This is to certify that the
thesis entitled

MODELING HABITAT ECOLOGY AND POPULATION VIABILITY OF THE EASTERN MASSASAUGA RATTLESNAKE IN SOUTHWESTERN LOWER MICHIGAN

presented by

Kristin Marie Bissell

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Fisheries and Wildlife

Major Professor's Signature

12/14/06

Date

MODELING HABITAT ECOLOGY AND POPULATION VIABILITY OF THE EASTERN MASSASAUGA RATTLESNAKE IN SOUTHWESTERN LOWER MICHIGAN

By

Kristin Marie Bissell

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

2006

ABSTRACT

MODELING HABITAT ECOLOGY AND POPULATION VIABILITY OF THE EASTERN MASSASAUGA RATTLESNAKE IN SOUTHWESTERN LOWER MICHIGAN

By

Kristin Marie Bissell

Michigan is considered the last stronghold for the Eastern Massasauga Rattlesnake (EMR, *Sistrurus catenatus catenatus*), where it is a species of special concern. Understanding the habitat ecology and characteristics of EMR populations is essential to conservation efforts. Populations of EMRs have not been previously examined in southwestern lower Michigan. The objectives of this study were to quantify movement and habitat use patterns, develop a habitat suitability model, and conduct a population viability analysis (PVA) for EMRs in southwestern lower Michigan. The study was conducted at 2 sites in Barry County, Michigan. EMRs (n = 12 in 2004, n = 18 in 2005) were captured, implanted with radio transmitters, and tracked daily throughout the April – October. Data were collected on snake location, vegetation type, structure, and composition, and population demographics. Mean 95% fixed kernel home range size was 2.8 ha. EMRs most commonly used early successional deciduous upland and wetland vegetation types. Suitability of vegetation types increased with higher percentages of live (62-71%) and dead (90-96%) herbaceous cover and decreased as stem density and absolute dominance of trees/shrubs >3 m tall increased. Based on PVA simulations, populations may be increasing over the next 50 years if following an extant trajectory. Caution must be used when applying these results due to data variability. Results of this study have implications for future conservation of EMRs in the area.

To Ed.

ACKNOWLEDGEMENTS

Funding and support for this project were provided by the Michigan Department of Natural Resources (MDNR), Wildlife Division; the United States Fish and Wildlife Service (USFWS); Michigan State University (MSU); Lansing Potter Park Zoo (PPZ); Pierce Cedar Creek Institute for Ecological Education (PCCI), MDNR Parks and Recreation Division; Michigan Agricultural Experimental Station, and the Michigan Society of Herpetologists. I'd like to specifically thank Dr. Patrick Lederle, Raymond Rustem, and Lori Sargent (MDNR) and Michael DeCapita (USFWS) for seeing the potential of this project to contribute to conservation of the massasauga in Michigan. I would also like to thank Dr. Tara Harrison, Dennis Laidler, and Gerald Brady (PPZ) for their interest and involvement in massasauga research and the use of their first-rate facilities and expertise. Michelle Skedgell (PCCI) deserves special thanks for being so accommodating of our needs and for making massasauga conservation a priority at PCCI.

I would also like to extend my gratitude to my committee members. To Dr. Rique Campa, my major advisor, thank you for taking a chance on a zealous undergraduate and giving me the opportunity to research the subject I love most. Thank you for your support, encouragement, praise, and for being just as excited about this project as I was; I could not have asked for a better advisor, mentor, and colleague. I owe much gratitude to Dr. Kelly Millenbah, for serving on my committee as an expert in endangered species research, for her guidance and assistance with population viability analyses, for always taking an interest in this project, and for introducing me to the joys of field work. I owe a special thanks to Jim Harding, for cementing my fascination with reptile and amphibian biology and conservation, for his ever-present support and guidance throughout my academic career, and for serving as an expert of Michigan herpetofauna on my committee.

Several others deserve special thanks for their direct involvement in this research. Dr. Tara Harrison's contribution to this project was invaluable. She performed surgeries with little notice, provided essential veterinary expertise to the project, and ensured the safety and health of the snakes in the study. I'd also like to thank Dr. Diana Rosenstein (MSU) for coming to work early to conduct ultrasounds on rattlesnakes at the MSU Veterinary Clinic and lending her expertise to gain a better understanding of the reproductive nature of this elusive species; her work on this project was priceless. Dr. Christine Hanaburgh (MDNR) was also very helpful in the development of an ecological classification system for the area, and her input is greatly appreciated. I owe special thanks to my amazing field assistants, Kile Kucher and Melissa Foster, for their unsurpassed dedication to the project, for their eagerness to learn, and for always pulling me out of the mud; I am so proud of both of them. I was also lucky enough to have two terrific volunteer assistants, Randy Counterman and Andrew Meyers, who worked as if they were getting paid. I must also thank Susan Jones for facing her fear of snakes to help out a friend once in a while.

In addition, I must thank Yu Man Lee (Michigan State University Extension Michigan Natural Features Inventory) for nurturing my interest in massasauga conservation and for her involvement in all things massasauga, Julie Oakes (MDNR) for giving me the chance to try my hand at radio-tracking massasaugas and for her valued friendship, and Timothy Payne (MDNR) for his interest in my research and my future.

I'd like to thank my mother, Vicki Wildman, for her encouragement and faith in me, for taking an interest in my research, and for tackling fieldwork and snake handling like a pro. I would also like to thank my father, Michael, and my twin sister, Kelly, for their unwavering love, support, and confidence. I would like to thank Jeff Tropf for his enthusiastic encouragement and involvement in my introduction to the field of wildlife management. Finally, a very special thanks is owed to my husband, Edward Bissell, for his hard work in the field, GIS expertise, support, friendship, and love; I couldn't have done it without him.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Images in this thesis are presented in color.

GENERAL INTRODUCTION

Understanding habitat requirements, activity patterns, spatial distribution, natural history, and population demographics of wildlife species is critical for making informed, ecologically sound management decisions. This information is especially crucial for the conservation and management of threatened and endangered species or species of special concern because it can be used to identify threats to species survival, conserve critical habitat, and predict the effects of events that may negatively impact populations and habitat. Unfortunately, biological information of this type is often lacking by the time species declines begin to receive attention; such is the case for the Eastern Massasauga Rattlesnake (EMR; *Sistrurus catenatus catenatus*).

The EMR ranges from western New York, western Pennsylvania, and southern Ontario, west to eastern Iowa and eastern Missouri (Harding 1997). Numerous anthropogenic factors threaten the existence of this species throughout its range. Perhaps the greatest threat to the species is habitat degradation, including the draining of wetlands for agriculture, residential development, and roads (Szymanski 1998). Other threats include vehicle caused mortality and indiscriminate killing of snakes (Szymanski 1998).

Although early accounts suggest that EMRs were once common throughout their range, by the mid-1970s, this species was recognized as nationally imperiled (Szymanski 1998). The distribution is now limited to isolated areas and the subspecies receives some level of legal protection in every state or province where it occurs. Michigan has been described as the last stronghold for the subspecies (Szymanski 1998), with a state protection status of "special concern." The EMR became a candidate for federal listing by the U.S. Fish and Wildlife Service (USFWS) in 1999, and may be proposed for future listing as threatened or endangered under the Endangered Species Act of 1973, as amended (USFWS 1999).

The Michigan Department of Natural Resources (MDNR) is in the process of developing a Candidate Conservation Agreement with Assurances (CCAA) with the USFWS. The CCAA ensures that the MDNR does not have to take further action if the candidate species becomes federally listed. As mandated by the CCAA, the MDNR must provide a plan for how they will manage state-owned properties to conserve and protect the EMR. This is difficult to do when knowledge regarding the EMR's area-specific habitat use, movement patterns, population demographics, and status is lacking.

The purpose of this project was to enhance our understanding of EMR habitat ecology and population viability within an area in which EMR populations have not been examined in detail. This study focuses on EMR populations in southwestern lower-Michigan. Specific objectives of this project include: (1) quantifying the movement and habitat use patterns of EMRs, (2) quantifying the habitat composition and vegetation structure of areas supporting EMRs and developing a habitat suitability index model, (3) quantifying EMR population parameters and conducting a population viability analysis (PVA) for EMRs in the study area, and (4) presenting habitat and population management implications for the EMR within the study area based on project findings.

STUDY AREA

In 2004, the study was initiated at the Pierce Cedar Creek Institute for Ecological Education (PCCI); and in 2005, it was expanded to include Yankee Springs State Recreation Area (YSRA) in Barry County, Michigan (Figure 1.1). EMRs have been documented to occur in these areas by Michigan Natural Features Inventory (MNFI) as recently as the summer of 2003 (Y. Lee, Zoologist and Associate Program Leader, MNFI, personal communication) and were identified by the Eastern Massasauga Rattlesnake Working Group as priority sites for further surveys and research. Research efforts focused on EMR populations at PCCI during 2004, expanding the survey area to the periphery of PCCI and west to YSRA in 2005.

Barry County has an area of approximately 150,000 ha; 62% of land is agricultural and 31% is woodland (Thoen 1990). Dairy farming dominates the livestock enterprise in Barry County and the major crops are corn, wheat, hay, and soybeans (Thoen 1990). Irrigation, drainage and reduced tillage systems are commonly used to increase farming efficiency (Thoen 1990).

The mean annual 30-year temperature in Barry County is 8.8 °C with a mean of 16.2 °C during the EMR activity season (April-October) and a mean of -1.5 °C during EMR inactive season (November-March) (Michigan Climatology 1980) (Table 1.1). The mean annual rainfall in Barry County is 79.3 cm with a mean of 54.9 cm during the active season and a mean of 24.4 cm during the inactive season (Michigan Climatology 1980) (Table 1.2). Mean annual snowfall is 7.4 cm during the EMR active season and 124.5 cm during the inactive season, with an annual average of 131.8 cm (Michigan Climatology 1980) (Table 1.2).

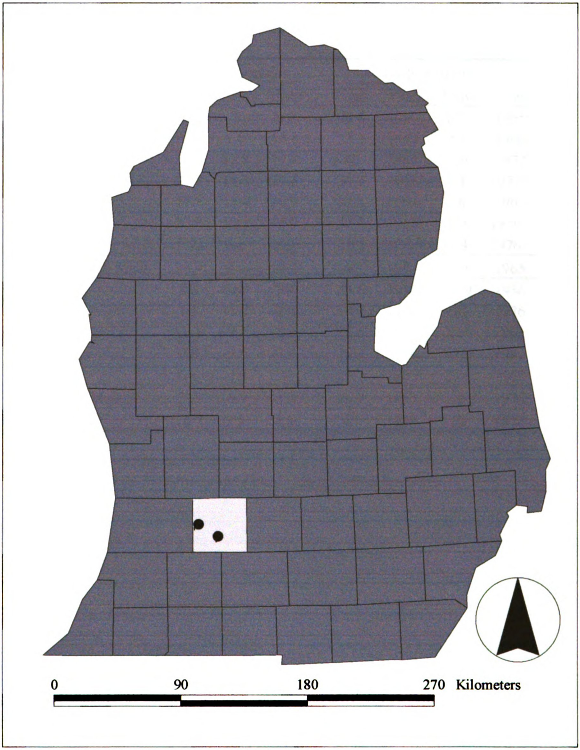

Figure 1.1. Study area location for research on the habitat ecology and population viability of the Eastern Massasauga Rattlesnake in southwestern lower Michigan at Pierce Cedar Creek Institute and Yankee Springs State Recreation Area in Barry County, Michigan.

Table 1.1. Temperature (°C) summary for Hastings, Barry County, Michigan for the 30-year period 1951-1980.

	Daily Averages			Daily Extremes			
Month	Max	Min	Mean	High	Year	Low	Year
April	14.8	2	8.4	30.6	1980	-13.9	1965
May	21.6	7.6	14.6	33.3	1953	-5.6	1966
June	26.7	12.8	19.7	40	1953	-0.6	1972
July	28.8	14.8	21.8	36.7	1955	4.4	1972+
August	27.8	13.9	20.9	37.8	1964	2.8	1965
September	23.8	10.1	16.9	37.8	1953	-2.8	1976+
October	17.2	4.4	10.8	32.2	1971+	-9.4	1976+
Activity Season Mean:	22.9	9.4	16.2	40	1953	-13.9	1965
November	8.6	-0.7	3.9	25.6	1953	-18.9	1956
December	1.5	-6.6	-2.6	18.9	1970	-30	1976
January	-1.1	-9.7	-5.4	15.6	1973+	-29.4	1961
February	0.8	-9.5	-4.4	19.4	1976	-27.8	1967
March	6.4	-4.4	1	26.7	1963	-23.9	1962
Hibernation Mean:	3.2	-6.2	-1.5	26.7	1963	-30	1976
Annual Mean:	14.7	2.9	8.8	40	1953	-30	1976

+ = Similar extreme on earlier dates

From: http://35.9.73.71/stations/3661/tmp1_nm.txt Michigan State Climatologist's Office

Table 1.2. Precipitation summary for Hastings, Barry County, Michigan for the 30-year period 1951-1980.

	Liquid Equivalent (cm)			Snowfall (cm)		
		Max Daily			Max Total Depth	
Month	Mean	Amount & Year		Mean	Amount & Year	
April	8.1	7.2	1975	6.6	33	1975+
May	7	4.7	1957	0	0	0
June	10	8	1978	0	0	0
July	7.1	5.9	1957	0	0	0
August	8	6.7	1958	0	0	0
September	7.9	8.1	1973	0	0	0
October	6.8	7.1	1954	0.8	10.2	1967
Active Season:	54.9	8.1	1973	7.4	33	1975+
November	5.9	3.7	1968	13	17.8	1978
December	5.3	3.5	1971	28.7	22.9	1973+
January	4.4	3.5	1978	37.6	68.6	1978
February	3.5	5.6	1954	24.9	61	1978
March	5.3	5.5	1954	20.3	35.6	1978+
Hibernation Season:	24.4	5.6	1954	125	68.6	1978
Annual:	79.3	8.1	1973	132	68.6	1978

+ = Similar extreme on earlier dates

From: http://35.9.73.71/stations/3661/prec_nm.txt Michigan State Climatologist's Office

PCCI consists of approximately 300 ha (PCCI 2004) and is located in Sections 19 and 30, T 02 N, R 08 W, Barry County. Public hiking trails traverse the property, which is managed as a preserve. The property is also used for outdoor education and several college-level research studies. Upland areas at PCCI include hay fields, fallow fields, young second growth forests, and mature beech-maple (*Fagus grandifolia-Acer spp.*) forest and oak (*Quercus spp.*) forest and approximately 12 ha of recently constructed tallgrass prairie (PCCI 2004). Wetlands at PCCI include tamarack (*Larix laricina*) swamp forests, white cedar (*Thuja occidentalis*) swamp forests, mixed hardwood swamp forests, marsh wetlands, bog, and fen (PCCI 2004). The PCCI property was not bordered by barriers (e.g., roads, expansive forest) other researchers believe may impair snake movements (Kjoss 2000, Sage 2005) (Figure 1.2).

Yankee Springs State Recreation Area is located in T 3 N, R 10 W. Foot trails, horse trails, bike trails and the North Country Trail all meander through the Game and Recreation Area. Selected areas within YSRA are open to hunting including the study site. The study site at YSRA was Section 27 of T 3 N, R 10 W, in Barry County and was called the "Hall Lake Fen". This area consists of habitat types including lowland deciduous forest, lowland shrub, upland conifer, upland field, upland deciduous forest, and upland mixed forest (MDNR 2003).

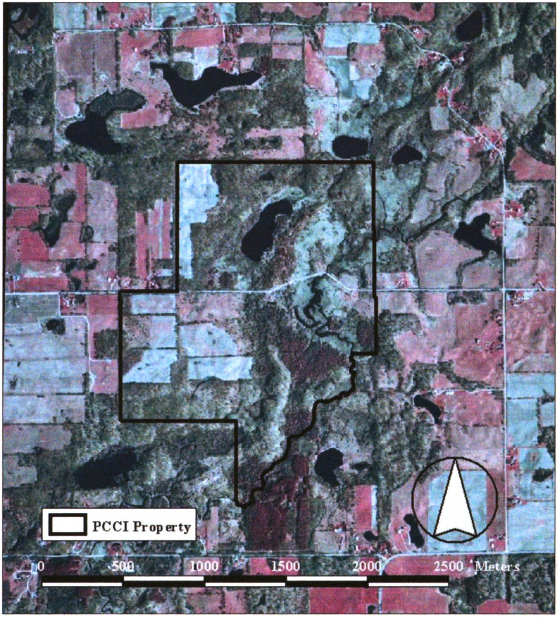

Figure 1.2. Pierce Cedar Creek Institute (PCCI) property in Barry County, Michigan, shown on a 1998 U.S. Geological Survey digital orthophoto quadrangle.

CHAPTER 1: Movement and habitat use patterns of Eastern Massasauga Rattlesnakes in southwestern lower Michigan.

INTRODUCTION

Studies focusing on the movement and habitat use patterns of EMRs are limited for Michigan populations, and throughout the entire EMR range. It is essential that managers understand movement and habitat use patterns of declining species to make sound conservation planning decisions. It has been widely accepted that EMRs occur in disjunct populations throughout the subspecies' range (Reinert and Kodrich 1982, Gibbs 1999, Kingsbury 2002) that encompass broad population variation. Although several generalizations can be made about EMR natural history across its range, EMR movement and habitat selection patterns may differ among these disjunct populations, requiring research focus at the local scale to develop a statewide conservation plan for the EMR in Michigan.

EMRs have been reported to travel mean daily distances of 9.1 m in Pennsylvania (Reinert and Kodrich 1982), 56 m in Ontario, Canada (Weatherhead and Prior 1992), 13.1 m in Illinois (Phillips et al. 2002), and 14.6 m in southeastern lower Michigan (Sage 2005); with a maximum of 1438 m in Ontario, Canada and a minimum of 0 m in every location. The 95% fixed kernel home range, or activity range, reported for a population of EMRs averaged 7.4 ha in New York (Johnson 2000), 6.2 ha in southeastern lower Michigan (Sage 2005), and 3.3 ha for a population in Illinois (Phillips et al. 2002). The mean minimum convex polygon (MCP) home range for EMRs in Indiana, Pennsylvania and Ontario, Canada were 1.0 ha (Kingsbury et al. 2003), 1.0 ha (Reinert and Kodrich 1982), and 25 ha (Weatherhead and Prior 1992), respectively. EMRs in Michigan are thought to have very different movement patterns throughout the state (B. Kingsbury, Indiana-Purdue University at Fort Wayne (IPFW), personal communication).

Although movement patterns evidently vary among populations of EMRs, there seems to be a consensus among researchers on the timing of the activity season and selection of hibernacula of EMRs across their range. Mauger and Wilson (1999) determined an activity season from early April to mid-October for EMR in Illinois; this is the activity season I defined for EMRs in southwestern lower Michigan. This activity season is generally uniform throughout the EMR's range (Wright 1941, Reinert and Kodrich 1982, Seigel 1986, Weatherhead and Prior 1992, Philips et al. 2001, Kingsbury 2002). The use of crayfish burrows as hibernacula was also described, and crayfish burrows seem to be preferred by EMRs.

General habitat use, seasonal movement and activity patterns have been described for the subspecies in various parts of its range. However, habitat use has mainly been presented as qualitative descriptions of vegetation types without reference to a particular classification system and resource use has rarely been compared to resource availability. The vegetation types described as preferred EMR habitat vary among populations across the EMR range. For example, EMRs studied in Canada used upland conifer forests (dominated by *Thuja occidentalis*, *Abies balsamea*, *Picea glauca*, and in some areas *Pinus banksiana*) (Weatherhead and Prior 1992), whereas snakes in Illinois appeared to prefer grasslands (old field and prairie dominated by *Solidago sp., Bromus sp., Poa sp., Andropogon gerardii, Sorghastrum nutans, Calamagrostis canadensis, Spartina pectinata, Danthonia spictata,* and *Carex sp.*) (Mauger and Wilson 1999). It is important to classify these vegetation types used by EMRs based on a standard classification accessible to and utilized by land managers and quantify vegetation use while considering the vegetation types available. The specific objective for this part of the project was to quantify movement and habitat use patterns of EMRs in southwestern lower Michigan.

METHODS

Capture, Telemetry, and Implant Procedures

Capturing, handling, and marking procedures were reviewed and approved by the Michigan State University All-University Committee on Animal Use and Care (Application #: 03/04-040-00). All procedures were carried out under Scientific Collector's Permits issued by the Michigan Department of Natural Resources Fisheries Division (Dates Issued: 12/03/2003, 3/22/2005, and 3/24/2006).

Researchers searched for snakes during the spring and summers of 2004 and 2005 by traversing vegetation types within the study area that were believed to support EMRs. Search efforts were concentrated in open to semi-open canopy vegetation when temperatures were between 10 and 27 °C, and winds were <24.1 kilometers/hour (Casper et al. 2001). Searches for snakes began in early May and were conducted through the first week of August or until all transmitters were used.

Locations of EMR capture sites were recorded using a Garmin® global positioning system (GPS) unit (Garmin International Inc., Olathe, Kansas). Captured snakes were cradled with a snake hook, or gently grasped with Gentle Giant® snake tongs (Midwest tongs.com, Greenwood, Missouri). EMRs were then placed in a medium-sized snake bag (Midwest tongs.com, Greenville, Missouri) and weighed with a spring scale. Individuals that weighed ≥100 g were considered acceptable for transmitter implantation because the smallest transmitters weighed 5 g (Holohil Systems Ltd., Carp, Ontario, Canada) and EMRs in this study were not implanted with any transmitters weighing >5% of the snake's body weight (Samuel and Fuller 1996, Parent and Weatherhead 2000).

Prior to radio transmitter implantation, EMRs were "tubed" by guiding them into a clear plastic tube (Midwest tongs.com, Greenwood, Missouri) that was slightly larger than the snake and grasping the snake so that it could not crawl further once two thirds of the body was inside the tube. Tubing allowed researchers to safely sex snakes using cloacal probing (Schaefer 1934), measure total and tail length, and clip a ventral scale for genetic analysis (Casper et al. 2001). This procedure was done in the field if the snake was not eligible for transmitter implantation; otherwise, it was done at the time of surgery. In 2005, snakes that were not included in the telemetry study were injected with passive, integrated transponders (PIT tags) (AVID® Identification Systems, Norco, California) in the field. The injection site was cleaned with chlorhexidine and alcohol solution and lidocane gel was applied as a local anesthetic and PIT tags were subcutaneously implanted in the dorsal region caudal to the cloaca. This method of marking is preferred for snakes and has no demonstrable impact on growth or movement (Casper et al. 2001, Jemison et al. 1995). Neonates did not receive PIT tags because they were considered too fragile by some researchers for any current implantation method (Jemison et al. 1995, Parent and Weatherhead 2000). In 2004 and 2005, EMRs with transmitter implants were given PIT tags during surgery.

EMRs to receive transmitters were transported to Potter Park Zoo (PPZ) Veterinary Clinic in Lansing, Michigan in a medium-sized snake bag in a cooler for holding (~1.5 hrs). Using a cooler to transport snakes allowed for better temperature retention than a bucket (T. Harrison, DVM, MPVM, Potter Park Zoo, personal communication).

Fecundity, Sex Structure, and Age Structure

Litter size per gravid female was determined by counting the maximum number of neonates at a parturition site in 2004. In 2005, ultrasounds and radiographs were conducted for EMRs. Researchers counted the number of offspring observed on the developed radiographs and the ultrasound monitor and recorded observations. Researchers decided which viable offspring count was more accurate based on the clarity of the image and level of confidence in the count. These counts were used to define the litter sizes for EMRs in 2005 because they were considered to be more accurate estimates than counting neonates at a parturition site (where all neonates were not necessarily visible at one time).

