“IFMAP”; MDNR 2001]) to locate areas that contain suitable vegetation or cover types for massasaugas (e.g., early successional deciduous or wetland vegetation types containing a high proportion of open, herbaceous vegetation with limited overstory cover; Bailey [2010]). For example, using the NLCD database at my study sites in southern Michigan, I identified areas containing suitable massasauga cover types which included grassland/herbaceous openings, woody wetlands, and emergent herbaceous wetlands (MRLC 2015). Further, using the IFMAP database which provides more detailed vegetation classification than NLCD, I identified the specific vegetation types that were available within my study sites. For identifying massasauga habitat using IFMAP, suitable early successional upland vegetation types include forage crop, herbaceous openland, row crop, and upland shrub; suitable early successional wetland vegetation types include emergent wetland, floating aquatic, lowland shrub, and mixed non-forest wetland (MDNR 2001).

Following a remote assessment of the available vegetation types, I recommend following up with ground truthing efforts to confirm that vegetation types in the database are representative of what currently exists at the site. This validation may involve a simple walk-through of the site to confirm that specific vegetation types of interest are still present at the location. Recent

management, development, or successional changes may result in stark differences between the database and current vegetation composition and structure. While in the field, microhabitats conducive to massasauga use can be located (e.g., high percentages of live or dead herbaceous cover, limited overstory; Chapter 1, Bailey 2010).

Assessing Habitat Suitability

For managers interested in assessing suitability of massasauga habitats to guide management, the Bailey (2010) HSI model can be used in its full form (i.e., accounting for all vegetation composition and structural variables; Chapter 1), using only the landscape level variables (% area in early successional deciduous upland or wetland areas), or using only the thermal stand-level variables (% live and dead herbaceous cover, basal area of trees, and stem density). Where resources are limited, an assessment using only the landscape-level variables can be conducted using GIS software and a landcover database and does not require the user to be present in the field. Likewise, the thermal variables may be used when landcover data is unavailable, which may be the case for some private lands, or for areas that have recently undergone extensive management.

As illustrated in Chapter 1, the resulting HSI score can then be used to determine the probability of occupancy for a given area. This method can be used in conjunction with my recommendations for identifying potential massasauga sites (see previous section), further indicating the likelihood of a site being occupied or suitable for massasaugas.

Detecting Massasaugas

I recommend that detection surveys, as described in Chapter 2, be implemented in areas where massasaugas are thought to exist (e.g., based on sighting reports or the availability of suitable vegetation types, composition, and structure, as defined in Chapter 1). Surveys should be carried out during the active period (i.e., spring and summer) when there is sufficient time to

spend at least 1-1.5 hours searching (e.g., to maximize detection probability; Chapter 2) per area of interest, and I recommend keeping the survey area to 2 ha (i.e., the smallest annual home range for massasaugas in southern Michigan; Bissell 2006) so the area can be sufficiently searched within that timeframe. I do not recommend conducting a survey at more than 2 2-ha areas per day, per person, as this resulted in considerable fatigue for searchers during the pilot work in 2015. Finally, it is imperative that suitable temperatures be considered when deciding on a day and/or time for a survey. In southern Michigan, detection probability is maximized (e.g., approaching 0.8) at 12.8 °C, is approximately 0.5 at 17 °C, and approaches 0.0 when temperatures exceed 24 °C. Considering the greater detection probability at cooler temperatures, I recommend searching earlier in the season (May, June) throughout the day, or in the morning during the hotter months (July, August) when temperatures are cooler, as a general rule.

Habitat Management

Though I did not assess impacts of habitat management or management practices on massasauga populations as a part of this study, I summarize findings in the literature to make recommendations for management practices and future research. Habitat management is an integral component of maintaining and restoring suitable massasauga habitat (e.g., Johnson et al. 2000, Cross et al. 2015), especially considering the threat of habitat degradation (i.e., driven by succession) impacting massasauga populations (USFWS 2016). Important methods for maintaining early successional vegetation types include mowing, targeted shrub removal, and burning (e.g., Johnson et al. 2000), but as a relatively sedentary, slow-moving species, massasaugas may be at an increased mortality risk from such management activities (e.g., mowing, burning; e.g., Durbian 2006, Cross et al. 2015). As such, managers may be interested in reducing incidental mortality of massasaugas resulting from management activities.

Cross et al. (2015) recommended that burns occur prior to emergence from hibernation or following movement into hibernation sites, that burns not be conducted around known hibernacula during ingress or egress, and that burns be conducted in the winter months when possible to avoid risk to massasaugas. For management occurring outside of this timeframe (i.e., during the active season), the authors state that burns be patchy to provide suitable areas for massasaugas to relocate to during the burn, that burn areas not be in close proximity to one another, and that refugia such as brush piles be removed from burn areas to reduce massasauga mortality.

For mowing, I recommend that mowing decks be set high to prevent massasauga mortalities; specifically, Johnson et al. (2000:24-25) recommend mowing at least 10.16-15.24 cm (“4-6 inches”) above the ground to avoid massasaugas that may be present. Johnson et al. (2000) also recommend mowing during times of day that massasaugas are least active (“11 a.m.-3 p.m.”), stating that this time is when most massasaugas are under cover. Further, the authors recommend that mowing take place prior to emergence in the spring or following hibernation in the fall (Johnson et al. 2000:24).

High stem density (stems/ha of trees and shrubs >3 m in height) was often the greatest contributing factor limiting habitat quality for massasaugas when I assessed habitat at the 27 20-ha study sites throughout southern Michigan in 2015 and 2016 (i.e., Chapter 1: Table 1.1). Specifically, for most of these sites, stem density estimates for all sites but one exceeded the optimal range (0-58 stems/ha of trees and shrubs >3 m in height), and 16 sites had stem density estimations ≥ 800 stems per ha (i.e., at which suitability = 0; Bailey 2010). Likewise, Shoemaker and Gibbs (2010) reported that decreased canopy cover (i.e., via cutting shrubs to 0.5-0.25 m in height) improved basking opportunities for massasaugas for a New York population. As such, I suggest reducing stem density at sites to within optimal (0-58 stems/ha) range of suitability via

shrub and tree removal at many sites as a primary step in improving massasauga habitat. As discussed in Chapter 1, reduction of this variable alone can result in improvement of the other habitat variables (e.g., increasing the amount of live and dead herbaceous cover) over time, further improving the suitability of the habitat. Shoemaker and Gibbs (2010) recommend that shrubs be cut to 0.25-0.5 m in height to decrease canopy cover and to allow for improved basking opportunities, while Johnson et al. (2016) recommend cutting shrubs to ≤ 0.25 m in height. Where habitat management is warranted for the massasauga, I recommend tree and shrub removal prior to implementing other management activities since this factor will likely positively influence other habitat attributes. This method is relatively simple to implement (i.e., removal of trees and shrubs) compared to the use of fire, and when possible, stems may be left on-site to create brush piles, offering refugia for massasaugas.

FUTURE RESEARCH

Future research for the massasauga throughout its range should seek to include not only well-studied or heavily-documented populations occurring in high quality habitats, but also smaller populations in lower-quality habitats that may otherwise remain undocumented (e.g., such as our study site NE_L1; Chapter 1). While heavily studied populations offer invaluable information and insight into the ecology, habitat, and dynamics of the species, smaller populations in poor quality habitats similar to our study site NE_L1 are equally important components of the species' potential metapopulation dynamics. Habitat management to improve these areas can increase connectivity throughout the landscape by creating additional suitable habitat, ultimately decreasing the opportunity for population isolation and extirpation. Further, population dynamics of massasaugas within lower-quality sites should be assessed (i.e., survivorship, fecundity) as indicators of population fitness. Many reports of massasauga survivorship come from well-studied populations in high quality habitats (e.g., Jones et al. 2012),

but may not be representative of massasauga populations occurring elsewhere within the species' range.

Massasauga movements should continue to be examined to determine individual and population home ranges and to further identify dynamics between movement and habitat quality. The movement of massasaugas through poor quality habitats may differ from movements occurring in high quality habitats (i.e., differing spatial distribution of resources and habitat components within poor- versus high-quality habitats) and can inform researchers of how massasaugas are using specific habitat components throughout the species' range. We expect that the habitat suitability index model described in detail in Chapter 1 and by Bissell (2006) and Bailey (2010) is applicable throughout southern Michigan, but may be limited in its usefulness in other parts of the species range (e.g., at the northernmost or western limits) due to differences in geomorphology, hydrology, and land cover or vegetation types, and may require modification for certain populations to address these limitations. As such, the continued study of massasauga movements and habitat use rangewide is imperative.

APPENDICES

APPENDIX A

Dissemination of Findings and Related Information

The following documents presentations, publication, and outreach where findings or information related to this project were disseminated to the scientific community or the public.

Peer-Reviewed Publication

Shaffer, S.A., G. Roloff, H. Campa, III. *In Progress*. Survey methodology for detecting eastern massasauga rattlesnakes in southern Michigan. *Wildlife Society Bulletin*.

Presentations: Professional Meetings

- The Wildlife Society 24th Annual Conference

- September 26, 2017; Albuquerque, New Mexico
- “Habitat Suitability for the Eastern Massasauga Rattlesnake throughout Southern Michigan”
- Authors: Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Daniel Kennedy

- Michigan Partners in Amphibian and Reptile Conservation

- March 22, 2017; Belle Isle Nature Zoo; Detroit, Michigan
- “Radiotelemetry and Detection of the Eastern Massasauga Rattlesnake across Southern Michigan”
- Authors: Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Daniel Kennedy

- 12th Annual Department of Fisheries and Wildlife Graduate Student Research Symposium

- February 24, 2017; Michigan State University; East Lansing, Michigan
- “Detection of the Eastern Massasauga Rattlesnake across Southern Michigan”
- Authors: Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Daniel Kennedy

- Midwest Fish and Wildlife 77th Annual Conference
 - February 7, 2017; Lincoln, Nebraska
 - “Detection and Occupancy of the Eastern Massasauga Rattlesnake across Southern Michigan”
 - Authors: Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Daniel Kennedy
- Midwest Fish and Wildlife 76th Annual Conference
 - January 26, 2016; Grand Rapids, Michigan
 - “Habitat Use and Detection of the Eastern Massasauga Rattlesnake across Southern Michigan”
 - Authors: Stephanie A. Shaffer, Henry Campa, III, Gary Roloff, Daniel Kennedy
- 10th Annual Department of Fisheries and Wildlife Graduate Student Research Symposium
 - February 27, 2015; Michigan State University; East Lansing, Michigan
 - “Assessing the Status, Habitat Quality, and Management of Eastern Massasauga Rattlesnake Populations in Michigan”
 - Authors: Stephanie A. Shaffer, Henry Campa, III

Presentations: Public Engagement and Outreach

- Sierra Club – Michigan Chapter; Crossroads Group Meeting
 - September 20, 2017; Brighton District Library; Brighton, Michigan
 - “There are Rattlesnakes in Michigan?”
 - Authors: Stephanie A. Shaffer, Henry Campa, III
- Huron Valley Audubon Society Meeting
 - October 10, 2016; Kensington Nature Center; Milford, Michigan
 - “Conservation of the Eastern Massasauga Rattlesnake in Michigan”
 - Authors: Stephanie A. Shaffer, Henry Campa, III

- Wildlife Weekend

- August 8, 2015; Indian Springs Metropark; White Lake, Michigan
- “The Eastern Massasauga Rattlesnake in Michigan”
- Authors: Stephanie A. Shaffer, Henry Campa, III

Media Engagement

- News Coverage: "MSU Researchers Work to Protect Rattlesnakes"

- July 2016; WILX News 10; Lansing, Michigan
- <<http://www.wilx.com/content/news/MSU-Researchers-work-to-protect-rattlesnakes-387616721.html>>

- Video Feature: "Sustaining a Ssssssspecies"

- 2016; MSU Today; Michigan State University; East Lansing, Michigan
- <<http://msutoday.msu.edu/feature/2016/sustaining-a-ssssssssspecies/>>

APPENDIX B

Snake Fungal Disease Sampling Results

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Introduction

Snake fungal disease, a fungal pathogen (*Ophidiomyces ophiodiicola*, formerly *Chrysosporium* sp.; hereafter “snake fungal disease” or “SFD”) is a recently emerging potential threat to snake populations (Allender et al. 2015). The spread of such a pathogen holds important implications, especially considering that many massasauga populations remain fragmented and isolated (USFWS 2016). Still, little is known about SFD (Allender et al. 2011, 2015) though the number of reports on the pathogen have increased in recent years (e.g., Dolinski et al. 2014, Allender et al. 2015). Snake fungal disease has been detected in multiple snake species across North America, Europe, Asia, and Australasia (Sigler et al. 2013). In the United States, reported instances of infection include the plains garter snake in Illinois (*Thamnophis radix*; Dolinski et al. 2014), black rat snake in Georgia (*Elaphe obsoleta obsoleta*; Rajeev et al. 2009), and eastern massasauga (*Sistrurus catenatus catenatus*) in Illinois (Allender et al. 2011).

Across multiple snake taxa, potential instances of infection include symptoms such as lumps or bumps under the skin (i.e., granuloma), lesions or ulcers on the skin, inflammation, crusty patches, or ‘dirty’ looking build-up under scales or scutes (Rajeev et al. 2009, Allender et al. 2011, 2016, Dolinski et al. 2014). It is also important to note that the pathogen may also be present upon the skin of an individual showing no physical signs of infection (Allender et al. 2016).

Snake fungal disease has been confirmed in Michigan (e.g., Barry, Cass, Crawford, and Kalkaska counties; Allender et al. 2016). In massasaugas specifically, this disease has been

reported to affect individuals around the nasolabial region (i.e., heat sensing pits) which can result in facial swelling and ulcers, and a distortion of mouth and eyes in more severe cases (Allender et al. 2011, 2016). Considering the conservation status of massasaugas (i.e., USFWS 2016), further assessment of SFD prevalence is warranted.

Study Area

Southern Michigan is a temperate region with moderate spring-summer (i.e., May–Aug) temperatures that ranged from approximately 10–32° C during our study (2015 to 2016 in Jackson, MI; NOAA-NWS 2017). Physiography of the counties within which this research was conducted (Barry, Calhoun, Jackson, Lenawee, Livingston, Oakland, and Washtenaw) consists of glacially deposited outwash plains, moraines, till plains, and lacustrine plains (Striker and Harmon 1961, Engberg and Austin 1974, Engel 1977, McLeese 1981, Feenstra 1982, Thoen 1990, Tardy 1997). Soils within our study areas were well drained or poorly drained and loamy with interspersed sandy-loam, loamy sand, or mucky soil types (USDA-NRCS 2017).

We identified 27 study sites based on confirmed reports of massasaugas within the last 25 years (Michigan Natural Heritage Database [MNFI] 2014). These 27 sites represented a range of vegetation types and habitat qualities for massasaugas on private and public lands (Appendix C: Table C.1). Of the 27 sites, 11 occurred on private lands owned by citizens, non-profit conservation groups, or corporations, while the remaining 16 sites occurred on public lands (Appendix C). Sites were 20 ha in size (the maximum home range for a massasauga in southern Michigan; Bissell 2006) and ≥ 600 m apart (the maximum distance moved by an individual massasauga in a single season in southern Michigan; Bissell 2006).

Methods

Capture and Marking

From May through August 2015 and 2016, we located and captured massasaugas via random encounter surveys within and around study sites. We checked all captured massasaugas for a passive integrated transponder (PIT) tag (12 mm in length; AVID; Norco, CA), and newly captured individuals were injected with a PIT tag subcutaneously into the dorsal region approximately 4–6 cm caudal to the cloaca (e.g., Bissell 2006).

