Population Demography of Eastern Massasauga Rattlesnakes in Relation to Habitat Management

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Abstract

Eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) are considered threatened or endangered in every state and province in which they occur, with the exception of Michigan, where they are a species of special concern. Though often required to control invasive plants and restore native vegetation, implementing prescribed burns may lead to direct and indirect mortality of massasaugas, posing a significant threat to already fragile populations. Even in Michigan, which is deemed the last stronghold for this species, remnant populations exist in isolated patches of suitable habitat and little is known about the long-term viability, or even current size, of most populations. We used closed population capture-recapture models ranked by Akaike's information criterion adjusted for small sample size (AIC_c) to estimate an abundance of 39 (SE=9, 95% CI=30-77) adult female eastern massasaugas within our study area at Pierce Cedar Creek Institute. Our top ranked model supported reproductive status as an important factor in explaining detection probability, with gravid females having higher detection than non-gravid females. We found that recently burned habitat was still utilized by several individuals. However, we lacked the data to assess changes in utilization of the burned area over time. Our analysis provides a baseline abundance estimate against which managers at PCCI can assess impacts of future land management activities, such as prescribed burns. We recommend that management activities consider the small scale at which massasaugas select habitat to meet thermoregulatory requirements. Additionally, to minimize mortality, burns should be conducted before snakes egress or after they ingress.

Introduction

In the current era of global biodiversity losses, reptiles represent some of the most imperiled species on the planet (Gibbons et al. 2000). In the U.S. alone, approximately 25% of all reptile species are currently federally listed as threatened or endangered (Szymanski 1998, Johnson et al. 2000). Despite the status of these imperiled species, we are often lacking very basic information on population demographics, critical to their effective management and recovery (Gibbons et al. 2000).

One such species is the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*), which is currently a candidate for listing under the U.S. Endangered Species Act. The eastern massasauga rattlesnake utilizes wetland habitats from early to late spring and upland meadows and woodlands during the summer. In the fall, snakes return to lowlands in search of crayfish or rodent burrows in which to hibernate (Harding and Holman 2006). Massasaugas are very cryptic and ambush small mammal prey from concealed, thermally favorable microhabitats (Harvey and Weatherhead 2011). The geographic range of the eastern massasauga extends throughout the Great Lakes region of the Midwestern United States and into southern Ontario in Canada. Eastern massasaugas are considered threatened or endangered in every state and province in which they occur, with the exception of Michigan, where they are a species of special concern.

Numerous threats have contributed to the decline of massasauga populations including habitat loss (Szymanski 1998), road mortality (Shepard et al. 2008), and direct human persecution (Parent and Weatherhead 2000). Most remnant populations occur on public land or nature preserves, so adaptive habitat management to remove invasive species (e.g., prescribed burns, cutting, herbicide application, or manual removal) and restore native vegetation occurs at many of these locations (Johnson et al. 2000). Invasive plant species are often responsible for converting otherwise open canopy, sedge, or grass dominant habitat into dense monocultures that limit the thermal variability that is necessary for rattlesnake thermoregulation and survival. However, management activities, especially burning, may pose yet another threat to already fragile massasauga populations. Prescribed burns may lead to direct and indirect mortality of massasaugas, especially if burns are conducted after snakes have already emerged from or before they enter overwintering sites (Durbian 2006, J. Moore pers. comm.). Population-level responses of eastern massasaugas to habitat management and restoration are poorly understood. However, population viability analyses have demonstrated that populations may be highly sensitive to even slight changes in adult and juvenile mortality rates (Seigel and Sheil 2000, Middleton and Chu 2004).

Although Michigan remains the stronghold for this species, an estimated 33% of historical populations have already been extirpated in the state (Szymanski 1998, Johnson et al. 2000). Remnant populations exist in isolated patches of suitable habitat and little is known about the long-term viability, or even current size, of most populations. Establishing baseline data is important if managers wish to assess how populations respond to management activities over time. Count data, such as minimum number known alive, are often used to generate baseline population data. However this method does not account for the probability of detection, which may be very low in cryptic species like the eastern massasauga. Capture-mark-recapture models, such as closed population models, do account for detection probability and can be a much more effective means of achieving a reliable population estimate (Mazerolle et al. 2007).

In 2011 and 2012, the Michigan Natural Features Inventory (MNFI), in collaboration with the Michigan Department of Natural Resources and Pierce Cedar Creek Institute (PCCI), conducted mark-recapture surveys using volunteers to initiate monitoring of the massasauga population at PCCI. The goals of this monitoring effort were to determine the status of the massasauga population, assess impacts of land management activities on the massasauga population and habitat, and obtain baseline data to inform future population monitoring and management activities at PCCI. This monitoring effort was envisioned to be a model and part of a long-term monitoring effort to assess population status and trends at PCCI and other sites that are being managed to benefit this species.

