Mark recapture population study of the eastern massasauga rattlesnake: Effects of prey abundance on habitat use

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Abstract

The eastern massasauga rattlesnake is listed as a candidate species for federal listing under the U.S. Endangered Species Act. Long term mark recapture studies are important to understand the population dynamics of a threatened species and to develop proper management strategies. From late April to early August of 2014 a mark recapture study was conducted on the eastern massasauga rattlesnake at Pierce Cedar Creek located in Hastings, Michigan. A total of 85 rattlesnakes were captured, 56 of which were unique individuals. 27 adult male and 20 adult female rattlesnakes were collected and used to estimate abundance and survivability. We estimated abundance to be 30 adult females, 35 adult males, and total estimate of 66 rattlesnakes in the population. Adult male survivability was estimated at 0.7 and for adult females 0.65. We also conducted a small mammal mark recapture study in an effort to correlate rattlesnake habitat use with prey abundance. We found a negative correlation between rattlesnake and prey habitat use equal to -1.72 with an R^2 value equal to 0.716. Genetic studies have revealed that these snakes historically have had small populations. Our findings show the small population trend of the eastern massasauga rattlesnake continues today. More studies on population structure and genetics across the geographical range of the species will be invaluable to management of the species.

Introduction

In our current era of biodiversity loss herpetofuana are considered to be some of the most imperiled species on the planet (Gibbons et al. 2000). Approximately 25% of all reptile species are federally listed as threatened or endangered in the U.S. alone (Szymanski 1998, Johnson et al. 2000). For many of these species, knowledge of basic information on population dynamics, which is essential for effective management and recovery (Gibbons et al. 2000), is lacking.

The eastern massasauga rattlesnake (*Sisturus catenatus catenatus*) is currently a candidate species for federal listing under the U.S. Endangered Species Act. While Michigan is considered the last remaining stronghold for this species, 33% of historical populations have been extirpated in the state (Szymanski 1998, Johnson et al. 2000). The primary causes that have led to the decline of the eastern massasauga rattlesnake populations include habitat loss (Szymanski 1998), road mortality (Shepard et al. 2008), and direct human persecution (Parent and Weatherhead 2000). This species, while not considered aquatic, is typically found in wetland habitats in spring to mid-summer and upland woodland meadows in the late summer. Before winter the snakes return to the wetlands in search of hibernacula, which consists of crayfish and small mammal burrows (Harding and Holman 2006). The geographic range of this reptile spans throughout the Great Lakes region and into southern Ontario, Canada. In every state or province in which this snake is found it is listed as threatened or endangered with the exception of Michigan.

Remnant massasauga populations are distributed in isolated patches of suitable habitat. Most of the remaining suitable habitat is on public land or nature reserves. A good understanding of the population dynamics and the long-term viability of the eastern massasauga rattlesnake is largely unknown. Herpetologists and like-minded conservation biologists have determined that long term research of these populations is the best course of action for protection of this species.

Most research on massasauga ecology has focused on habitat selection and spatial ecology with the use of radio telemetry and spatial analysis (Reinert and Kodrich 1982, Johnson 2000, Harvey and Weatherhead 2006, Marshall et al. 2006, Moore and Gillingham 2006, Bailey et al. 2012). Although results of these studies are not always applicable across the entire range of the species, these studies have provided solid baseline knowledge on the structural and thermal habitat preferences of the eastern massasauga rattlesnake in different locales. One factor of massasauga ecology and habitat selection that has been neglected is the abundance of prey. Studies have shown that massasaugas primarily feed on small mammals including meadow voles (*Microtus pennsylvanicus),* white-footed mice *(Peromyscus leucopus),* meadow jumping mice *(Zapus hudsonius),* and short-tailed shrews (*Blarina brevicauda*) (Keenlyne and Beer 1973, Shepard et al. 2004). It is unknown if prey density affects use or avoidance of certain habitats by massasaugas (Carfagno et al. 2006)

Data on demographic rates and abundance of these remnant populations is lacking due largely to the cryptic nature of the snakes and low capture rates. Studies that aim to understand more about the population dynamics of this species are arduous and time consuming. They often taking several years to compile sufficient data for proper statistical analysis. In most situations basic count data, such as minimum number alive, are used to generate baseline population data. However, this method does not account for probability of detection, which is very low for cryptic species such as the eastern massasauga rattlesnake. Capture-mark-recapture models such as closed population models are thus more appropriate because they can account for differences in detection probability due to factors such as sex or reproductive condition (Mazerolle et al. 2007).

