EASTERN MASSASAUGA RATTLESNAKE *SISTRURUS CATENATUS CATENATUS* POPULATION VIABILITY IN THE OJIBWAY PRAIRIE COMPLEX WINDSOR/LASALLE ONTARIO, CANADA

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Photo from the Animal Diversity Web, based at the University of Michigan

Summary

The eastern massasauga rattlesnake (EMR), *Sistrurus catenatus catenatus,* has been designated as "threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Threats to the massasauga include native habitat loss, reduced population sizes, and human development (Pither 2003; EMRT as reported in Austin, 2004). The distribution of this species is now restricted to only four areas in Ontario, including the Ojibway Prairie Complex (ibid). Within the Complex, one site is under medium threat (LaSalle Woodlot) and two others, the Ojibway Prairie Nature Reserve and the Tallgrass Prairie Heritage Park, have had no recent sightings (Pither 2003; Austin 2004; K Prior *pers com*).

Using RAMAS® GIS (Akçakaya & Root 2002) we conducted a series of simulations to explore the effect of population size, patch carrying capacities, re-introduction scenarios, and migration mortality on the viability of populations of the eastern massasauga rattlesnake (EMR), *Sistrurus catenatus catenatus* for the Ojibway Prairie Complex in south-western Ontario.

The results of the minimum viable population (MVP) analysis indicated that an initial population size of 35 females (of which 4 were adults) was required to limit the terminal extinction risk to less than 5% (i.e., 50 or fewer of the 1000 replicate simulations went extinct) after 100 years. At a density of 2.5 females per hectare, and assuming the patches were fully occupied, all patches in the Ojibway Prairie Complex would be viable over the long term. When a population's adult carrying capacity was lowered, the population size declined but the extinction risk for the Ojibway Prairie Complex as a whole was low. Even at a substantially lower density it would be relatively unlikely to go extinct over the next 100 years. However, longer local extinction durations suggested that the carrying capacity had a more significant impact on the survival of a single population. Given that connectivity between patches was low, any change to carrying capacity (e.g., from habitat loss) with no mitigation would likely result in permanent extinction for a patch. We considered the additional effect of dispersal mortality where individuals move but perish in the process. The Complex as whole was somewhat resilient to minor changes in the size of the 2 effects. However, their combined effects were particularly important for the individual population's persistence, particularly for smaller sized populations. Fencing off patches to prevent emigration into the hostile areas surrounding the patch is a possible strategy to enhance population persistence (K Prior *pers com*). The simulations we present show that a loss of more than 1% of the juveniles can have an impact on population size and extinction risk, particularly if the carrying capacity is also lower. These results support at least the potential of using snake barriers as a management tool to enhance persistence, especially

when population sizes are lower. Lower population sizes vulnerable to extinction will be expected initially after individuals are introduced to a currently vacant patch. Of the introduction scenarios we considered, releasing 9 female juveniles in the Ojibway Prairie Nature Reserve, either all at once, or staggered over 3 years, did not result in a population that was viable over the long-term. The numbers were insufficient to keep the terminal extinction risk below 5%. Augmenting the captive population by allowing breeding or by capturing gravid females and releasing some of their offspring for multiple years resulted in a viable population. However, when we included the effect of mortality of emigrants, the resulting reduction in population size suggests, as for the other scenarios, that preventing movement and its mortality (e.g., through snake barriers) would improve population persistence.

List of contents

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Disclaimer

The results provided in this report are subject to an unknown degree of uncertainty. There is substantial uncertainty in the knowledge of demographic data, such as fecundity, survival and dispersal distances. This uncertainty and its propagation over time are partly considered in the demographic and environmental stochasticity of the population model. Due to the stochastic nature of the population models, simulation runs were replicated up to 1000 times and results are averages of these replicates. Absolute numbers should be interpreted with caution. Instead, trends and differences between different simulated parameter combinations are generally more trustworthy. All information used in this report has been discussed with members of the recovery team and verified as well as substituted from the scientific, peer-reviewed literature. The work therefore represents our best possible educated “guess” based on our current knowledge of the biology, life history and habitat requirements for this species.

1. Introduction

The eastern massasauga rattlesnake (EMR), *Sistrurus catenatus catenatus,* has been designated as “threatened” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Threats to the massasauga include native habitat loss, reduced population sizes, and human development (Pither 2003; EMRT as reported in Austin, 2004). They use a variety of areas including wetlands for hibernating in crayfish and mammal burrows, shrub and grasslands habitat for foraging, and more open habitat for reproduction (Pither 2003; Austin 2004). The historic distribution of this species has been reduced substantially and is now restricted to only 4 areas in Ontario, including the Ojibway Prairie Complex (EMRT 2003; Pither 2003; Austin 2004). Within the Complex, one site is under medium threat (LaSalle Woodlot) and two others, the Ojibway Prairie Nature Reserve and Tallgrass Prairie Heritage Park, have had no recent sightings (Pither 2003; Austin 2004; K Prior *pers com*).

Different scenarios have been proposed for introducing individuals to the Nature Reserve e.g., releasing head-started juveniles in captivity, capturing gravid females from the LaSalle Woodlot and releasing their offspring (Pither 2003; Austin 2004). Some of these may be better than others and recommendations in Pither (2003) and Austin (2004) suggest evaluating them. We wanted to determine the relative potential success of 4 different scenarios. We also wanted to determine the viability of the Complex and its vulnerabilities. Using RAMAS® GIS (Akçakaya & Root 2002) we conducted a series of simulations to explore the effect of population size, patch carrying capacities, re-introduction scenarios, and migration mortality on the viability of populations of the eastern massasauga rattlesnake (EMR), *Sistrurus catenatus catenatus* for the Ojibway Prairie Complex in south-western Ontario. Specifically we wanted to answer the following questions:

1. What is the minimum viable population size needed to ensure population survival for specific numbers of years?
2. What is the effect of varying adult carrying capacity on the persistence of a single population (the Ojibway Prairie Nature Reserve in particular) and on the Complex as a whole?
3. What is the effect of dispersal mortality on population persistence?
4. What types of introduction scenarios are likely to be more successful in establishing a viable population in the Ojibway Prairie Nature Reserve?