Sample Collection

Captured massasaugas were immediately examined for clinical signs of SFD. Swab samples were collected from all massasaugas regardless of clinical signs (at least one sample in 2015, and at least two samples – one upon initial capture, and one at a later date - in 2016 when possible; e.g., Hileman et al. 2018). If clinical signs of SFD were present, a photograph was taken, and information provided to Dr. Matt Allender (including swab samples and photographs) as part of the data reporting process. Massasaugas were sampled at first, upon recommendation by Dr. Allender, by swabbing the nasolabial pits. This method proved to be impractical (and unsuccessful in many instances due to the difficulty of restraining the snake in a tube while attempting to swab its face), and so nasolabial pit swabs were only taken if there were clinical signs of SFD on the face of the massasauga in question. Otherwise, swab samples were taken from along the back and belly of an individual showing no clinical signs and directly from any locations on the body where clinical signs were present (i.e., lesion, lump, scab, or scar; each location sampled individually). In all instances, massasaugas were sampled while in the field, prior to transportation for radio transmitter implantation.

All snake capturing, handling and housing methods were approved by Michigan State University's Institutional Animal Care and Use Committee (IACUC), protocol 05/15-087-00,

and by the Michigan Department of Natural Resources (MDNR) Fisheries Division (Scientific Collectors Permit #PR8114). Public land access was approved by the Michigan Department of Natural Resources Permit to Use State Land #PR1136-1. Private land access was arranged directly with landowners prior to the start of any research activity at that property. In accordance with the protocol and requirements outlined in our IACUC approval and MDNR Scientific Collectors Permit, boots and all gear used in the field were disinfected using a 10% bleach solution following each day in the field and before moving among field sites to reduce the potential spread of pathogens (Appendix E).

Results

In 2015, 24 swab samples were collected and a single massasauga tested positive for SFD (Table B.1). This male was captured and sampled at site SE_H1 on 17 June 2015 and surgically implanted with a radiotransmitter but found dead (presumed depredation; Appendix H) on 31 July 2015.

In 2016, 46 swab samples were collected and two massasaugas tested positive for SFD, a juvenile male and an adult nongravid female (Table B.1). The juvenile male was captured and sampled at site SE_H1 on 5 July 2016 and was tracked to hibernation on 11 October 2016 (in 2015 this individual had been fitted with an external radiotransmitter and sampled for SFD, testing negative in that year). The adult female for which there was a positive SFD result in 2016 (based on a single sample collected) was captured at site SW_M2 and fitted with an external radiotransmitter on 15 Jun 2016 (the transmitter was found unattached the following day and the massasauga was never located again); a swab sample collected from this individual in 2015 tested negative for SFD.

Table B.1. All eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) sampled in 2015 and 2016 throughout southern Michigan for snake fungal disease (*Ophidiomyces ophiodiicola*) and outcome of testing for each (positive [+], negative [-]). Multiple samples were collected when an individual exhibited clinical signs of infection by the fungal pathogen.

Year	Site Code	Snake Identification	Date of Sample	Sample Record #	Number of Samples	Sample Vial Identification	Test Results
2015	NE_L1	836519789	25-May-15	4	1	NEL1_01	-
		836560332	9-Jul-15	16	1	NEL1_05	-
		836560350	29-Jun-15	10	1	NEL102	-
		836568071	9-Jul-15	15	1	NEL1_04	-
		836580078	29-Jun-15	11	1	NEL103	-
		836571332 840382378	13-Jul-15	19	1	NEL1_06	-
	NE_M1	836550298	13-Jul-15	18	1	NEM1_01	-
	SW_M2	836560014	29-Jul-15	21	1	SWM2_02	-
		836561814	28-Jul-15	20	1	SWM2_01	-
		836564778	29-Jul-15	22	2	SWM3_03_A, SWM3_03_B	-
	SE_H1	836551570	17-Jun-15	9	1	SEH1_02	-
		836574862	17-Jun-15	8	1	SEH1_01	+
	SE_H3	75578601	21-May-15	1	1	SEH3_01	-
		99873268	22-May-15	3	1	SEH3_03	-
		100075839	8-Jul-15	14	1	SEH3_08	-
		836546351	21-May-15	2	1	SEH3_02	-
		836549811	7-Aug-15	23	1	SEH3_10	-
		836550585	12-Jul-15	17	1	SEH3_09	-
		836559770	5-Jun-15	6	1	SEH304	-
		836567798	8-Jul-15	12	1	SEH3_06	-
		836570859	8-Jul-15	13	1	SEH3_07	-
		J_SEH3_2015_1	5-Jun-15	7	1	SEH305	-
	SW_H2	836547069	1-Jun-15	5	1	SWH0201	-
2016	NE_L1	836519789	17-Aug-16	136	1	NEL1_78	-
		840380005	19-May-16	104	1	NEL1_09	-
			4-Aug-16	126	1	NEL1_68	-
		840521571	4-Aug-16	127	1	NEL1_69	-
		840533265	9-Jun-16	113	1	NEL1_11	-
			1-Aug-16	125	1	NEL1_67	-
		840543607	28-Jul-16	124	1	NEL1_66	-
		836571332 840382378	19-May-16	105	1	NEL1_10	-

Table B.1. (cont'd)

Year	Site Code	Snake Identification	Date of Sample	Sample Record #	Number of Samples	Sample Vial Identification	Test Results
			17-Aug-16	137	1	NEL1_79	-
		J_NEL1_2016_1	19-May-16	103	1	NEL1_08	-
		N_NEL1_2016_1	15-Aug-16	135	1	NEL1_72	-
		N_NEL1_2016_2	15-Aug-16	135	1	NEL1_73	-
		N_NEL1_2016_3	15-Aug-16	135	1	NEL1_74	-
		N_NEL1_2016_4	15-Aug-16	135	1	NEL1_75	-
		N_NEL1_2016_5	15-Aug-16	135	1	NEL1_76	-
		N_NEL1_2016_6	15-Aug-16	135	1	NEL1_77	-
	SW_M2	836560014	15-Jun-16	115	3	SWM2_07a, SWM2_07b, SWM2_07c	+
		836571116	18-May-16	102	1	SWM2_04	-
		840517848	6-Jun-16	112	2	SWM2_05a, SWM2_05b	-
			5-Aug-16	129	1	SWM2_10	-
		840525562	15-Jun-16	114	1	SWM2_06	-
		840533081	21-Jun-16	116	1	SWM2_08	-
			5-Aug-16	128	1	SWM2_09	-
		840533890	9-Aug-16	130	1	SWM2_11	-
		840543057	12-Aug-16	131	1	SWM2_12	-
		N_SWM2_2016_1	12-Aug-16	132	1	SWM2_13	-
		N_SWM2_2016_2	12-Aug-16	133	1	SWM2_14	-
		N_SWM2_2016_3	12-Aug-16	134	1	SWM2_15	-
	SE_H1	836551570	5-Jul-16	119	2	SEH1_03a, SEH1_03b	+
		840525094	20-Jul-16	122	1	SEH1_04	-
		840532564	25-Jul-16	123	1	SEH1_05	-
	SE_H3	75567567	1-Jun-16	107	1	SEH3_11	-
		99874823	1-Jun-16	109	1	SEH3_13	-
		840382344	18-Jul-16	121	1	SEH3_18	-
		840516095	6-Jun-16	111	1	SEH3_15	-
		840520549	1-Jun-16	108	1	SEH3_12	-
		840524297	14-Jul-16	120	1	SEH3_17	-
		840527780	1-Jun-16	110	1	SEH3_14	-
		840544608	30-Jun-16	118	1	SEH3_16 ^a	n/a ^a
	SE_M1	836551889	12-May-16	101	1	SEM1_01	-
	SW_H2	840515348	23-Jun-16	117	1	SWH2_03	-

Table B.1. (cont'd)

Year	Site Code	Snake Identification	Date of Sample	Sample Record #	Number of Samples	Sample Vial Identification	Test Results
		840518007	24-May-16	106	1	SWH2_01	-

^a This sample was collected and stored following our snake fungal disease sampling protocol, but we were unable to locate the sample at the end of the field day.

Discussion

Our results indicate positive incidences of SFD occur in areas where the pathogen had not yet been located (Calhoun and Jackson counties, sites SW_M2 and SE_H1, respectively), though it is important to note that, to our knowledge, these massasauga populations have not previously been formally studied and it is possible that the pathogen existed within these populations prior to our study. The occurrence of SFD at these sites poses a potential long-term threat to these populations (e.g., Allender et al. 2015), yet additional study is necessary to evaluate these impacts.

There is a possibility of false negatives with the analysis used to test for SFD, particularly for individuals that show no clinical signs of the disease. Specifically, a negative relationship was illustrated between number of samples and rate of false positives for SFD (Hileman et al. 2018), which was the reasoning behind the decision to take a second sample later in the season in 2016. As such, it is possible that our sampling results underestimate the presence of SFD across our study sites; more samples (i.e., multiple samples per snake, per season; Hileman et al. 2018) will be necessary to assess whether the pathogen is present at sites where it was not detected. Researchers have assessed the potential increase susceptibility of telemetered massasaugas to SFD; Hileman et al. (2018) found no relationship between increased rates of SFD and individuals implanted with radiotransmitters.

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APPENDIX C

Study Site Information and Maps

Table C.1. The 27 20-ha study sites, locations, and property names that were included in the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) research throughout southern Michigan in 2015 and 2016.

Focal Area ^a	County	Site Code ^b	Property Name ^c
North-East	Livingston	NE_L2	Brighton State Recreation Area
		NE_L3	Brighton State Recreation Area
		NE_M2	Brighton State Recreation Area
	Oakland	NE_H1	Indian Springs Metropark
		NE_H2	Independence Oaks County Park
		NE_H3	Independence Oaks County Park
		NE_L1	Seven Lakes State Park
		NE_M1	Seven Lakes State Park
		NE_M3	Indian Springs Metropark
South-East	Jackson	SE_H1	Liberty Fen (private)
		SE_H2	Grand River Fen (The Nature Conservancy; private)
		SE_L4	Fay Lake (private)
	Lenawee	SE_H3	Ives Road Fen (The Nature Conservancy; private)
		SE_L1	Wacker Chemical Company (private)
		SE_L2	Ives Road Fen (The Nature Conservancy; private)
		SE_H4	Ives Road Fen (The Nature Conservancy; private)
	Washtenaw	SE_L3	Sharonville State Game Area
		SE_M1	Nan Weston (The Nature Conservancy; private)
South-West	Barry	SW_H1	Barry State Game Area
		SW_H2	Otis Audubon Sanctuary (private)
		SW_H3	Yankee Springs Recreation Area
		SW_L1	Yankee Springs Recreation Area
		SW_L2	Yankee Springs Recreation Area
		SW_L3	Yankee Springs Recreation Area
		SW_M3	Barry State Game Area
	Calhoun	SW_M1	Baker Audubon Sanctuary (private)
		SW_M2	Baker Audubon Sanctuary (private)

^a Focal area indicates the geographic region within which 9 sites were distributed; counties included in each focal area are listed.

^b Site code indicates focal region (NE = northeast, SE = southeast, SW = southwest), site suitability (L = Low, M = Medium, and H = High, based on our preliminary analysis of the proportions of available cover types using the NLCD land cover data [MRLC 2015]), and number of sites within that focal area at that level of suitability (ranging from 1-4).

^c Due to federal listing status of massasaugas, detailed locations of study sites are not provided. Locations for study sites are available via communication with Daniel Kennedy (Michigan Department of Natural Resources), Henry (Rique) Campa III (Michigan State University), or Stephanie Shaffer.

Table C.2. Site information for the 27 20-ha study sites where field work was carried out during the 2015 and 2016 field seasons for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) research throughout southern Michigan.

Site Code	Suitability (NLCD) ^a	Total EMR Observed ^b	EMR Telemetered ^c	Historical Observations ^d	Last sighting ^e	Primary Vegetation Class (IFMAP classification) ^f	Suitability (HSI) ^g	Recent Management ^h
NE_H1	High	0	0	Y	2006	early-mid-late deciduous wetland, early-mid upland deciduous	marginal-good	
NE_H2	High	0	0	Y (within 10m)	2009	early-mid-late deciduous wetland	marginal-good	
NE_H3	High	0	0	Y	2009	early-mid-late deciduous wetland	good	
NE_L1	Low	58 (+ 20 sightings)	12 ⁱ	Y	2014	late upland deciduous, early-mid upland deciduous	poor-marginal	shrub/brush removal (for this research)
NE_L2	Low	0	0	Y (on property)	2013	late upland deciduous	poor	
NE_L3	Low	0	0	Y	2013	late upland deciduous	poor	
NE_M1	Medium	1	1	Y	2014	late deciduous wetland, early-mid deciduous upland	marginal-good	
NE_M2	Medium	0	0	Y (on property)	2013	wetland deciduous early-mid, late upland deciduous	marginal-good	
NE_M3	Medium	0	0	Y	2006	early-mid upland deciduous, early-mid deciduous wetland	optimal	
SE_H1	High	4 (+ 1 sighting)	4 ^a	Y	2013	deciduous wetland early-mid-late	good-optimal	
SE_H2	High	0	0	other	n/a	deciduous wetland early-mid-late	good	
SE_H3	High	22 (+ 13 sightings)	4	Y	2013	late deciduous wetland, upland deciduous early-mid-late	good	ongoing
SE_H4	High	0	0	other	n/a	upland deciduous early-mid	marginal	ongoing
SE_L1	Low	0	0	other	n/a	upland deciduous early-mid-late	marginal	
SE_L2	Low	1	0	Y	2013	upland deciduous early-mid-late, late deciduous wetland	marginal-good	ongoing
SE_L3	Low	0	0	other	n/a	upland deciduous early-mid-late	marginal	Tree/shrub removal (for this research)
SE_L4	Low	0	0	Y (within 600m)	2010	late upland deciduous, late deciduous wetland	good	
SE_M1	Medium	1	0	Y (on property)	2004	late wetland deciduous, upland deciduous early-mid	marginal	

Table C.2. (cont'd)

Site Code	Suitability (NLCD) ^a	Total EMR Observed ^b	EMR Telemetered ^c	Historical Observations ^d	Last sighting ^e	Primary Vegetation Class (IFMAP classification) ^f	Suitability (HSI) ^g	Recent Management ^h
SW_H1	High	0	0	other	n/a	early-mid deciduous wetland	good	
SW_H2	High	9 (+ 2 sightings)	3	Y	2013	deciduous wetland	marginal-good-optimal	ongoing (herbicide)
SW_H3	High	1	0	Y	2009	early-mid deciduous wetland, late upland deciduous	good	
SW_L1	Low	0	0	Y	unknown	early-mid deciduous wetland, late upland deciduous	marginal	
SW_L2	Low	0	0	Y	2009	early-mid deciduous wetland, late upland coniferous/deciduous	marginal	
SW_L3	Low	0	0	Y	2009	late upland deciduous/coniferous	poor-marginal	
SW_M1	Medium	0	0	other	n/a	upland deciduous early-mid, wetland deciduous early-mid-late	optimal	ongoing
SW_M2	Medium	28 (+ 17 sightings)	12	other	n/a	early-mid deciduous wetland, upland deciduous early-mid-late	optimal	ongoing (burn/mow)
SW_M3	Medium	0	0	other	n/a	early-mid deciduous wetland, late upland deciduous	good	

^a Suitability (NLCD) represents the initial suitability assessment for each site using the NLCD land cover dataset (MRLC 2015; Chapters 1, 2, 3).

^b Total EMR observed is a count of all individual massasauga sightings.

^c EMR Telemetered is the number of individual massasaugas that were telemetered in 2015, 2016, or in both years, either by surgical implantation or external attachment methods.

^d Historical Observations (Yes [“Y”], or other) indicates past known presence of massasaugas based on the Michigan Natural Heritage Database of massasauga sightings (MNFI 2014). Sites where historical observation is “other” indicates that there was no record in the MNFI (2014) database, but recent reports from collaborating property owners or agencies were provided.

^e Last Sighting indicates the year of last observation recorded in the Michigan Natural Heritage Database of massasauga sightings (MNFI 2014).

^f Primary Vegetation Class was determined by examining landcover within each site using the IFMAP landcover dataset (MDNR 2001).

