Developing an Eastern Massasauga Conservation Plan for Michigan – Phase I

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Center photo – Eastern Massasauga (*Sistrurus catenatus*). Photo by Joseph Sage.

EXECUTIVE SUMMARY

The eastern massasauga (*Sistrurus catenatus*) is a small, thick-bodied rattlesnake that lives in shallow wetlands and adjacent uplands in portions of Illinois, Indiana, Iowa, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin, and Ontario (Harding 1997, Szymanski 1998). The species was once considered common throughout its range but its populations have severely declined primarily due to habitat loss and direct persecution (Szymanski 1998). As a result, the eastern massasauga was listed as a federal candidate species in 1999 (USFWS 1999). Michigan is considered to be the last stronghold for this species, with more historical and extant populations than any other state or province in the species' range (Szymanski 1998). The eastern massasauga is currently designated a species of special concern and a Species of Greatest Conservation Need (SGCN) in Michigan (Eagle et al. 2005). The Michigan Department of Natural Resources (MDNR) is interested in developing an eastern massasauga conservation plan for the state that identifies priority populations and management actions needed to maintain those populations. The purpose of this project was to assist the MDNR's efforts to develop an eastern massasauga conservation plan for Michigan by identifying and delineating extant massasauga populations in the state, and assessing the condition and/or viability of these populations.

Eastern massasauga (EMR) populations in Michigan were identified and delineated based on a population model using known element occurrences (EOs) of this species in Michigan's Natural Heritage Database (NHD) and a cost-weighted distance analysis. A model was created in ESRI Modelbuilder to process over 1,000 eastern massasauga source features associated with 263 known EOs in Michigan's NHD. Land cover cells around massasauga source features were assigned a weighted cost based on habitat suitability for massasaugas, and a maximum allowable distance a massasauga could move based on the species' ecology and the weighted cost.This analysis was used to determine the potential extent of massasauga populations, and to identify and delineate discrete populations in the state. Initial population delineations were reviewed and edited, and final population delineations were compiled in a GIS shapefile.

We assessed the condition and estimated the viability of each delineated massasauga population. The goal of this analysis was to identify priority or "core" massasauga populations to manage and conserve to sustain the species in perpetuity in the state. We developed five general criteria and a ranking and scoring system to assess and rank estimated viability of the populations. These criteria include number and frequency of recent massasauga observations, evidence of reproduction/recruitment, habitat quantity, landscape context, and threats facing the population. We utilized available EMR data in Michigan's NHD, land cover data, aerial imagery, and expert opinion to assess and rank estimated viability of mapped populations.

A total of 187 eastern massasauga populations were delineated as a result of the cost-weighted distance analysis and population model. Of these, 42 populations are located in the northern Lower Peninsula, and 145 populations are located in the southern Lower Peninsula. A total of 110 populations (59%) were ranked as having excellent, good, or fair estimated viability. Thirty-five populations (19%) were ranked as having fair to poor or poor viability. Forty-two populations (22%) were ranked as historical or extirpated. These results and other findings from this project provide a useful framework and baseline information for developing a statewide conservation plan for the eastern massasauga to help inform and prioritize conservation and management efforts for this species in Michigan.

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INTRODUCTION

The eastern massasauga (*Sistrurus catenatus*) is a small, thick-bodied rattlesnake that lives in shallow wetlands and adjacent uplands in portions of Illinois, Indiana, Iowa, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin, and Ontario (Harding 1997, Szymanski 1998). The species was once considered common throughout its range but its populations have severely declined. Most states or provinces within the species' range have lost over 50% of their historical populations, and less than one-third of extant populations are considered secure (Szymanski 1998). The eastern massasauga was listed as a federal candidate species by the U.S. Fish and Wildlife Service in 1999 (USFWS 1999). The primary factors that have led to the decline of this species are habitat loss and direct persecution (Szymanski 1998). Agricultural, residential, and urban development as well as vegetative succession and invasive species have resulted in the loss and degradation of this species' wetland and adjacent upland habitats (Szymanski 1998). Human fear, dislike of snakes, and concern for safety regarding potential rattlesnake bites have resulted in people killing massasaugas (Szymanski 1998).

Michigan is considered to be the last stronghold for this species, with more historical and extant massasauga populations than any other state or province in the species' range (Szymanski 1998). Therefore, the long-term viability and persistence of this species in Michigan has important implications for conservation of this species across its range. However, eastern massasauga populations in Michigan also have declined due to similar threats that have been identified in other states. As a result, the eastern massasauga has been designated a species of special concern and a Species of Greatest Conservation Need (SGCN) in Michigan (Eagle et al. 2005).

The Michigan Department of Natural Resources (MDNR) is interested in maintaining eastern massasaugas in Michigan. Developing an eastern massasauga conservation plan for the state that identifies priority populations and management actions needed to maintain those populations would greatly inform and facilitate efforts to sustain this species in Michigan. To date, a total of 285 element occurrences (EOs) of eastern massasaugas have been documented in Michigan's Natural Heritage Database (NHD) (Michigan Natural Features Inventory (MNFI) 2015). However, some occurrences may not be viable or may be less viable than other occurrences. Additionally, some element occurrences may actually be part of the same population. Available resources for conservation and management efforts for this species also are limited. Identifying priority populations and management needs at the statewide level would help focus resources and help ensure that a core set of viable massasauga populations are maintained and protected to sustain the species in Michigan.

The purpose of this project was to assist the MDNR's efforts to develop an eastern massasauga conservation plan for Michigan by identifying and delineating extant massasauga populations in the state, and assessing the condition and/or viability of these populations. This report summarizes the activities and results of this project. If additional funding becomes available in the future, we have proposed developing a habitat model for the eastern massasauga in Michigan, identifying priority or "core" massasauga populations to manage and conserve to sustain the species in perpetuity in the state, identifying management needed to protect and maintain priority or "core" populations in the state, and/or developing a management plan for each "core" population.

METHODS

Project Objectives

This project addressed the following specific objectives:

1) Identify and delineate known extant massasauga populations in Michigan.

2) Assess the condition or estimated viability of delineated massasauga populations in Michigan using population viability modelling (PVM) or analysis (PVA), and/or developing and applying criteria based on expert opinion.

Population Delineation

Eastern massasauga (EMR) populations in Michigan were identified and delineated based on a population model using known element occurrences of this species in Michigan's Natural Heritage Database (NHD) (MNFI 2015) and a cost-weighted distance analysis. The goal of the population modeling was to help evaluate and delineate eastern massasauga populations by assessing and mapping how far massasaugas might be able to move from known locations based on available information on the species' movement distances and home range sizes in Michigan, potential suitable habitat around known locations, and presence of barriers. The population model and cost-weighted distance analysis also were used to help identify where massasaugas might be able to move between known EOs, and thus potentially function as one population.

A model was created in ESRI Modelbuilder to process eastern massasauga source features (i.e. source points, lines and polygons) associated with known EOs in Michigan's NHD and convert them to a raster format (Figure 1). Over 1,000 massasauga source features associated with 263 element occurrences were incorporated in the model. The source features are the specific, individual locations or sites at which massasaugas have been observed and documented in the NHD. Some massasauga element occurrences are comprised of multiple source features. The source features were chosen instead of element occurrence features so as not to lose the precise locations of the small polygons that are often nested within larger, less locationally accurate polygons which are dissolved into the whole when an element occurrence is created from multiple source features. Massasauga element occurrence records and source features were reviewed and updated with additional information when it was available. Some polygons that were mapped with low precision (i.e., "general" precision records) were removed from the source dataset, as their usefulness for modeling current populations is questionable. Historical or older records were included in the analysis as long as the precision was acceptable for the analysis. The remaining features were carefully converted to raster format, ensuring that no features were lost in the rasterization process due to grid size (30 m), or to the possible situation where a larger polygon might overlay a smaller polygon. The smaller, more precisely mapped polygons were given first priority. These rules were encoded in the model (Figure 1) that can be easily re-run as massasauga locations are updated in the database.

