Range wide Extinction Risk Modeling for the Eastern Massasauga Rattlesnake (*Sistrurus catenatus catenatus)*

Final Report
April 11, 2011

Lisa Faust, Ph.D.
Research Biologist
Alexander Center for Applied Population Biology
Lincoln Park Zoo
Chicago, IL 60614
lfaust@lpzoo.org
312-742-7227

Jennifer Szymanski
US Fish & Wildlife Service – Division of Endangered Species
Jennifer_Szymanski@fws.gov
608-783-8455

Mike Redmer
US Fish & Wildlife Service – Chicago Field Office
Mike_Redmer@fws.gov
847-381-2253 x16

Table of Contents

MODEL PURPOSE AND ANTICIPATED USE

The goal of this work is to develop a demographic model of Eastern Massasauga Rattlesnake (EMR, *Sistrurus catenatus catenatus*) population ecology that can be used in evaluations of Federal listing priority by USFWS (e.g. the Candidate Notice of Review and other decisions).

The model has been developed to understand the relative "health" of different populations – to understand if some populations are more at risk than others and, collecting that picture across populations, give an estimate of potential range-wide risk. It also serves to summarize the state of our current information about populations across the range. This exercise is undertaken in the context of a great deal of uncertainty: although this is a well-studied species for many aspects of its spatial and behavioral ecology, relatively few long-term studies of closely monitored populations exist, which is essential for producing valid estimates of demographic rates (Szymanski 1998). Some demographic information is available from a handful of populations [Seigel 1986, Bissell 2006, Aldridge et al. 2008, Bailey 2010], but in depth information is not necessarily available on survival and fecundity rates or how massasauga population biology may vary across the range. Information is also lacking on the size, status, and threats to individual populations across the range.

Despite this uncertainty, it is possible to build a demographic model that can improve our understanding of what may make EMR populations vulnerable and how status varies across the range. It is important to recognize that this model is most appropriately used for comparisons between populations rather than absolute predictions of a population's viability for a given site. The main metric used to compare model output is the probability of quasi-extinction, which is a critical population size threshold that provides a benchmark for when a population might begin to experience the negative impacts of small population dynamics such as genetic drift, inbreeding depression, susceptibility to demographic stochasticity and random events, etc. (Ginzburg 1982). The model has been developed as a tool to compare relative risks of quasi-extinction across the range while still addressing the epistemic uncertainty in population ecology, appropriate model structure, and individual site status.

GENERAL MODEL APPROACH

This is not the only demographic modeling or Population Viability Analysis (PVA) completed for EMR; several PVAs have been completed with reports in the grey literature or in theses/dissertations (Seigel and Sheil, 1998; Middleton and Chu, 2004; Miller 2005, Bissell 2006, Bailey 2010, Dreslik, pers. comm.). These exercises used a variety of model packages (RAMAS, VORTEX, etc.) and different approaches to parameterization. Each model was also focused on viability at a single population or site.

Our approach was to build a customized model of generic EMR life history and dynamics, and apply this model across the range using site-specific information. To give a brief overview of our approach:

1. The baseline EMR model represents a hypothetical healthy population. The "healthy" population is assumed to have ample habitat (e.g. the population's vital rates are not affected by density-dependence), reliable and abundant resources (prey base, hibernacula, etc.), and high habitat quality with enough open canopy to meet EMR metabolic and ecological needs. Two versions of this baseline – one with early-maturing dynamics and one with late-maturing dynamics – were developed.
2. We identified the most likely factors (threats or subsidies) that might be impacting EMR populations across the range. Threats have a negative effect on one or more vital rates, and subsidies have a positive effect on one or more vital rates. For each factor, we identified the likely impact of the factor on a healthy population's vital rates (i.e. the change in mortality and reproductive rates which we would

anticipate if that factor was occurring). We added these factors to the model, with the ability to turn each factor on or off for a given model run.
3. We elicited site-specific information from known or suspected EMR sites across the range. Data collected included a population size estimate, factors operating at the site, and potential future management changes (planned or hypothetical) that might address those factors.
4. For each site, we ran the healthy EMR model with site-specific factors turned on to generate estimates of the probability of quasi-extinction, defined as the number of iterations in which the female population dropped below 25 individuals within 25 years (note that this would represent a total EMR population of 50 individuals at a site assuming an equal population sex ratio).

This approach was appropriate because the majority of EMR sites do not have detailed population information but can more readily provide information on the types of factors occurring at a site. Using a single model structure applied across the range means that the observed results can be attributed to differences between sites and not model structure. Finally, because the model is not being used for detailed, site-specific predictions of viability and/or to evaluate management actions at an individual site, having rigorous, site-specific estimates of vital rates is less essential.

MODEL BUILDING PROCESS

This project was a huge collaborative effort which involved the dedication, patience, and enthusiasm of many individuals.

The core project team is composed of Lisa Faust (Lincoln Park Zoo; population modeler), Jennifer Szymanski (USFWS; Project Lead); Mike Redmer (USFWS; lead for EMR within USFWS); Jack Dingledine (USFWS) and Kris Lah (USFWS).

A group of EMR species experts were convened November 13-14, 2008 to work on model development. The attendees either had topical expertise with aspects of massasauga biology or were considered to be experts on the current status of populations in specific states/provinces within the species' range (one expert per state/province). These experts included Frank Durbian (Missouri, habitat management), Mike Dreslik (Illinois, spatial and population ecology, monitoring), Robert Hay (Wisconsin, habitat management), Glenn Johnson (New York, spatial ecology), Bruce Kingsbury (Indiana and Michigan, spatial ecology), Yu Man Lee (Michigan, monitoring), Kent Prior (Ontario, population genetics), Howard Reinert (Pennsylvania, spatial and population ecology), Richard Seigel (Missouri, population ecology), Terry Van De Walle (Iowa, population ecology and monitoring), Doug Wynn (Ohio, population ecology and monitoring) and the core project team. The species experts made the following contributions to the project:
1. At the November 2008 meeting, developed model structure for "healthy" baseline population, including appropriate life history stages, baseline vital rates, and identification of most likely threats (both early-maturing and late-maturing baseline models were developed);
2. Completed electronic peer review of preliminary model results for the healthy population model;
3. Determined the impact of each potential factor (i.e. the amount of change from the baseline vital rate) through an electronic elicitation;
4. Completed electronic peer review of preliminary model results when individual factors were turned on in the model (factors turned on one by one, each factor's impact evaluated for appropriateness of model response).

In addition, some of these experts served as site experts.

After the above steps, site experts across the EMR range were invited to contribute to the project through a series of email invitations. This was a wide-spread invitation that went out to biologists, site managers, governmental and NGO employees, etc. Those interested in participating attended webinars to explain the project approach and the data sheet, and then submitted sheets for site(s) about which they were knowledgeable. Names of those submitting data are listed at the beginning of each state's results.

Both species experts and site experts had the opportunity to review the final model report. Specifically, we asked them:

1. If a particular state's or site's results seemed very different than expected, why did you have that expectation and what might not be captured in the model for that site? Remember, don't focus on a difference of 90% versus 100% probability of quasi-extinction, but larger scale results like a declining population for one you anticipated would be growing?
2. Is anything missing from the description of the modeling process that is important to represent?
3. Are any general patterns missing that are worthwhile pointing out?

MODEL DESCRIPTION

For a list of terms used in the project and throughout this document, see the Important Terms table at the end of this report.

Baseline Model – Early Maturing Population

Background

This general model can illustrate EMR population dynamics under healthy conditions, as well as the sensitivity of EMR life history to perturbations in vital rates (survival and reproductive parameters), life history parameters (age at maturity, maximum longevity), and starting conditions (starting population size).

The model is a stochastic, age-based matrix projection model programmed in Matlab 7.10. Matrix elements are formulated as birth-pulse with a post-breeding census, with all breeding occurring in a single pulse at the beginning of the model year and mortality being applied after (Morris and Doak 2002, Caswell 2001). The model is female-only. The baseline version of the model is an early-maturing life history, with age at sexual maturity of 3 years of age, first birth occurring at age 4, and 10 age classes (maximum longevity = 10) (Fig. 1).

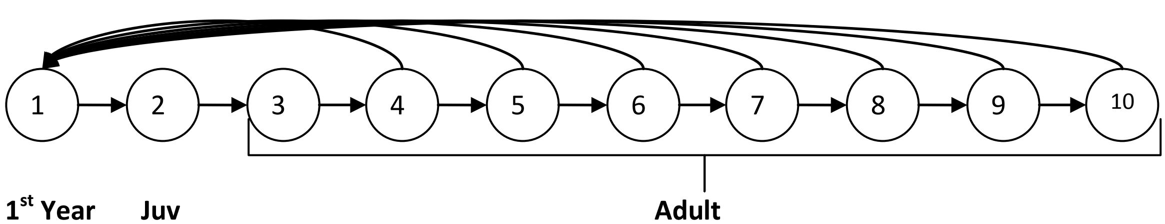


Figure 1. Life cycle figure of baseline, early-maturing matrix model for EMR

The matrix for the baseline model is:

$$
\begin{matrix}
0 & 0 & 0 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 & F_{10} \\
P_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & P_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & P_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & P_4 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & P_5 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & P_6 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & P_7 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & P_8 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_9 & 0
\end{matrix}
$$

Where:

F_i = *probability of breeding* * *mean litter size* * (1-*birth sex ratio*)

P_1 = *1st year survival*

P_2 = *juvenile survival*

P_3 = *adult non post-partum survival*

P_4 - P_9 = [*probability of breeding* * *adult post-partum survival]* + [(1-*probability of breeding*)**adult non post-partum survival]*

(females in the model produce offspring at the beginning of the year, and thus during the year the proportion of females that bred are subject to the post-partum survival rate)

Model Parameter Values

F_i and P_i matrix elements were calculated based on vital rate estimates from species experts at the November 2008 workshop. Vital rate estimates were elicited from the species experts through a series of iterative exercises, including an initial exercise in which experts submitted estimates anonymously without knowledge of other expert's responses and subsequent exercises to refine estimates. Experts gave their estimates for most likely, low, and high values for each parameter. The mean values used in the baseline model (Table 1) were calculated based on the median of the experts' most likely values. The variance values (Table 1) used were based on the variance of the experts' most likely values. Although this estimate is obviously not a true measure of likely parameter variance, such estimates are extremely difficult for experts to estimate (Meyer and Booker 2001); these values are used as a surrogate, and are comparable to values used in Miller (2005).

Table 1. Vital rate definitions and parameter values used in the baseline model

Vital Rate	Definition	Mean Value	Variance (V) or Standard Deviation (SD)
1st Year Survival	The survival rate for the first full year of life from birth in late summer until 12 months of age.	0.5	0.022 (V)
Juvenile Survival	The survival rate for age classes between 12 months and sexual maturity (first mating, so the year before snakes first give birth)	0.65	0.011 (V)

Adult Non-postpartum Survival	The survival rate for a sexually mature female who has **not** just given birth (e.g. she may be gestating and give birth at the beginning of the next model year, but even if that is occurring it does not incur any survival costs during the year). Also assigned to females in the first year of the adult stage when they have just become sexually mature.	0.7	0.010 (V)
Adult Postpartum Survival	The survival rate for a sexually mature female following parturition (birth).	0.6	0.016 (V)
Mean Litter size	Average number of neonates per birth event before any neonate mortality	8	1.47 (SD)
Prob. of Breeding	Probability that an individual adult female produces young (gives birth) in a given year	0.5	0.003 (V)
Birth Sex Ratio	The proportion of offspring that are male (> 0.5 indicates male-bias)	0.5	0.005 (V)

Uncertainty

There are multiple sources of potential uncertainty that affect this modeling exercise. The November 2008 workshop included discussions about the definitions of each life history stage and parameter value to minimize linguistic uncertainty (Table 1). Epistemic uncertainty, which can include measurement error, model structure uncertainty, parametric uncertainty, expert's subjective judgments, was minimized in part by carefully selecting experts for the November 2008 workshop, using standard elicitation methods to solicit model parameter values, using the median and variance of those elicited values for final model values, and testing multiple model structures. However, we recognize that there is incomplete knowledge about EMR population dynamics which is why we caution about the over-interpretation of model results.

Finally, the demographic and environmental stochasticity (i.e. aleatory or irreducible uncertainty) that is present in any biological system was addressed in multiple ways. Demographic stochasticity is the variability in vital rates due to the sampling process, which is exacerbated when population size is small. To reflect its impact in a model, demographic stochasticity is either explicitly simulated in the model using Monte Carlo simulations or a quasi-extinction threshold is selected that is high enough that the sampling effects of demographic stochasticity are negligible, typically anywhere from 20-100 individuals (Morris and Doak 2002). For our model we used the latter approach, and species experts chose a quasi-extinction threshold of 25 females (which would likely represent a total population of approximately 50 individuals).

Environmental stochasticity, representing the variability expected due to annual changes in the environment (food availability, weather, predator/prey density, etc.), is simulated in the model by selecting annual vital rate values from an appropriate distribution based on the parameter's mean and variance values (Table 1). This variability was simulated using a beta distribution for any model parameters that vary between 0 and 1, including survival parameters, probability of breeding, and birth sex ratio, and a log normal distribution for parameters that are $\geq$ 1, such as litter size (Morris and Doak, 2002). Note that the code to generate variation around litter size requires the SD rather than variance of the parameter. This approach means that each year each vital rate fluctuates around the mean rate.

Model Setup

Because we focused on creating a parsimonious model that would still adequately represent EMR population dynamics without adding additional processes that little information exists about, we did not include 1) correlations between vital rates, 2) autocorrelations within vital rates between years, and 3) density dependence. This does not mean that these factors may not influence EMR population dynamics.

To explore the general baseline model, the starting number of females was 100, with females distributed across age classes according to the matrix's stable age distribution (Caswell 2001, Morris and Doak 2002). The timeframe for the model was 25 years, which we believe was a reasonable timeframe for the site experts to predict whether stressors and management actions might occur.

The stochastic model is run for 3000 iterations, and results are reported as the mean values across those iterations. Mean stochastic growth rates (λ) were calculated as the geometric mean of annual λ, calculated as N_{t+1}/N_t where N is total number of females (Case 2001). The probability of quasi-extinction (P(QE)) was calculated as the proportion of 3000 iterations that dropped to a benchmark of 25 females within the model timeframe. The median time to quasi-extinction was calculated for those iterations that hit the benchmark.

Baseline Model Results

The baseline model had a long-term deterministic growth rate of 1.04; this growth rate is the dominant eigenvalue for the matrix and can be interpreted as the growth rate the population would eventually settle into if the environment remained constant (Caswell 2001). The mean (± 1 SD) stochastic growth rate was 1.03 ± 0.02, conforming to expectations that variability in vital rates decreases the long-term growth rate of a population.

Figure 2 shows the population trajectory of all model iterations, illustrating the considerable variability in possible outcomes for a population with this set of vital rates and level of stochastic variance. Clearly in the real world the population trajectories following the largest sizes would at some point be constrained by density-dependence. The P(QE) was 0 over 25 years. These results illustrate that the parameter values solicited based on experts at the meeting portray a "healthy" population with a small but realistic growth rate.

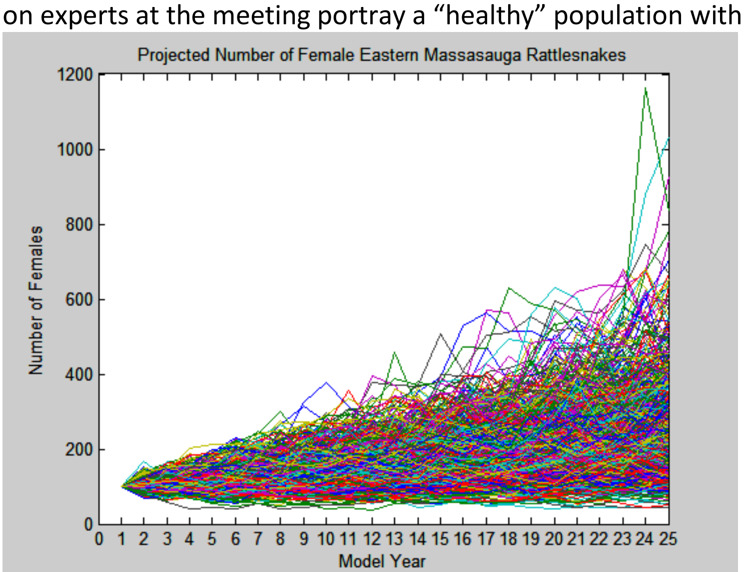


Figure 2. Projected number of females under the baseline early-maturing model conditions over 3000 iterations

Sensitivity Analysis

Sensitivity analysis is used to evaluate which model parameters have the most impact on population growth or other model outputs of interest (e.g. P(QE)). This information can help managers diagnose which life history characteristics might be the best targets for management or, if uncertainty exists in parameter estimates, which ones benefit most from additional research to improve estimates (Caswell 2001, Morris and Doak 2002). We examined model sensitivity in two ways.

We first used a deterministic version of the matrix model (e.g. vital rates were held constant at the mean values in Table 1) and calculated analytical elasticities for the vital rates (Fig. 3), which are defined as the proportional change in the long-term deterministic growth rate resulting from the proportional change in a vital rate (Caswell 2001, Morris and Doak 2002).

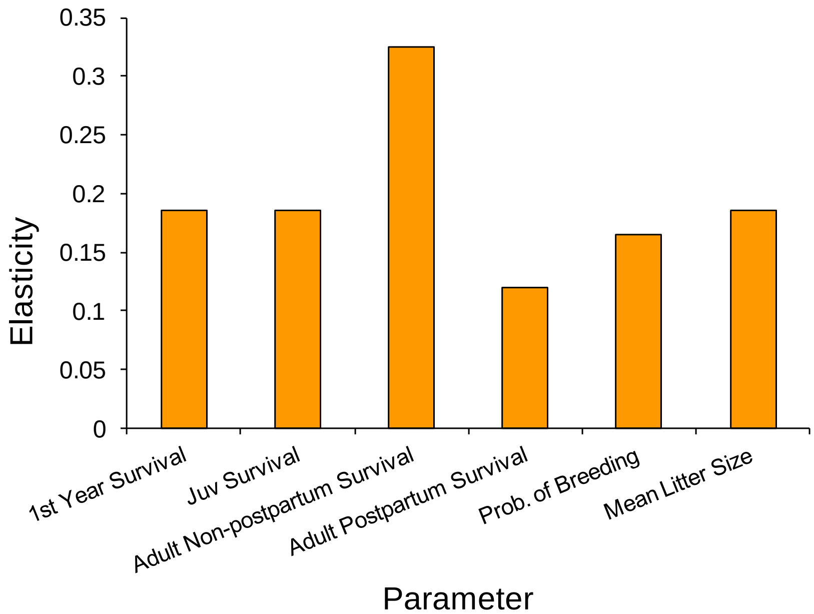


Figure 3. Elasticities for model vital rates for the baseline, early-maturing model

The deterministic baseline model is most sensitive to adult non-postpartum survival (Fig. 3), and about equally sensitive to the pre-adult survival rates and the rates related to reproduction. The sensitivity to adult non-postpartum survival is not surprising because it is applied in two ways in the model: as the survival rate for the first year of the adult stage, when females are mating but have not yet produced offspring, and in all the subsequent adult years' survival rates, which combine post-partum and non post-partum survival based on the proportion of females that are breeding each year. Typically, “fast” species (early maturing, large litter size, short-lived) have large elasticity values for fecundity terms and “slow” species (later maturing, smaller litter size, longer-lived) have higher elasticities in adult survival rate (Heppell et al. 2000, Saether and Bakke 2000, Oli and Dobson 2003). EMR may be illustrating a mixed strategy (or may be midway along the fast/slow continuum), with relatively large litters and early maturation but also relatively long-lived; Saether and Bakke (2000) found that bird populations with these types of characteristics also had large elasticities in adult survival.

We explored sensitivity of the stochastic model using a simulation approach in which we varied individual vital rates across their possible range to determine the threshold values where undesirable population results occurred. The baseline model had 0% P(QE), and the thresholds are the point at which P(QE) became greater than 10% (Fig 4). These thresholds should not necessarily be viewed as absolute predictions of such thresholds, as only a single vital rate was varied at a time. If multiple vital rate changes are occurring simultaneously in a population, one might expect that threshold values would be higher. Threshold value was also examined for litter size, with mean litter sizes below 5.75 resulting in P(QE)> 10% (baseline litter size = 8).

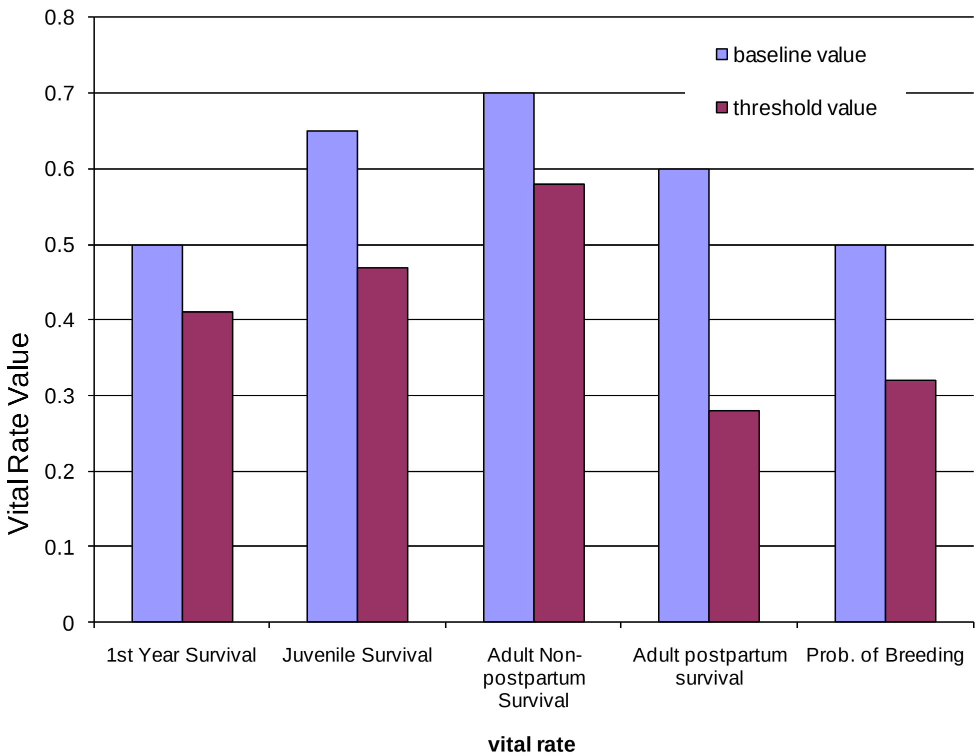


Figure 4. Baseline and threshold values of vital rates. The baseline values result in a P(QE) of 0%, and the threshold value indicates the point where vital rate values less than the threshold produce a P(QE) $\geq$ 10% in 25 years.