In this study we used closed population capture-recapture models to estimate abundance of eastern massasaugas at PCCI, where abundance refers to the number of individuals occurring within the study area. We also used spatial data to examine the distribution of snakes in relation to recently burned and unburned habitats. Our objectives were to 1) develop a baseline abundance estimate against which managers can assess impacts of future land management activities, (2) contribute to long-term monitoring efforts started at PCCI in 2011 by the Michigan Natural Features Inventory, and (3) gain a basic understanding of how massasaugas utilize recently burned areas.

Study Site

Our study was conducted at Pierce Cedar Creek Institute in Barry County, MI. PCCI is a 267 ha preserve, about 40% of which is classified as wetland. The study area encompassed approximately 22.2 ha composed primarily of prairie fen, wet meadow, and nearby upland prairie and old field plant communities surrounding Brewster Lake, Cedar Creek and adjoining tributaries (Figure 1).

PCCI property is actively managed to control for invasive species and to promote early successional communities through a variety of methods, including cutting of woody vegetation, prescribed burns, hand pulling of invasive herbaceous species, biological controls, herbicide applications, and prairie plantings. Prescribed burns have been conducted opportunistically within prairie, wet meadow, and old field communities beginning in 2003, with the most recent burn taking place during December 2012 within the boundaries of our study area. Extensive autumn olive removal via cutting and cut-stump herbicide application also occurred in the fall of 2012, in areas overlapping our study.

Materials and Methods

We conducted 48 days of visual encounter surveys from 7 May through 6 August 2013 to locate eastern massasauga rattlesnakes. Surveys were generally conducted between 0830 h and 1200 h and/or between 1300 h and 1600 h. Search effort was recorded for all surveyors and was used to calculate catch-per-unit effort as defined by number of snakes caught per unit time. Locations were recorded as waypoints using a handheld Garmin GPS map 62stc GPS unit. At each snake capture site, we visually estimated percent cloud cover (i.e., 0%, 25%, 75%, or 100%). We also recorded whether the area was recently burned (determined by visual evidence of blackened or charred vegetation) and if surface water was present within approximately 1 m.

Encountered snakes were captured and handled in compliance with IACUC 'Guidelines for Use of Live Amphibians and Reptiles in Field and Laboratory Research' to ensure the safety of the reptiles and researchers. Snake tongs were used to gently grab snakes and deposit them into pillowcases that were then tied shut and put into buckets for transport.

In the lab, all captured snakes were measured (snout-vent length, tail length) to the nearest cm using the squeezebox technique (Quinn and Jones 1974). We recorded each snake's mass (to the nearest g) by subtracting the weight of the pillowcase from the combined weight of the snake and pillowcase. Snakes were then tubed to enable us to safely sex (by probing for the presence of hemipenes) and palpate to determine whether they were gravid. All new snakes were individually marked by injecting a subdermal passive integrated transponder (PIT) tag and applying colored nail polish on 1-3 anterior rattle segments. When possible, up to 400 µl of blood was drawn from the caudal vein/artery, and stored in 95% EtOH to be used for future genetic analyses. After processing, snakes were released at their capture site, with approximately 95% of snakes returned the same day of capture. All captured massasaugas were documented with photos.

Data Analysis

We used Program MARK version 7.1 to estimate abundance of eastern massasaugas at PCCI (White and Burnham 1999). Only adults were used in this analysis because they are the only individuals capable of contributing to population growth. Snakes were categorized as adults based on snout-vent length (SVL), with females ≥42 cm and males ≥43 cm included in this age class. The cutoff for females was chosen based on the smallest gravid female found at PCCI and the cutoff for males was based on the smallest male with motile sperm found at another site in Southwestern Michigan with over seven years of data collected (E. Hileman pers. comm.). A preliminary analysis indicated that there were insufficient recapture data for adult males to estimate abundance with reasonable precision (Table 1). Therefore, we limited further analyses to adult females only.

To account for low daily recapture rates and ensure adequate detection probabilities for estimating abundance, mark-recapture data for the period of 7 May through 6 August 2013 were collapsed into six occasions. We varied occasion lengths in order to minimize data loss. The number of search effort days within each of the six occasions was 13, 6, 7, 6, 10, and 6, respectively. Binary capture histories were created for each individual based on whether that individual was captured at least once (=1) or not captured (=0) during each respective occasion.

Closed population capture-recapture models were used within Program MARK to estimate abundance of snakes within the study area. To minimize our chances of violating the assumptions of closure, only 2013 mark-recapture data were used. We used ClosedTest version 3, to evaluate our data for violations of closure (Stanley & Burnham 1999). A p-value ≤ 0.150 was considered to have some lack of fit, meaning some assumptions of closure may have been violated (Burnham & Anderson 2010).