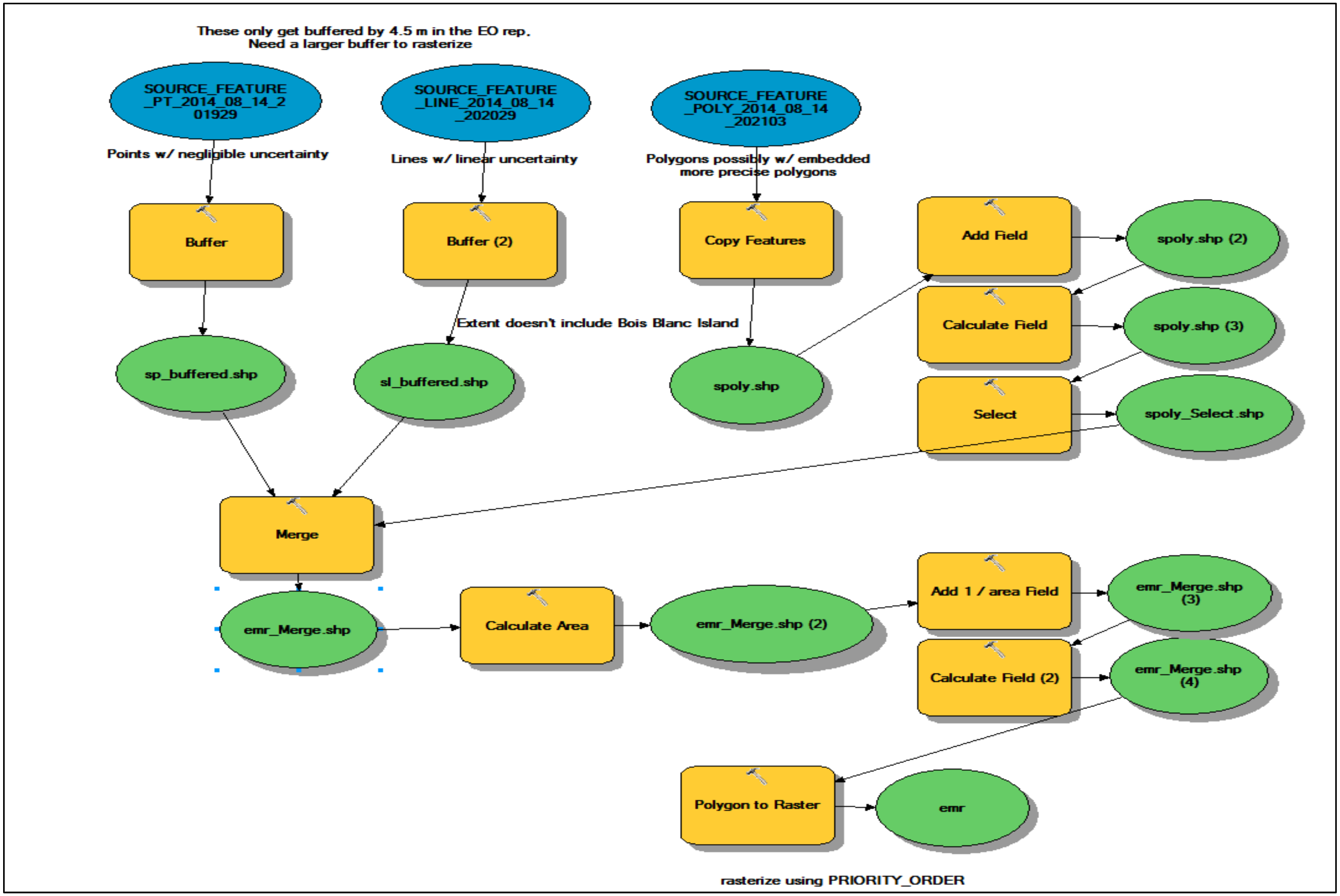

Figure 1. Model to convert eastern massasauga vector source locations to raster format.

To determine the potential extent of massasauga populations and whether source features are close enough to be part of the same population, we created a cost-weighted surface layer that takes into account distance as a cost factor along with other costs assigned to each cell on the landscape based on its suitability for massasauga movement (Figure 2). Distance can be measured by different methods. Euclidean distance is the shortest straight line distance between two points. Distance can be measured over a network such as a road system. In this case, we were interested in measuring distance from and between source features taking into account the cost for massasaugas of traveling over different types of land cover, of which some are optimal, sub-optimal, or poor habitats. The NOAA C-CAP 2006 raster layer (30 m) was used for land cover types, but first the stream lines and lakes from the GAP NHD streams and the Framework IFR 2004 lakes were inserted or "burned in" since smaller stream and water bodies don't always show up in 30 m satellite land cover, and we wanted to make sure these habitats were included in the analysis since they might be important for massasauga movement.

Each land cover type or class was assigned a weighted cost ranging from 1 (highly suitable habitat) to 10 (highly unsuitable habitat) (Table 1). A weighted cost value of 1 was equal to the Euclidian distance cost alone, and was assigned to all suitable habitat land cover cells. A cell with a weighted cost value of 10 was ten times more costly to move through, and was the value assigned to unsuitable land cover cells. The suitability of different types of land cover as habitat for massasaugas was determined based on available information on massasauga habitat use in the literature. We also consulted with several massasauga experts including Dr. Bruce Kingsbury (Indiana-Purdue University, Ft. Wayne), Dr. Michael Dreslik (Illinois Natural History Survey), Michael Redmer (U.S. Fish and Wildlife Service), and Kristen Bissell (MDNR Wildlife Division). Early to mid-successional wetlands and uplands, and forested wetlands and uplands with canopy gaps and/or adjacent to open wetlands and uplands were considered suitable habitats for massasaugas (Wright 1941, Smith, 1961, Reinert and Kodrich 1982, Seigel 1986, Weatherhead and Prior 1992, Johnson and Leopold 1998, Moore 2004, Dreslik 2005, Bissell 2006, DeGregorio 2008, Bailey 2010, Appendix 1). Unsuitable habitats and/or barriers that prevent or reduce movement for massasaugas included late successional, closed-canopy wetlands and uplands; extensive upland habitats with no wetlands nearby (i.e., >1 km wide); active agricultural lands (e.g., croplands, pasture, hay), especially extensive areas (500 m to 1 km in width and length); bare ground; areas with low, medium, and high-intensity development/ densely urbanized and human-altered landscapes; fast-flowing major rivers (500m – 1 km wide); large inland lakes (>500 m in width & length), and the Great Lakes (Wright 1941, Smith, 1961, Reinert and Kodrich 1982, Seigel 1986, Weatherhead and Prior 1992, Johnson and Leopold 1998, Moore 2004, Dreslik 2005, Bissell 2006, DeGregorio 2008, Bailey 2010, Appendix 1). As a result, land cover classes associated with palustrine wetlands were considered suitable habitats for massasaugas for the model, and were assigned a weighted cost value of 1 (Table 1). Land cover classes associated with open and forested upland habitats were considered marginally suitable habitats for massasaugas for the model, and were assigned a weighted cost value of 2 or 3. Remaining land cover classes associated with agricultural use, development, bare land, and open water were considered unsuitable habitats, and were assigned a weighted cost value of 10.

The cost allocation analysis calculated for each cell its nearest source feature (i.e., massasauga raster data) based on the least accumulated cost over the cost-weighted surface layer that was created. This cost allocation zone for each source feature (Figure 3a) provided an estimate of whether the population was separate or joined to another source population. The maximum total allowable cost distance for each source was set at five km (three miles). This was based on eastern massasauga element occurrence specifications developed by Natureserve which state that massasauga sites or source features that are separated by five km (three mi) or more of suitable habitat should constitute separate EOs (Hammerson 2002). We also reviewed and compiled information about maximum distances moved and maximum home range sizes for massasaugas based on radio-telemetry studies in Michigan and other states (Table 2 and Appendix 1). Maximum allowable cost distances varied depending on habitat suitability of land cover cells. Land cover cells in suitable habitats for massasaugas were assigned a weighted cost value of one, which resulted in a maximum allowable cost distance (i.e., maximum distance massasaugas could potentially "move" through these cells in the model) was five km (Table 1). Land cover cells in marginally suitable habitat types with weighted cost values of two or three were allowed maximum cost distances of three or four km (Table 1). Land cover cells in unsuitable habitat types with weighted cost values of ten were set at 0.5 km. Optional output from the cost allocation includes a backlink raster, which defines the direction or identifies the next neighboring cell along the least accumulative cost path from a cell to its source, and the distance raster (Figure 3b), that defines for each cell the least accumulated cost distance over the cost surface to the source locations.

