Population Viability Analysis
of the
Eastern Loggerhead Shrike
(Lanius ludovicianus migrans)

Version 2 (June 8th 2009)

prepared by

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for

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Table of contents

Notice

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 is partly considered in the demographic and environmental stochasticity of the population model. Due to the stochastic nature of the population model, simulation runs were replicated 1000 times and results are averages out of those replicate simulation runs. Absolute numbers should be interpreted with caution. Instead trends and differences between different simulation runs (scenarios) are generally more trustworthy. All information used in this work have been discussed with members of the recovery team and verified as well as substantiated 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 Summary

This report summarizes essential information about the current state and recent development of the Eastern Loggerhead Shrike population in Ontario followed by quantitative analyses of the population's viability and scenarios related to its unique mating system and recovery expectations as a result of the captive breeding program. This work would not have been possible without support and involvement of various members of the recovery team, experts and associated research scientists, in particular Ken Tuininga, Amy Chabot, Angela Darwin, Elaine Williams, Rich Russell, Greg Robertson and Jean-Pierre Savard. Some of the assumptions and preliminary results had been presented at the Eastern Loggerhead Shrike Recovery Meeting held at McGill University on October 15, 2008. This report also marks the preliminary endpoint of extensive data compilation and consolidation efforts as well as many fruitful discussions about various hypotheses and aspects related to the shared concern about the fate of this species not just in Ontario but across Eastern Canada.

The stories emerging from the compiled data unveil tremendous conservation and recovery efforts, a still declining population but also hope for a turn-around in that captive bred birds are now a significant proportion of Ontario's wild population. Over the last two decades, population estimates confirmed a steady decline at an average rate of loosing 2 breeding pairs every year. In 2008 a total of 28 breeding pairs were known in Ontario. This census might have been much worse in the absence of the captive breeding program, which allowed releasing a total of 419 fledglings (HY) between 2000 and 2008. Therefore 6 of the 28 known breeding pairs in Ontario in 2008 contain released birds from the captive breeding program. As a result, the actual negative trend in breeding pair abundance between 2003 and 2008 may have been reversed, presumed that the population count would be reduced to 22 breeding pairs in the absence of these captive bred birds. There seems to be a stable proportion of about 30% of single individuals in the population without a statistically significant association to population size. There also seems to be no evidence for a low density depression in either fecundity or survival and it must be assumed that the population does not suffer from an Allee effect. Yet, a rather unique mating and breeding behaviour may indicate problems in the social structure of this small population. Extra-pair copulation, polygynous males and multiple females attending one single nest have so far not been observed in other Loggerhead Shrike populations across North America. On average nest and breeding success in general appear to be normal, at least when compared to numbers obtained from other populations. As for habitat, most studies conclude that availability of breeding habitat is most likely not limiting Loggerhead Shrikes. The biggest unknown (similar to many other migratory species) remains over-winter survival. Previous studies suggest that the causes of declines in shrike populations are probably associated with over-winter survival.

The results of the PVA indicate an almost certain extinction risk within the next 100 years, if the demographic fingerprint remains as it has been observed throughout the last 18 years. This extinction risk is primarily determined by a rather deterministic imbalance between fecundity and survival resulting in a constant negative growth rate for the population. Stochastic events, such as bad or good years for nest and fledgling success contribute to but do most likely not determine the recent trend in population size. Comprehensive sensitivity analyses consistently identified survival rates of juveniles and young adults as the most important single factor affecting both population abundance and extinction risk. These results are in line with conclusions drawn from previous studies and emphasize the importance of over-winter survival to population viability of the Eastern Loggerhead Shrike.

A scenario based evaluation revealed some insights into quantitative expectations of the captive breeding program. Despite measurable positive effects of this program on the recent trend in breeding pair abundance, the magnitude of these effects is likely to remain far below theoretical expectations. Furthermore, the results of this study do not provide evidence in favour of a lasting positive effect of the captive breeding program toward a self-sustaining wild population in Ontario.

A significant change in intrinsic fecundity and/or survival would be necessary to achieve this goal. Furthermore, a meta-population model was projected to the 6 breeding areas in Ontario. Results of this model indicate that connectivity and dispersal are of minor importance to overall population viability at this time.

The initial evaluation of this work revealed the need to consider scenarios in support of setting meaningful population and recovery targets. Various scenarios with regard to potential effects of inflated survival rates, standard deviations around those as well as poor productivity years on population growth and extinction risk have been explored. The results suggest that a 20% increase in juvenile and/or adult survival would result in neutral population growth. The number of released birds should have a linear effect on population growth.

Based on this study it could be concluded that current recovery efforts are likely insufficient in restoring a self-sustaining wild population in Ontario and, that factors outside of the breeding grounds, in particular over-winter survival, must be understood and included in conservation and recovery efforts for this species.

2 Background - Observations, Concerns and Recovery Efforts

Migratory Loggerhead Shrike populations across North America have undergone a tremendous and continuous decline within the last three decades. This worrying trend has been documented in numerous studies (see sources in attached documents) and resulted in protecting this species under the umbrellas of state, provincial and federal species-at-risk legislation in both the United States and Canada. Despite ongoing research as well as conservation and recovery efforts, the reasons for these declines remain still enigmatic. Habitat restoration, food supplementation, predator control, captive breeding programs, extensive nest monitoring and banding of birds have shown singular effects on particular populations and provided valuable information on reproductive success, breeding and migration behaviour as well as population sizes and dispersal distances. Yet, the apparent wealth of information has not unanimously revealed the cause for this decline nor did conservation efforts succeed in returning the worrisome trend for this species. The following sections summarize some of the most important information available today with particular emphasis on the Loggerhead Shrike population in Ontario. This summation provides the basis for the population model, which serves as the core approach for the population viability analysis presented in this report.

2.1 Population Decline

According to BBS data, 9 out of 14 studied Loggerhead Shrike populations in the US showed a negative trend in population size between 1972 and 1995. Likewise, CBC data attribute 10 out of 14 of those populations a population decline (see sources in attached documents).

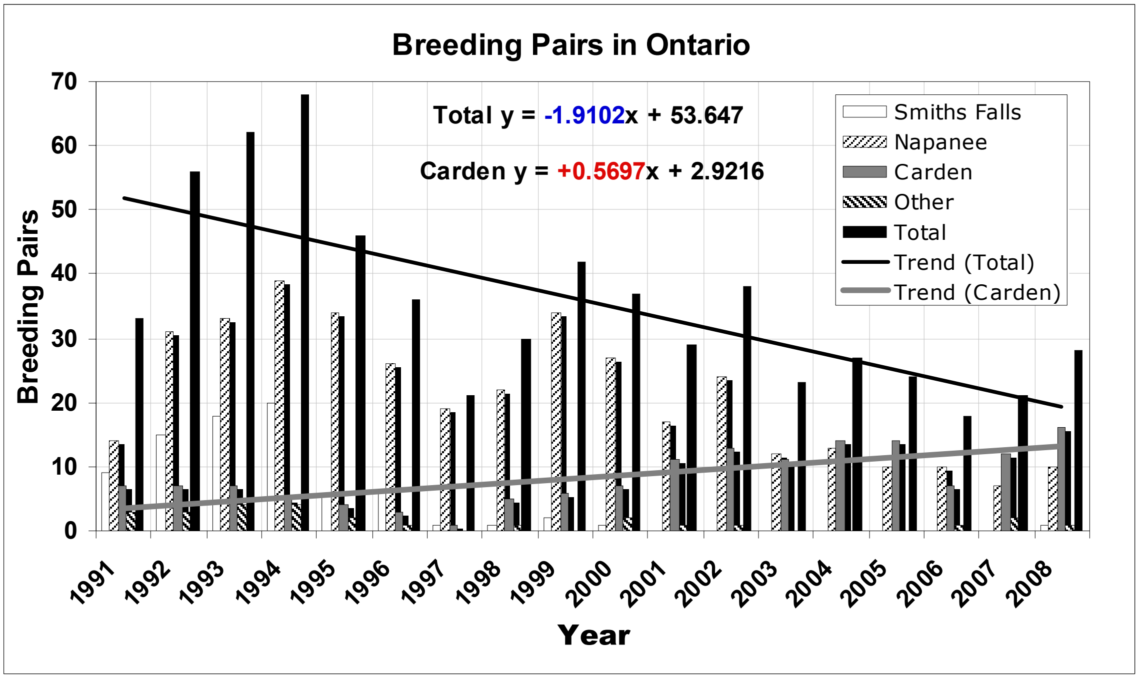


Figure 1: Number of breeding pairs as observed in Ontario between 1991 and 2008. The overall trend is negative with a rate of almost minus two breeding pairs per year. All subpopulations show a negative trend except for the Carden subpopulation, which shows an increase of about one breeding pair every two years. These numbers include wild and mixed (captive-wild) breeding pairs.

Loggerhead Shrike populations in Quebec are already extirpated, while small populations in Ontario and Manitoba are still declining. The recent trend of observed breeding pairs in Ontario is shown in Figure 1. These data are likely to reflect a conservative estimate of the actual population size in Ontario and it is not clear what kind of uncertainty factors into these numbers. In any case, the obvious negative trend cannot be disputed and resembles the fate of this species in other regions across its North American range.

2.2 Breeding and Nest Success

Between 1992 and 1995 at least 19 published studies reported on reproductive aspects of Loggerhead Shrike populations in the United States (see sources in attached documents). The average number of fledglings per successful nest across all these studies was about 4.24 with a range between 2.1 and 5.1. In comparison, the average number of fledglings per successful nest in Ontario between 1998 and 2008 was about 3.64. Nest success has consistently been reported as high with averages usually above 60%. In Ontario 245 out of 391 observed nests between 1998 and 2008 were successful, which amounts to about 62%. Second nest attempts after nest failures seem to be common even in Ontario. There are almost no accounts of raising two broods per year in Ontario. Overall, successful breeding pairs in Ontario raise about 4.2 fledglings per year. If unsuccessful breeding pairs are included, the ratio of fledglings per breeding pair drops to about 3.4 across all subpopulations between 1998 and 2008. In summary, the observed average reproductive output in Ontario has been steady (see Figure 2) and seems well within the range of common expectations if compared to other studies across North America.

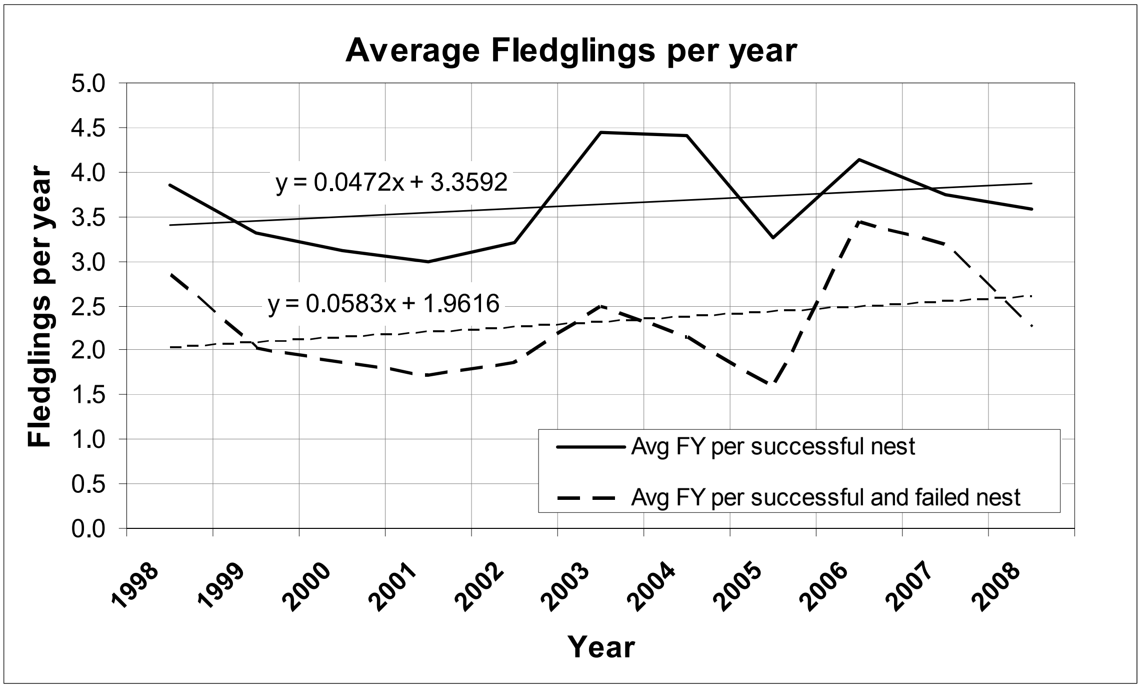


Figure 2: Average number of fledglings per successful nest and across successful and failed nests. Despite good and bad years the overall trend is slightly positive.

