2015 Abundance and Density Estimates of Eastern Massasaugas at Pierce Cedar Creek Institute

Danielle Bradke, Jeffrey Bartman, Nathan Kudla, and Sandra Breitenbach
Mentored by Dr. Jennifer A. Moore
Grand Valley State University
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Abstract

Eastern Massasaugas (*Sistrurus catenatus*) are threatened or endangered in every state and province where they occur, except Michigan, where they are a species of special concern. Even in Michigan, remnant populations exist in small, isolated patches of suitable habitat and little is known about the long-term viability 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 101 (95% CI=86–143) adult Eastern Massasaugas within our study area at Pierce Cedar Creek Institute. We estimated an adult male abundance of 49 (95% CI=35–89) and an adult female abundance of 52 (95% CI=50–63). Our top ranked models supported time and sex as important factors in explaining detection probability. Based on our abundance estimates, we estimated density of adult Eastern Massasaugas to be 4.3–7.2 snakes/ha within the study area.

Introduction

In the current era of global biodiversity loss, amphibians and reptiles represent some of the most imperiled species on the planet (Gibbons et al. 2000, Ananjeva 2015). Among reptiles, it has been estimated that 20% of all species are at risk of extinction (Böhm et al. 2013). Despite the status of these imperiled species, we often lack even basic information on population demographics, critical to their effective management and recovery (Gibbons et al. 2000).

One such species is the Eastern Massasauga (*Sistrurus catenatus*), which has been proposed for listing under the U.S. Endangered Species Act by U.S Fish and Wildlife Service. In Michigan, this snake generally prefers wetlands with adjacent upland habitat (Holman 2012). Massasaugas are cryptic and ambush small mammal prey from concealed, thermally favorable microhabitats (Harvey and Weatherhead 2011). In the fall, they seek out crayfish or rodent burrows in lowlands where they overwinter (Holeman 2012). 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 where they occur, except Michigan, where they are a species of special concern.

Numerous threats have contributed to the decline of Eastern Massasauga populations including habitat loss (Szymanski 1998), road mortality (Shepard et al. 2008), and direct human persecution (Parent and Weatherhead 2000). Although Michigan supports more populations than any other state or province, an estimated 33% of historical populations have already been extirpated in the state (Johnson et al. 2000), and the current status and future viability of most remnant populations is unknown. Collecting even the most basic demographic information is often difficult for snakes because cryptic coloration can make detection challenging and time-consuming. Additionally, because Eastern Massasaugas are relatively long-lived and take years to sexually mature (Johnson et al. 2000), it takes several years to obtain a meaningful estimate of population growth. Long-term capture-recapture datasets are costly and require much effort to produce, but are critical for monitoring population demographic parameters like annual survival, population abundance, and density, particularly for populations in habitats that are being actively managed and restored.

Pierce Cedar Creek Institute (hereafter the Institute) in Barry County, Michigan has a history of Eastern Massasauga research. In 2004, 2005, 2008, and 2009 radio telemetry data was collected at this site and used to study spatial ecology, habitat use, survival, and population viability of this species (Bissell 2006, Bailey 2010, Bailey et al. 2011, Bailey et al. 2012). In 2011 and 2012, the Michigan Natural Features Inventory (MNFI), initiated capture-recapture surveys of the massasauga population at the Institute, and in 2013 and 2014 researchers participating in the Institute's Undergraduate Research Grants for the Environment (URGE) program continued capture-recapture data collection, which was used to estimate abundance, density, and survival rates (Bradke et al. 2013, Bartman et al. 2014).

In this study we used closed population capture-recapture models to estimate 2015 abundance and density of Eastern Massasaugas at the Institute, where abundance refers to the total number of individuals occurring within the survey area and density refers to the number of individuals per unit area. Our objectives were to (1) continue long-term monitoring efforts at the Institute (2) provide the Institute with abundance and density estimates of adult Eastern Massasaugas, and (3) compare our adult female abundance estimate from 2015 to estimates from 2013 and 2014.

Study Site

Our study was conducted at Pierce Cedar Creek Institute in Barry County, Michigan. The study area was approximately 19.9 ha of prairie fen, wet meadow, and nearby upland prairie and old field habitat surrounding Brewster Lake and Cedar Creek (Figure 1).

Methods

Data Collection in Years Prior to 2015

GPS coordinates of massasauga captures in 2011 and 2012 were provided by MNFI and GPS coordinates of massasauga captures in 2013 and 2014 were obtained from Grand Valley State University URGE students. These data were collected using visual encounter surveys (see Bradke et al. 2013 and Bartman et al. 2014 for detailed methods). Additionally, Passive integrated transponder (PIT) tag identification numbers were obtained for all snakes captured and marked at The Institute in previous years (i.e., 2004, 2005, 2008, 2009, 2011, 2012, 2013, and 2014).