With the raster file outputs from the cost allocation analysis, we produced a preliminary map and GIS shapefile of potential massasauga population delineations in Michigan based on known massasauga source features and available land cover data and information on massasauga ecology. Additionally, for each massasauga population, we delineated the following four zones: 1) Zone 1 - mapped spatial extent and/or locational uncertainty around massasauga source features in the NHD that were included in the analysis; 2) Zone 2 – cost-weighted distance of 20 m up to 500 m (0.01 mi to 0.3 mi) around Zone 1; 3) Zone 3 – cost-weighted distance of 501 m up to 1 km (0.3 mi to 0.6 mi) around Zone 1; and 4) Zone 4 – cost-weighted distance of 1 km up to 5 km (0.6 mi to 3 mi) around Zone 1. Zones 2 and 3 represent inferred extent of habitat use for massasauga source features, and the outer boundary of Zone 4 represents the spatial extent of the delineated massasauga population. Inferred extent of habitat use refers to the area likely utilized or occupied by the species at that location, which may be useful for conservation planning purposes (NatureServe 2002). The inferred extent distance is essentially an approximate spatial requirement for certain species, typically based on the average home range (NatureServe 2002). The inferred extent distance generally does not exceed the maximum known single-year migration distance for the species (assuming nonvolant species) or the EO separation distance (NatureServe 2002). We defined the inferred extent distances for Zones 2 and 3 (i.e., 500 m and 1 km) based on maximum distances massasaugas moved during radio-telemetry studies in Michigan and other states (Table 2 and Appendix 1).

Table 1. Summary of land cover classes (NOAA C-CAP 2006), assigned weighted costs, and maximum allowable cost distances included in the massasauga population cost distance analysis and model. The weighted costs were assigned based on habitat suitability of the land cover class for massasaugas.

Land Cover Class	Weighted Cost	Maximum Allowable Cost Distance (km)
Palustrine Aquatic Bed	1	5
Palustrine Emergent Wetland	1	5
Palustrine Forested Wetland	1	5
Palustrine Scrub/Shrub Wetland	1	5
Unconsolidated Shore	1	5
Deciduous Forest	2	4
Evergreen Forest	2	4
Mixed Forest	2	4
Scrub/Shrub	2	4
Grassland/Herbaceous	3	3
Bare Land	10	0.5
Cultivated Crops	10	0.5
Developed, Low Intensity	10	0.5
Developed, Medium Intensity	10	0.5
Developed, High Intensity	10	0.5
Developed, Open Space	10	0.5
Open Water	10	0.5
Pasture/Hay	10	0.5

Table 2. Summary of information on ranges of maximum distances moved, average home range size, and maximum home range size for eastern massasaugas based on radio-telemetry studies in Michigan and other states within the massasauga's range.

Geographic Region	Maximum distance moved/individual	Average home range size/individual	Maximum home range size/individual
Southern MI[1]	~300-500 m	~ 1 – 6 ha	~ 20 – 30 ha
Northern MI[2]	~1 km	~ 4 - 17 ha	~ 40 – 95 ha
Other states[3]	~500 m to 1- 2 km	~ 3 – 26 ha	~ 5 – 140 ha

[1]Moore 2004, Sage 2005, Bissell 2006, Bailey 2010

[2]DeGregorio 2008

[3]Reinert and Kodrich 1982 (PA), Weatherhead and Prior 1992 (ONT), Johnson 2000 (NY), Phillips et al. 2002 (IL), Kingsbury et al. 2003 (IN), Dreslik 2005 (IL), Marshall et al. 2006 (IN), Durbian et al. 2008 (MO & WI)

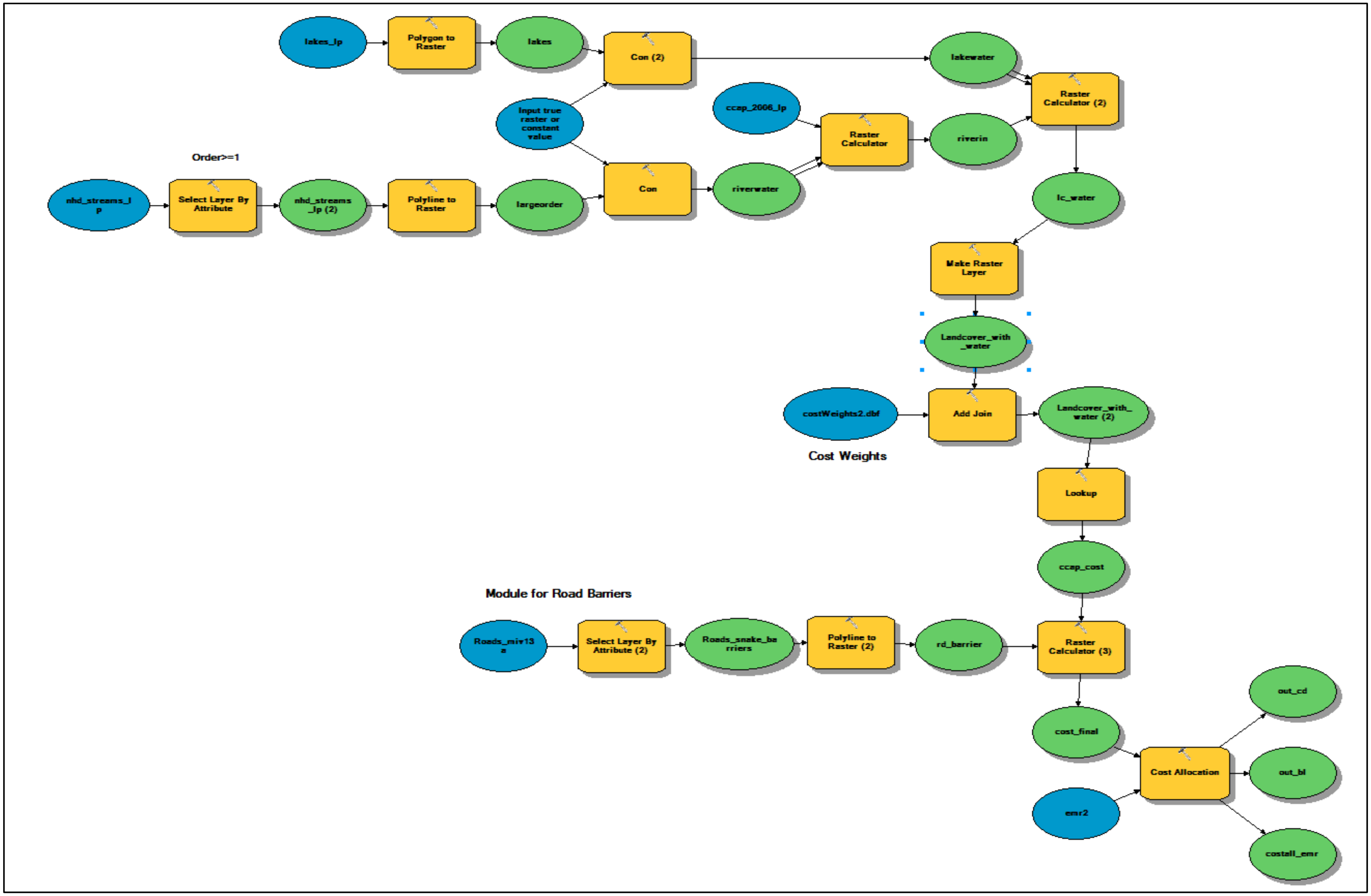

Figure 2. Model with streams and lakes inserted into 30-m land cover, and cost-weighted surface created based on massasauga habitat suitability.