2.3 Habitat Quality and Quantity

According to Brooks and Temple 1990, it seems that "*most studies conclude that availability of breeding habitat is not limiting Loggerhead Shrikes*". This assessment seems to be consistently confirmed for the situation in Eastern Canada. It is generally believed that habitat amount, at least from a landscape structural point of view, could support a much larger population and that the area of potentially high quality habitat is actually increasing mostly due to abandoned agricultural fields. Still, our understanding of breeding habitat for the Loggerhead Shrike may be limited and less quantifiable factors, such as food supply, pesticide use, predation or effects of invasive species may still affect population growth on this side of the migration route. Not much is actually known about the quantity and quality of the over-wintering grounds for the migrating birds. This also involves potential encounters with resident, non-migratory populations in the southern parts of the United States. Although over-wintering habitat does not directly affect reproduction, it may have a significant effect on over-winter survival.

2.4 Captive Breeding Program

After establishing captive breeding colonies in 1997 and 1998 in Ontario, experimental reintroduction efforts have been undertaken since 2000. Between 2000 and 2008, 419 captive bred hatchlings of the year (HY) were released in Ontario, 169 in Carden, 211 in Grey Bruce and 39 in Smith Falls. Between 2004 and 2008 a total of 392 captive bred HY were released in Ontario, more then the number of known wild born HY (313) during the same period (Figure 3). This impressive figure amounts to a 125% increase in reproductive output for the wild population residing in Ontario. Between 2005 and 2008, 14 captive bred birds were re-sighted on breeding grounds in Ontario, which amounts to about 3.3% of all released birds.

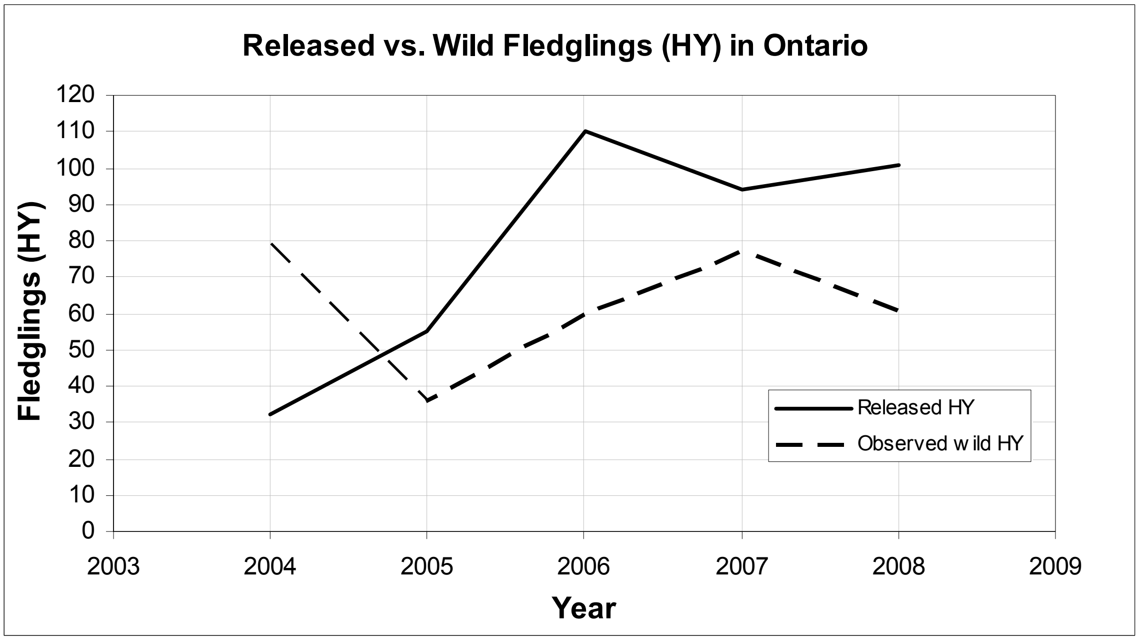


Figure 3: Number of released hatchlings of the year vs. number of observed wild fledglings across all subpopulations in Ontario.

Some of the re-sighted captive bred birds have successfully bred with wild mates and therefore contributed to the observed population size and to the reproductive output of the Ontario subpopulations, primarily in Carden. In 2008, 6 out of all 28 observed breeding pairs in Ontario contained captive bred birds. All of these identified captive-wild breeding pairs resided in Carden producing a total of at least 18 fledglings in 2008. The actual effect on the trend in population size has been positive for Ontario (Figure 4) and even more pronounced for the subpopulation residing in Carden (Figure 5).

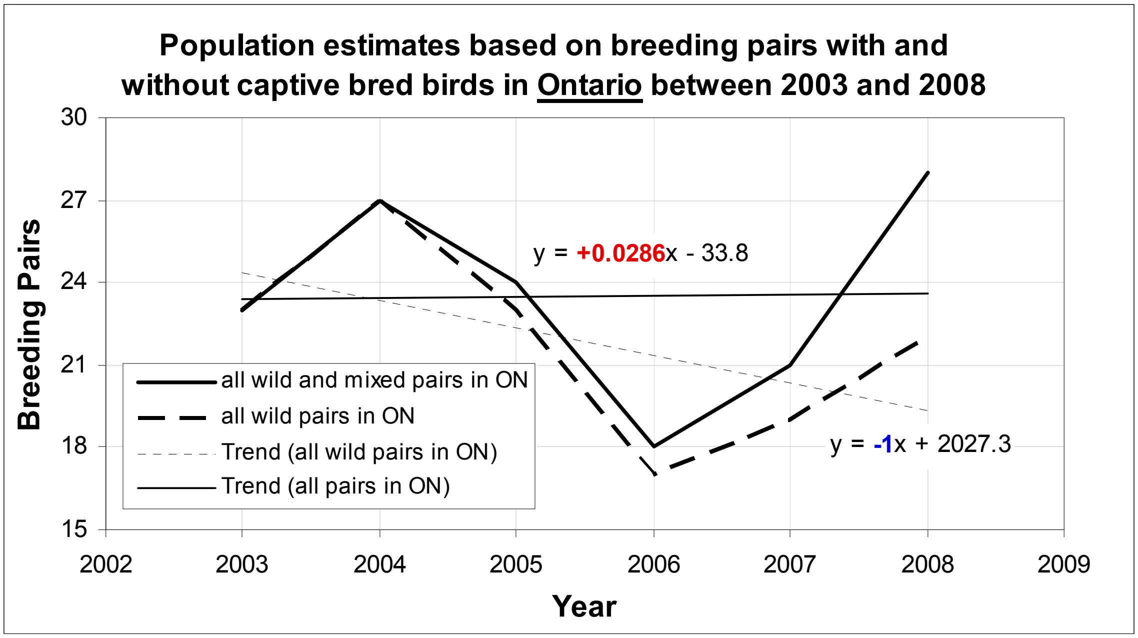


Figure 4: Difference between the number of observed all (wild and mixed) breeding pairs and wild only breeding pairs in Ontario. In 2008, 6 out of all 28 breeding pairs included captive bred birds reversing the linear trend in population size between 2003 and 2008 from negative to positive.

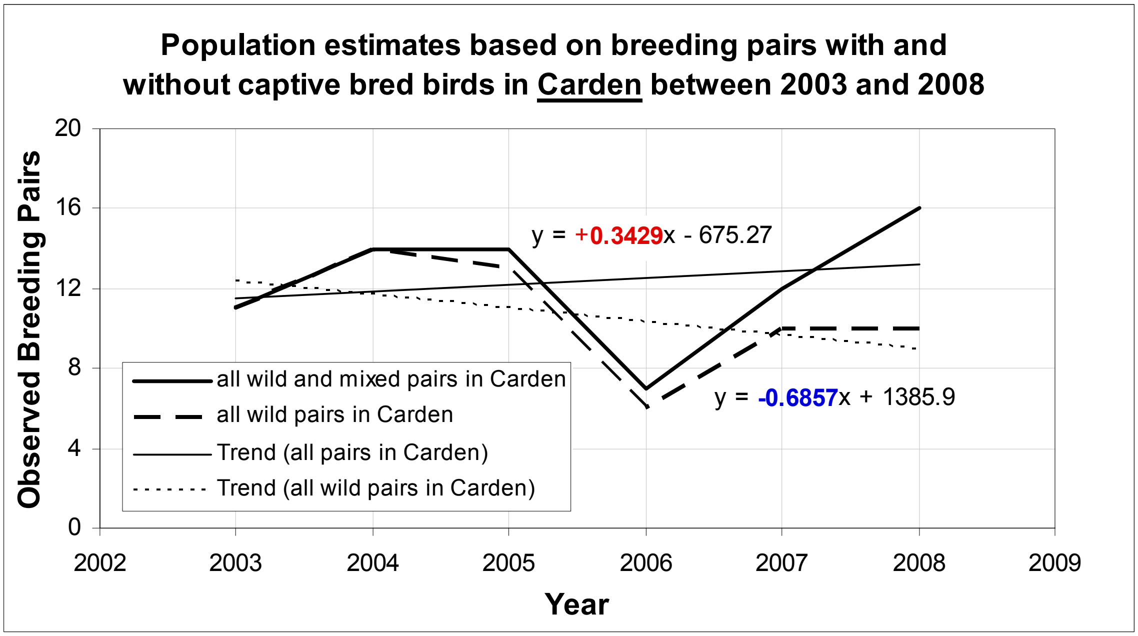


Figure 5: Captive bred birds contributed to 6 out of 16 breeding pairs in Carden in 2008, reversing the negative trend to an estimated growth rate of 1 breeding pair every 3 years.

Between 2005 and 2008, a total of 10 mixed breeding pairs raised at least 34 fledglings. The average ratio of fledglings per successful mixed breeding pair across these four years was 3.875, which is slightly lower than the long term average of 4.2 across all successful breeding pairs in

Ontario between 1998 and 2008 (see 2.2). This difference however, may not be statistically significant due to the low sample size.

Overall, positive effects of the captive breeding program are visible in population estimates for Ontario in recent years and it seems undisputable that Ontario's population would be off worse in the absence of such recovery efforts. Whether these results are in line with expectations will be assessed in the PVA.

2.5 Mating System and Breeding Behaviour

Loggerhead Shrikes generally breed as one-year old birds during the first spring after hatching. The ratio between males and females has consistently being estimated to be close to 1:1. Accordingly, Loggerhead Shrikes are believed to be monogamous. Yet, observations and genetic analyses revealed an apparent departure of Loggerhead Shrikes in Ontario from a monogamous mating system. Extra-pair copulations have been observed as well as multiple females contributing to one nest. This kind of behaviour is believed to be unique among Loggerhead Shrike populations. It is assumed that the polygynous tendency of the mating system is attributed to the lack of males or at least could compensate for the potential lack of males in Ontario's population. There is no clear evidence available yet for a biased sex ratio and the causes for this unique behaviour are not yet fully understood. The PVA will provide a scenario of the potential benefit of a polygynous mating system in the presence of a biased ratio between females and males.