We used a closed population capture-recapture model to estimate the abundance of adult eastern massasauga rattlesnakes at Pierce Cedar Creek Institute (PCCI).We used the Schnabel index to concurrently estimate abundances of small mammals in each of the rattlesnake survey units. The two objectives of the study were to 1) continue long-term monitoring of eastern massasauga rattlesnakes at PCCI in order to estimate adult abundance and annual survival probabilities and (2) study the effect of prey base on eastern massasauga rattlesnake habitat use.

Methods

We conducted our study at Pierce Cedar Creek Institute (PCCI), which is located in Barry County Michigan. PCCI is a biological field station with 661 acres of land composed of upland forests, prairie fen, wet meadow, upland prairie, and adjoining rivers. Half of all land at PCCI is classified as wetlands. The study site for the monitoring of the eastern massasauga rattlesnake and mammal trapping was 22.2 ha in size and can be classified as primarily prairie fen and wet meadow.

From May 6, 2014 through August 8, 2014, we conducted 60 days of visual encounter surveys for eastern massasauga rattlesnakes. Surveys were usually conducted between 0900 hours and 1200 hours and between 1300 hours and 1800 hours. Each surveyor monitored their search effort, total time spent actively looking for snakes. This data was used in order to calculate catch-per unit effort, which was expressed as the number of snakes caught per unit time. Locations of captured snakes were recorded using a Garmin GPSmap 62 stc handheld GPS unit. Flagging tape was placed at the captured snake, and waypoints were marked in order to return the snakes to their point of capture. At each snake capture location we recorded various environmental parameters. Percent cloud cover, precipitation, presence of surface water within one meter, percent of live and dead vegetation, percent rock, number of logs, number of woody stems, whether the area was burned, time of capture, and snake behavior upon capture were all visual estimates. Precipitation, shaded air temperature, relative humidity, and wind speed were measured on a Kestrel meter. Soil temperature was measured on a soil probe. Canopy cover was measured on a densiometer. Vegetation data was collected in an approximately 1 m^2 area around the capture location. Captured snakes were handled in compliance with GVSU IACUC (Permit number 14-04-A) to ensure the safety of both the snakes and the researchers.

Captured snakes were transported inside pillowcases within buckets to a field lab for morphological data. We calculated the snake mass by weighing the snake inside of the pillowcase and then subtracting the weight of the pillowcase without the snake inside. Photos were taken of each individual snake, and total length of the snakes was measured using the squeezebox technique (Quinn and Jones 1974). Snakes were restrained inside a tube to ensure safety of the handler. Tail length was measured and subtracted from the total length of the snake to calculate snout to vent length (SVL). Tubed snakes were sexed by probing for the presence or absence of hemipenes. Snakes were palpated for the presence of food and/or embryos. Using an AVID PIT tag scanner, we were able to determine if the snakes were previously captured. Snakes with pre-existing PIT tags had their PIT tag ID recorded, and snakes that did not were given a new PIT tag. A subdermal passive integrated transponder (PIT) was placed two thirds of the way down the body on the right dorsal flank. Snakes were marked by applying nail polish patterns to their rattles. Approximately200 µl of blood was taken from the caudal vein/artery of each snake and stored in 95% ethanol for future genetic work. After processing, each snake was released at their capture points on the same day of capture.

We estimated small mammal densities in the snake sampling units using data collected from five consecutive sampling days. We placed 104 Sherman traps throughout each of the snake sampling units. Traps were placed 20 meters apart in a grid formation with the number of traps varying depending on the size of the survey unit (to keep the trap density approximately equal in each sampling unit). The traps were baited with sunflower seeds and set at night. Traps were checked the following morning. For each capture, we recorded the species and whether the animal was an initial capture or a recapture. We marked each initial mammal capture with a unique numbered ear tag.