2015 Data Collection

To locate Eastern Massasaugas, we conducted 72 days of visual encounter surveys from 28 April through 14 August 2015. To increase detection, we supplemented visual surveys with active and passive traps from 21 May through 14 August. Four trapping arrays were installed in areas where 2013 and 2014 massasauga capture rates were high. Each array consisted of one drift fence, two funnel traps, seven carpet squares and seven coverboards. Drift fences were pre-fabricated 0.9 m tall x 30.5 m long silt fencing attached to wooden posts, with the bottom 15 cm buried into the ground. Funnel traps were constructed with hardware cloth and aluminum screening and were placed at either end of each drift fence. Coverboards were made of 0.64 cm thick plywood and all cover objects (i.e., carpet squares and coverboards) were 0.6 x 1.2 m. All surveys were conducted between 0845 h and 1700 h and each surveyor monitored their search effort (i.e. 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. Snakes captured outside of official surveys (i.e., encountered by chance by researchers, volunteers, or others when search effort was not being monitored) were not included in catch-per-unit-effort, but were included in maps and abundance estimates (described below), if captured within the survey area. Additional field surveys were conducted on 29 August and 30 August 2015 to capture and mark neonates. These data were used in our map and reported within our number of individuals captured (see **Results** section), but were not used to calculate catch-per-unit-effort or in any other analyses.

We recorded where we searched (i.e., “tracks”) and snake locations (i.e., “waypoints”) using handheld Garmin GPS units. Encountered snakes were captured and handled in compliance with GVSU IACUC (permit #13-02-1) under the Guidelines for Use of Live Amphibians and Reptiles in Field and Laboratory Research.

In the lab, snakes were measured (snout-vent length, tail length) to the nearest cm using the squeezebox technique (Quinn and Jones 1974) and mass was recorded to the nearest gram. We restrained snakes inside plastic tubes to determine sex (by probing for the presence or absence of hemipenes) and to palpate for presence of food and embryos. Using a MiniTracker Pro AVID scanner (Norco, CA), we determined if snakes were previously captured. All new yearlings, juveniles, and adults were individually marked by injecting a subdermal passive integrated transponder (PIT) tag and all new neonates were branded with a medical cautery unit. PIT tags were placed two thirds of the way down the body on the right flank. Brands were made on a unique combination of three posterior ventral scutes by making a latitudinal mark across the entire scute that continues approximately 0.5 cm up the left flank. 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 within 24 hours of capture. We sanitized lab equipment according to disinfection protocols recommended by Pierce Cedar Creek Institute to prevent the spread of Snake Fungal Disease (i.e. *Ophidiomyces ophiodiicola*).

Data Analysis

We used Program MARK version 8.0 to estimate abundance of Eastern Massasaugas at the Institute (White and Burnham 1999). Only adults were used in this analysis because they are the only individuals that contribute to population growth. Snakes were categorized as adults based on snout-vent length, with females ≥ 48.7 cm and males ≥ 43.0 cm included in this age class. The cutoff for females was chosen based on the smallest gravid female found at the Institute in 2015 and the cutoff for males was based on the smallest male with motile sperm found at another site in Southwestern Michigan (E. Hileman pers. comm.).

To account for low daily recapture rates and ensure adequate detection probabilities for estimating abundance, capture-recapture data for the period of 18 May through 14 August 2015 were collapsed into six occasions. Each occasion was approximately one half month long and consisted of 9–11 search effort days. 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.

We used full likelihood closed-capture models in Program MARK to estimate abundance of snakes within the study area. To minimize our chances of violating the assumptions of closure, only 2015 capture-recapture data were used. Additionally, exploratory data analyses indicated a lack of closure during the beginning of the study period. Therefore, data collected prior to 18 May were excluded from further abundance analysis. We used ClosedTest version 3, to evaluate our data for violations of closure (Stanley and 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 and Anderson 2010).

Candidate models included sex as a grouping variable and considered occasion-based covariates (time, effort, and rain), as well as a behavior effect. Variables were selected *a priori* based their biological plausibility and the availability of data for each variable. Effort included total search effort hours per sampling occasion. Rain included the total amount of rainfall during a given occasion and was obtained from a weather station located at the Institute. Behavior pertains to the presence of a handling effect on recapture probability. We modeled capture probability (p) and recapture probability (c) as variant over time or invariant (.) (Table 1).

Akaike's information criterion adjusted for small sample size (AIC_c) was used to rank models. Due to small sample size, we limited the number of candidate models to 14 in order to minimize the risk of spurious results (Anderson et. al 2001). Additionally, we restricted the number of parameters within a given model to 14 or fewer to avoid overfitting the data. To be conservative in our abundance estimate and to account for model selection uncertainty we model averaged our entire set of candidate models according to AIC_c weight. Lognormal 95% confidence intervals were calculated for all estimates.