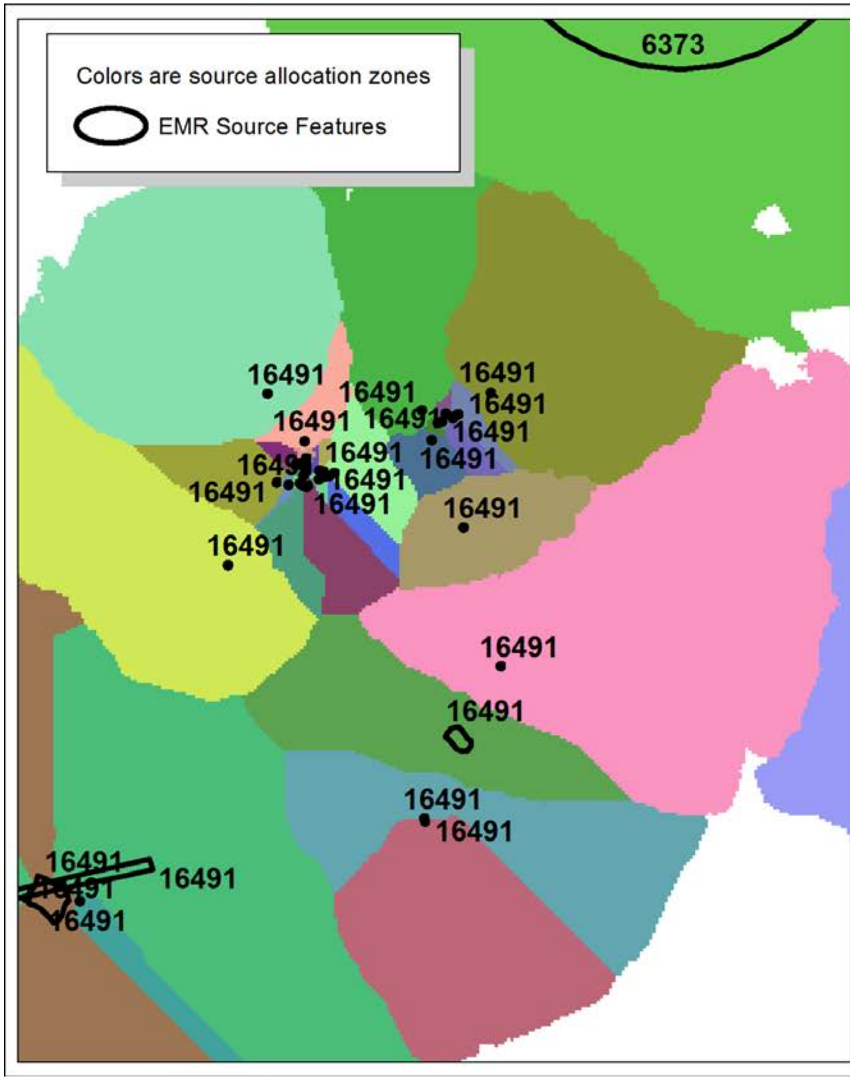

Figure 3a. Each color is the allocation zone for a massasauga source feature.

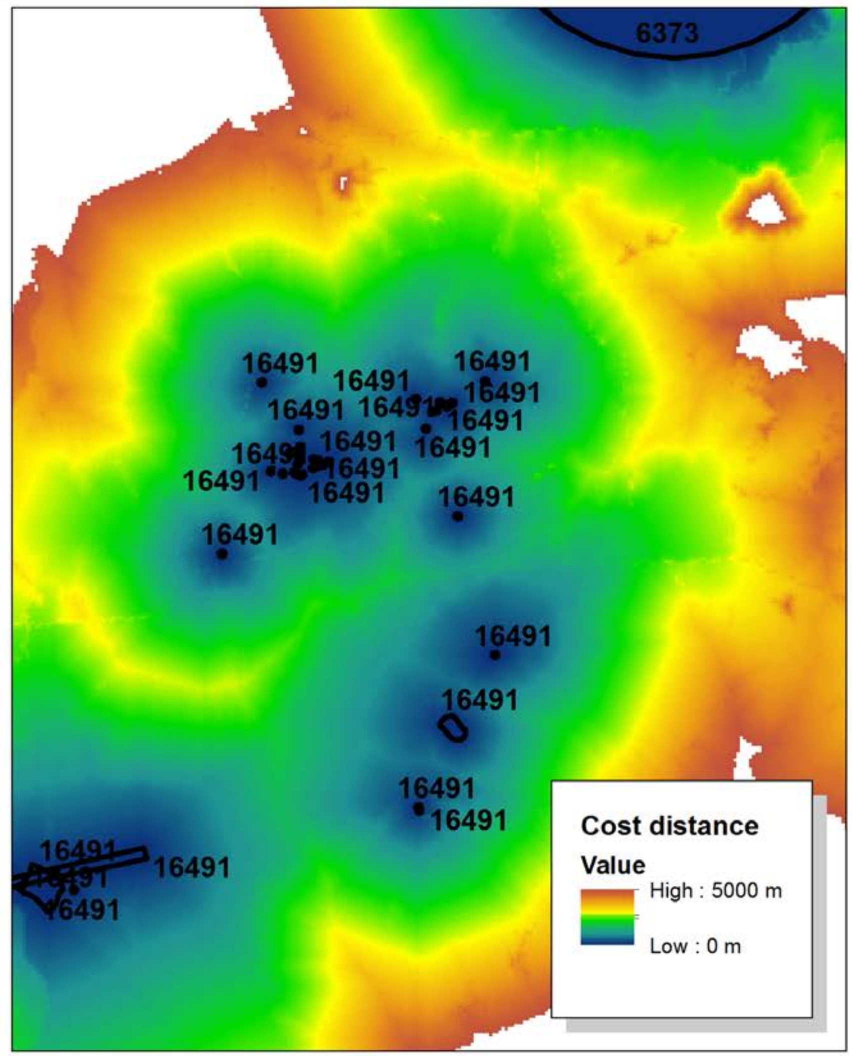

Figure 3b. The least cost distance for each source feature from Figure 3a.

We reviewed and evaluated each delineated population and all polygons/zones mapped within each population. We visually inspected each mapped population in ArcMap along with the best available aerial imagery, land cover data, hydrology data, and data on road locations and types to determine if the delineated populations needed to be revised or edited (e.g., if a multiple source features mapped as a single population should be mapped as separate populations, or if separate populations should be mapped as one population). The massasauga population polygons were edited manually as needed based on extent of suitable and unsuitable habitat indicated from aerial imagery and land cover data, and the presence of potential barriers and potential connectivity/dispersal or movement corridors (i.e., streams, rivers, and lakes). In particular, the mapped populations were reviewed for the presence and type of roads and rivers/streams within and along the outer extent of the populations. Recent studies have found that paved roads represent almost complete barriers to massasauga movement and dispersal due to behavioral avoidance/reluctance to cross roads and/or road mortality (Seigel 1986, Weatherhead and Prior 1992, Hammerson 2002, Shepard et al. 2008a, Shepard et al. 2008b, Dreslik pers. comm., Kingsbury pers. comm.). Snakes have been found to use streams/rivers though to move between habitat areas (Kingsbury pers. comm., Redmer pers comm.). For this project, we assumed that massasaugas could use streams/rivers to cross roads, although this likely depends on the type or nature of the stream crossing (e.g., type of culvert) (Bissell pers. comm.). As a result, busy highways and paved roads, especially high traffic roads, were considered barriers to massasauga movement and were used to delineate separate massasauga populations unless a stream/river connected suitable habitat on both sides of the road, or if suitable habitat appeared to be present on both sides of the road and road traffic was assumed to be light (e.g., dirt road through a relatively undeveloped area).

After preliminary population delineations were reviewed and edited, a new GIS shapefile of the final massasauga population delineations was created for distribution and future analysis, planning, and conservation efforts. This new shapefile contains just the outermost boundary or extent of each delineated massasauga population. Each delineated population was assigned a unique population identification number (i.e., EMRPOPXXX in the POP_ID2 attribute). This shapefile also contains some information about each population including the county in which the population is located, identification numbers for the massasauga EOs that were included in the population, dates when massasaugas were first and last observed within the population, estimated population viability rank, and ranks for different criteria used to assess the condition and potential viability of the population. This shapefile contains massasauga populations that are known to be extant as well as populations that are considered historical but may still be extant and need additional surveys to verify their status.

Population Viability Assessment and Ranking

We assessed the condition and estimated the potential viability of each massasauga population delineated as part of this project. The goal of this analysis was to identify priority or "core" massasauga populations to manage and conserve to sustain the species in perpetuity in the state. We initially had proposed potentially assessing or estimating the viability of some populations using population viability modelling (PVM) or analysis (PVA) (e.g., PVA developed by Lincoln Park Zoo). But upon further evaluation and consultation with several massasauga experts, we decided that, for the purposes of this project, it would be more appropriate and sufficient to assess the condition and estimate or rank the viability of massasauga populations in the state by developing and applying criteria based on available data and expert opinion.