Data Analysis

For our eastern massasauga rattlesnake population estimate at PCCI, we used the program MARK version 8.0 (White and Burnham 1999). For our population analysis, we only included adult individuals because they are the ones who contribute to population growth. Males with a snout to vent length (SVL) ≥43 cm and females with a SVL ≥ 42 cm were classified as adults. Preliminary analysis of the data collected indicated that we had sufficient data to estimate abundance and survival probability for both adult females and adult male eastern massasauga rattlesnakes (Table 1). For calculating our abundance estimates, we condensed our search effort days from April 22 through August 8, 2014 into 6 occasions. The number of days in each occasion is 10, 10, 9, 9, 9, and 9 days, respectively. Binary capture histories were created for each individual. The binary code was based on whether the snake was captured at least once (=1) or not captured (=0) during each occasion. Sex was included as a grouping variable. Males were listed as (1,0) and females were listed as (0,1).

We used "Full Likelihood p and c" closed capture models in MARK to estimate abundance. We used ClosedTest version 3to evaluate our data for violations of closure (Stanley and Burnham 1999). We calculated a p-value = 0.175 for adult males and a p-value = 0.170 for adult females. A p-value ≥ 0.15 is an indicator of good fit (Burnham & Anderson 2010). However, subcomponent statistics of NM vs. JS Test for occasion 5 was significant (p-value = 0.050). This provides evidence of emigration or mortality, i.e. dispersion between occasion 4 and 5. We omitted this small amount of dispersion and continued with our analysis.

We ran a set of 16 candidate models which considered sex, behavior, time, and effort, including additive and interactive effects. Akaike's information criterion (AIC_c) was used to rank the models, and model averaging was used to obtain abundance estimates for males and females separately and overall abundances for both sexes (Table 3). Behavior pertains to the presence of a handling effect on capture vs. recapture probability. We calculated lognormal confidence intervals for abundance estimates.

For calculating annual survival probability we condensed the data down into 6 occasions by year extending from 2008, 2009, 2011, 2012, 2013, and 2014. Sex was included as a grouping variable. Some animals from 2008 and 2009 were removed from the population due to their inclusion in a radiotelemetry study (i.e., they were recaptured with telemetry and not encounter surveys). To test for goodness of fit the bootstrap approach was used with 1,000 simulations. We found the p-value = 0.098. Our value indicates a slight departure from model assumptions. Due to this issue we estimated a c-hat value of 1.345 to correct for slight over dispersion.

We used Cormack Jolly-Seber models in MARK to estimate survival probability. A set of 7 candidate models which considered sex and time were run. The parameters for the first two recapture probabilities for males were fixed to zero because no males were recaptured on occasions 2 or 3. AIC_c was used to rank models and perform model averaging to estimate annual survival estimates and yearly recapture probabilities for both males and females.

To estimate the small mammal population densities at each of the snake sampling sites we first used ArcGIS to calculate the area of each sampling site. We then estimated total small mammal abundance using the Schnabel Index based on five days of mammal trapping. The Schnabel Index allowed us to estimate abundance even with low recapture rates. We used both the area and abundance data to calculate small mammal densities. We plotted snake density against small mammal density and ran a linear regression to determine if there was a correlation between the two densities.

Results

From April 22 to August 8, 2014 85 eastern massasauga rattlesnakes were captured in the various sampling units. From these 85 rattlesnakes, 56 were unique individuals. Of the 56 unique individuals, 14 were recaptures from previous years. The snakes were broken down by age class and sex. We captured 27 adult males (mean SVL= 53.96 cm, SD=6.73 cm), 20 adult females (mean SVL= 50.43 cm, SD= 5.25 cm), 6 male juveniles (mean SVL= 28.3 cm, SD= 7.43cm), and 3 juvenile females (mean SVL= 30.93 cm, SD= 8.51 cm).