^g Suitability (HSI) based on assessment of each site using Bailey (2010) habitat suitability index model for massasaugas.

^h Recent Management represents habitat management activity at the site during or prior to this project.

ⁱ One individual at this site was telemetered in both 2015 and 2016.

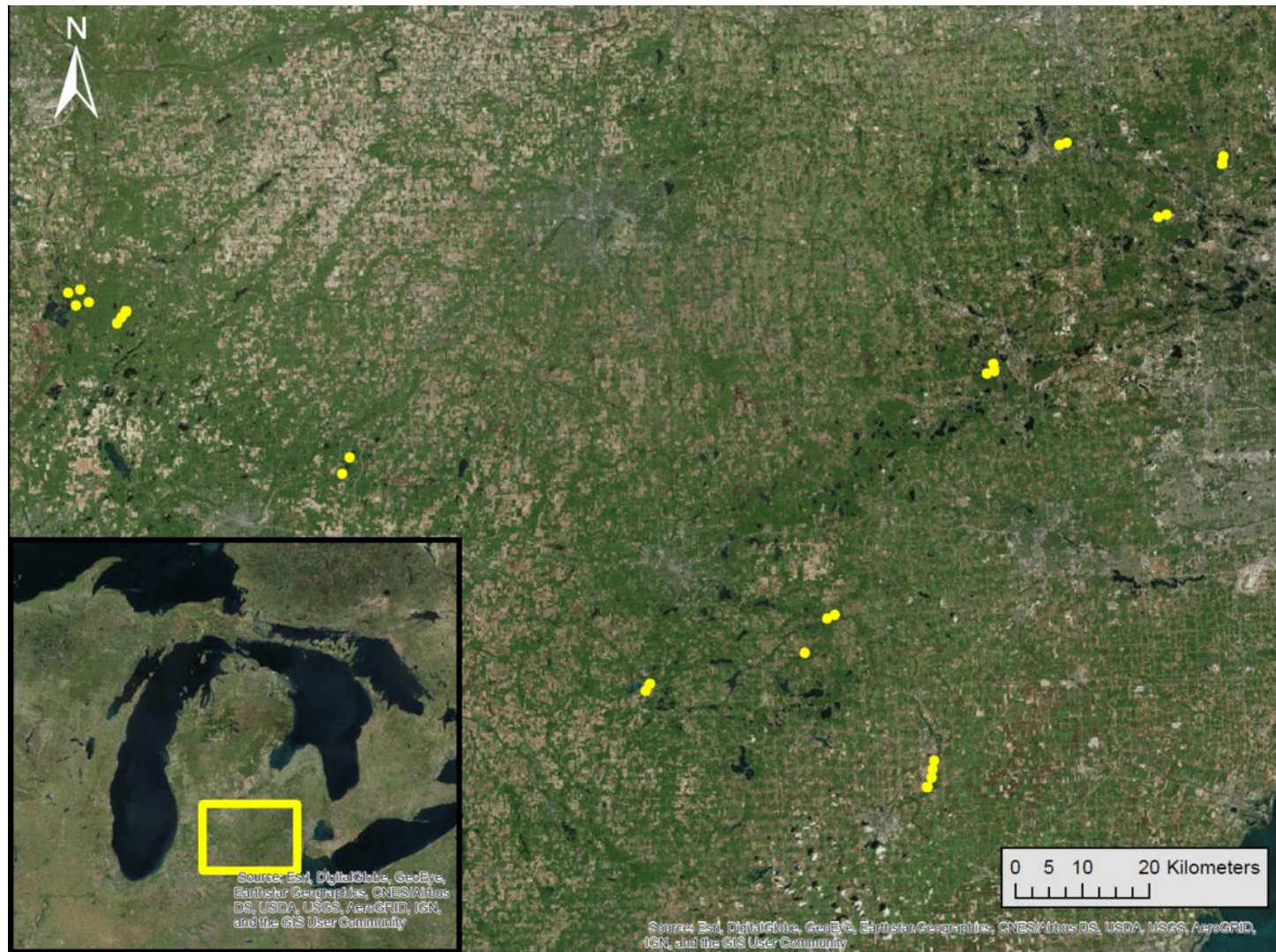


Figure C.1. The 27 20-ha study sites, represented by yellow dots, throughout southern Michigan where field work was conducted during 2015 and 2016 field seasons. Counties containing field sites included Barry, Calhoun, Jackson, Lenawee, Oakland, Washtenaw, and Livingston. These sites were selected based on historical presence of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*; MNFI 2014).

APPENDIX D

Documentation of All Encountered Eastern Massasauga Rattlesnakes

Table D.1. Eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) encountered and marked during this study (2015 and 2016) throughout southern Michigan, and fate of the individual at final date of the study.

Identification	Mark ^a	Site Code	Telemetry Frequency ^b	Stage, Sex ^c	# Obs. ^d	Capture Date ^e	Date of Final Obs. ^f	Fate
075566848 ^{g, h}	PIT	SE_H3		U	1	06-Jul-15	06-Jul-15	Unknown - single observation only
075567567 ^h	PIT	SE_H3		A, F	1	01-Jun-16	01-Jun-16	Unknown - single observation only
075578601 ^{g, h}	PIT	SE_H3		A, F	3	21-May-15	08-Jul-15	Unknown
099873268 ^{g, h}	PIT	SE_H3		A, U	1	22-May-15	22-May-15	Unknown - single observation only
099874823 ^h	PIT	SE_H3		A, F	2	01-Jun-16	06-Jun-16	Unknown - final location was a release - had been taken in for surgery, but surgery canceled
100075839 ^{g, i}	PIT	SE_H3		A, F	1	08-Jul-15	08-Jul-15	Unknown - single observation only
836519789	PIT	NE_L1		A, F	1	25-May-15	25-May-15	Unknown - single observation only
			149.264 (ext)	A, F	5	17-Aug-16	02-Sep-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
836546351 ^h	PIT	SE_H3	152.142 (int)	A, F	28	21-May-15	12-Aug-15	Mortality (Appendix H)
836547069	PIT	SW_H2	150.901 (ext)	J, M	3	01-Jun-15	04-Jun-15	Transmitter recovered - no observation of snake at final location
836549811	PIT	SE_H3		A, M	1	07-Aug-15	07-Aug-15	Unknown - single observation only
836550298	PIT	NE_M1	152.002 (int)	A, F	31	13-Jul-15	13-Dec-15	Hibernating - no observation of snake or transmitter; tracked to a potential hibernation site
836550585	PIT	SE_H3		A, F	1	12-Jul-15	12-Jul-15	Unknown - single observation only
836551570	PIT	SE_H1	150.692 (ext)	J, M	7	17-Jun-15	06-Jul-15	Unknown - lost signal, could not locate snake or transmitter at final attempt
			151.83 (int)	J, M	19	05-Jul-16	11-Oct-16	Hibernating - no observation of snake or transmitter; tracked to a potential hibernation site
836551889	PIT	SE_M1		A, F	1	12-May-16	12-May-16	Unknown - single observation only
836559770	PIT	SE_H3		A, F	2	05-Jun-15	08-Jun-15	Unknown - final location was a release - had been taken in for surgery, but surgery canceled
836560014	PIT	SW_M2		A, F	1	29-Jul-15	29-Jul-15	Unknown - single observation only
			151.62 (ext)	A, F	2	15-Jun-16	16-Jun-16	Transmitter recovered - no observation of snake at final location
836560332	PIT	NE_L1		A, F	5	09-Jul-15	25-Aug-15	Unknown - observed basking at final location
836560350	PIT	NE_L1	152.061 (int)	A, F	37	29-Jun-15	13-Dec-15	Hibernating - no observation of snake or transmitter; tracked to a potential hibernation site

Table D.1. (cont'd)

Identification	Mark ^a	Site Code	Telemetry Frequency ^b	Stage, Sex ^c	# Obs. ^d	Capture Date ^e	Date of Final Obs. ^f	Fate
836561814	PIT	SW_M2	152.042 (int)	A, F	20	28-Jul-15	01-Nov-15	Hibernating - no observation of snake or transmitter; tracked to a potential hibernation site
836564778	PIT	SW_M2		A, F	2	29-Jul-15	06-Aug-15	Unknown
836567798	PIT	SE_H3		A, F	1	08-Jul-15	08-Jul-15	Unknown - single observation only
836568071	PIT	NE_L1		A, F	1	09-Jul-15	09-Jul-15	Unknown - single observation only
836570859 ^h	PIT	SE_H3		A, F	2	08-Jul-15	07-Aug-15	Unknown
836571116 ^h	PIT	SW_M2		J, F	1	18-May-16	18-May-16	Unknown - single observation only
836574862	PIT	SE_H1	152.162 (int)	A, M	13	17-Jun-15	31-Jul-15	Mortality (Appendix H)
836580078 ^h	PIT	NE_L1		A, F	4	29-Jun-15	04-Sep-15	Unknown - last observed in close proximity to 4 neonates
840380005	PIT	NE_L1	152.181 (int)	A, F	34	19-May-16	02-Sep-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840382344 ^h	PIT	SE_H3		A, F	1	18-Jul-16	18-Jul-16	Unknown - single observation only
840515348	PIT	SW_H2	152.342 (int)	A, F	18	23-Jun-16	07-Oct-16	Unknown - observed basking in woodpile at last location
840516095 ^h	PIT	SE_H3		A, F	1	06-Jun-16	06-Jun-16	Unknown - single observation only
840517848	PIT	SW_M2	152.202 (int)	A, M	29	06-Jun-16	10-Oct-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840518007	PIT	SW_H2	152.102 (int)	A, M	24	24-May-16	07-Oct-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840520549 ^h	PIT	SE_H3		A, F	1	01-Jun-16	01-Jun-16	Unknown - single observation only
840521571	PIT	NE_L1	151.981 (ext)	A, F	6	04-Aug-16	17-Aug-16	Transmitter recovered - no observation of snake at final location
840524297	PIT	SE_H3	150.872 (ext)	J, F	3	14-Jul-16	18-Jul-16	Transmitter recovered - no observation of snake at final location
840525094	PIT	SE_H1	151.62 (ext)	A, F	2	20-Jul-16	25-Jul-16	Mortality (Appendix H)
840525562	PIT	SW_M2	151.77 (ext)	A, F	3	15-Jun-16	16-Jun-16	Transmitter recovered - no observation of snake at final location
840527780	PIT	SE_H3	152.02 (int)	A, F	29	01-Jun-16	10-Oct-16	Unknown - observed basking at last location
840532564	PIT	SE_H1	151.8 (int)	A, M	13	25-Jul-16	11-Oct-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840533081	PIT	SW_M2	150.581 (int)	A, F	20	21-Jun-16	10-Oct-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840533265	PIT	NE_L1	151.65 (ext)	A, F	6	09-Jun-16	10-Aug-16	Transmitter recovered - no observation of snake at final location
840533890	PIT	SW_M2		A, M	1	09-Aug-16	09-Aug-16	Unknown - single observation only

Table D.1. (cont'd)

Identification	Mark ^a	Site Code	Telemetry Frequency ^b	Stage, Sex ^c	# Obs. ^d	Capture Date ^e	Date of Final Obs. ^f	Fate
840543057	PIT	SW_M2	151.711 (ext)	A, F	2	12-Aug-16	16-Aug-16	Transmitter recovered - no observation of snake at final location
840543607	PIT	NE_L1	151.92 (ext)	A, F	13	28-Jul-16	10-Sep-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
840544608	PIT	SE_H3		A, F	1	30-Jun-16	30-Jun-16	Unknown - single observation only
836571332, 840382378 j	PIT	NE_L1	150.46 (int)	A, M	33	13-Jul-15	13-Dec-15	Unknown - found basking (on Dec 13) at final location; near what was presumed to be a hibernation site
			150.44 (int)	A, M	38	19-May-16	14-Oct-16	Hibernating - no observation of snake or transmitter; tracked to a potential hibernation site
J_NE_L1_2016_1	none	NE_L1	150.933 (ext)	J, U	9	19-May-16	09-Jun-16	Unknown - lost signal, could not locate snake or transmitter at final attempt
J_SE_H3_2015_1	whiteout	SE_H3	151.47 (ext)	J, U	10	05-Jun-15	01-Jul-15	Unknown - lost signal, could not locate snake or transmitter at final attempt
N_NE_L1_2016_1	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_10	whiteout	NE_L1	149.264 (ext)	N, U	2	15-Aug-16	17-Aug-16	Transmitter recovered - no observation of snake at final location
N_NE_L1_2016_11	whiteout	NE_L1	149.123 (ext)	N, U	7	15-Aug-16	10-Sep-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
N_NE_L1_2016_12	whiteout	NE_L1	149.143 (ext)	N, U	5	15-Aug-16	25-Aug-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location
N_NE_L1_2016_13	whiteout	NE_L1	149.284 (ext)	N, U	4	17-Aug-16	25-Aug-16	Unknown - observed moving through a meadow at last location
N_NE_L1_2016_2	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_3	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_4	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_5	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_6	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_7	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_8	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_NE_L1_2016_9	whiteout	NE_L1		N, U	1	15-Aug-16	15-Aug-16	Unknown - single observation only
N_SW_M2_2015_1	whiteout	SW_M2		N, U	2	20-Aug-15	21-Aug-15	Unknown - at final observation was found approximately 2.5 meters from location of initial observation
N_SW_M2_2015_2	whiteout			N, U	1	20-Aug-15	20-Aug-15	Unknown - single observation only
N_SW_M2_2015_3	whiteout	SW_M2		N, U	1	21-Aug-15	21-Aug-15	Unknown - single observation only
N_SW_M2_2016_1	whiteout	SW_M2	149.323 (ext)	N, U	2	12-Aug-16	16-Aug-16	Transmitter recovered - no observation of snake at final location

Table D.1. (cont'd)

Identification	Mark ^a	Site Code	Telemetry Frequency ^b	Stage, Sex ^c	# Obs. ^d	Capture Date ^e	Date of Final Obs. ^f	Fate
N_SW_M2_2016_2 ^k	whiteout	SW_M2	149.165 (ext)	N, U	3	12-Aug-16	18-Aug-16	Transmitter recovered - no observation of snake at final location
N_SW_M2_2016_3	whiteout	SW_M2	149.204 (ext)	N, U	2	12-Aug-16	16-Aug-16	Transmitter recovered - no observation of snake at final location
N_SW_M2_2016_4 ^k	whiteout	SW_M2	149.244 (ext)	N, U	2	16-Aug-16	18-Aug-16	Transmitter recovered - no observation of snake at final location
N_SW_M2_2016_5 ^l	whiteout	SW_M2		N, U	1	16-Aug-16	16-Aug-16	Unknown - single observation only
N_SW_M2_2016_6	whiteout	SW_M2	149.183 (ext)	N, U	3	16-Aug-16	24-Aug-16	Unknown - observed basking at last location
N_SW_M2_2016_7	whiteout	SW_M2	149.204 (ext)	N, U	3	16-Aug-16	24-Aug-16	Unknown - telemetry signal followed, but no observation of snake or transmitter at final location

^a Massasaugas were marked for identification in one or more of the following ways: PIT tag, “white out”, or nail enamel painted on rattle.

^b The radiotelemetry frequency associated with the transmitter attached to the massasauga; “int” indicates an internally implanted transmitter, “ext” indicates an externally attached transmitter. A blank indicates that no transmitter was attached.

^c Stage (A = adult, J = juvenile, N = neonate, U = unknown) and sex (F = female, M = male, U = unknown).

^d Number of times this massasauga was observed in the field either via radiotelemetry or by random encounter.

^e Date of initial capture.

^f Last date the individual was observed or tracked.

^g PIT tag from previous study.

^h Melanistic coloration.

ⁱ Blue nail enamel on rattle from previous study.

^j Original PIT tag lost at some point during summer 2016, was replaced.

^k Exhibited possible hypo-melanism (J. Harding, personal communication, 2018; Figure D.1a, D.1b).

^l Deformity - neck appears "kinked", body coiled, makes rolling movements (Figure D.2a, D.2b).