Comparing the results of our sensitivity analysis with those conducted during other PVAs for EMR is challenging, as each model has different structure, assumptions, sensitivity analysis approaches, and evaluation criteria. However, in general our sensitivity analysis patterns agree with those performed in other PVA exercises for EMR. To highlight a few, Miller (2005) found the highest sensitivity to female reproductive parameters, neonatal, and adult mortality. Seigel and Shell (1999) also identified thresholds where population dynamics became unstable, which were when adult mortality was > 22% (e.g. survival rate < 0.78) and 1st year mortality was > 80% (e.g. survival rate < 0.20). Our identified thresholds are higher in both cases (e.g. our threshold for 1st year survival of passing from "healthy" dynamics to "strongly declining" dynamics is 0.41), but our time frame and criteria are different, as Seigel and Shell used probability of extinction within 100 years, which is likely why our thresholds are higher. Our analysis and that of others indicate that EMR life history is vulnerable in many of its important life history stages – adult survival and reproduction, and 1st year/juvenile survival, with adult survival being the most sensitive.

Baseline Model – Late Maturing Population

Experts at the meeting identified that populations in the north of the range may have a later age at first maturity, suggesting that such populations may give birth for the first time at approximately age 6. Although there is a good deal of uncertainty about whether this late maturity phenomenon is occurring and, if so, for which populations it is applicable, we decided it was necessary to develop a late-maturing model as well. The differences between this and the early-maturing model are changes in the parameter values for age at first maturity, survival, and maximum longevity.

The baseline, early-maturing model described above is sensitive to age at first birth; if it is changed to 6, the model declines strongly in comparison to the early-maturing version of the model. The deterministic, long-term growth rate with this life history is 0.91 and the mean ± 1SD stochastic growth rate is even lower, 0.90 ± 0.01. This result is consistent with what we would expect as a consequence of only increasing age at first reproduction, without compensating in other vital rates.

Based on feedback from the November workshop and from outreach with additional experts on Canadian populations (Patrick Weatherhead, Dan Harvey, John Middleton, and Gabriel Blouin-Demers), we developed a late-maturing model reflecting several hypotheses:

- that late-maturing populations may have longer maximum longevities
- that a later age at first birth produces a longer juvenile stage that may have higher survival than that of the early-maturing life history: the 2nd year of life might be slightly more risky (when snakes are small) but years 3-5 might have rates that are closer to adult survival rates
- that late-maturing populations may not really be as delayed in reproduction as anticipated, they may just not be well-studied

We tested multiple potential models and ultimately selected one which produced a growing population. This model includes the following changes from the baseline early-maturing model (see Table 1 for full parameter descriptions and early-maturing values):

- Multiple juvenile survival rates: ages 2- 4 = 0.75; age 5 = 0.8
- Age at first birth = 5 (age at sexual maturity = 4)
- Maximum longevity = 17

When simulated under the same conditions as the early-maturing model (starting population size = 100, 3000 iterations, 25 year time frame), this late-maturing model grows slightly with a deterministic growth rate of 1.02 and stochastic growth rate of 1.01 ± 0.02 (Figure 5).

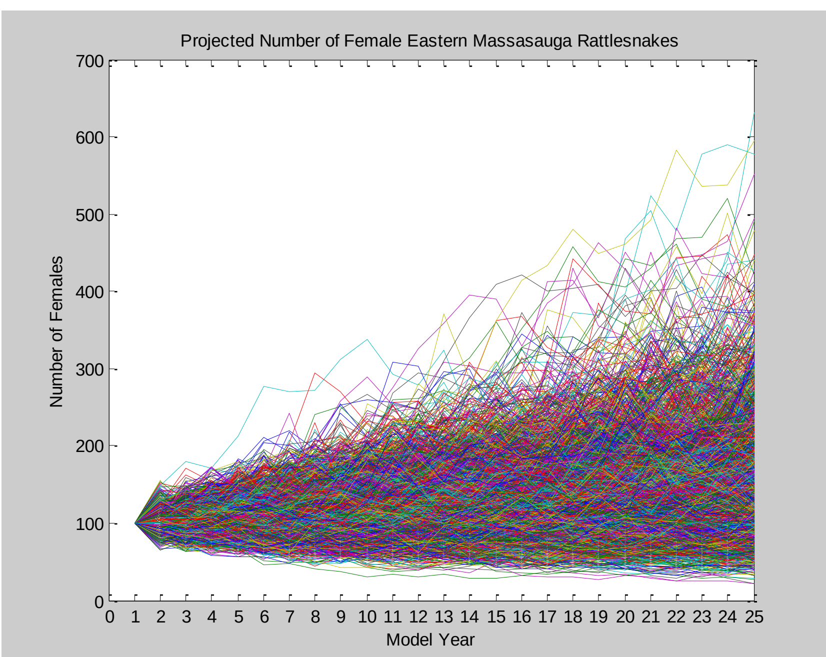


Figure 5. All iterations for projected number of females under the baseline late-maturing model conditions

Ecological and Management Factors Model

Identification of Factors

There are a variety of factors which can influence population dynamics that occur across the range of EMR. These factors may be threats (e.g. having a negative effect on one or more vital rates) or subsidies (having a positive effect). At the November 2008 workshop, species experts identified a suite of common and influential factors, prioritized the potential factor list based on which would have the largest impact on future EMR abundance at a site, and ultimately decided to incorporate the 11 most important factors (assessed using various elicitation methods) in the final model (Table 2). The additional factors that were considered but not included in the final model were either more site-specific (e.g. not occurring widely across the range) or had a smaller impact than those in Table 2. These additional factors were: climate change, disease, pesticide/ herbicide use, invasive plants, road mortality (note that this factor is likely partially included in fragmentation factors), research, persecution/collection, mowing/mechanical control, predation, and prey availability.

At the workshop, experts identified the vital rates each factor would impact (Table 3). Through subsequent webinars and discussions following the workshop, the species experts identified the ***direction*** of each factor's impact as either an increase (positive impact) or decrease (negative impact). The experts also identified the ***frequency*** of each factor occurring: a factor either impacts a vital rate in all model years (frequency = 1.0) or in a proportion of years (frequency is between 0 and 1). For example, a factor such as post-emergent fire will cause a decrease in survival rates in all age classes every time the burn occurs (e.g. the immediate mortality due to the fire); if the habitat is managed on a three year burn cycle, then this negative impact will occur randomly in 1/3 of model years (frequency = 0.33).

Table 2. The most essential factors affecting healthy EMR population dynamics as identified by species experts

FACTOR CODE	FACTOR	DEFINITION	DIRECTION	FREQUENCY
A	Vegetative Succession – midstory	Woody (shrub or tree) canopy is 33-66%	Decrease	Always on (1.0)
B	Vegetative Succession - late stage	Woody canopy is >66%	Decrease	Always on (1.0)
C	High fragmentation	Habitat is impermeable or physical characteristics isolate habitat patches.	Decrease	Always on (1.0)
D	Moderate fragmentation	Habitat is semi-permeable, and patches are not completely isolated.	Decrease	Always on (1.0)
E	Total habitat loss	Complete loss of occupied habitat regardless of population size (the frequency sets chance of this occurring in any given model year; if it occurs, that model iteration goes extinct).	Decrease	Proportional (between 0 and 1)
F	Moderate habitat loss/ modification	**Small sites** (<100-200 acres): any loss/modification; **Medium sites** (200-500 acres): up to 9% loss/modification; **Large sites** (>500 acres): >10% degradation or loss of suitable habitat	Decrease	Proportional (between 0 and 1)
G	Water fluctuation	Changes in normal water table or flood regimes that may adversely affect a population (e.g., through disease, drought, displacement, or drowning).	Decrease	Proportional (between 0 and 1)
H	Pre-emergent fire[1]	fire that affects surface habitat while population is dormant and underground, or that affects less than 1/3 of a population.	Decrease	Proportional (between 0 and 1)

FACTOR CODE	FACTOR	DEFINITION	DIRECTION	FREQUENCY
I	Post-emergent fire[1]	fire that affects less than 1/3 of surface habitat while population is active and above ground.	Decrease	Proportional (between 0 and 1)
J	Subst. habitat restoration	**Small site** (<100-200 acres): any addition of habitat or increase in connectivity; **Medium site** (200-500 acres): a >10% increase in suitable habitat or connectivity.	Increase	Always on (1.0)
K	Moderate habitat restoration	**Medium site** (200-500 acres): up to 10% increase in suitable habitat or connectivity. **Large site** (>500 acres) or **viable population**: addition of any habitat or increased connectivity.	Increase	Always on (1.0)

[1]Pre-emergent and post-emergent fire factors were defined based on the assumption that fire management at sites are carried out on a prescribed burn plan that complies with the 2000 EMR management guidelines to not burn more than 1/3 of a site (Johnson et al. 2000). We did not incorporate the impacts of fire that did not conform to these guidelines such as catastrophic fires or burning more than 1/3 of a site.

Determination of Magnitude of Factor Impact

The ***magnitude*** of each factor's impact on relevant vital rates was elicited from the species experts. The experts were asked to provide the expected change in a vital rate if a factor impacted a population in a single year. The elicitation of this data occurred electronically, with review and revision of magnitudes based on discussion of the experts in an iterative process that involved multiple review rounds. In each round, the change values were tested by turning each factor on one at a time in a model simulation, and the experts reviewed summarized model results and revised their estimates after discussion via webinar, conference call, and email dialogues. Table 3 shows the final values for the magnitude of changes on vital rates used in the model (i.e., the amount added to or subtracted from the baseline vital rate in any given year when a factor is occurring). Magnitude changes are additive, e.g. if a model had two factors turned on, their effects would be added together. These changes interact with the frequency for each factor indicated in Table 2. If a factor is always on, the change in vital rate occurs every year; if a factor is proportional, then the change only occurs in a subset of model years, which are stochastically determined. Note that the underlying simplifying assumption with this model construction is that the impact of factors will be the same across all sites in the range.

Table 3. Magnitude of factor effects in the model. The table values are the reduction/addition to the baseline vital rate value if a factor is turned on in the model. 0 indicates that a given factor was identified to have no effect on a specific vital rate. These reductions/additions change the baseline values either every year or in a proportion of years based on each factor's frequency as described in Table 2.

Code	Factors	1st Year Survival	Juvenile Survival	Non-post partum Survival	Post-partum Survival	Mean litter size	Prob. of breeding
	BASELINE VITAL RATE VALUE	0.5	0.65	0.7	0.6	8	0.5
A	Veg. Succession - midstory	0	0	0	0	-0.5	-0.05
B	Veg. Succession - late stage	-0.09	-0.15	-0.11	-0.25	-1	-0.1
C	High fragmentation	-0.2	-0.2	-0.1	-0.3	-1	-0.2
D	Moderate fragmentation	-0.05	-0.1	-0.05	-0.1	-1	-0.05
E	Total habitat loss	-0.5	-0.65	-0.7	-0.6	-8	-0.5
F	Moderate habitat loss/modific.	-0.2	-0.2	-0.1	-0.1	-1	-0.05
G	Water fluctuation	-0.10	-0.15	-0.15	-0.20	0	0
H	Pre-emergent fire	0	-0.05	-0.03	-0.03	0	0
I	Post-emergent fire	-0.2	-0.2	-0.13	-0.2	0	0
J	Subst. habitat restoration	0.08	0.10	0.10	0.10	1.6	0.2
K	Moderate habitat restoration	0.04	0.05	0.05	0.05	0.8	0.1

Baseline Model Results Incorporating Individual Factors

Figures 6 and 7 illustrate the impact of each factor (turned on one-at-a-time) on the baseline early-maturing population model dynamics. In comparison to the strong growth of the baseline scenario (which has no factors on), most factors cause the population to switch to a strong decline (Fig. 6, 7). For those factors that were proportional (Table 2), in these test scenarios the following frequencies were used: factor E = 0.05, F = 0.33, G = 0.33, H = 0.33, I = 0.33.

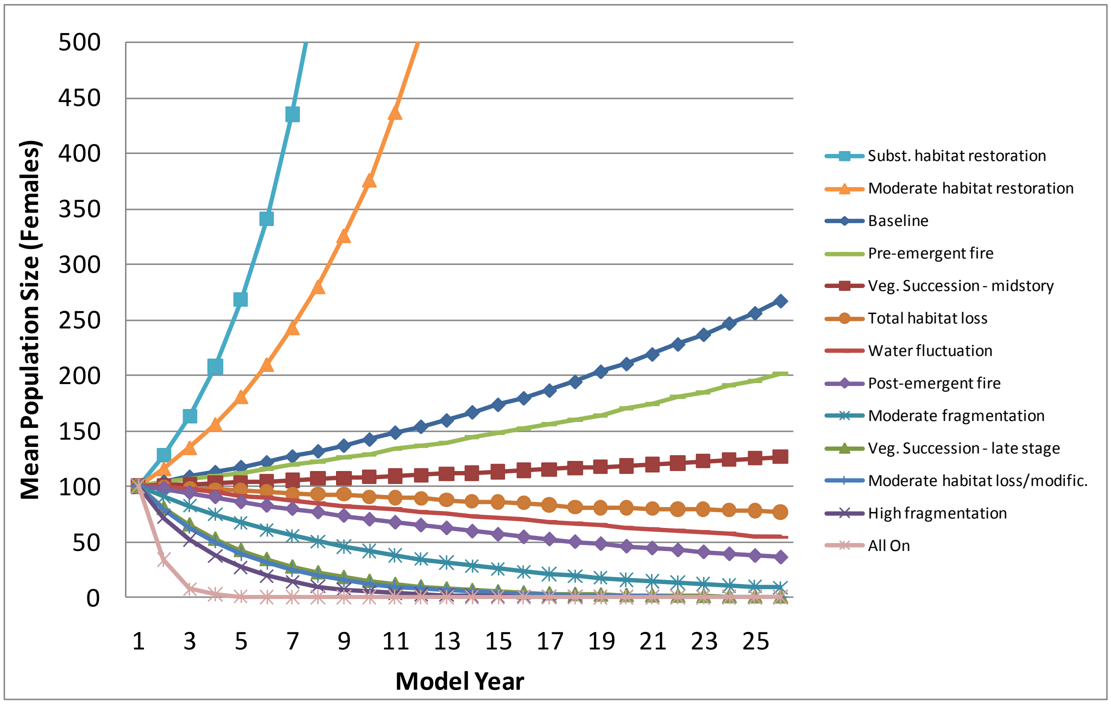


Figure 6. Mean projected number of females when each factor is turned on individually in the model. The baseline trajectory is using the baseline, early-maturing model without any factors. The All On scenario turns all factors on simultaneously.

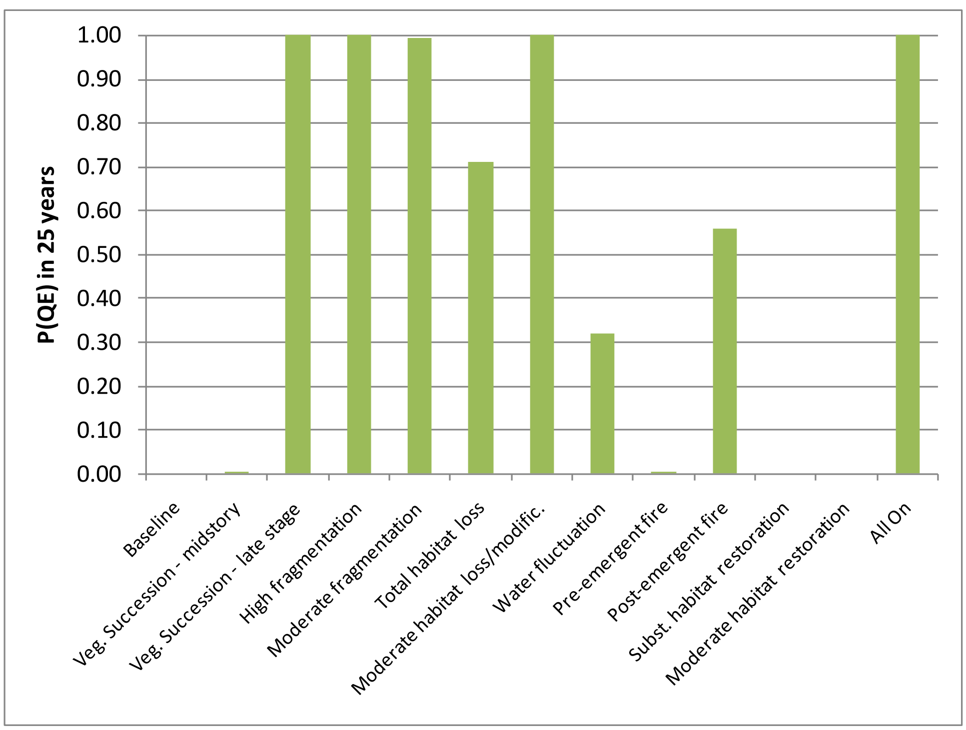


Figure 7. Probability of quasi-extinction (proportion of iterations that dropped to 25 females within 25 years) for scenarios in which each factor is turned on individually in the model, a baseline scenario (no factors on), and a scenario when all factors are simultaneously turned on (All On).

Site-Specific Model Approach

Site Data Solicitation & Standardization

After the model structure was finalized, data were elicited from site experts across the range. Potential sites were identified based on Szymanski (1998) and consultation with knowledgeable experts within each range state. In some states, all the potential or likely sites were identified (e.g. New York), while in others only some of the sites were represented (e.g. Michigan). Each site expert was asked to provide the following information:

1. Whether the site was **early- or late-maturing**
2. Estimated **female population size**: experts could enter an exact estimate or select an appropriate population size bin (1-25, 25-50, 50-100, etc.); they were asked to provide a rationale or source for the estimate and any comments about the estimate. Comments were often used to provide context for the expert's confidence in the estimate. Experts could enter "unknown" for this value.
3. **Always on factors** (those with factor codes A,B,C,D,J,K from Table 2): whether the factor is occurring at the site, comments about how the factor is occurring at that site, and whether the factor can/will be addressed through future management actions.
4. **Proportional factors** (those with factor codes E,F,G,H,I): whether the factors are occurring at the site, an estimate of the frequency of occurrence (e.g. 1 out of every 4 years, or 25%) for each factor, comments about how each factor is occurring at that site, and whether the factor can/will be addressed through future management actions
5. **Any additional factors** not described

Thirty-five site experts provided site-specific data for the project. At some sites, multiple experts submitted data sheets independently. For sites with multiple experts, we selected the model values through the following process. For any value in which the experts disagreed, we presented all responses to each expert and ask them to confer with each other to better understand why their colleagues held a different opinion. We reminded them that we were not looking for consensus but rather wanted to garner their belief based on a common understanding of the state of information at the site. For most sites, the experts came to an agreement on the values or one expert deferred to another as having better knowledge. For those sites in which the revised expert responses still differed, we selected the values backed by the strongest supporting rationale.

It is possible that the 35 experts varied in their interpretations of how to fill out the data sheets and/or how the factors might truly be applied at their sites; this is unavoidable when working with so many experts across a wide range of conditions and roles. To help standardize after data were submitted, Lisa Faust (LF) reviewed all sheets for consistency and, where necessary, made changes to the values used in final model runs. Where possible, experts were asked to clarify ambiguous data. For example, one of the most common issues with site data were that some experts would turn two factors on that were simply different levels of a single factor type (e.g. midstory and late stage succession, moderate and high fragmentation) rather than selecting the most prevalent factor at their site. As a result, for sites where experts submitted this kind of response, LF utilized the more severe of the two effects in that site's baseline version of the model. For all site models, experts were given the opportunity to review their site's results and, in some cases, LF and relevant experts revised site model setups to better reflect a site's situation and management.

Site-Specific Model Setup

As with the baseline model, the site-specific models were run for 3000 iterations, and results are reported as the mean values across those iterations. Mean stochastic growth rates (λ) were calculated as the geometric mean of annual λ, calculated as N_{t+1}/N_t where N is total number of females (Case 2000). In a growing population, $\lambda > 1.0$, in a stable population $\lambda \approx 1.0$, and in a declining population $\lambda < 1.0$. The probability of quasi-extinction

(P(QE)) was calculated as the proportion of 3000 iterations that dropped to a benchmark of 25 females (which would be equivalent to a total population size of approximately 50 individuals at a site) within 25 years. The median time to quasi-extinction was calculated for those iterations that hit the benchmark.

Although late-maturing population dynamics are suspected in some northern populations, based on expert response it was often not known whether specific populations fit this life history paradigm. To compensate for this, in states/provinces where one or more late-maturing populations are known or suspected, we ran a suite of model scenarios with the late-maturing model as well as a suite with the early-maturing model, and results for both are presented to enable comparisons within and between model types across the state/province.