When calculating abundance, we found no violations of closure using the Stanley & Burnham Closure Test (p-value = 0.175). We did not detect violations of assumptions using the (Otis et al. 1978) Closure Test (p-value = 0.170). Using the program MARK we estimated adult female abundance to be 30 individuals (SE=8.5, CI= 28-65) and estimated adult male abundance to be 35 individuals (SE=8.1, CI= 28-65). We found the pooled estimate for both adult males and adult females to be 66 individuals (SE=14.1, CI=51-114).

We used the bootstrap approach with 1000 simulations to estimate survival probability. We found a p-value= 0.098. Our p-value indicates there are modest violations of model assumptions. Therefore, we calculated a c-hat value of 1.3453 using the deviance statistic to correct for over dispersion. For adult male snakes we estimated an annual survival probability of 0.7 (SE=0.091, CI= 0.5-0.85). For adult female snakes we estimated an annual survival probability of 0.65 (SE= 0.112, CI=.42-0.83). Recapture rates for both adult male and adult female snakes was calculated (Table 2).

Small mammal abundances were calculated for each corresponding sampling (Figure 1). Using linear regression we found a slight negative correlation between snake densities and small mammal densities. We calculated an R^2 value of 0.716. The slope was -1.72.

Table 1: CJS_M-array showing number of recaptures in a given sampling period for both males and females. R(i) indicates the number of potential recaptures for any occasion. This table was created by program MARK and indicates that there is sufficient data to make estimates on abundance and survivability.

Group 1: males

Occasions	R(i)	j= 2	3	4	5	6	Total
1	7	0	0	0	1	0	1
2	13		0	1	2	0	3
3	0			0	0	0	0
4	3				0	2	2
5	13					5	5

Group 2: females

Occasions	R(i)	j= 2	3	4	5	6	Total
1	11	1	0	1	0	0	2
2	10		1	0	0	0	1
3	10			0	3	0	3
4	5				2	0	2
5	26					5	5

Table 2: Survival estimates and recapture probabilities for both adult male and female eastern massasauga rattlesnake. For each year recapture probabilities were estimated. Recapture estimates for males in years 1 and 2 were fixed to 0 because no males were recaptured in these years and this allows for better estimates.

Parameter	Estimate	SE	LCI	UCI
Apparent Survival Probability (Phi) male	0.70	0.091	0.50	0.85
Apparent Survival Probability (Phi) female	0.65	0.112	0.42	0.83
Recapture Probability (p) male 2009	0.00	0.000	0.00	0.00
Recapture Probability (p) male 2011	0.00	0.000	0.00	0.00
Recapture Probability (p) male 2012	0.29	0.183	0.06	0.70
Recapture Probability (p) male 2013	0.49	0.221	0.15	0.85
Recapture Probability (p) male 2014	0.43	0.172	0.16	0.75
Recapture Probability (p) female 2009	0.29	0.223	0.05	0.77
Recapture Probability (p) female 2011	0.23	0.171	0.05	0.66
Recapture Probability (p) female 2012	0.20	0.143	0.04	0.59
Recapture Probability (p) female 2013	0.38	0.203	0.10	0.77
Recapture Probability (p) female 2014	0.32	0.145	0.11	0.63

Table 3: Akaike Information Criteria (AIC_c) model selection for 2014 abundance estimate of adult male and female eastern massasauga rattlesnake at PCCI. Models are ranked in ascending Delta AIC_c order, AIC_c weights indicate the proportion of the data that is explained by each model, and deviance is the difference in -2log(L) of the current model and -2log(L) of the saturated model. Capture probability (p) and recapture probability (c) are included as variant over time (time) or invariant (.). Effort refers to total search effort time per sampling occasion. Behavior pertains to presence of a handling effect on capture vs. recapture probability. Sex refers to the gender of the animal.