2. The simulation model

2.1. Model characteristics

We used RAMAS® GIS (Akçakaya & Root 2002) software to conduct both non-spatial and spatial simulations of the population dynamics of the eastern massasauga rattlesnake. The program uses a Leslie matrix with user-defined stage classes and their associated survival and fecundity rates. It also allows the analysis of spatially subdivided populations. In the non-spatial version we considered the dynamics of a single population to determine the minimum viable population size. In the spatial version we considered the effects of carrying capacity. In this case we simulated the dynamics of 4 populations in the Ojibway Prairie Complex in south-western Ontario, Canada (Figure 1). We also used the software to examine a variety of introduction scenarios.

Table 1 shows the parameter values considered for the simulations. These values are described in additional detail in section 2.2. The life history information we used is based on the estimates provided in Middleton & Chu (2004). All simulations were conducted 1000 times and explore the population's dynamics over 100 years.

Table 1. Parameter values used for the simulation of population dynamics using RAMAS® GIS.
For additional information about the parameters see section 2.2. The life history information based on Middleton & Chu (2004) (from sections of Table 3.1) is denoted with an asterisk.

Parameter	Value/Range
Stage classes*	1 Neonate / 5 Juvenile / 1 Adult
Juvenile fecundity (all classes)*	0
Adult fecundity (female juveniles per female adult)*	2.075
Neonate survival*	0.30
Juvenile 1 survival*	0.70
Juvenile 2 survival*	0.90
Juvenile 3 survival*	0.90
Juvenile 4 survival*	0.90
Juvenile 5 survival*	0.90
Adult survival (lumped)*	0.69
Density dependence (carrying capacity)	Ceiling number of adult females per hectare (see section 2.2.3. and 4): Patch 3. Tallgrass Prairie Heritage Park=15 Patch 4. Spring Garden (ANSI)=52 Patch 5. Ojibway Prairie Nature Reserve=51 Patch 6. LaSalle Woodlot=36
Duration of simulation	100 years
Initial population size	Based on density of 2.5 female snakes/ha (K Prior *pers com*), and assumes patch is occupied (see Figure 1): Patch 3. Tallgrass Prairie Heritage Park=86 Patch 4. Spring Garden (ANSI)=310 Patch 5. Ojibway Prairie Nature Reserve=301 Patch 6. LaSalle Woodlot=216
Replications	1000
Extinction threshold	10
Dispersal	Juveniles only, see section 2.2.2 below: Movement between sites 3 and 5: 1% Other sites: only if by translocation

2.2. Model parameters

2.2.1. Study area

We based our simulations on populations of massasauga rattlesnakes in the Ojibway Prairie Complex in Windsor/LaSalle, Ontario, Canada. The relative spatial location and names of the population patches are shown in Figure 1.

Patches 1 and 2: According to Austin (2004), Pither (2003) and K Prior (*pers com*), Black Oak and Ojibway Park (patches 1 and 2) no longer have suitable habitat ("now dense woodlots unlikely to contain appropriate massasauga habitat," Austin 2004). We considered these patches as empty and did not include them in this PVA.

Patch 3: Tallgrass Prairie Heritage Park. This patch is owned by the city of Windsor (Pither 2003). Although adjacent to patch 5 (the Ojibway Prairie Nature Reserve) and containing similar habitat (oak savannah and tallgrass prairie, ibid) it is managed differently (e.g., no prescribed burns, K Prior *pers com*) and is of slightly lower quality (K Prior *pers com*).There have been no recent massasauga sightings (Pither 2003).

Patch 4: Spring Garden (ANSI). This patch is of mixed ownership and is not managed (K Prior *pers com*). It is not all considered massasauga habitat (about half, Pither 2003) but it is a protected area. There are massasauga rattlesnakes present in this patch (ibid).

Patch 5: Ojibway Prairie Nature Reserve. This patch is burned and managed as a prairie habitat (K Prior *pers com*). It contains high quality massasauga habitat consisting of tallgrass prairie and oak savannah (Pither 2003; K Prior *pers com*). All introduced individuals will be added to this patch (see section 6 of this report). There have been no sightings since the 1970's (Pither 2003).

Patch 6: LaSalle Woodlot. This patch is currently under development but has some areas within it that are protected (pick-nick/park area K Prior *pers com*). There are massasauga rattlesnakes present in this patch. There are probably fewer than 50 individuals (Austin 2004).

In terms of relative quality of massasauga rattlesnake habitat, patches 3 and 5 are highest, patch 4 is not quite as high, and 6 even less so (K Prior *pers com*).

Figure 1. Spatial location of the Ojibway Prairie Complex patches in Windsor/LaSalle, Ontario. Patches are delineated with dark lines. Patch number names: 1. Black Oak; 2. Ojibway Park; 3. Tallgrass Prairie Heritage Park; 4. Spring Garden (ANSI); 5. Ojibway Prairie Nature Reserve; 6. LaSalle Woodlot. Map courtesy of Wendy Dunford.