Sex and age structure were estimated as ratios using all EMR observations (including individuals that were not radio-tracked) at PCCI. There were not enough snake observations at YSRA to estimate sex and age structure and snakes at YSRA were not included in the estimate for PCCI because these populations were completely separate.

Surgery and Recovery Procedures

Snakes were allowed to rest in quarantine at PPZ Veterinary Clinic on the day of arrival and were not fed prior to surgery. The next morning, the PPZ Veterinarian surgically implanted radio transmitters (Advanced Telemetry Systems, Inc., Isanti, Minnesota and Holohil Systems Ltd., Carp, Ontario, Canada) in the body cavity of the snakes.

The transmitter implant surgery followed the procedures described by Reinert and Cundall (1982) and Weatherhead and Anderka (1984) as modified by B. Kingsbury

(IPFW) and T. Harrison (PPZ). Modifications included the use of isoflurane as an inhalant anesthetic, use of a small animal anesthesia machine (SurgiVet, Waukesha, Wisconsin), no refrigeration of snakes, use of a heating pad during surgery, use of plastic catheters for antenna placement, shortening of transmitter antennas so that the wire stopped caudal to the heart of the snake, implantation of transmitters in peritoneal cavity without cutting through ribs, two layers of sutures with introverting sutures and surgical glue used to close the skin, and administration of antibiotics and pain medication. On the day of surgery, snakes were "tubed" and the tube was connected to a Bain's anesthetic tubing through which isoflurane was administered via a small animal anesthesia machine. Once snakes were unresponsive to stimuli and lost their righting reflex, they were determined to be at an adequate level of anesthesia. Snakes were maintained under anesthesia using a mask connected to the anesthesia unit and the snake tube. Heart and respiratory rate were visually monitored during anesthesia. While under anesthesia, EMRs were placed on a covered heating pad to regulate body temperature. The incision was made about two thirds of the way down the body and three scale rows up from the ventral scutes. Reaching ventrally, the body wall (ribs and intercostals) was lifted and an incision was made in the peritoneum, large enough to insert the transmitter (5 g or 8 g, depending on the size of the animal). A plastic catheter was used to guide the whip-antenna of the transmitter subcutaneously towards the head of the snake. The antenna was cut to an appropriate length so that it would not extend past the heart (this would decrease the range of the transmitter; however, it decreases the risk of compromising the heart in the case of complications). Once the transmitter was in place, the peritoneum was sutured, the skin was closed using introverting sutures, and surgical glue was used to further close the incision. PIT tags were injected subcutaneously while snakes were under anesthesia and the injection site was sealed with surgical glue. After surgery, EMRs received antibiotics (Baytril, 10mg/kg intramuscularly) and pain medication (Ketoprofen, 0.5 mg/kg intramuscularly).

In 2005, radiographs and ultrasounds were done for all radio-tagged EMRs. These techniques were useful in confirming the sexual status of EMRs, determining the reproductive potential of gravid EMRs more accurately, determining the reproductive cycles of females, and for comparing the estimated number of young to the actual observed number of young at parturition sites. Most snakes were recovering from anesthesia when radiographs were taken so some snakes did not need to be held in place. Those that were more active were tubed and the tube and snake were taped to the film cartridge for the radiograph. Snakes were placed in an enclosure for recovery after radiographs were taken. Radiographs were developed and examined by researchers and the number of embryos counted was recorded. EMRs were taken to the Michigan State University Veterinary Clinic for ultrasounds performed by a professor of Veterinary Medicine. EMRs were always fully awake and tubed for ultrasounds. Researchers counted the number of offspring on the monitor and recorded observations. Researchers decided which viable offspring-count was more accurate based on the clarity of the image and level of confidence in the count.

All individuals were held for recovery in plastic enclosures (61 cm x 33 cm, Neodesha Plastics Inc., Neodesha, Kansas) at the PPZ Veterinary Clinic for 3-7 days. Enclosures contained water, paper bedding, and two thermometers, to monitor the temperature on either side of the cage and to ensure that a temperature gradient of 20 to

32 °C was offered. Lamps with 60-watt bulbs provided heat and direct light to the cage from 0800 to 2000 hours. Cages were washed with Chlorhexidine solution before and after containing a snake.

The PPZ veterinarian or zoo staff monitored snakes at least 3 times per day post-operation. A post-operation monitoring procedure was used to evaluate potential pain, recovery from anesthesia, evidence of infection, and behavior (Appendix A). Once snakes were fully recovered, usually within 3 days post-surgery, they were released at their point of capture. All snakes were released by the second week of August and no more were captured so that they had time to heal before hibernation (Rudolph et al. 1998). In 2005, EMRs from the 2004 field season that could be re-captured were taken to PPZ for transmitter-replacement. The surgical procedure followed the same methods as above, except the old transmitter was removed. Snakes may undergo replacement surgeries several times with no demonstrable effects on health (Reinert 1992). In spring of 2006, any EMRs remaining in the study that could be recaptured had radio-transmitters surgically removed and were released at their point of capture.

Radio-Tracking

Movement and habitat use patterns were quantified using radiotelemetry. All EMRs fitted with transmitters were tracked and located daily during one of three 8-hour time periods (0000-0759, 0800-1559, 1600-2359) to quantify diurnal and nocturnal movement patterns. Snake locations were recorded with a GPS unit in Universal Transverse Mercator (UTM) coordinates. To keep location error similar among nearby locations, subsequent locations were recorded as distances (m) and bearings (°) (measured using a meter tape and a compass) from the former GPS-recorded location to the new locations. This was done if the new location was 2-30 m from the last GPS location. When snakes were within 2 m of a former location, it was recorded as that location. Locations were recorded using the GPS unit once the snake moved farther than 30 m from the previous GPS location, if there was too much vegetation between the previous GPS location and the new location for distance and bearing measurements, or if the EMR was located in a different vegetation type than the former location. This method is a modification of that described by Parent and Weatherhead (2000). These locations were converted into point shapefiles in ArcView 3.2 geographical information system (GIS) (Appendices C and D). Radiotelemetry point locations were related to land cover data to determine habitat use and availability using GIS. Home ranges were derived for each snake from the point files using the Animal Movement Program (Hooge et al. 1999).

To classify the vegetation type of the stands occupied by EMRs on a daily basis, an ecological classification system (ECS) was devised (Table 1.3). This ECS was tailored to coincide with the non-forested compartment map descriptions being developed by the Michigan Department of Natural Resources (MDNR) (C. Hanaburgh, Wildlife Biologist; personal communication). The ECS was used because it takes into account hydrological, geological, and successional attributes of the vegetation types in the study areas, while generalizing vegetation to deciduous or coniferous, based on the dominant overstory species present. As an example, stands with saturated soils, sedges and wetland plant species in the understory, deciduous dominant overstory species, and a canopy consisting of shrub species were classified as a mid-successional deciduous wetland

(W/D-M) according to this system (Table 1.3). The Integrated Forest Management Analysis Program/Gap Analysis Program 2001 Land Cover, Land Use (IFMAP LCLU) (MDNR 2003) types can also be placed into this ECS (Table 1.4). However, stands classified according to this ECS were defined by researchers on the ground; therefore, it more accurately describes the successional stage and structure available to EMRs than the IFMAP LCLU data, although it is more general when defining the vegetation type at a particular point.

Movement Patterns and Analysis

Minimum, maximum, and mean daily distances traveled were summarized for each individual using the location statistics from the movement menu in the Animal Movement Program (Hooge et al. 1999). Significance testing for EMR movements was done using Wilcoxon Rank Sum where appropriate based on data normality in SAS 9.1 (2003).

Home range size and utilization distribution (UD) for EMRs were estimated using fixed kernel home range estimator in the Animal Movement Extension for ArcView 3.2 (Hooge et al. 1999). The fixed kernel estimator was used because the home range extent often stabilizes with $\leq$ 50 location points, it is less sensitive to autocorrelated data, it calculates the home range boundaries based on the complete utilization distribution, it is nonparametric, it calculates multiple centers of activity, and it is less sensitive to outliers than estimators like MCP (Kernohan et al. 2001). The fixed kernel method is considered to have lower bias than adaptive kernel because it does not attach more uncertainty to outer locations (Kernohan et al. 2001). Since every location point for EMRs is certain, fixed kernel is ideal because it does not attach more uncertainty to boundary points. For

Table 1.3. Ecological classification system used to describe the vegetation stands in which each Eastern Massasauga Rattlesnake was located daily in southwestern lower Michigan.

Class		Type	Succession			Abbreviation
Wetland	Fen	Herbaceous	Early	Mid	Late	WF/H- E,M,L
Wetland	Fen	Shrub	Early	Mid	Late	WF/S- E,M,L
Wetland	Sedge/Forb	Deciduous	Early	Mid	Late	W/D- E,M,L
Wetland	Sedge/Forb	Coniferous	Early	Mid	Late	W/C- E,M,L
Upland	Grass/Forb	Deciduous	Early	Mid	Late	U/D- E,M,L
Upland	Grass/Forb	Coniferous	Early	Mid	Late	U/C- E,M,L
Upland	Develop	N/A	N/A	N/A	N/A	U/Dev- E,M,L

Table 1.4. Placement of the Integrated Forest Management Analysis Plan/Gap Analysis Plan Land Cover, Land Use types into the ecological classification system (ECS) developed by researchers for the study on Eastern Massasauga Rattlesnake habitat ecology and population viability in southwestern lower Michigan.

IFMAP Land Cover / Land Use Classification	Corresponding ECS Class
Low Intensity Urban	Develop (N/A)
High Intensity Urban	Develop (N/A)
Airport*	
Road / Parking Lot	Develop (N/A)
Non-vegetated Farmland	Upland Deciduous (E/M)
Row Crops	Upland Deciduous (E/M)
Forage Crops / Non-tilled Herbaceous Agriculture	Upland Deciduous (E/M)
Orchards / Vineyard / Nursery*	Upland Deciduous (M)
Herbaceous Openland	Upland Deciduous (E/M)
Upland Shrub / Low-density Trees	Upland Deciduous (E/M)
Parks / Golf Courses	Develop (N/A)
Northern Hardwood Association	Upland Deciduous (L)
Oak Association	Upland Deciduous (L)
Aspen Association	Upland Deciduous (L)
Other Upland Deciduous	Upland Deciduous (L)
Mixed Upland Deciduous	Upland Decid or Conif (L)
Pines	Upland Coniferous (L)
Other Upland Conifers	Upland Coniferous (L)
Mixed Upland Conifers	Upland Coniferous (L)
Upland Mixed Forest	Upland Coniferous (L)
Water	Class surrounding water
Lowland Deciduous Forest	Wetland Deciduous (L)
Lowland Coniferous Forest	Wetland Coniferous (L)
Lowland Mixed Forest	Wetland Decid or Conif (L)
Floating Aquatic	Wetland Deciduous (E/M)
Lowland Shrub	Wetland Deciduous (E/M)
Emergent Wetland	Wetland Deciduous (E/M)
Mixed Non-forested Wetland	Wetland Deciduous (E/M)
Sand / Soil*	
Exposed Rock*	
Mud Flats*	
Other Bare / Sparsely Vegetated*	

* Land cover class did not occur with in the study area

the sake of comparison with previous EMR studies (e.g., Reinert and Kodrich 1982, Weatherhead and Prior 1992), minimum convex polygon home ranges were also calculated using the previous program in GIS.

Home range was estimated as the area within a 95% probability polygon and centers of activity were estimated as the area within a 50% probability polygon. The least squares cross validation (LSCV) method was used to calculate the bandwidth for each home range estimated using the fixed kernel analysis. LSCV is considered to produce an unbiased bandwidth for the input data and is currently recommended despite some disadvantages, such as producing a bandwidth of 0 if too many locations are near the same point (essentially indicating that the method has failed in calculating a utilization distribution) and clumping of utilization distributions can be problematic depending on the biology of the animal (Kernohan et al. 2001). However, the number of locations recorded for each home range produced was high enough to negate these disadvantages (≥30 locations per individual during the active season), and LSCV was never <2. Clumping was not an issue for this species because it represents the sedentary nature of some individuals in the study.

Site fidelity was examined for individuals that were in the study during 2004 and 2005 field seasons. The 2004 and 2005 95% fixed kernel home ranges were intersected in ArcView 3.2 and percent overlap was calculated for each of the individuals to determine if there was some fidelity to space use.

Resource Selection and Habitat Use

Fixed kernel home ranges were used to describe habitat use patterns based on associations to land cover IFMAP LCLU (MDNR 2003) supplemented with vegetation classification data collected in the field. Use of IFMAP LCLU (MDNR 2003) data was beneficial because it was available as georeferenced grid within GIS and is often used by the MDNR for various management activities. However, accuracy of the IFMAP LCLU (MDNR 2003) classifications ranged from 60-88% (Space Imaging 2004). Although there are concerns with accuracy, I believe the IFMAP LCLU (MDNR 2003) data was suited for use in calculation of a resource selection function (RSF) because I was able to correct mislabeled grid cells based on field observations in the study area.

An RSF was used to determine if vegetation types were selected disproportionate to availability. Calculations for the RSF were done in Microsoft Excel. Telemetry locations for individual EMRs within their 95% fixed kernel home ranges were intersected with IFMAP LCLU (MDNR 2003) to quantify the proportion of vegetation types used in ArcView GIS (Figure 1.3). Available vegetation types were defined as the proportion of the individual's 95% fixed kernel home range composed by each cover type in ArcView GIS (Figure 1.3). These proportions of used and available vegetation types were compared to determine Johnson's (1980) third order selection. This was the only order of selection examined because defining availability of vegetation types for home ranges of individual EMRs would have required imposing fixed boundaries for analysis and defining areas as available without any real justification. If the study area were restricted, bounded by barriers to EMR movements, Johnson's (1980) second order selection would have been examined as well.

Centers of vegetation use by all EMRs at PCCI were examined by developing a 95% and 50% fixed kernel utilization distribution for the study population using all radio-tracked EMR locations at PCCI from 2004 and 2005. Composition of the utilization

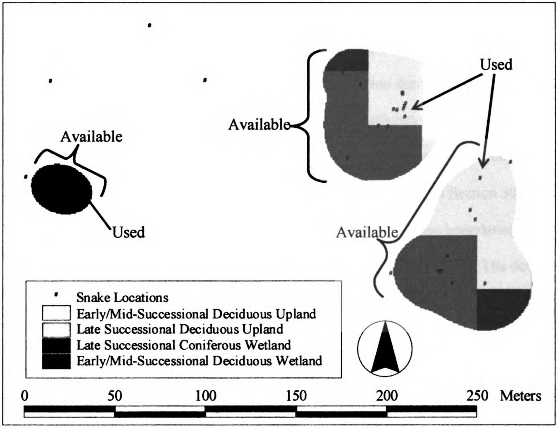

Figure 1.3. Point locations of a radio-tracked Eastern Massasauga Rattlesnake (EMR) and the area of vegetation classes within the 95% fixed kernel home range (FKHR) developed using those locations were used to define vegetation use and availability. The number of point locations observed within each vegetation type within the FKHR is the observed count for use of that vegetation type. The proportion of each vegetation class within the FKHR is the percent available (relative frequency) to that EMR.

distribution was calculated by intersecting the utilization distribution with IFMAP LCLU (MDNR 2003) to quantify the proportion of vegetation types used by EMRs at PCCI.

The resource selection for the EMR study population during 2004 and 2005 was calculated with the composition of the 95% fixed kernel utilization distribution defined as the used vegetation types while available vegetation types were defined by half sections (T 02 N, R 08W, South ½ of Section 19 and North ½ of Section 30) buffering the utilization distribution for the study population. These boundaries were determined based on property ownership, management, and composition. The defined area is owned by PCCI and is managed as a preserve with goals of maintaining and restoring native ecological communities. This boundary is centered on the Pierce Cedar Creek and associated wetlands and upland matrix where EMRs were found by researchers and is thought to represent areas available to EMRs at PCCI. However, the defined "landscape" does not include all of the PCCI property.

Temporal patterns in habitat use were examined by graphing the percent of locations within vegetation classes over time (months). The percent of locations recorded within each of the three time periods defined earlier were also graphed throughout time (months) for all vegetation classes lumped together and separate. Patterns were compared visually and movement data was also taken into consideration when interpreting the output.

RESULTS

Capture

In 2004, 12 EMRs were captured at PCCI and were surgically implanted with radio-transmitters between May 11 and July 11, 2004. Additional EMRs that were caught after all of the transmitters were implanted, or those not eligible for surgery (i.e., too small for implant, found too late in season, escaped capture), were caught from May 11 through August 25, 2004. Of the 12 radio-tagged EMRs, 10 were adult females (5 of which were gravid), 1 was a juvenile non-gravid female, and 1 was an adult male.

In 2005, 18 EMRs (16 at PCCI and 2 at YSRA) were radio-tagged between April 9 and August 3, 2005. Four of the EMRs radio-tracked at PCCI in 2004 were recaptured and radio-tracked in 2005. Additional EMRs that were not radio-tagged were caught from May 20 through August 24, 2005. Of the snakes tracked in 2005, 12 were adult females (10 of which were gravid), 2 were juvenile females, 3 were adult males, and 1 was a juvenile male. Two of the individuals captured at PCCI were not included in movement and habitat use analysis because they died early in the study (1 was only relocated once and the other had health complications and the data prior to death was not considered representative).

Data were recorded on 23 (19 in 2004 and 4 in 2005) additional EMRs that were captured and observed during the active seasons but not radio-tracked. Data collected on these individuals included geographic location, vegetation class, microhabitat conditions, activity, sex, weight, length, and age. When possible and appropriate, these additional EMRs had ventral scales clipped and stored as genetic samples and PIT tags were injected to uniquely identify snakes.

When researchers were deliberately searching specific areas for EMRs, the average time to find an EMR on successful search events was approximately 2 hours. However, not all search events were successful, 50% of search events at PCCI and YSRA were unsuccessful in finding EMRs. Unsuccessful search events lasted an average of 3 hours. However, EMRs were not always actively sought out when found. Many EMRs were found opportunistically (i.e., found while walking out to a site, found with a radio-tracked snake, or found with a tip from someone else on the property).

Fecundity, Sex Structure, and Age Structure

Mean litter size for gravid female EMRs was 9 individuals. The maximum litter size was 12 individuals. One gravid female in 2004 was also determined to be gravid in 2005, with use of ultrasonography. This would be the first record of annual reproduction for a female EMR in Michigan. Although 2 embryos were visible within the female, only one had a heartbeat. However, no neonates were observed at a parturition site in the field, but vegetation cover could make it very difficult to locate 1 neonate. The smallest viable litter size observed in the field was 4 individuals. The mean parturition date for gravid females from both years was August 17.

The mean male to female ratio at PCCI was 1:1.6. The mean adult male to female ratio was 1:2.6. The mean neonate to subadult to adult ratio was 4.2:1:2.4. Mean gravid female to non-gravid female ratio was 1:0.9.

Movement Patterns

The total distances traveled during an activity season ranged from 235.2 m to 5369.3 m with a mean of 1334.1 m traveled during the activity season (Table 1.5). Males

Table 1.5. Total distance (m) traveled by radio-tracked Eastern Massasauga Rattlesnakes during the activity season of 2004 and 2005 in Barry County, Michigan.

Reproductive Status	n	Observations	Mean	Min	Max	SE
Gravid	14	1105	1013.7[A*]	338.2	2561.6	378.2
Non-gravid	9	642	977.8[A]	235.2	1887.7	296.5
Male	5	238	2872.6[B]	955.9	5369.3	937.6
All EMRs	28	1985	1334.1	235.2	5369.3	902.0

*Means with the same letter were not significantly different from each other ($\alpha = 0.10$, Wilcoxon Rank Sum).

traveled greater total distances during the activity season than gravid females traveled ($p < 0.01$, $\alpha = 0.10$) and non-gravid females ($p < 0.01$, $\alpha = 0.10$). There was no difference between gravid and non-gravid female total distance traveled during the active season ($p = 0.46$, $\alpha = 0.10$) or prior to parturition ($p = 0.13$, $\alpha = 0.10$), with mean parturition date of August 17 used for non-gravid females. Total distance traveled between years for gravid females and non-gravid females was not different ($p = 0.40$, $p = 0.35$, $\alpha = 0.10$); therefore, data were pooled across years.

The mean distance traveled by EMRs per day was 11.8 m (Table 1.6). Male and gravid female mean daily distances traveled were different ($p < 0.01$, $\alpha = 0.10$) as were male and non-gravid female daily mean distances ($p < 0.01$, $\alpha = 0.10$) with males traveling farther distances per day than females. No difference was found between the mean daily distance traveled by gravid and non-gravid females during the activity season ($p = 0.49$, $\alpha = 0.10$) or prior to parturition ($p = 0.16$, $\alpha = 0.10$). The mean distance traveled per day by EMRs was not different between 2004 and 2005 for gravid females ($p = 0.50$, $\alpha = 0.10$) or non-gravid females ($p = 0.50$, $\alpha = 0.10$); therefore, the data were pooled across years.

The maximum daily distance moved was 315.6 m by a male (Table 1.7). The maximum daily distances moved by males were longer than the maximum traveled by gravid females ($p = 0.02$ $\alpha = 0.10$) and non-gravid females ($p = 0.02$, $\alpha = 0.10$). No difference was found for the maximum daily distance traveled during the activity season ($p = 1050$, $\alpha = 0.10$) or prior to parturition ($p = 0.3323$, $\alpha = 0.10$). The maximum daily distance traveled by EMRs was not significantly different between 2004 and 2005 for gravid females ($p = 0.3970$, $\alpha = 0.10$) or non-gravid females ($p = 0.3543$, $\alpha = 0.10$);

Table 1.6. Mean distance (m) traveled by radio-tracked Eastern Massasauga Rattlesnakes per day during the activity season of 2004 and 2005 in Barry County, Michigan.

Reproductive Status	n	Observations	Mean	Max	SE
Gravid	14	1105	7.1^{A*}	12.0	1.0
Non-gravid	9	642	7.6^{A}	17.2	3.6
Male	5	238	20.8^{B}	30.2	1.7
All EMRs	28	1985	11.8	30.2	4.6

*Means with the same letter were not significantly different from each other ($\alpha = 0.10$, Wilcoxon Rank Sum).

Table 1.7. Maximum distance (m) traveled by radio-tracked Eastern Massasauga Rattlesnakes per day during the activity season of 2004 and 2005 in Barry County, Michigan.

Reproductive Status	n	Observations	Mean	Max	SE
Gravid	14	1105	60.3^{A*}	147.8	21.2
Non-gravid	9	642	40.1^{A}	77.1	11.4
Male	5	238	198.8^{B}	315.6	52.4
All EMRs	28	1985	99.7	315.6	71.8

*Means with the same letter were not significantly different from each other ($\alpha = 0.10$, Wilcoxon Rank Sum).

therefore, data were pooled across years.

Home Range

Two EMRs radio-tracked in 2005 were not included in the home range analyses due to insufficient data. Mean 95% fixed kernel home range size for all EMRs included in analysis for both active seasons was 2.8 ha (0.1 ha to 17.3 ha) (Table 1.8). Although mean gravid female home range size was smaller than that of non-gravid females, they were not different ($p = 0.34$, $\alpha = 0.10$). Gravid female home range size was smaller than male home range size ($p < 0.01$, $\alpha = 0.10$). Non-gravid female home range size was also smaller than male home range size ($p = 0.02$, $\alpha = 0.10$).

