Individual Species Assessment

Eastern Massasauga (*Sistrurus catenatus*)

2015 TECHNICAL REPORT

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Abstract

Under the Endangered Species Act of 1973 (ESA), a species may be listed as endangered (one that is in danger of extinction throughout all or a significant portion of its range) or threatened (one that is likely to become endangered in the foreseeable future throughout all or a significant portion of its range). Prior to listing, a species believed to be imperiled is identified as a candidate. These candidate species receive no legal protection, and conservation actions for candidate species, while not mandatory, are highly encouraged by federal agencies. Early actions coordinated between landholders and regulators to protect candidate species may avoid the necessity of listing under the ESA. The Eastern massasauga rattlesnake (*Sistrurus catenatus*)—one such candidate species—is the focus of this individual species assessment. This report describes the current status and accepted conservation practices for this species at a range-wide scale.

The U.S. Fish and Wildlife Service (FWS) identified human fear and habitat loss as the two primary threats to the Eastern massasauga. To address these threats, the FWS has promoted conservation actions focusing on increased research, habitat management, and public outreach. Conservation of this species is complicated by inconsistent descriptions of the species in the literature, variation in vital rates across the range, and virtually no dispersal among populations. Because this species exhibits virtually no dispersal, conservation actions must be considered at the local level. Modeling suggests that conservation actions should be tailored to increasing adult survival, as this is the most critical demographic parameter for the Eastern massasauga.

Based on current conservation methods, it is estimated that similar conservation actions on a 20-acre plot will cost approximately $4–$10 million, however it should be noted that specific conservation actions and associated costs must be negotiated with FWS. Future studies at finer spatial resolution and with more specific occupancy and population data will allow for more precise estimates of costs and acceptable directions of potential conservation plans.

Keywords

Eastern massasauga rattlesnake
Endangered Species Act
Candidate species
Species recovery

Executive Summary

When a species is proposed for listing under the Endangered Species Act (ESA), it becomes a candidate species and is subject to a comprehensive review by the U.S. Fish and Wildlife Service (FWS) or National Oceanic and Atmospheric Administration (NOAA). Once a species is formally listed, the ESA affords special protections to the species and its habitat, triggering the enactment of conservation actions aimed at recovery. Candidate species, however, receive no legal protection, and conservation actions for such species, while not mandatory, are highly encouraged by federal agencies.

Conservation plans coordinated between private landholders and regulators can be enacted prior to the listing of a species; such plans may preclude listing by demonstrating sufficient existing protection. The burden of proof is allocated very differently in cases where a species is already listed versus not yet listed. For the purposes of this report, for a candidate species, the burden of proof is on the FWS and the situation is particularly conducive to voluntary preventative action. The Eastern massasauga rattlesnake (*Sistrurus catenatus*) is currently a candidate species under the ESA, and the FWS has already accepted several voluntary conservation agreements with the goal of precluding listing. This report describes the current status and accepted conservation practices for this species at a range-wide scale.

The Eastern massasauga represents a challenge for conservation professionals for four reasons: 1) little is known about the occupancy and populations across the range; 2) extant populations are generally very small and isolated; 3) studies have demonstrated a wide variation in demographic rates in snake populations across the range; and 4) massasaugas have extremely low rates of dispersal, making small local populations particularly susceptible to extinction. Modeling of hypothetical populations at the northern and southern extent of the range has identified adult survival as particularly important to determining extinction risk. Thus, conservation actions are most likely to have a positive effect if they are geared toward increasing adult survival.

Currently employed conservation actions, as endorsed by the FWS, are focused on three areas: increased research, habitat management, and public outreach. The results of this analysis suggest that focusing on these three actions to increase adult survival will likely yield the

best results. Furthermore, by identifying regions of suitable habitat and areas of high mortality risk within currently occupied areas, conservation actions may be tailored to increase adult survival and decrease risk of extinction.

This analysis provides a range-wide overview of how conservation actions should be considered and developed. Based on current conservation methods, it is estimated that similar conservation actions on a 20-acre plot will cost approximately $4–$10 million (excluding monitoring costs). This estimate is based on published recovery plans and conservation agreements; specific conservation agreements must be negotiated with the FWS. For the successful design and implementation of these conservation actions, follow-up studies at a smaller spatial scale and finer resolution should be conducted, including population viability analyses utilizing occupancy or abundance data.

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Section 1: Candidate Species Under the Endangered Species Act

The Endangered Species Act (ESA), passed by Congress in 1973, is designed to provide a formal program for the protection of threatened and endangered species their habitat. For a species to be afforded protections under ESA, it must first be added to the federal list of threatened and endangered species (Table 1-1). An endangered species is defined as one that is in danger of extinction throughout all or a significant portion of its range. A threatened species is one that is likely to become endangered in the foreseeable future throughout all or a significant portion of its range. A candidate species is one that regulators – either the United States Fish and Wildlife Service (FWS) or National Marine Fisheries Service (NMFS), depending on species – has determined may meet the definition of threatened or endangered upon review.

Table 1-1
Definitions of ESA listing categories.

Listing Category	Definition
Endangered	A species that is in danger of extinction throughout all or a significant portion of its range
Threatened	A species that is likely to become endangered in the foreseeable future throughout all or a significant portion of its range
Candidate	A species that may meet the definition of threatened or endangered, but which has not yet been officially reviewed or listed

Candidate Species

The listing process is initiated either through a FWS or NMFS status review, or through a petition by US citizens or non-governmental organizations. When a petition is received, the lead agency has 90 days to determine if there is substantial evidence to support listing. If the agency determines there is substantial evidence, a 12-month status review is begun to determine if listing is warranted, warranted but precluded by higher priority listings, or not warranted. If listing is deemed warranted, a proposed rule is published in the Federal Register for comment before a final rule is decided. If listing is warranted but precluded, the candidate species is added to the candidate species list, where the lead agency assesses its status annually and promotes candidate conservation measures until a listing decision is made (Fig. 1-1).

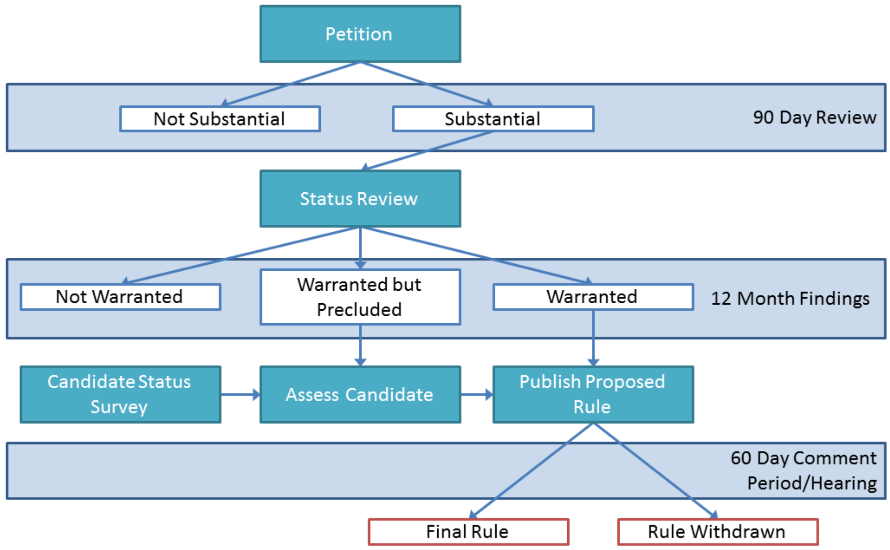

Figure 1-1
The ESA listing process. Image adapted from FWS.

Candidate conservation measures allow for the early development of conservation plans for species facing immediate threats (Figure 1-2). In addition to minimizing recovery costs, early actions frequently allow for more flexible approaches and include more stakeholders in the process. In their 2014 proposed Policy Regarding Voluntary Prelisting Conservation Actions, the FWS reinforced their support of these early actions and proposed that they have the potential to aid in species recovery and preclude listing (79 FR 42525). The 2003 Policy for Evaluation of Conservation Efforts When Making Listing Decisions notes federal agencies will take prelisting conservation actions into account when making listing decisions. If these decision-making bodies determine that prelisting conservation actions are likely to occur and be effective, they are given discretion to either not list or to list a species at a lower threat level (68 FR 15100). During the annual reassessment, candidate species may be removed from the candidate list if the lead agency determines the species is no longer threatened or endangered as described under Section 4 of the ESA, which includes among the criteria for listing an absence of sufficient existing protection. Alternatively, the listing priority of the species may be altered during these reviews. Currently, a total of 64 species have been removed from the candidate species list since the 1996 Candidate Notice of Review due to preemptive conservation action (FWS ECOS 2015).