2.6 Singles vs. Breeding Pairs

Between 1991 and 2008 a total of 192 single birds have been observed against the backdrop of 639 breeding pairs. This amounts to an average of about 30% of single birds in Ontario's population of Loggerhead Shrikes. The proportion of single birds seems to be unrelated to the population size as shown in Figure 6a, at least within the range of annual breeding pairs (18 – 68) as observed in Ontario between 1991 and 2008.

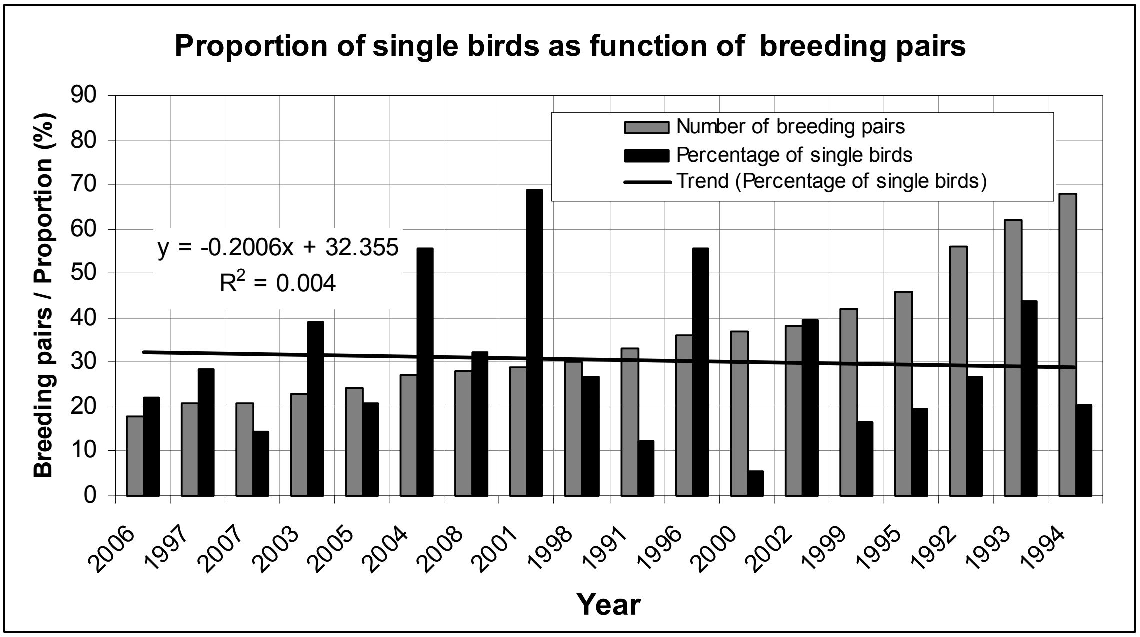


Figure 6a: The proportion of single birds in Ontario's population was fluctuating between 5 and 70 percent of all known breeding pairs. However, there seems to be no relationship with population size.

The scatter plot (figure 6b) reveals a slightly positive relationship between singles and breeding pairs.

An increasing number of single birds in smaller populations may be one indicator of a potential Allee effect (i.e. a reduction in fecundity or survival at very low population densities) based on the assumptions that a larger proportion of single birds results in fewer breeding pairs with a subsequent reduction in reproductive output. Based on the data available today, there seems to be no evidence for an increased proportion of single individuals in smaller populations. Together with the observations of a stable breeding and nest success (see 2.2 and Figure 2), a potential Allee effect on fecundity must be excluded at this time for Ontario's population.

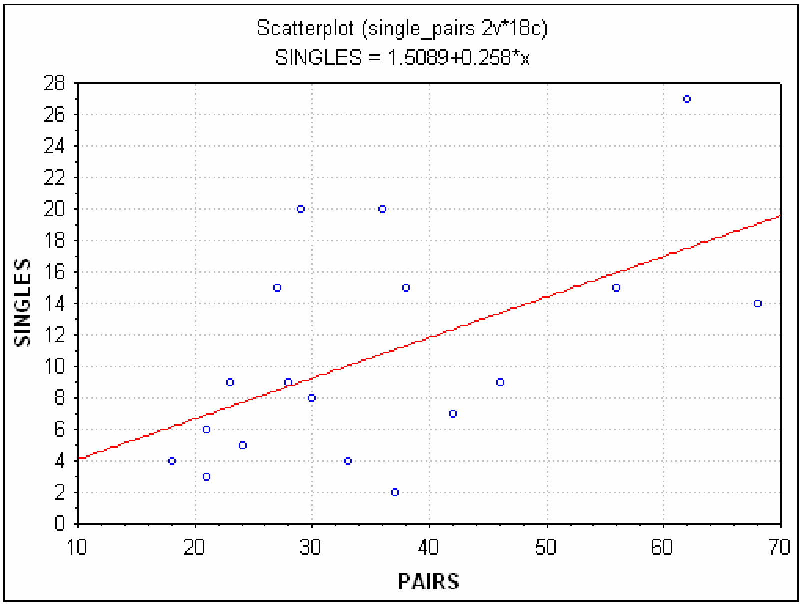


Figure 6b: Relationship between Singles vs. Breeding Pairs.

2.7 Dispersal

According to Collister and DeSmet 1997, juveniles moved significantly greater distances between encounters then adults, up to a maximum of about 80 km with average distances ranging between 13km and 15km. Observations in Ontario in 2002 resulted in displacement distances of re-encountered birds between 0km and 145km and a mean distance of 47km. There seems to be consensus about augmented site fidelity in adults, particular adult males and dispersal between breeding sites primarily accomplished by juveniles returning from their over-wintering grounds. It is still possible that individuals not returning from migration to their native breeding grounds may travel to different regions within North America and therefore disperse far greater distances as reported so far. With respect to the geographical distances between adjacent Ontario's breeding grounds not exceeding 80 km, dispersal among Ontario's subpopulations seems possible.

2.8 Re-sightings, age classes and over-winter survival

Survival rates and over-winter survival for migratory birds in particular are very difficult to estimate. The only direct clues are return rates of banded birds to their native breeding grounds. Return rates for juveniles are usually less then 5% and range mostly between 1% and 2%. Between 1999 and 2007 a total of 1091 captive and wild birds were banded and released in

Ontario. Re-sightings of banded birds in Ontario between 2000 and 2008 are summarized in Table 1 (Amy Chabot, pers. com.) Overall, 199 birds in 5 different age classes have been re-sighted in Ontario, with first year adults accounting for 50%. These 199 re-sighted birds amount to about 18% of all 1091 banded birds.

age/year	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total
AHY	5	4	10	8	19	8	16	15	4	**98**
SY	7	4	17	3	6	5		1	5	**45**
ASY	9	13	10	10	3	5				**44**
TY						2			2	**5**
ATY						3			5	**7**
Total	**21**	**21**	**37**	**21**	**28**	**23**	**16**	**16**	**16**	**199**

Table 1: Summary of re-sightings in Ontario between 2000 and 2008

The totals for each age group in Table 1 also provide a rough estimate on the potential age class distribution in Ontario. It appears that about 50% of all birds are one year adults, 22% are second year adults and 5% third year adults. The oldest re-sighted bird in Ontario between 2000 and 2008 was six years old. It should therefore be safe to assume that the Eastern Loggerhead Shrike in Ontario exhibits a maximum life expectancy of about 6 years in the wild.

Survival estimates based on re-sightings between 1999 and 2007 for the different age classes are summarized in Table 2 (Chabot, pers. com.) According to these data, at least 6.3 percent of fledglings survive to one year adults, at least 22.5% of one year adults, 11.8% of second year adults and 41.2% of older birds survive for one or more years. These data a much likely underestimates of actual survival rates. In contrast, Brooks and Temple 1990 estimated annual survival rates in support of a PVA of a Loggerhead Shrike population in Minnesota in 1990 to 47% for adults and 19% for juveniles.

Year/ age class	HY banded (captive and wild)	# surviving 1 or more years	HY banded (wild)	# surviving 1 or more years	SY banded	# surviving 1 or more years	ASY banded	# surviving 1 or more years	AHY banded	# surviving 1 or more years
1999	150	9	150	9	0	0	0		33	9
2000	131	7	131	7	10	2	13	9	2	0
2001	109	17	98	17	8	0	7	3	0	0
2002	112	8	98	8	11	2	6	0	1	0
2003	83	6	83	6	3	0	3	2	0	0
2004	99	7	67	7	0	0	0	0	4	0
2005	97	1	42	0	2	0	1	0	0	0
2006	110	3	0	2	0	0	0	0	0	0
2007	94	4	0	3	0	0	0	0	0	0
Total	**985**	**62**	**669**	**59**	**34**	**4**	**30**	**14**	**40**	**9**
(%)		**6.3%**		**8.8%**		**11.8%**		**41.2%**		**22.5%**

Table 2: Over-winter survival estimates per age class based on re-sightings of banded birds in Ontario. (provided by A. Chabot)

To summarize, return rates or re-sightings of banded birds in their native breeding grounds are generally low and should not be used as direct surrogates for over-winter survival rates. Previous studies suggested that "*Although minimal data on dispersal of both juvenile and adult shrikes have led to imprecise survival estimates in the past, low return percentages for both age classes*

documented by this and other studies suggest that low year-to-year survivorship may be a contributing factor to the decline of the species throughout its North American range" (Collins and DeSmet 1997) or "*Over-winter survival on the non-breeding range is, therefore, a likely point in the shrike's annual cycle to look for evidence of problems. In a six-year study of a declining population of Red-backed Shrikes (Lanius collurio) in Britain, Ash (1970) suggested that reductions in annual survival rates were responsible for that population's decline, rather than a reduction in the production of young*" (Brooks and Temple 1990).
The PVA will provide further insights into the relative importance of survival rates for the Loggerhead Shrike population in Ontario.

3 Population Model

The following sections describe the structure of the population model as well as the underlying assumptions and sources for model parameter values. The model represents an age-structured population of females based on the demographic fingerprint of the Eastern Loggerhead Shrike population in Ontario as outlined in section 2. The model was implemented using Ramas©MetaPop (Akçakaya and Root 2002).

3.1 Model expectations

In general, the structure of a population model and the values of its parameters are defined by quantified empirical observations and expert knowledge. However, some of the input data requirements cannot always be satisfied with hard numbers or even reliable expert knowledge. Therefore, pursuing a quantitative PVA in the presence of data gaps requires postulating assumptions or best guesses under the constraint of creative validation strategies. One possible strategy would be to validate the model output or simulation results against empirical data and to use this comparison for calibrating and tuning unknown or uncertain model parameter values. The first goal should therefore be a model, which reproduces empirical facts, such as population trajectories or age class distributions. Such a calibrated model may then be used to quantify viability measures, such as extinction risk or minimum viable population size, but also to explore consequences of scenarios in a quantitative manner. It is exactly this kind of information, which is generally more trustworthy and consistent then predicting population sizes for a future point in time.

3.1.1 Population Trend

As presented in section 2.1., the population model should reproduce a negative population trend with a growth rate of about -2 breeding pairs per year.

3.1.2 Age Class Distribution

As shown in section 2.8., the observed maximum life expectancy of Loggerhead Shrike's in the wild is about 6 years, although only one bird at the age of 6 years has been re-sighted in Ontario between 2000 and 2008.

3.2 Model parameters and assumptions

3.2.1 Time Step

The model uses a time step of one year and a time span of 18 to 100 years. All simulation runs were repeated 1000 times unless noted otherwise.

3.2.2 Age Classes

The population is partitioned into 6 age classes as follows:

- Juvenile - fledglings or hatchlings of the year
- Adult_1 – first year adults
- Adult_2 – second year adults
- Adult_3 – third year adults
- Adult_4 – fourth year adults
- Adult_5 – fifth plus year adults

These age classes allow keeping track of juveniles up to 5 plus year adults whereas individuals older then 5 years remain part of the Adult_5 age class.