The following criteria were used to assess the condition and estimate and rank the viability of delineated massasauga populations in the state based on available data and expert opinion:

1) Number and frequency of recent observations (i.e., within last 25 years/since 1990) documented within the population
2) Evidence of reproduction and/or recruitment within the population, including observations of gravid females, neonates, yearlings or young-of-the-year snakes, juveniles, sub-adults, and/or multiple age classes
3) Habitat quantity in terms of the amount of suitable habitat (i.e., primarily amount of open and/or forested wetlands) needed to sustain a massasauga population. Durbian et al. (2008) suggested a minimum of 100 ha (~500 ac) of suitable habitat (i.e., open canopy wetlands and adjacent open uplands) is needed to sustain a massasauga population (see Appendix 1). Populations in more forested habitats will likely need more than a minimum of 100 ha to sustain them (Kingsbury pers. comm.).
4) Landscape context in terms of the amount of natural habitat and level of habitat loss and fragmentation and/or barriers surrounding the population
5) Number and level of threats facing the population (i.e., within and/or immediately adjacent to the population) including documented and potential/likely threats. Threats that were included in this evaluation were habitat loss and fragmentation due to agricultural, residential, and other development; vegetative succession/woody encroachment; invasive species; paved and other roads as barriers to movement; road mortality; human persecution; and disease (i.e., snake fungal disease). We focused on threats that were likely to be recorded during field survey, in the NHD, and could be identified from aerial imagery (e.g., agricultural and residential development).

We also evaluated land ownership for each massasauga population as an indication of the potential for long-term management and protection of the population. But we did not include this criterion in the viability assessment and ranking. We also initially wanted to evaluate habitat quality as a criterion for assessing and ranking population viability. But we decided to not include this criterion in the assessment at this time because of limited information on habitat quality for most of the delineated massasauga populations, and because habitat quality could potentially vary dramatically across a population.

We developed a ranking and scoring system to evaluate each criterion and assess overall population viability (Table 3). Ranks for each criterion ranged from ‘A’ to ‘D’, except for the evidence of reproduction criterion which was ranked as either ‘Yes’ or ‘No’ (Table 3). For the threats criterion, we first indicated which threats occurred at the site by giving it a score of 1 if it occurred, 0 if it did not occur, ‘P’ if the threat potentially/likely occurred, or ‘U’ if it was not known whether the threat occurred at the site. We summed these up to get an overall threats score for the population. We then used the threats score and examined aerial imagery of the site to assess the level of threats facing the population to assign an overall rank and score for the threats criterion. Each rank was assigned a numerical score, ranging from 0 to 7 except for the evidence of reproduction criterion which ranged from 0 to 2 (Table 3). We calculated an overall viability score for each population by adding up the scores for all the viability criteria.

For each population, we reviewed the scores for the different criteria and the overall viability score to assign an estimated viability rank for the population (Table 4). We used the same estimated viability ranks that NatureServe uses to rank the estimated viability of element occurrences of rare species and natural communities (Table 4). The estimated viability rank provides an assessment of the probability or likelihood that, if current conditions prevail, the occurrence will persist for the foreseeable future (i.e., at least 20-30 years) (NatureServe 2002, Hammerson et al. 2008). The estimated viability ranks can be combination ranks (i.e., AB, AC, BC, and CD) to indicate the range of uncertainty regarding the appropriate rank for an occurrence. In fact, due to pervasive limited information about most occurrences, combination ranks are appropriate and encouraged (Hammerson et al. 2008).

Table 3. Summary of criteria developed and used to assess the condition and estimate and rank viability of eastern massasauga populations delineated in Michigan.

Viability Criteria	**Criteria Ranks and Scores**
Number and frequency of recent massasauga observations	• A – Multiple, frequent/regular observations within each year over multiple (3+) years within last 25 years (7 pts) • B – Multiple, frequent regular observations within each year over only a few (1-2) years within last 25 years (5 pts) • C – Few observations within a year but over multiple (3+) years within last 25 years (3 pts) • D – Few observations within last 25 years (1 pt) • U - No recent observations/reports (i.e., within last 25 years, historical record) (0 pts)
Evidence of reproduction and/or recruitment within the population	• Yes (2 pts) • No (0 pts)
Habitat quantity	• A - 200 ha (~500 ac) or greater (7 pts) • B – 100 – 199 ha (~250-500 ac) (5 pts) • C – 50 – 99 ha (~125-250 ac) (3 pts) • D - <50 ha (<~125 ac) (1 pt) • U – Unknown (0 pts)
Landscape context	• A – Landscape context relatively pristine/natural (i.e., 75-100% natural) (7 pts) • B – Low intensity/level of development and habitat loss around population, and landscape context still mostly pristine/natural around population (i.e., 50-74% natural) (5 pts) • C – Moderate intensity/level of development and habitat loss around population but landscape context still contains some natural/suitable habitat (i.e., 25-49% natural) (3 pts) • D – High intensity/level of development and habitat loss around population with little natural/suitable habitat available in landscape context (i.e., <25% natural) (1 pt) • U – Unknown/no information or assessment (0 pts)

Number and level of threats	• A - Little/no documented or potential threats, or threats are sufficiently managed/addressed (7 pts) • B – One or two documented threats and only one or two potential/likely threats (5 pts) • C – One or two known/documented threats plus multiple (3+) potential/likely threats (3 pts) • D – Multiple/several (3+) known/documented threats (1 pt) • U – Unknown (0 pts)

Table 4. Summary and definition of estimated viability ranks used to assess and rank the condition and estimated viability of eastern massasauga populations delineated in Michigan.

Estimated Viability Rank	**Viability Rank Definitions/Descriptions (from NatureServe 2002 and Hammerson 2008)**
A	*Excellent estimated viability* - Population exhibits optimal or at least exceptionally favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; and, if current conditions prevail, the population is very likely to persist for the foreseeable future (i.e., at least 20-30 years) in its current condition or better.
B	*Good estimated viability* - Population exhibits favorable characteristics with respect to population size and/or quality and quantity of occupied habitat; and, if current conditions prevail, the population is likely to persist for the foreseeable future (i.e., at least 20-30 years) in its current condition or better.
C	*Fair estimated viability* - Population characteristics (size, condition, and landscape context) are non-optimal such that persistence is uncertain under current conditions, or the population does not meet A or B criteria but may persist for the foreseeable future with appropriate protection or management, or the population is likely to persist but not necessarily maintain current or historical levels of population size or genetic variability.
D	Poor estimated viability - If current conditions prevail, population has a high risk of extirpation (because of small population size or area of occupancy, deteriorated habitat, poor conditions for reproduction, ongoing inappropriate management that is unlikely to change, or other factors).
E	*Verified extant* - Population recently has been verified as extant, but sufficient information on the factors used to estimate viability has not yet been obtained.
H	*Historical* - Recent field information verifying the continued existence of the population is lacking. For this project, H was used for populations that have not been reconfirmed for 25 or more years.
F	*Failed to find during recent surveys (within last 25 years)* - Population has not been found despite a search by an experienced observer under appropriate conditions for the element at previously known locations, but the population still might be confirmed with additional field survey efforts.
X	*Extirpated* - Adequate surveys by one or more experienced observers under appropriate conditions, or other persuasive evidence, indicate that the species no longer exists there or that the habitat or environment at the site has been destroyed to such an extent that it can no longer support the species.

RESULTS

Population Delineation

A total of 187 eastern massasauga populations were delineated as a result of the cost-weighted distance analysis and population model (Appendix 2). Of these, 42 populations are located in the northern Lower Peninsula (NLP), and 145 populations are located in the southern Lower Peninsula (SLP). Most of the populations contained only one massasauga EO although these could contain multiple source features/locations. Only 46 populations encompassed multiple massasauga EOs, ranging from two to fifteen EOs.

Population Viability Assessment and Ranking

Of the 187 massasauga populations that were delineated, 110 populations (i.e., 59%) were ranked as having excellent, good, or fair estimated viability or probability of persistence into the foreseeable future (i.e., at least 20-30 years) (i.e., viability ranks of A, AB, AC, B, BC, or C; Table 5, Appendix 3). Of these, 85 populations (77%) are located in the SLP, and 25 populations (23%) are located in the NLP (Appendix 3). Of the remaining populations, thirty-five (19% of the 187 total populations) were ranked as having fair to poor or poor viability (i.e., viability ranks of CD or D) (Table 5, Appendix 3). All but one of these populations are located in the SLP. The remaining 42 populations (22% of the total populations) were ranked as historical or extirpated (Table 5, Appendix 3). Almost two-thirds (i.e., 26 of 41populations/ 63%) of the historical or extirpated populations are located in the SLP, and over one-third of these populations (i.e., 15/ 37%) are located in the NLP (Appendix 3).