Although home range size seemed smaller in 2004 than in 2005, fixed kernel home range size was not different between years for gravid females ($p = 0.40$, $\alpha = 0.10$) or non-gravid females ($p = 0.27$ $\alpha = 0.10$). Since these data were not significantly different, data were pooled across years. The mean MCP home range size was 2.5 ha with a minimum of 0.1 ha and a maximum of 17.9 ha (Table 1.9).

Four individuals were in the study in 2004 and in 2005 (1 adult female that was gravid both years, 1 subadult female that was non-gravid both years, 1 adult female that was gravid in 2004 and non-gravid in 2005, and 1 adult male). The female that was gravid in 2004 and non-gravid in 2005 was not included in the 2005 analysis because health complications (i.e., intralesional bacterial colonization and intestinal coccidiosis and nematode parasites) (necropsy results on file, K. Bissell and H. Campa, III) may have influenced movement patterns (Appendix B). Site fidelity was evident for the other 3 individuals that were in the study during 2004 and 2005. The 95% fixed kernel home

Table 1.8. Mean 95% fixed kernel home range size (ha) calculated for Eastern Massasauga Rattlesnakes radio-tracked during the activity season of 2004 and 2005 in Barry County, Michigan.

Reproductive Status	n	Observations	Mean	Min	Max	SE
Gravid	14	1105	0.5^{A*}	0.1	1.6	0.4
Non-gravid	9	642	1.1^{A}	0.1	3.8	1.7
Male	5	238	6. 5^{B}	1.5	17.3	6.2
All EMRs	28	1985	2.8	0.1	17.3	4.1

*Means with the same letter were not significantly different from each other ($\alpha = 0.10$, Wilcoxon Rank Sum).

Table 1.9. Mean minimum convex polygon home range size (ha) calculated for Eastern Massasauga Rattlesnakes radio-tracked during the activity season of 2004 and 2005 in Barry County, Michigan.

Reproductive Status	n	Observations	Mean	Min	Max	SE
Gravid	14	1105	1.05	0.1	2.4	0.6
Non-gravid	9	642	1.13	0.1	2. 9	0.9
Male	5	238	5.33	0.1	17.3	9.0
All EMRs	28	1985	2.50	0.1	17.3	5.7

range sizes were smaller in 2004 than in 2005. Although 2005 home ranges expanded to include areas not used the previous year, each snake used at least 77.3% of their original home range (Table 1.10). The home range for the gravid female in 2004 was only 5.2% of the 2005 home range (Figure 1.4). The home range for the non-gravid female in 2004 was only 4.1% of the 2005 home range (Figure 1.5). The home range for the male in 2005 consisted of a larger portion (47.6%) of the 2004 home range (Figure 1.6).

Resource Selection and Habitat Use

A resource selection function was developed for vegetation types used by all individual EMRs at PCCI (defined as vegetation types in which snake point locations occurred) and the vegetation types available to them (defined as the area of the vegetation types within an EMR fixed kernel home range) for 2004 and 2005. Snakes in this area used herbaceous openland, oak association, and mixed non-forested wetland in greater proportions than available (Table 1.11). The most abundant vegetation types available within EMR home ranges were lowland shrub, herbaceous agriculture, and herbaceous openland. Each of the IFMAP land cover types used by EMRs more than expected were in early to mid-successional stages. Snakes most frequently used areas classified by the ECS as early successional deciduous uplands and early successional deciduous wetlands.

The 95% fixed kernel utilization distribution for the study population, developed using all of the EMR locations at PCCI (n = 1767), was composed of lowland shrub (36.1%), herbaceous openland (29.9%), and lowland deciduous forest (12.3%) (Table 1.12). The area most used by the study population, within the 50% fixed kernel core area, was primarily composed of herbaceous openland (99.6%) (Table 1.12). The 95% fixed kernel utilization distribution for the study population at PCCI during 2004 and

Table 1.10. Percent of 95% fixed kernel home range overlap between 2004 and 2005 for 3 individual EMRs radio-tracked during both years at Pierce Cedar Creek Institute in Barry County, Michigan.

Snake	Year	Observations	% Overlap with alternative home range
Gravid Female	2004	54	100.0%
Gravid Female	2005	85	5.2%
Non-Gravid Female	2004	91	100.0%
Non-Gravid Female	2005	85	4.1%
Male	2004	72	77.3%
Male	2005	87	47.6%

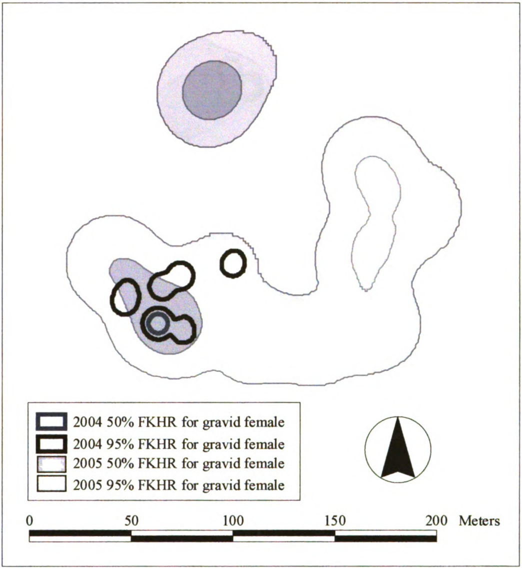

Figure 1.4. Fixed kernel home ranges (FKHR) for a radio-tracked female Eastern Massasauga Rattlesnake that was gravid in 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan.

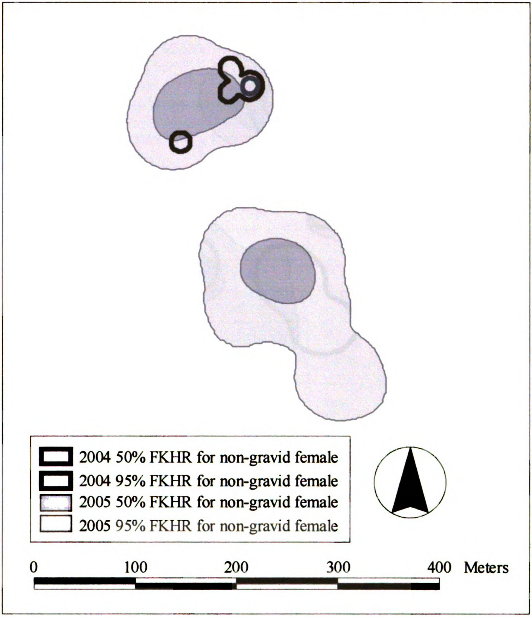

Figure 1.5. Fixed kernel home ranges (FKHR) for a radio-tracked female Eastern Massasauga Rattlesnake that was non-gravid in 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan.

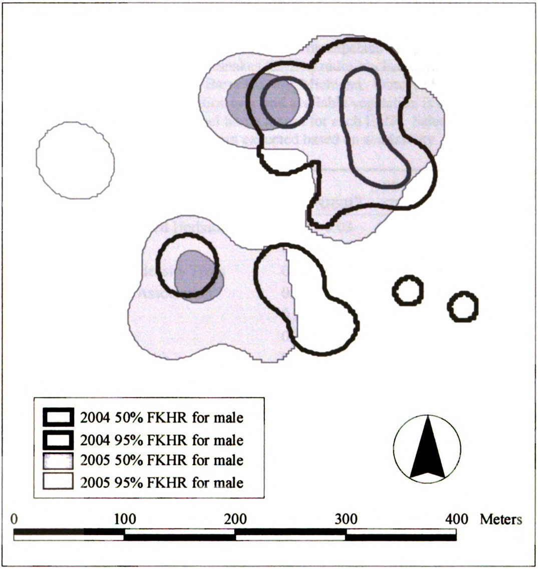

Figure 1.6. Fixed kernel home ranges (FKHR) for a male radio-tracked Eastern Massasauga Rattlesnake in 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan.

Table 1.11. Resource selection function based on expected use per availability calculated for all Eastern Massasauga Rattlesnakes (EMRs) radio-tracked during 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan. Observed use is the number of EMR locations within a vegetation type and available vegetation is the area of vegetation types within the 95% fixed kernel home ranges for each EMR. Selection is either more than expected, expected, or less than expected based on availability.

IFMAP Land Cover Type	RSF[A]	SESR[B]	L 95% CI	U 95% CI	Selection[C]
Forage Crops / Non-tilled Herbaceous Ag.	0.02	0.03	0.19	0.29	less
Herbaceous Openland	0.19	0.07	2.12	2.39	more
Upland Shrub / Low-density Trees	0.00	0.00	0.00	0.00	less
Northern Hardwood Association	0.08	0.24	0.40	1.37	expected
Oak Association	0.22	0.14	2.27	2.82	more
Aspen Association	0.13	0.52	0.43	2.51	expected
Mixed Upland Deciduous	0.00	0.00	0.00	0.00	less
Pines	0.00	0.00	0.00	0.00	less
Upland Mixed Forest	0.00	0.00	0.00	0.00	less
Lowland Deciduous Forest	0.03	0.04	0.31	0.48	less
Lowland Coniferous Forest	0.01	0.09	-0.09	0.28	less
Floating Aquatic	0.05	0.13	0.29	0.82	less
Lowland Shrub	0.07	0.03	0.75	0.88	less
Emergent Wetland	0.06	0.16	0.43	1.07	expected
Mixed Non-forest Wetland	0.14	0.25	1.15	2.15	more
Other Bare / Sparsely Vegetated	0.00	0.00	0.00	0.00	less

[A] Resource selection function (resource selection ratio / total resource selection ratio)
[B] Standard error for resource selection ratio
[C] Selection is expected if 1 is contained within the confidence interval (CI), selection is less than expected if 1 > Upper CI, and selection is more than expected if 1 < Lower CI.

Table 1.12. Percent composition of a 95% fixed kernel utilization distribution (FKUD) with 50% fixed kernel core area for the study population at Pierce Cedar Creek Institute in southwestern lower Michigan (developed using all radio-tracked Eastern Massasauga Rattlesnake locations from 2004 and 2005).

IFMAP Cover Type	% 95% FKUD	% 50% FKUD
Aspen Association	1.01	0.00
Emergent Wetland	3.13	0.00
Floating Aquatic	1.03	0.14
Forage Crops / Non-tilled Herbaceous Agriculture	3.51	0.00
Herbaceous Openland (Roads included)	29.93	99.61
Lowland Deciduous Forest	12.30	0.00
Lowland Shrub	36.13	0.25
Mixed Non-forest Wetland	1.64	0.00
Northern Hardwood Association	1.99	0.00
Oak Association	9.32	0.00

2005 was also used to calculate a resource selection function to evaluate whether the vegetation types within areas of concentrated EMR use were proportionate to availability of vegetation types in the surrounding landscape (Figure 1.7). The vegetation types that were used by EMRs more than expected based on availability were herbaceous openland, oak association, lowland deciduous forest, floating aquatic, lowland shrub, emergent wetland, and mixed non-forest wetland (Table 1.13). Again, the oak association was early to mid-successional. However, the lowland deciduous forest incorporated into the fixed kernel home range for all EMRs at PCCI during both study years was mid to late successional. All other vegetation types mentioned were early to mid-successional.

The percent of all EMR locations within each vegetation class did change throughout the season. Almost all EMRs were located in early successional deciduous uplands in April and October (Figure 1.8). During May through September, approximately half of the EMR locations were within the early successional deciduous uplands and most of the remaining snakes used early successional deciduous wetlands during these months (Figure 1.8). The most variety in vegetation type use was in July and August, however, locations within vegetation types other than the early successional deciduous uplands and wetlands were <10% of the locations recorded during those months.

Changes in the use of vegetation types among the 3 defined time periods (0000-0759, 0800-1559, 1600-2359) were not evident when graphical data was examined. The percent of locations recorded within each time period for each vegetation type were primarily related to the proportion of tracking events taking place during those time

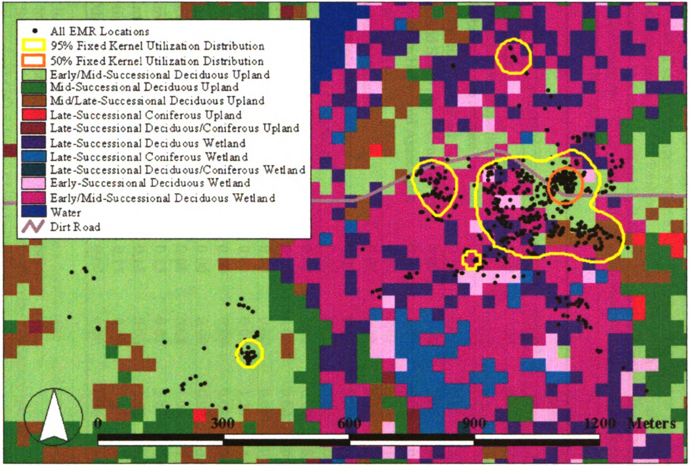

Figure 1.7. The 95% fixed kernel utilization distribution with 50% fixed kernel activity centers developed using all radio-tracked Eastern Massasauga Rattlesnake locations for 2004 and 2005 (n = 1767) overlaid on the land cover data with classifications converted to vegetation types classified according to an ecological classification system.

Table 1.13. Resource selection function based on expected use per availability calculated for the study population of Eastern Massasauga Rattlesnakes (EMRs), radio-tracked during 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan. Observed use is the area of vegetation types within a 95% fixed kernel utilization distribution (FKUD) calculated using all EMR locations. Available vegetation is the area of vegetation types within the half sections (T 02 N, R 08 W, South ½ of Section 19 and North ½ of Section 30) buffering the FKUD. Selection is either more than expected, expected, or less than expected based on availability.

Definition	RSF[A]	SESR[B]	L 95% CI	U 95% CI	Selection[C]
Row Crops	0.00	0.00	0.00	0.00	less
Forage Crops / Non-tilled Herbaceous Agriculture	0.02	0.00	0.20	0.22	less
Herbaceous Openland	0.24	0.02	3.19	3.26	more
Upland Shrub / Low-density Trees	0.00	0.00	0.00	0.00	less
Northern Hardwood Association	0.02	0.01	0.23	0.26	less
Oak Association	0.10	0.01	1.34	1.39	more
Aspen Association	0.05	0.02	0.60	0.68	less
Other Upland Deciduous	0.00	0.00	0.00	0.00	less
Mixed Upland Deciduous	0.00	0.00	0.00	0.00	less
Pines	0.00	0.00	0.00	0.00	less
Upland Mixed Forest	0.00	0.00	0.00	0.00	less
Water	0.00	0.00	0.00	0.00	less
Lowland Deciduous Forest	0.09	0.01	1.23	1.27	more
Lowland Coniferous Forest	0.00	0.00	0.00	0.00	less
Lowland Mixed Forest	0.00	0.00	0.00	0.00	less
Floating Aquatic	0.08	0.04	1.08	1.24	more
Lowland Shrub	0.13	0.01	1.83	1.86	more
Emergent Wetland	0.13	0.03	1.65	1.77	more
Mixed Non-forest Wetland	0.15	0.05	1.93	2.14	more
Other Bare / Sparsely Vegetated	0.00	0.00	0.00	0.00	less

[A] Resource selection function (resource selection ratio / total resource selection ratio)
[B] Standard error for resource selection ratio
[C] Selection is expected if 1 is contained within the confidence interval (CI), selection is less than expected if 1 > Upper CI, and selection is more than expected if 1 < Lower CI.

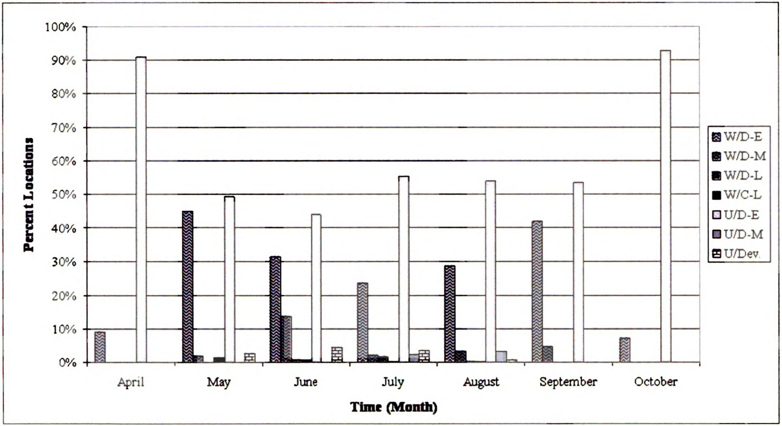

Figure 1.8. Percent locations of Eastern Massasauga Rattlesnakes radio-tracked in 2004 and 2005 at Pierce Cedar Creek Institute in Barry County, Michigan, recorded within vegetation types throughout the activity season. Vegetation types include early successional deciduous wetland (W/D-E), mid- successional deciduous wetland (W/D-M), late successional deciduous wetland (W/D-L), late successional coniferous wetland (W/C-L), early successional deciduous upland (U/D-E), mid-successional deciduous upland (U/D-M), and developed upland (U/Dev.).

periods (i.e., more tracking events took place during the 0800-1559 time period, especially when assistants were not available in fall) (Figure 1.9).

Snakes at PCCI hibernated in early to mid-successional deciduous uplands (40% in crayfish burrows, 60% in small mammal burrows) (n = 17). Most EMRs were heading towards and settling near hibernacula sites in September when the mean daily temperature for a 30-year period is 16.9 °C (Table 1.1) and practically all were using burrows in October when mean daily temperature is 10.8 °C (Table 1.1).

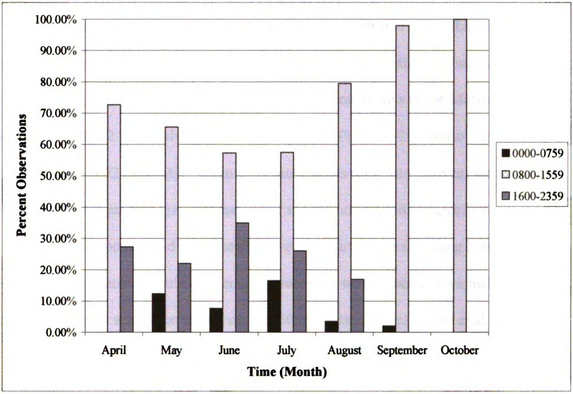

Figure 1.9. Percent of Eastern Massasauga Rattlesnakes radio-tracked during 2004 and 2005 in Barry County, Michigan, located during 3 time periods throughout the active season.

DISCUSSION

EMRs in the study area had mean daily movements of 11.8 m; this is slightly lower compared to the mean daily movements reported for EMRs in southeastern Michigan (14.6 m) (Sage 2005) and for other EMR populations in the Midwest (Reinert and Kodrich 1982 [Pennsylvania], Weatherhead and Prior 1992 [Ontario, Canada], Phillips et al. 2002 [Illinois]). Mean daily movements for males (20.8 m) were significantly longer than gravid females (7.1 m) and non-gravid females (7.6 m). This difference was documented for all male movement parameters including home range size. The difference between male and female movements was expected since male rattlesnakes must search for female mates within the landscape (Duvall et al. 1993).

Gravid and non-gravid female daily movements were expected to differ, as well. Differences in gravid and non-gravid female movement parameters were found for EMRs in New York and Indiana (Johnson 2000, Kingsbury et al. 2003). Gravid females stay fairly sedentary, spending most of their time basking during gestation and little time foraging (Keenlyne and Beer 1973, Lourdais et al. 2002, Kingsbury et al. 2003, Sage 2005), investing energy in the incubation of their offspring. Whereas, non-gravid females do not share the same energetic requirement allowing for more energy expenditure traveling and foraging and less time spent basking to incubate developing young; also, non-gravid females in estrus tend to increase movements because they are advertising for mates and perhaps harassed by males (Aldridge and Duvall 2002). For these reasons, I expected non-gravid females to have greater movement parameters than gravid females. However, there was no significant difference in the distances moved by gravid and non-gravid females in southwestern lower Michigan. Gravid females tend to increase movements after giving birth (Johnson 2000, Kingsbury et al. 2003), perhaps increasing foraging post-parturition to improve their emaciated body condition (Reinert 1981). Therefore, movement parameters were compared up to parturition for gravid females and the mean parturition date for non-gravid females. Still, there was no significant difference between gravid and non-gravid female distances moved.

Home range sizes for EMRs in the study area were also at the lower end of the scale for what is found in the literature, similar to the mean home range reported for EMRs in Illinois (Phillips et al. 2002). However, the mean was not the smallest reported. The mean 95% fixed kernel home range for EMRs in southwestern Michigan (2.8 ha) was 55% smaller than the mean home range reported for EMRs studied in southeastern Michigan (Sage 2005), and is one of the smallest reported in the literature (Weatherhead and Prior 1992, Johnson 2000). However, Reinert and Kodrich (1982) and Kingsbury et al. (2003) reported smaller mean home range size of 1.0 ha for EMRs in Pennsylvania and Indiana.

Small home range size for EMRs in southwest Michigan suggest that the life requisites that impact abundance and distribution of individuals can be fulfilled within a relatively small area (McDonald et al. 2005, Fuller et al. 2005). The PCCI property was not bordered by barriers (e.g., roads, expansive forest) other researchers believe may impair snake movements (Kjoss 2000, Sage 2005); and vegetation types selected by EMRs were available on neighboring properties (Figure 1.3). Therefore, the small home range size for EMRs at PCCI cannot be attributed to restriction. In addition, annual reproduction is occurring for at least some of the female EMRs at PCCI. This occurrence suggests that food intake and energy stores are plentiful enough for some individuals to invest in annual reproduction. The 2 EMRs radio-tracked at YSRA never left the fen vegetation type, which was bounded by a road on the north side and surrounded by predominantly late successional vegetation types. Although the EMRs may have been restricted to the site, their life requisites were met within the early successional scrub-shrub fen (including gestation and hibernation).

Vegetation types used by EMRs in southwest Michigan are similar to those described by Sage (2005) and Mauger and Wilson (1999). EMRs selected herbaceous openland and oak association early to mid-successional deciduous upland vegetation types and mixed non-forest early successional deciduous wetland vegetation throughout the activity season. EMRs selected against late successional vegetation types. This is different from the use of upland conifer forests described for EMRs in Canada (Weatherhead and Prior 1992). The frequently used vegetation types in southwestern lower Michigan were exposed to full sunlight during the day; however, provided enough structure on the ground and the midstory (mean of 70.6% live herbaceous vegetation and 89.5% dead herbaceous vegetation cover) for EMRs to find cover (see Chapter 2). Selection of these stands was most likely a result of selection for vegetation types that provide the best available thermoregulatory conditions. These particular vegetation types may also support a larger mammalian prey base than those selected less than expected based on availability, because they were early/mid-successional rather than late successional vegetation types (K. Wildman, unpublished data). Quantification of the structure of these vegetation types used will help guide habitat management for EMRs.

When all EMR locations were used to calculate one 95% fixed kernel home range, the 50% fixed kernel core area largely consisted of herbaceous openland (99.6%).

This vegetation type was selected more than expected based on availability. This is probably due to the thermoregulatory conditions provided by an early successional upland vegetation type with enough structure for suitable cover. However, there may be some bias for this vegetation type since most of the EMRs in the study were gravid females (50%) that tended to select early successional deciduous upland vegetation types; but all male EMRs in the study used this vegetation type and the minimum percent area within a male EMR home range was from 12.5% to 83.2%. Therefore, the importance of this vegetation type likely applies to all EMRs at PCCI.

The seasonal shift from approximately 90% locations in early successional deciduous uplands in early spring, to approximately 50% in uplands and 50% in early successional deciduous wetlands in the summer and a return to 90% locations in uplands illustrates the movement from and to hibernacula. EMRs had more variable vegetation use during the summer; however, all required the same conditions for hibernation.