3.2.2.1 Fecundity

Fecundity in the population model refers to the number of fledglings per adult female. All females of all adult age classes produce on average the same number of fledglings throughout their simulated life. Fecundity was derived based on the reported number of fledglings per breeding pair in Ontario between 2003 and 2008 and not based on the reported number of fledglings per nest. According to Ontario field reports (http://www.shrike.ca/recovery.html), the number of wild breeding pairs and fledglings between 2003 and 2008 is summarized in Table 3.

Year	# wild breeding pairs	# fledglings	#fledglings/#breeding pairs
2003	24	120	5
2004	27	79	2.925926
2005	24	36	1.5
2006	16	60	3.75
2007	18	77	4.277778
2008	21	61	2.904762
Total/Avg.	**130**	**433**	**3.393078**

Table 3: Wild breeding pairs and fledglings from Ontario field reports between 2003 and 2008. Numbers were cross-validated with data obtained from Chabot (pers. com.)

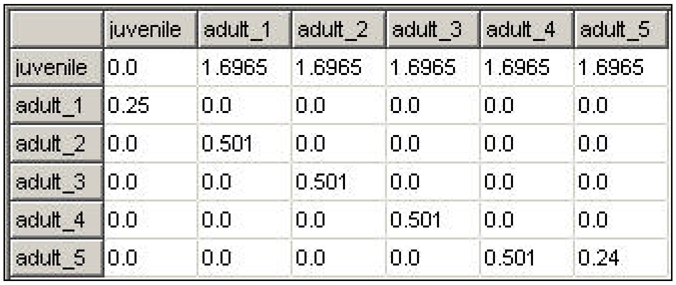
The average ratio between annual fledglings and breeding pairs (3.393078) as well as the corresponding standard deviation of 36% has been used as fecundity values for the population model. Since the population model tracks females only the fecundity was divided by two based on the initial assumption of an equal sex ratio.

3.2.2.2 Survival

Survival in the population model refers to an annual survival rate, i.e. the proportion of the age class in the population surviving from one year to the next. Since survival rates are practically unknown (as outlined in section 2.8) assumptions had to be made here. It was assumed that survival of juveniles was about 50% of adults and that 5 plus year adults experienced a lower survival rate then younger adults. Survival rates were then calibrated until the simulated population trajectory matched its empirical counterpart. Survival rates for juveniles were fixed to 25%, for adult_1 to adult_4 age classes to 50.1 % and for adult_5 to 24%. A standard deviation of 10 percent was used for all survival rates. This may seem low, but produced the closest fit between simulated population abundance and empirical population estimates.

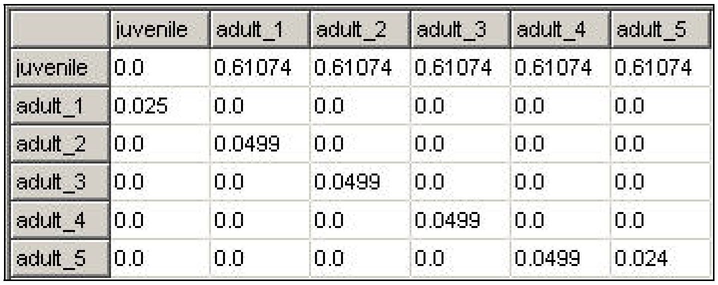
3.2.2.3 Stage Matrices

Figure 7 shows the stage matrix with fecundity values in the upper row and survival values in the diagonal row. Figure 8 shows the corresponding standard deviation matrix for fecundity and survival values shown in Figure 7.



	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	1.6965	1.6965	1.6965	1.6965	1.6965
adult_1	0.25	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.501	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.501	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.501	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.501	0.24

Figure 7: Stage matrix for Loggerhead Shrike population model



	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.61074	0.61074	0.61074	0.61074	0.61074
adult_1	0.025	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.0499	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.0499	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.0499	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.0499	0.024

Figure 8: Standard Deviation matrix for values shown in Figure 7

3.2.3 Sex structure and Mating System

The Loggerhead Shrike population model is a female only model with the exception of a simulated scenario in support of analysing the potential benefits of a polygynous mating system in section 4.1.5.

3.2.4 Density Dependence

No density dependence was used in this model. There appears to be no evidence for an Allee effect and population sizes are too small and unlikely to be constrained by limited habitat amount.

3.2.5 Stochasticity

Demographic stochasticity was used in the model as well as stochasticity originating from the standard deviations around fecundity and survival rates. The model was set so that fecundity and survival were not correlated based on the assumption that over-winter survival is uncorrelated to breeding success.

4 Results

4.1 Non-spatial, single population model

This section refers to the results obtained from a non-spatial, single population model. This model simulates the dynamics of one single population without consideration of dispersal or correlation with other populations. This non-spatial, single population model serves as the base for analysing various aspects of population viability as well as for exploring scenarios related to potential effects of a polygynous mating system and a captive breeding program.

Figure 9 shows an exemplary simulated population trajectory over 10 years against the empirical population estimate in Ontario between 1991 and 2008. The simulated abundance refers to the number of adult females in the model. The empirical population estimate refers to the number of breeding pairs in the population of Ontario. Both trajectories are very similar and result in a negative growth rate of about minus two. This result demonstrates the calibration of the model, in particular the survival rates and its ability to reproduce the empirical population trend. Figure 10 shows the corresponding simulated age class distribution.

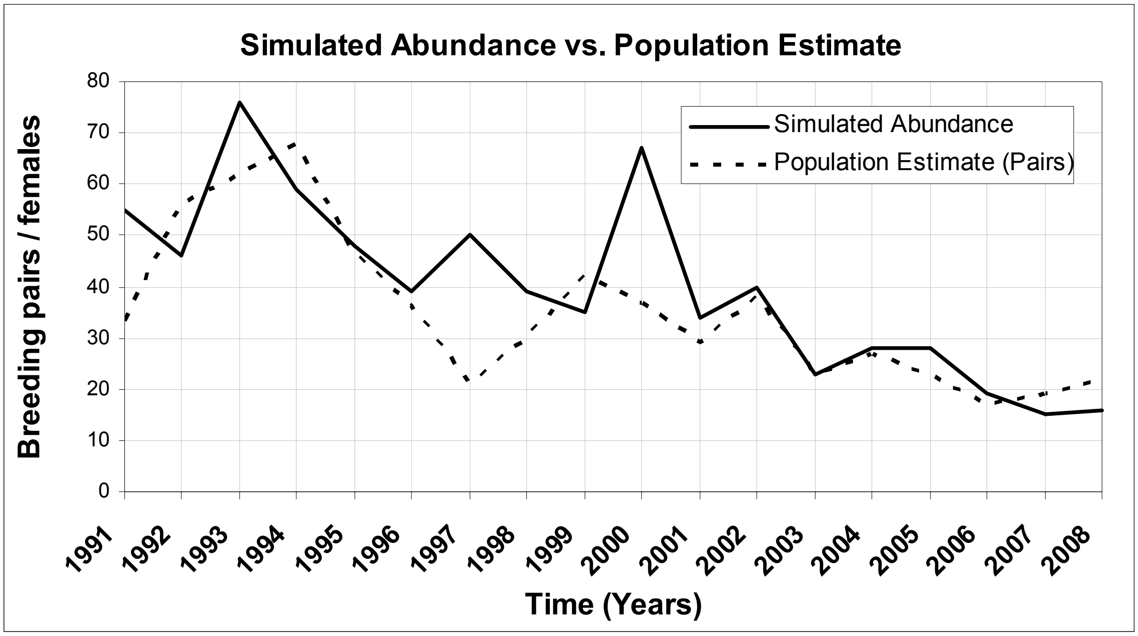


Figure 9: Simulated vs. empirical population trend over 18 years. Simulated abundance reflects the number of adult females in the model population.

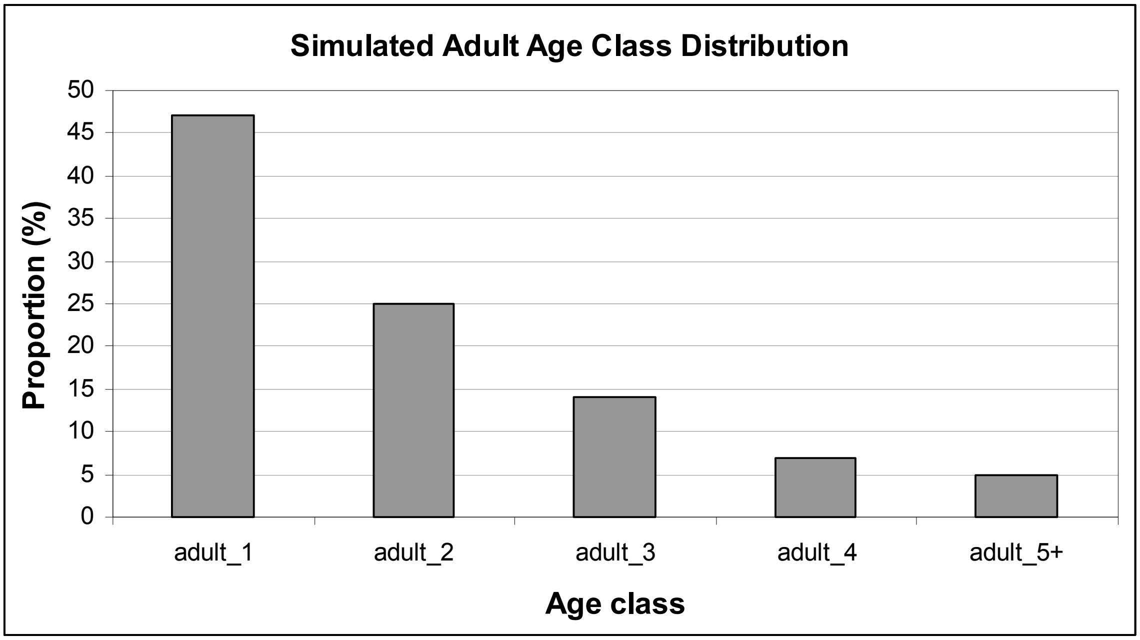


Figure 10: Simulated age class distribution

4.1.1 Population trajectory

The average abundance of females across 1000 replicate, stochastic simulation runs is shown in Figure 11. The initial population size was set to 54 females based on the y-intersection (53.647) of the trend line in Figure 1. The average abundance follows a nearly linear decline with a negative trend of minus 2 females per year resulting in 18 females (breeding pairs) after 18 years.

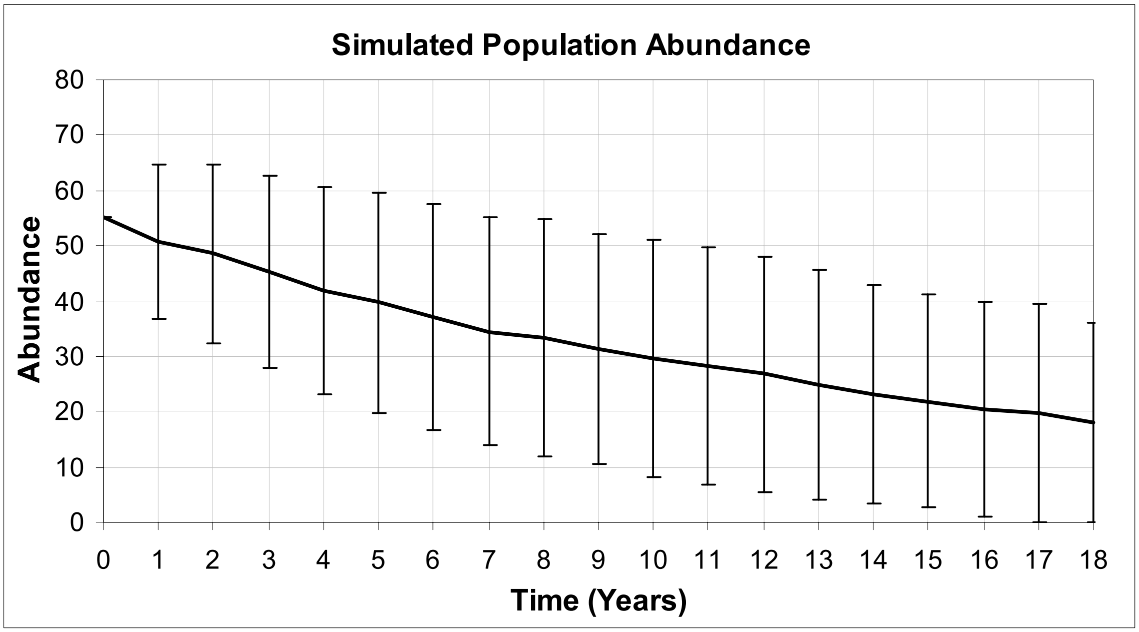


Figure 11: Simulated population abundance over 18 years. Averages are based on 1000 replicate, stochastic simulation runs. Error bars represent standard deviations around averages. Simulated abundance reflects adult females in the model population.