Starting population size was frequently not known with any precision. To address this uncertainty, the site-specific models use population size bins, with each model iteration randomly selecting an appropriate population size from within the bin based on a uniform random distribution. Many experts could not provide population estimates for their sites, entering a value of “unknown”; the 1-200 female bin was the default for these situations. Note that model results are sensitive to this uncertainty, as it means that a portion (roughly 12.5%) of the 3000 iterations will start below the defined QE threshold of 25 females, therefore always hitting the QE threshold quickly regardless of whether the population’s overall dynamics are increasing. Model results, especially P(QE) and median time to QE, are therefore less informative for populations with unknown starting size.

Multiple scenarios were modeled for each site, including:

1) An “all factors on” scenario, in which all factors that the site experts indicated were applicable to their site under current site management were turned on
2) Where appropriate, one or more alternate management scenarios, in which a single factor was changed from the “all factors on” scenario. These scenarios were created based on expert’s submitted data, which would indicate whether management changes were planned or likely in the future at a site or if the expert had uncertainty in whether/how a factor was or was not operating. Each management change (i.e. selecting a factor as “on” or “off”) was made one-by-one to allow comparison with the “all factors on” model, illustrating the impact of a specific management/factor change.
3) Where appropriate, an “all management changes combined” scenario that reflects the impact of all potential (future) management changes simultaneously. In the results tables and descriptions, these are indicated with a * (e.g. IA mgmt 2*).

SITE-SPECIFIC MODEL RESULTS

IOWA

Expert(s) providing site data: Terry VanDeWalle (Natural Resources Consulting, Inc.)

Model data & setup:

- There are seven potential or confirmed EMR sites identified in Iowa. Data were submitted for all seven sites (Table IA-1).
- Distribution of female population sizes (N) (Table IA-1):
    - Unknown N = 5 sites
    - Small N (1-25) = 1 site
    - Medium N (100-200) = 1 site
- No additional factors were identified for any of the sites (e.g. road mortality, poaching)
- Table IA-2 includes a description of all modeled scenarios for Iowa: each site has an ‘all factors on’ scenario and most sites have one or more management scenarios.

Model Results

- In their baseline “all factors on” scenario, all seven populations had a quasi-extinction probability P(QE) = 1.0 (e.g. 100% of 3000 iterations hit the QE threshold; Fig. IA-1).
- Four populations had reduced P(QE) (ranging from 0.11 – 0.73) when potential alternative management actions eliminated the impact of factors at the site (Fig. IA-1).
- Summary statistics across all modeled scenarios are presented in Table IA-3.

These modeling results imply that given the current status and management of sites, it is likely that Iowa’s populations are under potential threat. However, five out of the seven sites had unknown population sizes, reflecting a good deal of uncertainty about the current status of IA populations. With the correct management of factors, some populations do have the potential to reach a reduced level of threat.

Tables and figures:

Table IA-1. Site-specific data for Iowa sites used in each site’s “All Factors On” Scenario.

			FACTORS	**Veg. Succession - midstory**	**Veg. Succession - late stage**	**High fragmentation**	**Mod. fragmentation**	**Subst. habitat restoration**	**Mod. habitat restoration**	**Total habitat loss**	**Mod. habitat loss/ modification**	**Water fluctuation**	**Pre-emergent fire**	**Post-emergent fire**
Model Label	**Site Name**	**AFB** [1]	**Initial N**[2]	**A**[3]	**B**[3]	**C**[3]	**D**[3]	**J**[3]	**K**[3]	**E**[4]	**F**[4]	**G**[4]	**H**[4]	**I**[4]
IA 1	UWR - Sweet Marsh	early	1-25	x			x		x					0.75
IA 2	UWR - north of Sweet Marsh	early	?	x			x							0.25
IA 3	UWR - Hay-Buhr	early	100-200	x			x					0.25	0.25	
IA 4	LWR - Sherman Park	early	?	x			x							0.25

Model Label	Site Name	AFB [1]	Initial N[2]	Veg. Succession - midstory A[3]	Veg. Succession - late stage B[3]	High fragmentation C[3]	Mod. fragmentation D[3]	Subst. habitat restoration J[3]	Mod. habitat restoration K[3]	Total habitat loss E[4]	Mod. habitat loss/ modification F[4]	Water fluctuation G[4]	Pre-emergent fire H[4]	Post-emergent fire I[4]
IA 5	LWR -East	early	?	x			x					0.25		0.25
IA 6	Cedar River	early	?		x	x		x				0.25	0.25	0.25
IA 7	Willow Slough	early	?	x			x							0.75

[1]AFB = age at first birth
[2]Initial N = number of females at model start; unknown values (?) were set as 1-200
[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year
[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table IA-2. All modeled scenarios for Iowa sites, including "all factors on" and management scenarios

Model Scenario Name	Factors Turned On[1]	Description of changes from "all factors on" models[2]
IA 1 - all factors on	A,D,K, I (.75)	
IA 1 - mgmt 1	A,D,K,H (.75), I(0.1)	switching fire management to pre-emergence (predominantly) with small change of post-emergence since "site is so large they cannot get it all burned prior to emergence"
IA 1 - mgmt 2	D,K, I (.75)	addressing midstory succession using shrub removal
IA 1 - mgmt 3*	D,K,H (.75), I(0.1)	all management changes combined: switching fire management and addressing midstory succession through shrub removal
IA 2 - all factors on	A, D, I(.25)	
IA 2 - mgmt 1*	A, D, H(.25)	switching fire management to pre-emergence
IA 3 - all factors on	A, D, G(.25), H(.25)	
IA 3 - mgmt 1*	A, G(.25), H(.25)	Address fragmentation by management of greenbelt to maintain connectivity
IA 4 - all factors on	A, D, I(.25)	
IA 4 - mgmt 1	A, D, H(.25)	switching fire management to pre-emergence
IA 4 - mgmt 2*	A, D, J, H(.25)	all management changes combined: switching fire management and adding subst. habitat restoration based on "the county could add or restore small parcels over time"
IA 5 - all factors on	A, D, G(.25), I(.25)	
IA 5 - mgmt 1*	A, D, G(.25), H(.25)	switching fire management to pre-emergence
IA 6 - all factors on	B,C,J,G(.25),H(.25),I(.25)	
IA 6 - mgmt 1	C,J,G(.25),H(.25),I(.25)	address succession with management
IA 6 - mgmt 2	B,J,G(.25),H(.25),I(.25)	address fragmentation with management
IA 6 - mgmt 3	B,C,J,G(.25),H(.25)	make all fire management pre-emergence
IA 6 - mgmt 4*	J,G(.25),H(.25)	all management changes combined

Model Scenario Name	Factors Turned On[1]	Description of changes from "all factors on" models[2]
IA 7 - all factors on	A,D,I (.75)	
IA 7 - mgmt 1	A,D,H (.75), I(0.1)	switching fire management to pre-emergence (predominantly) with small change of post-emergence since "site is so large they cannot get it all burned prior to emergence"
IA 7 - mgmt 2	A, D, K, I (.75)	possible future habitat restoration
IA 7 - mgmt 3*	A,D,K, H (.75), I(0.1)	all management changes combined: switching fire management + habitat restoration

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table IA-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year

[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

*Starred scenarios are the "management" scenarios displayed in Figure IA-1.

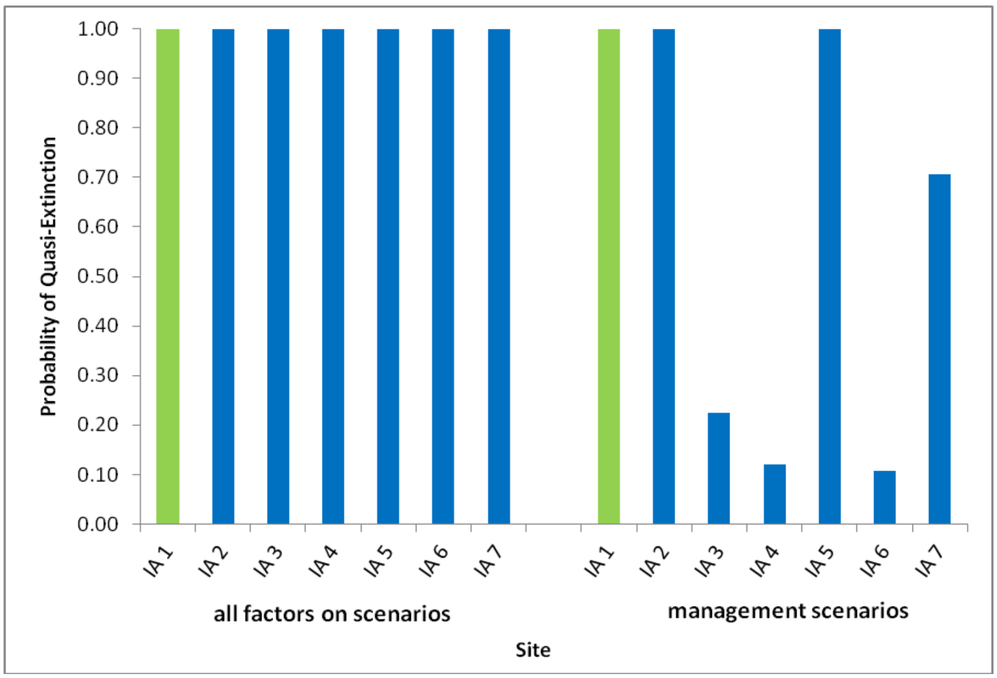


Figure IA – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Iowa populations. Each site (IA1 – IA7) has an "all factors on" scenario and a management scenario that describes the likely impact of potential future management changes (See Table IA-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table IA-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table IA-3. Summarized model results for all model scenarios for Iowa over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
IA 1 - all factors on	1.00	0.80	0.03	N/A		0.0	0.1
IA 1 - mgmt 1	1.00	0.93	0.03	N/A		2.1	2.9
IA 1 - mgmt 2	1.00	0.82	0.03	N/A		0.1	0.2
IA 1 - mgmt 3	1.00	0.96	0.03	N/A		4.1	5.4

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
IA 2 - all factors on	1.00	0.81	0.03	8	3.9	0.4	0.9
IA 2 - mgmt 1	1.00	0.87	0.02	11	5.2	2.5	2.8
IA 3 - all factors on	1.00	0.81	0.03	12	2.6	1.1	1.5
IA 3 - mgmt 1	0.23	0.94	0.03	22	3.6	47.0	50.2
IA 4 - all factors on	1.00	0.81	0.03	8	4.0	0.4	1.0
IA 4 - mgmt 1	1.00	0.87	0.02	11	5.3	2.4	2.8
IA 4 - mgmt 2	0.12	1.09	0.02	1	0.6	895.0	888.0
IA 5 - all factors on	1.00	0.76	0.04	6	3.2	0.1	0.3
IA 5 - mgmt 1	1.00	0.81	0.03	8	3.9	0.5	0.9
IA 6 - all factors on	1.00	0.55	0.04	4	1.6	0.0	0.0
IA 6 - mgmt 1	1.00	0.78	0.04	7	3.8	0.2	0.8
IA 6 - mgmt 2	0.96	0.88	0.04	11	6.6	3.4	12.7
IA 6 - mgmt 3	1.00	0.63	0.03	4	1.8	0.0	0.0
IA 6 - mgmt 4	0.11	1.21	0.03	1	0.1	9870.0	12800.0
IA 7 - all factors on	1.00	0.69	0.03	5	2.2	0.0	0.0
IA 7 - mgmt 1	1.00	0.82	0.03	8	4.1	0.6	1.1
IA 7 - mgmt 2	1.00	0.80	0.03	7	3.7	0.3	0.8
IA 7 - mgmt 3	0.71	0.93	0.03	15	8.0	16.4	23.6

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Some populations with a relatively small P(QE) may appear to hit the QE threshold "quickly" because a small proportion of their scenarios crash quickly (or start below 25) but the rest increase (e.g. IA 4 – mgmt 2).

ILLINOIS

Expert(s) providing site data: Mike Dreslik, Ben Jellen, Mike Redmer, Michelle Simone, Eric Smith

Model data & setup:

- There are seven potential or confirmed EMR sites identified in Illinois. Data were submitted for all seven sites (Table IL-1).
- Distribution of female population sizes (N) (Table IL -1):
  - Unknown N = 1 site
  - Small N (1-25) = 5 sites
  - Medium N (100-200) = 1 site
- Several experts identified additional site-specific factors that were currently threatening a site's population. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR persistence at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Road Mortality: Cisco, DeLong
  - Poaching/Human Persecution: American Bottoms, Lake Carlyle
  - Disease: Lake Carlyle
- Table IL-2 includes a description of all modeled scenarios for Illinois: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios six out of seven populations had a quasi-extinction probability P(QE) close to 1.0 (e.g. 99-100% of model iterations hit the QE threshold) (Fig. IL -1).
- Only three populations had scenarios with potential management improvements; of these, only the IL3 population had a reduced P(QE) when potential management actions eliminated the impact of factors at the site (Fig. IL -1, Table IL-3).
- Summary statistics across all modeled scenarios are presented in Table IL -3.

These modeling results imply that given the current status and management of sites, it is likely that Illinois' populations are under potential threat. At least one of the sites had unknown population size, and model results may reflect a good deal of uncertainty about the current status of its population. With the correct management of factors, some populations do have the potential to reach a reduced level of threat.

Tables and figures:

Table IL-1. Site-specific data for Illinois sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
IL 1	Allerton	early	1-25					x		0.02			0.85	
IL 2	American Bottoms	early	1-25		x	x				0.1	0.25			
IL 3	Lake Carlyle	early	100-200		x	x		x			0.10	0.29	0.33	
IL 4	Cisco (Heartland Pathways Railroad)	early	1-25	x			x	x		0.05	0.2		0.85	
IL 5	DeLong	early	?										0.25	
IL 6	Plum Creek/ Goodenow	early	1-25		x	x						0.15		
IL 7	Upper DesPlaines	early	1-25		x	x		x				0.15	0.2	

[1]AFB = age at first birth

[2]Initial N = number of females at model start; unknown values (?) were set as 1-200

[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year

[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table IL-2. All modeled scenarios for Illinois sites, including "all factors on" and management scenarios

Model Scenario Name	**Factors Turned On[1]**	**Description of changes from "all factors on" models[2]**
IL 1 - all factors on	J, E(.02), H(.85)	
IL 1 - mgmt 1	J, E(.02), H(.85), I(.25)	Burns always attempted as pre-emergent; test impact of occasional post-emergent burns
IL 2 - all factors on[3]	B,C,E(0.1),F(0.25)	
IL 3 - all factors on	B,C,J,F(.1),G(.29),H(.33)	
IL 3 - mgmt 1	C,J,F(.1),G(.29),H(.33)	address succession with habitat management
IL 3 - mgmt 2	B,J,F(.1),G(.29),H(.33)	address fragmentation on site
IL 3 - mgmt 3*	J,F(.1),G(.29),H(.33)	all management actions combined: address fragmentation + succession
IL 4 - all factors on	A,D,J,E(.05), F(.2), H(.85)	
IL 5 - all factors on	H(.25)	
IL 5 - mgmt 1	H(.25), G(.25)	occasional flooding (unknown whether this occurs at site)
IL 5 - mgmt 2	I(.25)	impact of post-emergent burning strategy rather than pre-emergent (expert has never seen late burning but is not positive about private owners practices)
IL 6 - all factors on	B,C,G(.15)	
IL 6 - mgmt 1	C,G(.15),H(.25)	impact of starting fire management on four year rotational schedule and addressing succession
IL 6 - mgmt 2	B,C	removing tiles which addresses water fluctuations
IL 6 - mgmt 3*	C, H(.25)	all management actions combined: add fire and remove tiles

Model Scenario Name	Factors Turned On[1]	Description of changes from "all factors on" models[2]
IL 7 - all factors on	B, C, J, G(.15), H(.2)	
IL 7 - mgmt 1	B, C, J, H(.2)	removing tiles which addresses water fluctuations
IL 7 - mgmt 2	C, J, G(.15), H(.2)	address succession
IL 7 - mgmt 3*	C, J, H(.2)	all management actions combined: address succession + remove farm tiles

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table IL-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year

[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

[3]Note that no alternative management scenarios were possible for site IL 2 or IL 4 based on expert's responses

*Starred scenarios are the "management" scenarios displayed in Figure IL-1.

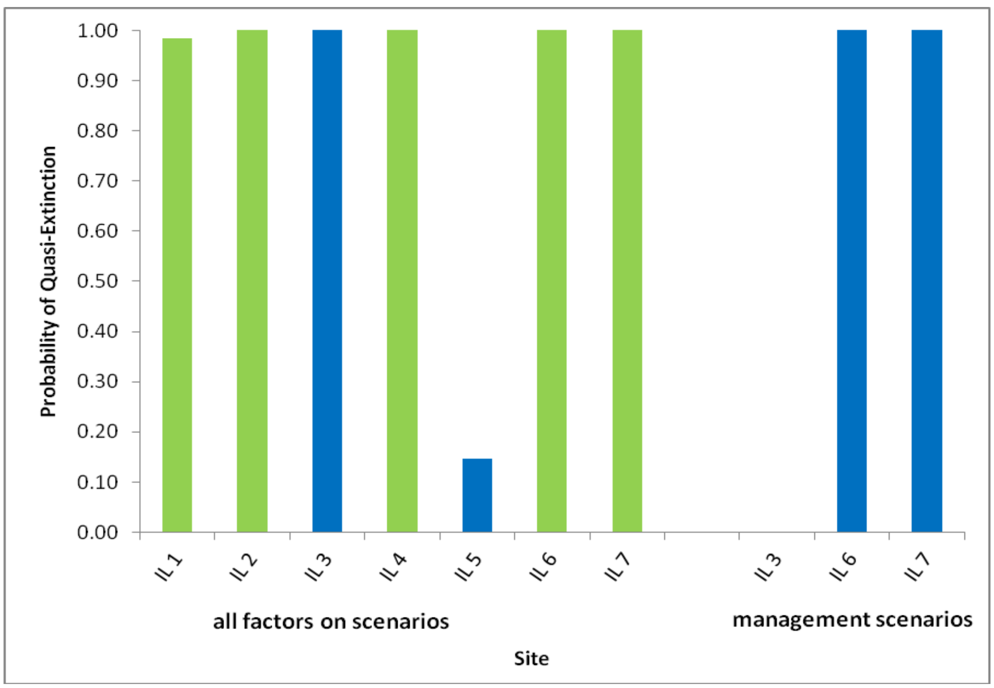


Figure IL – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Illinois populations. Each site (IL1 – IL7) has an "all factors on" scenario and some had possible management scenarios that describe the likely impact of potential future management changes (See Table IL-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table IL-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table IL-3. Summarized model results for all model scenarios for Illinois over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
IL 1 - all factors on	0.99	1.18	0.10	N/A		1070.0	2370.0
IL 1 - mgmt 1	0.991	1.10	0.11	N/A		228.0	765.0
IL 2 - all factors on	1.00	0.39	0.15	N/A		0.0	0.0
IL 3 - all factors on	1.00	0.59	0.03	5	1.1	0.0	0.0
IL 3 - mgmt 1	1.00	0.82	0.04	10	3.3	0.9	2.2
IL 3 - mgmt 2	0.75	0.91	0.04	17	5.1	15.9	25.0
IL 3 - mgmt 3	0.00	1.17	0.03	1	0.0	6910.0	7490.0
IL 4 - all factors on	1.00	0.70	0.28	N/A		0.0	19.4
IL 5 - all factors on	0.15	1.03	0.02	N/A		175.0	184.0
IL 5 - mgmt 1	0.37	0.97	0.03	8	8.8	42.9	62.0
IL 5 - mgmt 2	0.44	0.97	0.03	11	8.7	37.1	72.0
IL 6 - all factors on	1.00	0.47	0.02	N/A		0.0	0.0
IL 6 - mgmt 1	1.00	0.67	0.03	N/A		0.0	0.0
IL 6 - mgmt 2	1.00	0.51	0.02	N/A		0.0	0.0
IL 6 - mgmt 3	1.00	0.70	0.02	N/A		0.0	0.0
IL 7 - all factors on	1.00	0.66	0.03	N/A		0.0	0.0
IL 7 - mgmt 1	1.00	0.69	0.02	N/A		0.0	0.0
IL 7 - mgmt 2	1.00	0.88	0.03	N/A		0.5	0.8
IL 7 - mgmt 3	1.00	0.92	0.02	N/A		1.4	1.7

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Some populations with a relatively small P(QE) may appear to hit the QE threshold "quickly" because a small proportion of their scenarios crash quickly (or start below 25) but the rest increase (e.g. IL 5 – all factors on).

INDIANA

Expert(s) providing site data: Gary Glowacki , Ralph Grundel

Model data & setup:

- There were 19 potential or confirmed EMR sites identified in Indiana; data were submitted for only one of the sites, Indiana Dunes National Lakeshore (Table IN-1).
- Distribution of female population sizes (N) (Table IN-1):
  - Small N (1-25) = 1 site
- The experts identified additional site-specific factors that were currently threatening the site's population. The following factors are additional threats to EMR persistence at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Poaching/Human Persecution
- The site was modeled with a baseline of "all factors on"; no management scenarios were identified for the sight based on the expert's responses (Table IN-1).

Model Results

- The population had a quasi-extinction probability P(QE) = 1.0 (e.g. 100% of model iterations hit the QE threshold) in the "all factors on" scenario. Summary statistics are presented in Table IN-2.

These results imply that given the current status and management, it is likely that the modeled population is under potential threat. Without additional data from Indiana, it is impossible to draw conclusions about EMR status in the state.