2.2.2. Dispersal

Juvenile massasauga rattlesnakes were the stages (stages juvenile 2 to 5) considered to disperse (K Prior *pers com*). Adults are quite faithful to the general area (though not necessarily to a specific hibernaculum) (ibid) but juveniles are less so as their smaller size allows them to hibernate in a greater range of sized of holes. If a snake's site becomes unavailable (e.g., destroyed or reduced in quality), it may not easily start using another (EMRT 2003).

The Tallgrass Prairie Heritage Park and Ojibway Prairie Nature Reserve (patches 3 and 5) are relatively connected as only bicycle path separates them (K Prior *pers com*). We set the dispersal rate between these 2 patches at 1% for each juvenile stage. Otherwise, there is no dispersal among the patches unless through translocation (ibid). As Spring Garden (ANSI) (patch 4) and the LaSalle Woodlot (patch 6) are known to contain massasauga rattlesnakes, they may represent a source of individuals for translocation (ibid) to the likely vacant patches. Any attempted dispersal results in high mortality (ibid). There is the possibility of fencing off the areas to prevent movement and thus mitigate its mortality (ibid). We explore the effect of this mortality in section 5.

2.2.3. Initial population size

The default density was 5 individuals per hectare (K Prior *pers* com) and thus, given the 1:1 sex ratio, 2.5 females per hectare. Patches were referenced in space and their size known. We calculated the initial number of female individuals based on the size and density. We assumed that all patches were fully occupied for our calculations. The values are found in Table 1. The number of females within an individual stage class was calculated based on the stable age distribution that would be expected given the Leslie matrix settings (fecundity and survival rates, Table 1). Patch sizes differ, yet density is the same, so absolute number of individuals will differ.

2.2.4. Density dependence

We used a ceiling as the type of density dependence for this species (Middleton & Chu 2004). We applied the ceiling to the adult stage class as they are relatively faithful to an area and may be limited in their choice of hibernacula due to their size (K Prior *pers com*). The default density was 5 individuals per hectare (ibid) and thus, given the 1:1 sex ratio, 2.5 females per hectare. We calculated the number of adult females by using the size of the patch, the density, and the stable age distribution (see section 2.2.3.). At a density of 2.5, the number of adult females is found in Table 1. For example, if there are 310 individuals in total, 52 of these will be adults given the stable age distribution.

When we examined the effect of carrying capacity on population viability, we considered ceiling values that were the result of lowering carrying capacity by 20, 40, 80, 90, and 95%. We chose these percentage as they would reflect a reduction in the population density from 2.5/ha to 2/ha, 0.5/ha (i.e., 1 per 2 ha), 0.25/ha (i.e., 1 per 4 ha), and 0.125/ha (i.e., 1 per 8 ha). This range in reductions is meant to simulate an increasing deterioration in habitat quality to an extremely low level.

2.2.5. Extinction

A population was considered extinct if its size fell below 10 individuals. An extinction at the end of the 100 years is termed the terminal extinction, and it is quantified as the proportion of the 1000 simulations where the population size fell below 10 (terminal extinction risk). We chose this threshold to acknowledge, as did Middleton & Chu 2004, that smaller population may suffer from Allee effects. As Middleton & Chu 2004 also points out, this pseudo-extinction risk may be conservative but takes into account "that there are acute conservation problems even before a population goes to zero." Extinction duration for a particular population is the number of time steps a population's size is below this 10-individual threshold. The values are averaged over the replicate simulations.

2.2.6. Fecundity and survival rates

We based our life history parameter settings on the estimates provided in Middleton & Chu (2004). They did a thorough job of reviewing the existing literature and consulting experts to get what were the “best” estimates available at the time of writing our report. However, as they recommend, as more data become available they should be built in to future PVA’s.

3. Minimum viable population (MVP) size

We used RAMAS® GIS (Akçakaya & Root 2002) to determine what the minimum population size would be to ensure the population’s long-term survival based on the fecundity and survival rates from Table 1. The carrying capacity was set at 10,000 (effectively making it unlimited) so that we could determine the MVP without the constraints of a ceiling. We explore the effect of carrying capacity in the next section.

Figure 2 shows the minimum viable population size (MVP) for a 95% viable population. It depicts what the minimum initial female population size, and adult population size at the stable age distribution, must be to ensure that the extinction risk is less than 5% at the end of the time period. For example, an initial population size of 35 females (of which 4 are adults) is required so that the population only goes extinct 5% of the time (in our case, in 50 of the 1000 replicate simulations) after 100 years. This suggests that a patch where the population size is constrained to below 35 individuals may not be viable over the long term (we explore this effect below).