Assessment of the different viability criteria provided additional insights into the overall status and condition of the massasauga populations delineated in the state, and helped identify information gaps. Only 21% of the delineated populations in the state had information documenting multiple, frequent or regular observations of massasaugas annually over a few or multiple years within the last 25 years, while 58% of the populations had only a few observations and 22% of the populations had no observations of massasaugas documented within the last 25 years (Table 6). Only 36% of the populations had documented evidence of reproduction or recruitment (Table 6). Most (79%) of the populations appeared to contain at least the suggested minimum amount of habitat needed to sustain a massasauga population (i.e., 100 ha/~250 ac, Durbian et al. 2008), with 65% of the populations potentially having at least 200 ha (~500 ac) of suitable habitat and an additional 14% of the populations potentially having between 100 and 200 ha (~250-500 ac) of suitable habitat (Table 6). Most (79%) of the populations were fairly isolated or fragmented within the landscape, with the landscape context around these populations characterized by moderate to high levels of development and habitat loss and less than 25-50% natural habitat within the surrounding landscape (Table 6). Only 41 (22%) of the populations occur primarily on public lands, while 146 (78%) of the populations occur partially or primarily on private lands, which has implications for long-term conservation and management efforts for this species (Table 6).

Most (94%) of the massasauga populations are facing multiple threats (i.e., C- and D-ranks for the threats criterion; Table 6, Appendix 3). Paved roads and other roads (e.g., gravel and dirt roads) were the most common or frequent threat to massasauga populations in the state, with roads occurring within or around over 90% of the populations. Agricultural and residential development were the next most common threats to massasauga populations, with agricultural development documented at 78% and residential development documented at 61% of the populations, although the level of development varied among sites. Other development (e.g., golf courses, industrial or commercial development) was documented at 38% of the populations. Persecution, road mortality, vegetative succession, and invasive species were documented at 15-20% of the populations, although these threats were likely underreported and underestimated. Snake fungal disease has been documented in only three populations in the state to date (Allender et al. 2014), but testing for this disease and other diseases in massasaugas has been fairly limited.

Table 5. Summary of estimated viability ranks for eastern massasauga populations delineated in the northern and southern Lower Peninsula of Michigan in 2015.

Estimated Viability Rank	**Number of EMR Populations in the Northern Lower Peninsula**	**Number of EMR Populations in the Southern Lower Peninsula**	**Total Number of EMR Populations**
A	4	1	5
AB	7	11	18
AC	5	0	5
B	2	18	20
BC	7	38	45
C	1	16	18
CD	1	23	24
D	0	11	11
H	15	26	39
X	0	1	1
TOTAL	**42**	**145**	**187**

Table 6. Summary of viability criteria and rankings to assess the condition and estimated viability of eastern massasauga populations delineated in Michigan in 2015.

Viability Criteria	Number of Populations – A-Rank	Number of Populations – B-Rank	Number of Populations – C-Rank	Number of Populations – D-Rank	Number of Populations – U-Rank
Recent Observations	28	11	34	73	42
Evidence of Reproduction	68 (Yes)	119 (No)			
Habitat Quantity	122	26	21	17	0
Landscape Context	15	23	64	85	0
Threats	12	52	61	62	0
Ownership[1]	6	35	64	82	0

[1]Additional criterion ranked but was not scored or included in estimated viability ranking. A-rank = Population entirely on public lands. B-rank = Population mostly on public lands. C-rank = Population partially on public and private lands. D-rank = Population primarily on private lands.

Of the 187 delineated populations in the state, only 23 populations (12%) were ranked as having excellent (A-viability rank) or excellent to good estimated viability (AB-viability rank) (Table 5 and Appendix 3). These populations were distributed fairly evenly among the NLP (11 populations) and SLP (12 populations). All of these populations have had recent massasauga observations and surveys (i.e., last observed and survey dates ranging from 2003 to 2014) (Appendix 3). Eastern massasaugas have been documented at a majority of these populations for over 30 to 50 years. Most of these populations (i.e., 18 of 23/78%) have had multiple and frequent/regular observations of massasaugas documented annually over a few or multiple years within the last 25 years (Appendix 3). Evidence of reproduction was documented at all but two of these populations. All of these populations contained at least 200 ha (~500 ac) of suitable habitat, and many of these populations had significantly greater than 200 ha (Appendix 3). The landscape context around these populations ranged from mostly pristine or natural (i.e., A or B rank) to moderately or highly developed with some to little natural habitat surrounding the populations (i.e., C or D rank). The number and level of threats facing these populations ranged from little to no documented or potential threats to multiple documented/known threats, with 9 of the 23 populations facing no or only one or two documented threats and/or only one or two potential/likely threats, and 14 of the populations facing several documented and potential/likely threats. About half these populations occur either entirely or mostly on publicly-owned lands (Appendix 3).

A total of 65 populations (35%) were ranked as having good (B-viability rank) or good to fair estimated viability (BC-viability rank) (Table 5, Appendix 3). Most of these populations are located in the southern Lower Peninsula with 56 populations, and only nine are in the northern Lower Peninsula. About 65% of these populations have had massasauga reports since 2000 (Appendix 3). Eastern massasaugas have been documented at 28 (43%) of these populations for over 30 years. Most of these populations (i.e., 48 of 65/74%) have only had a few observations of massasaugas documented within a year and/or over multiple years within the last 25 years (Appendix 3). Evidence of reproduction was documented at only about half (i.e., 32 populations/49%) of these populations. Almost all (i.e., 59 populations/91%) of these populations contained at least 200 ha (~500 ac) of suitable habitat, and five of the remaining six populations had between 100 and 200 ha of suitable habitat (Appendix 3). The landscape context around these populations ranged from mostly pristine or natural (i.e., A or B rank) to moderately or highly developed with some to little natural habitat surrounding the populations (i.e., C or D rank), but most (83%) of these populations were located within moderately or highly developed landscapes (Appendix 3). Most (69%) of these populations face multiple documented and/or potential/likely threats (i.e., C or D rank). A majority (77%) of these populations occurs either partially or primarily on privately owned lands, and only 23% of these populations occur primarily on publicly-owned lands (Appendix 3).

A total of 41 populations (22%) were ranked as having fair (C-viability rank) or fair to poor estimated viability (CD-viability rank) (Table 5, Appendix 3). Almost all (i.e., 39) of these populations are located in the southern Lower Peninsula. About 51% of these populations have had massasaugas reports since 2000 (Appendix 3). Eastern massasaugas have been documented at only nine of these populations for over 30 years, and at only three of these populations for over 50 years. Most of these populations (i.e., 37 of 41 populations/90%) have only had a few observations of massasaugas documented within a year and/or over multiple years within the last

25 years (Appendix 3). Evidence of reproduction was documented at only 11 (27%) of these populations. About two-thirds of these populations appeared to contain over 100 ha (~250 ac) of suitable habitat for massasaugas, with 17 of the 41 populations containing at least 200 ha (~500 ac) of suitable habitat (Appendix 3). The landscape context around most (93%) of these populations were moderately or highly developed with some to little natural habitat surrounding the populations (i.e., C or D rank) (Appendix 3). Most (76%) of these populations face multiple documented and/or potential/likely threats (i.e., C or D rank). A majority (93%) of these populations occurs either partially or primarily on privately owned lands (Appendix 3).

The viability assessment ranked 11 massasauga populations (6%) as having poor estimated viability (D-viability rank) (Table 5, Apppendix 3). These populations are all located in the southern Lower Peninsula. Only about 45% these populations have had massasaugas reports since 2000, and, in general, very few massasaugas have been documented at all these populations within the last 25 years (Appendix 3). Eastern massasaugas have been documented at six (55%) of these populations for over 20 years, and at one population for over 50 years. Evidence of reproduction was documented at only three (27%) of these populations. Only one of these populations appeared to contain at least 100 ha (~250 ac) of suitable habitat for massasaugas, which is the suggested minimum amount of suitable habitat needed to sustain a population of eastern massasaugas (Durbian et al. 2008, Appendix 3). Seven of these populations appeared to contain less than 50 ha (~125 ac) of suitable habitat. The landscape context around almost all of these populations was highly developed with little natural habitat surrounding the populations (i.e., D rank) (Appendix 3). Most (73%) of these populations face multiple documented and/or potential/likely threats (i.e., C or D rank). A majority (82%) of these populations occurs either partially or primarily on privately owned lands (Appendix 3).