4.1.2 Extinction risk

The extinction risk is calculated as the proportion of the 1000 replicate simulation runs in which the population abundance went to zero throughout the simulation run. For example, an extinction risk of 10 corresponds to 100 out of 1000 simulation runs with a simulated zero population size over the course of 100 years. The extinction risk is a function of time and naturally increases with a larger time span. The negative growth rate of the simulated Loggerhead Shrike population predicts certain extinction within 100 years. Still, due to stochastic and deterministic influences, the extinction probability does not increase linearly over time as shown in Figure 12. Likewise, the final population abundance does not decrease linearly over time. The model predicts an estimated time to extinction of 43 years based on an initial population size of 54 breeding pairs. The time to extinction is the median of the distribution of extinction events (population size becomes zero) over time.

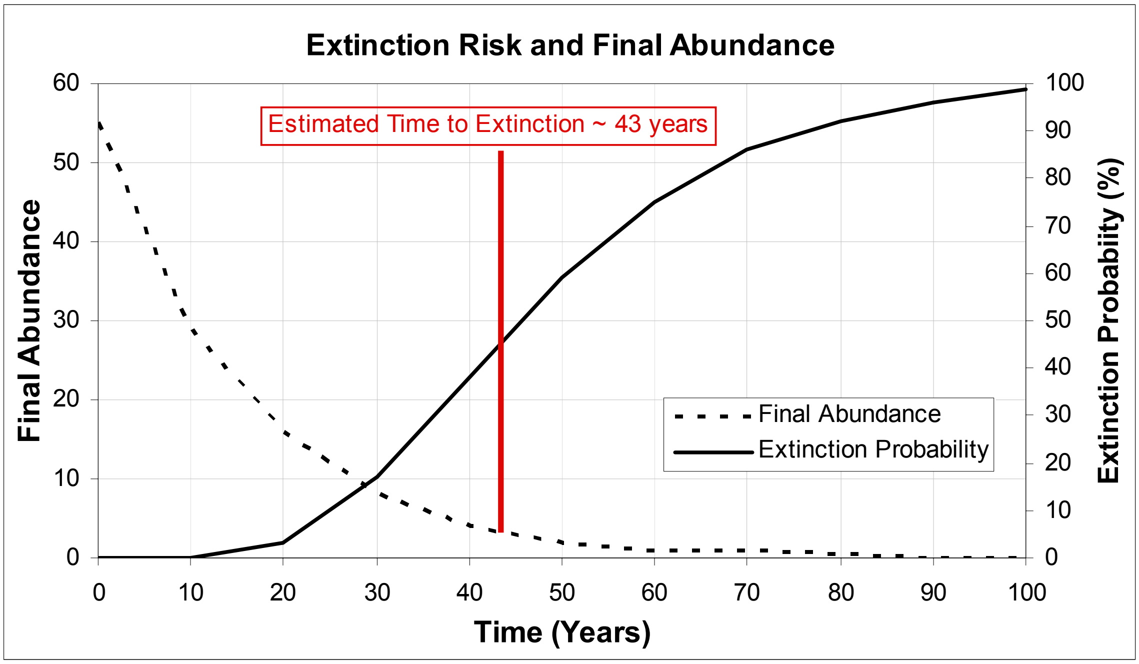


Figure 12: Extinction probability and final population abundance (adult females) as a function of time. For example, the extinction risk for a 30 year time frame is about 10% with an estimated final abundance of 9 breeding pairs. The estimated time to extinction is about 43 years based on an initial population size of 54 females or breeding pairs. The extinction risk over a time horizon of 100 years amounts to nearly 100 percent.

4.1.3 Minimum viable population size

The minimum viable population size (MVP) was simulated for time horizons between 10 and 100 years under consideration of a final extinction probability of 5% (Figure 13).

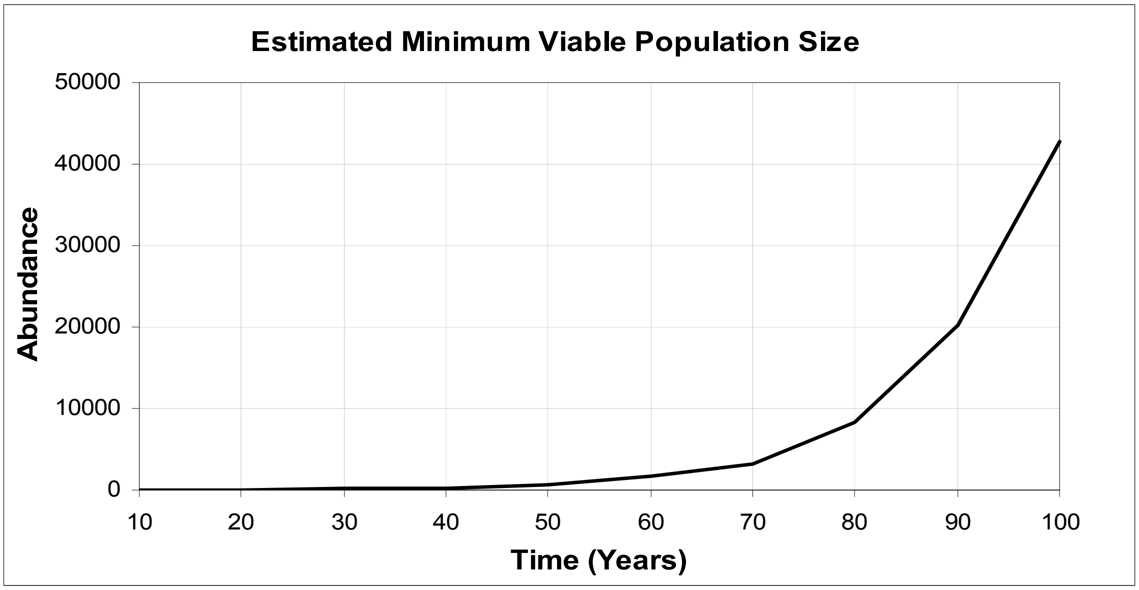


Figure 13: MVP as a function of time. At least 20000 breeding pairs would be necessary to ensure a 5% extinction risk over 90 years if the current population trend remains.

4.1.4 Sensitivity analysis

In a conventional sensitivity analysis relationships between single model parameters and a simulated response variable (e.g. final abundance or extinction risk) are evaluated separately by varying one model parameter at a time. Such functional relationships are insightful, but do not consider interaction effects with other model parameters and they do not reveal the relative importance of this or all model parameters to the simulated response variable.
Another approach would be to vary all model parameters over a comparable range and simulate a factorial or randomized set of model parameter combinations. The simulated data set could then be scrutinized by statistical methods, which could reveal more comprehensive sensitivities and relative importance of all model parameters.

So far this has not been feasible using established population simulators such as Ramas©MetaPop. However, thanks to recent efforts by Janelle M. R. Curtis and Ilona Naujokaitis-Lewis at the Centre for Applied Conservation Research, University of British Columbia, a program GRIP was developed (supported in part by Parks Canada), which allows automated execution of a set of randomized model parameter combinations. GRIP (Curtis and Naujokaitis-Lewis 2008) varies model parameters randomly and executes RAMAS for each randomized parameter combination, hence providing for an automated sensitivity analysis based on randomized parameter variations of the initial Ramas@Metapop population model.

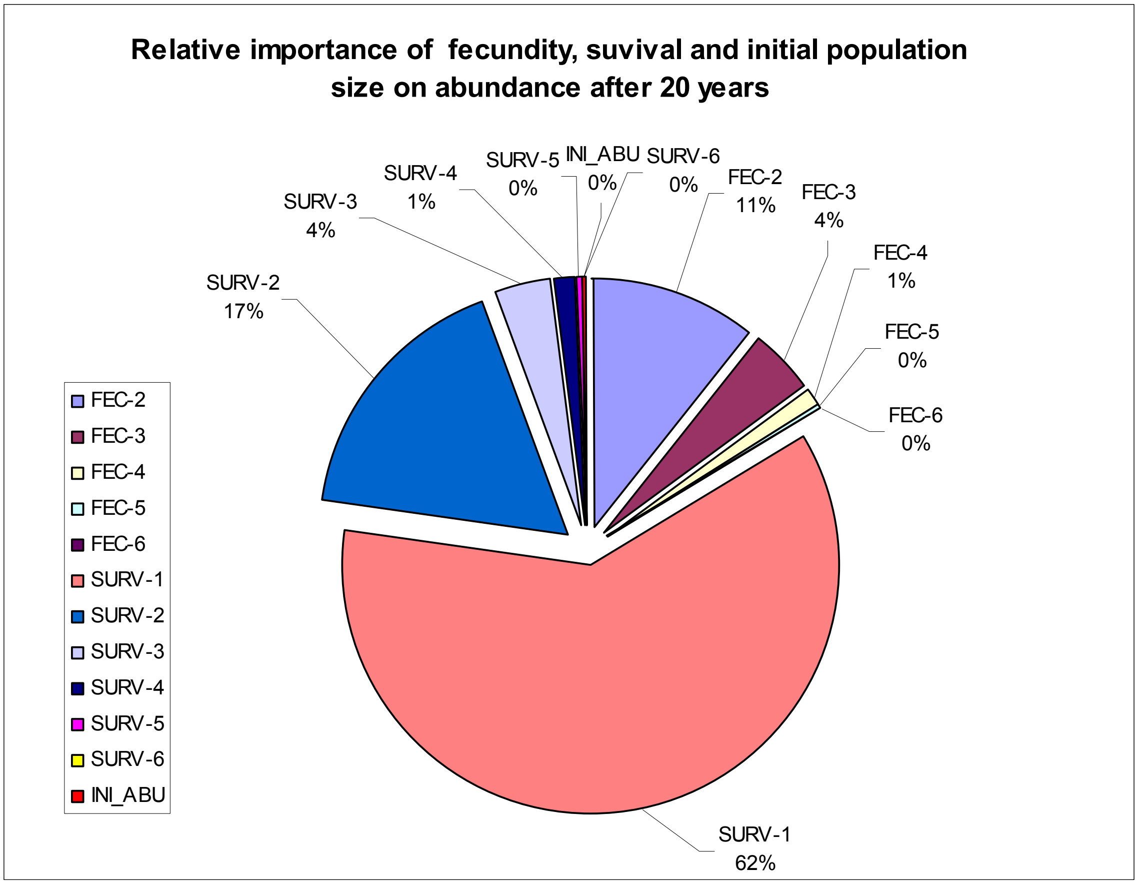


Figure 14: Relative importance of model parameters. “FEC“ refers to fecundity of a certain age class and “SURV” to survival rates of a certain age class. INI_ABU refers to the initial abundance of females in the model. Survival of fledglings accounted for 62 percent in abundance variation after 20 years and survival of all age classes combined explained 83 percent of abundance variation. The relative importance of combined fecundity amounts to 17 percent. Initial abundance did not show a significant effect.

GRIP was made available for the purpose of this project in order to conduct a comprehensive sensitivity analysis of the population model. A slightly modified version of GRIP was used to vary the following model parameters randomly by drawing random numbers from normal distributions with a standard deviation of 10 percent (fecundity, survival, initial abundance).