Researchers tracked more EMRs during the 0800-1559 time period during both field seasons; and, 33.4% of all location events occurred during the evening and early morning time periods (1600-2359 and 0000-0759), which included night hours. When only one researcher was available, tracking was always done in daylight. Therefore, most night tracking was done May through the first week of August, the months when two people were usually available. However, researchers often radio-tracked EMRs during two different time periods in consecutive days to observe if they were moving out of the vegetation stand they previously occupied. It was not evident that EMRs in southwestern lower Michigan were using vegetation types at night different from those used during the day. EMRs tended to stay within the same vegetation stand used during the day. Given the fairly sedentary nature of the EMRs within the study and the fact that most EMRs stayed at or near the same location for days at a time, it is not likely that EMRs were moving into a different vegetation stand at night and returning in the morning. Often, EMRs moved into a hole or under some vegetation within the same stand at night and emerged the next morning. This demonstrates the use of microhabitat and microclimates within the occupied stand to fulfill cover and thermoregulatory requirements without exerting energy to move among alternative vegetation types every morning and night.

Hibernation occurred in early successional upland vegetation types, not in wetlands, as documented by some other researchers (Maple and Orr 1968 [Ohio], Hallock 1991 [Michigan], Szymanski 1998 [Midwest]). Some wetlands in southwestern lower Michigan, with hydric soils and plants, may be too dynamic for EMR hibernation because of fluctuating groundwater levels. Flooding (Seigel et al. 1998) as well as decreasing water levels (Dunn 1999) at hibernacula sites during hibernation could negatively impact an EMR population. However, these upland hibernation areas were adjacent to wetlands. Most of these hibernacula were in Perrinton loam, some were in Marlette loam and Thetford loamy sand; but all soil types in which EMR hibernacula were located bordered Houghton muck (Thoen 1990). These areas often had crayfish burrows available for hibernacula; however, EMRs at PCCI used small mammal burrows and crayfish burrows for overwintering. These hibernacula characteristics were similar to those described for southeast Michigan (Sage 2005). Burrow type did not seem to matter at PCCI, as long as the burrow was in an upland vegetation type adjacent to a wetland.

Site fidelity was indicated by the overlapping of home ranges for the 3 EMRs radio-tracked during both years. This site fidelity has been previously described for

EMRs (Sage 2005). There was also fidelity to the hibernation sites for 2 of the 3 EMRs. Although the same burrow was not used, EMRs returned to the same stand for overwintering. This fidelity indicates a need for conservation planning of suitable habitat conditions where EMRs are known to exist.

Eastern Massasauga Rattlesnakes in Barry County used both early successional deciduous upland and wetland vegetation types to meet their habitat requirements. These results also emphasize the requirement for adjacency between habitat types used by EMRs. Short distances moved by EMRs and small home range size suggest a preference to minimize travel while using different vegetation types to fulfill habitat requirements. Conservation efforts need to focus on managing EMR habitat in early successional stages and minimizing fragmentation between upland and wetland vegetation types which may act as barriers to movements.

CHAPTER 2: Habitat composition and vegetation structure of areas supporting Eastern Massasauga Rattlesnakes in southwestern lower Michigan and the development of a habitat suitability model.

INTRODUCTION

Very little information is available on EMR habitat relationships specifically describing the vegetation structure and composition of areas used by EMRs. General descriptions of vegetation types and their dominant species are often given for areas frequented by EMRs as the complete description of their habitat use patterns (Wright 1941, Reinert and Kodrich 1982, Weatherhead and Prior 1992, Wilson and Mauger 1999). For example, Wilson and Mauger (1999) reported one "habitat" used as old field dominated by goldenrod (*Solidago sp.*) and Eurasian grasses (*Bromus sp.*, *Poa sp.*). Although these descriptions are helpful in visualizing and defining the vegetation type, they provide little quantitative information about the structure and composition of stands used by EMRs to meet their habitat requirements. The vegetation structure and composition are factors that likely influence snake body temperature and the thermoregulatory potential for an organism in a particular stand (Anderson and Gutzwiller 2005).

Most of the previous studies on EMR habitat use patterns describe early successional vegetation types as important to EMRs (Wright 1941, Reinert and Kodrich 1982, Weatherhead and Prior 1992, Johnson and Leopold 1998); however, EMRs are also reported to use late successional forested stands throughout their range (Weatherhead and Prior 1992, Anton 1998, Johnson 2005). Differences and similarities between vegetation type structure have not been quantified.

Some researchers who have examined habitat use of EMRs and other snakes have quantified the vegetation structure and composition surrounding the exact location of the animal (Hutchinson et al. 1992, Cross and Petersen 2001, Sage 2005). While this method is helpful in identifying specific habitat features being selected as microhabitat, this information does not describe the structure and composition of the specific vegetation stands being used. This type of information may be important to land managers as they develop stand-level strategies to help conserve wildlife species.

Wildlife and land managers need decision-making tools that will help them identify habitat for a species and predict species response to changes within that habitat (Hurley 1986), especially for species and habitats considered threatened, endangered, or of special concern (Berry 1986). Therefore, structural and compositional attributes should be quantified and incorporated into habitat models to help plan and evaluate management activities.

Use of habitat suitability index models (HSI) is one modeling approach that can be helpful to guide management for a specific species (Berry 1986). These models are developed by defining critical habitat attributes and their suitability for a species. Use of these models allows managers to identify areas that could potentially support populations and the attributes of those areas that will influence those populations when changed or managed (Berry 1986). Therefore, a validated HSI model can be very useful to wildlife and land managers when making decisions and developing management plans for wildlife species.

An HSI model for the EMR would be exceptionally valuable to the conservation effort for the subspecies because it is proposed for federal listing under the Endangered

Species Act and state and federal agencies are in the process of developing a conservation plan. Conservation planning for the EMR can be difficult because there is very little structural and compositional data available for EMR habitat. Discussions among resource managers and researchers currently focus on deciding how to best manage EMR habitat. With a better understanding of the vegetation structural and compositional attributes characterizing suitable EMR habitat, options for management will be clearer.

A hierarchical HSI model could also be used as a tool to predict other areas where EMRs may occur in southwestern lower Michigan. This type of HSI model can be developed by first evaluating the composition and structure of the landscape in which a population occurs at a coarse scale, then, at a finer scale, evaluating the vegetation types used within the landscape and structure and composition of those particular vegetation types. Therefore, if the coarse scale characteristics are met, managers may continue to examine the vegetation stands at a finer scale and potentially predict and/or verify EMR presence.

The objectives for this portion of the research on EMRs in southwestern lower Michigan involved quantifying the structure and composition of vegetation stands used by EMRs and, using these results and data from the literature, developing a preliminary HSI model for EMRs within the study area.

METHODS

Vegetation Sampling

Vegetation composition and structural attributes (i.e., nine cover attributes, shrub and tree stem densities, and basal area of trees) associated with each radio-tracked snake were measured weekly or when the snake moved to a new stand (whichever came first) prior to July 15 and bi-weekly after July 15 following peak plant productivity. Frequent vegetation sampling was necessary to promote a better understanding of the temporal dynamics of EMR habitat requirements. Snake locations served as vegetation sampling points that were used to quantify critical vegetation types and their associated habitat attributes that are important to EMRs using transects and plots.

The first transect and plot were sampled 5 m away from the snake with additional sampling locations established throughout the stand (usually 15 m at a bearing of 45, 135, 225, or 315 degrees from another plot corner) (Figure 2.1). The line-intercept method (Canfield 1941) was used to measure percent vertical cover using meter tape as transects at sampling locations. Cover attributes measured were percent cover of trees and shrubs >1 m tall; trees and shrubs <1 m tall; cattails and reeds (live or dead and standing); grasses, sedges and forbs; dead herbaceous material; dead, downed, woody debris; moss and lichen; standing water; bare ground, muck, and rock. Quadrats were used to quantify stem densities of trees and shrubs 1-3 m tall and trees and shrubs >3 m tall. Diameter at breast height of trees >3 m tall was measured using a DBH tape and basal area was calculated [using the formula (π x dbh^2) / 4]. Absolute dominance of trees >3 m was calculated by multiplying the mean basal area in meters by the density in stems/ha.

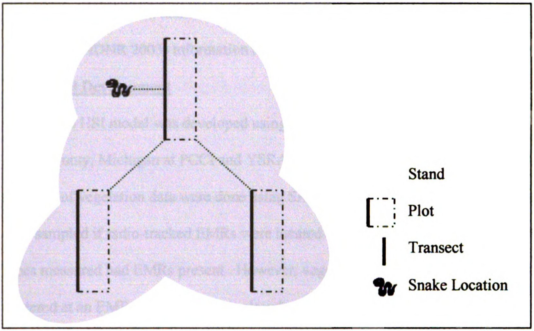

Figure 2.1. Vegetation sampling design for stands used by Eastern Massasauga Rattlesnakes where the first sample was established 5 m away from the snake location, 20-m line transects were used to quantify percent cover, and 20 m x 5 m plots were used to quantify stem densities. Additional transects and plots were then established elsewhere in the stand.

Vegetation composition and structural information supplements large-scale generalized land cover (MDNR 2003) information to refine descriptions of EMR habitat.

HSI Model Development

The HSI model was developed using vegetation data collected in the field in Barry County, Michigan at PCCI and YSRA during 2004 and 2005. All statistical analyses of vegetation data were done using SAS 9.1 (2003). Vegetation stands were only sampled if radio-tracked EMRs were located within them; therefore, all vegetation types measured had EMRs present. However, vegetation sampling was conducted either centered at an EMR location or were elsewhere within the stand. Sampling plots that were centered at the radio-tracked EMR location were defined as "presence" plots. Sampling plots that were located elsewhere within the stand were defined as "absence" plots. Therefore, these represented "presence" versus "absence" data. However, if vegetation characteristics associated with "absence" plots were not determined to be different from the characteristics associated with "presence" locations after statistical analyses were conducted, they were pooled as "presence" data because EMRs were present within the stand. Normality of data was tested; however, all data were symmetrically skewed. Therefore, Wilcoxon Rank Sum was used to compare vegetation attribute values.

Vertical vegetation attributes with values <5% cover were not used for model construction. These attributes were originally measured because they were anticipated to have a potential positive influence on EMR presence; however, they tended to be inconsequential within stands used by EMRs, and appeared sporadically and infrequently within vegetation types. Remaining vegetation attributes were further analyzed using

Wilcoxon Rank Sum to determine if there were statistical differences ($\alpha = 0.10$) between samples where EMRs were present versus absent for each vegetation attribute within each vegetation type and among all vegetation types. The most frequently used vegetation types (>10% of all vegetation samples) were selected for the model. Vegetation attributes were selected for model input if they were significant within at least one of the frequently used vegetation types sampled.

Data used to develop the production functions of the model were collected in the frequently used vegetation types; data collected in vegetation types rarely used by EMRs were excluded. Optimal values for production functions of vegetation attributes were the mean values for "presence" data. Sub-optimal/unsuitable values were defined as the range between the mean values for "absence" data and the most extreme of the "absence" values.

The proportion of area within 2 of the frequently selected vegetation types was also considered to be important to EMRs and model development; because, it has been indicated that adjacency of uplands and wetlands is important for EMR hibernation sites (Sage 2005). Therefore, production functions were developed for these vegetation types with the optimal values defined as the range between the mean percent of individual 95% fixed kernel home ranges composed of the vegetation type, and the proportion of the 95% fixed kernel home range for all EMRs consisting of the vegetation type. The natural history of EMRs was also considered when determining the structure of the HSI model; variable influences on the overall suitability value were adjusted based on how they would affect EMR life requisites (i.e., hibernation and gestation).

RESULTS

The most frequently used and sampled vegetation types were early successional deciduous uplands (58%), deciduous wetlands (32%), and scrub-shrub fen (11%). Early successional deciduous uplands were dominated by grasses, golden rod (*Solidago spp.*), wild carrot (*Daucus carota*), wild bergamot (*Monarda fistulosa*), with mid-overstory species including autumn olive (*Elaeagnus umbellate*), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*). Early successional deciduous wetlands included overstory species such as red osier dogwood (*Coruns sericea*), gray dogwood (*Cornus racemosa*), willow (*Salix spp.*), American elm (*Ulmus americana*), and tamarack (*Larix laricina*), with ground cover species including sedges (*Carex spp.*), purple loostrife (*Lythrum salicaria*), spotted Joe-Pye-weed (*Eupatorium maculatum*), Angelica (*Angelica atropurpurea*), and Cattail (*Typha latifolia*). Early successional scrub-shrub fen was dominated by shrubby cinquefoil (*Potentilla spp.*), with sedges (*Carex spp.*), ferns, rushes, Jack-in-the-pulpit (*Arisaema stewardsonii*), sphagnum moss (*Sphagnum andersonianum*), sundew (*Drosera*) ground cover and red osier dogwood (*Coruns sericea*), poison sumac (*Rhus vernix*), tamarack (*Larix laricina*), and red maple (*Acer rubrum*) in the overstory.

Other vegetation types used included mid-successional deciduous wetlands and uplands, late successional deciduous wetlands, and late successional coniferous wetlands. These other vegetation types were not included in the model because they were rarely used by EMRs and the mid-late successional stage was not expected to be optimal habitat when early successional vegetation types are available based on information in the literature (Wright 1941, Reinert and Kodrich 1982, Weatherhead and Prior 1992, Johnson and Leopold 1998) and resource selection functions calculated for EMRs at PCCI. For all vegetation types used, most vertical cover was provided by live and dead herbaceous vegetation and the density of trees/shrubs 1-3 m tall was greater than the density of trees/shrubs > 3 m tall (Table 2.1). The percent cover of cattails/reeds, dead downed woody debris, standing water, and bare ground/muck/rock were not included in statistical analysis because they constituted <5% cover, tended to be inconsequential within stands used by EMRs, and appeared sporadically and infrequently within vegetation types. Of the remaining variables, percent live herbaceous ($p = <0.01$) and dead herbaceous cover ($p = 0.02$), density of trees >3 m tall ($p = 0.07$), and absolute dominance of trees >3 m tall ($p = 0.04$) were different when comparing snake presence and absence in early successional deciduous uplands. Percent live herbaceous cover ($p = 0.04$) and density of trees >3 m tall ($p = 0.01$) were different between presence and absence in early successional deciduous wetlands. These variables were selected for the model because they appear to quantify ground/mid-story cover selected by EMRs as well as the successional conditions selected.

HSI Model Variables

Vegetation types in which the following variables should be measured are in early successional deciduous wetlands and uplands, as well as early successional scrub-shrub fen. The selected variables are expected to contribute to habitat requirements concerning thermoregulation, gestation, food, and hibernation (Figure 2.2).

Variable 1 (Percent Live Herbaceous Vertical Cover)

The average of the mean value for percent live herbaceous cover for "presence" plots in early successional deciduous wetlands and uplands and the mean value for

Table 2.1. Mean values for all vegetation attributes measured in all vegetation types used by Eastern Massasauga Rattlesnakes radio-tracked in Barry County, Michigan during 2004 and 2005.

Variable	Mean	Standard Error	Maximum
% Tree/Shrub Cover >1 m	9.31	0.56	84.50
% Tree/Shrub Cover <1 m	2.24	0.19	40.75
% Cattail/Reed Cover	1.29	0.26	89.50
% Live Herbaceous Cover	70.60	0.94	100.00
% Dead Herbaceous Cover	89.49	0.71	100.00
% Dead Downed Woody Debris	0.30	0.12	100.00
% Moss/Lichen	0.41	0.09	44.75
% Surface Water	3.13	0.43	89.50
% Bare Ground/Muck/Rock	2.42	0.27	87.75
Density of Trees >3 m (stems/ha)	75.41	7.56	2900.00
Density of Trees/Shrubs 1-3 m (stems/ha)	534.80	44.54	10900.00
Absolute Dominance of Trees >3 m (m^2/ha)	0.78	0.50	422.92

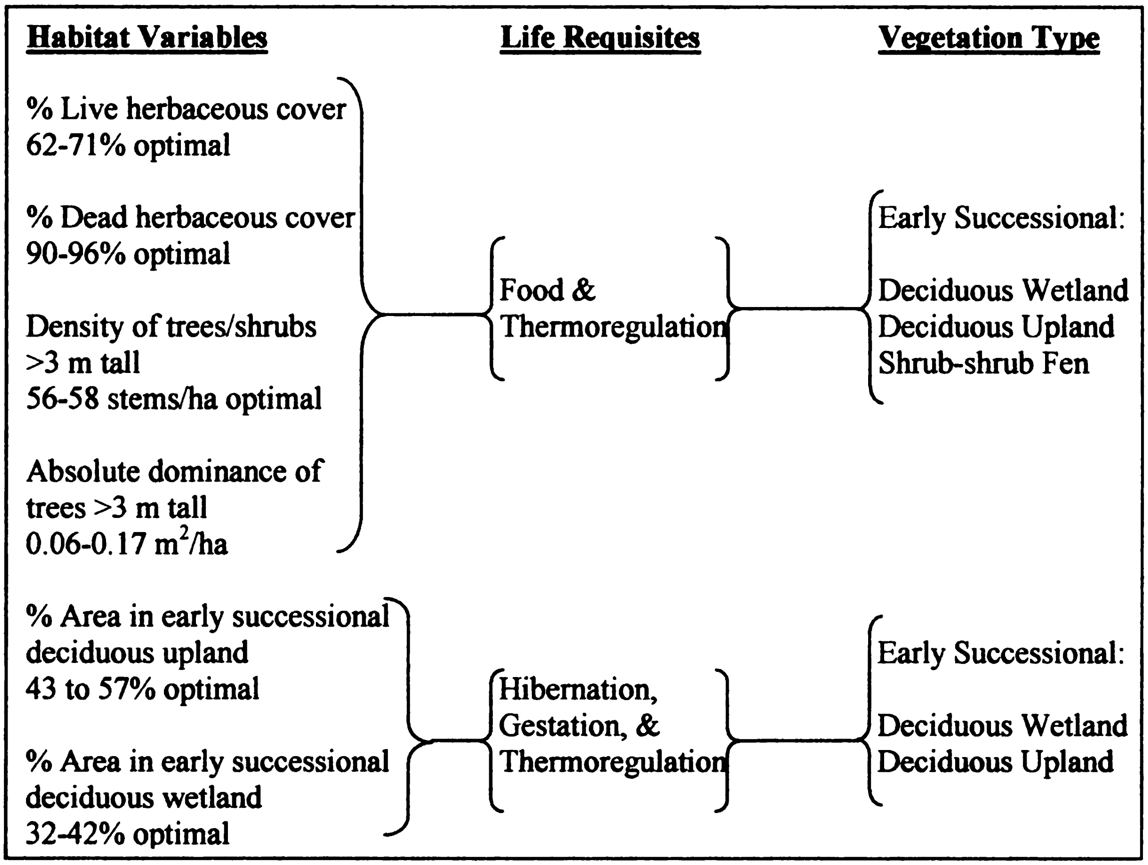

Figure 2.2. Relationship of habitat variables, life requisites, and vegetation type to a habitat suitability index value for Eastern Massasauga Rattlesnakes in southwestern lower Michigan.

pooled "presence" and "absence" plots in early successional scrub-shrub fen was 62%. This was defined as the optimal value for the production function (Figure 2.3). The maximum live herbaceous cover where an EMR was located was 99%. However, the mean live herbaceous cover at "absence" plots was 71%. Therefore, 71% to 100% live herbaceous cover defined the descent of suitability to zero. This production function shows that while EMRs prefer thick live herbaceous cover, they need some open gaps for thermoregulation.

Variable 2 (Percent Dead Herbaceous Vertical Cover)

The average of the mean value for percent dead herbaceous cover for "presence" plots in early successional deciduous uplands and pooled data for "presence" and "absence" plots in early successional deciduous wetlands and scrub-shrub fen was 90%. This was defined as the optimal value for the production function (Figure 2.4). The maximum dead herbaceous cover for "presence" and "absence" plots was 100%. However, the mean dead herbaceous cover for "absence" plots was 96%. It is highly doubtful that areas with 100% dead herbaceous cover should have a suitability of zero, since 43% of "presence" plots had this value. Therefore, the 96% to 100% dead herbaceous cover defined the descent of suitability to 0.6. This production function demonstrates the utilization of herbaceous detritus as cover and basking substrate within these vegetation types.

Variable 3 (Density of Trees/Shrubs >3 m)

The average of the mean value for stem densities of trees/shrubs >3 m tall for "presence" plots in early successional deciduous uplands and wetlands and pooled data for plots in early successional scrub-shrub fen was 56 stems/ha. This was defined as the

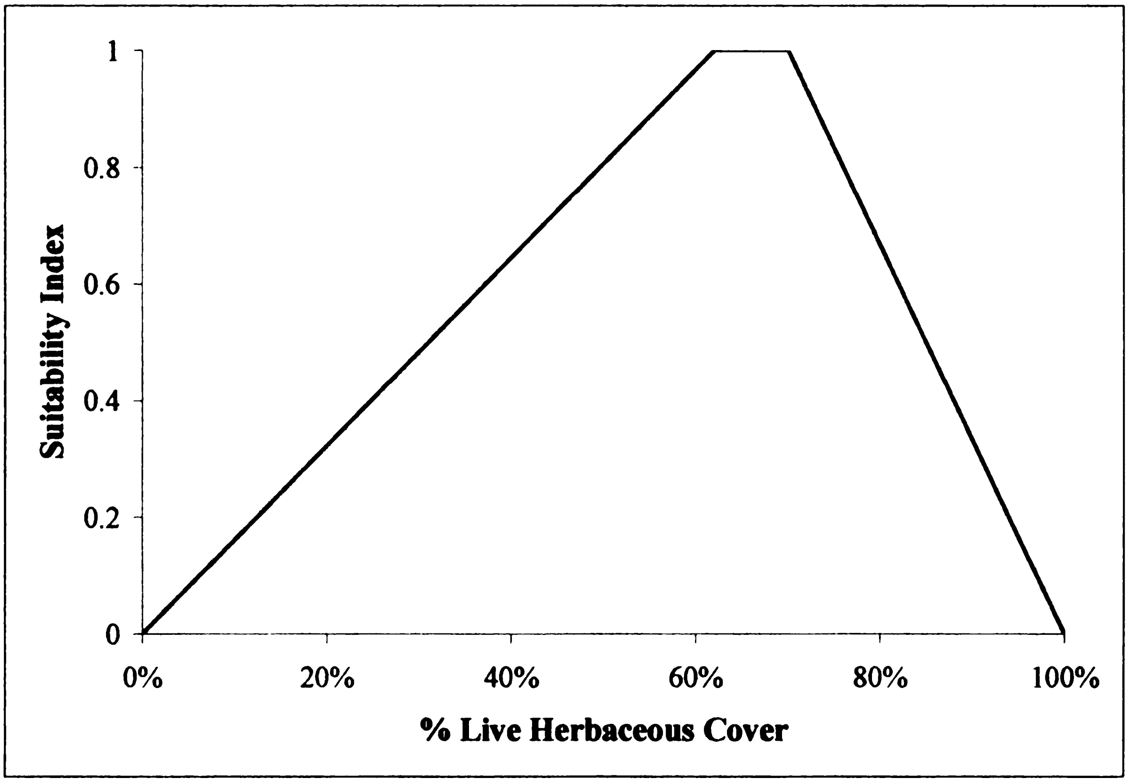

Figure 2.3. Production function for the relationship between percent live herbaceous vertical cover and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

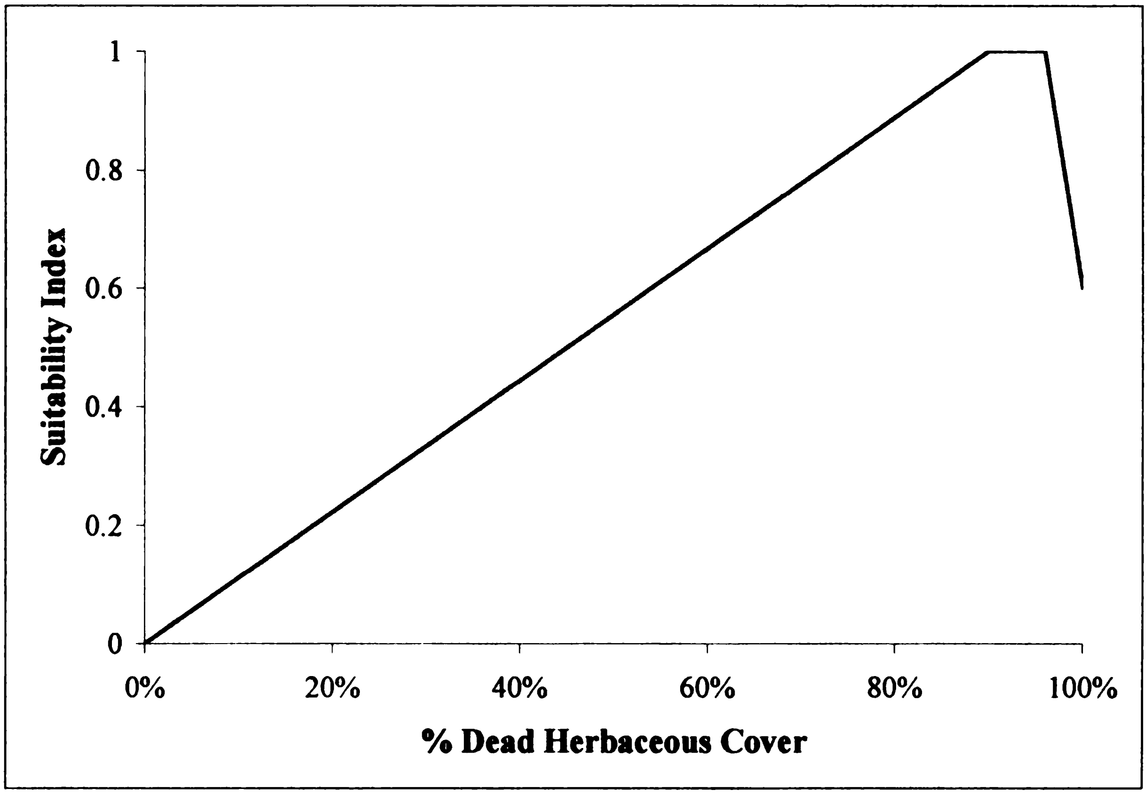

Figure 2.4. Production function for the relationship between percent dead herbaceous vertical cover and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

optimal value for the production function (Figure 2.5). However, the maximum density of trees >3m tall at "presence" plots was 700 stems/ha. The mean stem density for "absence" plots was 58 stems/ha and the smallest maximum between the 2 vegetation types was 1600 stems/ha. Therefore, 58-800 stems/ha of trees/shrubs >3 m defined the descent to suitability of zero because 800 is half of the maximum for "absence" plots; however it still brackets the maximum for "presence" plots. This production function demonstrates selection of areas with some tall trees and shrubs by EMRs, but the avoidance of dense woody vegetation and closed overstory canopy.