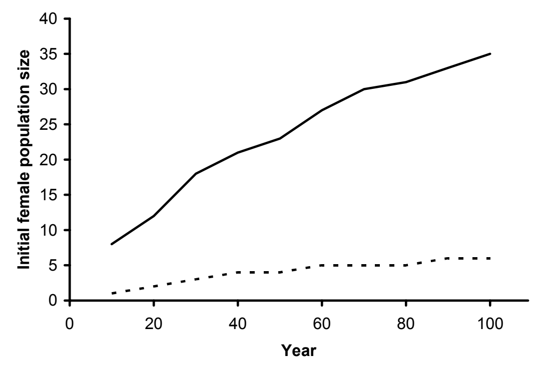


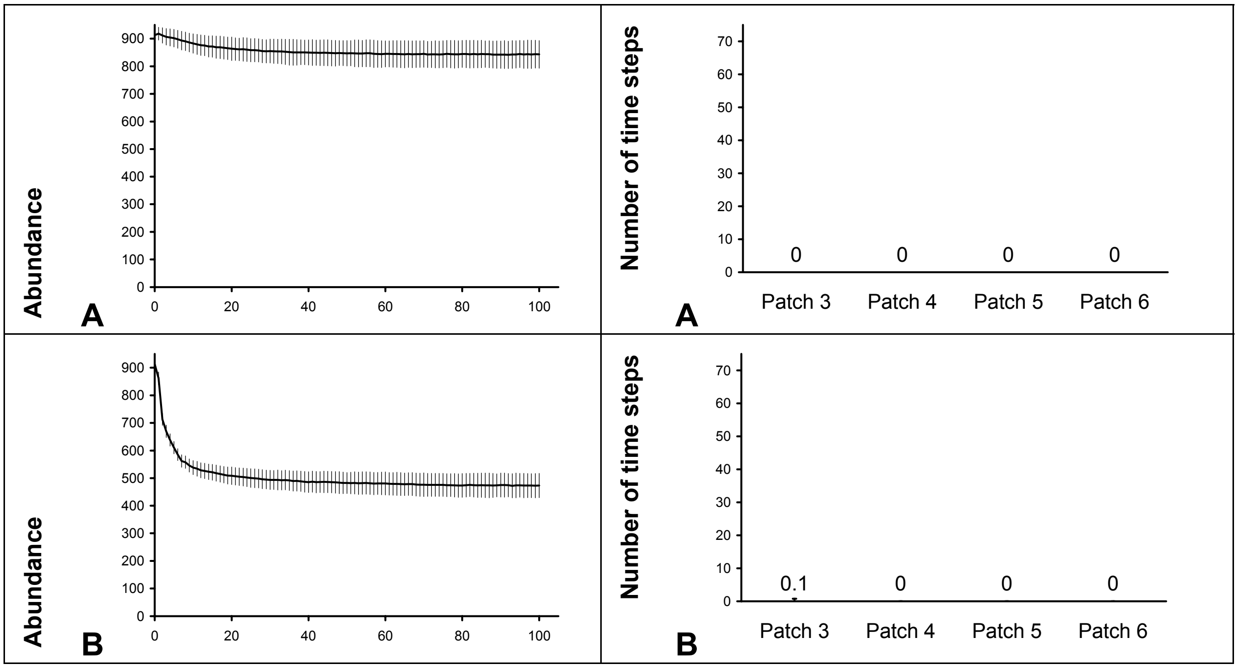
Figure 2. Simulated minimum viable population (MVP) size.
The solid line represents the minimum initial female population size required to ensure that the extinction risk is less than 5% for a given number of years. The dashed line represents the number of adults (at the stable age distribution).

4. Effect of carrying capacity on extinction risk and the population viability

Using RAMAS® GIS (Akçakaya & Root 2002), we explored the effect of carrying capacity on the projected population abundance over 100 years, local extinction duration, and terminal extinction risk for patches 3 to 6 (Figure 1) in the Ojibway Prairie Complex and for patch 5 alone. The carrying capacity changes affected the adults only. We set the default (BASE) carrying capacity at the numbers of adult females that are present when density is 2.5 females per hectare and assuming the stable age distribution (shown in Table 1). Because the patch sizes differ yet density is the same, the absolute number of initial individuals will also differ among patches. We then examined the effect of lowering the carrying capacity by 20, 40, 80, 90 and 95%. This adjustment would represent the number of adults present when the female density was changed to 2/ha, 1/ha, 0.5/ha (i.e., 1 per 2 ha), 0.25/ha (i.e., 1 per 4 ha), and 0.125/ha (i.e., 1 per 8 ha) respectively. We chose these values to simulate progressively deteriorating habitat quality. All other parameters are set at the values in Table 1.

Figure 3 depicts the results of simulations based on these 4 patches for the default carrying capacity and those reduced by 40, 80, and 90%. The total initial population size for the 4 patches was 913 females. The mean projected population sizes over 100 years declined with decreasing carrying capacity, as might be expected (Figure 3, left panels). However, only the adult carrying capacities associated with a density of 1/4ha or lower resulted in an extinction risk above 0 after 100 years: the predicted extinction risk after 100 years was 0.01 and 0.28 for a reduction in adult carrying capacity of 90% and 95% respectively. The risk to individual patches did increase significantly with decreasing carrying capacity (Figure 3, right panels). The smaller patches were particularly affected as their size went below the 95% minimum viable population size (Figure 2) with the decreasing ceiling. For the simulations with patch 5 alone, the extinction risk after 100 years was above 0 for a decrease in carrying capacity of 80% or more: the risk was 0.016, 0.264, and 0.608 for a reduction in carrying capacity of 80, 90, and 95% respectively. For patch 5, at an 80% reduction in carrying capacity (that associated with a density of 1/2ha) or more, the population size would be below the 95% minimum viable population size.

These population size projection results suggest that even at lower densities (but above 1/2ha), and assuming all patches were fully occupied and were 100% habitat, the Complex as a whole would be relatively unlikely to go extinct over the next 100 years. The local extinction results suggest, however, that the carrying capacity has a more significant impact on the survival of a single population. Given the fact that the amount of habitat within a patch is not likely 100% (see section 2.2.1.), and that each patch is not necessarily fully occupied, the absolute number of individuals in a patch and globally would not be as high. As a result, the true patch density may be much less than even 1/2ha. If so, the populations in the Complex are more likely to go extinct over time.