Model	AICc	Delta AICc	AICc Weights	Num. Par	Deviance
p(.) = c(.)	93.67	0.00	0.32	3	74.39
p(sex) = c(sex)	94.88	1.21	0.18	4	73.54
p(effort) = c(effort)	95.60	1.93	0.12	4	74.26
p(.) , c(.)	95.68	2.01	0.12	4	74.35
p(effort) = c(effort) +sex	96.82	3.15	0.07	5	73.41
p(sex) = c(sex) + behavior	96.88	3.21	0.06	5	73.47
p(effort) = c(effort) + behavior	97.67	4.00	0.04	5	74.26
p(sex), c(sex)	98.83	5.16	0.02	6	73.33
p(sex* effort) = c(sex*effort)	98.84	5.17	0.02	6	73.34
p(effort), c(effort)	98.91	5.24	0.02	6	73.41
p(time) = c(time)	101.97	8.30	0.01	8	72.23
p(time) = c(time) + sex	103.26	9.59	0.00	9	71.38
p(time) = c(time) +behavior	103.66	10.00	0.00	9	71.79
p(time) = c(time) + sex + behavior	104.17	10.50	0.00	10	70.14
p(time), c(time)	109.57	15.90	0.00	13	68.97
p(sex*time) = c(sex*time)	110.08	16.41	0.00	14	67.25

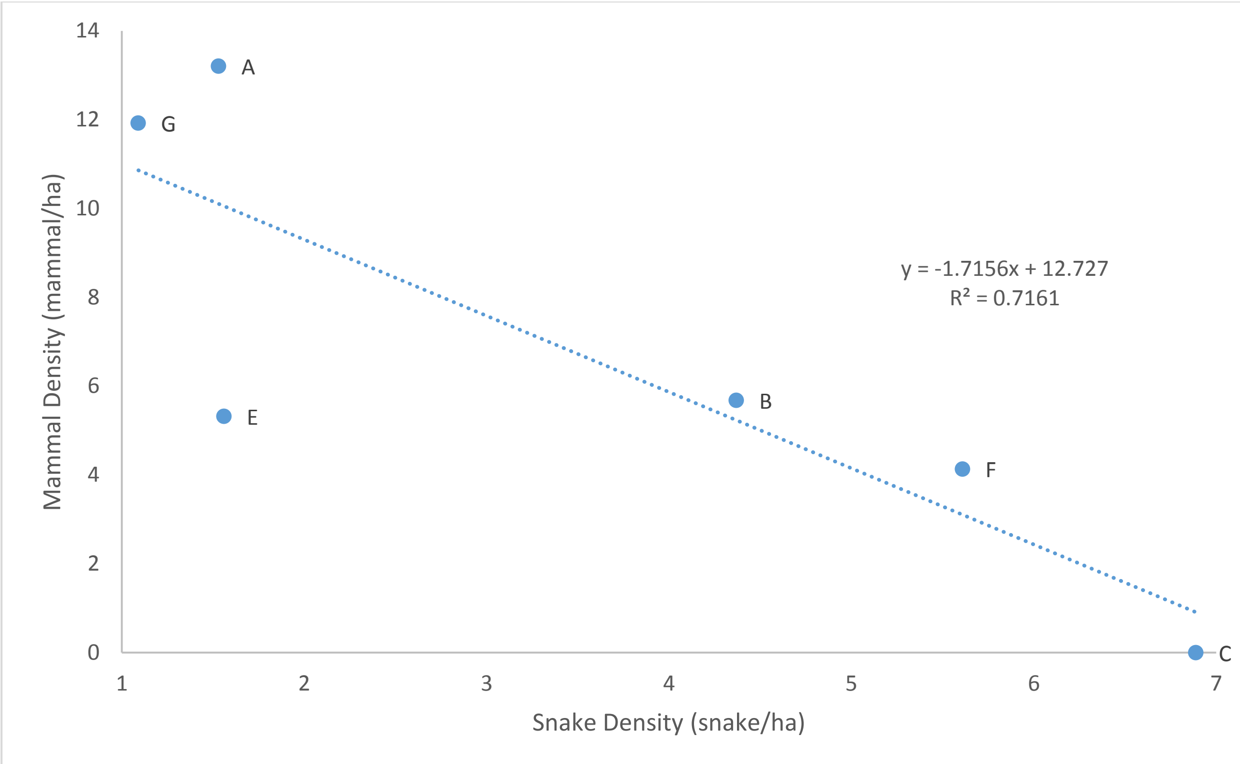

Figure 1: Graph of snake density plotted against mammal density. Each point indicates a survey unit from which densities were calculated. The graph shows a negative trend between snake and mammal densities i.e. as mammal densities increase snake densities decrease and vice versa.