Variable 4 (Absolute Dominance of Trees >3 m)

The average of the mean value for absolute dominance of trees > 3 m tall for "presence" plots in early successional deciduous uplands and pooled data for plots in early successional deciduous wetlands and scrub-shrub fen was 0.06 m^2/ha. This was defined as the optimal value for the production function (Figure 2.6). The maximum absolute dominance of trees >3 m at a snake location was 3.47 m^2/ha. However, the mean absolute dominance of trees >3m for "absence" plots was 0.17 m^2/ha, but the maximum was 8.35 m^2/ha. Therefore, 0.17 to 8.35 m^2/ha of trees >3 m tall defined the descent of suitability to zero. This production function demonstrates avoidance of closed overstory canopy and late successional vegetation types.

Variable 5 (Percent of Area in Early Successional Deciduous Upland)

The proportion of the 95% fixed kernel utilization distribution for the study population at PCCI (8.9 ha) in early successional deciduous upland was 57% and the mean proportion of all individual EMR 95% fixed kernel home ranges (2.8 ha) in the vegetation type was 43%. Therefore, 43 to 57% area in early successional deciduous

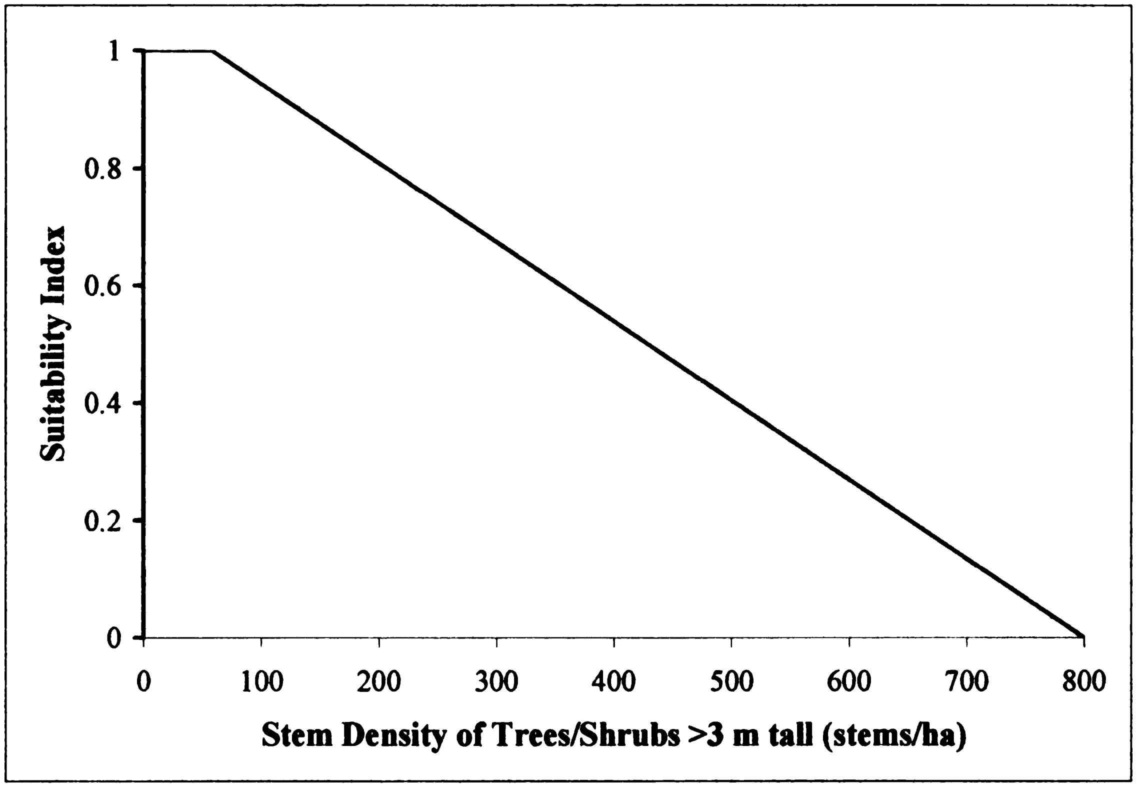

Figure 2.5. Production function for the relationship between the density of trees/shrubs >3 m tall and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

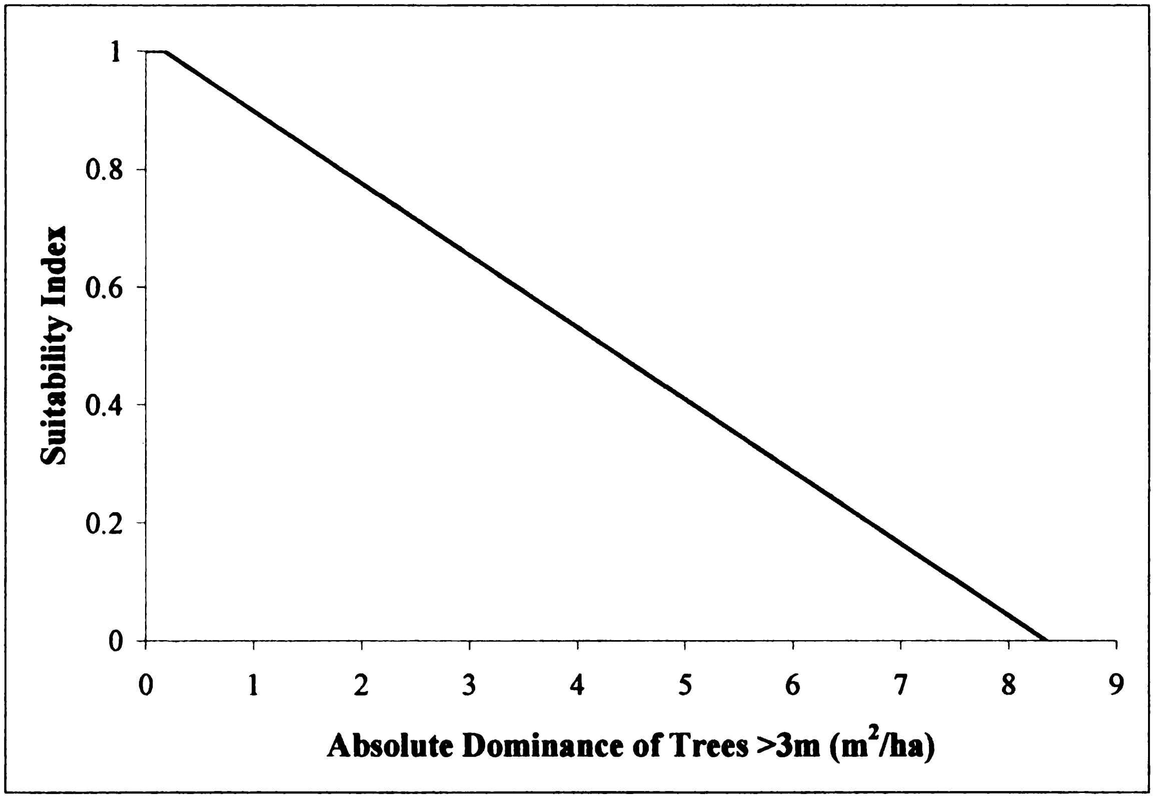

Figure 2.6. Production function for the relationship between the absolute dominance of trees >3 m tall and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

upland was defined as optimal for the production function (Figure 2.7). This demonstrates that approximately half of EMR habitat use is in an early successional upland vegetation type or in areas transitioning into this vegetation type. The importance of this vegetation type to EMRs is probably related to thermoregulatory requirements, especially those of gravid females.

Variable 6 (Percent of Area in Early Successional Deciduous Wetland)

The proportion of the 95% fixed kernel utilization distribution for the study population at PCCI (8.9 ha) in early successional deciduous wetland was 42% and the mean proportion of all individual EMR 95% fixed kernel home ranges (2.8 ha) in the vegetation type was 32%. Therefore, 32 to 42% area in early successional deciduous wetland was defined as optimal for the production function (Figure 2.8). This demonstrates that approximately a third of EMR habitat use is in an early successional wetland vegetation type or in areas transitioning into this vegetation type. The importance of wetland availability is probably related to hibernacula requirements (Sage 2005) and prey requirements (Hallock 1992).

HSI Model Determination

Each of the variables 1-4 is expected to contribute to the overall HSI for EMRs similarly. A suitability index of 0 for one variable does not necessarily mean that the habitat is unsuitable, because if one cover attribute is lacking, another may make up for it (e.g., 40% dead herbaceous with 70% live herbaceous available would likely be acceptable conditions for EMRs). However, the availability of early successional wetland and upland vegetation types may be very important for availability of suitable hibernacula and gestation sites, variables 5 and 6 are considered to be more important

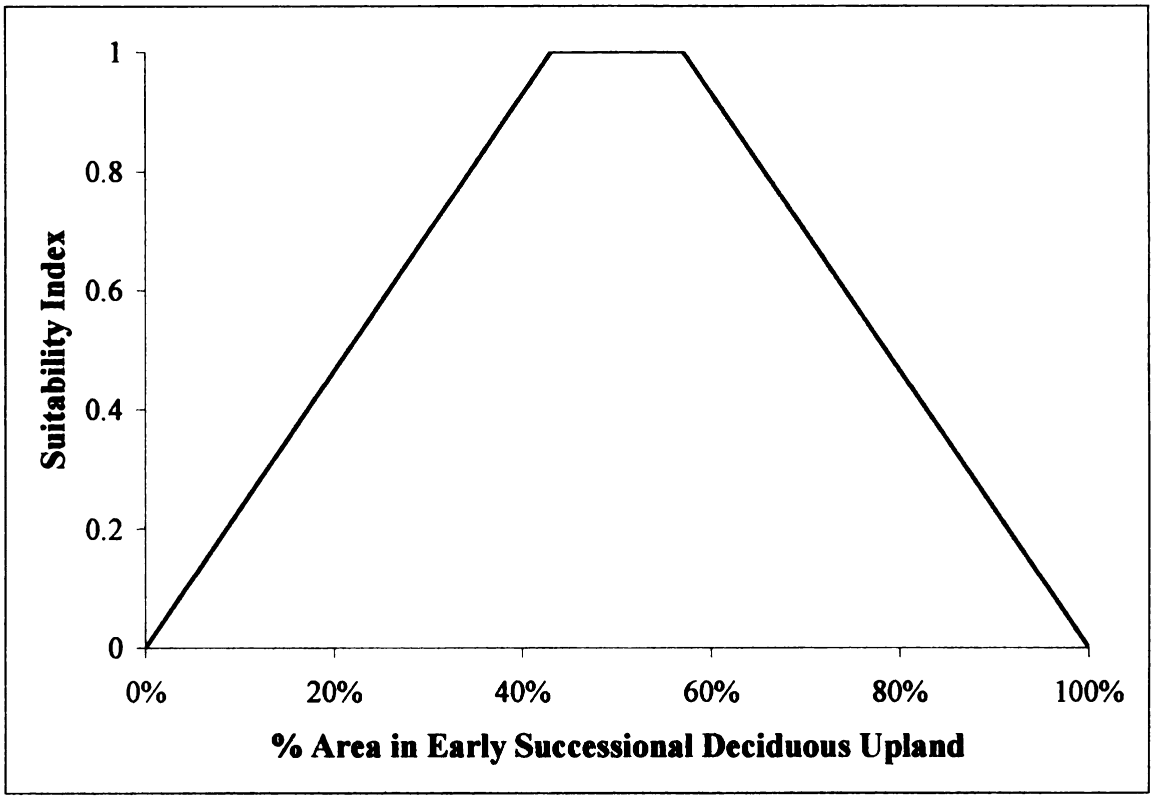

Figure 2.7. Production function for the relationship between the percent area in early successional deciduous upland and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

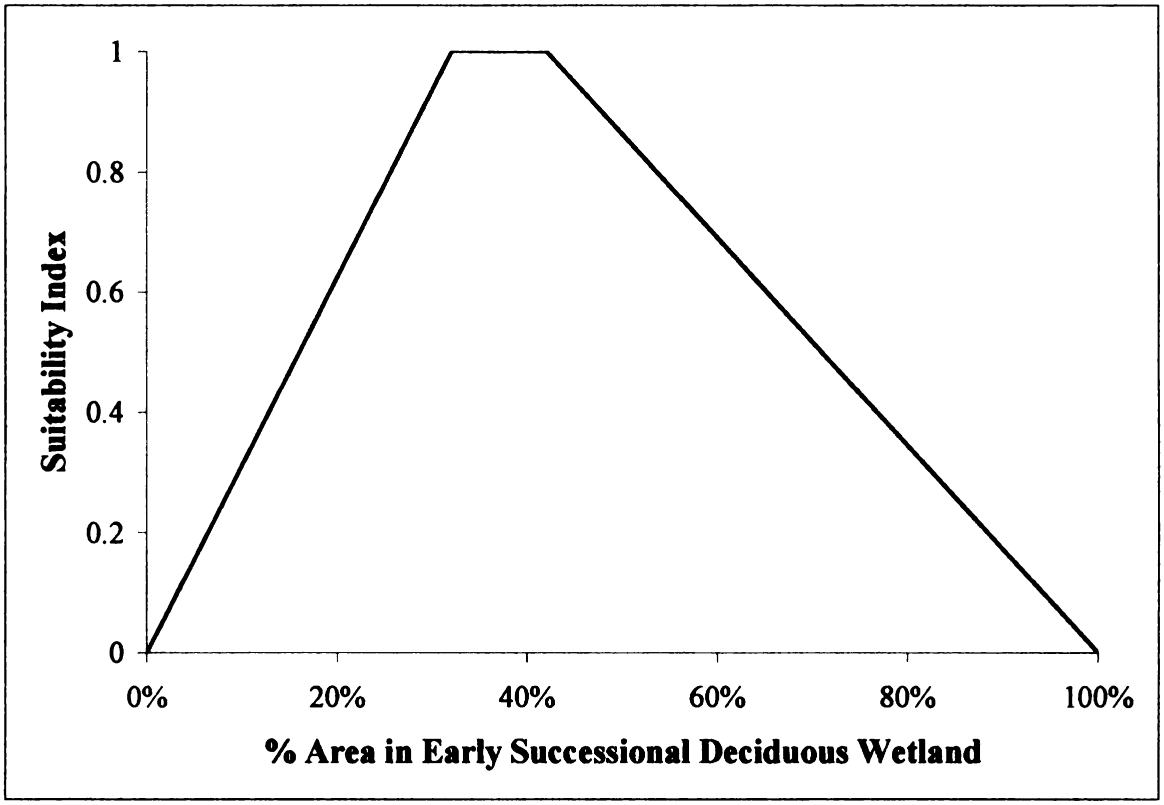

Figure 2.8. Production function for the relationship between the percent area in early successional deciduous wetland and Eastern Massasauga Rattlesnake habitat suitability in southwestern lower Michigan.

than 1-4, but equally important as each other. Therefore, SI5 and SI6 will modify the average of the other 4 SI values in the final HSI equation:

$$\mathbf{HSI = [(SI5 + SI6)/2] * [(SI1 + SI2 + SI3 + SI4)/4]}.$$

I recommend this model be applied at a scale of 1-20 ha. One hectare should be considered the smallest size area for applying the model because this was the size of the smallest area used by EMRs at YSRA. However, it is preferable to apply the model to areas of at least 8.9 ha because the data used to develop variables 5 and 6 of the model were calculated based on a 95% fixed kernel utilization distribution (8.9 ha) for the study population of EMRs at PCCI. Twenty hectares should be considered the largest area for application of the model because the largest home range for an individual EMR in the study was approximately 20 ha.

DISCUSSION

Quantitative information on EMR habitat suitability is scant and there are no previous data on the structure and composition of EMR habitat in southwestern lower Michigan. With current concerns about EMR conservation, managers need to be able to identify, quantify, and qualify potential EMR habitat. This habitat suitability model is a first step in obtaining a better understanding of required vegetation structure and composition for EMRs.

Every vegetation type and attribute used to develop this model indicates a preference for early successional vegetation types by EMRs in southwestern Michigan. Within the most frequently selected vegetation types, EMRs displayed a preference for thick live and dead herbaceous vegetation; however, optimal vertical ground cover was <100%. This selection for slightly less than complete cover is likely for thermoregulation. EMRs tended to avoid of late successional vegetation types with low stem densities and absolute dominance of trees >3 m tall. Selection for an open canopy likely optimizes thermoregulatory capabilities and prey densities. The early successional deciduous upland and wetland vegetation types were practically used by EMRs at a 1:1 ratio. These vegetation types provide food and cover for thermoregulation as well as the transition area between these two vegetation types provides EMRs with suitable hibernacula for overwintering (Sage 2005).

The early successional scrub-shrub fen was included in the model as a vegetation type to measure; however, this vegetation type was exclusively used by EMRs at the YSRA throughout the activity season. The proportion of this vegetation type comprising a 95% fixed kernel distribution for pooled EMR locations at YSRA was 61%. It is questionable if this 5 ha-area is very suitable or isolated. There was minimal early successional upland vegetation available at YSRA (9%) and the fen is almost entirely\ surrounded by forest. Although the vegetation attributes of the fen at YSRA and the early successional deciduous wetlands at PCCI were significantly different from each other; percent dead herbaceous cover, density of trees >3 m tall, and absolute dominance of trees >3 m tall were not significantly different between the fen and early successional deciduous upland vegetation type. Therefore, the fen is a wetland with vegetation structure similar to that of an early successional deciduous upland. One reason that both wetlands and adjacent uplands are said to be important for EMRs is that the hydrology of the wetland provides conditions in which EMRs can hibernate in uplands, without the risk of flooding (Sage 2005). However, the fen at YSRA tends to become very dry in late summer and is bordered by upland forest. Gravid females at the YSRA site spent the gestation period in the fen, and were never located in upland vegetation types. Therefore, it is probable that EMRs hibernate at the edges of the fen, never moving to find the early successional deciduous wetland and upland vegetation types. Therefore, SI5 and SI6 could probably be excluded from the HSI model if the majority of the area being evaluated consists of early successional scrub-shrub fen.

Other vegetation types were used by EMRs at PCCI. These included mid-late successional deciduous and coniferous wetlands and mid-successional deciduous upland. Use of vegetation similar to this has been documented in other parts of the EMR range including Ontario, Canada, Illinois, and southeastern lower Michigan (Weatherhead and Prior 1992, Anton 1998, Sage 2005). However, these areas are not recommended for evaluation as potential EMR habitat if the vegetation types included in the model are available. An avoidance of late successional vegetation types by EMRs is likely because these vegetation types do not provide optimal thermoregulatory and food conditions as early successional vegetation types.

This habitat suitability model represents a hypothesis of the significance of structural and compositional vegetation attributes and how they contribute to habitat suitability for EMRs in southwestern lower Michigan. Data used to develop this model were collected in Barry County, Michigan, primarily at PCCI. Therefore, this model is specifically applicable to southwestern lower Michigan. The model was developed with radiotelemetry location data, not relative abundance of snakes, and, therefore, sample sizes were relatively small (data based on 24 radio-tracked EMRs with 1877 locations). All vegetation data collected were used to build the suitability model, and the model was not validated. Therefore, model validation should occur within Barry County prior to extensive use.

Brotons et al. (2004) suggests that presence-absence modeling methods are better for predicting habitat suitability than presence data alone. Although analyses comparing "presence" and "absence" plots from vegetation stands used by EMRs were done, stands never used by EMRs were not sampled. Therefore, some stands in which "absence" plots were not significantly different from "presence" plots could be a result of homogeneity. Without significant differences, data had to be pooled for some attributes and absence data for dead herbaceous cover and absolute dominance of trees >3 m tall were based on information for the early successional deciduous upland vegetation type. Actual survey data with abundance information would be helpful in modifying this model. Regression analyses could not be used relating abundance to vegetation structure because, as mentioned earlier, EMRs were radio-tracked and unused stands were not examined, creating an almost categorical data set.

This model was developed to evaluate optimal vegetation types and attributes that could indicate habitat suitability and presence of EMRs. Therefore, it could be considered fairly conservative in that respect. The habitat suitability model presented here has the potential to be very useful in the assessment of suitable EMR habitat within the southwest region of the state.

CHAPTER 3: Population demographics for Eastern Massasauga Rattlesnakes in southwestern lower Michigan and the development of a preliminary population viability model.