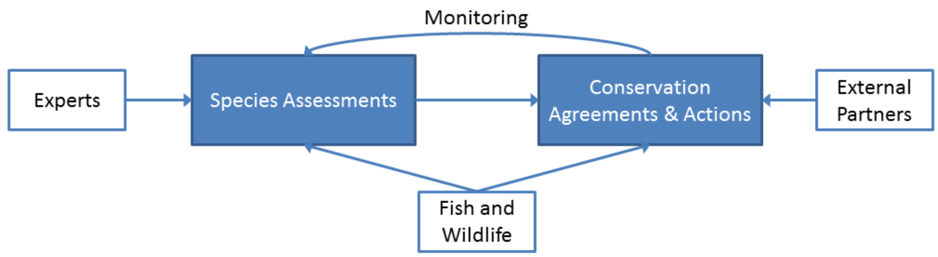

Figure 1-2
The FWS Candidate Conservation Process. Image adapted from FWS.

The reassessments of candidate species rely upon the best available science. Researchers in government, academia, and industry can directly improve the quality of listing decisions by providing insights into the population status of candidate species. Additionally, research on potential conservation measures for candidate species have the potential to inform all future listing actions, including critical habitat designations and conservation plans, and successful implementation of conservation actions may preclude listing at all. As such, researchers have a unique opportunity to contribute to the science underlying all future management actions for candidate species.

Burden of Proof

A key difference between the decision to list a candidate species versus the decision to downlist or de-list a protected species lies in the notion of "burden of proof". If regulatory decisions are primarily driven by precaution, then listing a species should generally require less evidence than delisting, simply because the risks are strongly asymmetric from the perspective of conservation. While most of the world employs the precautionary principle in regulatory decision-making, the United States does not. Regulation in the US uses a cost-benefit approach. The net difference between precaution and cost-benefit depends on the definition of costs and benefits, which may vary by application. The burden of proof during the review of candidate species is on the regulator. FWS or NOAA must defend the decision to list. In contrast, the burden of proof to downlist or delist a species is on stakeholders. The regulator is charged with taking appropriate actions to protect listed species, but is under no duress to demonstrate that those protections have achieved their goal.

The shift of the burden of proof from regulator to stakeholder following a decision directly affects the interpretation of incomplete information. For a candidate species, such as Eastern massasauga, uncertainty stemming from sparse or qualitative data makes the decision to list more difficult to support. For a listed species, such as Indiana bat, that same uncertainty makes the decision to downlist more difficult.

Section 2: Rapid Assessment of Threatened and Endangered Species

The overarching goal of effective conservation planning is to establish quantitative metrics and corresponding thresholds for action. While it is generally agreed that the gold standard by which conservation decisions are supported is population viability analysis (PVA), this type of assessment generally requires practitioners to have a thorough understanding of the biology of the species being assessed. While PVA or related approaches can sometimes help identify conservation action priorities with surprisingly incomplete information, in many cases little is known about the distribution, biology, or population status, such that an in-depth assessment of population viability is impossible.

IUCN Red List

The International Union for Conservation of Nature (IUCN) has established a rigorous and widely accepted set of criteria by which both qualitative and quantitative information can be adapted to a quantitative framework for conservation action. This type of framework allows for the incorporation of a variety of data of different qualities and resolutions to categorize the threat status of each assessed species (Fig. 2-1). Such "rapid assessment" frameworks allow policymakers and conservation planners to make decisions based on the best available science, indiscriminate of the format or quality of that information. For many species, however, even this data is unavailable; 15.2% of the 5,488 mammals assessed by the IUCN were deemed "data deficient" – there was not enough quantitative or qualitative data available about these species to use even the IUCN's rapid assessment framework. (IUCN 2015).

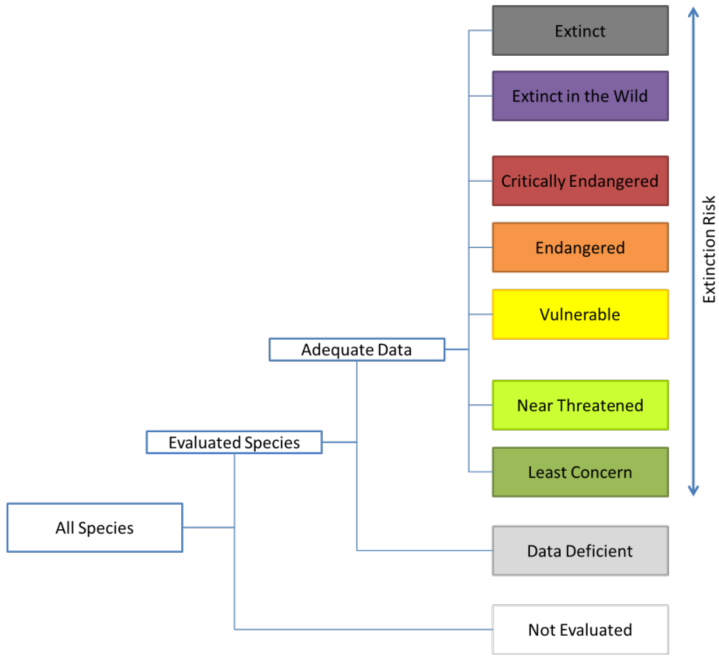

Figure 2-1
Categories of the IUCN conservation status classification system. The categorization process is standardized and can make use of a variety of types of data. Image adapted from IUCN.

Defining Rapid Assessment

Rapid assessments of endangered species are tools that allow conservation practitioners to make decisions with the data that area currently available to them.

For endangered species conservation, the Red List criteria take advantage of data indicating (or even suspicion of) trends in population size, geographic extent, or patterns of occupancy. Even without trend information, established thresholds can be used to rapidly assess status from current population size or geographic extent.

The Red List framework's usefulness lies as much in its promulgation of carefully negotiated thresholds as in its accommodation of diverse forms of evidence. Whereas the criteria for listing a species under ESA are set forth without indication of their relative importance or combinatorial significance, Red List criteria are, as much as possible, quantitative rules linking data to classifications.

Similar rapid methods have become common in other fields of ecology. Ecosystem ecologists have developed Rapid Ecological Assessments (REAs) to aid in ecosystem-level conservation planning (Sayre et al. 2000). This type of ecosystem approach has been used widely by the NOAA in their conservation planning of coral reefs (Ayotte, et al. 2011). In these coral reef ecosystem REAs, NOAA scientists collect data about species occupancy and habitat, including biotic and abiotic features.

Rapid assessment is an active field of research. A primary goal is to develop methods for conservation status classification that can draw conclusions from even less information. Bianchi (2010) noted, “there are three fundamental questions to be answered when dealing with potentially threatened species: (1) what is the species’ distribution?; (2) what is the extent of the species’ habitat in time and space?; and (3) how does the species use its habitat and how are populations distributed and arranged?” He developed a new rapid assessment framework with the motivation that it might be possible to answer these questions even for species whose IUCN status would be data deficient.

Given the role that good science can play in the conservation of candidate species, it is useful to explore what constitutes a good framework for the assessment of species conservation needs. Ideally, such a framework will

- make maximal use of existing information, avoiding the delay and expense of additional data collection in the field;
- result in quantitative measurements such that the potential benefit of conservation actions can be judged against their cost; and
- provide transparency so that assessments can be effectively communicated and reviewed by stakeholders and regulators alike.

This report presents a rapid assessment of the eastern massasauga rattlesnake. As such, it will address several of the questions Bianchi suggested. Additionally, the following sections will address emerging risks to these populations and discuss the current state of knowledge regarding these risks. Lastly, we demonstrate that full quantitative modeling can be performed even under large uncertainty. Though our example is limited in its scope, we show how modeling can help evaluate the potential efficacy of specific conservation actions, generate expectations about possible outcomes, define time horizons on which to judge outcomes, and focus further empirical research.