Table IN-1. Site-specific data for Indiana sites used in each site's "All Factors On" Scenario.

			FACTORS	**Veg. Succession - midstory**	**Veg. Succession - late stage**	**High fragmentation**	**Mod. fragmentation**	**Subst. habitat restoration**	**Mod. habitat restoration**	**Total habitat loss**	**Mod. habitat loss/ modification**	**Water fluctuation**	**Pre-emergent fire**	**Post-emergent fire**
Model Label	**Site Name**	**AFB [1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
IN 1	Indiana Dunes National Lakeshore	early	1-25		x		x	x				0.05	0.07	

[1]AFB = age at first birth

[2]Initial N = number of females at model start

[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year

[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table IN-2. Summarized model results for the model scenario for Indiana over 3000 iterations.

Scenario Name	**P(QE)**	**mean of observed, stochastic lambdas**	**SD of observed, stochastic lambdas**	**median time to QE (years)[1]**	**SD time to QE (years)**	**Median Final N**	**SD final N**
IN 1 - all factors on	1.00	0.87	0.02	N/A		0.36	0.47

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A.

MICHIGAN

Expert(s) providing site data: Andy Bacon, Brittany Bird, Kristen Bissell, Steve Chadwick, Bob Grese, Steve Griffith, Yu Man Lee, Paul Muelle, Brian Piccolo, Mike Redmer, Chris Schumacher

Model data & setup:

- Based on lists compiled from the 1998 report and input from Yu Man Lee, there may be over 150 sites in Michigan (these may have populations or may just be locations of historic sightings). Data were submitted and modeled for 21 sites in the state, with an attempt to capture sites that had a large geographic spread across the state (Table MI-1).
- Distribution of female population sizes (N) (Table MI-1):
  - Unknown N (?) = 5 sites
  - Small N (1-50) = 10 sites
  - Medium N (50-200) = 3 sites
  - Large N (200+) = 3 sites
- Experts identified additional site-specific factors that are currently threatening populations. Note that some of these were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR persistence at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Road Mortality: Seven Lakes State Park, Long Lake, Bois Blanc Island
  - Poaching/Human Persecution: Little Manistee River, Stony Creek Metro Park, Indiana Springs Metro Park, Hudson Mills Metro Park, Kensington Metro Park, Independence Oaks Park, Skegemog Wildlife Area, Orion Oaks – Lake Sixteen, Bois Blanc Island
  - Invasive species: Calla Burr/MNA/Rattalee Lake
  - Incompatible Maintenance (mowing, brush clearing): Stony Creek Metro Park, Indiana Springs Metro Park, Hudson Mills Metro Park, Green Swamp/Rattlesnake Hills
- Michigan may have some late-maturing populations. In their data sheets, experts sometimes did not provide age at maturity or identified the southern-most populations as early-maturing and the northern-most populations as late-maturing (Table MI-1). To facilitate comparison with other states' results and among sites within the state, both early (E) and late (L) maturing model scenarios were run, and results are presented for both.
- Table MI-2 includes a description of all modeled scenarios for Michigan: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios
  - using early-maturing models, 14 out of 21 Michigan sites had quasi-extinction probabilities P(QE) close to 1.0 (e.g. 93-100% of model iterations hit the QE threshold) (Fig. MI-1a, b).
  - under late-maturing models, 15 out of 21 Michigan sites had quasi-extinction probabilities P(QE) close to 1.0 (Fig. MI – 1c, d).
- Focusing on their alternative management scenarios, 5 out of 21 scenarios (using either early- or late-maturing models) showed a reduction in P(QE) when potential alternative management actions eliminated the impact of factors at the site (Fig. MI-1, Table MI-3).
- Summary statistics across all modeled scenarios are presented in Table MI-3.

These modeling results imply that, given the current status and management of the modeled sites in Michigan, many of these modeled sites are under potential threat. However, 5 out of the 21 sites had unknown population sizes, reflecting a good deal of uncertainty about the current status of MI populations. With the correct management of factors, some of the populations have the potential to reach a reduced level of threat. Because of the large number of sites in Michigan, it is difficult to draw state-wide conclusions, but these results indicate that model sites found across all regions of the state are potentially at risk.

Tables and figures:

Table MI-1. Site-specific data for Michigan sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
MI 1	Little Manistee River	?	25-50		x		x						0.25	
MI 2	Matthaei Gardens	?	1-25		x				x				0.14	
MI 3	Mill Cr. Wetlands	?	1-25	x							0.1	0.25		
MI 4	Gourdneck SGA-N	?	1-25	x							0.1			
MI 5	Head Property (Little Wolf Creek)	?	1-25		x			x						
MI 6	Calla Burr/MNA/Rattalee Lake (Oakland Co.)	?	?	x			x	x			1		0.125	.125
MI 7	Big Valley Preserve - Buckhorn Lake (Oakland County)	?	?	x			x	x			1	0.25	0.125	.125
MI 8	Stony Creek Metro Park	?	25-50	x			x	x			0.1		0.2	
MI 9	Indiana Springs Metro Park	?	50-100	x			x	x					0.2	
MI 10	Hudson Mills Metro Park	?	25-50	x			x				0.1		0.2	
MI 11	Kensington Metro Park	?	1-25				x						0.2	
MI 12	Independence Oaks Park	?	1-25	x					x				0.33	
MI 13	Skegemog Wildlife Area	?	?								0.5	0.25	0.2	
MI 14	Orion Oaks - Lake Sixteen	?	1-25	x									0.33	
MI 15	Cedar Creek (Pierce Cedar Creek Institute)	early	500									.0025	0.12	0.13
MI 16	Big Rock Valley (Edward Lowe Foundation)	early	50-100	x			x	x					0.25	
MI 17	Green Swamp/Rattlesnake Hills	late (presumed)	200-500											
MI 18	Smokey Hollow Swamp	late (presumed)	?											
MI 19	Seven Lakes State Park	early	25-200	x			x				0.1		0.25	0.5
MI 20	Long Lake	early	?	x			x	x			0.1		0.25	.625
MI 21	Bois Blanc Island	late (presumed)	500-1000								0.04			

[1]AFB = age at first birth; ? = expert did not make estimate of age at first birth; all MI sites were modeled using both early and late-maturing versions

[2]Initial N = number of females at model start; unknown values (?) were set as 1-200

[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year

[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table MI-2. All modeled scenarios for Michigan sites, including "all factors on" and management scenarios

Model Scenario Name[1]	Factors Turned On[2]	Description of changes from "all factors on" models[3]
MI 1 E - all factors on	B,D,H(.25)	
MI 1 E - mgmt 1	B,D,H(.33)	varying fire freq (expert used "variable") - 1 out of 3 years
MI 1 E - mgmt 2	B,D,H(.20)	varying fire freq (expert used "variable") - 1 out of 5 years
MI 1 E - mgmt 3*	D,H(.25)	address succession through prescribed burns
MI 2 E - all factors on	B,K,H(.14)	
MI 2 E - mgmt 1	B,K,H(.14), I(.14)	adding post-emergent fire (possible in future)
MI 2 E - mgmt 2*	K,H(.14)	addressing succession
MI 3 E - all factors on[4]	A,F(.1),G(.25)	
MI 4 E - all factors on[4]	A,F(.1)	
MI 5 E - all factors on[4]	B,J	
MI 6 E - all factors on	A, D, J, F(1), H(.13), I(.13)	
MI 6 E - mgmt 1	A, D, J, H(.13), I(.13)	eliminated moderate habitat loss to test parameter uncertainty (no numeric frequency of occurrence from expert, just stated "very slow")
MI 6 E - mgmt 2	A, D, J, F(1), H(.25)	push all burns to pre-emergence
MI 6 E - mgmt 3*	D, J, H(.25)	all management action combined: address vegetative succession + moderate habitat loss through land management (factors appear linked in expert's interpretation), push burns to pre-emergence
MI 7 E - all factors on	A,D,J,F(1),G(.25),H(.13),I(.13)	
MI 7 E - mgmt 1	A,D,J,G(.25),H(.13),I(.13)	eliminated moderate habitat loss to test parameter uncertainty (no numeric frequency of occurrence from expert, just stated "very slow")
MI 7 E - mgmt 2	A,D,J,F(1),G(.25),H(.25)	push all burns to pre-emergence
MI 7 E - mgmt 3	A,D,J,F(1),G(.15),H(.13),I(.13)	lower water fluctuation effect (expert's statement "<25% of every 4 years" is difficult to interpret)
MI 7 E - mgmt 4	D,J,F(1),G(.25),H(.13),I(.13)	address vegetative succession
MI 7 E - mgmt 5*	D,J,G(.25),H(.25)	all management action combined: address vegetative succession + moderate habitat loss through land management (factors appear linked in expert's interpretation), push burns to pre-emergence
MI 8 E - all factors on	A, D, J, F(.1),H(.2)	
MI 8 E - mgmt 1*	D, J, F(.1),H(.2); I(0.05)	address vegetative succession - midstory (partially by adding post-emergence burns)
MI 9 E - all factors on	A, D, J, H(.2)	
MI 9 E - mgmt 1*	D, J, H(.2), I(0.05)	address vegetative succession - midstory (partially by adding post-emergence burns)
MI 10 E - all factors on	A, D, F(.1),H(.2)	
MI 10 E - mgmt 1	D, F(.1),H(.2), I(.05)	address vegetative succession - midstory (partially by adding post-emergence burns)
MI 10 E - mgmt 2	A, D, H(.2)	if park building projects are undertaken so as to not impact EMR areas
MI 10 E - mgmt 3*	D, H(.2),I(.05)	all management actions combined
MI 11 E - all factors on	D,H(.2)	
MI 11 E - mgmt 1*	H(.2),I(.05)	adding post-emergent fire (possible in future) to increase connectivity (turn off fragmentation)
MI 12 E - all factors on	A, K, H(.33)	
MI 12 E - mgmt 1	A, K, F(1),H(.33)	mod habitat loss on (uncertainty about parameter)
MI 12 E - mgmt 2	A, K, G(.25),H(.33)	beaver-caused water fluctuations on with freq of 0.25 (uncertainty about parameter)
MI 12 E - mgmt 3*	K, H(.33)	address succession
MI 13 E - all factors on	F(.5),G(.25),H(.2)	
MI 13 E - mgmt 1*	K,F(.5),G(.25),H(.2)	habitat restoration through purchase of privately owned property by state

Model Scenario Name[1]	Factors Turned On[2]	Description of changes from "all factors on" models[3]
MI 14 E - all factors on	A,H(.33)	
MI 14 E - mgmt 1*	H(.33)	fully address vegetative succession
MI 15 E - all factors on[4]	G(0.0025), H(.12), I(.13)	
MI 16 E - all factors on	A, D, J, H(.25)	
MI 16 E - mgmt 1	A,D,K,H(.25)	if habitat restoration is only moderate, not substantial (could be either for the site)
MI 16 E - mgmt 2	D,J,H(.25)	ongoing management addresses midstory succession
MI 16 E - mgmt 3	A,J,H(.25)	ongoing management addresses fragmentation
MI 16 E - mgmt 4*	J,H(.25)	all management actions combined
MI 17 E - all factors on		
MI 17 E - mgmt 1*	K	moderate habitat restoration possible through timber harvesting and/or creating new openings
MI 18 E - all factors on		
MI 18 E - mgmt 1	F(.075)	reflects uncertainty about potential for small loss of habitat due to partial private holdings being lost
MI 19 E - all factors on	A,D,F(.1),H(.25),I(.5)	
MI 19 E - mgmt 1	D,F(.1),H(.25),I(.5)	address vegetative succession
MI 19 E - mgmt 2	A,F(.1),H(.25),I(.5)	address fragmentation (expert was uncertain whether this was possible)
MI 19 E - mgmt 3*	F(.1),H(.25),I(.5)	all mgmt actions on: address succession + fragmentation
MI 20 E - all factors on	A,D,J,F(.1),H(.25),I(.63)	
MI 20 E - mgmt 1	D,J,F(.1),H(.25),I(.63)	address vegetative succession
MI 20 E - mgmt 2	A,J,F(.1),H(.25),I(.63)	address fragmentation (expert was uncertain whether this was possible)
MI 20 E - mgmt 3*	J,F(.1),H(.25),I(.63)	all mgmt actions on: address succession + fragmentation
MI 21 E - all factors on[4]	F(0.04)	

[1]E = Early-maturing model scenarios; a set of identical scenarios was run using the late-maturing model
[2]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table MI-1 for the factor codes.
[3]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.
[4]Note that no alternative management scenarios were possible for these sites based on the expert's responses
*Starred scenarios are the "management" scenarios displayed in Figure MI-1.

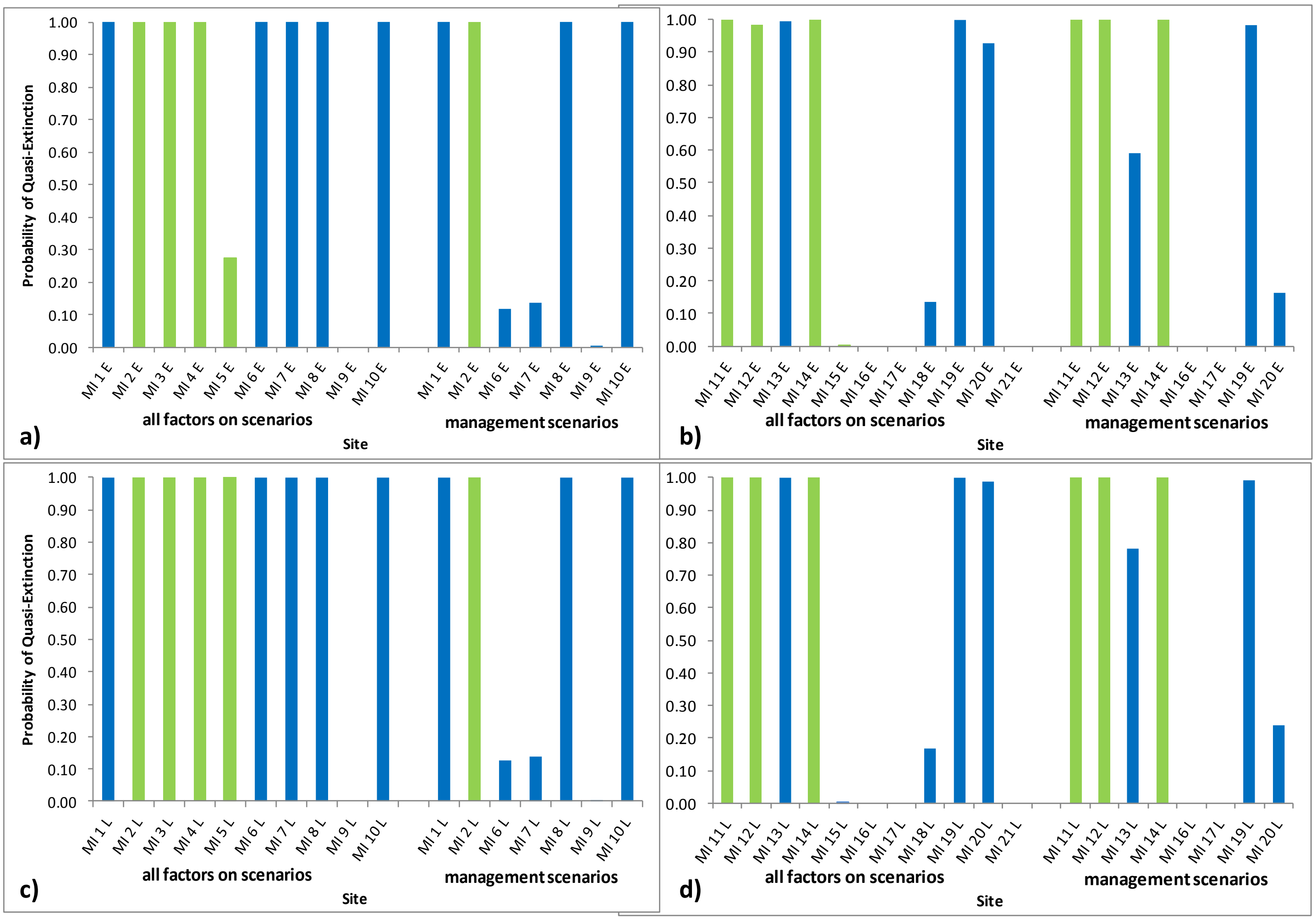


Figure MI – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) in Michigan for: a) Populations MI 1-10 under the early-maturing model, b) Populations MI 11-21 under the early maturing-model, c) Populations MI 1-10 under the late-maturing model, d) populations MI 11-21 under the late-maturing model. Each site (MI 1 – MI 21) has an "all factors on" scenario and most (where possible) have a management scenario that describes the likely impact of potential future management changes (see Table MI-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table MI-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table MI-3. Summarized model results for all model scenarios for Michigan over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
EARLY MATURING MODEL RESULTS							
MI 1 E - all factors on	1.00	0.67	0.02	2	0.6	0.0	0.0
MI 1 E - mgmt 1	1.00	0.67	0.02	2	0.6	0.0	0.0
MI 1 E - mgmt 2	1.00	0.67	0.02	2	0.6	0.0	0.0
MI 1 E - mgmt 3	1.00	0.89	0.02	5	2.4	2.2	1.7
MI 2 E - all factors on	1.00	0.91	0.02	N/A		1.0	1.1
MI 2 E - mgmt 1	1.00	0.87	0.03	N/A		0.3	0.6
MI 2 E - mgmt 2	1.00	1.15	0.02	N/A		377.0	358.0
MI 3 E - all factors on	1.00	0.93	0.03	N/A		1.7	3.2
MI 4 E - all factors on	1.00	0.98	0.03	N/A		6.6	8.3
MI 5 E - all factors on	0.28	1.02	0.02	6	6.3	60.7	42.3
MI 6 E - all factors on	1.00	0.80	0.03	7	3.8	0.3	0.8
MI 6 E - mgmt 1	0.15	1.06	0.03	1	2.1	401.0	567.0
MI 6 E - mgmt 2	1.00	0.84	0.02	9	4.5	1.3	1.8
MI 6 E - mgmt 3	0.12	1.12	0.02	1	0.3	1640.0	1630.0
MI 7 E - all factors on	1.00	0.74	0.04	6	3.1	0.0	0.2
MI 7 E - mgmt 1	0.25	1.01	0.03	2	7.9	104.0	205.0
MI 7 E - mgmt 2	1.00	0.78	0.03	7	3.4	0.2	0.5
MI 7 E - mgmt 3	1.00	0.76	0.04	6	3.3	0.1	0.4
MI 7 E - mgmt 4	1.00	0.76	0.04	6	3.3	0.1	0.5
MI 7 E - mgmt 5	0.14	1.07	0.03	1	2.6	428.0	631.0
MI 8 E - all factors on	1.00	0.84	0.02	4	1.7	0.5	0.5
MI 8 E - mgmt 1	1.00	0.85	0.03	4	1.9	0.6	0.7
MI 9 E - all factors on	0.00	1.10	0.02	-		746.0	478.0
MI 9 E - mgmt 1	0.00	1.11	0.03	9	0.0	961.0	722.0
MI 10 E - all factors on	1.00	0.84	0.02	4	1.7	0.5	0.5
MI 10 E - mgmt 1	1.00	0.85	0.03	4	2.1	0.7	1.0
MI 10 E - mgmt 2	1.00	0.87	0.02	4	1.9	1.0	0.8
MI 10 E - mgmt 3	1.00	0.88	0.02	4	2.4	1.6	1.4
MI 11 E - all factors on	1.00	0.89	0.02	N/A		0.7	0.8
MI 11 E - mgmt 1	1.00	1.01	0.02	N/A		16.6	18.5
MI 12 E - all factors on	0.98	1.11	0.02	N/A		172.0	163.0
MI 12 E - mgmt 1	1.00	0.86	0.02	N/A		0.3	0.3
MI 12 E - mgmt 2	0.99	1.06	0.03	N/A		48.7	64.5
MI 12 E - mgmt 3	1.00	1.14	0.02	N/A		322.0	331.0
MI 13 E - all factors on	1.00	0.84	0.04	9	5.4	1.1	5.0
MI 13 E - mgmt 1	0.59	0.95	0.04	11	8.2	25	72.6
MI 14 E - all factors on	1.00	0.99	0.02	1	0.5	10.1	10.9
MI 14 E - mgmt 1	1.00	1.02	0.02	N/A		20.1	20.3
MI 15 E - all factors on	0.00	0.99	0.03	22	0.0	440.0	390.0
MI 16 E - all factors on	0.00	1.09	0.02	-		707.0	467.0
MI 16 E - mgmt 1	0.23	0.98	0.02	20	5.0	43.6	31.5
MI 16 E - mgmt 2	0.00	1.12	0.02	-		1280.0	797.0
MI 16 E - mgmt 3	0.00	1.24	0.02	-		14800.0	8690.0