Table D.2. Number of eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) encounters of either unidentified or unknown individuals observed during 2015 and 2016 field seasons throughout southern Michigan.

Site Code	Year	Stage	Number Observed ^a	Beginning Date	End Date
NE_L1	2015	Juvenile	1	31-Jul-15	n/a
		Neonate	30	2-Sep-15	19-Sep-15
		Unknown	3	6-Jul-15	13-Aug-15
	2016	Adult	5	26-May-16	28-Jul-16
		Neonate	16	10-Aug-16	25-Aug-16
		Unknown	3	1-Jul-16	1-Aug-16
SE_H1	2016	Unknown	6 ^b	8-Jun-16	9-Jun-16
			1	29-Jul-16	n/a
			1 ^b	19-Jul-16	n/a
SE_H3	2015	Adult	1	12-Jun-15	n/a
		Juvenile	1	21-May-15	n/a
		Unknown	6	20-Jun-15	11-Aug-15
	2016	Adult	2	9-Aug-16	11-Aug-16
		Juvenile	2 ^b	29-Jun-16	29-Jun-16
			1	29-Jun-16	n/a
			3	9-Aug-16	9-Aug-16
		Neonate	4	2-Jul-16	18-Jul-16
		Unknown	4 ^b	29-Jun-16	2-Jul-16
SE_L2	2016	Unknown	1	22-Jul-16	n/a
SW_H2	2015	Juvenile	1	29-May-15	n/a
	2016	Adult	3	16-Jun-16	11-Aug-16
		Neonate	4	24-Aug-16	24-Aug-16
SW_H3	2016	Unknown	1	3-Aug-16	n/a
SW_M2	2015	Neonate	22	13-Aug-15	24-Aug-15
	2016	Adult	2	11-Aug-16	24-Aug-16
		Neonate	1 ^b	17-Jun-16	n/a
			1	10-Oct-16	n/a
			1	9-Aug-16	n/a
		Unknown	2 ^b	16-Jun-16	n/a

^a These data do not include counts of massasaugas that were marked for telemetry or recapture or individually identifiable in any way.

^b Observed during a detection survey (Chapter 2).

Table D.3. Weights (g) and lengths (snout-to-vent, “SVL”; mm) of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) captured during the 2015 and 2016 field seasons in southern Michigan. Additional metadata associated with each massasauga are provided in Appendix D: Table D.1.

Stage	Sex	PIT tag I.D.	Year	Gravid ^a	SVL (mm)	Weight (g) ^b
Adult	Female	75567567	2016	Y	555	189
		75578601	2015	Y	529	198 (211)
		99874823	2016	Y	610	289
		100075839	2015	Y	544	205
		836519789	2015	unk	550	206
			2016	unk	574	225
		836546351	2015	Y	527	163
		836550298	2015	Y	548	277
		836550585	2015	Y	545	244
		836551889	2016	unk	555	308
		836559770	2015	Y	526	165
		836560014	2015	unk	653	332
			2016	N	654	267
		836560332	2015	Y	530	211
		836560350	2015	Y	605	395 (181*)
		836561814	2015	Y	569	265 (162*)
		836564778	2015	unk	657	357
		836567798	2015	Y	528	250
		836568071	2015	Y	535	254
		836570859	2015	Y	530	222 (199)
		836580078	2015	Y	520	206
		840380005	2016	unk	650	268 (282)
		840382344	2016	unk	531	224
		840515348	2016	Y	540	274
		840516095	2016	unk	520	165
		840520549	2016	Y	493	149
		840521571	2016	unk	517	164
		840525094	2016	unk	569	307
		840525562	2016	Y	560	226
		840527780	2016	Y	607	259
		840533081	2016	Y	568	230 (214)
		840533265	2016	Y	534	193 (205, 208)
		840543057	2016	unk	534	131
		840543607	2016	Y	658	566 (234*)
		840544608	2016	Y	559	204
	Male	836549811	2015	n/a	599	150
		836574862	2015	n/a	458	157
		840517848	2016	n/a	655	405 (411)
		840518007	2016	n/a	645	305
		840532564	2016	n/a	444	140
		840533890	2016	n/a	640	192

Table D.3. (cont'd)

Stage	Sex	PIT tag I.D.	Year	Gravid ^a	SVL (mm)	Weight (g) ^b
Juvenile	Unknown	836571332 840382378	2015	<i>n/a</i>	480	188
			2016	<i>n/a</i>	535	170 (183, 194)
		99873268	2015	<i>n/a</i>	607	209
		836571116	2016	<i>n/a</i>	464	106
		840524297	2016	<i>n/a</i>	358	52
	Male	836547069	2015	<i>n/a</i>	246	28
		836551570	2015	<i>n/a</i>	298	44
			2016	<i>n/a</i>	434	103
	Unknown	J_NEL1_2016_1	2016	<i>n/a</i>	204	14
		J_SEH3_2015_1	2015	<i>n/a</i>	263	16
Neonate	Unknown	N_NEL1_2016_1	2016	<i>n/a</i>		8
		N_NEL1_2016_10	2016	<i>n/a</i>		12
		N_NEL1_2016_11	2016	<i>n/a</i>		13
		N_NEL1_2016_12	2016	<i>n/a</i>		8
		N_NEL1_2016_13	2016	<i>n/a</i>		12
		N_NEL1_2016_2	2016	<i>n/a</i>		12
		N_NEL1_2016_3	2016	<i>n/a</i>		12
		N_NEL1_2016_4	2016	<i>n/a</i>		14
		N_NEL1_2016_5	2016	<i>n/a</i>		12
		N_NEL1_2016_6	2016	<i>n/a</i>		13
		N_NEL1_2016_7	2016	<i>n/a</i>		14
		N_NEL1_2016_8	2016	<i>n/a</i>		14
		N_NEL1_2016_9	2016	<i>n/a</i>		12
		N_SWM2_2015_2	2015	<i>n/a</i>	185	9
		N_SWM2_2015_3	2015	<i>n/a</i>	172	10
		N_SWM2_2016_1	2016	<i>n/a</i>		9
		N_SWM2_2016_2	2016	<i>n/a</i>		12
		N_SWM2_2016_3	2016	<i>n/a</i>		13
		N_SWM2_2016_4	2016	<i>n/a</i>		13
		N_SWM2_2016_5	2016	<i>n/a</i>		12.5
		N_SWM2_2016_6	2016	<i>n/a</i>		11
		N_SWM2_2016_7	2016	<i>n/a</i>		13

^a Reproductive status for female massasaugas (gravid = “Y”, nongravid = “N”, unknown status = “unk”).

^b Weights in parentheses indicate additional weight measurements taken at a later date; weights marked with an asterisk (*) indicate a measurement taken following parturition.

D.1a



D.1b



Figure D.1. Possible hypo-melanism (J. Harding, personal communication, 2018) observed in two neonate eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) in Calhoun County in southern Michigan in 2016. Figure D.1a shows a close-up of head. Figure D.1b shows a neonate exhibiting possible hypo-melanism beside a normal-colored neonate, presumed to be a litter mate, for comparison.

D.2a



D.2b



Figure D.2. Apparent deformity observed in one neonate eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) in Calhoun County in southern Michigan in 2016. Figure D.2a: individual did not move normally; a rolling motion was used for locomotion, the neck appeared permanently “kinked”, and body coiled. Figure D.2b shows the individual in a clear plastic bag, which were used for weighing small juveniles and neonates.

APPENDIX E

Snake Fungal Disease Disinfection Protocol

Field biosecurity protocol used by all personnel involved in this research while in the field to reduce potential spread of snake fungal disease (*Ophidiomyces ophiodiicola*) between sites. This protocol was developed by M. Allender (University of Illinois, Wildlife Epidemiology Laboratory), discussed with all massasauga researchers, and was required by the Michigan Department of Natural Resources Scientific Collector's Permit issued for this research.

1) Field Biosecurity Protocols

- a) Aim: Keep wildlife populations healthy
- b) Prevent the introduction of wildlife diseases
- c) Prevent the spread of wildlife diseases between populations
- d) Prevent transmission of diseases between animals and field workers
- e) Minimize costs (both financial and environmental) of disease outbreaks

2) Personal hygiene

- a) Wear latex or nitrile examination gloves
- b) Change gloves between each individual
- c) Wash hands frequently
- d) Wash clothes daily or wear a washable scrub top/ lab coat
- e) Wear rubber boots when possible and rinse with 10% bleach between sites.
- f) If rubber boots are not used, still rinse and spray with dilute bleach between sites
- g) The use of disposable latex gloves when handling cameras, phones, backpacks, etc. These items are rarely disinfected, and are frequently used after handling snakes.

- 3) Sampling Gear – Any gear that physically touches animals, including snake tongs, hooks, holding bags, tubes, buckets, gender probes, PIT tag injectors, etc.
- a) Wash sampling gear in between sites (site=interbreeding population of the species being handled).
 - b) Wash all sampling gear in a disinfecting solution. A disinfecting solution such as diluted bleach [nine parts water to one part bleach] or a commercially prepared solution, such as *Virkon* is recommended. *Chlorhexidine* and *Novalsan* are effective with bacteria, but do not appear to kill *Ophidiomyces ophiodiicola* in culture, and are not recommended.
 - c) Soaking gear in a solution is more effective than spraying. Be sure to rinse all solution from gear.
 - d) Soaking of tubes is recommended for 1 hour and then overnight
 - e) When not feasible, then all equipment is wiped with Chlorox wipe
 - f) Contact time is critical, the longer the disinfection solution is applied, the more effective it will be. Also, mechanical action (i.e. scrubbing) will also increase effectiveness.
 - g) Washing should be done between individuals in the population.
 - h) Machine launder snake holding bags using detergent and bleach with hot water. It may be helpful to use different bags for different sites.
 - i) Using disposable (one time use) sterilized PIT tag injectors are recommended.
 - j) If this is not possible, the use of an alcohol soak can be used to clean injectors, as well as other items, such as gender probes, and should be done between individuals, even if within the same site as these tools are invasive.
 - k) Be sure there is no remaining alcohol within the tip of the PIT tag injector.

Protocol credit: M. Allender, University of Illinois Wildlife Epidemiology Laboratory

Snake Fungal Disease Disinfection Checklist **** Fill out and between each study area ****			Date _____
			Time _____
			Area _____
			# People _____
~ Use a solution of 10% bleach and 90% water to soak/spray all items listed below ~ Any item that touches a snake or the habitat must be bleached. ~ Certain gear items can be wiped with a Clorox wipe (PIT tag reader and wand) ~ Use a scrubber on rough surfaces and boot bottoms ~ If a certain piece of equipment was not used AND it remained in the "clean tub" OR inside the car the entire time you were in the field, it does not need to be bleached. Put an N/A in the check box for these items.			
Name _____	Name _____	Name _____	
Name _____	Name _____	Name _____	
Soaked/sprayed/wiped with bleach:			
Snake tubes _____	Scales _____	Boots _____ # pairs:	
Snake bags _____	Gender probes _____	Storage tubs _____	
Snake hooks _____	Measuring tapes _____	Buckets _____	
Snake tongs _____	Snake coolers _____	Measuring cups _____	
PIT injectors _____	Sample cooler _____	Bleach bottle _____	
(other, please list) _____	(other, please list) _____	Spray bottle _____	
		Car tires _____	
Bleached and disposed:			
Rubber gloves _____		Swab handles _____	
(other, please list) _____		(other, please list) _____	
All bleached reusable items have been stored in the "clean tub" _____ Coolers have been closed and placed in the car _____ Scrubbers are soaking in a closed container of bleach solution _____ All bleached disposable items have been stored in the "disposal tub" _____			
I have overseen and completed this disinfection process in order to prevent the spread of snake fungal disease between sites. _____			
I have assisted with this disinfection process and confirm that the all of the above is accurate. _____			
<i>This checklist is based on the protocol developed by M. Allender (University of Illinois) for preventing the spread of Snake Fungal Disease (Ophidiomyces ophiodiicola), a potentially fatal fungal pathogen affecting snake species across North America. There is no record of this type of pathogen spreading to humans.</i>			
<i>Consult the Snake Fungal Disease Disinfection Protocol if you have any questions or concerns.</i>			
<i>This protocol is required as part of our Michigan State University Animal Use Forms, and by MSU's Institutional Animal Care and Use Committee.</i>			
<i>This protocol is required as part of our Michigan Department of Natural Resources Scientific Collector's Permit.</i>			

Figure E.1. Disinfection checklist developed for this project used before leaving each field site to prevent the spread of snake fungal disease (*Ophidiomyces ophiodiicola*) between sites in southern Michigan during the 2015 and 2015 field seasons (see Appendix B).

APPENDIX F

Study Site and Detection Survey Subsite Naming Description

All study sites were given a code (i.e., “Original Site Code”, Tables F.1 and F.2) upon site selection and estimation of general suitability for massasaugas (see Site Selection in Chapters 1, 2, or 3) and qualified as low, medium, or high quality based on the proportion of available vegetation types considered suitable for the massasauga based on the Bailey (2010) habitat suitability index model. Upon visiting the site this initial suitability assessment was either confirmed or contradicted. For 2 of the 27 study sites, the initial assessment was found to be based on vegetation types that were available prior to extensive habitat manipulations at the site in question and thus these sites were assigned a new code (i.e., “Final Site Code”; Tables F.1 and F.2). All sites codes were formatted to reflect the difference between the original code and the final code and are shown in Tables F.1 and F.2 for all study sites and subsites included in this research.

Table F.1. Site code names for the 20-ha study sites included in the 2015 and 2016 eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) field work in southern Michigan.

Original Site Code ^{a, b}	Final Site Code ^{b, c}	Property Name
NEH1	NE_H1	Indian Springs Metropark
NEH2	NE_H2	Independence Oaks County Park
NEH3	NE_H3	Independence Oaks County Park
NEL1	NE_L1	Seven Lakes State Park
NEL2	NE_L2	Brighton State Recreation Area
NEL3	NE_L3	Brighton State Recreation Area
NEM1	NE_M1	Seven Lakes State Park
NEM2	NE_M2	Brighton State Recreation Area
NEM3	NE_M3	Indian Springs Metropark
SEH1	SE_H1	Liberty Fen (private)
SEH2	SE_H2	Grand River Fen
SEH3_M	SE_H3 ^b	Ives Road Fen
SEH4	SE_H4	Ives Road Fen
SEL1	SE_L1	Wacker Chemical Company
SEL2	SE_L2	Ives Road Fen
SEL3	SE_L3	Sharonville State Game Area
SEL5	SE_L4 ^b	Fay Lake (private)
SEM1	SE_M1	Nan Weston
SWH1	SW_H1	Barry State Game Area
SWH2	SW_H2	Otis Audubon Sanctuary
SWH3	SW_H3	Yankee Springs Recreation Area
SWL1	SW_L1	Yankee Springs Recreation Area
SWL2	SW_L2	Yankee Springs Recreation Area
SWL3	SW_L3	Yankee Springs Recreation Area
SWM1	SW_M1	Baker Audubon Sanctuary
SWM2	SW_M2	Baker Audubon Sanctuary
SWM3	SW_M3	Barry State Game Area

^a Site code used in initial data collection, data sheets, raw data files, and analyses (e.g., R code).

^b Within the site codes, NE = northeast focal area, SE = southeast focal area, and SW = southwest focal area (Appendix C); H = high suitability, M = medium suitability, L = low suitability.

^c Site code used throughout this dissertation and in any related publications; altered from the original for clarity and consistency among sites.

Table F.2. Site and subsite code names (original and final) for 20-ha study sites and respective 2-ha detection survey subsites included in the 2015 and 2016 eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) field work throughout southern Michigan.