Section 3: The Eastern Massasauga Rattlesnake (*Sistrurus catenatus*)

The Eastern massasauga rattlesnake was listed as a candidate in 1999, and listing of the species was deemed warranted by precluded by higher priority actions (Figure 3-1). Due to recent litigation, the FWS will be making listing decisions for 251 candidate species, including the Eastern massasauga (Szymanski, et al. 2015). In a recent status review, the FWS outlined plans to make a listing decision for this species within FY2015 (Szymanski, et al. 2015).

Figure 3-1
Eastern massasauga rattlesnake. Photo: Lincoln Park Zoo.

Until 2011, the FWS considered the Eastern massasauga to be a subspecies and proposed for listing as a distinct population segment of the massasaugua rattlesnake (Szymanski, et al. 2015). Genetic studies, however, have indicated that the Eastern massasauga is sufficiently distinct to be considered a separate species (Szymanski, et al. 2015). While the FWS has identified this as a distinct species and much of the scientific community has adopted this practice. The International Commission for Zoological Nomenclature was petitioned for and subsequently adopted separate scientific names for the Eastern and Western massasaugas (ICZN 2013). Not all scientific bodies have adopted this convention, however. For example, the International Union for the Conservation of Nature (IUCN) Red List, the leading inventory of species population status, has not yet identified the Eastern massasauga as a species distinct from the Western massasauga (Frost, et al. 2007).

Physical Appearance

The Eastern massasauga is a small, thick-bodied snake with the characteristic heart-shaped head of a rattlesnake. Mean adult length is approximately two feet (Szymanski, et al. 2015). Pigmentation patterns can be variable, however generally they are brown or gray with large dark brown spots along the dorsal side, with smaller spots at the margins (Figures 3-1, 3-2). In some regions, including northern Indiana, southern Michigan, and northern Ohio, a high proportion of individuals may be black in color (Szymanski, et al. 2015). Juvenile snakes have similar, but more vivid, patterns (Szymanski, et al. 2015).

Figure 3-2
Eastern massasauga rattlesnake

Range and Occurrence

The Eastern massasauga's range extends from western New York through southern Iowa and north through Ontario, Canada. Historically, the species range followed similar margins, however many of the historic populations have been extirpated from within this range boundary (Szymanski, et al. 2015). Populations are sporadic and isolated throughout this range (Fig. 3-3). The recent status assessment by the FWS concluded that it is likely the Eastern massasauga has been completely extirpated from Minnesota and western and southern Missouri (Szymanski, et al. 2015). In the United States, occurrence is most highly concentrated in Michigan. Due to a decline in this historically widespread species, the massasauga is listed as threatened or endangered in every state or province it occupies.

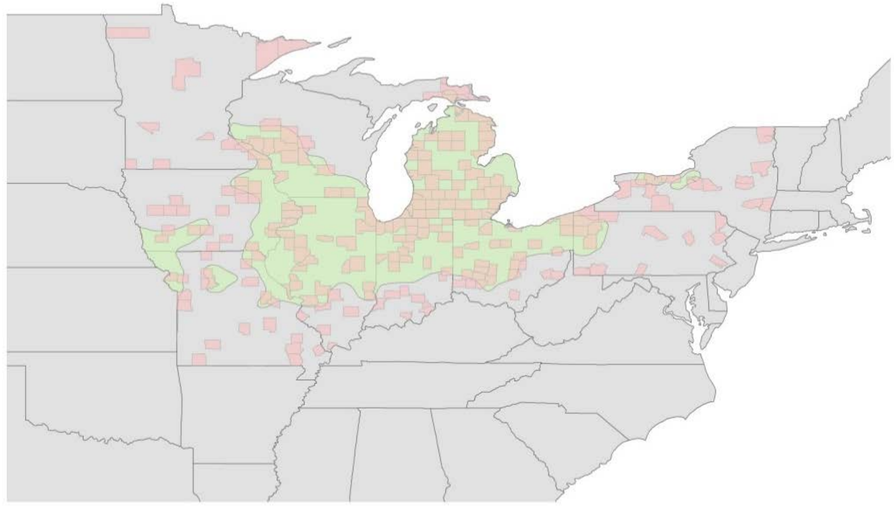

Figure 3-3
Range and occupancy of the Eastern massasauga rattlesnake. Green regions indicate the range limits, as defined by the IUCN. Red areas indicate occupied counties according to FWS.

Life History

Massasaugas live an estimated 10 years with first reproduction occurring as early as the second year (Szymanski, et al. 2015). Individuals hibernate during winter and are active from early spring through late fall. Mating occurs in the spring. While reproductive behavior varies across their range, all massasaugas bear live young. Reproduction occurs once every one to three years, dependent upon population and available resources (Aldridge, et al. 2008). The timing of mating and birth are variable across their range, as is the mean litter size, which ranges from 5 to 20 young (Aldridge, et al. 2008; Szymanski, et al. 2015). Aldridge, et al. suggested that this difference in reproductive rates across range may be due to differences in the activity season length across latitudes (Aldridge, et al. 2008).

Pomara et al. (2014) suggested that the dispersal of these snakes is virtually nonexistent. In addition, the mean home range size of an individual snake is thought to be less than 200 square meters, however this is highly variable, dependent upon age and local environmental conditions (Szymanski, et al. 2015). Other studies have documented larger movements. Some studies have suggested that males may have larger ranges than females, as evidenced by a greater tendency to disperse (Szymanski, et al. 2015). Additionally, range size increases from the juvenile to the adult stage. This may have additional consequences for massasauga populations. In their 2008 study, Shepard, et al. noted increased road mortality of males during the active season, which could explain the documented female bias in adult survival (Shepard, et al. 2008; Szymanski, et al. 2015).

The massasauga diet consists primarily of small mammals, though reptiles and amphibians may be more important sources of food for juveniles (Szymanski, et al. 2015). Massasauga diet has been demonstrated to be relatively stable over short periods of time but highly variable interannually (Szymanski, et al. 2015). Natural enemies include opportunistic mammalian scavengers, such as skunks and raccoons, as well as birds of prey (Vogt 1981).

Habitat requirements

Massasaugas are generally found in moist areas and adjacent upland habitat. These snakes emerge from hibernation in the spring when soil temperature is consistently above 10°C (Mauger and Wilson 1999). For approximately one to two weeks following arousal, these snakes remain in basking areas very close to their hibernacula (Marshall, et al. 2006). The snakes then move 200-600 meters upland to establish activity areas in "structurally complex vegetation communities" (Marshall, et al. 2006; Szymanski, et al. 2015). In the active season, these snakes generally use upland, dry habitats, or open canopy wetlands and adjacent dry habitats, consisting of a patchwork of basking and foraging sites, however some regional variability has been observed in these habitat preferences (Szymanski, et al. 2015). The use of diverse upland habitats, including meadows, old fields, and agricultural land has been documented. Basking sites are essential for the snakes to allow for effective thermoregulation and physiological control. The snakes seem to prefer open areas with lowlying vegetation in close proximity to taller vegetation or more complex structural elements, presumably allowing for quick retreat from predators and shelter from extreme temperatures (Szymanski, et al. 2015). These basking sites may be most important for gravid females, which only feed after birth and require more thermoregulation during embryo development thus do not require foraging habitat for much of the year (Szymanski, et al. 2015).

Hibernation takes place in wetlands, during which it is commonly thought that individuals inhabit crayfish burrows or tree roots or other structures that provide access to a wet environment below the frost line to avoid dessication and freezing (Szymanski, et al. 2015). Massasauga generally hibernate while fully submerged in water and likely rely on extrapulmonary respiration through the skin (Szymanski, et al. 2015). These snakes return to the same hibernacula or area annually, and hibernate either alone or in small groups. Neonate massasauga exclusively inhabit hibernacula shared with other snakes (Szymanski, et al. 2015). Suitable hibernacula appear to be determined by subterranean abiotic factors, including oxygen availability and watertable elevation.

Neonate and juvenile habitat requirements are similar to those of adult snakes. Neonate massasaugas, born in late summer, have a small window of time available for feeding prior to hibernation. Shepard, et al. suggested that due to gape limitation these newborns are likely limited in their prey choice, so other snakes are common prey (Shepard, et al. 2004). King, et al. further proposed that because of this reliance on other snakes as prey, the presence of garter snakes (*Thamnophis sirtalis*) may be indicative of exceptional neonate foraging habitat (King, et al. 2004).