Adult female abundance estimates for 2013 (Bradke et al. 2013) and 2014 (Bartman et al. 2014), were compared to current year estimates by examining the amount of overlap in 95% confidence intervals between years.

Using ArcMap 10.0 we created a map of 2011–2015 massasauga captures throughout the study site. We outlined the 2015 study area using GPS tracks taken during surveys as a guide. Based on our outlined polygon, we approximated the total area surveyed using the “calculate area” tool in ArcMap. Density of massasaugas was estimated using the upper and lower bounds of the 95% confidence intervals for our 2015 abundance estimates and dividing by the total area surveyed.

Results

From 28 April to 30 August 2015 we captured 269 Eastern Massasaugas, including 128 unique individuals. These numbers comprise all Eastern Massasaugas caught on Pierce Cedar Creek Institute property, including captures made outside of official surveys, outside the study area, and outside the time period associated with our abundance estimates. Of these individuals, 50 were first captured in previous years (two individuals in 2008, two individuals in 2009, three individuals in 2011, seven individuals in 2012, 20 individuals in 2013, and 16 individuals in 2014). Age and sex classes represented include 51 adult females, 33 adult males, 15 Juveniles, two yearlings, and 27 neonates. Out of 51 adult females captured, 45 were gravid. Catch-per-unit-effort was 0.5 snakes/person hour.

We estimated abundance of adults within our study area to be 101 individuals (SE=13.2, 95% CI=86–143). Adult male abundance was estimated to be 49 individuals (SE=12.3, 95% CI=35–89) and adult female abundance was estimated to be 52 individuals (SE=2.8, 95% CI=50–63; Figure 2). Note that data collected prior to 18 May were excluded from this analysis (see **Methods** section), and therefore individuals captured only in late April and early May are not accounted for in these estimates. AIC_c weights indicate that models including both sex and time effects, with equal capture and recapture probabilities are most strongly supported (Tables 1 and 2). We estimated adult male density to be 1.8–4.5 snakes/ha and adult female density to be 2.5–3.2 snakes/ha. Overall adult density is estimated to be 4.3–7.2 snakes/ha within the study area.

We did not detect violations of the assumptions of closure using the Stanley and Burnham Closure Test (p=0.55). The Otis et al. (1978) Closure Test was deemed inappropriate for this data set, because it does not allow capture probabilities to vary with time. Based on the results of AIC_c model selection, we conclude that this assumption is biologically unrealistic.

95% confidence intervals of adult female abundance estimates overlapped for 2013, 2014, and 2015 (Figure 2).

Discussion

Estimating population size, population growth, and responses of populations to management activities are primary goals in massasauga conservation. Detailed, long-term, capture-recapture data provide the most reliable method to achieve these goals. However, estimating demographic trends is often difficult for snakes because cryptic behavior and coloration can make snake detection challenging and time consuming. Furthermore, 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). Therefore, employing intensive, long-term, capture-recapture studies for assessing population trends in reptiles is important (Magnuson 1990, Moore et al. 2007).

Our abundance estimates are consistent with previous year estimates, based on substantial overlap in confidence intervals (Bradke et al. 2013, Bartman et al. 2014). There was insufficient data to estimate male abundance in 2013 (Bradke et al. 2013), so only adult female abundance is directly comparable for all three years (2013–2015; Figure 2). Due to higher detection rates in the present year, we were able to estimate female abundance with greater precision. We attribute these higher detection rates, at least in part, to an increase in survey hours (Figure 2) and to more experienced surveyors.

In considering an 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 (Williams et al. 2002). Most massasauga populations are relatively isolated and small, 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 mortality associated with prescribed burns and other types of habitat management.

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 AIC_c model ranking, we can infer that sex was an important factor in whether we were able to find adult massasaugas during visual encounter surveys, with females having higher detection probability than males. Additionally, we found that time had a strong effect on detection with a peak in capture/recapture probabilities during the second half of June and first half of July (Table 2).

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Table 1. Akaike Information Criteria (AIC_c) model selection for 2015 abundance estimate of adult Eastern Massasaugas at Pierce Cedar Creek Institute, Barry County, Michigan. Models are ranked in ascending ΔAIC_c order and AIC_c weights indicate the proportion of the data that is explained by each model. Deviance is the difference in $-2\log(\mathcal{L})$ of the current model and $-2\log(\mathcal{L})$ of the saturated model, where $\mathcal{L}$ is the maximized likelihood for each model. Capture probability (p) and recapture probability (c) are equal (=) or unequal (≠ ; presumably due to a handling effect on capture vs. recapture probability). Parameters considered for an effect on p and c include: time, sex, effort, and rain. Effort refers to total search effort time per sampling occasion. Rain refers to the total amount of rainfall per sampling occasion. Additional model notation: (*) interaction term; (+) additive term; (.) invariant parameter.