Year	Property Name	Original Site Code ^{a, b}	Final Site Code ^{b, c}	Original Subsite Code ^a	Final Subsite Code ^b
2015	Baker Audubon Sanctuary	SWM1	SW_M1	5y	SW_M1_s1
2015	Baker Audubon Sanctuary	SWM2	SW_M2	7y	SW_M2_s1
2015	Fay Lake (private)	SEL5	SE_L4	16	SE_L4_s1
2015	Indian Springs Metropark	NEH1	NE_H1	18	NE_H1_s1
2015	Indian Springs Metropark	NEM3	NE_M3	17y	NE_M3_s1
2015	Ives Road Fen	SEH3_M	SE_H3	8	SE_H3_s1
				32	SE_H3_s2
2015	Liberty Fen (private)	SEH1	SE_H1	0	SE_H1_s1
2015	Otis Audubon Sanctuary	SWH2	SW_H2	18	SW_H2_s1
2015	Seven Lakes State Park	NEL1	NE_L1	19y	NE_L1_s1
2015	Seven Lakes State Park	NEM1	NE_M1	27y	NE_M1_s1
2015	Sharonville State Game Area	SEL3	SE_L3	16	SE_L3_s1
2016	Baker Audubon Sanctuary	SWM2	SW_M2	7	SW_M2_s1
				17-21	SW_M2_s2
2016	Ives Road Fen	SEH3_M	SE_H3	8	SE_H3_s1
				32	SE_H3_s2
2016	Liberty Fen (private)	SEH1	SE_H1	25	SE_H1_s1
				111	SE_H1_s2
2016	Seven Lakes State Park	NEL1	NE_L1	15	NE_L1_s1
				19-24	NE_L1_s2

^a Site or subsite code used in initial data collection, data sheets, raw data files, and analyses (e.g., R code). Original subsite code was based on vegetation sampling points and named thusly. Final subsite code reflects the name of the larger study site for clarity.

^b Within the site codes, NE = northeast focal area, SE = southeast focal area, and SW = southwest focal area (Appendix C); H = high suitability, M = medium suitability, L = low suitability.

^c Site or subsite code used throughout this dissertation and in any related publications; altered from the original for clarity and consistency among sites.

APPENDIX G

R Code

Chapter 1: Kernel Home Ranges and Resource Selection Probability Function Analysis

```
#####  
# SEVEN LAKES  
#####  
NEL1_emrlocs <- read.table("NEL1_emrlocs_TableToExcel.txt", header=TRUE, sep="") #reads in the raw data  
NEL1_emr <- NEL1_emrlocs #17T  
NEL1_emr <- subset(NEL1_emr, select=c("UTMeasting", "UTMnorthin", "Code")) #extract the columns of data I need  
coordinates(NEL1_emr) <- c("UTMeasting", "UTMnorthin") #turn snake locations into a "spatial points data frame"  
proj4string(NEL1_emr) <- CRS("+init=epsg:32617") # add CRS information...  
NEL1s <- spTransform(NEL1_emr, CRS("+init=epsg:32617")) # transform  
  
# Utilization distribution.  
NEL1_kud <- kernelUD(NEL1s, h="href") ## Reference smoothing parameter.  
  
# Estimating a home range from a utilization distribution.  
NEL1_homerange95 <- getverticeshr(NEL1_kud, percent=95)  
NEL1_homerange90 <- getverticeshr(NEL1_kud, percent=90)  
NEL1_homerange85 <- getverticeshr(NEL1_kud, percent=85)  
NEL1_homerange80 <- getverticeshr(NEL1_kud, percent=80)  
NEL1_homerange70 <- getverticeshr(NEL1_kud, percent=70)  
NEL1_homerange60 <- getverticeshr(NEL1_kud, percent=60)  
NEL1_homerange50 <- getverticeshr(NEL1_kud, percent=50)  
NEL1_homerange25 <- getverticeshr(NEL1_kud, percent=25)  
  
# Clip homeranges to the extent of the study site, export/import shapefile for ArcGIS and save to ArcGIS folder  
library(GISTools)  
library(rgdal)  
  
# Create directory in ArcGIS folder to save from R  
#dir.create("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR")
```

```

# save polygon to Arc folder for clipping and/or determining use/availability of veg sampling sites in Arc
writeOGR(NEL1_homerange95, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_95", driver="ESRI Shapefile")
writeOGR(NEL1_homerange90, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_90", driver="ESRI Shapefile")
writeOGR(NEL1_homerange85, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_85", driver="ESRI Shapefile")
writeOGR(NEL1_homerange80, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_80", driver="ESRI Shapefile")
writeOGR(NEL1_homerange70, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_70", driver="ESRI Shapefile")
writeOGR(NEL1_homerange60, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_60", driver="ESRI Shapefile")
writeOGR(NEL1_homerange50, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_50", driver="ESRI Shapefile")
writeOGR(NEL1_homerange25, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="NEL1_HR_25", driver="ESRI Shapefile")

# Import clipped homerange polygon (clipped to the extent of the site)
NEL1_HR_95_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_95_proj_Clip")
NEL1_HR_95_clip <- spTransform(NEL1_HR_95_clip, CRS("+init=epsg:32617")) #transform
NEL1_HR_90_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_90_proj_Clip")
NEL1_HR_90_clip <- spTransform(NEL1_HR_90_clip, CRS("+init=epsg:32617")) #transform
NEL1_HR_85_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_85_proj_Clip")
NEL1_HR_85_clip <- spTransform(NEL1_HR_85_clip, CRS("+init=epsg:32617")) #transform
NEL1_HR_80_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_80_proj_Clip")
NEL1_HR_80_clip <- spTransform(NEL1_HR_80_clip, CRS("+init=epsg:32617")) #transform
NEL1_HR_70_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_70_proj_Clip")
NEL1_HR_70_clip <- spTransform(NEL1_HR_70_clip, CRS("+init=epsg:32617")) #transform
NEL1_HR_60 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_60_proj")
NEL1_HR_60 <- spTransform(NEL1_HR_60, CRS("+init=epsg:32617")) #transform
NEL1_HR_50 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_50_proj")
NEL1_HR_50 <- spTransform(NEL1_HR_50, CRS("+init=epsg:32617")) #transform
NEL1_HR_25 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "NEL1_HR_25_proj")
NEL1_HR_25 <- spTransform(NEL1_HR_25, CRS("+init=epsg:32617")) #transform

# resource selection probability function:
library(ResourceSelection)

```

```

NEL1_veg_use_avail <- read.table("NEL1_vegsamples_TableToExcel.txt", header=TRUE, sep="")
head(NEL1_veg_use_avail) #REMOVE EARLY SAMPLES AND UNNECESSARY DATA BEFORE BRINING INTO R

NEL1_RSPF_95 <- rspf(status95 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_90 <- rspf(status90 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_85 <- rspf(status85 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_80 <- rspf(status80 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_70 <- rspf(status70 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_60 <- rspf(status60 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_50 <- rspf(status50 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)
NEL1_RSPF_25 <- rspf(status25 ~ LHC + DHC + woody3m + avgDBH, NEL1_veg_use_avail, m=0, B = 99)

## Visualize the relationships
par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_95) # FIT LINE WITH CI
par(mfrow=c(2,3))
mep(NEL1_RSPF_95)
summary(NEL1_RSPF_95)

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_90)
par(mfrow=c(1,1))
par(mfrow=c(2,3), ask=FALSE)
mep(NEL1_RSPF_90)
summary(NEL1_RSPF_90)

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_85)
par(mfrow=c(2,3))
mep(NEL1_RSPF_85)
summary(NEL1_RSPF_85)

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_80)
par(mfrow=c(2,3))
mep(NEL1_RSPF_80)
summary(NEL1_RSPF_80) # did not converge

par(mfrow=c(2,2), ask=FALSE)

```

```

plot(NEL1_RSPF_70)
par(mfrow=c(2,3))
mep(NEL1_RSPF_70)
summary(NEL1_RSPF_70)

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_60)
par(mfrow=c(2,3))
mep(NEL1_RSPF_60)
summary(NEL1_RSPF_60) # TOP MODEL

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_50)
par(mfrow=c(2,3))
mep(NEL1_RSPF_50)
summary(NEL1_RSPF_50)

par(mfrow=c(2,2), ask=FALSE)
plot(NEL1_RSPF_25)
par(mfrow=c(2,3))
mep(NEL1_RSPF_25)
summary(NEL1_RSPF_25)

# Rank with consistent AIC - all models that converged
caic_NEL1 <- CAICtable(NEL1_RSPF_95,NEL1_RSPF_90,NEL1_RSPF_85,NEL1_RSPF_70,NEL1_RSPF_60,NEL1_RSPF_50,NEL1_RSPF_25)
write.table(caic_NEL1, file = "caic_NEL1.txt", sep = "\t")

#####
# IVES NORTH
#####
SEH3_emrlocs <- read.table("SEH3_emrlocs_TableToExcel.txt", header=TRUE, sep="") #reads in the raw data
SEH3_emr <- SEH3_emrlocs #17T
SEH3_emr <- subset(SEH3_emr, select=c("UTMeasting", "UTMnorthin", "Code")) #extract the columns of data I need
coordinates(SEH3_emr) <- c("UTMeasting", "UTMnorthin") #turn snake locations into a "spatial points data frame"
proj4string(SEH3_emr) <- CRS("+init=epsg:32617") # add CRS information...
SEH3s <- spTransform(SEH3_emr, CRS("+init=epsg:32617")) # transform

# Utilization distribution.
SEH3_kud <- kernelUD(SEH3s, h="href") ## Reference smoothing parameter.

```

```

# Estimating a home range from a utilization distribution.
SEH3_homerange95 <- getverticeshr(SEH3_kud, percent=95)
SEH3_homerange90 <- getverticeshr(SEH3_kud, percent=90)
SEH3_homerange85 <- getverticeshr(SEH3_kud, percent=85)
SEH3_homerange80 <- getverticeshr(SEH3_kud, percent=80)
SEH3_homerange70 <- getverticeshr(SEH3_kud, percent=70)
SEH3_homerange60 <- getverticeshr(SEH3_kud, percent=60)
SEH3_homerange50 <- getverticeshr(SEH3_kud, percent=50)
SEH3_homerange25 <- getverticeshr(SEH3_kud, percent=25)

# Clip homeranges to the extent of the study site, export/import shapefile for ArcGIS and save to ArcGIS folder
# save polygon to Arc folder for clipping and/or determining use/availability of veg sampling sites in Arc
writeOGR(SEH3_homerange95, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_95", driver="ESRI Shapefile")
writeOGR(SEH3_homerange90, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_90", driver="ESRI Shapefile")
writeOGR(SEH3_homerange85, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_85", driver="ESRI Shapefile")
writeOGR(SEH3_homerange80, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_80", driver="ESRI Shapefile")
writeOGR(SEH3_homerange70, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_70", driver="ESRI Shapefile")
writeOGR(SEH3_homerange60, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_60", driver="ESRI Shapefile")
writeOGR(SEH3_homerange50, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_50", driver="ESRI Shapefile")
writeOGR(SEH3_homerange25, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SEH3_HR_25", driver="ESRI Shapefile")

# Import clipped homerange polygon (clipped to the extent of the site)
SEH3_HR_95_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_95_proj_Clip")
SEH3_HR_95_clip <- spTransform(SEH3_HR_95_clip, CRS("+init=epsg:32617")) #transform
SEH3_HR_90_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_90_proj_Clip")
SEH3_HR_90_clip <- spTransform(SEH3_HR_90_clip, CRS("+init=epsg:32617")) #transform
SEH3_HR_85_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_85_proj_Clip")
SEH3_HR_85_clip <- spTransform(SEH3_HR_85_clip, CRS("+init=epsg:32617")) #transform
SEH3_HR_80_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_80_proj_Clip")
SEH3_HR_80_clip <- spTransform(SEH3_HR_80_clip, CRS("+init=epsg:32617")) #transform

```

```

SEH3_HR_70 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_70_proj")
SEH3_HR_70 <- spTransform(SEH3_HR_70, CRS("+init=epsg:32617")) #transform
SEH3_HR_60 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_60_proj")
SEH3_HR_60 <- spTransform(SEH3_HR_60, CRS("+init=epsg:32617")) #transform
SEH3_HR_50 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_50_proj")
SEH3_HR_50 <- spTransform(SEH3_HR_50, CRS("+init=epsg:32617")) #transform
SEH3_HR_25 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SEH3_HR_25_proj")
SEH3_HR_25 <- spTransform(SEH3_HR_25, CRS("+init=epsg:32617")) #transform

# resource selection probability function:
SEH3_veg_use_avail <- read.table("SEH3_vegsamples_TableToExcel.txt", header=TRUE, sep="")
head(SEH3_veg_use_avail) #REMOVE EARLY SAMPLES AND UNNECESSARY DATA BEFORE BRINING INTO R

SEH3_RSPF_95 <- rspf(status95 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_90 <- rspf(status90 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_85 <- rspf(status85 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_80 <- rspf(status80 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_70 <- rspf(status70 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_60 <- rspf(status60 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_50 <- rspf(status50 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)
SEH3_RSPF_25 <- rspf(status25 ~ LHC + DHC + woody3m + avgDBH, SEH3_veg_use_avail, m=0, B = 99)

## Visualize the relationships
par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_95) # FIT LINE WITH CI
par(mfrow=c(2,3))
mep(SEH3_RSPF_95)
summary(SEH3_RSPF_95)

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_90)
par(mfrow=c(2,3))
mep(SEH3_RSPF_90)
summary(SEH3_RSPF_90) #did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_85)
par(mfrow=c(2,3))
mep(SEH3_RSPF_85)

```

```

summary(SEH3_RSPF_85) # top model

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_80)
par(mfrow=c(2,3))
mep(SEH3_RSPF_80)
summary(SEH3_RSPF_80) # did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_70)
par(mfrow=c(2,3))
mep(SEH3_RSPF_70)
summary(SEH3_RSPF_70)

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_60)
par(mfrow=c(2,3))
mep(SEH3_RSPF_60)
summary(SEH3_RSPF_60) # DID NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_50)
par(mfrow=c(2,3))
mep(SEH3_RSPF_50)
summary(SEH3_RSPF_50) # did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SEH3_RSPF_25)
par(mfrow=c(2,3))
mep(SEH3_RSPF_25)
summary(SEH3_RSPF_25) # did not converge

# RANK WITH consistent AIC - all models that converged
caic_SEH3 <- CAICTable(SEH3_RSPF_95,SEH3_RSPF_85,SEH3_RSPF_70)
write.table(caic_SEH3, file = "caic_SEH3.txt", sep = "\t")

#####
# OTIS
#####

```

```

SWH2_emrlocs <- read.table("SWH2_emrlocs_TableToExcel.txt", header=TRUE, sep="") #reads in the raw data
SWH2_emr <- SWH2_emrlocs #17T
SWH2_emr <- subset(SWH2_emr, select=c("UTMeasting", "UTMnorthin", "Code")) #extract the columns of data I need
coordinates(SWH2_emr) <- c("UTMeasting", "UTMnorthin") #turn snake locations into a "spatial points data frame"
proj4string(SWH2_emr) <- CRS("+init=epsg:32616") # add CRS information...
SWH2s <- spTransform(SWH2_emr, CRS("+init=epsg:32616")) # transform

# Utilization distribution.
SWH2_kud <- kernelUD(SWH2s, h="href") ## Reference smoothing parameter.

# Estimating a home range from a utilization distribution.
# Create a __% polygon home range (note: these are not clipped to the study site yet)
SWH2_homerange95 <- getverticeshr(SWH2_kud, percent=95)
SWH2_homerange90 <- getverticeshr(SWH2_kud, percent=90)
SWH2_homerange85 <- getverticeshr(SWH2_kud, percent=85)
SWH2_homerange80 <- getverticeshr(SWH2_kud, percent=80)
SWH2_homerange70 <- getverticeshr(SWH2_kud, percent=70)
SWH2_homerange60 <- getverticeshr(SWH2_kud, percent=60)
SWH2_homerange50 <- getverticeshr(SWH2_kud, percent=50)
SWH2_homerange25 <- getverticeshr(SWH2_kud, percent=25)

# Clip homeranges to the extent of the study site, export/import shapefile for ArcGIS and save to ArcGIS folder
# save polygon to Arc folder for clipping and/or determining use/availability of veg sampling sites in Arc
writeOGR(SWH2_homerange95, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_95", driver="ESRI Shapefile")
writeOGR(SWH2_homerange90, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_90", driver="ESRI Shapefile")
writeOGR(SWH2_homerange85, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_85", driver="ESRI Shapefile")
writeOGR(SWH2_homerange80, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_80", driver="ESRI Shapefile")
writeOGR(SWH2_homerange70, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_70", driver="ESRI Shapefile")
writeOGR(SWH2_homerange60, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_60", driver="ESRI Shapefile")
writeOGR(SWH2_homerange50, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_50", driver="ESRI Shapefile")
writeOGR(SWH2_homerange25, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWH2_HR_25", driver="ESRI Shapefile")