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
MI 16 E - mgmt 4	0.00	1.26	0.02	-		25900.0	15200.0
MI 17 E - all factors on	0.00	1.03	0.02	-		803.0	532.0
MI 17 E - mgmt 1	0.00	1.15	0.02	-		12000.0	7720.0
MI 18 E - all factors on	0.14	1.03	0.02	1	2.2	213.0	221.0
MI 18 E - mgmt 1	0.18	1.01	0.02	1.0	6.0	127.0	157.0
MI 19 E - all factors on	1.00	0.71	0.04	6	2.2	0.0	0.1
MI 19 E - mgmt 1	1.00	0.73	0.04	6	2.4	0.0	0.2
MI 19 E - mgmt 2	1.00	0.84	0.04	10	4.7	1.3	4.0
MI 19 E - mgmt 3	0.98	0.86	0.04	11	5.4	2.6	7.4
MI 20 E - all factors on	0.93	0.89	0.04	12	7.0	4.8	15.2
MI 20 E - mgmt 1	0.84	0.92	0.04	12	7.4	8.9	34.0
MI 20 E - mgmt 2	0.20	1.04	0.04	1	6.1	196.0	514.0
MI 20 E - mgmt 3	0.16	1.06	0.04	1	4.8	346.0	801.0
MI 21 E - all factors on	0.00	1.02	0.02	-		1340.0	1020.0
LATE MATURING MODEL RESULTS							
MI 1 L - all factors on	1.00	0.66	0.02	2	0.6	0.0	0.0
MI 1 L - mgmt 1	1.00	0.66	0.02	2	0.6	0.0	0.0
MI 1 L - mgmt 2	1.00	0.67	0.02	2	0.6	0.0	0.0
MI 1 L - mgmt 3	1.00	0.88	0.02	4	2.0	1.4	1.0
MI 2 L - all factors on	1.00	0.88	0.02	N/A		0.5	0.5
MI 2 L - mgmt 1	1.00	0.85	0.03	N/A		0.2	0.3
MI 2 L - mgmt 2	1.00	1.07	0.03	N/A		70.8	84.9
MI 3 L - all factors on	1.00	0.91	0.03	N/A		1.1	2.0
MI 4 L - all factors on	1.00	0.96	0.02	N/A		4.7	5.3
MI 5 L - all factors on	1.00	0.99	0.02	1	0.0	8.3	7.9
MI 6 L - all factors on	1.00	0.78	0.03	7	3.2	0.2	0.4
MI 6 L - mgmt 1	0.17	1.03	0.03	1	4.3	170.0	229.0
MI 6 L - mgmt 2	1.00	0.82	0.02	8	3.8	0.6	0.7
MI 6 L - mgmt 3	0.13	1.08	0.02	1	0.5	583.0	569.0
MI 7 L - all factors on	1.00	0.73	0.04	6	2.7	0.0	0.1
MI 7 L - mgmt 1	0.41	0.97	0.03	9	8.6	43.0	82.9
MI 7 L - mgmt 2	1.00	0.76	0.03	6	2.9	0.1	0.2
MI 7 L - mgmt 3	1.00	0.75	0.03	6	3.0	0.1	0.2
MI 7 L - mgmt 4	1.00	0.74	0.04	6	2.9	0.0	0.1
MI 7 L - mgmt 5	0.14	1.07	0.03	1	2.6	428.0	631.0
MI 8 L - all factors on	1.00	0.82	0.02	3	1.4	0.2	0.2
MI 8 L - mgmt 1	1.00	0.82	0.02	4	1.5	0.2	0.3
MI 9 L - all factors on	0.00	1.06	0.02	-		312.0	185.0
MI 9 L - mgmt 1	0.00	1.05	0.02	19	7.1	232.0	156.0
MI 10 L - all factors on	1.00	0.83	0.02	4	1.6	0.4	0.4
MI 10 L - mgmt 1	1.00	0.84	0.03	4	1.8	0.5	0.5
MI 10 L - mgmt 2	1.00	0.86	0.02	4	1.7	0.8	0.5
MI 10 L - mgmt 3	1.00	0.87	0.02	4	2.0	1.0	0.8
MI 11 L - all factors on	1.00	0.88	0.02	N/A		0.5	0.5
MI 11 L - mgmt 1	1.00	0.99	0.02	N/A		9.9	10.3

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
MI 12 L - all factors on	1.00	1.08	0.02	N/A		89.1	77.8
MI 12 L - mgmt 1	1.00	0.85	0.02	N/A		0.2	0.2
MI 12 L - mgmt 2	1.00	1.03	0.03	N/A		24.4	30.2
MI 12 L - mgmt 3	1.00	1.11	0.02	N/A		146.0	129.0
MI 13 L - all factors on	1.00	0.83	0.04	8	4.7	0.7	2.5
MI 13 L - mgmt 1	0.78	0.93	0.04	12	7.7	11.4	32.6
MI 14 L - all factors on	1.00	0.98	0.02	N/A		6.7	6.4
MI 14 L - mgmt 1	1.00	1.00	0.02	N/A		11.8	11.1
MI 15 L - all factors on	0.00	0.97	0.03	23.5	1.4	261.0	219.0
MI 16 L - all factors on	0.00	1.06	0.02	-		296.0	164.0
MI 16 L - mgmt 1	0.00	1.19	0.02	-		5750.0	3000.0
MI 16 L - mgmt 2	0.64	0.96	0.02	19	4.9	23.2	14.7
MI 16 L - mgmt 3	0.00	1.08	0.02	-		480.0	273.0
MI 16 L - mgmt 4	0.00	1.21	0.02	-		9260.0	4800.0
MI 17 L - all factors on	0.00	1.01	0.02	-		469.0	293.0
MI 17 L - mgmt 1	0.00	1.12	0.02	-		120.0	283.0
MI 18 L - all factors on	0.17	1.01	0.02	1	4.5	122.0	120.0
MI 18 L - mgmt 1	0.23	0.99	0.02	1	8.1	1.6	4.7
MI 19 L - all factors on	1.00	0.71	0.04	6	2.1	0.0	0.1
MI 19 L - mgmt 1	1.00	0.72	0.04	6	2.3	0.0	0.1
MI 19 L - mgmt 2	1.00	0.83	0.04	9	4.2	0.9	2.4
MI 19 L - mgmt 3	0.99	0.85	0.04	10	4.7	1.6	4.7
MI 20 L - all factors on	0.99	0.87	0.04	10	6.0	2.2	6.3
MI 20 L - mgmt 1	0.96	0.88	0.04	11	6.5	3.4	10.6
MI 20 L - mgmt 2	0.29	1.00	0.04	4	8.1	75.8	183.0
MI 20 L - mgmt 3	0.24	1.02	0.04	1	7.4	120.0	283.0
MI 21 L - all factors on	0.00	1.00	0.02	-		783.0	543.0

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Some populations with a relatively small P(QE) may appear to hit the QE threshold "quickly" because a small proportion of their scenarios crash quickly but the rest increase (e.g. MI 6 – mgmt 1, 3). Scenarios with a "-" never reach QE in any of their iterations.

MISSOURI

Expert(s) providing site data: Jeff Briggler, Trish Crabill, Frank Durbian

Model data & setup:

- There are six potential or confirmed EMR sites identified in Missouri. Data were submitted for all six sites (Table MO-1).
- Distribution of female population sizes (N) (Table MO-1):
    - Small N (1-50) = 3 sites (two of which may be extirpated – see Appendix 1 for expert comments)
    - Medium N (50-200) = 2 sites
    - Large N (200+) = 1 site
- Several experts identified additional site-specific factors that were currently threatening a site's population. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR survival at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
    - Chemical control of vegetation: Swan Lake NWR
    - Road Mortality: Squaw Creek NWR
- Table MO-2 includes a description of all modeled scenarios for Missouri: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios all six populations had a quasi-extinction probability P(QE) close to 1.0 (e.g. 96-100% of model iterations hit the QE threshold) (Fig. MO-1).
- Three populations had reduced P(QE) (ranging from 0-0.72) when potential alternative management actions eliminated the impact of factors at the site (Fig. MO-1, Table MO-3).
- Summary statistics across all modeled scenarios are presented in Table MO-3.

These modeling results imply that given the current status and management of sites, it is likely that Missouri's populations are under potential threat. With the correct management of factors, some populations do have the potential to reach a reduced level of threat.

Tables and figures:

Table MO-1. Site-specific data for Missouri sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
MO 1	Bilby Ranch Lake CA	early	1-25				x							0.25
MO 2	Bigelow Marsh	early	25-50				x						0.2	0.2
MO 3	Fountain Grove Conservation Area[5]	early	1-25			x								0.25
MO 4	Squaw Creek NWR	early	200-500				x		x		0.5	0.75	0.25	
MO 5	Swan Lake NWR	early	100-200	x			x				0.25	0.5	0.25	
MO 6	Pershing State Park	early	50-100						x		0.5	0.5	0.33	

[1]AFB = age at first birth
[2]Initial N = number of females at model start; unknown values (?) were set as 1-200
[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year
[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year
[5]Note that although experts provided data for this site, the population is likely already extirpated based on their comments ("only report for this area was a 1955 record. Surveys were conducted in 2005 and 2006 with no new information")

Table MO-2. All modeled scenarios for Missouri sites, including "all factors on" and management scenarios

Model Scenario Name	**Factors Turned On[1]**	**Description of changes from "all factors on" models[2]**
MO 1 - all factors on	D,I(.25)	
MO 1 - mgmt 1	D, H(.25)	impact of shifting to pre-emergent fire
MO 1 - mgmt 2	I(.25)	address habitat fragmentation with management
MO 1 - mgmt 3*	H(.25)	all management actions on: shift to pre-emergent fire + address habitat fragmentation
MO 2 - all factors on	D, H(.2), I(.2)	
MO 2 - mgmt 1*	D, H(.2)	impact of shifting to pre-emergent fire
MO 3 - all factors on	C,I(.25)	
MO 3 - mgmt 1	C, G(1.0), I(.25)	expert sited water fluctuations were an issue but just said "hydrology is intensively managed for waterfowl"; set G to 100% in model scenario, but this may not be interpreted correctly
MO 3 - mgmt 2	C,H(.25)	impact of shifting to pre-emergent fire
MO 3 - mgmt 3*	C, G(1.0), H(.25)	all management actions on: shift to pre-emergent fire + water fluctuations occurring on site
MO 4 - all factors on	D, K, F(.5),G(.75),H(.25)	

Model Scenario Name	Factors Turned On[1]	Description of changes from "all factors on" models[2]
MO 4 - mgmt 1*	D, K, H(.25)	address hydrology issues
MO 5 - all factors on	A, D, F(.25), G(.5), H(.25)	
MO 5 - mgmt 1	D, F(.25), G(.5), H(.25)	address midstory succession
MO 5 - mgmt 2*	A, D, J, F(.25), G(.5), H(.25)	add substantial habitat restoration based on comment "roughly 330 acres is being proposed for restoration to wet meadow…"
MO 6 - all factors on	K, F(.5), G(.5), H(.33)	
MO 6 - mgmt 1*	K, F(.25), G(.25), H(.33)	address flooding issues by "construction of water control structures in vicinity" which reduces freq of occurrence for F,G

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table MO-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year

[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

*Starred scenarios are the "management" scenarios displayed in Figure MO-1.

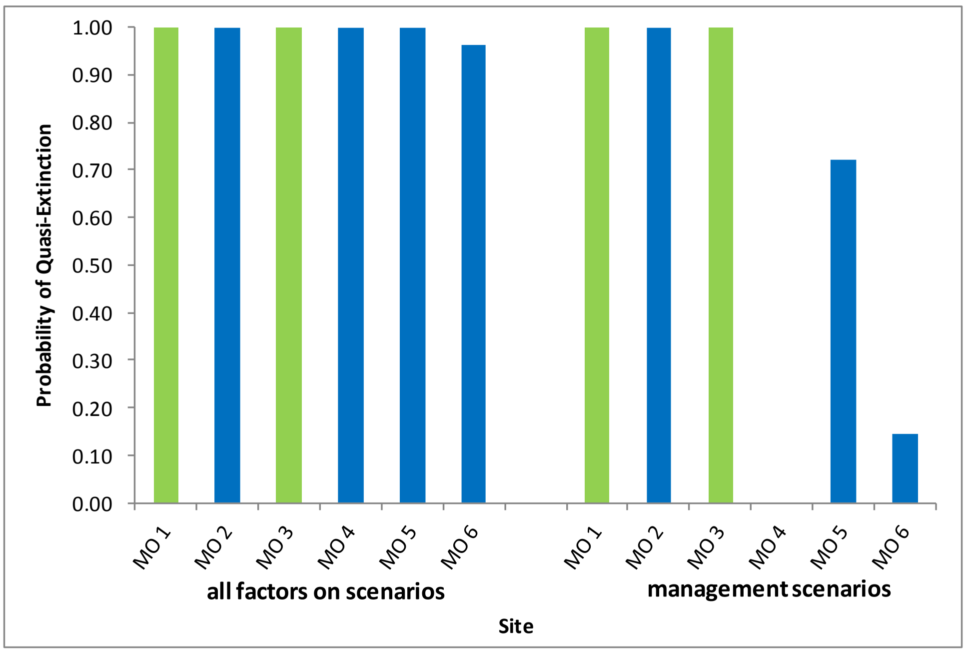


Figure MO – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Missouri populations. Each site (MO1 – MO6) has an "all factors on" scenario and a management scenario that describes the likely impact of potential future management changes (See Table MO-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table MO-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table MO-3. Summarized model results for all model scenarios for Missouri over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
MO 1 - all factors on	1.00	0.84	0.03	N/A		0.1	0.3
MO 1 - mgmt 1	1.00	0.89	0.02	N/A		0.7	0.8
MO 1 - mgmt 2	1.00	0.97	0.03	N/A		4.9	8.6

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
MO 1 - mgmt 3	1.00	1.03	0.02	N/A		22.3	22.9
MO 2 - all factors on	1.00	0.84	0.03	4	1.9	0.5	0.7
MO 2 - mgmt 1	1.00	0.89	0.02	5	2.6	2.2	1.8
MO 3 - all factors on	1.00	0.64	0.03	N/A		0.0	0.0
MO 3 - mgmt 1	1.00	0.44	0.04	N/A		0.0	0.0
MO 3 - mgmt 2	1.00	0.70	0.02	N/A		0.0	0.0
MO 3 - mgmt 3	1.00	0.51	0.02	N/A		0.0	0.0
MO 4 - all factors on	1.00	0.71	0.04	9	2.3	0.1	0.3
MO 4 - mgmt 1	0.00	1.01	0.02	-		393.0	297.0
MO 5 - all factors on	1.00	0.70	0.04	7	1.7	0.0	0.1
MO 5 - mgmt 1	1.00	0.72	0.04	7	1.9	0.0	0.2
MO 5 - mgmt 2	0.72	0.91	0.04	17	5.3	15.7	35.5
MO 6 - all factors on	0.96	0.89	0.04	10	5.2	4.4	14.6
MO 6 - mgmt 1	0.15	1.02	0.04	14	6.3	113.0	176.0

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Some populations with a relatively small P(QE) may appear to hit the QE threshold "quickly" because a small proportion of their scenarios crash quickly (or start below 25) but the rest increase (e.g.MO 1 – mgmt 3). Scenarios with a "-" never reach QE in any of their iterations.

NEW YORK

Expert(s) providing site data: Glenn Johnson

Model data & setup:

- There are two potential or confirmed EMR sites identified in New York. Data were submitted for both sites (Table NY-1).
- Distribution of female population sizes (N) (Table NY-1):
    - Small N (1-50) = 2 sites
- The expert identified additional site-specific factors that were currently threatening a site's population. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR survival at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
    - Road Mortality: Cicero Swamp
- The expert identified both populations as late-maturing; however, to facilitate comparison with other states' results, both early (E) and late (L) maturing model scenarios were run and results are presented for both.
- Table NY-2 includes a description of all modeled scenarios for New York: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios, Cicero Swamp had a quasi-extinction probability P(QE) close to 1.0 (e.g. 96-100% of model iterations hit the QE threshold), while Bergren Swamp had a lower P(QE) of 0.41 in the early maturing and 0.59 in the late-maturing models (Fig. NY-1). This pattern held out whether the early or late-maturing model was used.
- Only Bergren Swamp showed a reduction in P(QE) when potential alternative management actions eliminated the impact of factors at the site (Fig. NY-1, Table NY-3).
- Summary statistics across all modeled scenarios are presented in Table NY-3.

These modeling results imply that given the current status and management of sites, it is likely that at least one New York's populations is under potential threat; the other population is moderately threatened and with the correct management of factors, it can reach a reduced level of threat.

Tables and figures:

Table NY-1. Site-specific data for New York sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
NY1	Cicero Swamp	late	25-50		x									
NY2	Bergen Swamp	late	25-50	x										

[1]AFB = age at first birth

[2]Initial N = number of females at model start; unknown values (?) were set as 1-200

[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year

[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table NY-2. All modeled scenarios for New York sites, including "all factors on" and management scenarios

Model Scenario Name[1]	Factors Turned On[2]	Description of changes from "all factors on" models[3]
NY 1 E - all factors on	B	
NY 1 E - mgmt 1	B, K	habitat restoration in planning stages
NY 2 E - all factors on	A	
NY 2 E - mgmt 1	A,K	restoration activities are in discussion stage per expert
NY 1 L - all factors on	B	
NY 1 L - mgmt 1	B, K	habitat restoration in planning stages
NY 2 L - all factors on	A	
NY 2 L - mgmt 1	A,K	restoration activities are in discussion stage per expert

[1]E = Early-maturing model scenarios; L = Late-maturing model scenarios

[2]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table NY-1 for the factor codes.

[3]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

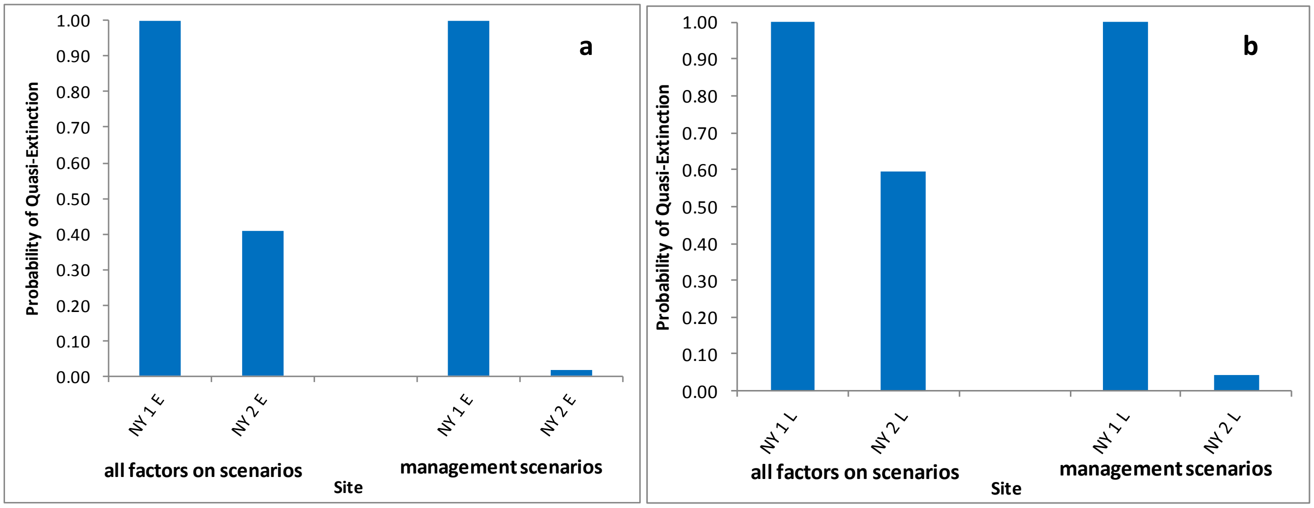


Figure NY – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for New York populations, using a) the early-maturing model and b) the late-maturing model. Each site (NY 1, NY 2) has an “all factors on” scenario and a management scenario that describes the likely impact of potential future management changes (See Table NY-2 for full details on scenario setup). Comparing each site’s all factors on and management scenario illustrates the potential impact of addressing factors at a given site.

Table NY-3. Summarized model results for all model scenarios for New York over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
NY 1 E - all factors on	1.00	0.80	0.02	3	1.2	0.1	0.1
NY 1 E - mgmt 1	1.00	0.91	0.02	5	3.0	3.4	2.8
NY 2 E - all factors on	0.41	1.00	0.02	8	6.9	40.9	27.3
NY 2 E - mgmt 1	0.02	1.12	0.02	2	0.6	684.0	410.0
NY 1 L - all factors on	1.00	0.79	0.02	3	1.1	0.1	0.1
NY 1 L - mgmt 1	1.00	0.89	0.02	5	2.2	1.9	1.3
NY 2 L - all factors on	0.59	0.99	0.02	9	7.3	28.5	16.8
NY 2 L - mgmt 1	0.04	1.10	0.02	1	1.0	361.0	196.0

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Some populations with a relatively small P(QE) may appear to hit the QE threshold “quickly” because a small proportion of their scenarios crash quickly but the rest increase (e.g.NY2 L – mgmt 1, NY2 E = mgmt 1).

OHIO

Expert(s) providing site data: Greg Lipps, Doug Wynn

Model data & setup:

- There were fourteen potential or confirmed EMR sites identified in Ohio:
  - Models were run for six sites (Table OH-1)
  - One site did not have sufficient data to run the model
  - Two of the sites (Orwell Township, Resthaven WA) were identified by a site expert as extirpated
  - Five of the sites had no data submitted
- Distribution of female population sizes (N) at the modeled sites (Table OH-1):
  - Small N (1-25) = 5 sites
  - Large N (200+) = 1 site
- Experts identified additional site-specific factors that were currently threatening population. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR survival at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Road Mortality: Godfrey/Sherman, Mosquito Creek, Willard Marsh Wildlife Area
  - Poaching/Human Persecution: Buckeye Lake, Killdeer Plains, Rome State Nature Preserve
  - Mowing: Godfrey/Sherman, Mosquito Creek, Willard Marsh Wildlife Area
  - Heavy machinery disturbance: Godfrey/Sherman
  - Agriculture: Mosquito Creek Wildlife Area
  - Invasive plant species: Mosquito Creek Wildlife Area, Willard Marsh Wildlife Area, Godfrey/Sherman
  - Incompatible land management directives: Mosquito Creek Wildlife Area
- Table OH-2 includes a description of all modeled scenarios for Ohio: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios five of the six sites had P(QE) = 1.0 (e.g. 100% of model iterations hit the QE threshold); one site (Killdeer Plains) had P(QE) = 0% (Fig. OH-1).
- Potential alternative management actions improved outcomes at one of the sites (Fig. OH-1, Table OH-3).
- Summary statistics across all modeled scenarios are presented in Table OH-3.