The low dispersal rate of Massasaugas places increased importance on the stability and quality of habitat. Hence, this species is particularly sensitive to changes in vegetation structure or hydrology.

Conservation Threats

Several studies have documented the sensitivity of the Eastern massasauga to changes in population size (Middleton and Chu 2004; Miller 2005; Bailey 2010). Middleton and Chu demonstrated that the loss of a single snake from a population increases the risk of local extirpation. The FWS has identified two primary threats to the Eastern massasauga: eradication efforts and habitat loss. Human fear of venomous snakes has led to eradication efforts throughout their range, including many state-sponsored bounty programs. Public education programs, such as FWS' "Why Conserve a Venomous Snake" and the Michigan State University's "Learning to Live with the Eastern Massasauga", are designed to alleviate fear of these snakes and have become more common throughout its range. Habitat loss, however, remains a significant threat. Habitat loss and fragmentation are driven by human modification of the landscape. Wetland draining for urban development remains a considerable problem. Additionally, construction of roads or other development may prevent seasonal migration and effectively isolate small populations from each other, as the propensity of these snakes to disperse is generally very low.

In a discussion of threats to the Eastern massasauga, Faust, et al. (2011) identified 11 risk factors and found that 95% of the 60 populations they studied were affected by at least one of these risks and 77% experienced 3 or more risks, with vegetative succession occurring at 81% of the sites studied (Table 3-1).

Table 3-1
Risk factors for Eastern massasauga populations, as identified by FWS and Faust, et al. 2011

Risk Factors
Vegetative succession
Habitat fragmentation
Hydrologic alteration
Prescribed burns
Mowing
Road mortality
Persecution
Collection
Predation
Disease

Established Conservation Priorities

The FWS has identified the following as the primary conservation actions necessary to protect the Eastern massasauga:

- Research: understand population status, life history characteristics, and habitat use
- Habitat management: alter harmful land management practices
- Education: public outreach to educate the public about venomous snake conservation

To accomplish these goals, the FWS has strongly promoted collaboration with private landowners through Candidate Conservation Agreements (CCAs) and Candidate Conservation Agreements with Assurances (CCAAs). Currently, it is estimated that 59% of the extant populations occur, at least in part, on public lands managed at the county, state, or federal level. Much of these public lands are already managed in accordance with FWS land management guidelines and, as such, threats to these populations are considered only moderate (78 FR 70122). Private lands, however, have been identified by FWS as encompassing the populations most at risk of habitat loss and human persecution.

Section 4: Assessing Population Status

While there are several local monitoring programs of the Eastern massasauga, little is known about the population status across its range. Much of the work that has been completed to date focuses on small, highly defined, regions of interest to particular user groups. While these spatial units are of importance to particular stakeholders, the arbitrary boundaries frequently relate neither to biological populations nor to management units. The FWS has aggregated data on the suspected occupancy of the Eastern massasauga by county (Fig. 2-2). These data, however, are too coarse to gain an adequate understanding of population status. Additionally, many of the historical studies of the Eastern massasauga were conducted before it was recognized as a different species than the Western massasauga. It is now recognized that much of the literature may have pooled data on both species. In fact, Szymanski, et al. noted that the first population viability analysis conducted for this species by Seigel and Sheil (1999) likely inappropriately pooled Eastern and Western massasauga demographic parameters (Szymanski, et al. 2015).

Large Uncertainties

Any assessment of the eastern massasauga's population status or ranking of conservation priorities faces tremendous challenges. The uncertainties regarding the snake's basic biology would seem to preclude, for instance, any precise definition of its habitat requirements. There are two main areas of uncertainty. The first is the real variability that exists across the species' range as well as through time. Variation in vital rates, behavior, and habitat preference has been identified among subpopulations within the geographic range, but this variation is still poorly characterized. As a result, definitive statements (and hence models) of geographic variability remain elusive. The second area of uncertainty, lack of knowledge of all possible population and habitats, also remains an obstacle to confident assessment.

Populations Modeling With Uncertainty

Surprisingly, quantitative population modeling, which is often avoided in favor of more qualitative methods due to its high information demands (IUCN 2010), may be the best way to identify priority conservation actions for this poorly-understood species. First, population viability analyses have already been performed, meaning there are published sets of parameters available. Any newer or competing information can be incorporated, as well. Second, a full quantitative analysis can exhaustively explore the limits of what is known by employing *all* information *and* its uncertainty to generate a "cloud" of models that in turn help identify robust conservation actions.

For this preliminary report, we demonstrate a simple population viability analysis (without the full uncertainty characterization). Even this basic modeling exercise leads to geographically-differentiated conclusions on the efficacy of conservation actions aimed at reducing human-caused mortality of eastern massasaugas.

A Brief Introduction to Population Modeling

Population models use the formal logic of mathematics to organize and leverage our understanding of each population, their spatial structure, and vital rates to project possible future states of the population and to identify the key factors that may cause or alleviate risks of decline. Many types of population models exist, spanning a range from simple, theoretical models to complex models of interacting individuals.

For this report, we employed a common approach called age-based modeling. An age-based model requires information on the annual survival and reproduction rates of individuals as they age. Hence, it is necessary to have information on the average number of eggs laid by a female of a given age, as well as the survival of those offspring through their first year of life. It is common, especially for poorly understood species, to include age classes for the first year up through the year at which all individuals are expected to be mature. This final age class is structured so that individuals remain in it until they die (Lande 1988).

Besides the schedule of survival and reproduction, all population models require an initial abundance. Abundance may not always be known for the areas which are being modeled. However, estimates of average population density can be derived from other, better-studied populations.

There are two uses of age-based population models that have particular power for supporting conservation decisions. The first is called asymptotic analysis (Caswell 2006). This is a set of mathematical methods that distill important quantitative and qualitative information from the model. The most common result of asymptotic analysis is to find the long term population growth rate. It is often overlooked that there are many reasons why this rate might not be achieved by a population in the real world, even if the model has precisely described its biology. This is because the real world is variable and long term expectations are often violated by random events. Asymptotic analysis also provides estimates of the sensitivity of the population growth rate to small changes in the vital rates. This result is of great qualitative importance, as it generally identifies a particular age class that will be most responsive to conservation action. Asymptotic sensitivity analysis was most famously successful in sea turtle conservation, where it identified adult survival as more important than juvenile survival for long term recovery (Crouse, et al. 1987).

The second powerful way to use an age-based population model is for the projection of future population trajectories. In particular, this method allows for the introduction of random variation around the expected vital rates. This variability enters in two forms. The first is called demographic stochasticity and is the random errors in survival and reproduction rates that would occur in a small population (much as a coin flipped 10 times is will not always yield 5 heads). The second, called environmental stochasticity, is the potentially larger influence of variation in environmental conditions. As is familiar in any discussion of the weather, no year is average and the factors affecting survival and reproduction may vary widely from one year to the next. Projections of population growth over time that consider stochasticity can be used to characterize the probability that a population will decline or go extinct within a given time horizon.

Dispersal and Spatial Context

The highly restricted movement behavior of massasaugas means that the events determining the species long term persistence are taking place on scales much smaller than most counties. Population biologists consider low dispersal and geographic isolation a high risk factors for extinction because random events that lead to local extinction (even for only one of the sexes) are not often compensated by recolonization events. One advantage of the isolation of individual massasauga populations, however, is its removal of the need to consider spatial dynamics at broad scales when assessing population status or the conservation value of local habitat. Individual habitat patches or suites of neighboring patches are an acceptable focus for conservation efforts as well as for population modeling.

Vital Rates

While the data regarding individual populations and their spatial structure is currently unavailable, there have been several studies examining differences in vital rates across the massasauga's range. In their Range-Wide Analysis of Eastern Massasauga Survivorship, Jones, et al. (2012) discovered dramatic variation in survival of the snake, ranging from 35% to 95% survival per year (Table 4-1). The authors noted an increase in survival along a southwest to northeast axis. Similarly, Aldridge, et al. (2008) found variation in reproductive biology across the range, with annual reproduction producing smaller broods in the southern extent of the range, and biennial to triennial reproduction of larger broods in the northern extent. Despite this apparent variation in vital rates across the range, in their 2015 species status assessment, the FWS modeled massasauga populations explicitly assuming there is no spatial variation in vital rates. Additionally, they analyzed the species within three distinct management units: Western (Minnesota, Missouri, Iowa, Wisconsin, and Illinois), Central (Indiana, Michigan, Ohio, and Ontario), and Eastern (New York, Pennsylvania, and parts of Michigan and Ontario). It should be noted, however, that given the north-south gradient in vital rates across the range, population analyses within these units may not capture the variability among populations. Ranges in vital rate estimates identified in the literature are presented in Table 4-1.