```

```

# Import clipped homerange polygon (clipped to the extent of the site)
SWH2_HR_95_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_95_proj_Clip")
SWH2_HR_95_clip <- spTransform(SWH2_HR_95_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_90_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_90_proj_Clip")
SWH2_HR_90_clip <- spTransform(SWH2_HR_90_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_85_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_85_proj_Clip")
SWH2_HR_85_clip <- spTransform(SWH2_HR_85_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_80_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_80_proj_Clip")
SWH2_HR_80_clip <- spTransform(SWH2_HR_80_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_70_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_70_proj_Clip")
SWH2_HR_70_clip <- spTransform(SWH2_HR_70_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_60_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_60_proj_Clip")
SWH2_HR_60_clip <- spTransform(SWH2_HR_60_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_50_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_50_proj_Clip")
SWH2_HR_50_clip <- spTransform(SWH2_HR_50_clip, CRS("+init=epsg:32616")) #transform
SWH2_HR_25 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWH2_HR_25_proj")
SWH2_HR_25 <- spTransform(SWH2_HR_25, CRS("+init=epsg:32616")) #transform

# resource selection probability function:
SWH2_veg_use_avail <- read.table("SWH2_vegsamples_TableToExcel.txt", header=TRUE, sep="")
head(SWH2_veg_use_avail) #REMOVE EARLY SAMPLES AND UNNECESSARY DATA BEFORE BRINING INTO R

#SWH2_RSPF_95 <- rspf(status95 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99) #does not work (all
veg points fall within the 95% home range)
SWH2_RSPF_90 <- rspf(status90 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_85 <- rspf(status85 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_80 <- rspf(status80 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_70 <- rspf(status70 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_60 <- rspf(status60 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_50 <- rspf(status50 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)
SWH2_RSPF_25 <- rspf(status25 ~ LHC + DHC + woody3m + avgDBH, SWH2_veg_use_avail, m=0, B = 99)

## Visualize the relationships
#par(mfrow=c(2,2), ask=FALSE)
#plot(SWH2_RSPF_95) # FIT LINE WITH CI
#par(mfrow=c(2,3))
#mep(SWH2_RSPF_95)
#summary(SWH2_RSPF_95)

```

```

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_90)
par(mfrow=c(2,3))
mep(SWH2_RSPF_90)
summary(SWH2_RSPF_90)

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_85)
par(mfrow=c(2,3))
mep(SWH2_RSPF_85)
summary(SWH2_RSPF_85) # does not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_80)
par(mfrow=c(2,3))
mep(SWH2_RSPF_80)
summary(SWH2_RSPF_80) # DOES NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_70)
par(mfrow=c(2,3))
mep(SWH2_RSPF_70)
summary(SWH2_RSPF_70) # DOES NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_60)
par(mfrow=c(2,3))
mep(SWH2_RSPF_60)
summary(SWH2_RSPF_60)

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_50)
par(mfrow=c(2,3))
mep(SWH2_RSPF_50)
summary(SWH2_RSPF_50) # DOES NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SWH2_RSPF_25)

```

```

par(mfrow=c(2,3))
mep(SWH2_RSPF_25)
summary(SWH2_RSPF_25) # did not converge

# RANK WITH consistent AIC - all models that converged
caic_SWH2 <- CAICtable(SWH2_RSPF_90,SWH2_RSPF_60)
write.table(caic_SWH2, file = "caic_SWH2.txt", sep = "\t")

#####
# BAKER NORTH
#####
SWM2_emrlocs <- read.table("SWM2_emrlocs_TableToExcel.txt", header=TRUE, sep="") #reads in the raw data
SWM2_emr <- SWM2_emrlocs #17T
SWM2_emr <- subset(SWM2_emr, select=c("UTMeasting", "UTMnorthin", "Code")) #extract the columns of data I need
coordinates(SWM2_emr) <- c("UTMeasting", "UTMnorthin") #turn snake locations into a "spatial points data frame"
proj4string(SWM2_emr) <- CRS("+init=epsg:32616") # add CRS information...
SWM2s <- spTransform(SWM2_emr, CRS("+init=epsg:32616")) # transform

# Utilization distribution.
SWM2_kud <- kernelUD(SWM2s, h="href") ## Reference smoothing parameter.

# Estimating a home range from a utilization distribution.
SWM2_homerange95 <- getverticeshr(SWM2_kud, percent=95)
SWM2_homerange90 <- getverticeshr(SWM2_kud, percent=90)
SWM2_homerange85 <- getverticeshr(SWM2_kud, percent=85)
SWM2_homerange80 <- getverticeshr(SWM2_kud, percent=80)
SWM2_homerange70 <- getverticeshr(SWM2_kud, percent=70)
SWM2_homerange60 <- getverticeshr(SWM2_kud, percent=60)
SWM2_homerange50 <- getverticeshr(SWM2_kud, percent=50)
SWM2_homerange25 <- getverticeshr(SWM2_kud, percent=25)

# Clip homeranges to the extent of the study site, export/import shapefile for ArcGIS and save to ArcGIS folder
# save polygon to Arc folder for clipping and/or determining use/availability of veg sampling sites in Arc
writeOGR(SWM2_homerange95, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWM2_HR_95", driver="ESRI Shapefile")
writeOGR(SWM2_homerange90, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWM2_HR_90", driver="ESRI Shapefile")
writeOGR(SWM2_homerange85, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
        layer="SWM2_HR_85", driver="ESRI Shapefile")

```

```

writeOGR(SWM2_homerange80, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
  layer="SWM2_HR_80", driver="ESRI Shapefile")
writeOGR(SWM2_homerange70, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
  layer="SWM2_HR_70", driver="ESRI Shapefile")
writeOGR(SWM2_homerange60, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
  layer="SWM2_HR_60", driver="ESRI Shapefile")
writeOGR(SWM2_homerange50, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
  layer="SWM2_HR_50", driver="ESRI Shapefile")
writeOGR(SWM2_homerange25, dsn="C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF/HR_shapefiles_fromR",
  layer="SWM2_HR_25", driver="ESRI Shapefile")

# Import clipped homerange polygon (clipped to the extent of the site)
SWM2_HR_95_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_95_proj_Clip")
SWM2_HR_95_clip <- spTransform(SWM2_HR_95_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_90_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_90_proj_Clip")
SWM2_HR_90_clip <- spTransform(SWM2_HR_90_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_85_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_85_proj_Clip")
SWM2_HR_85_clip <- spTransform(SWM2_HR_85_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_80_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_80_proj_Clip")
SWM2_HR_80_clip <- spTransform(SWM2_HR_80_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_70_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_70_proj_Clip")
SWM2_HR_70_clip <- spTransform(SWM2_HR_70_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_60_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_60_proj_Clip")
SWM2_HR_60_clip <- spTransform(SWM2_HR_60_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_50_clip <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_50_proj_Clip")
SWM2_HR_50_clip <- spTransform(SWM2_HR_50_clip, CRS("+init=epsg:32616")) #transform
SWM2_HR_25 <- readOGR("C:/Users/Stephy/Documents/ArcGIS/MSU/habitat_selection/RSPF", "SWM2_HR_25_proj")
SWM2_HR_25 <- spTransform(SWM2_HR_25, CRS("+init=epsg:32616")) #transform

# resource selection probability function:
SWM2_veg_use_avail <- read.table("SWM2_vegsamples_TableToExcel.txt", header=TRUE, sep="")
head(SWM2_veg_use_avail) #REMOVE EARLY SAMPLES AND UNNECESSARY DATA BEFORE BRINING INTO R

SWM2_RSPF_95 <- rspf(status95 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_90 <- rspf(status90 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_85 <- rspf(status85 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_80 <- rspf(status80 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_70 <- rspf(status70 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_60 <- rspf(status60 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)

```

```

SWM2_RSPF_50 <- rspf(status50 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)
SWM2_RSPF_25 <- rspf(status25 ~ LHC + DHC + woody3m + avgDBH, SWM2_veg_use_avail, m=0, B = 99)

## Visualize the relationships
par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_95) # FIT LINE WITH CI
par(mfrow=c(2,3))
mep(SWM2_RSPF_95)
summary(SWM2_RSPF_95) # did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_90)
par(mfrow=c(2,3))
mep(SWM2_RSPF_90)
summary(SWM2_RSPF_90) # DID NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_85)
par(mfrow=c(2,3))
mep(SWM2_RSPF_85)
summary(SWM2_RSPF_85) # DID NOT CONVERGE

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_80)
par(mfrow=c(2,3))
mep(SWM2_RSPF_80)
summary(SWM2_RSPF_80)

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_70)
par(mfrow=c(2,3))
mep(SWM2_RSPF_70)
summary(SWM2_RSPF_70) # did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_60)
par(mfrow=c(2,3))
mep(SWM2_RSPF_60)
summary(SWM2_RSPF_60) # did not converge

```

```

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_50)
par(mfrow=c(2,3))
mep(SWM2_RSPF_50)
summary(SWM2_RSPF_50) # did not converge

par(mfrow=c(2,2), ask=FALSE)
plot(SWM2_RSPF_25)
par(mfrow=c(2,3))
mep(SWM2_RSPF_25)
summary(SWM2_RSPF_25) # DID NOT CONVERGE

# RANK WITH consistent AIC - all models that converged
caic_SWM2 <- CAICtable(SWM2_RSPF_80)
write.table(caic_SWM2, file = "caic_SWM2.txt", sep = "\t")

```

Chapter 2: Detection Factors and Predicted Occupancy Estimates.

```
#####  
# Detection using program 'Unmarked'  
#####  
library(unmarked) # For estimating detection  
library(AICcmodavg) # For AIC tables  
library(MuMIn) # For model averaging  
library(ggplot2) # For plotting predicted detection probabilities based on top covariates  
  
#####  
# Read in Data  
#####  
AllData <- read.table("DetectionSurveyData.txt", header=TRUE, sep="\t") #properly formatted  
AllData <- AllData[! AllData$Year.1 == "2015", ] #Remove 2015 data (only want to analyze 2016)  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.1", ] #Remove unoccupied subsite (the site that we  
#never found an EMR at, SEH1.25)  
  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.2", ]  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.3", ]  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.4", ]  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.5", ]  
AllData <- AllData[! AllData$SurveyID == "GRLF.SEH1.25.6", ]  
  
#####  
# COVARIATES  
#####  
# Detection history:  
EMRDet <- AllData[,73:74] # detection history column numbers from the data table  
  
# Site covariate:  
EMRsitecovs <- AllData[,c("QualityRank")] # site covariates, i.e., site quality. 1=low, 2=medium, 3=high  
  
# Observation covariates:  
EMRobscovs <- list(SubsiteCode=AllData[,c("SubsiteCode.1", "SubsiteCode.2")],  
  Prec=AllData[,c("Prec.1", "Prec.2")],  
  SiteOccu=AllData[,c("SiteOccu.1", "SiteOccu.2")],  
  SrchrCode=AllData[,c("SrchrCode.1", "SrchrCode.2")],  
  RankSnake=AllData[,c("RankSnake.1", "RankSnake.2")],  
  RankSnakePerSite=AllData[,c("RankSnakePerSite.1", "RankSnakePerSite.2")],
```

```

OverallRank=AllData[,c("OverallRank.1","OverallRank.2")],
DaysSince=AllData[,c("DaysSince.1","DaysSince.2")], #continuous
StartMins=AllData[,c("StartMins.1","StartMins.2")], #continuous
EndMins=AllData[,c("EndMins.1","EndMins.2")], #continuous
SqmHerb=AllData[,c("SqmHerb.1","SqmHerb.2")], #continuous
SqmWood=AllData[,c("SqmWood.1","SqmWood.2")], #continuous
herbtowood=AllData[,c("herbtowood.1","herbtowood.2")], #continuous
AirDif=AllData[,c("AirDif.1","AirDif.2")], #continuous
PrevDayMinNOAA=AllData[,c("PrevDayMinNOAA.1","PrevDayMinNOAA.2")], #continuous
SurfAvg=AllData[,c("SurfAvg.1","SurfAvg.2")], #continuous
SurfMax=AllData[,c("SurfMax.1","SurfMax.2")], #continuous
SoilAvg=AllData[,c("SoilAvg.1","SoilAvg.2")], #continuous
SoilMin=AllData[,c("SoilMin.1","SoilMin.2")], #continuous
SoilMax=AllData[,c("SoilMax.1","SoilMax.2")], #continuous
SolRadAvg=AllData[,c("SolRadAvg.1","SolRadAvg.2")], #continuous
SolRadMin=AllData[,c("SolRadMin.1","SolRadMin.2")], #continuous
SolRadMax=AllData[,c("SolRadMax.1","SolRadMax.2")], #continuous
SolRadSD=AllData[,c("SolRadSD.1","SolRadSD.2")], #continuous
SolRadSE=AllData[,c("SolRadSE.1","SolRadSE.2")], #continuous
HumAvg=AllData[,c("HumAvg.1","HumAvg.2")], #continuous
HumMin=AllData[,c("HumMin.1","HumMin.2")], #continuous
HumMax=AllData[,c("HumMax.1","HumMax.2")], #continuous
difNOAAminSurfmin=AllData[,c("difNOAAminSurfmin.1","difNOAAminSurfmin.2")],#continuous
difNOAAminAirmax=AllData[,c("difNOAAminAirmax.1","difNOAAminAirmax.2")], #continuous
difNOAAminAirmin=AllData[,c("difNOAAminAirmin.1","difNOAAminAirmin.2")], #continuous
PropHerb=AllData[,c("PropHerb.1","PropHerb.2")], #continuous
PropWood=AllData[,c("PropWood.1","PropWood.2")], #continuous
Julian=AllData[,c("Julian.1","Julian.2")], #continuous
SurveyOrder=AllData[,c("SurveyOrder.1","SurveyOrder.2")], #continuous
TotalMins=AllData[,c("TotalMins.1","TotalMins.2")], #continuous
MMTs=AllData[,c("MMTs.1","MMTs.2")], #continuous
SearchMins=AllData[,c("SearchMins.1","SearchMins.2")], #continuous
AirMin=AllData[,c("AirMin.1","AirMin.2")], #continuous
SameDayMinNOAA=AllData[,c("SameDayMinNOAA.1","SameDayMinNOAA.2")], #continuous
AirAvg=AllData[,c("AirAvg.1","AirAvg.2")], #continuous
AirMax=AllData[,c("AirMax.1","AirMax.2")], #continuous
SurfMin=AllData[,c("SurfMin.1","SurfMin.2")] #continuous