1000 model runs (each run was internally repeated 1000 times resulting in 1 million actual runs) were performed, each with a different set of model parameter values. The resulting data set was analyzed by means of ANOVA (using SAS, SAS 1990) and the relative importance of each significant model parameter was then determined using Type III Sums of Squares. The results are shown in Figures 14, 15, 16 and 17.

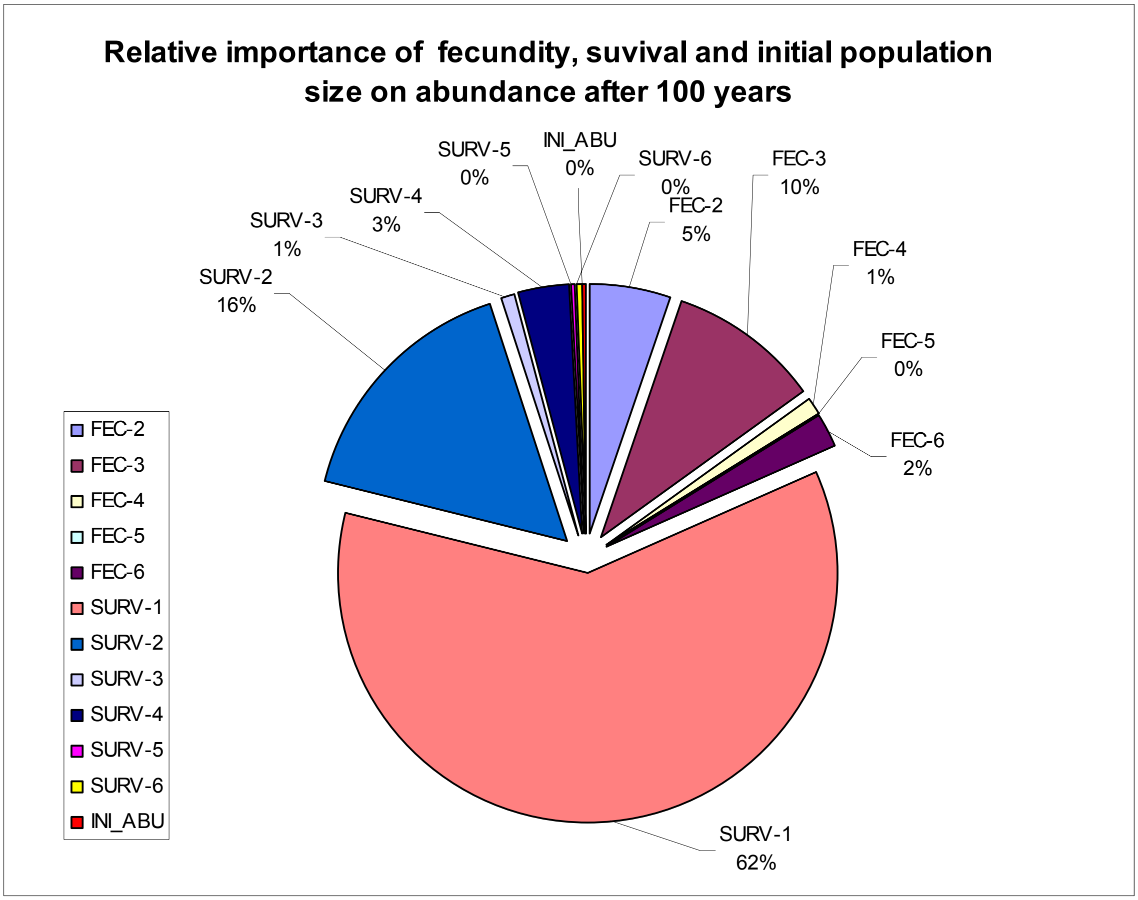


Figure 15: Relative importance of model parameters related to final abundance after 100 years. Results are very similar compared to those presented in Figure 14.

Figures 14 to 17 consistently reveal the main drivers of the simulated population dynamics. Survival rates of juveniles (SURV-1) and young adults account for more then three quarters of variation in population abundance and extinction risk over 20 and 100 years. The remaining variation is consistently explained by fecundity although not evenly distributed amount the five age classes and also not consistently across time frames and response variables. The importance of fecundity of a certain age class seems to be a matter of the response variable and the time frame under consideration. It is noteworthy that initial population size, which was also varied randomly by 10 % did not show a significant effect on any of the response variables and is therefore much likely of lesser relative importance for the long term fate of the population.

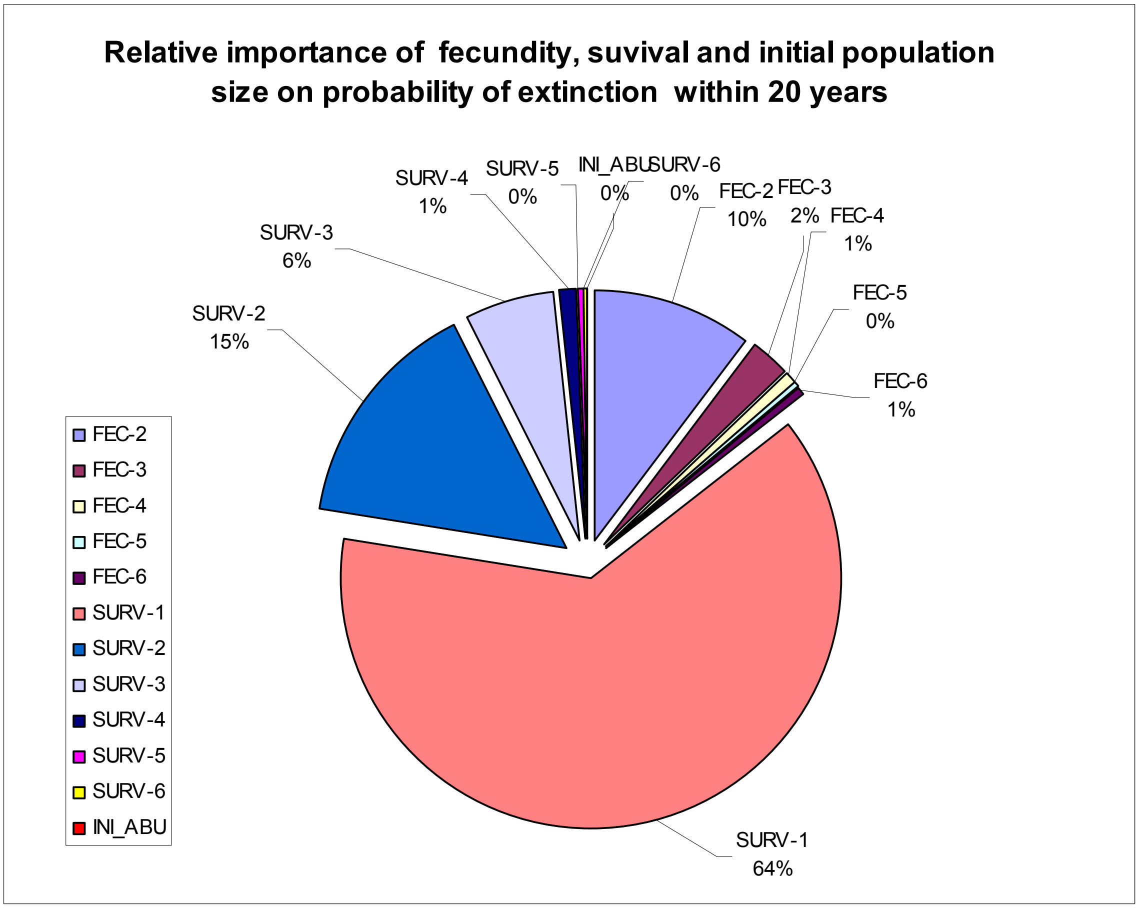


Figure 16: Relative importance of model parameters related to extinction probability within 20 years. Results are similar to those presented for final population abundance in Figures 14 and 15.

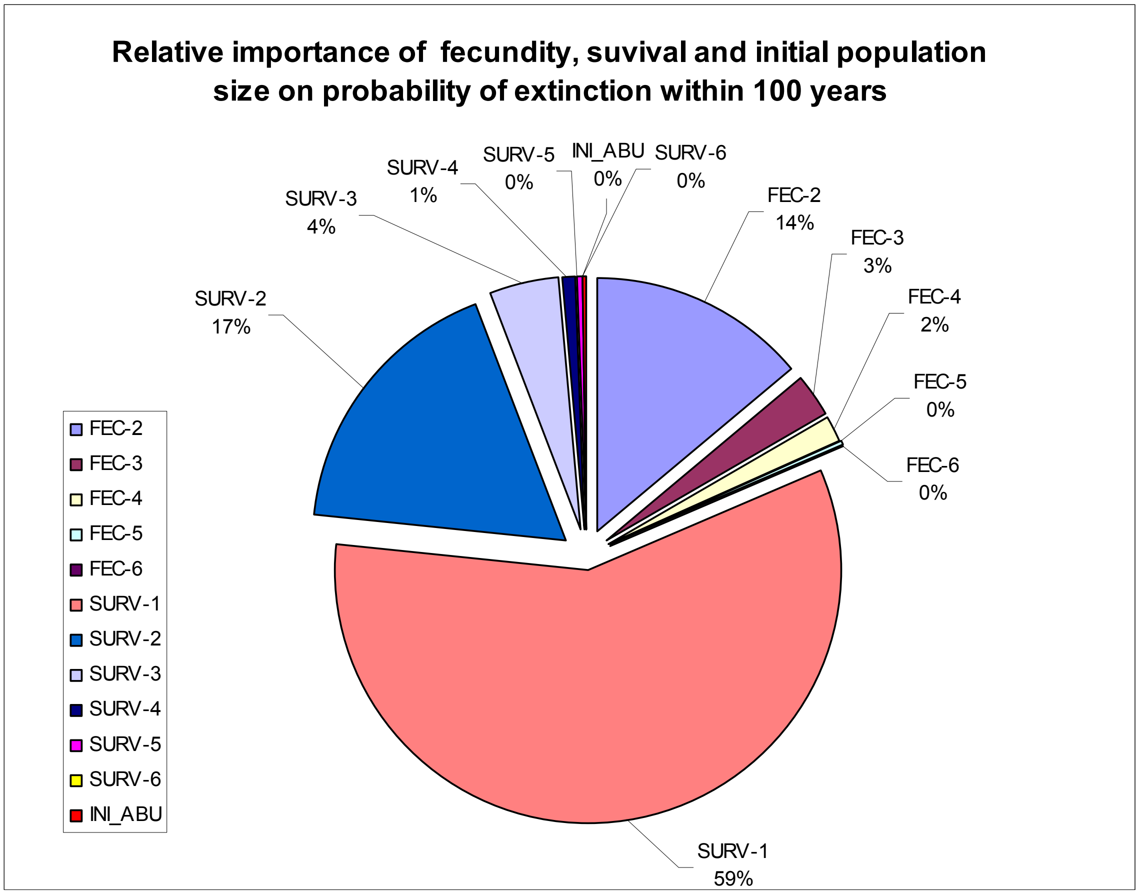


Figure 17: Relative importance of model parameters related to extinction probability within 100 years. Combined survival rates explained 81 percent of variation in extinction risk.

4.1.5 Polygynous vs. monogamous mating system

As outlined in section 2.5, Loggerhead Shrikes in Ontario exhibit a rather unique mating system with multiple females sometimes attending one nest and males occasionally breeding with multiple females. Although the reasons for this behavioural anomaly are not completely understood, the potential effect on the viability of the Ontario population is of imminent interest. The population model was therefore modified from a female only model to a male/female model with the opportunity to model a strictly monogamous or partly polygynous mating system.

Polygynous or polyandrous mating systems are of benefit to population viability only if the sex ratio in the population is biased either naturally or by a disadvantage of one gender with respect to survival rates. The following scenario was therefore based on the assumption that all adult males in the simulated population have a 10 percent lower survival rate then their female counterparts. This adjustment results in a biased sex ratio and opens the opportunity for exploring the beneficial effects of a polygynous mating system on population abundance and potential extinction risk. The results are shown in Figures 18 and 19. These results demonstrate that even a partially polygynous mating system may have a positive effect on population abundance and consequently on the viability of a population with fewer males than females.