Table 4-1
Vital rates of the Eastern massasauga

Vital Rate	Estimate	Sources
Adult Survival	0.35-0.95	Bailey 2010 Bissell 2006 Dreslik, et al. 2011 Faust, et al. 2011 Harvey and Weatherhead 2006 Jones, et al. 2012 Keenlyne 1978 King 1999 Middleton and Chu 2004 Miller, et al. 2005 Seiggel and Sheil 1999
Age at Maturity	2-3 years	Johnson 1995 Pomara, et al. 2014 Seugek abd Sgeuk 1998
Fecundity	1.3-5.8 females/year	Keenlyne 1978 Johnson 1990 Pomara, et al. 2014 Reinert 1981 Seigel and Sheil 1998 Szymanski 1998
Neonate Survival	0.15-0.378	Dreslik, et al. 2011 Jones 2012 Szymanski 1998
Juvenile Survival	0.5-0.695	Dreslik, et al. 2011 Keenlyne 1978
Senescence	10 years	Faust, et al. 2011 Johnson, et al. 2000 Miller 2006 Pomara, et al. 2014
Sex Ratio	1:1	Johnson 1995 Seigel and Sheil 1998

A Population Model for Eastern Massasauga

A population viability analysis was conducted to project future abundance trajectories and the risk of extinction under scenarios of reduced human-caused mortality. Humans kill eastern massasaugas either through direct persecution or by hitting them as they cross or bask on roads (Shepard 2008). Conservation actions to reduce human-caused mortality therefore include public education programs, signage along roadside, and the construction of culverts for safe dispersal under roadways. Such actions can be expensive. The PVA helps to identify whether such actions will have a biologically significant benefit.

Acknowledging the deficiency in available data across the entire range, low dispersal of the species, and variable vital rates across populations, we developed two models to illustrate the population dynamics at the southern and northern extents of the range. These models do not encompass the full uncertainty around massasauga population biology but serve to demonstrate the utility of population modeling as a tool for rapid assessment.

The northern and southern models shared most of their parameters. Neonate survival was 0.15 (Jones, et al. 2012). Juvenile and adult survival was 0.616 under baseline conditions and up to 0.67 with human-caused mortality reduced (Jones et al., 2012). Reproductive frequency, the probability that a female reproduces in a given year, was 0.6 (Seigel and Sheil 1998). Half of offspring were assumed to be female (Johnson 1995; Siegel and Sheil 1998). Population density was assumed to be 0.56 individuals per hectare, the low end of the range of estimates we identified (Johnson 1995), and the population model was assumed to address 1000 acres (405 hectares) of suitable habitat, resulting in 113 females at the start of simulations.

The only parameter that differed between our hypothetical northern and southern populations was the number of offspring per reproducing female. We used a smaller brood size for the southern population, 6.4, based on a study in Missouri (Seigel and Sheil 1999). A larger brood size for the north, 13.3, was based on a study in Ontario (Aldridge 2008). Though there have been reports of higher reproductive frequency in the south, which might compensate for brood size, this pattern has not been convincingly documented (Aldridge 2008). Our use of the same reproductive frequency at the latitudinal range limits is meant to be conservative.

Simulations were conducted using RAMAS Metapop version 6 (Akçakaya and Root 2013), a software tool developed in part with EPRI support. No environmental variability was added to the model, but the program simulates demographic stochasticity, which contributed substantial variation to projected abundance. Simulations were run for 50 years with 1000 replicates for every level of reduction in human-caused mortality between 0 and 100%. We recorded the fraction of replicates that went extinct within the 50 y simulation period. To obtain a shorter-term metric of population status, we also recorded the mean and standard deviation of abundance after only 5 years. The latter metric provides information not only on the expected change in population size but on how widely variable outcomes of a conservation action can be even in the highly idealized terms of this simple model.

PVA Results

Baseline

The population viability analysis indicated that both southern and northern populations of eastern massasaugas are at some risk of extinction within 50 years under current levels of human-caused mortality (14%, Jones, et al. 2012). With its lower fecundity, the southern population had a high risk of extinction within 50 years (Fig. 4-1), with 50% of replicates going extinct within 21 years (4-2). The model yielded a very high extinction risk, likely due to demographic stochasticity within a small population. Results indicate that there is a 50% probability of extinction within 25 years.

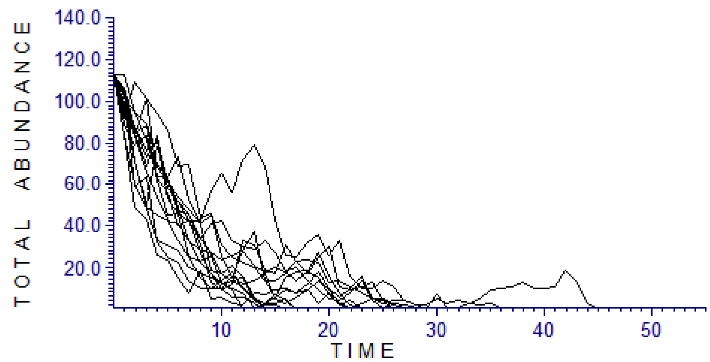

Figure 4-1
Example replicate trajectories of the hypothetical southern population of eastern massasaugas over 50 years.

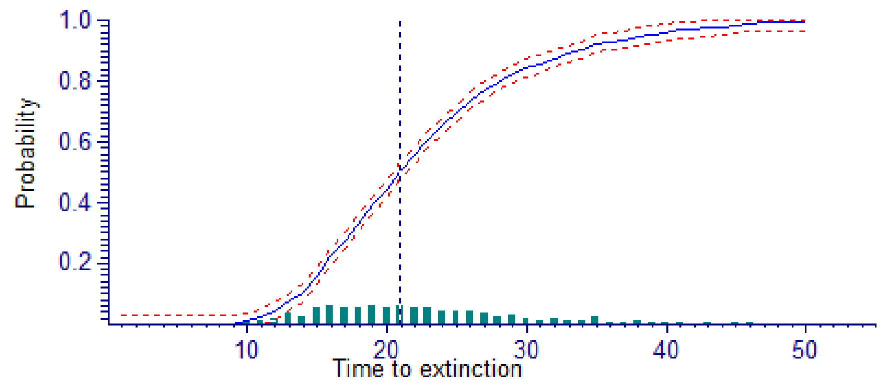

Figure 4-2
Projected extinction risk for a hypothetical eastern massasauga population at the southern range extent. The vertical dashed line marks the median time to extinction of 21 years.

The northern population displayed some risk of extinction, but far less than its southern counterpart, with trajectories that both increased and declined over time

(Fig. 4-3). Only 20% of replicates went extinct in 50 years and the median time to extinction was longer than the simulation period (Fig. 4-4).

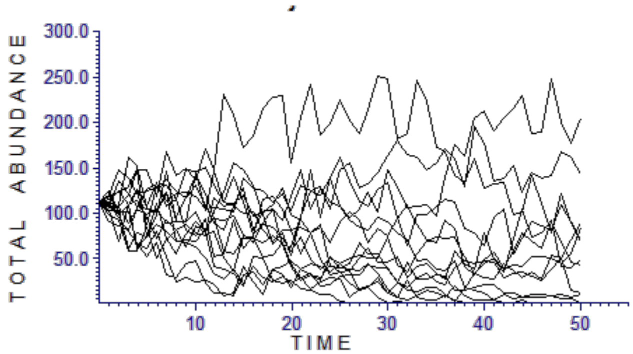

Figure 4-3
Example replicate trajectories of the hypothetical northern population of eastern massasaugas over 50 years.