Figure 2: Map of rattlesnake sampling sites at PCCI. Green points represent massasauga captures and recaptures in 2014. Removed for publication on the web. Please contact Sara Syswerda (syswerdas@cedarcreekinstitute.org) for the full version.

Discussion

Estimating population size and survival probability through long term studies is a primary goal for eastern massasauga rattlesnake conservation and for creating proper management plans and monitoring the impact of management activities. Long term mark recapture provides the most reliable method to achieve this goal. Due to the cryptic nature of the eastern massasauga rattlesnake, it becomes a very challenging and time consuming task to collect accurate data for the mark recapture study. In addition, this snake species is relatively long lived so it takes a long time to recognize changes in the population demographics (Parker and Plummer 1987). The combination of these two factors reinforces the necessity for intensive, long term, mark recapture studies (Magnuson 1990, Moore et al. 2007).

Our findings on the small mammal populations suggests that rattlesnake habitat use does not correlate with small mammal abundances (i.e., could not be used as an indicator of quality massasauga habitat). Previous diet studies have shown that these snakes primarily eat small mammals but have been known to prey upon other food items such as garter snakes (*Thamnophis*) and fledgling black birds (*Turdus merula*) (Keenlyne and Beer 1973). It has been shown that neonate eastern massasauaga rattlesnakes primarily prey upon garter snakes (Shepard et al. 2004). Snakes are ectotherms and, therefore, have a lower metabolic rate than endotherms, which would allow them to eat less frequently. This, along with the dietary study findings, could explain why the eastern massasauga rattlesnake habitat uses does not correlate with small mammal abundances.

When analyzing abundance estimates to avoid overestimation, use the lower confidence interval. If the land manager does not use the lower confidence interval, it can possibly lead to less cautious land management practices and increased mortalities. We estimated there to be 35 adult males and 30 adult females in the population, which is very close to a 1:1 sex ratio as found in past studies (Fisher 1930). Isolated and small populations, such as the population of eastern massasauga rattlesnakes at PCCI, are highly vulnerable to even slight increases in adult mortality (Seigel and Sheil 2000, Middleton and Chu 2004). Gravid females are more likely to be found out basking and have significantly smaller home ranges (Reinert and Kodrich 1982), which may cause them to be more susceptible to direct and indirect mortalities. Gravid female mortality would have great repercussions in the population because they are the individuals directly contributing to recruitment.

The survival estimates found for the population of eastern massasauga rattlesnakes at PCCI are consistent with the survival estimates found in a range wide study of eastern massasauga rattlesnakes. The survival estimates found in the range wide study had a mean of 0.67 with a range from 0.35 to 0.95 (Jones et al 2012). When comparing the survival estimate of the population from PCCI to the range wide survival estimates, the population at PCCI appears to be viable even though the population is small. Throughout their range, massasaugas exist in small populations that are genetically isolated (Gibbs et al 1997). Further research is needed to better understand the direct and indirect effects of habitat management activities on demographic rates, and long-term studies such as ours are critical for understanding temporal fluctuations in population dynamics.

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References

Bailey, R. L., H. Campa, K. M. Bissell, and T. M. Harrison. 2012. Resource selection by the eastern massasauga rattlesnake on managed land in southwestern Michigan.

Burnham, K. P. and D. R. Anderson. 2010. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York.

Fisher, R. A. 1930. The genetical theory of natural selection. Clarendon Press, Oxford.

Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L.

Greene, T. Mills, Y. Leiden, S. Poppy, and C. T. Winne. 2000. The global decline of reptiles, Deja Vu amphibians. Bioscience 50:653-666.

Gibbs, H.L., K.A. Prior, P.J. Weatherhead, and G. Johnson. 1997. Genetic structure of populations of the eastern massasauga rattlesnake, *Sistrurus catenatus catenatus*: evidence from microsatellite DNA markers. Molecular Ecology 6:1123-1132.

Harding, J.H. and J.A. Holman. 2006. Michigan Snakes: A Field Guide and Pocket Reference. East Lansing, MI: Cooperative Extension Service, Michigan State University.