Model	ΔAIC_c	AIC_c Weights	No. Parameters	Deviance
p(time + sex) = c(time + sex)	0.00	0.46	9	99.10
p(sex*time) = c(sex*time)	0.84	0.30	14	89.39
p(effort + sex) = c(effort + sex)	2.55	0.13	5	109.92
p(effort*sex) = c(effort*sex)	3.69	0.07	6	109.00
p(time + sex) ≠ c(time + sex)	4.79	0.04	10	101.80
p(sex) = c(sex)	9.37	0.00	4	118.78
p(effort) ≠ c(effort)	13.76	0.00	5	121.13
p(rain + effort) = c(rain + effort)	18.10	0.00	5	125.46
p(time) = c(time)	18.62	0.00	8	119.80
p(time) ≠ c(time)	20.05	0.00	9	119.15
p(effort) = c(effort)	20.96	0.00	4	130.37
p(.) ≠ c(.)	22.75	0.00	4	132.16
p(.) = c(.)	27.59	0.00	3	139.03
p(rain) = c(rain)	28.86	0.00	4	138.27

Table 2. Capture and recapture probabilities estimated by the model: p(time+sex) = c(time+sex). This was the top ranked model using Akaike Information Criteria (AICc) in model selection for 2015 abundance estimate of adult Eastern Massasaugas at Pierce Cedar Creek Institute, Barry County, Michigan.

Sex	**Detection Probability**	**Dates**	**Estimate**	**95% CI**
Male	Capture	16 May–31 May	0.05	0.02–0.12
	Capture and recapture	1 June–15 June	0.11	0.05–0.21
	Capture and recapture	16 June–30 June	0.18	0.10–0.32
	Capture and recapture	1 July–15 July	0.19	0.10–0.33
	Capture and recapture	16 July–31 July	0.13	0.07–0.25
	Capture and recapture	1 Aug–14 Aug	0.12	0.06–0.23
Female	Capture	16 May–31 May	0.18	0.11–0.30
	Capture and recapture	1 June–15 June	0.32	0.22–0.45
	Capture and recapture	16 June–30 June	0.47	0.35–0.59
	Capture and recapture	1 July–15 July	0.48	0.36–0.60
	Capture and recapture	16 July–31 July	0.38	0.27–0.50
	Capture and recapture	1 Aug–14 Aug	0.35	0.25–0.47

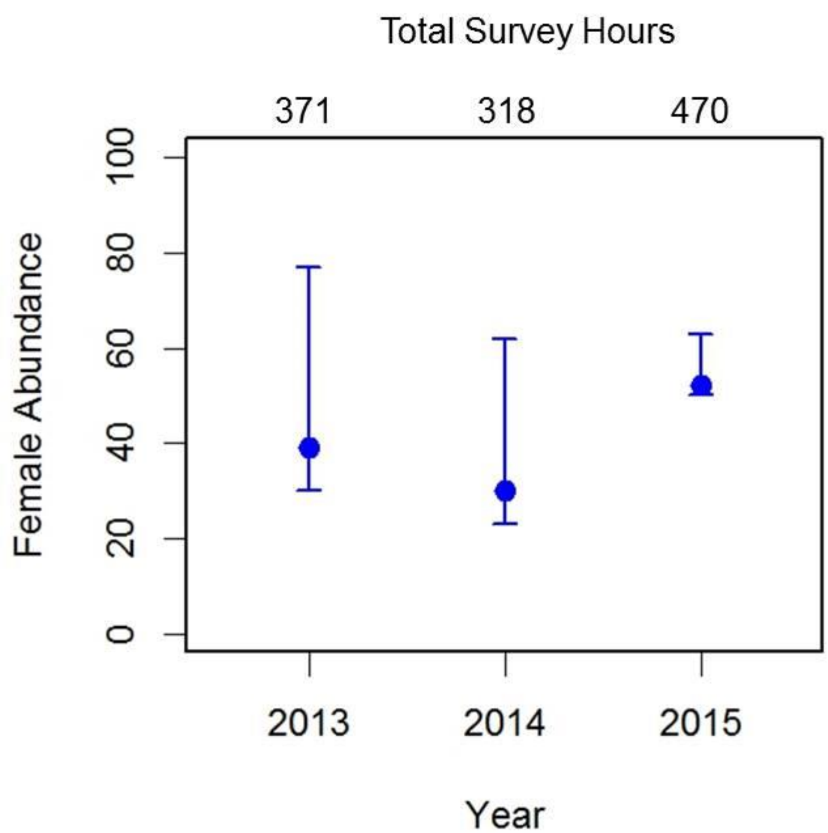

Figure 2. Eastern massasauga adult female abundance estimates from 2013 to 2015. Error bars represent 95% confidence intervals. Total survey hours (i.e., search effort) for each year are indicated along the top of the graph.