These modeling results imply that given the current status and management, it is likely that the majority of the populations that were modeled in Ohio are under potential threat, and one population is large and secure. With the correct management of factors, some populations do have the potential to reach a reduced level of threat.

Ohio experts also indicated that two sites in northeast Ohio, Rome State Nature Preserve and Godfrey/Sherman, which are relatively close together (approximately 2.6 miles) may potentially represent a larger metapopulation rather than two separate populations. Surveying in parcels between the two sites that were recently purchased and never surveyed have identified EMR and there may be additional suitable habitat (G. Lipps, pers. comm.). Additional investigation of the dynamics in this area is likely warranted.

Tables and figures:

Table OH-1. Site-specific data for Ohio sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
OH 1	Buckeye Lake	unknown	1-25[5]	x		x			x	0.05	0.075		0.25	0.25
OH 2	Godfrey/ Sherman	early (suspected)	1-25				x			0.6	1	0.25		
OH 4	Killdeer Plains	early	500-1000	x			x		x				0.25	
OH 5	Mosquito Creek Wildlife Area	early (suspected)	1-25	x			x			0.25	0.25	0.001	0.33	
OH 6	Rome State Nature Preserve	unknown	1-50		x	x		x		0.05	0.1		0.5	0.25
OH 7	Willard Marsh Wildlife Area	early (suspected)	1-25	x						0.05		1		

[1]AFB = age at first birth

[2]Initial N = number of females at model start

[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year

[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

[5]Although site experts for this site actually submitted an initial N of 0-50, based on expert comments ("population is probably extirpated. I have surveyed the area for approximately 4 seasons with no results") LF changed this to 1-25 for the model to reflect how other sites with similar circumstances were modeled

Table OH-2. All modeled scenarios for Ohio sites, including "all factors on" and management scenarios

Model Scenario Name	**Factors Turned On[1]**	**Description of changes from "all factors on" models[2]**
OH 1 - all factors on	A,C,K,E(.05),F(.075),H(.25),I(.25)	
OH 1 - mgmt 1	A,C,K,E(.05),F(.075)	testing without impact of burning, since expert did not give actual frequencies for burning (uncertainty in factor)
OH 1 - mgmt 2*	C,K,E(.05),F(.075),H(.25),I(.25)	address succession
OH 2 - all factors on	D, E(0.6), F(1),G(.25)	
OH 2 - mgmt 1*	D, J, F(1),G(.25)	Assuming that conservation organization is able to acquire private property when private owner passes away. Removes threat of total habitat loss, and considered substantial restoration since site is small
OH 4 - all factors on	A, D, K, H(.25)	
OH 4 - mgmt 1*	D, K, H(.25)	Management to address succession
OH 5 - all factors on	A,D,E(.25),F(.25),G(.001),H(.33)	
OH 5 - mgmt 1	A,D,E(.25),F(.25),G(.25),H(.33)	Using expert's flood estimate
OH 6 - all factors on	B,C,J,E(.05),F(.1),H(.5),I(.25)	
OH 6 - mgmt 1	C,J,E(.05),F(.1),H(.5),I(.25)	address succession
OH 6 - mgmt 2	B,J,E(.05),F(.1),H(.5),I(.25)	address fragmentation

Model Scenario Name	Factors Turned On[1]	Description of changes from "all factors on" models[2]
OH 6 - mgmt 3*	J,E(.05),F(.1),H(.5),I(.25)	All management actions combined; address succession and fragmentation
OH 7 - all factors on	A,E(0.05),G(1)	
OH 7 - mgmt 1*	A,J,E(0.05), G(1)	with planned habitat restoration
OH 7 - mgmt 2	A,E(0.05),F(0.1),G(1)	with expert's original habitat loss/modification factor

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table OH-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year

[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

*Starred scenarios are the "management" scenarios displayed in Figure OH-1.

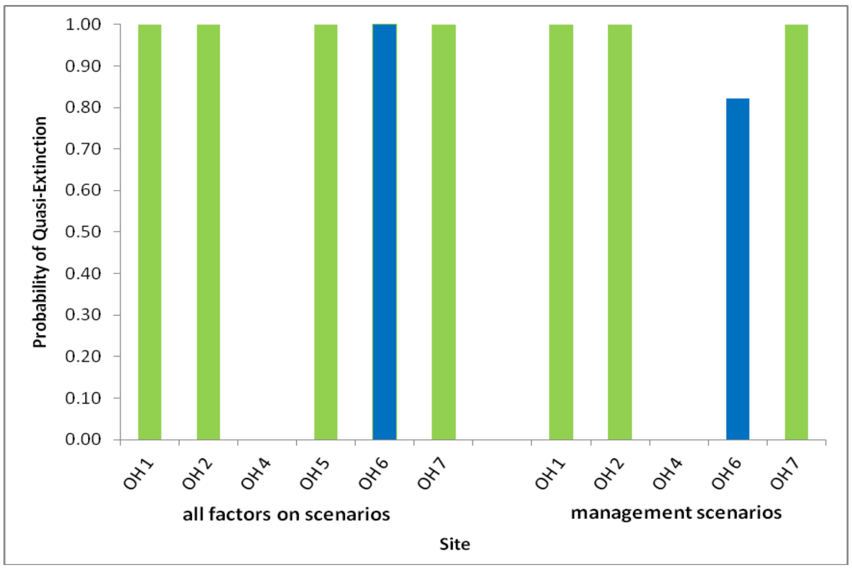


Figure OH – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Ohio populations. Each site (OH1 – OH7) has an "all factors on" scenario and a management scenario that describes the likely impact of potential future management changes (See Table OH-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table OH-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table OH-3. Summarized model results for all model scenarios for Ohio over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas[1]	SD of observed, stochastic lambdas	median time to QE (years)[2]	SD time to QE (years)	Median Final N	SD final N
OH 1 - all factors on	1.00	0.72	0.03	N/A		0.0	0.0
OH 1 - mgmt 1	1.00	0.80	0.02	N/A		0.0	0.0
OH 1 - mgmt 2	1.00	0.74	0.03	N/A		0.0	0.0
OH 2 - all factors on	1.00	NaN	-	N/A		0.0	0.0
OH 2 - mgmt 1	1.00	0.70	0.03	N/A		0.0	0.0
OH 4 - all factors on	0.00	0.98	0.02	-		425.0	298.0
OH 4 - mgmt 1	0.00	1.01	0.02	-		844.0	568.0
OH 5 - all factors on	1.00	0.82	0.00	N/A		0.0	0.0

Scenario Name	P(QE)	mean of observed, stochastic lambdas[1]	SD of observed, stochastic lambdas	median time to QE (years)[2]	SD time to QE (years)	Median Final N	SD final N
OH 5 - mgmt 1	1.00	0.74	0.01	N/A		0.0	0.0
OH 6 - all factors on	1.00	0.57	0.04	N/A		0.0	0.0
OH 6 - mgmt 1	1.00	0.80	0.04	N/A		0.0	0.2
OH 6 - mgmt 2	1.00	0.69	0.18	N/A		0.0	2.7
OH 6 - mgmt 3	0.82	0.98	0.16	N/A		18.9	984.0
OH 7 - all factors on	1.00	0.81	0.02	N/A		0.0	0.1
OH 7 - mgmt 1	1.00	0.84	0.16	N/A		0.0	23.0
OH 7 - mgmt 2	1.00	0.78	0.03	N/A		0.0	0.0

[1]Stochastic lambda could not be calculated by the model for some scenarios (OH 2 all factors on) in which population declines were too rapid.

[2]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Scenarios with a "-" never reach QE in any of their iterations.

ONTARIO, CANADA

Expert(s) providing site data: Paul Pratt, Kent Prior, Jeremy Rouse, Anne Yagi

Model data & setup:

- There are four potential or confirmed EMR sites identified in Ontario. Data were submitted for all sites (Table ON-1).
- Distribution of female population sizes (N) (Table ON-1):
    - Small N (1-50) = 1 sites
    - Medium N (50-100) = 1 site
    - Large N (200+) = 2 sites
- Experts identified additional site-specific factors that were currently threatening populations. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR persistence at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
    - Poaching/Human Persecution: Wainfleet
    - Peat Mining: Wainfleet
    - Problems with prey base: Wainfleet
- The experts identified the southern-most populations as early-maturing and the northern-most populations as late-maturing; however, to facilitate comparison with other state's results, both early (E) and late (L) maturing model scenarios were run, and results are presented for both.
- Table ON-2 includes a description of all modeled scenarios for Ontario: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios, three out of four sites had quasi-extinction probabilities P(QE) close to 1.0 (e.g. 100% of model iterations hit the QE threshold) (Fig. ON-1a, b); this occurred under both the early and late maturing models.
- Focusing on their alternative management scenarios, two out of four scenarios (using either early- or late-maturing models) showed a reduction in P(QE) when potential alternative management actions eliminated the impact of factors at the site (Fig. MI-1, Table MI-3).
- Summary statistics across all modeled scenarios are presented in Table ON-3.

These modeling results imply that given the current status and management of sites, it is likely that three of the four populations in Ontario are under potential threat. With the correct management of factors, two of the populations have the potential to reach a reduced level of threat.

Tables and figures:

Table ON-1. Site-specific data for Ontario sites used in each site's "All Factors On" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
ON1	Ojibway Prairie Complex	early	1-25	x			x	x		0.05		0.05		
ON2	Wainfleet	early	50-100	x			x		x					0.15
ON3	Georgian Bay	late	4000		x		x				1			
ON4	Bruce Peninsula	late (presumed)	1000-2000				x				1			

[1]AFB = age at first birth

[2]Initial N = number of females at model start

[3]These factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed for a population, their effect occurs every year

[4]These factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table ON-2. All modeled scenarios for Ontario sites, including "all factors on" and management scenarios

Model Scenario Name[1]	**Factors Turned On[2]**	**Description of changes from "all factors on" models[3]**
ON 1 E - all factors on	A,D,J,E(.05),G(.05)	
ON 1 E - mgmt 1	D,J,E(.05),G(.05)	new management plan addresses succession
ON 1 E - mgmt 2	A,J,E(.05),G(.05)	management addresses linkage of subpopulations
ON 1 E - mgmt 3*	J,E(.05),G(.05)	all management actions combined
ON 2 E - all factors on	A, D, K, I(.15)	
ON 2 E - mgmt 1*	A, K, I(.15)	fragmentation ameliorated through management
ON 3 E - all factors on	B,D,F(1)	
ON 3 E - mgmt 1*	B,D	without "ongoing moderate loss" (factor is likely partially captured in habitat fragmentation factor)
ON 4 E - all factors on	D,F(1)	
ON 4 E - mgmt 1*	D	without "ongoing moderate loss" (factor is likely partially captured in habitat fragmentation factor)
ON 1 L - all factors on	A,D,J,E(.05),G(.05)	
ON 1 L - mgmt 1	D,J,E(.05),G(.05)	new management plan addresses succession
ON 1 L - mgmt 2	A,J,E(.05),G(.05)	management addresses linkage of subpopulations
ON 1 L - mgmt 3*	J,E(.05),G(.05)	all management actions combined
ON 2 L - all factors on	A, D, K, I(.15)	
ON 2 L - mgmt 1*	A, K, I(.15)	fragmentation ameliorated through management
ON 3 L - all factors on	B,D,F(1)	
ON 3 L - mgmt 1*	B,D	without "ongoing moderate loss" (factor is likely partially captured in habitat fragmentation factor)

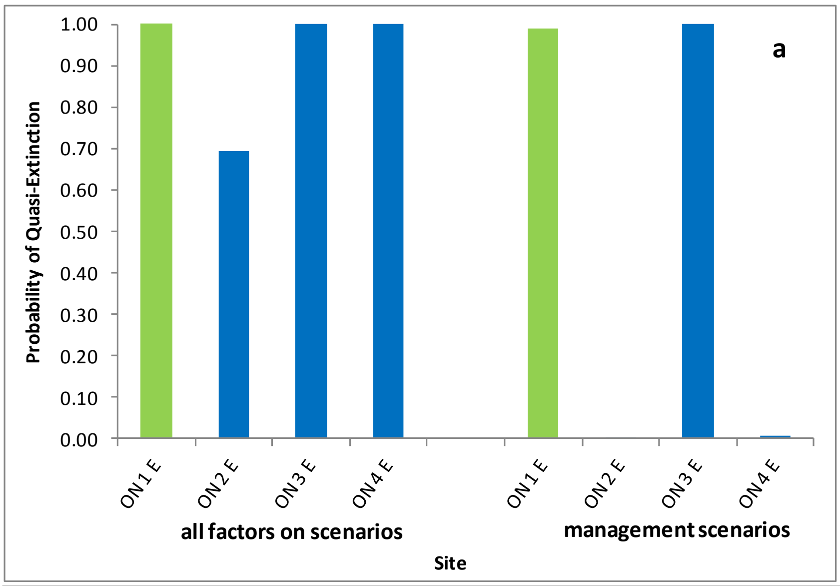
Model Scenario Name[1]	Factors Turned On[2]	Description of changes from “all factors on” models[3]
ON 4 L - all factors on	D,F(1)	
ON 4 L - mgmt 1*	D	without "ongoing moderate loss" (factor is likely partially captured in habitat fragmentation factor)

[1]E = Early-maturing model scenarios; L = Late-maturing model scenarios

[2]This column provides a quick summary of model settings; each listed factor code was turned “on” for a given model run. Refer to Table ON-1 for the factor codes.

[3]The alternate management scenarios were based on expert’s comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

*Starred scenarios are the “management” scenarios displayed in Figure ON-1.



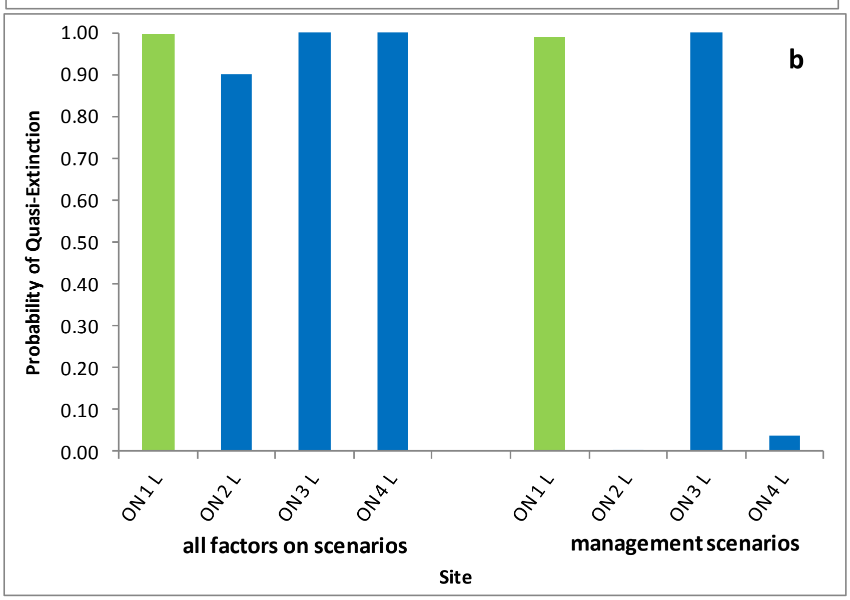


Figure ON – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Ontario populations, using a) the early-maturing model and b) the late-maturing model. Each site (ON 1 - ON 4) has an “all factors on” scenario and a management scenario that describes the likely impact of potential future management changes (See Table ON-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table ON-2). Comparing each site’s all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table ON-3. Summarized model results for all model scenarios for Ontario over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
Early Maturing Model Results							
ON 1 E - all factors on	1.00	0.83	0.23	N/A		0.2	81.4
ON 1 E - mgmt 1	1.00	0.89	0.20	N/A		0.9	149.0
ON 1 E - mgmt 2	0.99	1.09	0.13	N/A		132.0	1780.0
ON 1 E - mgmt 3	0.99	1.12	0.13	N/A		243.0	2920.0
ON 2 E - all factors on	0.69	0.95	0.03	16	5.7	19.9	22.5
ON 2 E - mgmt 1	0.00	1.08	0.03	16	1.4	567.0	511.0
ON 3 E - all factors on	1.00	0.44	0.02	8	0.8	0.0	0.0
ON 3 E - mgmt 1	1.00	0.68	0.02	15	1.3	0.2	0.2
ON 4 E - all factors on	1.00	0.66	0.02	11	1.3	0.0	0.1
ON 4 E - mgmt 1	0.01	0.90	0.02	25	1.3	111.0	82.0
Late Maturing Model Results							
ON 1 L - all factors on	1.00	0.89	0.16	N/A		1.4	37.2
ON 1 L - mgmt 1	1.00	0.92	0.14	N/A		1.9	53.6
ON 1 L - mgmt 2	0.99	1.07	0.11	N/A		77.6	657.0
ON 1 L - mgmt 3	0.99	1.10	0.11	N/A		164.0	1090.0
ON 2 L - all factors on	0.90	0.93	0.03	14	5.3	11.4	11.3
ON 2 L - mgmt 1	0.00	1.06	0.03	19	6.6	284.0	245.0
ON 3 L - all factors on	1.00	0.45	0.02	8	0.7	0.0	0.0
ON 3 L - mgmt 1	1.00	0.67	0.02	14	1.2	0.2	0.2
ON 4 L - all factors on	1.00	0.66	0.02	11	1.2	0.0	0.0
ON 4 L - mgmt 1	0.04	0.89	0.02	25	1.6	71.6	46.7

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A.

PENNSYLVANIA

Expert(s) providing site data: Ben Jellen, David Johnson, Matt Kowalski, Howard Reinert

Model data & setup:

- There are five potential or confirmed EMR sites identified in Pennsylvania, with data submitted for all five sites (Table PA-1). State experts believe that one site from the Szymanski (1998) status assessment (Greece City/Boydstown) is extirpated.
- Distribution of female population sizes (N) (Table PA -1):
  - Small N (1-50) = 3 sites
  - Medium N (100-200) = 1 site
  - Large N (200+)= 1 site
- Experts identified additional site-specific factors that were currently threatening a site's population. Note that some of the factors experts listed on their sheets were factors operating in the past that were no longer threats (e.g. historic mining or farming practices), or factors that were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR survival at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Mowing: Glades
  - Persecution: Glades, Jennings, Rattlesnake Swamp, Ten Mile Bottom
- Table PA-2 includes a description of all modeled scenarios for Pennsylvania: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios four out of the five populations had a quasi-extinction probability P(QE) close to 1.0 (e.g. 99-100% of model iterations hit the QE threshold) (Fig. PA -1).
- Potential alternative management actions improved outcomes for two populations (Fig. PA-1, Table PA-3).
- Summary statistics across all modeled scenarios are presented in Table PA -3.

These modeling results imply that given the current status and management of sites, it is likely that Pennsylvania's populations are under potential threat. With the correct management of factors, some populations do have the potential to reach a reduced level of threat.

Tables and figures:

Table PA-1. Site-specific data for Pennsylvania sites used in each site's "all factors on" Scenario.

			FACTORS	Veg. Succession - midstory	Veg. Succession - late stage	High fragmentation	Mod. fragmentation	Subst. habitat restoration	Mod. habitat restoration	Total habitat loss	Mod. habitat loss/ modification	Water fluctuation	Pre-emergent fire	Post-emergent fire
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
PA1	Fenelton	early	1-25	x		x				0.75	1	0.05	0	0
PA2	Glades	early	200-500	x			x		x		0.65	0.35	0.35	0.15
PA3	Jennings	early	25-50									0.05	0.4	0.1
PA4	Rattlensnake Swamp	early	1-25		x	x					1	0.25		
PA5	Ten Mile Bottom	early	100-200	x			x			0.025	0.95	0.1		

[1]AFB = age at first birth
[2]Initial N = number of females at model start; unknown values (?) were set as 1-200
[3]All of these factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed, the factor effect occurs every year
[4]All of these factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

Table PA-2. All modeled scenarios for Pennsylvania sites, including "all factors on" and management scenarios

Model Scenario Name	**Factors Turned On[1]**	**Description of changes from "all factors on" models[2]**
PA 1 - all factors on	A,C,E(.75),F(1),G(.05)	
PA 1 - mgmt 1*	C,E(.75),F(1),G(.05)	address vegetative succession - land management being maintained for gas pipeline right-of-way
PA 2 - all factors on	A,D,K,F(.65),G(.35), H(.35), I(.15)	
PA 2 - mgmt 1	A,D,K,F(.65),G(.35), H(.35)	stopping post emergent fire
PA 2 - mgmt 2	A,D,K,G(.35), H(.35),I(.15)	addressing moderate habitat loss
PA 2 - mgmt 3	D,K,F(.65),G(.35), H(.35),I(.15)	addressing succession
PA 2 - mgmt 4*	D,K,G(.35), H(.35)	all management actions combined
PA 3 – all factors on	G(.05),H(.4),I(.1)	
PA 4 - all factors on[3]	B,C,F(1),G(.25)	
PA 5 - all factors on	A,D,E(.03),F(.95),G(.1)	
PA 5 - mgmt 1	D,E(.03),F(.95),G(.1)	easements to address succession
PA 5 - mgmt 2*	A,E(.03),G(.1)	if land acquisition and habitat protection occurs; addresses moderate habitat loss, fragmentation

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table PA-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year
[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.
[3]Note that no alternative management scenarios were possible for site PA4 based on expert's responses
*Starred scenarios are the "management" scenarios displayed in Figure PA-1.