```

)

```

EMRsitecovsdf <- data.frame(EMRsitecovs) # Observation covariates as dataframe
EMR.data <- unmarkedFrameOccu(y=EMRDet, siteCovs=EMRsitecovsdf, obsCovs=EMRobscovs)

# Standardize continuous covariates, which is what we want.
ocforscale <- obsCovs(EMR.data) # remove the observation covariates from the dataframe
ocforscale[,8:43] <- scale(ocforscale[,8:43]) # scale the continuous variables
obsCovs(EMR.data) <- ocforscale # put them back into the dataframe
summary(EMR.data)

#####
# Correlation among covariates
#####
#using the "ocforscale" dataframe (data is scaled here)

# These are all covariates significant at 5%, plus PropHerb and PropWood (which we did not ultimately end
# up using because of their non-significance)
correlation_5percent <- cor(ocforscale[32:43], method="pearson")
correlation_5percent
pairs(correlation_5percent)
CorrTable <- as.table(correlation_5percent)

#####
# Fitting models:
#####
# Null Model:
#~~~~~
EMRfm1 <- occu(~1 ~1, EMR.data)
backTransform(EMRfm1, 'det') # backtransform to get actual detection estimate, for no-covariate models
backTransform(EMRfm1, 'state') # backtransform to get actual occupancy estimate, for no-covariate models

#####
# Univariate Models:
#####
# significant at alpha = 0.05
#~~~~~
TotalMins <- occu(~ TotalMins ~ 1, EMR.data) #sig
backTransform(linearComb(TotalMins, coefficients = c(1,0), type = 'det'))

MMTs <- occu(~ MMTs ~ 1, EMR.data) #sig

```

```

backTransform(linearComb(MMTs, coefficients = c(1,0), type = 'det'))

SearchMins <- occu(~ SearchMins ~ 1, EMR.data) #sig
backTransform(linearComb(SearchMins, coefficients = c(1,0), type = 'det'))

AirMin <- occu(~ AirMin ~ 1, EMR.data) #sig
backTransform(linearComb(AirMin, coefficients = c(1,0), type = 'det'))

SameDayMinNOAA <- occu(~ SameDayMinNOAA ~ 1, EMR.data) #sig. As min temp gets colder, detection prob increases
backTransform(linearComb(SameDayMinNOAA, coefficients = c(1,0), type = 'det'))

AirAvg <- occu(~ AirAvg ~ 1, EMR.data) #sig
backTransform(linearComb(AirAvg, coefficients = c(1,0), type = 'det'))

AirMax <- occu(~ AirMax ~ 1, EMR.data) #sig
backTransform(linearComb(AirMax, coefficients = c(1,0), type = 'det'))

SurfMin <- occu(~ SurfMin ~ 1, EMR.data) #sig
backTransform(linearComb(SurfMin, coefficients = c(1,0), type = 'det'))

SurveyOrder <- occu(~ SurveyOrder ~ 1, EMR.data) #sig
backTransform(linearComb(SurveyOrder, coefficients = c(1,0), type = 'det'))

Julian <- occu(~ Julian ~ 1, EMR.data) #sig
backTransform(linearComb(Julian, coefficients = c(1,0), type = 'det'))

#~~~~~
# significant at alpha = 0.10
#~~~~~
AirDif <- occu(~ AirDif ~ 1, EMR.data) # close to significant!
backTransform(linearComb(AirDif, coefficients = c(1,0), type = 'det'))

#~~~~~
# non-significant
#~~~~~
StartMins <- occu(~ StartMins ~ 1, EMR.data)
backTransform(linearComb(StartMins, coefficients = c(1,0), type = 'det'))

SolRadSE <- occu(~ SolRadSE ~ 1, EMR.data)

```

```

backTransform(linearComb(SolRadSE, coefficients = c(1,0), type = 'det'))

SubsiteCode <- occu(~ SubsiteCode ~ 1, EMR.data)
backTransform(linearComb(SubsiteCode, coefficients = c(1,0), type = 'det'))

Prec <- occu(~ Prec ~ 1, EMR.data)
backTransform(linearComb(Prec, coefficients = c(1,0), type = 'det'))

SrchrCode <- occu(~ SrchrCode ~ 1, EMR.data)
backTransform(linearComb(SrchrCode, coefficients = c(1,0), type = 'det'))

RankSnake <- occu(~ RankSnake ~ 1, EMR.data)
backTransform(linearComb(RankSnake, coefficients = c(1,0), type = 'det'))

RankSnakePerSite <- occu(~ RankSnakePerSite ~ 1, EMR.data)
backTransform(linearComb(RankSnakePerSite, coefficients = c(1,0), type = 'det'))

OverallRank <- occu(~ OverallRank ~ 1, EMR.data)
backTransform(linearComb(OverallRank, coefficients = c(1,0), type = 'det'))

DaysSince <- occu(~ DaysSince ~ 1, EMR.data)
backTransform(linearComb(DaysSince, coefficients = c(1,0), type = 'det'))

EndMins <- occu(~ EndMins ~ 1, EMR.data)
backTransform(linearComb(EndMins, coefficients = c(1,0), type = 'det'))

PrevDayMinNOAA <- occu(~ PrevDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(PrevDayMinNOAA, coefficients = c(1,0), type = 'det'))

SurfAvg <- occu(~ SurfAvg ~ 1, EMR.data)
backTransform(linearComb(SurfAvg, coefficients = c(1,0), type = 'det'))

SurfMax <- occu(~ SurfMax ~ 1, EMR.data)
backTransform(linearComb(SurfMax, coefficients = c(1,0), type = 'det'))

SolRadAvg <- occu(~ SolRadAvg ~ 1, EMR.data)
backTransform(linearComb(SolRadAvg, coefficients = c(1,0), type = 'det'))

SolRadMin <- occu(~ SolRadMin ~ 1, EMR.data)

```

```

backTransform(linearComb(SolRadMin, coefficients = c(1,0), type = 'det'))

SolRadMax <- occu(~ SolRadMax ~ 1, EMR.data)
backTransform(linearComb(SolRadMax, coefficients = c(1,0), type = 'det'))

SolRadSD <- occu(~ SolRadSD ~ 1, EMR.data)
backTransform(linearComb(SolRadSD, coefficients = c(1,0), type = 'det'))

HumAvg <- occu(~ HumAvg ~ 1, EMR.data)
backTransform(linearComb(HumAvg, coefficients = c(1,0), type = 'det'))

HumMin <- occu(~ HumMin ~ 1, EMR.data)
backTransform(linearComb(HumMin, coefficients = c(1,0), type = 'det'))

HumMax <- occu(~ HumMax ~ 1, EMR.data)
backTransform(linearComb(HumMax, coefficients = c(1,0), type = 'det'))

difNOAAminSurfmin <- occu(~ difNOAAminSurfmin ~ 1, EMR.data)
backTransform(linearComb(difNOAAminSurfmin, coefficients = c(1,0), type = 'det'))

difNOAAminAirmax <- occu(~ difNOAAminAirmax ~ 1, EMR.data)
backTransform(linearComb(difNOAAminAirmax, coefficients = c(1,0), type = 'det'))

difNOAAminAirmin <- occu(~ difNOAAminAirmin ~ 1, EMR.data)
backTransform(linearComb(difNOAAminAirmin, coefficients = c(1,0), type = 'det'))

PropHerb <- occu(~ PropHerb ~ 1, EMR.data)
backTransform(linearComb(PropHerb, coefficients = c(1,0), type = 'det'))

PropWood <- occu(~ PropWood ~ 1, EMR.data)
backTransform(linearComb(PropWood, coefficients = c(1,0), type = 'det'))

SqmHerb <- occu(~ SqmHerb ~ 1, EMR.data)
backTransform(linearComb(SqmHerb, coefficients = c(1,0), type = 'det'))

SqmWood <- occu(~ SqmWood ~ 1, EMR.data)
backTransform(linearComb(SqmWood, coefficients = c(1,0), type = 'det'))

herbtowood <- occu(~ herbtowood ~ 1, EMR.data)

```

```

backTransform(linearComb(herbtowood, coefficients = c(1,0), type = 'det'))

#SiteOccu <- occu(~ SiteOccu ~ 1, EMR.data) # Does not converge. Omitted from analysis.
#SoilMax <- occu(~ SoilMax ~ 1, EMR.data) # Does not converge. Omitted from analysis.
#SoilAvg <- occu(~ SoilAvg ~ 1, EMR.data) # Does not converge. Omitted from analysis.
#SoilMin <- occu(~ SoilMin ~ 1, EMR.data) # significant, but does not converge. Omitted from analysis.

#####
# AIC table - Univariates only
#####
# AIC table for all univariate models (except models that did not converge, SiteOccu, SoilMax, SoilAvg, and SoilMin)

univar.set.all <- list(EMRfm1, SubsiteCode, Prec, SrchrCode, RankSnake, RankSnakePerSite, OverallRank,
                      SurveyOrder, DaysSince, Julian, StartMins, EndMins, TotalMins, MMTs, SearchMins, AirAvg,
                      AirMin, AirMax, AirDif, PrevDayMinNOAA, SameDayMinNOAA, SurfAvg, SurfMin, SurfMax, SolRadAvg,
                      SolRadMin, SolRadMax, SolRadSD, SolRadSE, HumAvg, HumMin, HumMax, difNOAAminSurfmin,
                      difNOAAminAirmax, difNOAAminAirmin, PropHerb, PropWood, SqmHerb, SqmWood, herbtowood)
allmodelsAIC <- aictab(univar.set.all, modnames=c("EMRfm1", "SubsiteCode", "Prec", "SrchrCode", "RankSnake",
                                                "RankSnakePerSite", "OverallRank", "SurveyOrder",
                                                "DaysSince", "Julian", "StartMins", "EndMins", "TotalMins",
                                                "MMTs", "SearchMins", "AirAvg", "AirMin", "AirMax", "AirDif",
                                                "PrevDayMinNOAA", "SameDayMinNOAA", "SurfAvg", "SurfMin",
                                                "SurfMax", "SolRadAvg", "SolRadMin", "SolRadMax", "SolRadSD",
                                                "SolRadSE", "HumAvg", "HumMin", "HumMax", "difNOAAminSurfmin",
                                                "difNOAAminAirmax", "difNOAAminAirmin", "PropHerb",
                                                "PropWood", "SqmHerb", "SqmWood", "herbtowood"),
                      second.ord=FALSE, nobs=NULL, sort=TRUE)

#####
# Multivariate Models
#####
# All significant at alpha = 0.05
#~~~~~
multivar.sig_0.05 <- occu(~ TotalMins + MMTs + SearchMins + AirMin + SameDayMinNOAA + AirAvg + AirMax +
                          SurfMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(multivar.sig_0.05, coefficients = c(1,0,0,0,0,0,0,0,0,0), type = 'det'))

#AIC table
multivar.sig_0.05_AIC <- list(TotalMins, MMTs, SearchMins, AirMin, SameDayMinNOAA, AirAvg, AirMax, SurfMin,

```

```

SurveyOrder, Julian, EMRfm1)
aictab(multivar.sig_0.05_AIC, modnames=c("TotalMins", "MMTs", "SearchMins", "AirMin", "SameDayMinNOAA",
                                         "AirAvg", "AirMax", "SurfMin", "SurveyOrder", "Julian", "EMRfm1"),
      second.ord=FALSE, nobs=NULL, sort=TRUE)

# In "multivar.sig_0.05", the following covariates are correlated with one another:
#   TotalMins      corr w/   MMTs
#   TotalMins      corr w/  SearchMins
#   MMTs           corr w/   SearchMins
#   AirMin         corr w/   AirAvg
#   AirMin         corr w/   AirMax
#   AirMin         corr w/   SurfMin
#   SameDayMinNOAA corr w/   SurfMin
#   SameDayMinNOAA corr w/   Julian
#   AirAvg         corr w/   AirMax
#   AirAvg         corr w/   SurfMin
#   AirMax         corr w/   SurfMin

#~~~~~
# Final Set
#~~~~~
# From all covariates significant at 0.05:
#   Omitted TotalMins and MMTs because they are quite redundant with SearchMins (and not relevant to people
#   implementing the surveys)
#   Omitted AirAvg and AirMax because they are redundant with AirMin and rank lower with AIC than AirMin
#   SearchMins, AirMin, SameDayMinNOAA, SurveyOrder, Julian, SurfMin

FinalSet <- occu(~ SearchMins + AirMin + SameDayMinNOAA + SurfMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(FinalSet, coefficients = c(1,0,0,0,0,0,0), type = 'det'))

#AIC table
# second.ord=TRUE for AICc, second.ord=FALSE for AIC.
FinalSet_AIC <- list(SearchMins, AirMin, SameDayMinNOAA, SurveyOrder, Julian, SurfMin, EMRfm1)
aictab(FinalSet_AIC, modnames=c("SearchMins", "AirMin", "SameDayMinNOAA", "SurveyOrder", "Julian", "SurfMin",
                                "EMRfm1"), second.ord=FALSE, nobs=NULL, sort=TRUE)

# In "FinalSet", the following covariates are correlated with one another:
#   SurfMin      corr w/   AirMin
#   SurfMin      corr w/   SameDayMinNOAA

```

```

# Julian    corr w/    SameDayMinNOAA

#~~~~~
# Non-correlated Final Models
#~~~~~
# All combinations of our FinalSet covariates
# No combination contains correlated covariates; all are significant at alpha = 0.05

SearchMins_SurfMin_SurveyOrder_Julian <- occu(~ SearchMins + SurfMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurfMin_SurveyOrder_Julian, coefficients = c(1,0,0,0,0), type = 'det'))

SearchMins_SurfMin_SurveyOrder <- occu(~ SearchMins + SurfMin + SurveyOrder ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurfMin_SurveyOrder, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_SurfMin_Julian <- occu(~ SearchMins + SurfMin + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurfMin_Julian, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_SurveyOrder_Julian <- occu(~ SearchMins + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurveyOrder_Julian, coefficients = c(1,0,0,0), type = 'det'))

SurfMin_SurveyOrder_Julian <- occu(~ SurfMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(SurfMin_SurveyOrder_Julian, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_SurfMin <- occu(~ SearchMins + SurfMin ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurfMin, coefficients = c(1,0,0), type = 'det'))

SearchMins_SurveyOrder <- occu(~ SearchMins + SurveyOrder ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurveyOrder, coefficients = c(1,0,0), type = 'det'))

SearchMins_Julian <- occu(~ SearchMins + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_Julian, coefficients = c(1,0,0), type = 'det'))

SurfMin_SurveyOrder <- occu(~ SurfMin + SurveyOrder ~ 1, EMR.data)
backTransform(linearComb(SurfMin_SurveyOrder, coefficients = c(1,0,0), type = 'det'))

SurfMin_Julian <- occu(~ SurfMin + Julian ~ 1, EMR.data)
backTransform(linearComb(SurfMin_Julian, coefficients = c(1,0,0), type = 'det'))

SurveyOrder_Julian <- occu(~ SurveyOrder + Julian ~ 1, EMR.data)

```

```

backTransform(linearComb(SurveyOrder_Julian, coefficients = c(1,0,0), type = 'det'))

SearchMins_AirMin_SurveyOrder_Julian <- occu(~ SearchMins + AirMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin_SurveyOrder_Julian, coefficients = c(1,0,0,0,0), type = 'det'))

SearchMins_AirMin_SurveyOrder <- occu(~ SearchMins + AirMin + SurveyOrder ~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin_SurveyOrder, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_AirMin_Julian <- occu(~ SearchMins + AirMin + Julian ~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin_Julian, coefficients = c(1,0,0,0), type = 'det'))

AirMin_SurveyOrder_Julian <- occu(~ AirMin + SurveyOrder + Julian ~ 1, EMR.data)
backTransform(linearComb(AirMin_SurveyOrder_Julian, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_AirMin <- occu(~ SearchMins + AirMin ~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin, coefficients = c(1,0,0), type = 'det'))

AirMin_SurveyOrder <- occu(~ AirMin + SurveyOrder ~ 1, EMR.data)
backTransform(linearComb(AirMin_SurveyOrder, coefficients = c(1,0,0), type = 'det'))

AirMin_Julian <- occu(~ AirMin + Julian ~ 1, EMR.data)
backTransform(linearComb(AirMin_Julian, coefficients = c(1,0,0), type = 'det'))

SearchMins_AirMin_SurveyOrder_SameDayMinNOAA <- occu(~ SearchMins + AirMin + SurveyOrder + SameDayMinNOAA
~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin_SurveyOrder_SameDayMinNOAA, coefficients = c(1,0,0,0,0), type = 'det'))

SearchMins_AirMin_SameDayMinNOAA <- occu(~ SearchMins + AirMin + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(SearchMins_AirMin_SameDayMinNOAA, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_SurveyOrder_SameDayMinNOAA <- occu(~ SearchMins + SurveyOrder + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SurveyOrder_SameDayMinNOAA, coefficients = c(1,0,0,0), type = 'det'))

AirMin_SurveyOrder_SameDayMinNOAA <- occu(~ AirMin + SurveyOrder + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(AirMin_SurveyOrder_SameDayMinNOAA, coefficients = c(1,0,0,0), type = 'det'))

SearchMins_SameDayMinNOAA <- occu(~ SearchMins + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(SearchMins_SameDayMinNOAA, coefficients = c(1,0,0), type = 'det'))