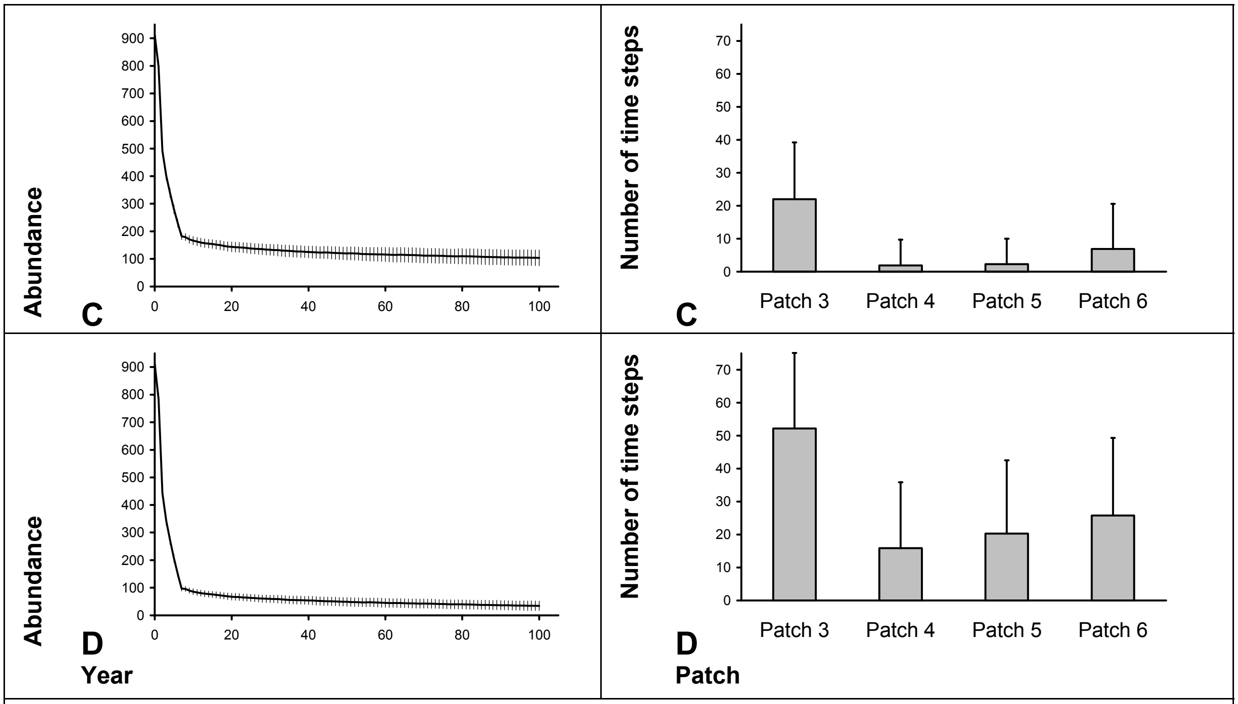


Figure 3. Effect of carrying capacity on the simulated mean abundance and local extinction duration over 100 years.
In the **left panels**, the dark lines represent the mean predicted abundance of females (averaged over 1000 simulations) in the population over 100 years for all 4 patches combined. Vertical lines are the range for ±1SD. In the **right panels**, each bar represents the average extinction duration in years (=time steps) for each patch (see Figure 1), plus 1 standard deviation. For carrying capacities reduced by **(A)** 0% (default), **(B)** 40%, **(C)** 80%, and **(D)** 90%.

5. Effect of dispersal on extinction risk and the population viability

The area found outside the 4 patches considered for this PVA (Figure 1) is generally inhospitable for the massasauga rattlesnake as it consists of non-habitat (e.g., forested areas), human developed areas (e.g., housing, roads), etc. Many of any migrants who venture beyond the patch boundaries may be killed. In the PVA conducted by Middleton & Chu (2004) incidental mortality was considered to have an important effect on viability. We determined the potential impact of failed juvenile dispersal on population persistence, duration of local extinction, and terminal extinction risk. We “allowed” 1, 5, 10, and 15% of juveniles to disperse into the matrix attempting to move between patches only to perish. We also examined the interaction of dispersal mortality with decreasing carrying capacity. All other parameters were set at the values in Table 1.

Table 2. Effect of carrying capacity and dispersal rate on the predicted terminal extinction risk after 100 years.

	Percent of juveniles "lost" to dispersal							
Percent change to carrying capacity	**All 4 patches**				**Patch 5 only**			
	1	**5**	**10**	**15**	**1**	**5**	**10**	**15**
0	0	0	0	0	0	0	0.017	0.139
20	0	0	0	0.001	0	0	0.020	0.140
40	0	0	0	0	0	0	0.024	0.117
80	0	0	0.001	0.017	0.033	0.032	0.117	0.220
90	0.013	0.018	0.025	0.051	0.248	0.259	0.308	0.382
95	0.245	0.265	0.268	0.310	0.639	0.648	0.657	0.672

Table 2 shows the predicted terminal extinction risk after 100 years with changes to carrying capacity and dispersal. The risks are presented both for the Complex as a whole and for patch 5 alone. Generally the Complex had a relatively low terminal extinction risk (under 5%) regardless of disperser mortality or lower carrying capacity. Only once carrying capacity fells to 90 or 95% of its original value did the extinction risk become significant. At those capacities, changes to dispersal had little relative effect on the extinction risk (Table 2). However, predicted mean population size over 100 years did decrease significantly with both effects and was relatively low even when extinction risk was 0 (Figure 4). Furthermore, the duration of local extinction increased significantly for the individual patches with changes in both effects, particularly for those with smaller population sizes. For patch 5, extinction risk responded to less dramatic changes in dispersal loss and carrying capacity than the Complex as a whole (Table 2). Extinction risk is above 5% when dispersal rate was set to 15%, and this increased risk was compounded when changes in carrying capacity were 80% (i.e., carrying capacity associated with a density of 1/2ha) or larger. The predicted mean population size over 100 years decreased very quickly with time for all scenarios but in a similar pattern as the Complex as a whole (Figure 4).