Candidate models considered individual (reproductive status) and occasion-based covariates (time, effort, environmental index), as well as behavior and heterogeneity effects. Reproductive status refers to whether or not an individual was gravid. Effort includes total search effort hours per sampling occasion. Environmental index refers to the number of days within a sampling occasion that include at least one survey meeting weather conditions hypothesized as most conducive to detecting EMRs (i.e., mean temp of 12.8-18.3 °C with ≤ 50% cloud cover or mean temp of 18.4-26.1 °C with≥ 50% cloud cover). For the environmental index, mean temperature was calculated using hourly data obtained from the Michigan State University weather station on PCCI property and cloud cover was visually estimated at the beginning and end of each survey (0%, 25%, 50%, or 100%). Behavior pertains to the presence of a handling effect on capture vs. recapture probability. Heterogeneity refers to unexplained individual differences in detection. In this instance we modeled heterogeneity as two mixtures within our adult female group, resulting in two different detection probabilities for each parameter estimated (with the exception of abundance). We modeled capture probability (p) and recapture probability (c) as variant over time (t) or invariant (.) (Table 2).

Akaike's information criterion adjusted for small sample size (AICc) was used to rank models. Due to small sample size, we limited the number of candidate models to 13 in order to minimize the risk of spurious results (Anderson et al. 2001). Additionally, we restricted the number of parameters within each model to nine to avoid overfitting the data. To be conservative in our abundance estimate and to account for model selection uncertainty we used model averaging to average our entire set of candidate models according to AICc weight.

All snake locations were plotted in ArcMap 10.0 and maps were created to show distribution of individuals throughout the study site. Study units were drawn in ArcMap and total area was calculated using the "calculate area" tool. Density of massasaugas was estimated using the upper and lower 95% confidence intervals of our abundance estimate and the total area surveyed. The area burned in the fall of 2012 was also drawn in ArcMap as indicated by PCCI stewardship manager, Jennifer Howell.

Results

From 7 May to 6 August 2013 we captured 78 eastern massasauga rattlesnakes within our study area, including 51 unique individuals. Of these individuals, 10 were first captured in previous years (two individuals in 2008, three individuals in 2009, two individuals in 2011, and three individuals in 2012). Age and sex classes represented include 27 adult females (mean SVL=51.6 cm, SD=5.8), 13 adult males (mean SVL=54.7 cm, SD=6.8), six juvenile females (mean SVL=33.0 cm, SD=5.5), and five juvenile males (Mean SVL=34.4 cm, SD=4.2). Out of 27 adult females captured, 19 were gravid. Catch per unit effort was 0.2 snakes/person hour.

We did not detect any violations of the assumptions of closure using the Stanley & Burnham Closure Test (p=0.284). We did detect a modest departure of assumptions using the Otis et al. (1978) Closure Test (p=0.117). However, this test is prone to Type I errors when capture probabilities vary with time or behavior (White et al. 1982).

We estimated abundance of adult females within our study area to be 39 individuals (SE=9, 95% CI=30-77). AICc scores indicate the model including reproductive status with equal capture and recapture probabilities that remain constant over time is most strongly supported (Table 2). We estimated density of adult females within our study area to be 1.4-3.5 snakes/ha.

Table 1. M-arrays generated in Program MARK for adult male and female eastern massasaugas at Pierce Cedar Creek Institute, Hastings MI displaying number of individuals released (R_i) in each sampling occasion and number of respective recaptures within each following sampling occasion.

			Number recaptured in sampling occasion					Total
	Occasion	**R_i**	**2**	**3**	**4**	**5**	**6**	recaptures
Males	1	1	0	0	0	0	0	0
	2	3		0	0	0	0	0
	3	2			1	0	0	1
	4	2				0	0	0
	5	3					0	0
	6	3						0
Females	1	7	1	2	0	1	1	5
	2	5		1	1	0	0	2
	3	11			1	1	1	3
	4	6				3	1	4
	5	5					2	2
	6	8						0

Table 2. Akaike Information Criteria (AIC_c) model selection for 2013 abundance estimate of adult female eastern massasauga rattlesnakes at Pierce Cedar Creek Institute, Hastings MI. Models are ranked in ascending ΔAIC_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 (t) or invariant (.). Reproductive status pertains to whether or not an individual was gravid. Effort refers to total search effort time per sampling occasion. Environmental index refers to the number of days within a sampling occasion that include at least one survey meeting weather conditions hypothesized as most conducive to detecting EMRs (i.e. mean temp of 12.8-18.3 ◦C with ≤ 50% cloud cover or mean temp of 18.4-26.1 ◦C with≥ 50% cloud cover). Behavior pertains to presence of a handling effect on capture vs. recapture probability. Heterogeneity refers to unexplained individual differences in detection.