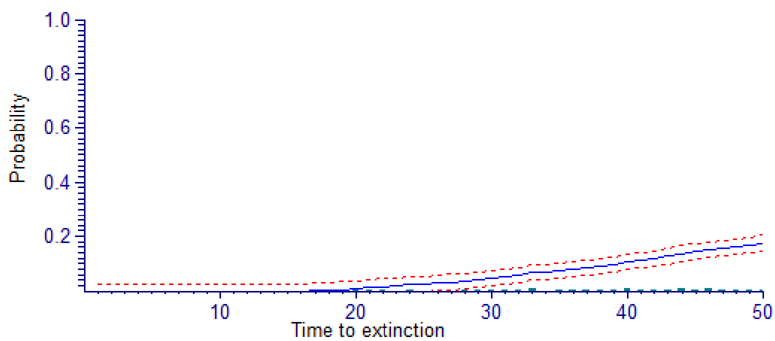

Figure 4-4
Projected extinction risk for a hypothetical eastern massasauga population at the northern range extent.

Sensitivity Analysis

Asymptotic elasticity analysis provides insight into the sensitivity of population growth rate to small changes in vital rates. It has the benefit of not requiring an estimate of population size or environmental variability. Elasticity analysis of the four northern and southern models indicated that Eastern massasauga populations are particularly sensitive to adult survival. This sensitivity is higher in the southern population, where the lower fecundity puts more pressure on adult survival to generate sufficient reproductive output.

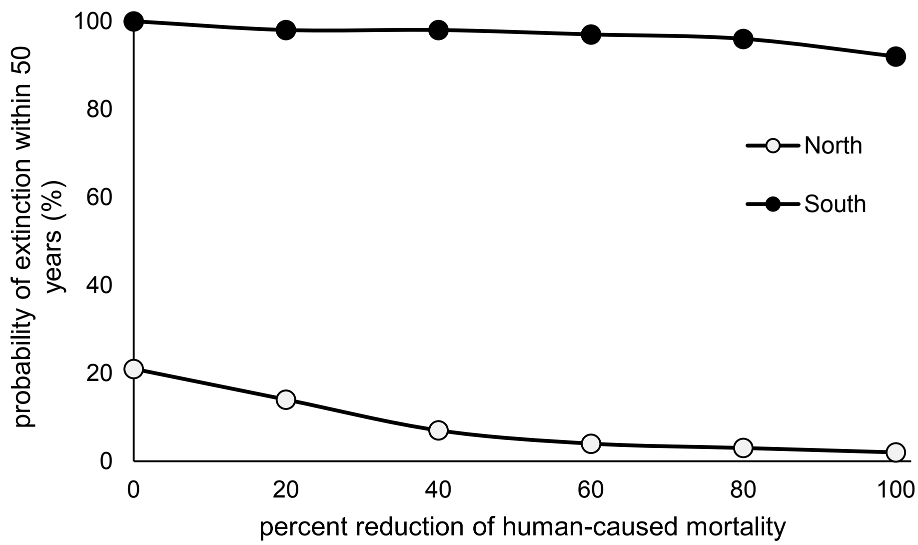

Figure 4-5
The effect of reduced human-caused mortality on the probability of extinction in hypothetical eastern massasauga populations at the northern and southern range limits.

Reducing Human-Caused Mortality

Given the sensitivity to adult survival, we used PVA to examine whether a reduction in human-caused mortality of juveniles and adults could generate biologically significant increases in conservation status. We examined a range of reduction in human-caused mortality in both the northern and southern populations. Figure 4-5 illustrates that reduced human-caused mortality has the potential to nearly eliminate the risk of extinction in northern populations. However, even complete elimination of human-caused mortality did not greatly impact extinction risk in the south.

Though preventing extinction is a primary goal for conservation actions, intermediate metrics are required to judge the efficacy of efforts once they are underway. We recorded the change in population size after 5 years of reducing human-caused mortality. This metric provides both a sense for the expected change as well as an impression of how variable actual outcomes might be. Variability in this case is a complicating factor because it obscures what the long-term response of the population will be to the conservation action.

For northern populations, mean abundance increased following reductions in human-caused mortality of at least 20%. (Fig. 4-6). Variability in population change was great enough, however, that decreases were still highly likely even with maximum survival. Southern populations showed some improvement in mean population change, from a nearly 60% decline under baseline conditions to about a 40% decline with maximum survival. However, variability in population change was such that it is likely no response would be detected within 5 years.

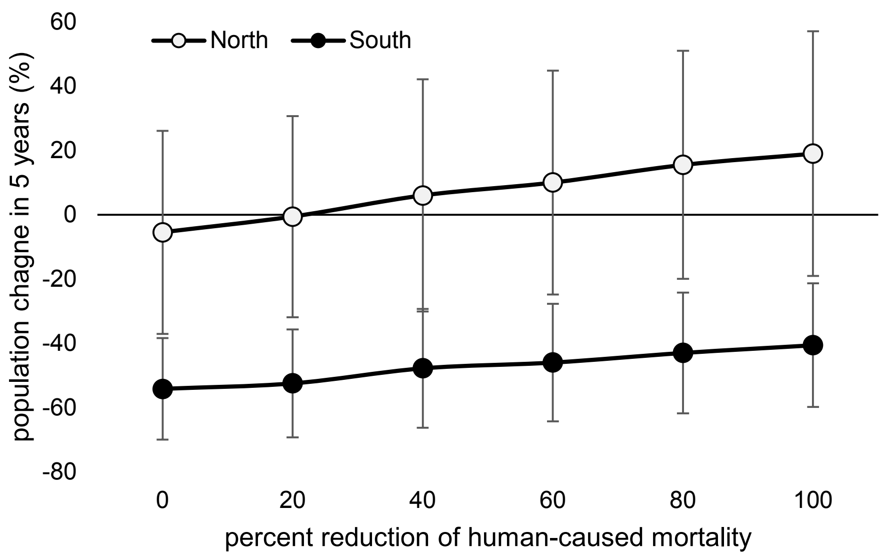

Figure 4-6
Percent change in population size after 5 years of reduced human-caused mortality for hypothetical massasauga populations at the northern and southern range limits. Points are means and error bars represent 1 SD.

PVA Conclusions

We conclude that conservation actions to reduce human-caused mortality would be effective for northern populations but are unlikely to change conservation status in the south. A large disclaimer accompanies this conclusion, as the factor we varied to represent latitudinal variation in demography, brood size, has been found to vary substantially within the range. For instance, brood sizes similar to those we used in our southern population model have been recorded in Wisconsin (King 1996) and Pennsylvania (Reinert 1981). For application to specific populations of Eastern massasauga, it may be appropriate to review estimates of brood size from local studies or to sample the full range of estimates found in the literature.

Despite the large uncertainties surrounding massasauga status and demography, the cursory modeling exercise presented here achieves some notable goals. It provides a sophisticated result – that conservation actions may vary geographically in their efficacy – and delivers some information that is likely robust to specific parameter values, including the high importance of adult survival.

Section 5: Conservation Actions

We have identified eradication efforts and habitat loss as the two primary threats to the Eastern massasauga. Additionally, the FWS has identified the following as the primary conservation actions necessary to protect the Eastern massasauga:

- Research: understand population status, life history characteristics, and habitat use
- Habitat Management: alter harmful land management practices
- Education: public outreach to educate the public about venomous snake conservation

To address the identified conservation needs, a comprehensive review of management plans and mitigation reports was conducted to determine the broadly accepted conservation actions and inflation-adjusted cost estimations (Table 5-1).

Research

The research needs for the Eastern massasauga are considerable and come in two categories: (1) basic population and demographic data across their range; (2) monitoring data, including habitat occupancy and censusing. While there have been some studies examining variation in vital rates by population, this work has been isolated and frequently dependent upon few and sometimes very old marking studies. In their study of survival rates across the range, Jones et al. (2012) noted that this type of variability is likely to become more important as the effects of climate change become more apparent (Jones, et al. 2012). Additionally, there is considerable variation in much of the demographic data currently published, and it is unclear if this is due to inherent variability in vital rates or if the variability is representative of observation error. Lastly, more detailed habitat models are critical to understand and direct conservation actions. More information, including mark-recapture and population genetic studies across the range would elucidate many of these unknown variables.

Table 5-1
Conservation actions and estimated costs addressing research needs for the Eastern massasauga. Note that estimated costs are estimated inflation-adjusted costs (2015 USD) incurred by recent FWS-approved conservation programs.