Forty-two populations (22%) did not have recent massasauga observations documented within the last 25 years, and were ranked as historical or extirpated populations (Table 5, Appendix 3). Massasaugas were last observed at or reported from 23 (55%) of these populations over 50 years ago (Appendix 3). Evidence of reproduction was documented at only two of these populations in the past (Appendix 3). Extensive suitable habitat for massasaugas appeared to still be available at many (67%) of these populations, with over 200 ha of suitable habitat available at 18 populations and between 100 and 200 ha at an additional 10 populations (Appendix 3). Nine of these populations had less than 50 ha of suitable habitat. The landscape context around most of these populations was moderately or highly developed and fragmented with some natural habitat surrounding the populations (i.e., C - D rank) (Appendix 3). Eight of these historical populations were surrounded by relatively pristine or natural habitats with little development. While 25 (60%) of these populations face multiple documented and/or potential threats (i.e., C or D rank), 17 of these populations face minimal threats (i.e., A or B rank). As with the other populations, a majority (81%) of these populations occurs either partially or primarily on privately owned lands (Appendix 3).

DISCUSSION

The cost-weighted distance analysis/model, resulting population delineations, and associated population viability assessment provide a useful tool and framework to help inform, focus, and prioritize conservation and management efforts to sustain eastern massasaugas in Michigan in the future. It is important to note though that the cost-weighted distance model and resulting population delineations were based on several major assumptions. These include treating paved roads as barriers to massasauga movement and using them to delineate separate massasauga populations in some cases. Another major assumption was allowing streams to connect occupied areas and/or areas with suitable habitat including areas separated by paved roads and busy highways. Streams may connect areas and provide suitable dispersal or movement corridors at some sites but perhaps not at other or all sites. These assumptions should be revisited and further evaluated in the future. The overall maximum allowable cost distance of five km and maximum cost distances for specific land cover classes also could potentially be reconsidered and refined. Additional information about massasauga distribution and ecology, particularly habitat use and dispersal, as well as information about habitat conditions on the ground for individual populations could help refine the population model and delineations. Additional massasauga observations and/or surveys in areas with suitable habitat that connect documented sites but currently lack massasauga sightings could help inform and refine population delineations.

More detailed and current information on land cover data and available suitable habitat for massasaugas also would be useful for refining the population model and delineations. A model that identifies and/or predicts areas with suitable habitat for eastern massasaugas could be used in conjunction with the cost-weighted distance analysis to refine massasauga population delineations. A GIS-based habitat model for eastern massasaugas has recently been developed for northeast Ohio and southern Michigan by Eric McCluskey, a doctoral student at Ohio State University. MNFI has been providing data and technical assistance to help develop and evaluate this model. A draft habitat model has been developed and is in the process of being evaluated with massasauga data from Michigan's NHD and some targeted field surveys this spring. The model also tried to identify and predict habitat for massasaugas in northern Michigan, but the current model does not appear to be very effective or adequate for predicting massasauga habitat in northern Michigan at this time (McCluskey pers. comm.). After the habitat model is completed, it could be used to help refine the massasauga population delineations.

The massasauga population viability assessment was able to identify and rank massasauga populations that are likely more viable than others in Michigan. These results provide a framework and baseline information for evaluating and prioritizing populations for future management and conservation efforts, especially given the large number of populations delineated in the state. The twenty-three populations that were ranked as having excellent (A-viability rank) or excellent-to-good (AB-viability rank) estimated viability could be considered high priority sites for management and conservation in the state (Appendix 3). The sixty-five populations that were ranked as having good (B-viability rank) or good-to-fair (BC-viability rank) estimated viability, or a subset of these sites, could be considered high to moderate priority sites for management and conservation in the state (Appendix 3). The forty-one populations that were ranked as having fair (C-viability rank) or fair-to-poor (CD-viability rank) estimated viability could be considered moderate to low priority sites for management efforts (Appendix 3). However, it is important to note that these viability assessments were based on currently available information, and limited information in many cases (e.g., documented observations of only one or a few snakes). These viability rankings could potentially change in the future as new information becomes available. For example, some of the populations currently ranked as having fair estimated viability and even some of the historical populations could potentially have higher estimated viability in reality if additional information indicates massasaugas are more abundant in these populations than originally thought. Populations should be further evaluated and prioritized for management and conservation efforts on a case-by-case basis.

The viability assessment provided some additional insights about the status and condition of massasauga populations in the state that may have important implications for future research and management efforts. The viability assessment revealed how pervasive roads are within and around massasauga populations, and the potential impact of roads on massasauga populations and viability in the state. Future research and conservation efforts should consider investigating and quantifying the impact of roads on massasauga populations in Michigan locally and statewide, and how and where these impacts can/should be mitigated. The viability assessment also provided additional data that emphasizes the importance of conservation and management efforts for massasaugas on private lands in Michigan given that 78% of the delineated populations occur partially or primarily on private lands. The viability assessment also indicated that most populations in Michigan face multiple threats, including populations that have excellent or good estimated viability. This suggests that continued management and monitoring are needed even at sites that appear to be viable. Fortunately, the viability assessment also indicated that most populations in the state appear to contain at least the minimum amount of habitat needed to potentially sustain the population. This finding needs more research and analysis, but resource managers could use this information to prioritize sites for habitat management and restoration to maintain and increase the amount of suitable habitat needed to sustain populations. Finally, the assessment revealed how little information we have on massasauga distribution and abundance in the state, particularly on private lands and given how much suitable habitat for massasaugas potentially occurs in the state.

Similar to the population model and delineations, the massasauga population viability assessment was based on some assumptions, and could be revisited and refined in the future. While the general approach and criteria for assessing and ranking the estimated viability of delineated populations in the state were likely adequate for an initial assessment, some of the criteria and the ranking and scoring system could be refined and improved. The overall viability score was calculated by simply summing up the assigned scores for the different viability criteria. It may be appropriate to give more weight to certain criteria in calculating the overall viability score (e.g., recent massasauga observations, habitat quantity), particularly if we are able to obtain additional and enhanced information on some of these criteria. Another important assumption related to this is that we can accurately estimate massasauga population viability based primarily on habitat quantity, threats and other criteria with little information on massasauga abundance and/or distribution. Many of the populations had only a few documented observations of massasaugas within the last 25 years. The habitat quantity criterion and ranks were based on a recommended minimum amount of habitat needed to sustain a massasauga population (i.e., 100 ha/~250 ac, Durbian et al. 2008) rom radio-telemetry studies of massasauga populations in Missouri and Wisconsin. More information or research is needed to determine if this minimum amount of suitable habitat is adequate for sustaining massasauga populations in Michigan, and if not, how much suitable habitat is needed. It also may be more informative to use a broader range of habitat sizes for the ranks for this criterion (e.g., range from <50 ha to >400 ha instead of <50 ha to >200 ha) since most populations were given the highest rank for the habitat quantity criterion. Enhanced information on land cover and habitat suitability for massasaugas (e.g., a predictive habitat model) also could help us better assess and rank this criterion.

The viability assessment helped identify information needs and additional criteria that would be useful for future assessments. For example, we were not able to incorporate habitat quality or active management (or management impacts/benefits) in the viability assessment due to limited information and resources, but including these criteria in future assessments would be very useful. We also did not have sufficient information and/or resources to adequately assess some of the threats such as vegetative succession, invasive species, persecution, road mortality, and disease. These threats were likely underestimated in the viability assessment, although they were identified as potential/likely threats in many cases. Future surveys and viability assessments should try to obtain better information on these threats within individual populations.

Future viability assessments also would benefit greatly from additional information on current massasauga distribution, abundance, demographics, and ecology within delineated populations. This would provide sufficient information to conduct more detailed population viability analyses (e.g., PVA's) in the future. However, obtaining this information can be extremely time- and resource-intensive. Results from the current viability assessment could help identify potential priority sites for future surveys, research, and monitoring. In particular, populations with few massasauga observations, especially recent observations, but extensive suitable habitat would be good candidate sites for additional surveys and monitoring. This includes several historical populations that had fairly high viability scores but lack recent massasauga observations.