Model	ΔAIC_c	AIC_c Weights	No. Parameters	Deviance
p(.) = c(.) + reproductive status	0	0.39	2	174.72
p(.) = c(.)	1.10	0.23	1	177.88
p(.) = c(.) + effort	2.90	0.09	2	177.62
p(.) = c(.) + environmental index	2.93	0.09	2	177.65
p(.) ,c(.) + behaviour	3.06	0.08	2	177.78
p(.), c(.) + behavior + effort	4.98	0.03	3	177.62
p(.), c(.) + heterogeneity	5.23	0.03	3	177.88
p(t) = c(t) + reproductive status	5.58	0.02	7	169.65
p(t) = c(t)	6.59	0.01	6	172.84
p(.), c(.) + heterogeneity + behavior	7.24	0.01	4	177.78
p(t), c(t) + behaviour	8.70	0.01	7	172.77
p(t), c(t) + heterogeneity	10.98	0.00	8	172.84
p(t), c(t) + heterogeneity + behavior	13.16	0.00	9	172.77

Several snakes moved across unit boundaries during the study period. The recently burned area was utilized by several snakes. We lacked the data that would allow us to determine any differences in the utilization of the burned area over time.

Discussion

Estimating population size, population growth, and responses of populations to management activities is a primary goal for massasauga conservation. Detailed, long-term, mark-recapture data provide the most reliable method to achieve this goal. However, understanding demographic trends is often difficult for snakes because cryptic behavior and coloration can make detection challenging and time consuming, and some snake species are relatively long-lived, which may mean that changes in population parameters take a long time to detect (Parker and Plummer 1987). The benefit of intensive, long-term, mark-recapture studies (Magnuson 1990, Moore et al. 2007) for assessing population trends in reptiles therefore cannot be overstated.

The data collected for this study provide a baseline abundance estimate against which managers at PCCI can assess impacts of future land management activities. However, continued monitoring is also crucial for achieving this goal. By conducting yearly mark-recapture surveys within the same survey areas, it will eventually be possible to obtain population growth estimates which can indicate whether management activities, such as prescribed burns, are harming or helping the massasauga population. Additionally, continued monitoring of this population may provide enough data to assess temporal differences in densities between survey units and their relationship to habitat management.

In considering the abundance estimate, it is important for managers to bear in mind the lower confidence interval, because overestimating abundance may lead to less cautious land management practices and increased mortalities. Although we were unable to estimate abundance of adult males, it is reasonable to infer the sex ratio is approximately 1:1 (Fisher 1930). Massasauga populations are relatively isolated and small, such as the one at PCCI, and may be highly vulnerable to small increases in mortality (Seigel and Sheil 2000, Middleton and Chu 2004). Gravid females are especially important because they directly contribute to recruitment. However, these individuals are more likely to be out basking and have significantly smaller home ranges (Reinert and Kodrich 1982), which may make them most susceptible to direct and indirect (predation) mortality associated with prescribed burns and other types of habitat management.

During their study conducted at PCCI over spring and summer of 2004, 2005, 2008, and 2009, Bailey et al. (2012) found massasauga movement did not appear to be impaired by management activities of burning or shrub removal. Our surveys support that massasaugas are still utilizing recently burned habitat (i.e., habitat burned in December 2012). However, it is unknown whether these snakes experience higher predation as a result. We were unable to quantitatively assess changes in use of burned or otherwise managed areas since previous surveys at PCCI did not include enough captures to estimate baseline population abundance. To minimize mortality, we recommend that managers conduct prescribed burns before snakes egress or after they ingress. At another site in Southwest Michigan, emergence of massasaugas has been detected as early as mid-March and ingress generally occurs between mid to late October (pers. comm. E. Hileman). Additionally, management activities should consider the small scale at which massasaugas select habitat to meet thermoregulatory requirements. Burning too large an area may decrease suitable massasauga habitat because snakes require cover as well as open areas for basking (Bailey et al. 2012).

Multimodel inference can lend insight into what may be important in the detection of individuals when models are based on a priori biological information (Lebreton et al. 1992, Mazerolle et al. 2007). Based on the AICc model ranking, we can infer that reproductive status was an important factor in whether we were able to find adult female massasaugas during visual encounter surveys, with gravid females having higher detection probability than non-gravid females. However, we anticipated search effort would better explain detection probability than was indicated by AICc scores. This may be a result of a high volume of search effort contributed by less experienced volunteers during MNFI surveys held the second week of May and third week of June. During the MNFI surveys, the catch per unit effort was 0.11 snakes/person hour compared to 0.31 snakes/person hour when these surveys were excluded. Because the catch per unit effort was much lower during the MNFI surveys it is likely that including these surveys in our analysis hindered the capacity of search effort to explain detection probability. It should be noted though that 17 out of the 78 total captures were found by volunteers or other URGE grant students, demonstrating the valuable contribution they made to this study.

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