INTRODUCTION

Population dynamics may vary considerably between localized populations or different reaches of the EMR's range. In southwestern Wisconsin, Keenlyne (1978) concluded that reproduction among EMRs was annual; however, in western Pennsylvania, Reinert (1981) found evidence of biennial reproduction among EMRs. B. Kingsbury (Indiana-Purdue University at Fort Wayne (IPFW), personal communication) suspects biennial or triennial reproduction in Michigan based on the observed sex ratio of EMRs captured at study sites in north central and southeastern parts of the Lower Peninsula.

Gibbs et al. (1998) and Gibbs (1999) found that a substantial portion of the genetic variability among the EMR as a subspecies is attributed to the heterozygosity between localized populations; however, the genetic structure within these populations was homozygous. These researchers also suggested that genetically distinct populations exist on extremely small geographic scales of <2 km. This reproductive and genetic variation among geographically distinct populations of EMRs warrants a more detailed examination of localized populations.

Seigel and Sheil (1999) presented a preliminary population viability analysis (PVA) for EMRs in northwestern Missouri. They found that EMR populations were stable only when adult mortality rates were $\leq 22\%$ per year and neonate mortality rates were $\leq 80\%$ per year. These researchers concluded that populations of EMRs with an initial size of <50 individuals are likely candidates for extinction. However, populations with 200–300 individuals had zero probability of extinction. The authors cautioned against extrapolating their findings to other portions of EMR range as some demographic variables are not similar among areas (i.e., higher age to maturity and lower annual juvenile mortality rates in Ontario than Missouri). Thus, it is imperative to quantify population demographic information and its resultant influence on long-term survival potential of EMRs throughout its range.

Population viability analyses can be useful to predict the future size of a population, estimate the probability of a population going extinct over a period of time, and compare the consequences of different management practices (Coulson et al. 2001). However, criticisms and cautions about the use of PVA must be taken into consideration. The lack of sufficient, long-term data for species population demographics and environmental stochasticity may cause difficulty in parameter estimation and may result in unreliable model estimates (Ellner et al. 2002). It has been suggested that projections be made over shorter time periods, simple models be used, and that uncertainty is carefully accounted for to increase PVA precision (Ellner et al. 2002). Model results will also be more reliable if the mean and distribution of vital rates or population growth rates are consistent throughout the years (Coulson et al. 2001, Ellner et al. 2002). PVA may be most helpful for comparing the relative effects of potential management actions on population growth or persistence (Reed et al. 2002); however, it is important to remember that PVAs are meant to be tools used for population management.

Development of a representative model for EMR could potentially drive management efforts for the conservation of the species. A detailed understanding of population demography is essential for the effective use of these models. Therefore, more research must be conducted at a local scale for the accurate use of PVAs as a management tool. EMR populations in southwestern Michigan have not previously been examined. Specific objectives for this part of the project include quantifying EMR population demographics and developing a preliminary PVA for EMRs in the study area to guide population management in southwestern Michigan.

METHODS

Annual Survival

Survival was estimated using the Kaplan-Meier (Kaplan and Meier 1958) analysis because it allows for staggered entry of individuals into the study and it does not assume constant survival. The probability of surviving to time j ($\hat{S}_j$) = Π [1– number of deaths at time j / number at risk at time j]. Newly radio-tagged individuals are assumed to have the same survival function as previously radio tagged animals. In this case, since all EMRs radio-tagged were at least 2-years-old,Iknow that individuals entered later in the period were alive at t_0. Other assumptions of this method include random samples, independence of experimental units, independence of observation periods, working radios are always located, random censoring is allowed, and radios do not impact survival (Winterstein et al. 2001).

Survival periods were defined as May 14, 2004 – April 15, 2005 and April 15, 2005 – October 28, 2005. In cases where the actual date of mortality was unknown because more than one day had passed between the last day observed alive and the day declared dead, the mean between the dates was used as the date of death. Survival was calculated for all EMRs, and for all adult EMRs, excluding subadults. The sample sizes for subadults and males were too small to calculate survival for those specific groups in 2004. In 2005, sample sizes for subadults and males were slightly larger; however, survival could not be estimated for subadults because none died. Survival for males in 2005 was estimated but was not included in any population analysis due to the poor sample size. Student's t-Test was used to test statistical significance using SAS 9.1 (2003).

Population Viability Analysis

Vortex 9.50 (Lacy et al. 2005) was used to run population simulations to analyze viability of EMRs at PCCI. Vortex was used because many of the required parameters to run the model were available from data collected in the field and literature was available to substitute when field data was lacking (Appendix E). No default values were used; however, literature describing other snake species was used for parameters where data on EMRs was lacking. In these population simulations, no emigration or immigration was assumed; the EMR population at PCCI was described as a single, isolated population. Simulations were also run in which the adult mortality rate was decreased by 10% or the age at first reproduction was reduced, while keeping the other parameter values thought to best represent the EMR population at PCCI constant.

Scenario Settings and Species Description

Three scenarios were run with 1000 iterations simulated for 50 years. Extinction was defined as the absence of one or both sexes. It was assumed that there is no inbreeding depression and that environmental variation in mortality is concordant among age-sex classes but independent from variation in reproduction.

Reproductive System

The first age at reproduction is 3 years; however a range of 3 to 4 is usually reported (Harding 1997, Siegel and Sheil 1999). King et al. (2004) reported a female that was gravid at age 2. This suggests that conditions exist under which a female EMR may mature earlier than normal. However, no female EMRs <3 years of age were found to be sexually mature at PCCI. The maximum breeding age was defined as 14 years (MacLeod 2005). A neonate sex ratio of 1:1 was used based on the findings of Keenlyne and Beer

(1973). Although many report a maximum of 20 offspring for EMRs (Harding 1997), snakes at PCCI never had more than 12 viable young at a time, so this value was used. No density dependence was assumed based on literature suggesting that breeding is dependent on individual condition (Aldridge and Duvall 2002). Distribution of the number of offspring per breeding female per year was assumed to be normal since data is lacking. Duvall et al. (1993) indicated a polygamous mating system for vipers in general; therefore, it was assumed this was the case for EMRs at PCCI.

Reproductive Rates

The percent of adults breeding was calculated from field data from 2004 and 2005 and the standard deviation was used to describe environmental variability of this proportion. The mean number of progeny per breeding female was calculated as the mean litter size estimated for females in 2004 and 2005 using data from the observed litter size at parturition sites and counts of viable embryos from ultrasonography and radiography. These data were also used to determine the maximum litter size.

Mortality Rates

Male and female mortality rates were assumed to be the same for each age class because, although the sample size to calculate the male mortality rate was small, it was not different from the mean mortality rate of females in 2004 and 2005. Age class 0 to 1 was defined as neonates; age classes 1-3 were defined as subadults; and age class 3 and beyond was defined as breeding adults.

Data from the literature was used to define the neonate mortality rate because these data were not available from field data collection. King (1998) radio-tracked EMR neonates to hibernation and reported mortality of 78%. Iassumed a 10% lower mortality because neonates were radio-tracked in King's study, and radio transmitter implants may influence survival since they may be too fragile for any current implantation method (Jemison et al. 1995, Parent and Weatherhead 2000). A standard deviation for neonate mortality rates was calculated using the rates reported by King (1998) for EMRs, Stanford and King (2004) for Plains Gartersnake (*Thamnophis radix*), Charland (1999) for Western Rattlesnakes (*Crotalis viridis*), and Kissner (2005) Northern Watersnake (*Nerodia sipedon*).

Information from the literature and field data were used for subadult mortality rate inputs. King et al. (2004) reported a mortality rate of 46.7% for subadult EMRs born in captivity and released in the summer. This rate was considered to be a "worst case scenario" for the population at PCCI because the individuals in the King et al. (2004) study were repatriated, and there is some question about the survivability of repatriated snakes. Also, no radio-tracked subadults died in the study in southwest Michigan. For these reasons, a scenario was also run in which the mortality rate presented by King et al. (2004) for subadults was reduced by half to 24% mortality. The standard deviation for subadult mortality was calculated using more specific data presented for subadult Plains Gartersnakes (*Thamnophis radix*) by Stanford and King (2004) and this was used as input for environmental variability in the mortality rate.

The mortality rate for adult EMRs at PCCI was calculated using survival data for adults within the study. Kaplan-Meier was use to estimate survival which was subtracted from 100% to determine mortality rate. The mean mortality rate for EMRs in 2004 and 2005 was used as the parameter. These data were also used to calculate the standard deviation which served as the environmental variability in mortality rates for adult EMRs at PCCI.

Catastrophe

No "catastrophes", defined by the software program as an event affecting a population at a particular frequency that would affect reproduction and/or survival of all individuals, were assumed for the PCCI EMR population. The only catastrophes reported in the literature to affect EMR populations have been floods (Seigel et al. 1998). However, documented negative impacts on EMRs after a flood were recorded for a population in an area bound on all sides by roads and dikes and was inundated with water, leaving few hibernacula above the water's surface. In this study, however, several EMRs at PCCI hibernated in small mammal burrows in upland habitat types away from water and those that did hibernate near the edges of wetlands in crayfish burrows had easy access to areas further from possible flooding sources. Also, the creek running through the PCCI property would have to swell to a width 18 times its size to affect the closest hibernacula area. The likelihood of a catastrophic event negatively impacting the whole PCCI population is very slim and would not make much of a difference in the model.

Mate Monopolization

Mate monopolization in the program refers to the male breeding characteristics of the population. For polygynous populations, one of three parameters must be specified and the program calculates the other two. The percent of males in the breeding pool was the input parameter used for this portion of the model. The percent of breeding males in the population was calculated using field data collected on all EMRs in the study. Data was averaged over both 2004 and 2005. Of the males found at PCCI, 60% were determined to be sexually mature.

Initial Population Size

The first scenario was run using an initial population size of 17700. This population size was calculated for PCCI (300 ha) using the minimum density of garter snakes (*Thamnophis atratus*) (59 snakes /ha) reported by Lind et al. (2005). Garter snake density was used because there is not much data available on snake densities in the literature. However, this species of garter snake does not occur in Michigan and tends to use more riparian habitat types and preys on more ectothermic species. Although they are fairly cryptic, viviparous, and use vegetation similar to that used by EMRs, this density most likely overestimates the population size of EMRs at PCCI.

Another scenario was run using an initial population size of 376. This was estimated by calculating the area of a minimum convex polygon using the locations of all individuals found at PCCI (n = 99), subtracting the area of unsuitable cover types, and calculating EMR density per hectare (1.3 snakes /ha). This density most likely underestimates the population size of EMRs at PCCI.

A final scenario used field data collected on EMRs at PCCI; however, I assumed that snakes observed in the field represent 10 percent of the population. Lind et al. (2005) found that field observations of garter snakes in their study represented 5-10 percent of the population size estimated using 16 years of mark-recapture data. Therefore, the observed number of individuals at PCCI was divided by 0.10 and used to calculate EMR density (12.5 snakes /ha) for a conservative estimate of the EMR population size using data collected in the field, without extreme underestimation. I found this initial population size to be the most reasonable with the available information. Stable age distribution was assumed for the PCCI population of EMRs because stage specific data is limited.

Carrying Capacity

The maximum carrying capacity allowed by the model is 30000 individuals. Since carrying capacity is not foreseen to be an issue influencing the population of EMRs at PCCI, the maximum of 30000 individuals was selected for this particular parameter. Because no real influence of carrying capacity is expected, a standard deviation of 0.001 was chosen to represent the environmental variation of the carrying capacity of this population.

Harvest and Supplementation

There is no harvesting or supplementation of EMRs at PCCI.

Genetic Management

Genetic data for the EMR population at PCCI has not been analyzed and will not be used in the development of this preliminary PVA.

RESULTS

Annual Survival

Survival for all EMRs in 2004 (n = 12) was 83.3% (SD = 0.01) and 57.9 % in 2005 (n = 18) (SD = 0.01) with a mean of 70.6% survival (SD = 0.18). Adult survival in 2004 was 81.8% (SD = 0.01) and 50.0% in 2005 (SD = 0.01) with a mean of 65.9% survival (SD = 0.22). Female survival in 2004 was 81.8% (SD = 0.01) and 53.3% in 2005 (SD = 0.01) with a mean of 67.6% survival (SD = 0.20). Male survival was calculated for 2005, despite the small sample size (n = 4), and was 75% (SD = 0.04). Since male survival was not different from the mean female survival and data on males was limited, it can be assumed that male and female survival rates are similar. The primary cause of death for EMRs in the study was predation.

Population Viability Analysis

The probability of extinction of the EMR population at PCCI, within 50 years, was 90.10% (SE = 0.94) with an initial population size of 17700 and a subadult mortality rate of 47% (Figure 3.1). Using an initial population size of 17700 and a subadult mortality rate of 24%, the probability of extinction was 82.40% (SE = 1.20), however, it was much more variable (Figure 3.2) then when using 47% for subadult mortality. The probability of extinction was 93.00% (SE = 0.81) with an initial population size of 3761 and a subadult mortality rate of 47% (Figure 3.3). However, when the subadult mortality rate was 24%, the probability of extinction was reduced to 82.7% (SE = 1.20), with an initial population size of 3761 (Figure 3.4). When the initial population size was set at 376 and the subadult mortality was 47%, the probability of extinction was 97.40% (SE =

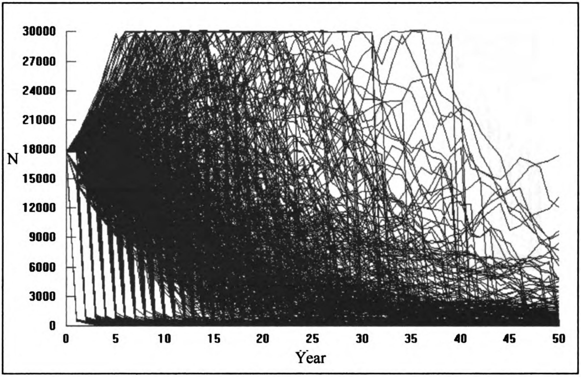

Figure 3.1. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 17700 individuals and a subadult mortality rate of 47%.

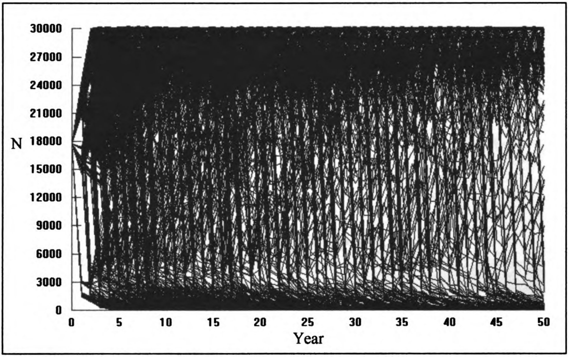

Figure 3.2. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 17700 individuals and a subadult mortality rate of 24%.

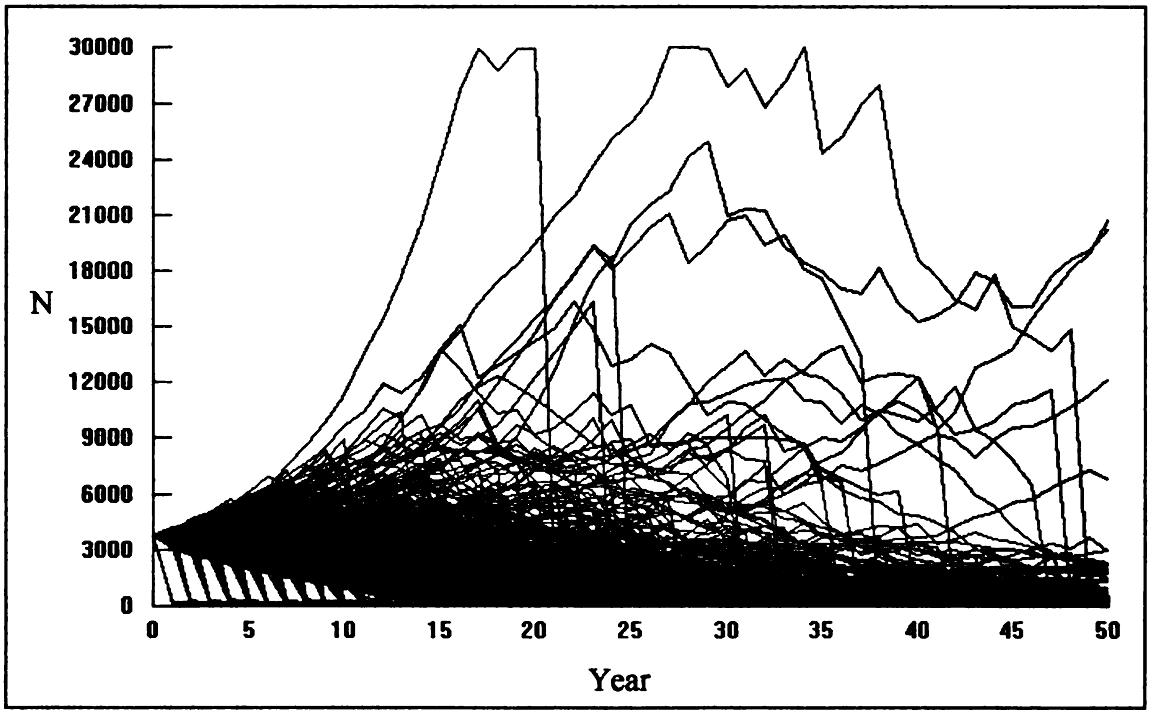

Figure 3.3. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 3761 individuals and a subadult mortality rate of 47%.

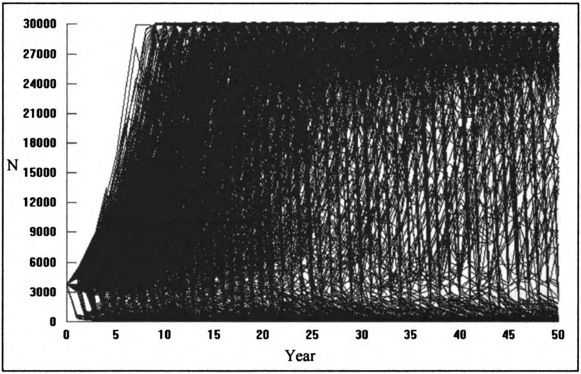

Figure 3.4. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 3761 individuals and a subadult mortality rate of 24%.

0.50) (Figure 3.5). When subadult mortality was reduced to 24%, the probability of extinction was reduced to 81.80% (SE = 1.22) with a population size of 376 (Figure 3.6).

The scenario with an initial population size of 3761 individuals perhaps best represents existing conditions given the available data. Using this initial population size allowed data collected in the field to be combined with snake density information from a long-term garter snake-population study. Field data alone seemed to underestimate the EMR population size at PCCI; however, using the density from a garter snake population seemed to overestimate the EMR population size. The information from the long-term study on garter snakes indicated that snake observations accounted for 10% of the actual population size. Since both species are fairly cryptic, viviparous, and use similar vegetation, I assumed that this 10% rule could hold true for EMRs at PCCI. This resulted in the population estimate of 3761 EMRs at PCCI. When the scenario for this population size was run with the subadult mortality rate of 47%, the mean population size for all 1000 simulations decreased to a mean final population of 108 in the 50th year (Figure 3.7). However, 70 simulations projected an extant population. The mean population size for the 70 extant simulations decreased and leveled off at approximately 1500 in 40 years (Figure 3.7). The mean time to first extinction in this scenario was 17.57 years (SE = 0.44). When the scenario was run with a subadult mortality rate of 24%, the final mean population size for all 1000 simulations was 4464 in the 50th year (Figure 3.8). However, 173 simulations projected an extant population. The mean population size for these extant simulations increased and leveled off at about 25000 in about 40 years (Figure 3.8). The mean time to first extinction in this scenario was 19.12 years (SE = 0.49).

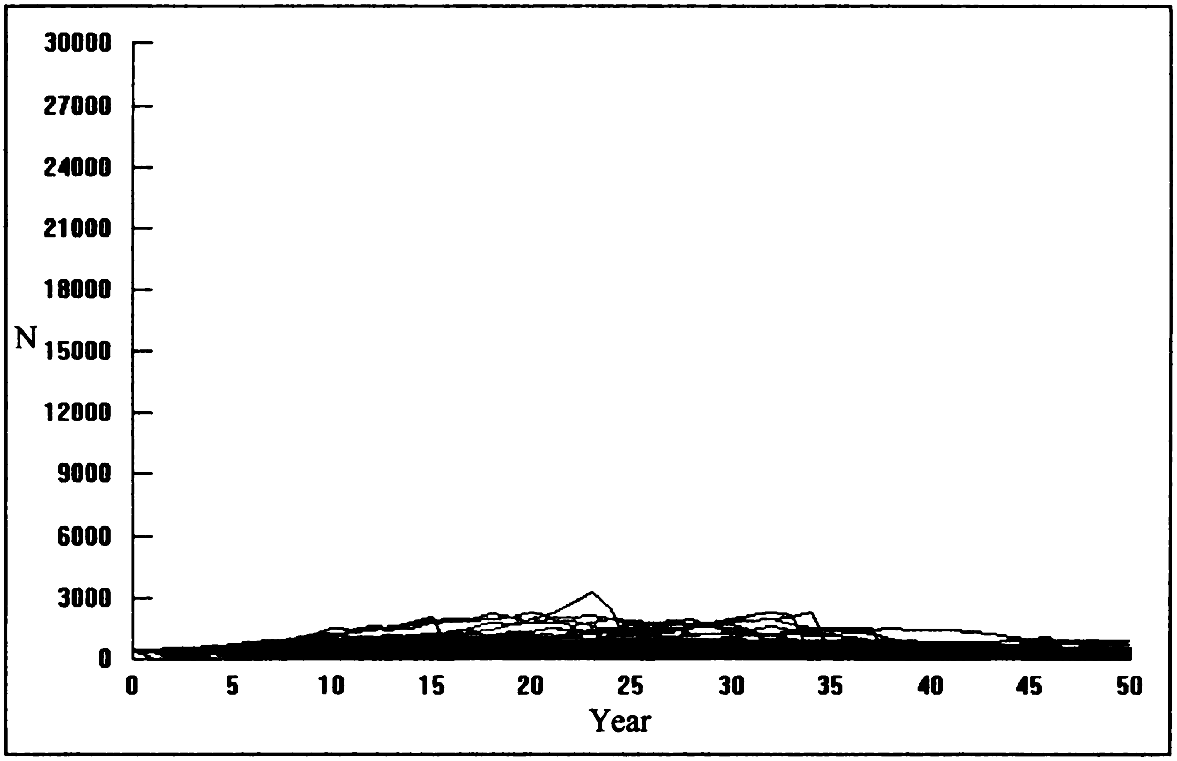

Figure 3.5. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 376 individuals and a subadult mortality rate of 47%.

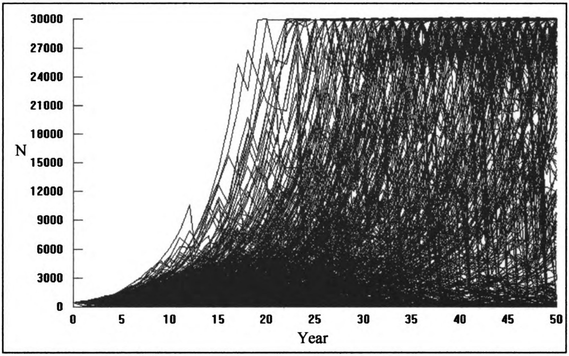

Figure 3.6. Simulations (1000) using VORTEX for the Eastern Massasauga Rattlesnake population at Pierce Cedar Creek Institute, in southwestern lower Michigan, with an initial population size of 376 individuals and a subadult mortality rate of 24%.