We envision and hope that the eastern massasauga population delineations and viability assessments will continue to be evaluated and refined in the future. The cost-weighted distance analysis and model is now set up and could be repeated or re-analyzed with new information pretty quickly. The viability assessment also is set up so that current and new populations could be re-assessed as new information becomes available. We are considering developing a geodatabase with the relevant information about delineated massasauga populations to help facilitate future population delineation and viability assessments, and conservation planning efforts. Results from this project will hopefully be used to assist the MDNR and other partners in in their efforts to develop and implement a statewide conservation plan and associated management efforts to sustain the eastern massasauga in Michigan for the foreseeable future.

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APPENDICES

Appendix 1. Summary of background information on habitat, movement distances, and home range sizes for eastern massasaugas, based on available information and literature, that was used to help inform development of the massasauga cost-distance analysis/model, population delineations, and viability assessment.

Suitable habitat – habitat capable of supporting reproduction or used regularly for feeding or other essential life history functions; a habitat in which you would expect to find the species (assuming appropriate season and conditions); includes marginally suitable habitat that is contiguous with clearly suitable habitat (from NatureServe 2004).

- Early to mid-successional wetlands and uplands
- Forested uplands and wetlands with canopy gaps and/or adjacent to open uplands or wetlands
- Macrohabitats used by *S. c. catenatus* range-wide include bogs, marshes, peatlands, swamp forests, fens, coniferous forests and lowland hardwood forests (Wright, 1941; Smith, 1961; Reinert and Kodrich, 1982; Seigel, 1986; Weatherhead and Prior, 1992; Johnson and Leopold, 1998).
- 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. 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. (Bissell 2006)
- Preferred early to mid-successional wetlands and uplands followed by roads and other bare ground features (Bailey 2010)
- Emergent>scrub-shrub> lowland >agric>bare>upland>golf>grass>residential (Moore 2004)
- Barrens (BA): open areas with no canopy and ground cover dominated by lichen and blueberry (*Vaccinium spp*); Closed Canopy Deciduous (CCD): forest with greater than 50% canopy and dominated by either red maple (*Acer rubrum*), oak (*Quercus spp*), or quaking aspen (*Populus tremuloides*); Forest Edge (ED): 15m in either direction of the boundary of a forested habitat and an open habitat; and Scrub Shrub Open (SSO): an area with low canopy cover, <30%, and dominated by low growing shrubs such as blueberry, black cherry (*Prunus serotina*), speckled alder (*Alnus incana*), or willow (*Salix spp*). (DeGregorio 2008)
- IL - grasslands (Dreslik 2005)

Unsuitable habitat - habitat through which the species may successfully disperse but that cannot support
reproduction or long-term survival (NatureServe 2004).

- Late successional closed-canopy forest – uplands and wetlands, densely shaded
- EMRs tended to avoid late-successional veg types (wetlands and uplands) with low stem densities and absolute dominance of trees >3 m tall. (Bissell 2006)
- Heavily forested cover/coniferous forests seldom selected unless associated with forest openings (Bailey 2010)

- Snakes avoided human-altered landscapes & adj upland hardwoods; none found on road and never entered golf courses (Moore 2004) – [*But have been found on golf courses at other sites*.]
- Closed Canopy Coniferous (CCC): forest with greater than 50% canopy cover and dominated by either black spruce (*Picea mariana*) or white cedar (*Thuja occidentalis*); Pine (PN): forest dominated by either red pine or jack pine (DeGregorio 2008)
- Densely urbanized area dominated by buildings and pavement / human-altered landscapes

<u>Eastern massasauga movement and home range information based on radio-telemetry studies</u>:

State/ Location	**Reference**	**Mean / Max Distance Moved/Day (m/d)**	**Mean and Max Range Length (m)**	**95% fixed kernel home range - mean & max (ha/ac)**	**MCP home range - mean & max (ha/ac)**
SW MI	Bissell 2006	11.6 mean / 315.6 mean daily max	(1,334 mean/ 5,369 max sum/ total distance travelled)	2.8 ha/ 7 ac mean / 17.3 ha / ~40 ac max	2.5 ha mean / 17.9 ha max
SW MI	Bailey 2010	-	-	5.21 ± 4.28 ha / 13 ± 10.6 ac	-
SE MI	Sage 2005	14.6 mean	-	6.2 ha / 15 ac mean	-
SE MI	Moore 2004	6.87 ± 1.14 / 19.27 max	225.73 ± 32.63 mean (1 female moved 465 m)	2.88 ha/ 7 ac mean / 14.19 ha max	1.29 ha / 3 ac mean/ 4.52 ha/11 ac max
N. MI	DeGregorio 2008	-	660 ± 60.1 mean/ 963.3 ±95 max; suitable habitats should be within 500 m	3.8 ± 1.0 ha / 9.4 ± 2.5 ac mean (50% core); males – 6.9 ± 1.9 ha (50% core)	16.7 ha ± 2.7 / 41 ac ± 6.7 ac mean; 95.07 ha max; males – mean 29.8 ± 4.9 ha
W. PA	Reinert & Kodrich 1982	9.1 mean	89.0 mean	-	1.0 ha / 2.5 ac mean
IL	Phillips et al. 2002	13.1 mean		3.3 ha / 8.2 ac mean	
IL	Dreslik 2005	163 m mean / 600 m max	-	Max – males – 2.57 ± 1.24 ha mean / 4.48 max	Max – males – 5.04 ± 6.68 ha mean/ 32.36 ha max
IN	Kingsbury et al. 2003				1.0 ha / 2.5 ac mean
IN	Marshall et al. 2006	Max – males – 15.13 mean	Max – males – 417.19 ± 69.70 mean; total dist. Moved –1653 ± 239	Max – males – 12.5 ± 2.3 ha	Max – males – 7.32 ± 1.44 ha
WI - MC	Durbian et al. 2008		272 ± 74 mean	5.5 ± 3.1 ha 95%	2.4 ± 1.6 ha

NY	Johnson 2000	19.5 m	797 ± 81 m mean; max mean 1212 ± 110 m (max total dist moved - 3712	7.4 ha / 18 ac; 50% MCP – 5.2 ha mean / 6.3 ha max	26.2 ± 4.49 ha / 65 ac mean/ max – NG females – 41.4 ± 3.36 ha
ONT	Weatherhead & Prior 1992	56 mean / 1,438 max	1030.40 mean		25 ha / 62 ac mean / 76 ha /188 ac max
WI - JC	Durbian et al. 2008		1,378.6 ± 1,102 mean	25.8 ± 24.5 ha 95%	135.8 ± 134.2 ha
MO - SCNWR	Durbian et al. 2008		669.9 ± 83.7 mean	18.8 ± 4.3 ha 95%	17.2 ± 4.3 ha
MO - PSP	Durbian et al. 2008		643.2 ± 147.3 mean	18.8 ± 8 ha 95%	11.9 ± 3.8 ha
MO - SLNWR	Durbian et al. 2008		475.6 + 72.9 mean	6.5 ± 1.0 ha 95%	7.4 ± 1.5 ha

Note: 1 km^2 = 100 ha

From Durbian et al. 2008 -

Our data indicate that male massasaugas have the largest spatial requirements and that an average male will require 38.3 ha of habitat based on MCP home range size. We chose to use the MCP home range size because this was the largest of our spatial use calculations and therefore represents the most conservative estimate of required space. Nongravid females were reported to have the largest spatial requirements (41.4 ha) in New York, whereas males had the largest spatial requirements (33.3 ha) in Ontario (Weath erhead and Prior 1992, Johnson 2000). Therefore, all published data indicate that approximately 40 ha of suitable habitat is large enough for the average massasauga, but massasauga populations require more habitat than do individuals.

Population level home range data from the PSP, SCNWR, and SLNWR (MO populations) may represent the first opportunity to examine massasauga spatial ecology for populations not in decline. Therefore, using these study sites as models, we contend that 100 ha, the smallest area used by the 3 Missouri populations (Table 3), should be considered the minimal amount of habitat for sustaining a massasauga population. MANAGEMENT IMPLICATIONS Using our Missouri study sites as models, managers interested in restoring or enhancing habitat for massasaugas should use 100 ha as a minimum target. The mosaic of xeric and mesic habitats within this space should be open-canopy and < 1,800 m across at any point, based on the mean range length for the PSP population (Table 1), which was the smallest for the Missouri populations and therefore the most conservative estimate (Johnson et al. 2000). If that is not possible, providing suitable habitat within easy traveling distance of hibernation sites (approx. 400 m) is most desirable. We interpret easy traveling distance as mean range length for our nongravid females, the cohort with the smallest range length on our Missouri study sites.