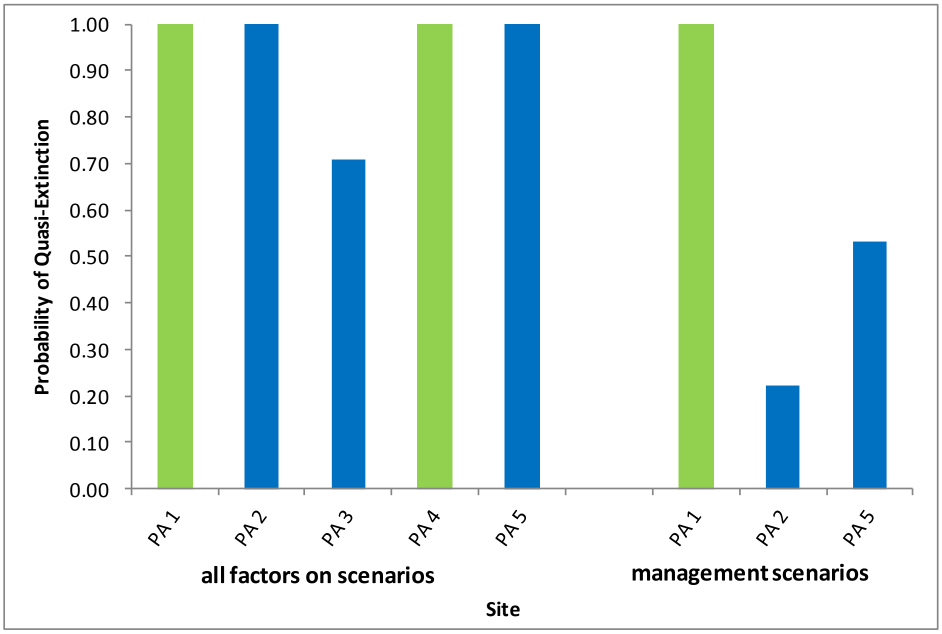


Figure PA – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Pennsylvania populations. Each site (PA1 – PA5) has an "all factors on" scenario and some had possible management scenarios that describe the likely impact of potential future management changes (See Table PA-2 for full details on scenario setup; the management scenario displayed in this figure is each site's "all management changes combined" scenario, which not all sites had). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table PA-3. Summarized model results for all model scenarios for Pennsylvania over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas[1]	SD of observed, stochastic lambdas	median time to QE (years)[2]	SD time to QE (years)	Median Final N	SD final N
PA 1 - all factors on	1.00	NaN		N/A		0.0	0.0
PA 1 - mgmt 1	1.00	NaN		N/A		0.0	0.0
PA 2 - all factors on	1.00	0.68	0.05	9	2.4	0.0	0.3
PA 2 - mgmt 1	1.00	0.73	0.04	10	2.6	0.1	0.6
PA 2 - mgmt 2	0.90	0.86	0.04	18	4.4	7.5	15.5
PA 2 - mgmt 3	1.00	0.70	0.05	9	2.6	0	0.4
PA 2 - mgmt 4	0.22	0.93	0.03	23	3.4	51.2	69.9
PA 3 - all factors on	0.71	0.98	0.03	8	6.78	24.4	24.3
PA 4 - all factors on	1.00	NaN		N/A		0.0	0.0
PA 5 - all factors on	1.00	0.62	0.03	5	1.2	0.0	0.0
PA 5 - mgmt 1	1.00	0.65	0.03	6	1.3	0.0	0.0
PA 5 - mgmt 2	0.53	0.98	0.02	11	7.1	0.0	81.6

[1]Stochastic lambda could not be calculated by the model for some scenarios (PA 1, PA 4 scenarios) in which population declines were too rapid.

[2]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A.

WISCONSIN

Expert(s) providing site data: Robert Hay, Kris Johansen

Model data & setup:

- There are five potential or confirmed EMR sites identified in Wisconsin. Data were submitted for all five sites (Table WI-1).
- Distribution of female population sizes (N) (Table WI-1):
  - Small N (1-25) = 4 sites
  - Medium N (50-100) = 1 site
- Experts identified some additional site-specific factors that were currently threatening a site's population. Note that some of the factors experts listed on their sheets were either operating in the past and were no longer threats (e.g. historic mining or farming practices), or were assumed to be incorporated into basic model dynamics (e.g. predation). The following factors are additional threats to EMR survival at these sites but were not explicitly incorporated into the model. Thus, the modeling results for those sites may be optimistic given that these additional factors were not included in the model:
  - Poaching/Human Persecution: Nelson Trevino Bottom, Warrens
  - Lack of upland habitats: Turtle Creek
- Table WI-2 includes a description of all modeled scenarios for Ohio: each site has an 'all factors on' scenario and most sites have one or more management scenarios.

Model Results

- In their baseline "all factors on" scenarios four of the five populations had a quasi-extinction probability P(QE) = 1.0 (e.g. 100% of model iterations hit the QE threshold (Fig. WI-1); one population (Nelson Trevino Bottom) was relatively secure (P(QE) = 0.15) in comparison.
- None of the high risk populations had substantially reduced P(QE) when potential alternative management actions eliminated the impact of factors at the site (Fig. WI-1).
- Summary statistics across all modeled scenarios are presented in Table WI-3.

These modeling results imply that given the current status and management of sites, it is likely that four of five Wisconsin populations are under potential threat. With appropriate management, risk at the relatively secure site can be reduced even further, but modeled management actions were not as effective for the other four, smaller populations.

Table WI-1. Site-specific data for Wisconsin sites used in each site's "All Factors On" Scenario.

			FACTORS	**Veg. Succession - midstory**	**Veg. Succession - late stage**	**High fragmentation**	**Mod. fragmentation**	**Subst. habitat restoration**	**Mod. habitat restoration**	**Total habitat loss**	**Mod. habitat loss/ modification**	**Water fluctuation**	**Pre-emergent fire**	**Post-emergent fire**
Model Label	**Site Name**	**AFB[1]**	**Initial N[2]**	**A[3]**	**B[3]**	**C[3]**	**D[3]**	**J[3]**	**K[3]**	**E[4]**	**F[4]**	**G[4]**	**H[4]**	**I[4]**
WI 1	Nelson Trevino Bottom/Tiffany Wildlife Mgmt Area	early	50-100		x			x				0.09	0.15	
WI 2	Yellow River Bottoms[5]	early	1-25		x						1			
WI 3	Black River Bottoms[5]	early	1-25		x						1	1	0.25	
WI 4	Warrens[5]	early	1-25	x							1			
WI 5	Turtle Creek[5]	early	1-25				x	x			1		0.25	

[1]AFB = age at first birth

[2]Initial N = number of females at model start

[3]These factors (A,B,C,D,J,K) are "always on" parameters – if an "x" is listed for a population, their effect occurs every year

[4]These factors (E,F,G,H,I) only occur in a proportion of model years; the table value represents the probability of the factor effect occurring in any given model year

[5]Although site experts for these sites actually submitted an initial N of 0-50, based on expert comments (see Appendix 1) LF changed this to 1-25 for the model to reflect how other sites with similar circumstances were modeled.

Table WI-2. All modeled scenarios for Wisconsin sites, including "all factors on" and management scenarios

Model Scenario Name	**Factors Turned On[1]**	**Description of changes from "all factors on" models[2]**
WI 1 - all factors on	B,J,G(.09),H(.15)	
WI 1 - mgmt 1*	J,G(.09),H(.15)	Management to address succession
WI 2 - all factors on	B,F(1)	
WI 2 - mgmt 1*	F(1)	address vegetative succession (possible but unlikely due to current ownership)
WI 3 - all factors on	B,F(1),G(1), H(.25)	
WI 3 - mgmt 1	B, H(.25)	address flooding/habitat loss through dam removal (unlikely)
WI 3 - mgmt 2	J, F(1), G(1), H(.25)	address succession, initiate restoration
WI 3 - mgmt 3*	J, H(.25)	all management actions combined (dam removal, restoration, address succession)
WI 4 - all factors on	A, F(1)	
WI 4 - mgmt 1*	F(1)	address succession (unlikely given ownership)
WI 5 - all factors on	D,J,F(1),H(.25)	
WI 5 - mgmt 1*	D,J,H(.25)	address moderate habitat loss (current ownership limits opportunities)

[1]This column provides a quick summary of model settings; each listed factor code was turned "on" for a given model run. Refer to Table WI-1 for the factor codes. If a factor code is followed by a number (e.g. H(.75)), it signifies the probability of the factor effect occurring in any given model year

[2]The alternate management scenarios were based on expert's comments submitted about planned or likely changes to the site, or explore uncertainty in setup of the model for a particular site.

*Starred scenarios are the "management" scenarios displayed in Figure WI-1.

Figure WI – 1. Modeled probability of quasi-extinction (N < 25 females within 25 years) for Wisconsin populations. Each site (WI1 – WI5) has an "all factors on" scenario and a management scenario that describes the likely impact of potential future management changes (See Table WI-2 for full details on scenario setup; the management scenario displayed is the starred scenario from Table WI-2). Comparing each site's all factors on and management scenario illustrates the potential impact of addressing factors at a given site. Green bars represent populations with an initial population estimate of 1-25; their P(QE) is automatically 1.0 because of this starting point.

Table WI-3. Summarized model results for all model scenarios for Wisconsin over 3000 iterations.

Scenario Name	P(QE)	mean of observed, stochastic lambdas	SD of observed, stochastic lambdas	median time to QE (years)[1]	SD time to QE (years)	Median Final N	SD final N
WI 1 - all factors on	0.15	0.99	0.03	18	5.5	64.1	58.8
WI 1 - mgmt 1	0.00	1.25	0.03	-	-	18900.0	12200.0
WI 2 - all factors on	1.00	0.56	0.02	N/A		0.0	0.0
WI 2 - mgmt 1	1.00	0.79	0.02	N/A		0.0	0.0
WI 3 - all factors on	1.00	0.33	0.03	N/A		0.0	0.0
WI 3 - mgmt 1	1.00	0.79	0.02	N/A		0.0	0.1
WI 3 - mgmt 2	1.00	0.78	0.02	N/A		0.0	0.0
WI 3 - mgmt 3	0.98	1.26	0.02	N/A		4210.0	3820.0
WI 4 - all factors on	1.00	0.76	0.02	N/A		0.0	0.0
WI 4 - mgmt 1	1.00	0.79	0.02	N/A		0.0	0.0
WI 5 - all factors on	1.00	0.86	0.02	N/A		0.3	0.3
WI 5 - mgmt 1	0.99	1.12	0.02	N/A		203.0	198.0

[1]The median time to QE is based on only those model iterations that hit the QE threshold out of 3000 iterations. Populations with an initial N of 1-25 will obviously start below the threshold and have a value of N/A. Scenarios with a "-" never reach QE in any of their iterations.

RANGE-WIDE SUMMARY & CONCLUSIONS

In the course of this initiative, species experts described healthy EMR population dynamics, identified the most important factors impacting those dynamics, and estimated each factor's potential impact. Site experts described conditions at their site and with their starting population. We received appropriate data to model 64 sites, including data from all states and provinces in the EMR range.

Summarized Model Assumptions

Any modeling exercise requires assumptions, either due to lack of data or the need to maintain a simple and parsimonious model design. The assumptions implicit in this modeling exercise include:

1) Males are not limiting on population dynamics
2) Environmental stochasticity/variation is not correlated across vital rates, e.g. a "bad" year for one vital rate does not guarantee a "bad" year for another vital rate.
3) Vital rates are not autocorrelated between years, e.g. a "bad" year in a vital rate does not influence the next year's rate
4) Density dependence is not impacting population dynamics
5) There is no spatial variation in vital rates at sites across the range, other than those considered in the early-maturing and late-maturing models
6) The definition of each factor is identical across the range, e.g. two sites are both identifying "pre-emergent fire" as the same phenomenon
7) The magnitude of each factor's impact is identical across sites, e.g. at all sites, the factor described as moderate fragmentation decreased first-year survival by 0.3. Factor effects are also identical whether applied to the early- or late-maturing model.
8) Factor effects are additive rather than multiplicative or synergistic; if multiple factors occur at a site, the effects of those factors are added together.
9) For "always on" factors, the simplifying assumption was applied that factors have a constant impact across all model years; in reality, factors such as succession may have an increasing impact over time, or other factors may have a strong immediate effect that then fades over time
10) For "proportional" factors, the model randomly determines with a specific frequency whether that factor is applied. For factors such as management fires, which may be done on a regular schedule, such as every 3 years, this is applied as a 33% chance of a factor occurring in any given year. Consequently, by chance that factor may occasionally be applied for multiple years in a row. In general across the 3000 iterations the effects of this should not be large.

Sensitivity Analysis of EMR Life History

The sensitivity analyses suggest several important life history characteristics of EMR: the deterministic baseline model is most sensitive to adult non-postpartum survival (Fig. 3) and about equally sensitive to the pre-adult survival rates and the rates related to reproduction. Typically, "fast" species (early maturing, large litter size, short-lived) have large elasticity values for fecundity terms and "slow" species (later maturing, smaller litter size, longer-lived) have higher elasticities in adult survival rate (Heppell et al. 2000, Saether and Bakke 2000, Oli and Dobson 2003). EMR may be illustrating a mixed strategy (or may be midway along the fast/slow continuum), with relatively large litters and early maturation but also relatively long-lived. This also means that, in terms of management targets, most life history rates (adult, juvenile, first-year survival; fecundity) would be good targets. Further exploration of model dynamics may provide more information about likely targets at specific sites (based on site-specific models).

Current EMR Population Sizes

While a few large populations exist, the vast majority of populations were either under 50 females (55%) or of unknown size (17%) (Fig. 8). Often the expert's comments about their population size estimates gave additional details about the source and background for their population size estimates; site names, expert estimates, and these comments are provided in Appendix 1. Because EMR are shy and difficult to survey for, determining accurate population size estimates is extremely difficult, but clearly this parameter is important to better understanding the status of EMR across the range.

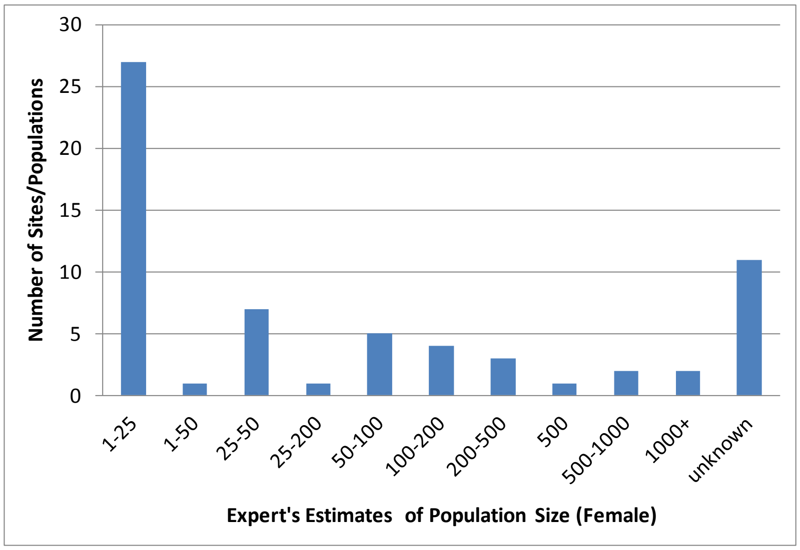


Figure 8. Distribution of expert's estimates of starting population size (one estimate per site) across 64 sites with known or suspected Eastern Massasauga Rattlesnake populations. Note that some bins are overlapping based on what experts designated as the most likely population size (e.g. selecting 1-50 rather than 1-25 or 25-50)

For those populations where current size was unknown (N = 11 sites), the model was set up with an equal probability of drawing a starting population size between 1-200 females. The model results at such sites are clearly sensitive to this, as drawing from this distribution ensures that some populations start below the quasiextinction threshold and hit the threshold right away. Model results for these populations are therefore less informative or insightful, and more effort should be put into assessing population status and size at these sites before conclusions can be drawn.

Impacts of Factors on EMR Populations

When considering the experts' estimated impacts of each factor on EMR biology one at a time, certain factors more strongly impacted the dynamics of a theoretical, healthy EMR population than others (Fig. 6,7). Many of the factors were able to change the theoretical population from growing to declining, including: vegetative succession – late stage (B), high fragmentation (C), moderate fragmentation (D), total habitat loss (E), moderate habitat loss (F), water fluctuation (G), and post-emergent fire (I). These were the factors that experts estimated to have the most severe impact on EMR dynamics.

When examining how factors occurred across the range, 62 out of 64 sites had one or more factor currently affecting their sites, and many had multiple factors (Fig. 9). Each state's results give the detailed site-specific factors occurring, but Figure 10 provides a range-wide context of the proportion of sites with individual factors that are currently believed to be occurring at the site (e.g. in their baseline "all factors on" model scenario). When aggregating these data across these 64 sites, we find that:

1) Eighty-three percent (83%) of sites have three or more factors operating – EMR sites are being affected by multiple factors, the majority of which are threats.
2) Succession is the most common factor occurring across the range. 75% of sites (48/64) are being impacted by midstory or late stage succession. More are experiencing mid-story (32/64) compared to late-stage (16/64).
3) Fire management is the second most common factor at these sites, occurring at 69% of sites (44/64). Twenty-five sites used pre-emergent fire only, 8 sites used post-emergent fire only, and 11 sites used both pre- and post-emergent fire as a management tool.
4) Fragmentation is the third-most prevalent factor at these sites, occurring at 67% of sites (43/64). More sites are experiencing moderate fragmentation (31/64) than high fragmentation (12/64).
5) 52% of sites (33/64) are at risk from some kind of habitat loss. Eight sites are experiencing risk from both moderate (F) and total (E) habitat loss/modification. 22 sites are experiencing only moderate habitat loss/modification. Three sites are at risk from only total habitat loss. The identified EMR sites seem well-secured from total loss in the minds of experts – only 17% (11/64) are at risk of total habitat loss.
6) To combat the above threats, 42% of the sites (27/64) are currently doing either moderate or substantial habitat restoration (9/64 doing moderate, 18/64 doing substantial). Despite these restoration efforts, of these 27 sites, 21 still had high extinction risk in the model, with P(QE) > 90%. This indicates that it may be challenging for habitat restoration to combat other forces (small initial population size, other threats affecting a site).

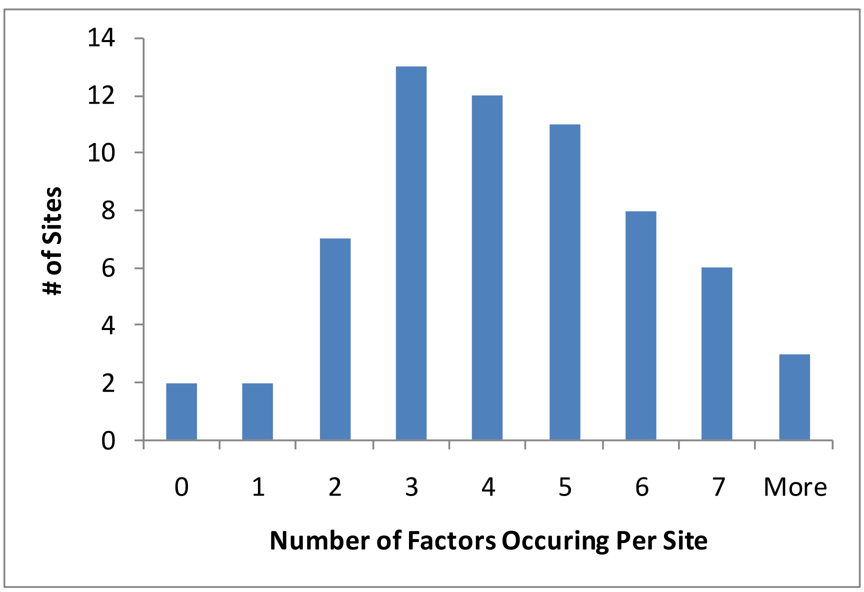


Figure 9. Distribution of the number of factors occurring per EMR site.

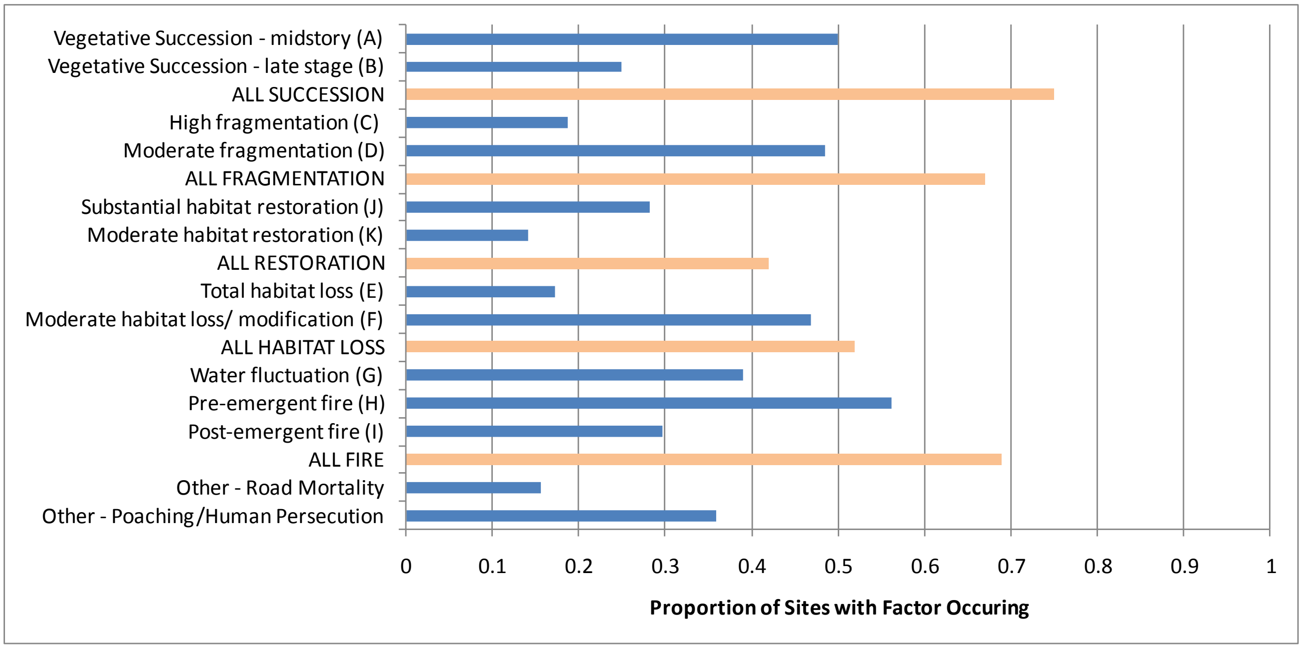


Figure 10. The proportion of the 64 modeled EMR sites that had the factor currently occurring at the site. Orange bars represent summarized factors, e.g. combining pre- and post-emergent fire frequency to see the prevalence of any type of fire management at a site. Blue bars are individual factors; those with letters were included in the modeling, "other" factors were not included in the modeling but present additional risks to persistence at individual sites that experts identified.