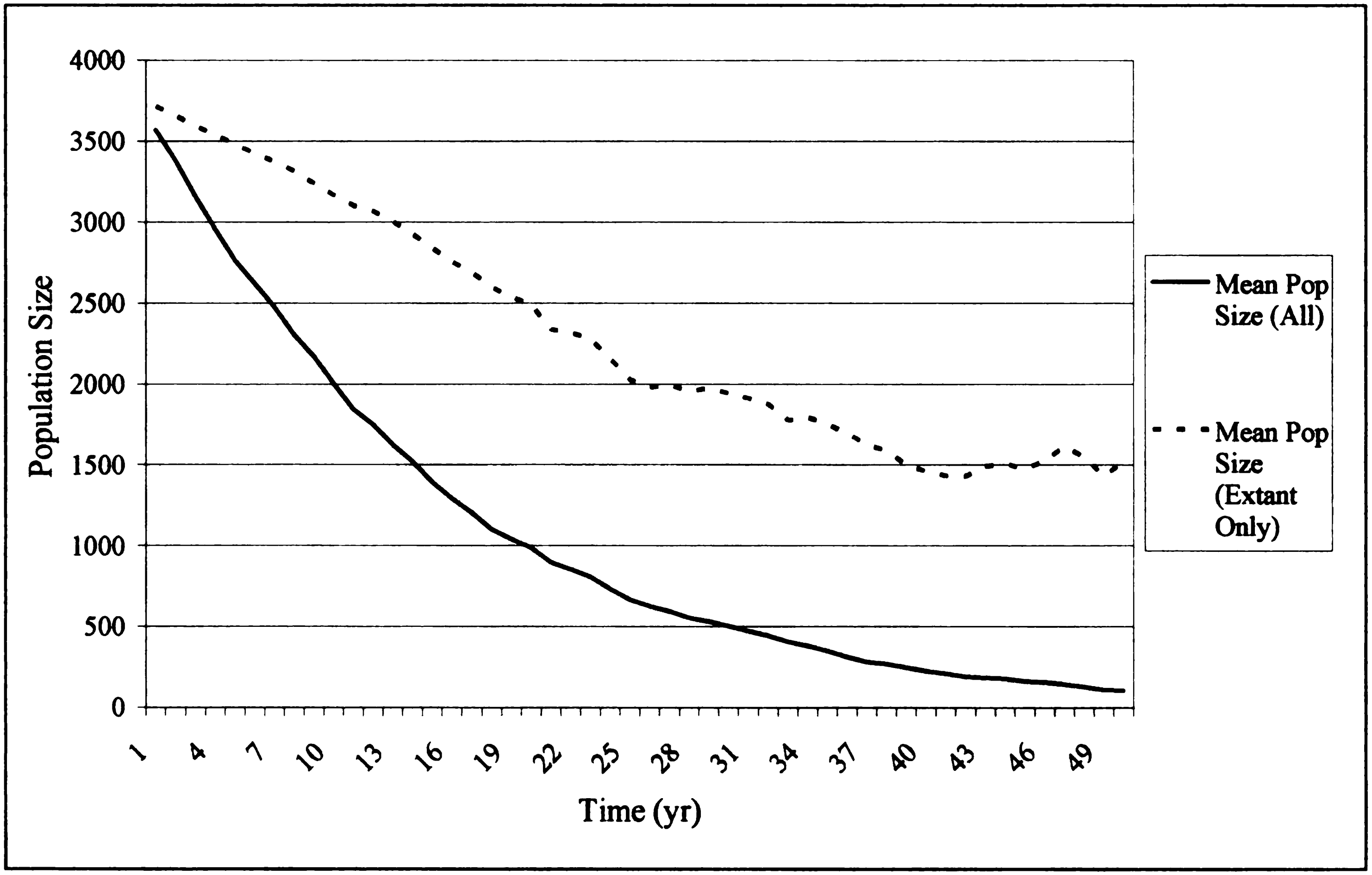

Figure 3.7. Mean Eastern Massasauga Rattlesnake population size at Pierce Cedar Creek Institute, in southwestern lower Michigan, for 1000 simulations with an initial population size of 3761 individuals and a subadult mortality rate of 47%, and the mean population size of the 70 extant simulations.

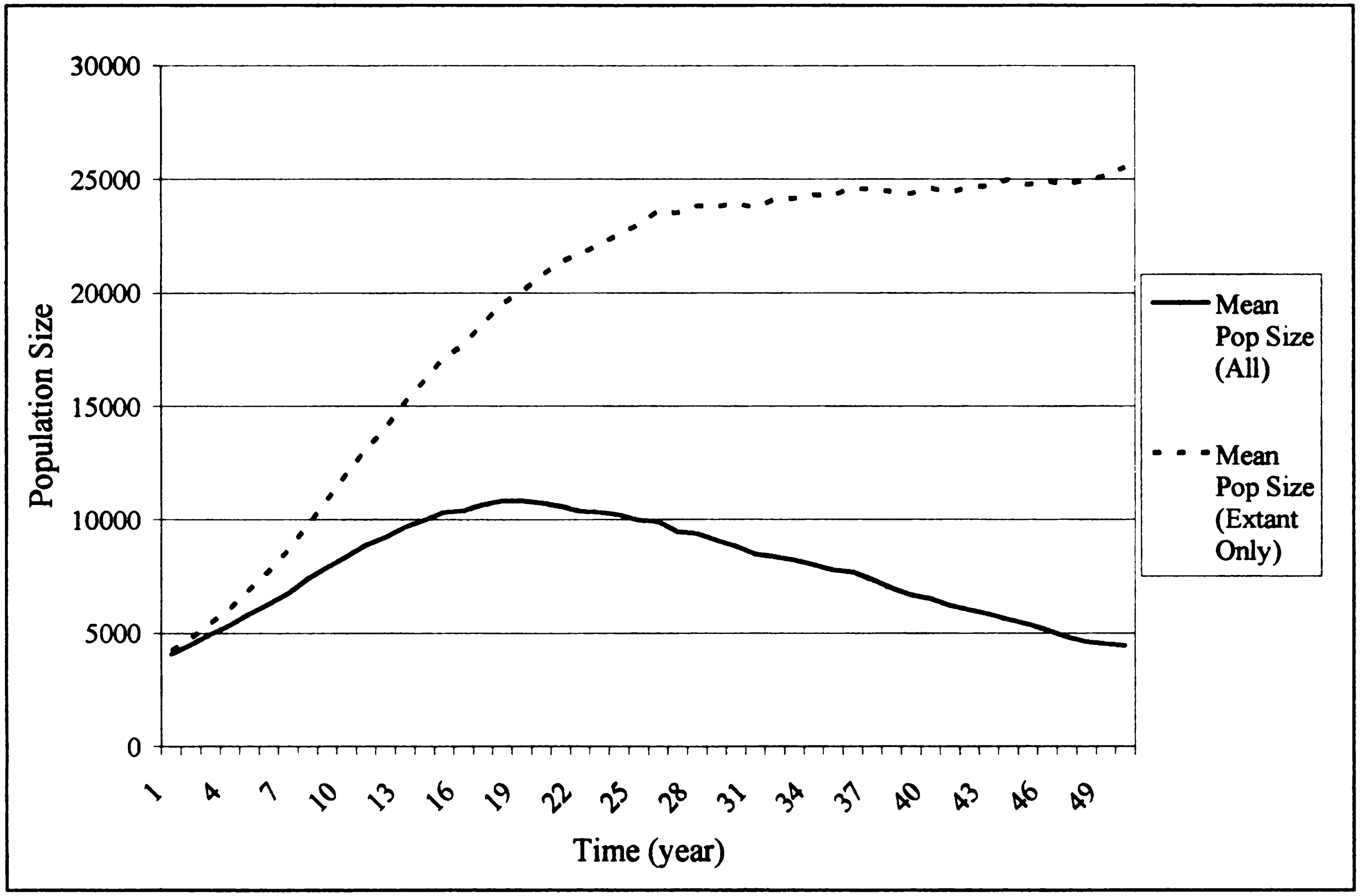

Figure 3.8. Mean Eastern Massasauga Rattlesnake population size at Pierce Cedar Creek Institute, in southwestern lower Michigan, for 1000 simulations with an initial population size of 3761 and a subadult mortality rate of 24%, and mean population size for the 173 extant simulations.

Lowering adult mortality by 10% and keeping subadult mortality at 47% resulted in a probability of extinction of 89.40% (SE = 0.97). Lowering the adult mortality rate by 10% and setting the subadult mortality at 24% resulted in an extinction probability of 79.70% (SE = 1.27). Lowering the age at first reproduction to 2 years also reduced probability of extinction; however, this is not a natural history trait that can be influenced by population or habitat management.

DISCUSSION

Managing a population that is of special concern can be problematic because of the need for information on demographics, dynamics, and habitat suitability of the population in question. These data are necessary if biologists are to be better equipped to make management decisions that minimize the probability of the population being eliminated; however, this type of information is usually scarce for species like the EMR. Under the current conditions, snakes at PCCI have a high probability of decline and extinction over the next 50 years, according to the model using the 47% mortality rate for subadults. Even with a larger population size of 17700, the EMRs at PCCI are expected to have a high probability of extinction with the current population demographics. The probability of extinction decreases for the population when subadult mortality rate is lower (24%). The scenario in which the initial population size is 3761 and subadult mortality is 24% probably best represents the PCCI EMR population given the data available. Although it is possible that the initial population size in this scenario is an overestimate, an initial population size based solely on the density of EMRs observed at PCCI (n = 376) would be an underestimate given the elusive and cryptic nature of the species. The mortality rate for EMR subadults from King et al. (2004) seems high for our population because no radio-tracked subadults died in our study and they were not repatriated (therefore, they were experienced within their environment). Also, a subadult mortality rate of 24% is more realistic in relation to an adult mortality rate of 34% because subadults are not at risk in the ways that adults are at risk (Bonnet et al. 1999). For example, adult females bask more often and sacrifice meals when incubating, and adult males traverse more area searching for mature females (Bonnet et al. 1999).

This model could be considered a "worst case scenario" because it was run as a closed population; however, it is unlikely that the PCCI EMR population is closed. Barriers to snake movement (e.g., roads, expansive forest) (Kjoss 2000, Sage 2005) do not bound the PCCI property and similar habitat conditions are available on neighboring properties. Mortality rate inputs may have also influenced the high probability of extinction in the output of this model, as well.

Seigel and Sheil (1999) found that an EMR population of 200 to 300 individuals in northwestern Missouri would stabilize and survive if adult mortality rates were ≤ 22% per year and neonate mortality rates were ≤ 80% per year. This was not true for the model that I ran. This difference could be related to the number of input variables for which they had data and the programs selected to run the model. Although, Seigel and Sheil (1999) presented results from POPDYN4.5, they used RAMAS-AGE and VORTEX to support the assumption that results were not related to the program selection. The difference could also be related to the selection of parameter values (e.g., extinction was defined as only 1 sex left in the population). Another explanation for survival differences between the model run by Seigel and Sheil (1999) and this model is the environmental variability factors (standard deviations) used. Although I had an adult mortality rate of 34%, in some years it could be substantially higher or lower with an environmental variability of 22%. For example, in 2004 adult mortality was 18.2%, however, in 2005 adult mortality was 50.0%. However, all but 2 mortalities occurred after parturition in late summer/early fall. Therefore, almost all of the radio-tracked gravid females in the study contributed offspring to the population prior to predation.

Probability of extinction in 50 years was relatively high for both scenarios using an initial population size of 3761 EMRs; however, extant populations simulated by the model leveled off at 1500 and 2500 individuals in approximately 40 years. These results suggest that if the EMRs at PCCI are following one of these "extant" trajectories, current conditions are suitable for supporting a viable population. Therefore, the EMRs at PCCI are not necessarily experiencing certain population decline. Based on current knowledge of the population, the EMRs at PCCI are probably following an "extant" population trajectory because there was an overall mean annual survival of 71%, at least some females are able to reproduce annually, most mortalities took place post-parturition, and home range sizes are relatively small (mean 2.8 ha; see Chapter 1). These factors indicate that EMRs at PCCI have fairly high survival, access to food and energy is plentiful enough for biennial and some annual reproduction (Bonnet et al. 2001), and life requisites are being met by current habitat conditions without requiring large movements (Fuller et al. 2005, McDonald et al. 2005).

Although field data were available for many of the model parameters, information from the literature was used for some of the model inputs. MacLeod (2005) reported an average lifespan of 14 years; therefore, this was used as the maximum age at reproduction for EMRs in the model. However, I had to assume that all adults were sexually mature until death. Data on neonate and subadult mortality are also sparse. The estimate for the initial population size was developed using data obtained on the number of individual EMRs found within the area of a minimum convex polygon of all snake locations at PCCI. However, it was not a true estimation from a mark re-capture study. Carrying capacity was also a default parameter, with the highest allowable used because

EMRs are not known to be territorial or density dependent. Finally, genetic data were not used in this model.

It is important to note that although there were some data limitations, I am confident that the values chosen to run the model are the most appropriate with the available data. This PVA is meant to be a tool for increasing understanding of how population characteristics may influence probability of extinction under current habitat conditions and guiding management strategies to conserve the species. Lowering adult mortality by 10% and keeping subadult mortality at 47% decreased the probability of extinction by approximately 4.4%. Lowering the adult mortality rate by 10% and setting the subadult mortality at 24% decreased the probability of extinction probability by approximately 3%. Lowering the age at first reproduction to 2 years also reduced probability of extinction; however, this is not a natural history trait that can be influenced with population or habitat management. Therefore, conservation efforts focusing on minimizing and reducing EMR mortalities could decrease the probability of population extinction.

Future research should focus on EMR population demographics and should include efforts to describe mortality rates of different stage classes of EMRs, estimate population size, and describe a possible metapopulation. Maintaining viable EMR populations in southwestern lower Michigan will require a better understanding of variation in population characteristics and habitat use and the effects of habitat and land management practices on populations. Maintenance of viable EMR populations will also require increased awareness of EMR conservation issues and efforts to reduce mortality. Although the main cause of death for radio-tracked EMRs was predation, there was evidence of road-killed EMRs at PCCI. Road-signage and outreach programs about living with EMRs may help to reduce human influenced mortalities. Since most of the land in Barry County is privately owned, efforts should also focus on outreach to encourage EMR conservation on properties potentially supporting EMRs.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Survival and health of EMRs within the study area seemed relatively good. Survival data for EMRs are seldom reported in the literature, but snakes in southwestern Michigan had higher mean annual survival than EMRs in Canada and repatriated EMRs in Wisconsin (Parent and Weatherhead 2000, King et al. 2004). Overall mean annual survival of EMRs was 71% and at least some of the females are able to reproduce annually; which suggests that food intake and energy stores are plentiful enough for some individuals to invest in annual reproduction (Bonnet et al. 2001). Home range sizes were also relatively small (mean 2.8 ha), indicating that life requisites are being met by current habitat conditions in this area without requiring large movements (McDonald et al. 2005, Fuller et al.2005).

Selection of early successional deciduous upland and wetland vegetation types was prominent among EMRs at PCCI. Use of wetlands and uplands has been reported for EMRs throughout the literature (Wright 1941, Reinert and Kodrich 1982, Seigel 1986, Wilson and Mauger 1999, Sage 2005). It is clear that these vegetation types are important to EMRs in southwestern lower Michigan. Specifically, the transition area between wetlands and uplands is important for hibernacula sites, and barriers to EMR movement between the 2 vegetation types should be minimized where EMR populations are present. Radio-tracked EMRs had a mean maximum distance moved of 99.7 m between consecutive locations, and the longest distance moved by an EMR between locations was 315.6 m. Therefore, EMRs in southwestern Michigan should have access to suitable vegetation types within 315.6 m.

Snakes at YSRA stayed in the early successional scrub-shrub fen throughout the year. EMRs may not require upland habitat types if this early successional scrub-shrub fen is available. However, the infrequent use of late successional vegetation types was evident at this site, with EMR locations concentrated in the more open canopied portion of the fen with avoidance of the forested areas surrounding it. It is possible that the late successional vegetation types were acting as a barrier (Sage 2005), confining EMRs to the early successional fen. It is clear that the maintenance of these frequently used vegetation types in an early successional stage are important for EMR habitat conservation planning in southwestern lower Michigan.

Efforts focusing on locating areas supporting EMRs in southwestern Michigan should concentrate surveys in landscapes consisting of an area with early successional deciduous uplands (43-57%) and early successional deciduous wetlands (32-42%) and in early successional scrub-shrub fens. Although the HSI presented earlier has not been validated, the amount of live and dead herbaceous cover, stem density of trees and shrubs >3 m tall, and absolute dominance of trees >3 m tall may indicate habitat suitability for the EMR. Vegetation types used in the study area had high herbaceous cover and minimal stem densities and absolute dominance of trees/shrubs >3 m tall. Future researchers, biologists, and land managers should take a hierarchical approach to identifying suitable habitat. Examining the landscape composition, determining presence of suitable vegetation types and their proportions, and determining the structure and composition of those vegetation types by quantifying the listed parameters will aid in identifying potential EMR habitat and determining the suitability of known EMR habitat in southwestern Michigan.

Individual EMRs that were radio-tracked during both 2004 and 2005 (n = 3) exhibited some site fidelity with overlapping home ranges and selection of hibernation areas. Therefore, if hibernation sites and gestation sites have been identified, major disturbances within those areas should be avoided.

Although the EMRs studied seemed to have relatively high survival, the probability of extinction within 50 years was also relatively high (82.4%) based on simulations using Vortex 9.50 (Lacy et al. 2005). Therefore, efforts to minimize EMR mortality should be made. The main cause of mortality was predation. Although maintenance of suitable habitat should help to minimize predation, human-caused mortality can be managed as well. Fragmentation of habitat by roads can negatively impact EMRs by increasing mortality and acting as barriers to movements (Seigel 1986, Sage 2005). EMRs at PCCI seldom crossed the "two-lane" dirt road intersecting the property, but 3 individuals crossed it successfully. However, PCCI staff, visitors, and researchers have encountered road-killed EMRs annually. Therefore, efforts to decrease this cause of mortality are encouraged. Signage has been used in Ontario, Canada, urging drivers to "Please Break for Snakes" (Johnson 1999). In addition, outreach programs about living with EMRs may help to reduce human-caused mortalities. Most of the land in Barry County is privately owned; therefore, efforts should also focus on encouraging EMR tolerance and conservation on properties potentially supporting EMRs.

Most importantly, EMRs in southwestern lower Michigan need further research. The research presented here opens the door for increased examination and sets a baseline for future data collection. Future research should focus on strengthening data on EMR population parameters and vegetation structure and composition, validating the HSI model, and evaluating population level responses to habitat management.

APPENDICES

APPENDIX A. Eastern Massasauga Rattlesnake (EMR) post operation monitoring sheet used to evaluate the recovery of EMRs that had radio-transmitters surgically implanted in 2004 and 2005.

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:____
____
____

APPENDIX B. **Researcher summary of the mortality event of a radio-tracked, non-gravid, adult female Eastern Massasauga Rattlesnake.**

Notes regarding the mortality event of a radio-tracked non-gravid adult female Eastern Massasauga Rattlesnake (EMR) in June 2005 summarized by Kristin M. Wildman:

Researchers noticed the infrequent movement, inattentive behavior, and emaciated appearance of a non-gravid adult female EMR #3, AVID 096036072, and captured the snake on June 3, 2005 for closer examination in the field. Once the snake was in hand, researchers confirmed that the snake was quite emaciated, having lost 14.3% body weight within 3 weeks, and that the end of the radio-transmitter antenna wire was protruding through the skin (most likely a result of the weight loss). Researchers transported the EMR to the Potter Park Zoo (PPZ) Veterinary Clinic in Lansing and administered antibiotics (Baytril) intramuscularly. The EMR was held overnight until the veterinarian could examine it the next day. On June 4, 2005, the protruding wire was trimmed, radiographs were taken to determine if any internal damage had been caused by the transmitter, two small food items were offered (live "pinkies") and the EMR was held for one more night. EMR #3 was released at the point of capture on June 5, 2005 in the evening. The snake was found dead the next morning at approximately 0800 hours. Researchers took the carcass to the PPZ Veterinary Clinic for necropsy. The carcass was unspoiled and time of death was assumed to be very recent because the heart was still pumping, although all other functions had ceased. Although there was evidence of that the lack of appetite and emaciation could be attributed to parasites, transmitter implantation surgery most likely complicated and worsened the condition of the snake resulting in mortality.

Background:

This particular EMR had been implanted with a radio-transmitter in 2004, as well. During the 2004 activity season, EMR #3 was gravid however only 1 neonate was found at the parturition site. The neonate was dead; however the cause of death was unknown. EMR #3 went on to hibernate that winter and was recaptured and had the transmitter replaced on May 12, 2005.

APPENDIX C. Metadata for radio-tracked Eastern Massasauga Rattlesnake locations in Barry County, Michigan from 2004 – digital point file.

Title: 2004_emr_pts

Format: ArcView 3.2 shapefile and all associated files (*.shp, *.dbf, *.shx)

Originator: Michigan State University

Kristin M. Wildman, Graduate Research Assistant, Dept. Fisheries and Wildlife,
13 Natural Resources, Michigan State University,
East Lansing, MI 48824-1222; wildmank@msu.edu (517) 353-7981

Henry Campa III, Professor, Dept. Fisheries and Wildlife,
13 Natural Resources, Michigan State University,
East Lansing, MI 48824-1222; campa@msu.edu (517) 353-2042

Funding: Financial support for this project was provided by: Michigan State University, Michigan Natural Resources Department Nongame Program, Pierce Cedar Creek Institute, Lansing Potter Park Zoo, and the Michigan Society of Herpetologists.

Created: 2006

Description: Digital pint file of all locations recorded for Eastern Massasauga Rattlesnakes (EMR, *Sistrurs catenatus catenatus*) radio-tracked during the 2004 field season for a study examining habitat ecology and population viability of EMRs in southwestern lower Michigan. EMRs in the study were found and radio-tracked at Pierce Cedar Creek Institute Barry County, Michigan in 2004. Attributes include EMR identification, date of location, and coordinate location.

Spatial Reference: Michigan Georef from Oblique Mercator projection

Scale factor at center = 0.9996
Azimuthal angle = 337.25556
False easting = 2546731.496
False northing = - 4354009.816
Horizontal datum name = North American Datum 1983 (NAD83)

Map Units: meters

Contact: Technical questions regarding digital EMR locations:

Kristin M. Wildman
13 Natural Resources
Michigan State University
East Lansing, MI 48824
(517) 353-7981
wildmank@msu.edu

Methods:

All EMRs fitted with transmitters were tracked and located daily during one of three 8-hour time periods (0000-0759, 0800-1559, 1600-2359). Locations were recorded with a Garmin® Global Positioning System unit (Garmin International Inc. Olathe, KS) in Universal Transverse Mercator (UTM) coordinates. UTM coordinates were recorded as northings and eastings in a .dbf file.

In order to keep location error similar among nearby locations, subsequent locations were recorded as distances (m) and bearings (°) (measured using a meter tape and a compass) from the former GPS-recorded location to the new locations. This was done if the new location was 2-30 m from the last GPS location. When snakes were within 2 meters of a former location, it was recorded as that location. Locations were recorded using the GPS unit once the snake moved farther than 30 m from the previous GPS location, if there was too much vegetation between the previous GPS location and the new location for distance and bearing measurements, or if the EMR was located in a different vegetation type than the former location.

The northing and easting coordinates recorded in the .dbf files for each snake were added as themes and converted to shapefiles in ArcView 3.2. A script was written to generate coordinates from the distance and bearing information collected in the field. The resulting coordinates were then converted to a point shapefile. Shapefiles for GPS locations were then merged with shapefiles for distance/bearing locations and the resulting shapefile was projected in Michigan Georef.