Action	Estimated Cost
Support scientific research through grants and other funding opportunities focused on Eastern massasauga: ♦ Population dynamics ♦ Life history ♦ Habitat use	$160,000-$500,000 (per grant) Variable, dependent upon discipline and project
Monitoring, including: ♦ Occupancy survey ♦ Annual population monitoring	Variable dependent upon methodology, personnel and spatial extent

Habitat Conservation and Management

To effectively manage potential massasauga habitat, we must first develop precise habitat suitability models. As mentioned previously, this is an active research area. While scientists have a broad understanding of general habitat preferences across the range, there is little discussion or research regarding the fine-scale habitat preferences of this species. Using our current understanding, it is possible to identify potential regions of suitable habitat at a very coarse spatial resolution (collected in the USGS 1:250,000-scale). Using the USGS STATSGO soils database, we identified areas across the domestic range of the massasauga which had hydric soils, the primary habitat feature of this species (USDA). Suitable habitat in counties where massasauga currently occur is identified in Figure 5-1, 5-2, and 5-3. It should be noted that to complete this analysis for the entire range of the massasauga, the spatial resolution is quite low. To identify particular regions for conservation actions to occur, a higher resolution analysis at a smaller spatial scale would be necessary.

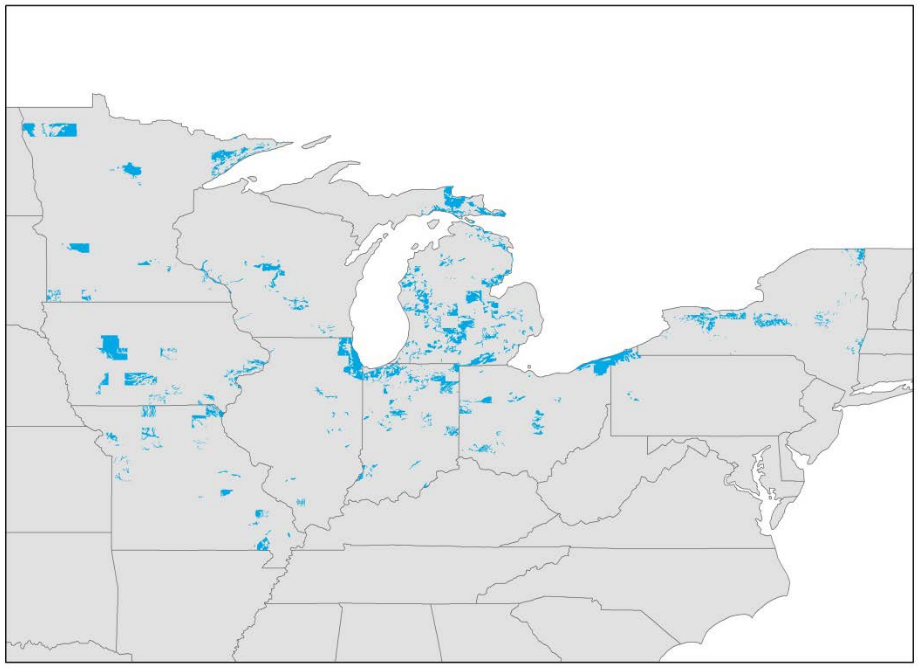

Figure 5-1
Suitable habitat for Eastern massasauga within currently occupied counties.

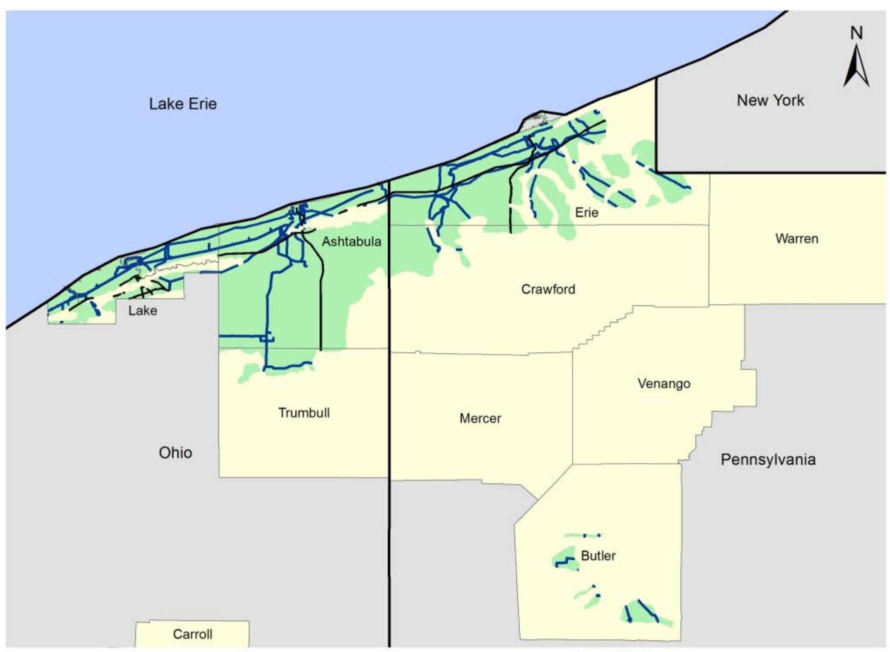

Figure 5-2
Suitable habitat (green) of Eastern massasauga in the occupied counties of northern Ohio and Pennsylvania (yellow). Regions of interest to electric utilities include transmission lines (blue) and highways (black).

Figure 5-3
Suitable habitat (green) of Eastern massasauga in the occupied counties of southern Ohio (yellow). Regions of interest to electric utilities include transmission lines (blue) and highways (black).

Within these regions of suspected occupancy and suitable habitat, several habitat management actions have been suggested (Table 5-2). Land clearing is a documented method of managing habitat for this species, allowing for appropriate structure for thermal regulation, the removal of perching structures for predatory birds, and habitat corridors among patches. It should be noted, however, that some of these management practices are somewhat controversial. Durbian (2005) cited reasonably high mortality associated with prescribed burns and mowing, although other research has suggested that when performed properly, mortality is minimized and the benefits to habitat structure likely outweigh any deaths. Roads have also been identified as an important contributor to snake mortality, particularly in males (Shepard, et al. 2008). In a study on reptile road morality, Ashely, et al. (2007) found that these animals were struck more often than would be expected, suggesting that approximately 3% of drivers may be targeting these individuals. Other studies have found that the presence of wetlands within 100 meters of roads increases the rate of road mortality in amphibians and reptiles (Figure5-4) (Langen, et al. 2009). The development of habitat corridors, specifically through the construction of suitable habitat patches and the placement of wildlife exclusion and road crossing structures, has been strongly supported. The specific structures and costs associated with installation are highly variable and strongly dependent upon spatial context. Acquisition of land in areas of particular concern is another common method of massasauga conservation. Conservation organizations have strongly relied upon this method in the past through the implementation of conservation easements and direct land purchase. The costs associated with land acquisition are quite variable due to the large range of this species.

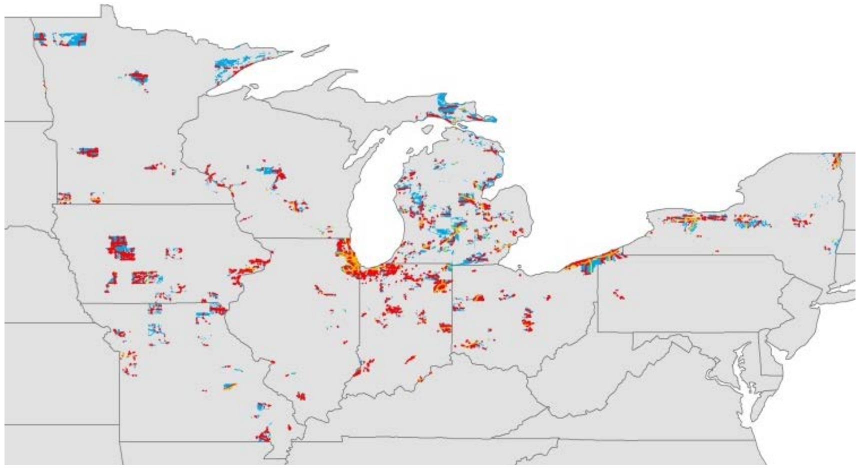

Figure 5-4
Suitable habitat for Eastern massasauga (blue), overlaid electrical transmission lines (red) and primary arterial roads (orange).