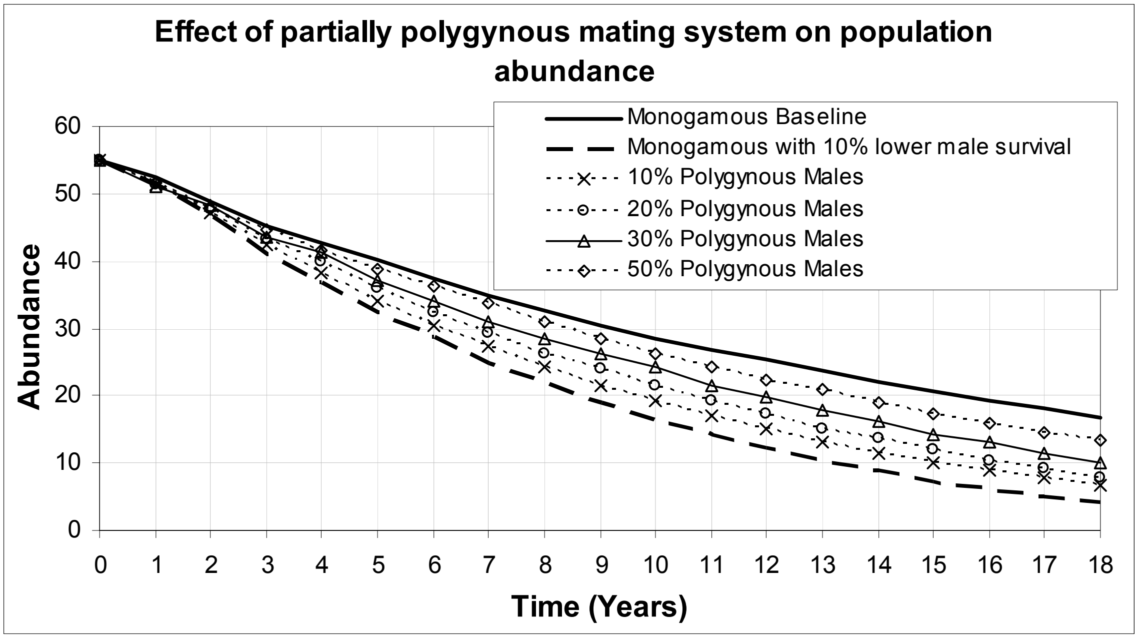


Figure 18: Simulated population abundance for a monogamous population with equal and biased (10% lower) male survival. The proportion of polygynous males in the population can compensate for the effect of a biased sex ratio as simulated abundance increases with increasing number of polygynous males in population.

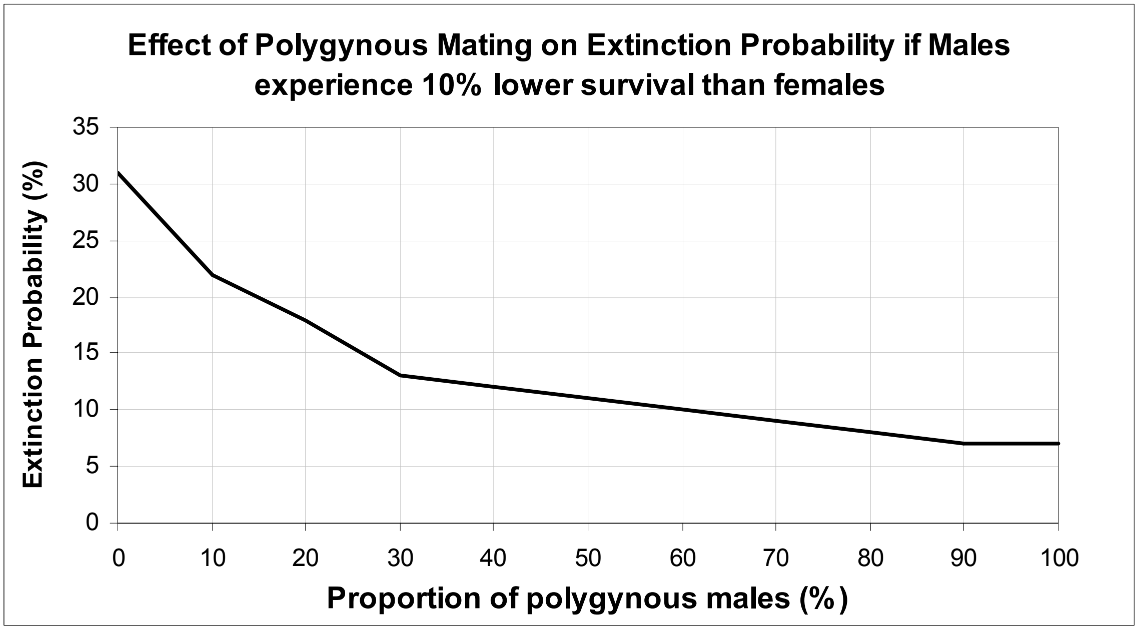


Figure 19: Simulated relationship between extinction risk and proportion of polygynous males in population when males experience a 10 percent lower survival rates than females.

4.1.6 Captive Breeding – reality vs. theoretical expectations

The observed effect of the captive breeding program on population abundance in Ontario has been outlined in section 2.4. Despite the positive effect on the recent population trend primarily in the Carden subpopulation, it remains unclear as to whether this effect should have been expected or whether a much stronger effect could have been expected. In other words, a quantitative assessment by means of a simulated scenario should allow us to put the observed success into the perspective of calculated expectations.

As presented in section 2.4, between 2004 and 2008 a total of 392 captive bred HY were released in Ontario – on average about 78 HY per year. Due to constraints in introducing a different number of individuals to a population in different years in Ramas@Metapop, the average number of 78 HY was introduced to the simulated population as of year 14. The introduced HY would be subject to the same vital rates as those produced from the simulated adult females. The results are shown in Figure 20. It appears that introducing on average 78 HY to a population of about 23 breeding pairs annually should result in a significant population growth even within 4 to 5 years of the initial release. Given that all other model assumptions and parameter values remain unchanged, the simulation predicts a final population size of about 70 breeding pairs – a threefold increase compared to the starting point of the simulated releases.

Unfortunately, the real outcome has remained far below such predictions. This situation triggers the question as to how many birds would have to be released in order to predict a population growth as observed in Ontario (see Figures 4 and 5). In a separate scenario, the number of introduced HY was lowered to a point where the change in simulated population growth resembled its empirical counterpart as presented in section 2.4.

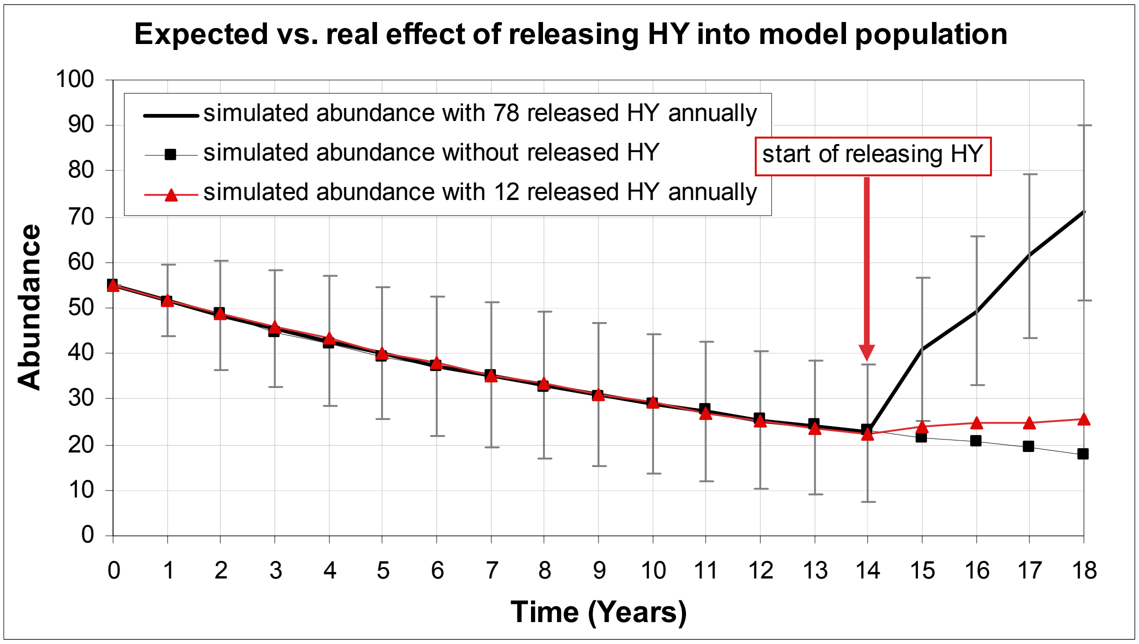


Figure 20: Simulated scenario of introducing HY into a simulated population. When 78 HY are introduced annually and all else being equal, the simulated population would triple after just 4 years. Just 12 HY must be introduced into a simulated population in order to mimic the observed change in population trend.

The results suggest that on average 12 introduced HY should reverse the negative population growth to a slightly positive trend. In other words, the results of this scenario suggest that about 12 of 78 HY released annually should produce a population trend as observed in Ontario since 2003. One could conclude that about 60 HY or about 80 percent of all released birds do not contribute to population growth in Ontario and that the ratio of released to effective HY is about 1/6.

Figure 21 shows the relationship between the time frame of releasing HY into a simulated population and the resulting change in extinction risk within 100 years. This relationship demonstrates that without any change in the demographics of the Loggerhead Shrike populations as observed so far, the captive breeding program may indeed become a long-term life line for the population in Ontario. The captive breeding program would have to show a lasting positive impact on either fecundity and/or survival rates in order to facilitate a self-sustaining wild population in Ontario. So far there has been no empirical evidence for either an increased reproductive performance of mixed wild-captive breeding pairs or an increases survival rate. In fact, most of the released birds did much likely not contribute to population growth in Ontario. The reasons for the lack of expected returns or re-sightings may be attributed to an elevated over-winter mortality or to birds returning to different breeding grounds in North America. If the latter hypothesis holds true, benefits of the captive breeding program in Ontario should be seen elsewhere.

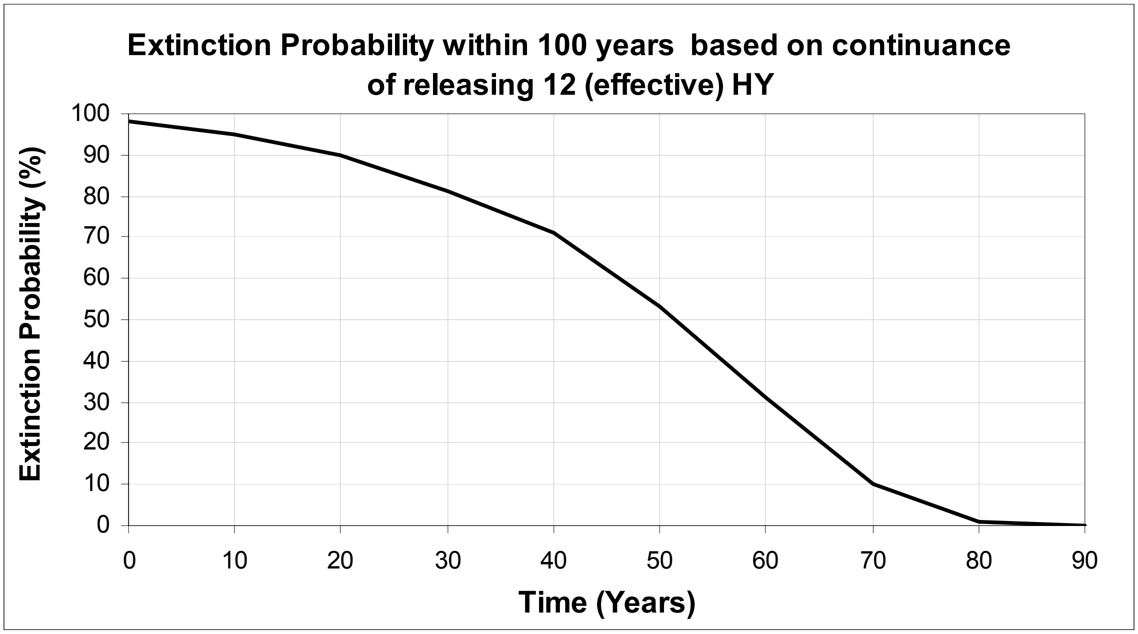


Figure 21: Relationship between the time frame of continuation of the annual release of captive bred HY and the resulting extinction risk over 100 years. For example, if the release of 78 (effective 12) HY would continue for 20 years, the extinction risk over 100 years would be reduced by 10 percent.