Data Quality:

Projected point shapefiles of EMR locations were overlaid with 1998 Series United States Geological Survey (USGS) Digital Orthophoto Quadrangles in ArcView 3.2. The researcher who recoded the EMR locations in the field examined the projected point locations in relation to the aerial photo imagery to ensure that the shapefile was representative of actual EMR locations within the landscape. All point locations are representative.

Final Digital Shapefile:
12 individuals
847 locations

Data Accuracy:

All locations of EMRs were recorded at the exact location of the animals. Researchers typically had a visual of individuals at every location event and were able to pinpoint hidden individuals within 1 m using radiotelemtry. Estimated Position Error (EPE - measurement of horizontal position error in feet or meters based upon a variety of factors including Dilution Of Precision and satellite signal quality) for GPS locations were never greater than 5.2 m and Dilution Of Precision (DOP - measure of the GPS receiver/satellite geometry. A low DOP value indicates better relative geometry and higher corresponding accuracy) for GPS locations were never higher than 1.3. Therefore, researchers conclude that human and equipment error was minimal.

APPENDIX D. Metadata for radio-tracked Eastern Massasauga Rattlesnake locations in Barry County, Michigan from 2005 – digital point file.

Title: 2005_emr_pts

Format: ArcView 3.2 shapefile and all associated files (*.shp, *.dbf, *.shx)

Originator: Michigan State University
Kristin M. Wildman, Graduate Research Assistant, Dept. Fisheries and Wildlife,
13 Natural Resources, Michigan State University,
East Lansing, MI 48824-1222; wildmank@msu.edu (517) 353-7981
Henry Campa III, Professor, Dept. Fisheries and Wildlife,
13 Natural Resources, Michigan State University,
East Lansing, MI 48824-1222; campa@msu.edu (517) 353-2042

Funding: Financial support for this project was provided by: Michigan State University, Michigan Natural Resources Department Nongame Program, Pierce Cedar Creek Institute, Lansing Potter Park Zoo, and the Michigan Society of Herpetologists.

Created: 2006

Description: Digital pint file of all locations recorded for Eastern Massasauga Rattlesnakes (EMR, *Sistrurs catenatus catenatus*) radio-tracked during the 2005 field season for a study examining habitat ecology and population viability of EMRs in southwestern lower Michigan. EMRs in the study were found and radio-tracked at Pierce Cedar Creek Institute and Yankee Springs State Recreation Area in Barry County, Michigan in 2005. Attributes include EMR identification, date of location, and coordinate location.

Spatial Reference: Michigan Georef from Oblique Mercator projection
Scale factor at center = 0.9996
Azimuthal angle = 337.25556
False easting = 2546731.496
False northing = - 4354009.816
Horizontal datum name = North American Datum 1983 (NAD83)

Map Units: meters

Contact: Technical questions regarding digital EMR locations:

Kristin M. Wildman
13 Natural Resources
Michigan State University
East Lansing, MI 48824
(517) 353-7981
wildmank@msu.edu

Methods:

All EMRs fitted with transmitters were tracked and located daily during one of three 8-hour time periods (0000-0759, 0800-1559, 1600-2359). Locations were recorded with a Garmin® Global Positioning System unit (Garmin International Inc. Olathe, KS) in Universal Transverse Mercator (UTM) coordinates. UTM coordinates were recorded as northings and eastings in a .dbf file.

In order to keep location error similar among nearby locations, subsequent locations were recorded as distances (m) and bearings (°) (measured using a meter tape and a compass) from the former GPS-recorded location to the new locations. This was done if the new location was 2-30 m from the last GPS location. When snakes were within 2 meters of a former location, it was recorded as that location. Locations were recorded using the GPS unit once the snake moved farther than 30 m from the previous GPS location, if there was too much vegetation between the previous GPS location and the new location for distance and bearing measurements, or if the EMR was located in a different vegetation type than the former location.

The northing and easting coordinates recorded in the .dbf files for each snake were added as themes and converted to shapefiles in ArcView 3.2. A script was written to generate coordinates from the distance and bearing information collected in the field. The resulting coordinates were then converted to a point shapefile. Shapefiles for GPS locations were then merged with shapefiles for distance/bearing locations and the resulting shapefile was projected in Michigan Georef.

Data Quality:

Projected point shapefiles of EMR locations were overlaid with 1998 Series United States Geological Survey (USGS) Digital Orthophoto Quadrangles in ArcView 3.2. The researcher who recoded the EMR locations in the field examined the projected point locations in relation to the aerial photo imagery to ensure that the shapfile was representative of actual EMR locations within the landscape. All point locations are representative.

Final Digital Shapefile:
16 individuals
1030 locations

Data Accuracy:

All locations of EMRs were recorded at the exact location of the animals. Researchers typically had a visual of individuals at every location event and were able to pinpoint hidden individuals within 1 m using radiotelemtry. Estimated Position Error (EPE - measurement of horizontal position error in feet or meters based upon a variety of factors including Dilution Of Precision and satellite signal quality) for GPS locations were never greater than 5.2 m and Dilution Of Precision (DOP - measure of the GPS receiver/satellite geometry. A low DOP value indicates better relative geometry and higher corresponding accuracy) for GPS locations were never higher than 1.3. Therefore, researchers conclude that human and equipment error was minimal.

APPENDIX E. Vortex parameters for modeling Eastern Massasauga Rattlesnake population viability in southwestern lower Michigan.

Table A.1. Vortex parameters for modeling eastern massasauga population viability at Pierce Cedar Creek Institute in Barry County, Michigan, using field data collected 2004-2005 and information from the literature.

	Parameter	Value	Data Source
Scenario Settings	Number of Iterations	1000	
	Number of Years	50	
	Extinction Definition	1 sex left	
	Number of Populations	1	Field data
Species Description	Inbreeding Depression?	No	Assumption
	EV^A (reproduction) Correlated with EV (survival)	No	Assumption
Labels and (Optional) State Variables	Population 1 Label	PCCI	
	Population State Variables	Don't use	
Reproductive System	Mating System	Polygamous	Duvall et al. 1993 - vipers in general
	Age of First Offspring for Females	3.5	3-4 in Harding 1997, and Siegel & Sheil 1998
	Age of First Offspring for Males	3.5	3-4 in Harding 1997, and Siegel & Sheil 1999
	Maximum Age of Reproduction	14	MacLeod
	Maximum Number of Progeny per Year	12	Field data
	Sex Ratio at Birth -- in % Male	50	Keenlyne & Beer 1973
	Density Dependent Breeding	No	Assumption based on literature suggesting breeding is dependent on individual condition (Aldridge & Duvall 2002)
Reproductive Rates	% Adult Females Breeding	64%	Field data (2004 & 05 avg)
	EV in % Breeding	0.16	SD for the % adult females breeding (2004 & 05 mean)
	Distribution of Number of Offspring per Female per Year	Normal	Since data is lacking, will assume normal
	Mean Litter Size	9	Field Data
	SD	3.36	Field Data
Mortality Rates	Female Mortality from Age 0 to 1	68%	King 1999- radio-tracked neonates to hibernation and reported mortality of 78%,Ireduced it by 10% because neonates were radio-tracked which may influence survival.

Table A.1 (cont). Vortex parameters for modeling eastern massasauga population viability at Pierce Cedar Creek Institute in Barry County, Michigan, using field data collected 2004-2005 and information from the literature.

	Parameter	Value	Data Source
Mortality Rates (continued)	SD in 0 to 1 Female Mortality due to EV	17%	Standard Deviation for neonate mortality rates reported by King 1999, Stanford & King 2004, Charland 1999, Kissner 2005.
	Female Mortality from Age 1 to 2	47%	King et al. 2004- repatriated subadults had 47% mortality. This may be high because subadults were repatriated and no subadults radio-tracked at PCCI were determined dead. So, 47% was changed to 24% mortality.
	SD in 1 to 2 Female Mortality due to EV	4.49%	Calculated from juvenile plains garter mortality rates from Stanford & King (2004)
	Female Mortality from Age 2 to 3	47%	King et al. 2004- repatriated subadults had 47% mortality. This may be high because subadults were repatriated and no subadults radio-tracked at PCCI were determined dead. So, 47% was changed to 24% mortality.
	SD in 2 to 3 Female Mortality due to EV	4.49%	Calculated from juvenile plains garter mortality rates from Stanford & King (2004)
	Annual Mortality After Age 3.5	34%	Field Data: Mean between 2004 & 05 for all adults
	SD in Mortality Age After 3.5	22%	Field Data: Standard Deviation
	Male Mortality from Age 0 to 1	68%	King 1999- radio-tracked neonates to hibernation and reported mortality of 78%,Ireduced it by 10% because neonates were radio-tracked which may influence survival.
	SD in 0 to 1 Male Mortality due to EV	17%	Standard Deviation for neonate mortality rates reported by King 1999, Stanford & King 2004, Charland 1999, Kissner 2005.

Table A.1 (cont). Vortex parameters for modeling eastern massasauga population viability at Pierce Cedar Creek Institute in Barry County, Michigan, using field data collected 2004-2005 and information from the literature.

	Parameter	Value	Data Source
Mortality Rates (continued)	Male Mortality from Age 1 to 2	47%	King et al. 2004- repatriated subadults
	SD in 1 to 2 Male Mortality due to EV	4.49%	Calculated from juvenile plains garter mortality rates from Stanford & King (2004)
	Male Mortality from Age 2 to 3	47%	King et al. 2004- repatriated subadults
	SD in 2 to 3 Male Mortality due to EV	4.49%	Calculated from juvenile plains garter mortality rates from Stanford & King (2004)
	Annual Mortality After Age 3.5	34%	Field Data: Mean between 2004 & 05 for all adults
	SD in Mortality Age After 3.5	22%	Field Data: Standard Deviation
Catastrophe	Catastrophe 1	Flood	Seigel et al. 1998
	Percent Frequency of Catastrophe 1	0.0	Highly unlikely that a catastrophe will happen and impact population.
	Severity on Reproduction	1.0	Highly unlikely that a catastrophe will happen and impact population.
	Severity on Survival	1.0	Highly unlikely that a catastrophe will happen and impact population.
Mate Monopolization	% Males in Breeding Pool	60%	Field data (2004 & 05 avg)- calculated as % males found to be adults among all males found in the study.
Initial Population Size	Stable Age Distribution?	Yes	Assume
	Specified Age Distribution?	No	Too specific, don't have data
	Population Size for Stable Age Distribution	Variable	Varies by simulation. Based on field data and data presented by Lind et al. (2005)
Carrying Capacity	Carrying Capacity	3000000	Highest allowable in model program
	SD in Carrying Capacity due to EV	0.001	Assume little variation
	Change in Carrying Capacity?	No	Assumed
Harvest	Population Harvested?	No	Rare species on a preserve
Supplementation	Population Supplemented?	No	No current supplementation, effects unknown
Genetic Management		No	Not enough data to include

LITERATURE CITED

LITERATURE CITED

Aldridge, R.D., and D. Duvall. 2002. Evolution of the mating season in the pitvipers of North America. Herpetological Monographs.

Anderson, S.H. and K.J. Gutzwiller. 2005. Wildlife Habitat Evaluation. Pp. 489-502 *in*: C.E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Anton, T.G. 1999. Massasaugas in northeastern Illinois: Current status of *Sistrurus catenatus catenatus* in Cook and Lake Counties, Illinois. Pp. 94-98

Berry, K.H. 1986. Introduction: Development, testing, and application of wildlife-habitat models. Pp. 3-4 *in*: J. Verner, M.L. Morrison, and C.J. Ralph, editors. Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates. University of Wisconsin Press, Madison, Wisconsin

Bonnet, X., G. Naulleau, and R. Shine. 1999. The dangers of leaving home: dispersal and mortality in snakes. Biological Conservation 89: 39-50.

Bonnet, X., G. Naulleau, R. Shine, and O. Lourdais. 2001. Short-term versus long-term effects of food intake on reproductive output in a viviparous snake, *Vipera aspis*. Oikos 92: 297-308.

Brotons, L., W. Thuiller, M.B. Araujo, and A.H. Hirzel. 2004. Presence-absence versus presence-only modeling methods for predicting bird habitat suitability. Ecography 27: 437-448.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388-394.

Casper, G.S., T.G. Anton, R.W. Hay, A.T. Holycross, R.S. King, B.A. Kingsbury, D. Mauger, C. Parent, C.A. Phillips, A. Resetar, R.A. Seigel, T.P. Wilson. 2001. Recommended standard survey protocol for the eastern massasauga, *Sistrurus catenatus catenatus*. http://midwest.fws.gov/endangered/reptiles/mass-surv-prot.pdf.

Charland, M.B. 1999. Size and winter survivorship in neonatal western rattlesnakes (*Crotalus viridis*). Canadian Journal of Zoology 67: 1620-1625.

Coulson, T., G.M. Mace, E. Hudson, and H. Possingham. 2001. The use and abuse of population viability analysis. Trends in Ecology and Evolution 16: 219-221.

Cross, C.L. and C.E. Petersen. 2001. Modeling snake microhabitat from radiotelemetry studies using polytomous logistic regression. Journal of Herpetology 35: 590-597.

Dunn, S. 1999. Snakes in bogs and wetland ecosystems. Pp.151-154 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

Duvall, D., G.W. Schuett, and S.J. Arnold. 1993. Ecology and evolution of snake mating systems. Pp. 165-200 *in*: R.A. Seigel and J.T. Collins, editors. Snakes: Ecology and Behavior. McGraw-Hill, N.Y.

Ellner, S.P., J. Fieberg, D. Ludwig, and C. Wilcox. 2002. Precision of population viability analysis. Conservation Biology 16: 258-261.

Fuller, M.R., J.J. Millspaugh, K.E. Church, and R.E. Kenward. 2005. Wildlife radiotelemetry. Pp. 377-417 *in*: C.E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Gibbs, H.L. 1999. Conservation genetics of Eastern Massasauga Rattlesnakes *Sistrurus catenatus catenatus*. Pp. 50-52 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

Harding, J.H. 1997. Amphibians and reptiles of the Great Lakes Region. University of Michigan Press. Ann Arbor. 378 pp.

Hallock, L.A. 1991. Habitat utilization, diet and behavior of the Eastern Massasauga (*Sistrurus catenatus*) in southern Michigan. M.S. Thesis, Michigan State University. 40 pp.

Holycross, A.T. and S.P. Mackessy. 2002. Variation in the diet of *Sistrurus catenatus* (massasauga), with emphasis on *Sistrurus catenatus edwardsii* (Desert Massasauga). Journal of Herpetology 36: 454-464.

Hooge, P.N., W. Eichenlaub, and E. Solomon. 1999. The animal movement program. USGS, Alaska Biological Science Center.

Hurley, J.F. 1986. Summary: Development, testing, and application of wildlife-habitat models—the manager's viewpoint. Pp. 151-153 *in*: J. Verner, M.L. Morrison, and C.J. Ralph, editors. Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates. University of Wisconsin Press, Madison, Wisconsin.

Hutchinson, B., C. Duchesne, and H. Schryver. 1992. GIS analysis of habitat use by massasauga rattlesnakes in Bruce Peninsula National Park. Pp. 45-47 *in*: B. Johnson and V. Menzies, editors. "International symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*". Toronto Zoo, Toronto, Ontario.

Jemison, S.C., L.A. Bishop, P.G. May, and T.M. Farrell. 1995. The impact of PIT-tags on growth and movement of the rattlesnake, *Sistrurus milarius*. Journal of Herpetology 29: 132-136.

Johnson, B. 1999. Managing attitudes: Education strategies for the recovery of the Eastern Massasauga Rattlesnake. Pp. 33-41 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61: 65-71.

Johnson, G. and D.J. Leopold. 1998. Habitat management for the eastern massasauga in a central New York peatland. Journal of Wildlife Management 62(1): 84-97.

Johnson, G. 2000. Spatial ecology of the eastern massasauga (*Sistrurus c. catenatus*) in a New York peatland. Journal of Herpetology 34: 186-192.

Kaplan, E.L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 53: 457-481.

Keenlyne, K.D., and J.R. Beer. 1973. Note on the size of *Sistrurus catenatus catenatus* at birth. Journal of Herpetology 7: 381-382.

Kernohan, B.J., R.A. Gitzen, and J.J. Millspaugh. 2001. Analysis of animal space and movements. Pp. 125-166 *in*: J.J. Millspaugh and J.M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California.

King, R.S. 1999. Habitat use and movement patterns of the eastern massasauga rattlesnake in Wisconsin. P. 80 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

King, R., C. Berg, and B. Hay. 2004. A repatriation study of the eastern massasauga (*Sistrurus catenatus catenatus*) in Wisconsin. Herpetologica 60: 429-437.

Kingsbury, B. 2002. Massasauga ecology at Indian Springs Metropark. Interim Report to Michigan Department of Natural Resources. On File. Lansing, Michigan.

Kingsbry, B.A., J.C. Marshall, and J. Manning. 2003. Activity patterns and spatial resource selection of the Eastern Massasauga Rattlesnake in northeastern Indiana. Final Report, Indiana-Purdue University. 24 pp.

Kissner, K.J. and P.J. Weatherhead. 2005. Phenotypic effects on survival of neonatal Northern Watersnakes *Nerodia sipedon*. Journal of Animal Ecology 74: 259-265.

Kjoss, V.A. 2000. Community structure of snakes in a fragmented landscape. M.S. Thesis, University of New Hampshire. 56 pp.

Lacy, R.C., M. Borbat, and J.P. Pollak. 2005. *VORTEX: A Stochastic Simulation of the Extinction Process*. Version 9.50. Brookfield, IL: Chicago Zoological Society.

Lind, A.J., H.H. Welsh, D.A. Tallmon. 2005. Garter snake population dynamics from a 16-year study: Considerations for ecological monitoring. Ecological Applications 15: 294-303.

Lourdais, O., X. Bonnet, and P. Doughty. 2002. Costs of anorexia during pregnancy in a viviparous snake (*Vipera aspis*). Journal of Experimental Zoology 292: 487-493.

MacLeod, H. 2005. The Eastern Massasauga Rattlesnake. McMaster University, Hamilton, Ontario, Canada. http://www.science.mcmaster.ca/Biology/CBCN/genetics/mac_mass.htm.

Mauger, D. and T.P. Wilson. 1999. Home range and habitat use of *Sistrurus catenatus catenatus* in Will County, Illinois. Pp. 125-134 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

Maple, W.T. and L.P. Orr. 1968. Overwintering adaptations of *Sistrurus c. catenatus* in northeastern Ohio. Journal of Herpetology 2(3-4): 179-180.

McDonald, L.L., J.R. Alldredge, M.S. Boyce, and W.P. Erickson. 2005. Measuring availability and vertebrate use of terrestrial habitats and foods. Pp. 465-488 *in*: C.E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

MDNR, Michigan Department of Natural Resources Forest, Mineral, and Fire Management Department. 2003. 2001 Integrated Forest Management Analysis Program/Gap Analysis Program Land Cover. MDNR, Lansing, Michigan.

Parent, C. and P.J. Weatherhead. 2000. Behavioral and life history responses of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) to human disturbance. Oecologia 125: 170-178.

Phillips, C.A., M.J. Dreslik, D.B. Shepard, B.C. Jellen. 2002. Population and spatial ecology of the Eastern Massasauga Rattlesnake (*Sistrurus catenatus catenatus*) at Carlyle Lake, Clinton County, Illinois. Report to the State of Illinois, Department of Natural Resources, Springfield, Illinois and U.S. Fish and Wildlife Service. 50 pp.

Reed, J.M., L.S. Mills, J.B. Dunning, E.S. Menges, K.S. McKelvey, R. Frye, S.R. Bessinger, M. Anstett, and P. Miller. 2002. Emerging issues in population viability analysis. Conservation Biology 16: 7-19.

Reinert, H.K. and D. Cundall. 1982. An improved surgical implantation method for radio-tracking snakes. Copeia 1982: 702-705.

Reinert, H.K. and W.R. Kodrich. 1982. Movements and habitat utilization by the massasauga, *Sistrurus catenatus catenatus*, Journal of Herpetology 16: 162-171.

Reinert, H.K. 1992. Radiotelemetric field studies of pitvipers: data acquisition and analysis. Pp. 185-197 *in*: J.A. Campbell and E.D. Brodie, eds. Biology of the pitivipers. Selva, Tyler, Texas.

Rudolph, D.C., S.J. Burgdorf, R.R. Schafer, and R.N. Conner. 1998. Snake mortality associated with late season radio-transmitter implantation. Herpetological Review 29: 155-156.

Sage, J.R. 2005. Spatial ecology, habitat utilization, and hibernation ecology of the Eastern Massasauga Rattlesnake (*Sistrurus catenatus catenatus*) in a disturbed landscape. M.S. Thesis, Purdue University, Fort Wayne, Indiana. 93 pp.

Samuel, M.D., and M.R. Fuller. 1996. Wildlife Radiotelemetry. Pp. 370-418 *in*: T.A. Bookout, editor. Research and management techniques for wildlife and habits. Fifth ed., rev. The Wildlife Society, Bethesda, Maryland.

Schaefer, W.H. 1934. Diagnosis of sex in snakes. Copeia 1934: 181.

Seigel, R.A. 1986. Ecology and conservation of an endangered rattlesnake, *Sistrurus catenatus*, in Missouri, USA. Biological Conservation 35: 333-346.

Seigel, R.A., C.A. Sheil, and J.S. Doody. 1998. Changes in a population of an endangered rattlesnake *Sistrurus catenatus* following a severe flood. Biological Conservation 83:127-131.

Seigel, R.A. and C.A. Sheil. 1999. Population viability analysis: Applications for the conservation of massasaugas. Pp. 17-22 *in*: B. Johnson and M. Wright, editors. "Second international symposium and workshop on the conservation of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*: Population and habitat management issues in urban, bog, prairie, and forested ecosystems". Toronto Zoo, Toronto, Ontario.

Space Imaging. 2004. Integrated forest monitoring assessment and prescription IFMAP: Review of remote sensing technologies used in the IFMAP project. On File. Lansing, Michigan.

Stanford, K.M. and R.B. King. 2004. Growth, survival, and reproduction in a North Illinois population of the Plains Gartersnake (*Thamnophis radix*). Copeia 2004: 465-478.

Szymanski, J.A. 1998. Status assessment for the eastern massasauga. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota. 71 pp.

Thoen, G.F. 1990. Soil survey of Barry County, Michigan. USDA, Soil Conservation Service.

USFWS, Unites States Fish and Wildlife Service. 1999. Eastern Massasauga Rattlesnake. http://midwest.fws.gov/endangered. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota.

Weatherhead, P.J. and F.W. Anderka. 1984. An improved radio-transmitter implantation technique for snakes. Journal of Herpetology 18: 264-269.

Weatherhead, P.J. and K.A. Prior. 1992. Preliminary observations of habit use and movements of the Eastern Massasauga Rattlesnake. Journal of Herpetology 26: 447-452.

Weatherhead, P.J. and C. Parent. 2000. Behavioral and life history responses of eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) to human disturbance. Oecologia 125: 170-178.

Winterstein, S.R., K.H. Pollock, and C.M. Bunck. 2001. Analysis of survival data from radiotelemetry studies. Pp. 351-380 *in*: J.J. Millspaugh and J.M. Marzluff, editors. Radio Tracking and Animal Populations. Academic Press, San Diego, California, USA.

Wright, B.A. 1941. Habit and habitat studies of the massasauga rattlesnake (*Sistrurus catenatus catenatus* Raf.) in northeastern Illinois. American Midland Naturalist 25: 659-672.