Harvey, D.S. and P.J. Weatherhead. 2011. Thermal ecology of Massasauga Rattlesnakes (*Sistrurus catenatus*) near their northern range limit. Canadian Journal of Zoology 89:60 -68.

Johnson, G., B. A. Kingsbury, R. B. King, C. Parent, R. A. Seigel, and J. Szymanski. 2000. The eastern massasauga rattlesnake: a handbook for land managers in U. S. F. A. W. Service, editor., Fort Snelling, Minnesota, USA.

Jones, P.C. R.B. King, R.L. Bailey, N.D. Bieser, K. Bissell, H. Campa, T. Crabill, M.D. Cross, B.A. Degregorio, M.J. Dreslik, F.E. Durbian, D.S. Harvey, S.E. Hecht, B.C. Jellen, G. Johnson, B.A. Kingsbury, M.J. Kowalski, J. Lee, J.V. Manning, J.A. Moore, J. Oakes, C.A. Phillips, K.A. Prior, J.M. Refsnider, J.D. Rouse, J.R. Sage, R.A. Seigel, D.B. Shepard, C.S. Smith, T.J Vandewalle, P.J Weatherhead, and A.Yagi. 2012. Range-wide analysis of eastern massasauga survivorship. Journal of Wildlife Management 76:1576 -1586.

Keenlyne, K.D. and J.R Beer. 1973. Food habits of *Sistrurus catenatus catenatus*. Journal of Herpetology 7:382-384.

Magnuson, J. J. 1990. Long-term ecological research and the invisible present - uncovering the processes hidden because they occur slowly or because effects lag years behind causes. Bioscience 40:495-501.

Mazerolle, M. J., L. L. Bailey, W. L. Kendall, J. A. Royle, S. J. Converse, and J. D. Nichols. 2007. Making great leaps forward: Accounting for detectability in herpetological field studies. Journal of Herpetology 41:672-689.

Middleton, J. and J. Y. Chu. 2004. Population viability analysis (PVA) of the eastern massasauga rattlesnake, *Sistrurus catenatus catenatus*, in Georgian Bay Islands National Park and elsewhere in Canada. Prepared for the Eastern Massasauga Rattlesnake Species Recovery Team.

Moore, J. A., J. M. Hoare, C. H. Daugherty, and N. J. Nelson. 2007. Waiting reveals waning weight: Monitoring over 54 years shows a decline in body condition of a long-lived reptile (tuatara, Sphenodon punctatus). Biological Conservation 135:181-188.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical-inference from capture data on closed animal populations. Wildlife Monographs:7-135.

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.

Parker, W. S. and M. V. Plummer. 1987. Population ecology. Pages 253-301 in R. A. Seigel, J. T. Collins, and S. S. Novak, editors. Snakes: Ecology and Evolutionary Biology. McGraw-Hill, New York.

Quinn, H. and J. P. Jones. 1974. Squeeze box technique for measuring snakes. Herpetological Review 5:35.

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

Seigel, R. A. and C. A. Sheil. 2000. Population Viability Analysis: Applications for the conservation of massasaugas.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.

Shepard, D.B., C.A. Phillips, M.J. Dreslik, and B.C. Jellen. 2004. Prey preference and diet of neonate eastern massasaugas (*Sistrurus catenatus catenatus*). The American Midland Naturalist 152:360-368.

Shepard, D. B., M. J. Dreslik, B. C. Jellen, and C. A. Phillips. 2008. Reptile road mortality around an oasis in the Illinois Corn Desert with emphasis on the endangered Eastern Massasauga. Copeia:350-359.

Stanley, T. R. and K. P. Burnham. 1999. A closure test for time-specific capture-recapture data. Environmental and Ecological Statistics 6:197-209.

Szymanski, J. 1998. Status assessment for the eastern massasauga (*Sistrurus c. catenatus*). US Fish and Wildlife Service, Ft. Snelling, Minnesota, USA.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. LA-8787-NERP, Los Alamos National Laboratory, Los Alamos, New Mexico, USA.

White, G. C. and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120-139.