Public Education and Outreach

The last component of the FWS's suggested conservation actions is the development of public outreach programs (Table 5-3). Fear of venomous snakes has led to eradication efforts throughout their range, including many state-sponsored bounty programs. While these bounty programs are no longer active, the fear that spawned such programs remains. Public education programs, such as FWS' "Why Conserve a Venomous Snake" and the Michigan State University's "Learning to Live with the Eastern Massasauga", are designed to alleviate fear and develop a sense of stewardship for this species. Michigan State University's program has reported some success at reaching a wide audience, however their efforts are primarily focused upon a small portion of the range. Public outreach programs such as these, as well as others developed for use on military bases, and other conservation lands, have included the development of websites, brochures, and DVDs, as well as organizing workshops for school groups and landowners. The FWS has also identified collection of these snakes for private collectors to be a potential concern, particularly if they are listed as endangered or threatened. Courchamp, et al. proposed that species considered threatened or endangered may be deemed more desirable and valuable and thus more vulnerable to exploitation (Courchamp, et al. 2006).

Table 5-2
Conservation actions and estimated costs addressing habitat conservation and management needs for the Eastern massasauga. Note that estimated costs are estimated inflation-adjusted costs (2015 USD) incurred by recent FWS-approved conservation programs.

Action	Estimated Cost
Land clearing through: ♦ Removal of brush ♦ Mowing ♦ Prescribed burns ♦ Herbicide	$200-500/acre/year
Develop habitat corridors through: ♦ Seeding of native prairie ♦ Animal exclusion fencing near roads ♦ Wildlife crossing structures ♦ Wildlife crossing road signs	$500/acre (seeding) $25,000/mile Cost dependent on structure type $75-150
Land acquisition through purchase or permanent easements	$4,000-$6,000/acre

Table 5-3
Conservation actions and estimated costs addressing public outreach needs for the Eastern massasauga. Note that estimated costs are estimated inflation-adjusted costs (2015 USD) incurred by recent FWS-approved conservation programs.

Action	Estimated Cost
Development of public outreach program, possibly including: ♦ Workshops ♦ DVD ♦ Website development ♦ Brochure publication	$5,000-15,000

Putting it into Context: A Hypothetical Example

To provide context for the estimated conservation actions and costs, consider a hypothetical 20-acre plot within the massasauga range. We reviewed cost estimates associated with published recovery and conservation plans. Only actions predicted to have impacts on this particular spatial area were included. Actions predicted to have more widespread benefits, including research funding and public outreach, would be recommended on a larger spatial scale, and were thus excluded from the present analysis. We did not pursue any validation of these cost estimates.

Table 5-4
Estimated costs associated with conserving and managing a 20-acre parcel of land for Eastern massasauga habitat

Action	Estimated Cost
Research	
Monitoring, including: ♦ Occupancy survey ♦ Annual population monitoring	Dependent upon methodology
Habitat Management	
Land clearing through: ♦ Removal of brush ♦ Mowing ♦ Prescribed burns ♦ Herbicide	$850-2,200/year Assuming: Annual brush clearing Biannual mowing Burns every 4 years Annual herbicide application
Develop habitat corridors through: ♦ Seeding of native prairie ♦ Animal exclusion fencing near roads ♦ Wildlife crossing structures ♦ Wildlife crossing road signs	$ 4,051,410- 6,325,356 Assuming: One-time seeding One-time fencing of 10 miles of road One-time development of 2 underpass wildlife crossing structures Installation of 10 signs
Land acquisition through purchase or permanent easements	$80,000-$120,000
TOTAL	One-time cost: $4,131,410-6,405,356 Annual costs: (not including monitoring) $850-2,200

Table 5-4 summarizes our findings for the potential cost breakdown associated with the research and habitat management. If all the recommended conservation actions were undertaken, a one-time cost between $4 million and $6 million dollars would be incurred, with an additional $1,000 to $2,000 annual habitat maintenance cost. This recurring cost does not include monitoring, for which we found cost estimates to vary depending on method.

Section 6: Conclusions and Recommendations

This study has identified several factors which make the conservation of the Eastern massasauga particularly difficult, including:

1. information about the occupancy and populations across the range is sparse;
2. extant populations are generally very small and isolated;
3. demographic rates in snake populations vary widely across the range; and
4. Eastern massasaugas have extremely low rates of dispersal, making these populations particularly susceptible to extinction associated with demographic stochasticity.

Due to these factors, a direct analysis of the range-wide population status of this species is impossible. However, quantitative modeling to identify conservation actions of large effect is made possible by the available of sufficient information in published literature, allowing rapid assessment without further data collection.

By modeling northern and southern massasauga populations, we determined that while both are at high risk of extinction due to demographic stochasticity, the northern populations are more stable than their southern counterparts and may be more responsive to conservation efforts. This is, in part, due to the larger brood size observed in northern populations. Additional factors that we conservatively excluded from our analysis may further contribute to the relative stability of northern populations and imperilment of those in the southern part of the range. In particular, a gradient of increasing adult survival rates from south to north has been suggested.

The population models suggest that adult survival has the greatest proportional impact on Eastern massasauga population growth rate. The sensitivity to adult survival has important implications for the development of conservation plans. Conservation actions should potentially target increasing adult survival. Indeed, many of the particular actions proposed by the FWS could be adapted to target this life stage. In particular, habitat management plans could be tailored to provide suitable habitat and corridors for adult snakes and public outreach programs could be developed to minimize public fear of adult rattlesnakes.

This report also provides an initial analysis of suitable habitat within occupied regions, to aid in the identification of regions where conservation action should be prioritized (Figure 5-1). The present study, conducted at the scale of the entire species range, utilized a coarse spatial resolution that precludes fine-scale identification of habitat, dispersal corridors, or potential human-habitat conflicts. Future analyses to identify specific local and regional conservation could be conducted at a smaller spatial scale and finer resolution. Such analyses could be linked with monitoring data within the region to allow for simulations and population viability analyses of real populations.

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Appendix A: Responses to Questions on the Draft Report

The distinction between northern and southern populations

Q: You divided the eastern massasauga populations up into northern and southern. Could comment on the robustness of this? For instance, does the fact that the northern population is more robust say something about their prevalence?

A: We cannot conclude from the literature that northern populations are inherently more robust than southern ones. Despite the claim of one large-scale study (Jones, et al. 2012), we did not see convincing evidence for higher survival in northern populations. In our example models, we used a lower litter size for southern populations as reported for one location in Missouri. It has been suggested, but not documented, that southern populations may reproduce more often. If so, this increased reproductive frequency may more than offset the lower number of offspring per litter. Our creation of a robust and declining scenario is designed only to address some of the geographic variation observed among studies. There is also high variation in observed vital rates among local populations at similar latitudes.

Habitat destruction and population viability

Q: Could you comment on habitat destruction with respect to the PVA?

A: Our PVA models were preliminary in nature and did not include a link to habitat quality or area. The data necessary to develop such a link are probably not available, but the model could be amended in several ways to explore hypothetical links between habitat destruction and population viability. Mechanisms to explore would include:

- Pure area effects, with a fixed population density per area
- Change in exposure to predators
- Change in exposure to roads
- Change in hydrology affecting quality of overwintering locations
- Loss of connectivity between adjacent habitat patches

Temporary construction

Q: Could you comment on whether you think temporary work (like temporary construction) in a right of way could cause problems in a population?

A: While we cannot make specific comments without details of the work being performed, we can offer some guidance based on what is known about the species. This guidance is our professional judgement and does not reflect the judgement of state or federal regulators.

The eastern massasauga's complex and not fully documented winter habitat may make it difficult to entirely avoid directly disturbing or destroying individuals during hibernation. Efforts should be taken to ensure a sufficient buffer around wetlands and to inspect for any moist cavities that may offer winter habitat. Work during the warmer months has the potential to disturb or destroy active or basking individuals. This hazard could be reduced by surveying and, if necessary, removing individuals from the work site. Eastern massasauga populations are often so small that the loss of individuals has the potential to affect the persistence of the population locally.

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