These results suggest that changes to carrying capacity and dispersal loss have an additive effect on reducing population persistence. The Complex as whole was somewhat resilient to minor changes in the size of the 2 effects. Their combined effects were particularly important for the individual population persistence, particularly for smaller sized populations. Fencing off patches to prevent emigration into the hostile areas surrounding the patch is a possible strategy to enhance population persistence (K Prior *pers com*). The simulations we present show that a loss of more than 1% of the juveniles can have an impact on population size and extinction risk, particularly if the carrying capacity is also lower. These results support at least the potential of using fences (snake barriers, see Austin 2004) as a management tool to enhance persistence, especially when population sizes are lower. Lower populations sizes vulnerable to extinction will be expected initially after individuals are introduced to a currently vacant patch (see following section).

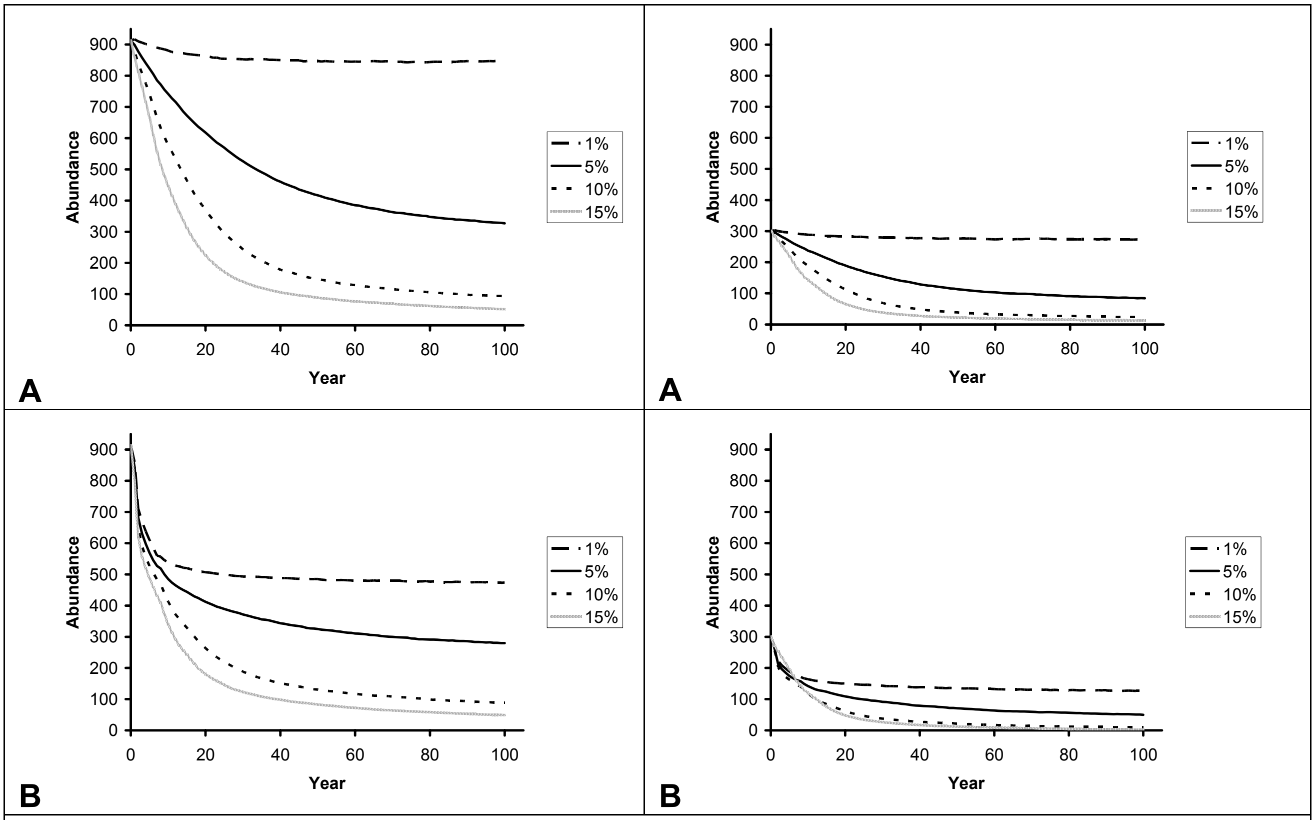


Figure 4. Mean simulated population size over 100 years for different attempted dispersal rates. The **left panels** show the mean simulated population trajectory for all 4 patches and the **right panels** show that for patch 5 alone. Each line represents the mean for the different failed dispersal rates of 1, 5, 10, or 15% (see legend). For carrying capacities reduced by **(A)** -0% (default) and **(B)** -40%.

6. Reintroduction to the Ojibway Prairie Nature Reserve

6.1. Captive population

There will be 19 2-year-old juveniles available in 2005 for reintroduction (K Prior *pers com*). The actual number of females among the juveniles was not available at the time of writing this report but we do know that the sex ratio is expected to be 1:1 (ibid). We decided to consider a conservative half of 19, i.e., 9, females for our simulations.

We assigned revised survival and fecundity rates in our simulations for the captive population as compared to the simulated wild populations. Survival in the captive population is 100% so far, and should be higher throughout the snakes' lives while in captivity (K Prior *pers com*). We thus increased the original survival rates in Table 1 by 20%. Fecundity of the captive population (should the juveniles be allowed to age and breed in captivity) would be higher than that estimated based on wild populations (ibid). Clutch size will be likely similar but the snakes should reproduce more often, e.g., every year (ibid). We therefore increased the rate in Table 1 to a fecundity rate of 5. Middleton & Chu 2004 (see their Table 3.1) calculated fecundity as litter size (10) * breeding frequency (every other year or 0.5) * sex ratio (0.5) = 2.5. If reproduction is every year, fecundity is 10 * 1 * 0.5 = 5. There is no evidence to suggest inbreeding within this captive population (Lougheed 2004).