Model Projections Across the Range

Based on each of the 64 sites' baseline "all factors on" scenario, which portrays the current status of factors at the site, the majority of modeled sites are under potential threat, with high probabilities of quasi-extinction (e.g. probability of dropping to 25 females, equivalent to a total population size of 50 EMR) within 25 years. In these scenarios (in sites in which age at maturity was unknown, the early-maturing model results were used), 81% of the populations had a P(QE) of 90% or higher. Alternate management scenarios, in which planned or potential actions to address one or more site factors were modeled, were possible for 52 of the sites, and aggregated model results across those 52 sites show that with management actions 37% (19/52) of the populations could have a reduced P(QE) of 30% or less. These results are consistent with the findings that prompted the listing of EMR as a federal candidate species. At that time, agency biologists determined that a good number of populations occurred on protected properties and for many of these threatened populations, EMR compatible management could reverse the decline and substantially reduce the threat (J. Szymanski, pers. comm.).

Conclusions

This modeling effort investigates patterns in EMR status across the range. It is particularly useful for making comparisons between sites. Although the model is simplistic in some key aspects of EMR biology, and thus cannot be relied upon to produce precise estimates of viability for individual populations, it does provide a general picture of risk for each site and insights of how specific factors are influencing this risk. It also represents the first attempt to categorize current status and factors operating across the range.

New genetic information supports the idea that massasauga populations have lived in small and relatively isolated populations over a long historical time frame (since the Pleistocene), and are likely adapted to the genetic impacts of small population size (e.g. inbreeding depression) (Chiuchi and Gibbs, 2011). Anecdotal data from different areas across the range suggests that some sites may be able to sustain small but stable EMR populations for a long period (e.g., small EMR populations appear to have "held on" at sites over a long period without existing at high densities). Other small populations (e.g. some in IL) seem to have rapidly transitioned from small but stable remnant populations to steeply declining/extirpated populations, even where they occur on preserved or protected land with managed habitats. These contrasting anecdotes illustrate that there is still a great deal that is not understood about the population dynamics of this species and how other factors contribute to cause at least some small populations to rapidly decline. It appears that demographic, ecological, and management factors likely function together to have a large impact on long-term survival of individual populations. This may be especially true when populations decline to a point where quasi-extinction thresholds are crossed and small population dynamics take effect. With this in mind, and recognizing that managers will rarely have an accurate and current population estimate available for their sites, it is prudent for managers to implement management activities crucial to maintaining massasauga habitat. However, in doing so they should take measures to minimize the risk of avoidable mortality whenever possible to avoid further affecting EMR dynamics.

More detailed study of the status and viability of individual populations is warranted before conclusions are made about how and where to invest conservation efforts at an individual site. For example, a population with a high probability of quasi-extinction in this modeling exercise may have population traits that don't necessarily conform to our general model, or the effect of factors at that given site may be more or less harsh than the general effects estimated by our species experts. In addition, this assessment reflects our current knowledge of sites, and more detailed study may turn up new populations outside of the identified sites (as referenced in the Ohio report) or better information on dynamics within a site. The most prudent approach for sites with high P(QE) should not necessarily be to consider them doomed, but that vigilance and monitoring should be a high priority for such sites so a full evaluation of viability can be made.

Despite these caveats, the conclusions that this tool allows us to make are that, in general, **most of the modeled EMR populations are likely imperiled, and that conservation and management actions to improve the species' chances of persistence continue to be important.** Especially telling is the summarized population sizes (Fig. 8) and site-specific factors operating (Fig. 10) across the state, which gives a clear picture of the types of threats operating across EMR range and their frequency of occurrence, regardless of whether or not their impact is easily predictable. This work also clearly highlights that **more information is needed to inform site status, EMR population biology, population sizes, and the potential impacts of management factors.** This information will be critical to planning for better conservation in the future.

IMPORTANT TERMS

Term	Abbreviation	Definition in the context of this project
1st Year Survival		The survival rate for the first full year of life from birth in late summer until 12 months of age.
Adult Non-postpartum Survival		The survival rate for a sexually mature female who has **not** just given birth (e.g. she may be gestating and give birth at the end of the model year, but even if that is occurring it does not incur any survival costs during the year). Also assigned to females in the first year of the adult stage when they have just become sexually mature.
Adult Postpartum Survival		The survival rate for a sexually mature female following parturition (birth).
Birth Sex Ratio		The proportion of offspring that are male (> 0.5 indicates male
Factors		Threats or subsidies that might be impacting EMR populations across the range. Threats have a negative effect on one or more vital rates, and subsidies have a positive effect on one or more vital rates.
High fragmentation	C	A factor in the model. Habitat is impermeable or physical characteristics isolate habitat patches.
Juvenile Survival		The survival rate for age classes between 12 months and sexual maturity (first mating, so the year before snakes first give birth)
Juvenile Survival		The survival rate for age classes between 12 months and sexual maturity (first mating, so the year before snakes first give birth)
Mean Litter size		Average number of neonates per birth event before any neonate mortality
Moderate fragmentation	D	A factor in the model. Habitat is semi-permeable, and patches are not completely isolated.
Moderate habitat loss/ modification	F	A factor in the model. **Small sites** (<100-200 acres): any loss/modification; **Medium sites** (200-500 acres): up to 9% loss/modification; **Large sites** (>500 acres): >10% degradation or loss of suitable habitat
Moderate habitat restoration	K	A factor in the model. **Medium site** (200-500 acres): up to 10% increase in suitable habitat or connectivity. **Large site** (>500 acres) or **viable population**: addition of any habitat or increased connectivity.
Population		One or more local breeding units whose dynamics or extinction risk is not substantially altered by the extinction of individuals in other breeding units. For example, if one breeding unit went extinct, it would not substantially affect the 100-year extinction risk of other breeding units.
Population Size	N	Number of females (of all age classes)
Post-emergent fire	I	A factor in the model. Fire that affects less than 1/3 of surface habitat while population is active and above ground.
Pre-emergent fire	H	A factor in the model. Fire that affects surface habitat while population is dormant and underground, or that affects less than 1/3 of a population.
Prob. Of Breeding		Probability that an individual adult female produces young (gives birth) in a given year

Term	Abbreviation	Definition in the context of this project
Probability of Quasi-Extinction	P(QE)	A critical population size threshold larger than 1 that provides a benchmark for when the population might begin to experience the negative impacts of true small population dynamics, such as genetic drift, inbreeding depression, susceptibility to demographic stochasticity, etc. (Ginzburg 1982). For the purposes of this model, the benchmark chosen by the species experts was 25 females within the model timeframe (25 years). Note that this benchmark represents a population of ~50 individuals assuming an equal sex ratio. The probability of QE (P(QE)) is calculated as the proportion of 3000 model iterations that dropped to 25 females within 25 years.
Site experts		The group of experts who provided data on specific populations/sites across the range.
Species experts		The group of experts used to develop the baseline and factor-specific models
Subst. habitat restoration	J	A factor in the model. **Small site** (<100-200 acres): any addition of habitat or increase in connectivity; **Medium site** (200-500 acres): a >10% increase in suitable habitat or connectivity.
Total habitat loss	E	A factor in the model. Complete loss of occupied habitat regardless of population size.
Vegetative Succession - late stage	B	A factor in the model. Woody canopy is >66%
Vegetative Succession – midstory	A	A factor in the model. Woody (shrub or tree) canopy is 33-66%
Water fluctuation	G	A factor in the model. Changes in normal water table or flood regimes that may adversely affect a population (e.g., through disease, drought, displacement, or drowning).

LITERATURE CITED

Aldridge, RD, Jellen, BC, McAllender, MJ, Shepard, D, Cox, J, and C Phillips. 2008. Reproductive biology of the Massasauga (*Sistrurus catenatus*) from South-Central Illinois. *Biology of the Rattlesnake.* Loma Linda University Press, Loma Linda, California, USA, 403–412.

Bailey, RL 2010. Modeling Habitat Suitability and Population Demographics of the Eastern Massasauga Rattlesnake in Managed Lands in Southwestern Michigan. Thesis, Michigan State University, East Lansing, USA.

Bissell, KM 2006. Modeling habitat ecology and population viability of the eastern massasauga rattlesnake in southwestern lower Michigan. Thesis, Michigan State University, East Lansing, USA.

Caswell, H. 2001. *Matrix Population Models: Construction, Analysis, and Interpretation*. Sinauer Associates, Inc., Sunderland, MA.

Ginzburg, LR, LB Slobodkin, K Johnson, AG Bindman. 1982. Quasiextinction probabilities as a measure of impact on population growth. Risk Analysis 2(3): 171-181.

Johnson, G, Parent, G, Kingsbury, B, Seigel, R, King, R, and J Szymanski. 2000. *The Eastern Massasauga Rattlesnake: A Handbook for Land Managers.* U.S. Fish and Wildlife Service, Fort Snelling, MN 55111-4056. 52 pp. + appdx.

Heppel, SS, H Caswell, and LB Crowder. 2000. Life histories and elasticity patterns: perturbation analysis for species with minimal demographic data. Ecology 81(3): 654-665.

Middleton, J, and JY Chu. 2004. Population Viability Analysis (PVA) of the Eastern Massasauga Rattlesnake, *Sistrurus catenatus catenatus*, in Georgian Bay Islands National Park and Elsewhere in Canada. Report to the Canadian Eastern Massasauga Rattlesnake Species Recovery Team.

Miller, P. 2006. Population viability assessment for the eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) on the Bruce Peninsula, Ontario, Canada. Third international symposium and workshop on conservation of the eastern massasauga, *Sistrurus catenatus*: population viability and outreach. Massasauga Recovery Team, 12–14 October 2005, Toronto, Ontario, Canada.

Morris, W, and D Doak. 2002. *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis.* Sinauer Associates, Inc., Sunderland, MA.

Meyer, MA, and JM Booker. 2001. *Eliciting and Analyzing Expert Judgment: A Practical Guide.* Academic Press Limited, London.

Oli, MK, and FS Dobson. 2003. The relative importance of life-history variables to population growth rate in mammals: Cole's prediction revisited. The American Naturalist 161(3): 422-440.

Saether, BE, and O Bakke. 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology 81(3): 642-653.

Seigel, RA. 1986. Ecology and conservation of an endangered rattlesnake, *Sistrurus catenatus*, in Missouri, USA. Biological Conservation 35:333–346.

Seigel, RA, and CA Sheil. 1999. Population viability analysis: applications for the conservation of massasaugas. Pages 17–22 i*n* B. Johnson and M. Wright, editors. Second international symposium and workshop on the conservation of the eastern massasauga rattlesnake, S*istrurus catenatus catenatus*: population and habitat management issues in urban, bog, prairie and forested ecosystems. Toronto Zoo, 2–3 October 1998, Toronto, Ontario, Canada.

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

APPENDIX 1.

Table of initial female population size for modeled populations, with expert's comments about size estimate (comments were submitted in spring/early summer 2010)

Model Label	Site Name	Initial N (Females)	Expert Comments
IA1	UWR - Sweet Marsh	1-25	Last snake (female) found at site in 2004; surveys 2000-2005
IA2	UWR - north of Sweet Marsh	?	First specimen (DOR male) from this area found in 2009
IA3	UWR - Hay-Buhr	100-200	10 year mark recapture study
IA4	LWR - Sherman Park	?	No population studies done, no recent specimens
IA5	LWR -East	?	No population studies done, no recent specimens
IA6	Cedar River	?	No population studies done; only a few recent specimens;
IA7	Willow Slough	?	No population studies done; only a few recent specimens;
IL1	Allerton	1-25	Surveys for 11 consecutive years with radio telemetry of massasaugas captured. Last snake observed 3 years ago despite yearly searches
IL2	American Bottoms	1-25	Few records over the last decade. Three individuals during limited effort in the early 00's
IL3	Carlyle Lake	100-200	Based on a decade of surveying hibernacula
IL4	Cisco (Heartland Pathways Railroad INAI)	1-25	Annual surveys since 2004; Surveys have yielded maybe 5 snakes, one that gave birth to several young
IL5	DeLong	?	No EMR found during surveys
IL6	Plum Creek/Goodenow	1-25	Three seasons (2005-2007) of intensive surveys have identified no individuals of either sex. Last confirmed individual was in 2001. Since we're just leaving the potential lifespan of an individual massasauga, this population may still be extant but is likely very small.
IL7	Upper DesPlaines	1-25	Four seasons of intensive mark-recapture surveys have identified only 10 females (in any age class), with high initial re-capture rates.
IN1	Indiana Dunes National Lakeshore	1-25	Intensive visual encounter surveys in 2002-2003 (>400 search hours), cover board checks, and the operation of drift fence/funnel traps in historic massasauga sites yielded only 1 Eastern Massasauga (EMR), a juvenile. In addition, ~50 drift fences/funnel traps were operated from 1999-2003 at INDU with no captures of EMRs. Other observations are noted in: GLKN/2005/02 - Status of the Eastern Massasauga at the Indiana Dunes National Lakeshore.
MI 1	Little Manistee River	25-50	Very little data, conservative estimate; Bruce Kingsbury concurred with population estimate.
MI 2	Matthaei Gardens	1-25	This is based clearly on conjecture for now. We are starting a population assessment and should know more about our populations in the next year or so. Based on observations of animals on trails; My guess is that this is a low estimate.
MI 3	Mill Cr. Wetlands	1-25	Guess - anecdote
MI 4	Gourdneck SGA-N	1-25	Guess - anecdote
MI 5	Head Property (Little Wolf Creek)	1-25	Based on my field observations, I am estimating there to be between 50-100 snakes that use this site (wildlife biologist opinion).
MI 6	Calla Burr/MNA/Rattalee Lake (Oakland Co.)	?	Unknown.
MI 7	Big Valley Preserve - Buckhorn Lake (Oakland County)	?	Unknown, probably much lower than a few decades ago

Model Label	Site Name	Initial N (Females)	Expert Comments
MI 8	Stony Creek Metro Park	25-50	Sightings by park patrons and staff scattered across entire Metropark; most sightings in north end of park
MI 9	Indiana Springs Metro Park	50-100	Might be a little higher.
MI 10	Hudson Mills Metro Park	25-50	Sightings by park patrons and staff scattered across entire Metropark
MI 11	Kensington Metro Park	1-25	Small site; few sightings despite frequent use of the site by park patrons and staff.
MI 12	Independence Oaks Park	1-25	Based on number of annual observations of individual snakes by Park staff and visitors; Largely anecdotal evidence; some photo confirmations
MI 13	Skegemog Wildlife Area	?	We have not done any population studies at this site. Although I believe the Michigan Natural Features Inventory may have access to some population studies.
MI 14	Orion Oaks - Lake Sixteen	1-25	Based on number of annual observations of individual snakes by Park staff and visitors; Largely anecdotal evidence; some rattlesnake-dog bite confirmations and photo confirmations
MI 15	Pierce Cedar Creek	500	Assuming 1:1 male:female sex ratio for the population & based on density information from literature & Bissell 2006 & Bailey 2010 unpublished data
MI 16	Big Rock Valley (Edward Lowe Foundation)	50-100	Based on Lincoln-Peterson for first two years of mark-recapture (female population N= 60) with similar sampling period, and relatively even effort. Baily's mod (N=43) is even lower. However, this site has also been difficult to survey due to dense vegetation. It may be too early to make a population size estimate, and I suspect this estimated female pop size is low.
MI 17	Green Swamp/ Rattlesnake Hills	200-500	May be conservative, could maybe be as high as 500-1000. Expert opinion based on how many snakes we have found at this site during surveys, percentage of snakes likely observed during surveys and survey effort, and extent of available habitat (very large site).
MI 18	Smokey Hollow Swamp	?	Don't know/don't have population estimate - recent observations but limited surveys and info
MI 19	Seven Lakes State Park	25-200	Expert opinion based on how many snakes we have found at this site during surveys, survey effort, and extent of available habitat (not a very big site).
MI 20	Long Lake	?	Don't know/don't have population estimate.
MI 21	Bois Blanc Island	500-1000	Number of females could be a little lower but I estimate the total EMR population size on island to potentially be at least 1,000 snakes and maybe as high as 2,000 or more, so I selected 500-1000 as a compromise. Expert opinion based on how many snakes we have found at this site during surveys, percentage of snakes likely observed during surveys and survey effort, and extent of available habitat (very large site).
MO1	Bilby Ranch Lake CA	1-25	Only 2 snakes have been found on this area to date; a road kill in 2007 and a photograph in 2008; Surveys are being conducted to determine if a population exist on the area.
MO2	Bigelow Marsh	25-50	Estimate is likely low; based on numbers captured in 2006 by Durbian et al.
MO3	Fountain Grove Conservation Area	0	Only report for this area was a 1955 record. Surveys were conducted in 2005 and 2006 with no new information.
MO4	Squaw Creek NWR	200-500	Research using total annual new captures per acre and 50:50 sex ratio. Continued flooding since 2007 has likely decreased the population size by at least 50%. Prior to 2007, the population likely contained 500-1000 females.
MO5	Swan Lake NWR	100-200	Relative small portion of habitat available. Expert opinion based on review of existing data and past research efforts.
MO6	Pershing SP	50-100	Continued flooding since 2007 has likely decreased the population size by at least 50%. Prior to 2007, the population likely contained 100-200 females.
NY1	Cicero Swamp	25-50	Some empirical evidence (mark-recapture in early 90s)

Model Label	Site Name	Initial N (Females)	Expert Comments
NY2	Bergen Swamp	25-50	Expert opinion based upon repeated surveys in early 90s
OH1	Buckeye Lake	0-50	Population is probably extirpated. I have surveyed the area for approximately 4 seasons with no results.
OH2	Godfrey/Sherman	1-25	10 PIT tagged adult females have been captured a total of 24 times (14 recaptures) from 2005-2007.
OH4	Killdeer Plains	500-1000	This is a 9,000 acre site with massasaugas occurring in most areas. One 8 acre field was estimated to have between 116 and 416 individuals. Estimate from capture/recapture estimates
OH5	Mosquito Creek Wildlife Area (Mecca Township site included in this area)	1-25	6 PIT tagged adult females have been captured a total of 8 times (2 recaptures) from 2005-2007.
OH6	Rome State Nature Preserve	1-50	Empirical evidence
OH7	Willard Marsh Wildlife Area	1-25	5 PIT tagged adult females have been captured a total of 7 times (2 recaptures) from 2005-2007.
ON1	Ojibway Prairie Complex	1-25	Limited isolated habitat (~450 ha in total) infrequent sightings via standardized surveys or opportunistic encounters
ON2	Wainfleet	50-100	Knowledgeable/expert opinion based upon Catch/area searched verses total area suitable habitat. Only small percentage of area is searched annually for snakes.
ON3	Georgian Bay	4000	Vast region of habitat (~2000 km2), much of it undisturbed; estimated population >8000; short term and long-term demography studies at multiple locations and population and habitat modeling
ON4	Bruce Peninsula	1000-2000	Vast region of habitat (~550 km2), much of it undisturbed; expert opinion and extrapolation of local estimates
PA1	Fenelton	1-25	This population is on verge of extirpation. Only 3 snakes observed in past 6 years.
PA2	Glades	200-500	Estimate based on number of encounters within a portion of the suitable habitat at the site. Relatively large area with 2-3 subpopulations
PA3	Jennings	25-50	Estimated from capture data
PA4	Rattlesnake Swamp	1-25	Habitat succession and residential development have all but extirpated this population as the continued existence of the massasauga at this locale is "doubtful" (Jellen 2005). Last snakes observed 10 years ago.
PA5	Ten Mile Bottom	100-200	Extent of distribution within site unknown. Site is large and anecdotal evidence exists to suggest a robust population spread over a large area
WI1	Nelson Trevino Bottom/Tiffany Wildlife Mgmt Area	50-100	Based on telemetry surveys and mark recapture surveys conducted on the property. Based on the number of gravid females captured in any one year after five non-consecutive years of relatively intense surveys.
WI2	Yellow River Bottoms	0-50	No females found since late 1990s. Only 2 road kills reported since 2000, no EMRs from surveys
WI3	Black River Bottoms	0-50	Small numbers of EMRs observed since 1993; most gravid females observed in one year = 4
WI4	Warrens	0-50	Small numbers of EMRs observed since 1993; most gravid females observed in one year = 2
WI5	Turtle Creek	0-50	Only 1 EMR observed since 1989 (one neonate observed in 1999)