```

```

AirMin_SameDayMinNOAA <- occu(~ AirMin + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(AirMin_SameDayMinNOAA, coefficients = c(1,0,0), type = 'det'))

SurveyOrder_SameDayMinNOAA <- occu(~ SurveyOrder + SameDayMinNOAA ~ 1, EMR.data)
backTransform(linearComb(SurveyOrder_SameDayMinNOAA, coefficients = c(1,0,0), type = 'det'))

#~~~~~
# Univariate models, and the null model
#~~~~~
#AIC table

# All combinations of the covariates included in FinalSet.
# Each combination contains non-correlated covariates, and all covariates are significant at alpha = 0.05.
# 32 SINGLE SEASON OCCUPANCY MODELS USING THE 6 FINAL COVARIATES: (there are 32 models)

FinalAll_list <- list(AirMin,AirMin_Julian,AirMin_SameDayMinNOAA,AirMin_SurveyOrder,
                     AirMin_SurveyOrder_Julian,AirMin_SurveyOrder_SameDayMinNOAA,EMRfm1,Julian,
                     SameDayMinNOAA,SearchMins,SearchMins_AirMin,SearchMins_AirMin_Julian,
                     SearchMins_AirMin_SameDayMinNOAA,SearchMins_AirMin_SurveyOrder,
                     SearchMins_AirMin_SurveyOrder_Julian,SearchMins_AirMin_SurveyOrder_SameDayMinNOAA,
                     SearchMins_Julian,SearchMins_SameDayMinNOAA,SearchMins_SurfMin,
                     SearchMins_SurfMin_Julian,SearchMins_SurfMin_SurveyOrder,
                     SearchMins_SurfMin_SurveyOrder_Julian,SearchMins_SurveyOrder,
                     SearchMins_SurveyOrder_Julian,SearchMins_SurveyOrder_SameDayMinNOAA,SurfMin,
                     SurfMin_Julian,SurfMin_SurveyOrder,SurfMin_SurveyOrder_Julian,SurveyOrder,
                     SurveyOrder_Julian,SurveyOrder_SameDayMinNOAA)
FinalAll_AICc_table <- aictab(FinalAll_list, modnames=c("AirMin","AirMin_Julian","AirMin_SameDayMinNOAA",
               "AirMin_SurveyOrder","AirMin_SurveyOrder_Julian",
               "AirMin_SurveyOrder_SameDayMinNOAA","EMRfm1",
               "Julian","SameDayMinNOAA","SearchMins",
               "SearchMins_AirMin","SearchMins_AirMin_Julian",
               "SearchMins_AirMin_SameDayMinNOAA",
               "SearchMins_AirMin_SurveyOrder",
               "SearchMins_AirMin_SurveyOrder_Julian",
               "SearchMins_AirMin_SurveyOrder_SameDayMinNOAA",
               "SearchMins_Julian","SearchMins_SameDayMinNOAA",
               "SearchMins_SurfMin","SearchMins_SurfMin_Julian",
               "SearchMins_SurfMin_SurveyOrder",
               "SearchMins_SurfMin_SurveyOrder_Julian",

```

```

"SearchMins_SurveyOrder",
"SearchMins_SurveyOrder_Julian",
"SearchMins_SurveyOrder_SameDayMinNOAA", "SurfMin",
"SurfMin_Julian", "SurfMin_SurveyOrder",
"SurfMin_SurveyOrder_Julian", "SurveyOrder",
"SurveyOrder_Julian", "SurveyOrder_SameDayMinNOAA"),
second.ord=TRUE, nobs=NULL, sort=TRUE) # note: second.ord=TRUE for AICc, =FALSE for AIC

#####
# Model Averaging (using package MuMin)
#####
# All models included:
FinalAll_AICc_modavg <- model.avg(FinalAll_list)
FinalAll_AICc_modavg_summary <- summary(model.avg(FinalAll_list))

# model average everything where delta < 7 (Burnham and Anderson 2002)
# create a new model list to subset only models where delta < 7 based on the model.avg of the full model
FinalAll_subset_list_delta7 <- list(SearchMins, SearchMins_AirMin, SearchMins_AirMin_Julian,
SearchMins_AirMin_SameDayMinNOAA, SearchMins_AirMin_SurveyOrder,
SearchMins_AirMin_SurveyOrder_Julian,
SearchMins_AirMin_SurveyOrder_SameDayMinNOAA, SearchMins_Julian,
SearchMins_SameDayMinNOAA, SearchMins_SurfMin, SearchMins_SurfMin_Julian,
SearchMins_SurfMin_SurveyOrder, SearchMins_SurfMin_SurveyOrder_Julian,
SearchMins_SurveyOrder, SearchMins_SurveyOrder_Julian,
SearchMins_SurveyOrder_SameDayMinNOAA)

# Only models where delta < 7 included:
FinalAll_subset_AICc_delta7_modavg <- model.avg(FinalAll_subset_list_delta7)
FinalAll_subset_AICc_delta7_modavg_summary <- summary(model.avg(FinalAll_subset_list_delta7))

confint(FinalAll_subset_AICc_delta7_modavg_summary, full=TRUE)
# full=TRUE gives the CI for the full averaged results;
# full=FALSE is default and gives the CI for the conditional results (the subset)

#####
# PREDICTING
#####
# All scaled and unscaled code values for the following predict and ggplot code are from using 2016
# data only, and only including only the 7 occupied subsites.

```

```

# This includes our top univariate models based on the AIC table for FinalSet
# SearchMins, AirMin

#~~~~~
# SearchMins_AirMin
#~~~~~
prediction_test_searchmins_airmin <- data.frame(SearchMins = -2.5:5.5, AirMin = -2.5:5.5)
#these are the standardized values

# the ranges set here need to cover the range of BOTH covariates for each of the
# covariates to be able to include all rows for each covariate.
round(predict(SearchMins_AirMin, type = 'det', newdata = prediction_test_searchmins_airmin, appendData=TRUE), 3)

#~~~~~
# SearchMins
#~~~~~
predict_searchmins <- data.frame(SearchMins = -3:6) #these bound the standardized values, see 'predict_searchmins_a'
predict_searchmins_a <- round(predict(SearchMins, type = 'det', newdata = predict_searchmins, appendData=TRUE), 3)
predict_searchmins_df <- as.data.frame(predict_searchmins_a)
scatterplot(Predicted ~ SearchMins, data=predict_searchmins_df)

#ggplot:
searchmins_ggplot <- ggplot(predict_searchmins_df, aes(SearchMins, Predicted)) + geom_line()
searchmins_ggplot <- searchmins_ggplot + geom_ribbon(data=predict_searchmins_df, aes(ymin=lower, ymax=upper),
                                                    ,alpha=0.4) #alpha is the shade of the CI

#The following line relabels the standardized numbers (the decimals, e.g., -2.81247) with the
# appropriate unstandardized associated "actual value"
#(e.g., "-2.81247,"="30") determined using the Excel spreadsheet from G. Roloff ("Plot formulas (from G Roloff)":
searchmins_ggplot <- searchmins_ggplot + scale_x_continuous(name="Minutes Spent Actively Searching",
                                                            breaks=c(-2.81247,-2.05594,-1.29942,-0.54290,
                                                            0.21363,0.97015,1.72668,2.48320,
                                                            3.23972,3.99625,4.75277,5.50930),
                                                            limits=c(-3,6),
                                                            labels=c("-2.81247,"="30", "-2.05594"="40",
                                                            "-1.29942"="50", "-0.54290"="60",
                                                            "0.21363"="70", "0.97015"="80",
                                                            "1.72668"="90", "2.48320"="100",
                                                            "3.23972"="110", "3.99625"="120",
                                                            "4.75277"="130", "5.50930"="140"))

```

```

searchmins_ggplot <- searchmins_ggplot + scale_y_continuous(name="Predicted Detection Probability",
                                                             breaks=c(0.0,0.2,0.4,0.6,0.8,1.0))

#variance-covariance matrix
vcov(SearchMins)

#~~~~~
# AirMin:
#~~~~~
predict_airmin <- data.frame(AirMin = -2.5:2.5) #these bound the standardized values,
                                                #see in #predict_airmin_a
predict_airmin_a <- round(predict(AirMin, type = 'det', newdata = predict_airmin, appendData=TRUE), 3)
predict_airmin_df <- as.data.frame(predict_airmin_a)
scatterplot(Predicted ~ AirMin, data=predict_airmin_df)

#ggplot:
airmin_ggplot <- ggplot(predict_airmin_df, aes(AirMin, Predicted)) + geom_line()
airmin_ggplot <- airmin_ggplot + geom_ribbon(data=predict_airmin_df,aes(ymin=lower,ymax=upper),alpha=0.4)
#alpha is the shade of the CI
#The following line relabels the standardized numbers (the decimals, e.g., -3.13278) with the
#appropriate unstandardized associated "actual value" (e.g., "-3.13278"="55") determined using the Excel
#spreadsheet from G. Roloff ("Plot formulas (from G Roloff)"):
airmin_ggplot <- airmin_ggplot + scale_x_continuous(name="Minimum Air Temperature During Survey (Deg F)",
                                                    breaks=c(-3.13278,-2.37675,-1.62071,-0.86468,-0.10864,
                                                            0.64739,1.40343,2.15946,2.91550),
                                                    limits=c(-2.5, 2.5),
                                                    labels=c("-3.13278"="55", "-2.37675"="60",
                                                            "-1.62071"="65", "-0.86468"="70",
                                                            "-0.10864"="75", "0.64739"="80",
                                                            "1.40343"="85", "2.15946"="90",
                                                            "2.91550"="95"))

airmin_ggplot <- airmin_ggplot + scale_y_continuous(name="Predicted Detection Probability",
                                                    breaks=c(0.0,0.2,0.4,0.6,0.8,1.0))

#variance-covariance matrix
vcov(AirMin)

```

APPENDIX H

Documentation of Three Mortality Events

2015: Site SE_H3 - Adult Female

Adult female (gravid, PIT tag # 836546351; Appendix D) massasauga was first captured on 21 May 2015. Brought in for surgical implantation of radiotransmitter (7g ATS) on 22 May, released back at location of capture on 26 May 2015. Continued to collect locations and closely monitored this individual as we expected parturition to occur in early-mid August. Following a final visual observation on 4 Aug where behavior appeared normal, the massasauga moved to a different location and remained unseen for the next two telemetry locations (6 Aug and 7 Aug), then moved to a final location and remained unseen for one telemetry location (10 Aug). Upon our second visit to this final location (12 Aug), we noticed the ground had been slightly dug up (apparently by a scavenging animal as claw marks were seen) where we had assumed the female was burrowed for parturition. Upon further inspection, we discovered the snake carcass and the transmitter was recovered (PIT tag scanner confirmed the identity of this massasauga). Carcass was too decomposed for necropsy to determine cause of mortality. Prior to this finding, we saw no indication that parturition had occurred at any of the final locations (i.e., no signs of neonates or neonatal ecdysis).

2015: Site SE_H1 - Adult Male

Adult male (PIT tag # 836574862; Appendix D) captured and transported for surgical implantation of radiotransmitter on 17 Jun 2015. Following surgery, released at location of capture on 20 Jun. Located via telemetry approximately twice per week until last observed alive on 24 July 2015 where the massasauga was found basking in the garden of the landowner whose property we were allowed access to for this research. Radiotracked again on 28 Jul and found

behind the landowner's house (opposite the garden) with no visual observation of the massasauga. On 31 Jul, radiotracking again behind the house revealed the radiotransmitter laying at the base of a tree with the anchoring suture used by the veterinarian still intact around the transmitter with a massasauga rib attached. Bite marks found on the transmitter may indicate that this individual was depredated, and the landowner informed us that he had seen many raccoons around his house recently. Additionally, this individual tested positive for snake fungal disease (Appendix B) but it is unknown if this influenced the mortality of the individual.

2016: Site SE_H1 - Adult Female

Adult female (nongravid, PIT tag # 840525094; Appendix D) captured and fitted with an external radiotransmitter on 20 Jul 2016. During capture and handling, we noted sluggish behavior and an emaciated appearance. Released at location of capture the same day. Relocating the individual via radiotelemetry on 25 Jul led us to the carcass of this massasauga where a PIT tag scan identified the individual and the radiotransmitter was recovered. Carcass too decomposed for necropsy.

APPENDIX I

Data Sheets

The following pages (Figures I.1-I.4) illustrate and describe the data sheets used during the 2015 and 2016 field seasons for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) study throughout southern Michigan in 2015 and 2016.

[illegible]

Figure I.1. Data sheet used to record all pertinent information for captured eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) during the 2015 and 2016 field seasons throughout southern Michigan.

Site _____

Date _____

DETECTION SURVEY

Subsite _____

Precipitation _____

Searcher _____

	Time	Air temp	Soil temp	Solar Rad	Humidity	# Snakes	Comments
Start							
End							
Δ						Total:	

Comments: _____

Subsite _____

Precipitation _____

Searcher _____

	Time	Air temp	Soil temp	Solar Rad	Humidity	# Snakes	Comments
Start							
End							
Δ						Total:	

Comments: _____

Subsite _____

Precipitation _____

Searcher _____

	Time	Air temp	Soil temp	Solar Rad	Humidity	# Snakes	Comments
Start							
End							
Δ						Total:	

Comments: _____

Figure I.3. Detection survey data sheet used during eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) detection surveys (see Chapter 2) conducted throughout southern Michigan. developed during the 2015 and 2015 field seasons.

Snake ID: _____ Date: _____ Time: _____ Observer: _____

Pain of snake post-operatively

- (1) High pain, snake recoils from surgical site, has abnormal movement; treatment with analgesics (Butorphanol)
- (2) Moderate pain, snake has slight abnormal movement; treatment with analgesics (Ketoprofen)
- (3) No detectible pain, snake is moving normally; treatment with analgesics at time of surgery (Ketoprofen)

Recovery from anesthesia

- (1) Snake does not recover from anesthesia; attempt to resuscitate, euthanize if only partially successful
- (2) Snake is not righting itself into normal posture and is not moving, yet is breathing; attempt to resuscitate, increase temperature in cage other methods of recovery
- (3) Snake is able to right itself and is moving normally, normal anesthetic recovery; no treatment

Evidence of infection

- (1) There is a swelling, discoloration, or granulomatous material emitting from the surgical site and snake is less active than usual; surgically clean the area that is infected if needed, treatment with antibiotics (Enrofloxacin), euthanasia if not able to treat
- (2) There is a slight swelling, discoloration, or granulomatous material emitting from the surgical site, snake is acting normally; treatment with antibiotics if needed (Enrofloxacin)
- (3) The incision is healing normally and the snake is acting normally; antibiotics at time of surgery, no other treatments needed

Snake behavior

- (1) Snake is less active than it should be; perform examination and diagnostics to evaluate the cause of decreased attitude, treat as warranted
- (2) There is a slight swelling, discoloration, or granulomatous material emitting from the surgical site, snake is acting normally; treatment with antibiotics if needed (Enrofloxacin)
- (3) Snake is acting normally; continue to monitor, no examinations or treatments needed

Comments/Notes: _____

Figure I.4. Postoperative monitoring data sheet (Bailey 2010) used following radiotransmitter implantation surgeries for eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) captured throughout southern Michigan during the 2015 and 2016 field seasons.

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