6.2. Introduction scenarios

Patch 5, the Ojibway Prairie Nature Reserve, is a proposed site for introduction (Austin 2004; K Prior *pers com*). The LaSalle Woodlot would be the source of individuals for translocation or captive breeding (Pither 2003; K Prior *pers com*). We created a simulated captive population of 9 females with the revised survival and fecundity rates described in section 6.1. from which we drew individuals for introduction into patch 5. Evidence suggests that patch 5, though of good quality, is empty (Pither 2003) thus its initial size was set at 0 for all introduction scenarios. The carrying capacity was set to 51 adult females (see sections 2.2.4. and 4). All other parameters, including fecundity and survival rates, were as in Table 1. Only juveniles were released in the scenarios we considered as adult introductions are often unsuccessful (see Pither 2003; Austin 2004). We also considered the effect on the persistence of the introduced population of each scenario described below when 5% or 10% of the juveniles were lost to dispersal mortality.

6.2.1. One introduction

In these simulations all 9 2-year-old juvenile females (juvenile stage 2) were released into patch 5 at time 1. The population's mean predicted size increased over the 100 years (Figure 5a) but its terminal risk of extinction was high (Table 3). The stochasticity in the projected size lead to many of the 1000 replicated runs ending with extinction. The projected mean population size was reduced when we considered the effect of juvenile dispersal mortality (5 and 10%, Figure 5a, right panels show results for 10%), and the terminal extinction risk increased (Table 3).

Because of the relatively high extinction risk in spite of an increase in the mean population size over time, the results suggest that the number of introduced females may be inadequate. If more individuals were available for release, viability would be likely. The 95% MVP was 35 (see section 3). Further, as the mean projected population size decreased with the increased rate of failed dispersal, the results suggest that it may be necessary to limit emigration from the patch (e.g., by creating a physical barrier) to ensure the long-term survival of the population.

6.2.2. Multi-year introduction

In these simulations, we released 3 2-year-old snakes in year 1, 3 3-year old snakes in year 2, and 3 4-year-old snakes in year 4. We assumed no mortality for the 3 years. The mean predicted population size over 100 years was only marginally larger than that for the previous scenario (Figure 5a vs. 5b). The terminal extinction risk was also somewhat lower (Table 3). Similarly, when we considered the effect of juvenile dispersal mortality, the effects on population projection and terminal extinction risk were only marginally lower than for when all snakes were added at once (Figure 5b vs. 5a, right panels). These results suggest that this scenario of staggered introduction may not represent a significant improvement in long term survival when compared to the all at once introduction. Were there a significant cost to maintaining the captive population over 3 years, the marginal improvement in viability associated with this scenario may not outweigh the cost.

6.2.3. Introduction post captive breeding

In these simulations we allowed the 9 2-year-old juveniles to survive, mature (4 years later), and reproduce in captivity according to the rates described in section 6.1. As of year 7 (there could be 2-year old offspring by then) we released all 2-year-old juveniles present in the population each year for 10 more years. At year 17, the captive population went extinct.

The mean predicted population size over 100 years was significantly larger than that for the previous 2 scenarios (Figure 5a and 5b vs. 5c). By allowing the snakes to breed in captivity, the size of the source population grew. As a result there were more snakes available to introduce. The terminal extinction risk was 0 (Table 3). When juvenile dispersal mortality was considered, the mean population over 100 years decreased significantly (Figure 5c, right panels). The extinction risk when 10% of the juveniles disperse and fail was 0.076 (Table 3).

These results suggest that captive breeding, depending on the associated costs, may be one of the better scenarios for ensuring persistence of the introduced population. The reduction in population size associated with mortality of emigrants suggests, as for the other scenarios, that preventing movement (e.g., through snake barriers) that would result in mortality would improve population persistence.

6.2.4. Capture gravid females and introduce offspring

In these simulations we introduced the 9 currently available 2-year-old females at year 1, but also supplemented them with a release of a portion of the offspring from a captured gravid female. We simulated a yearly capture of a gravid female (2 such snakes have been rescued from patch 6, and are held at the Toronto Zoo, Austin 2004), the birth of her litter in captivity, and an introduction of 3 of her litter once they reached 2-years-old. The female and her remaining offspring would be returned to the source population (these latter numbers of mothers and remaining offspring are not relevant to the simulations). Thus 3 2-year-old females were introduced from year 2 until year 10 (assuming the introduction program lasts 10 years).

The mean predicted population size over 100 years increased relatively significantly with time but was not as large as for the captive breeding introduction scenario (Figure 5d vs. 5c). By continuously supplementing the source population with the offspring from a captured gravid female (possibly rescued from the LaSalle woodlot, Austin 2004, Pither, 2003), the number of introduced snakes climbed from 9 to 36 (adding 27=[9 years *3]). As a result, there were more snakes available to introduce. The terminal extinction risk was 0.015 (Table 3) even though the mean population size increased over 100 years. When juvenile dispersal mortality was considered, the mean population over 100 years decreased significantly (Figure 5d, right panels). These results suggest that this scenario is a feasible one for ensuring the long-term survival of the introduced population. As for the other scenarios, loss of a number of juveniles from failed emigration is also to be avoided, suggesting the potential use of a barrier to movement.

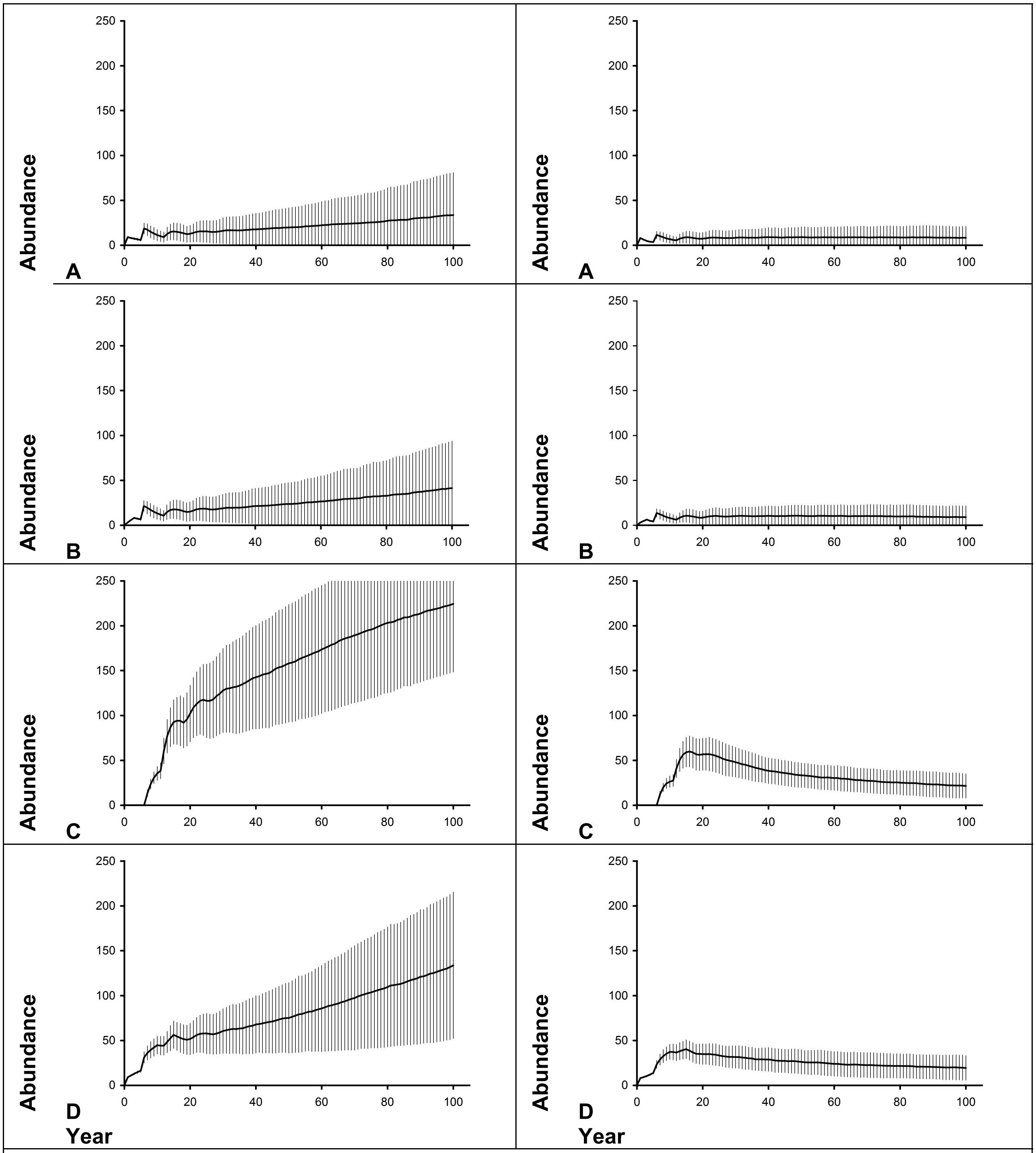


Figure 5. Effect of introduction scenario and failed dispersal on the simulated mean abundance over 100 years.

The dark lines represent the mean predicted abundance of females (averaged over 1000 simulations) in patch 5 over 100 years for the different introduction scenarios: **(A)** all individuals introduced in 1 year, **(B)** 3 individuals for 3 years, **(C)** captive breeding, and **(D)** gravid female (see text for description). Vertical lines are the range for ±1SD. In the **left panels**, there is no dispersal from patch 5. In the **right panels**, 10% of each of the juvenile stage classes disperses and fails.

Table 3. Effect of introduction scenario and dispersal rate on the predicted terminal extinction risk after 100 years for patch 5.

Scenario	Percent of juveniles "lost" to dispersal		
	0%	5%	10%
Add all in year 1	0.387	0.378	0.577
Add 3 per year for 3 years	0.308	0.335	0.502
Captive breeding	0	0.001	0.076
Captured gravid female	0.015	0.015	0.101

References

Akçakaya, H. R. & Root, W. 2002. RAMAS Metapop: Viability analysis for stage-structured metapopulations (version 4.0). *Applied Biomathematics*, Setauket, New York.

Austin, J. 2004. A *Discussion Paper and Prospectus for Recovery of Tallgrass Massasaugas*. Prepared for the Massasauga Recovery Team.

Lougheed, S. C. 2004. *Conservation genetics of the isolated Ojibway/LaSalle Complex massasauga rattlesnake population*. Prepared for the Massasauga Recovery Team.

Middleton, J & 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*. Prepared for the Eastern Massasauga Rattlesnake Species Recovery Team.

Pither, R. 2003. *Contingency Plan for the Management of the LaSalle Massasauga Rattlesnakes.* Prepared for the Massasauga Recovery Team.

Figures

Tables