4.1.7 Summary

The non-spatial, single population model reproduces the observed empirical population trend and predicts a nearly 100 percent extinction risk within a time period of 100 years. The estimated time to extinction is about 43 years, much likely shorter if the rate of population decline as observed over the last 18 years remains unchanged. A theoretical minimum viable population size to compensate for the negative population growth rate would be at least 5 orders of magnitude above the current population size in Ontario. This result should be deemed as an unrealistic conservation target.

A comprehensive sensitivity analysis of all model parameters against two response variables over two different time spans consistently revealed the main driver of the population dynamics to be survival rates of juveniles and young adults. This result confirms and is consistent with conclusions from previous studies in that over-winter survival seems to be the single most important cause for the decline of migratory Loggerhead Shrike populations across North America (section also 2.8).

Two scenario based simulations revealed insights into potential effects of a polygynous mating system and provided a quantitative benchmark for recovery expectations in the presence of continuous releases of captive bred fledglings to the wild population. The results suggest that polygynous males are likely to be beneficial for overall population viability in the presence of lower male survival rates. The simulated introductions of 78 HY annually to a declining population resulted in a much stronger population growth then observed in Ontario's population between 2003 and 2008. These results suggest that an annual release of just 12 HY should match the population growth in Ontario. This raises the questions to the whereabouts of 1/6 of all released birds, which most likely do not contribute to population growth in Ontario. In addition, without a lasting positive impact on demographic rates, the captive breeding program alone may not be sufficient to re-store Ontario's Loggerhead Shrike population to be self-sustaining.

4.2 Spatially explicit meta-population model

This section presents the results of a spatially explicit meta-population model of Ontario's subpopulations. From a genetic point of view it seems unlikely that Ontario's population represents a true meta-population. Still, the geographic arrangement of 6 distinctive breeding grounds as shown in Figure 22 warrants the exploration of potential effects of connectivity by means of dispersal between subpopulations. The primary concern of a meta-population model relates to the re-colonization of locally extirpated populations, which in turn facilitates utilizing all available habitat. Meta-population dynamics become more important when overall habitat amount is low and populations are constrained by amount and/or quality of their breeding habitat.

Figure 22: Boundaries around observed Loggerhead Shrike nests delineate 6 subpopulations in Ontario. (Map obtained from Rich Russell)

Based on known dispersal distances of up to 147 km (see section 2.7) dispersal between any two adjacent breeding grounds in Ontario seems possible because edge-to-edge distances of adjacent breeding grounds do not exceed 80 km. The population model as described in section 3.1 was slightly modified. First of all, the single population was split up into 6 populations. Initial population size for each population was calculated proportional to the average abundance of breeding pairs between 1991 and 2008 (data as provided for section 2.1). Furthermore, due to sufficient data for the Carden and Napanee subpopulations, separate fecundity values could be calculated and were used for these two populations in the meta-population model. For all other populations demographic rates as defined for the non-spatial, single population model were used.

Figure 23 shows a schematic presentation of the meta-population model. Dispersal rates are shown in Figure 24. A complete summary of the meta-population model is provided in the Appendix.

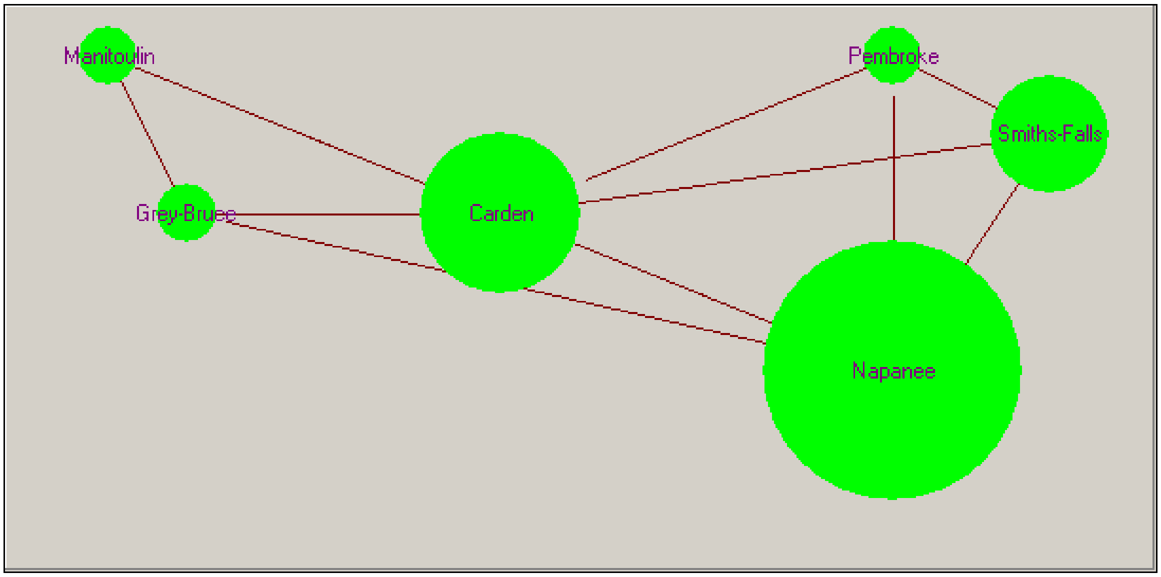
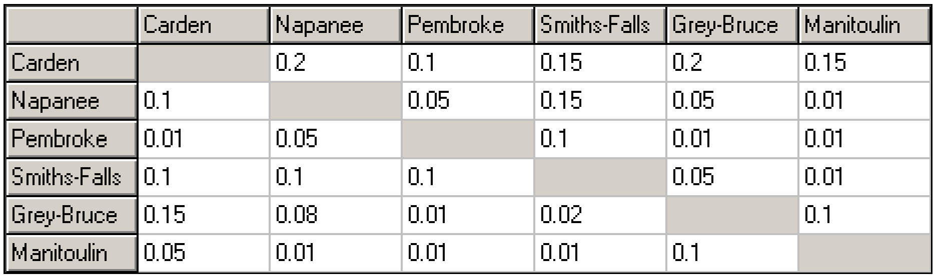


Figure 23: Schematic presentation of the meta-population model. The size of the circles indicates the proportional initial population size. Lines between circles identify connections based on dispersal rates between these populations. The distances between circles are not based on the geographical distances as shown in Figure 22.



	Carden	Napanee	Pembroke	Smiths-Falls	Grey-Bruce	Manitoulin
Carden		0.2	0.1	0.15	0.2	0.15
Napanee	0.1		0.05	0.15	0.05	0.01
Pembroke	0.01	0.05		0.1	0.01	0.01
Smiths-Falls	0.1	0.1	0.1		0.05	0.01
Grey-Bruce	0.15	0.08	0.01	0.02		0.1
Manitoulin	0.05	0.01	0.01	0.01	0.1	

Figure 24: Dispersal rates between any two populations in the meta-population model. (provided by Rich Russell) Only juveniles and 50 percent of one year adults could disperse in the meta-population model. These rates would apply to the number of individuals in these two age classes.

4.2.1 Population Trajectory

The simulated average population trajectory (average across 1000 replicated simulation runs) is shown in Figure 25. This result almost resembles the simulated population abundance of the non-spatial, single population model (compare to Figure 11). This similarity indicates that the spatial configuration of the 6 subpopulations and potential isolation might have a very minor effect on the population dynamics in Ontario. Even in the presence of no simulated dispersal, the outcome remains virtually unchanged, indicating a very low relative importance of dispersal, which will be analysed in more detail in section 4.2.3.

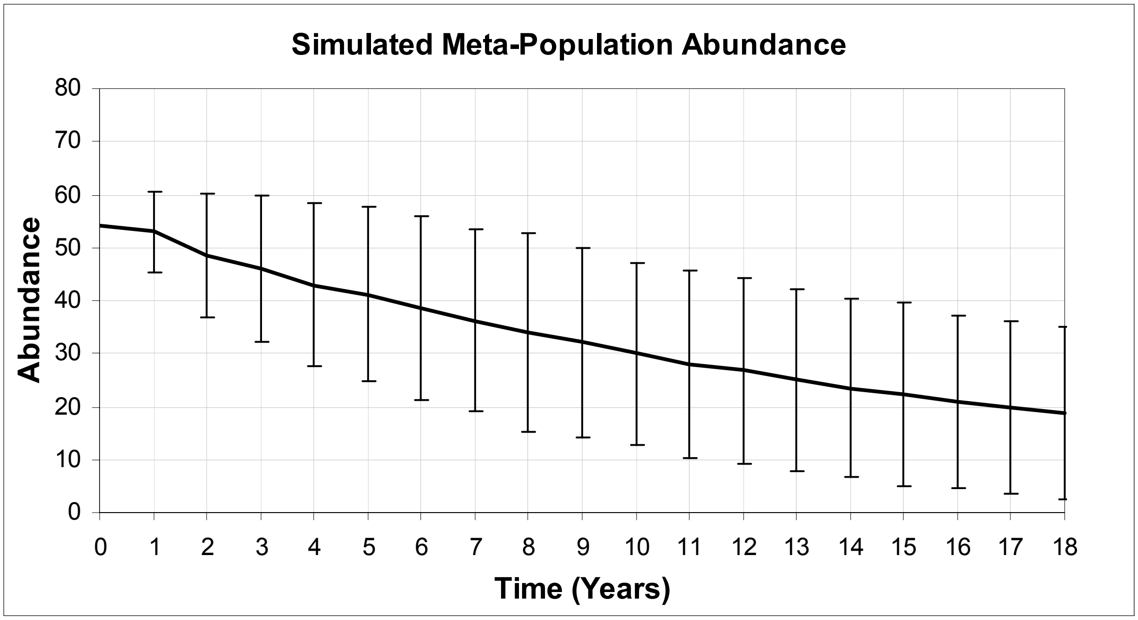


Figure 25: Simulated meta-population abundance over 18 years. Averages are based on 1000 replicate, stochastic simulation runs. Error bars represent standard deviations around averages. Simulated abundance reflects adult females in the model population.

4.2.2 Extinction risk

The extinction risk as predicted for the meta-population model is also virtually identical to that obtained for the non-spatial, single population model (see section 4.1.2) indicating again that isolation or dispersal may be of minimal importance to the viability of the Loggerhead Shrike population in Ontario in the presence of a strong negative growth rate.

4.2.3 Sensitivity analysis

A similar sensitivity analysis as described and presented in section 4.1.4 has been conducted for the meta-population model. In addition to the varied model parameters (fecundity, survival and initial population size) dispersal rates among populations were varied so that the resulting average dispersal rate between all populations varied within 10 percent standard deviation. The results are shown in Figures 26 and 27.

Overall, this sensitivity analysis confirms a comparatively low sensitivity of dispersal for population abundance and extinction risk within a 100 year time frame. This result should not be misinterpreted or generalized. Dispersal among disconnected populations is mostly beneficial for the viability of meta- or spatially structured populations and dispersal does have a positive effect even for the Loggerhead Shrike subpopulations in Ontario. The low sensitivity merely reflects the fact that other demographic characteristics currently have a far greater impact and therefore a much larger relative importance to the viability of the meta-population.

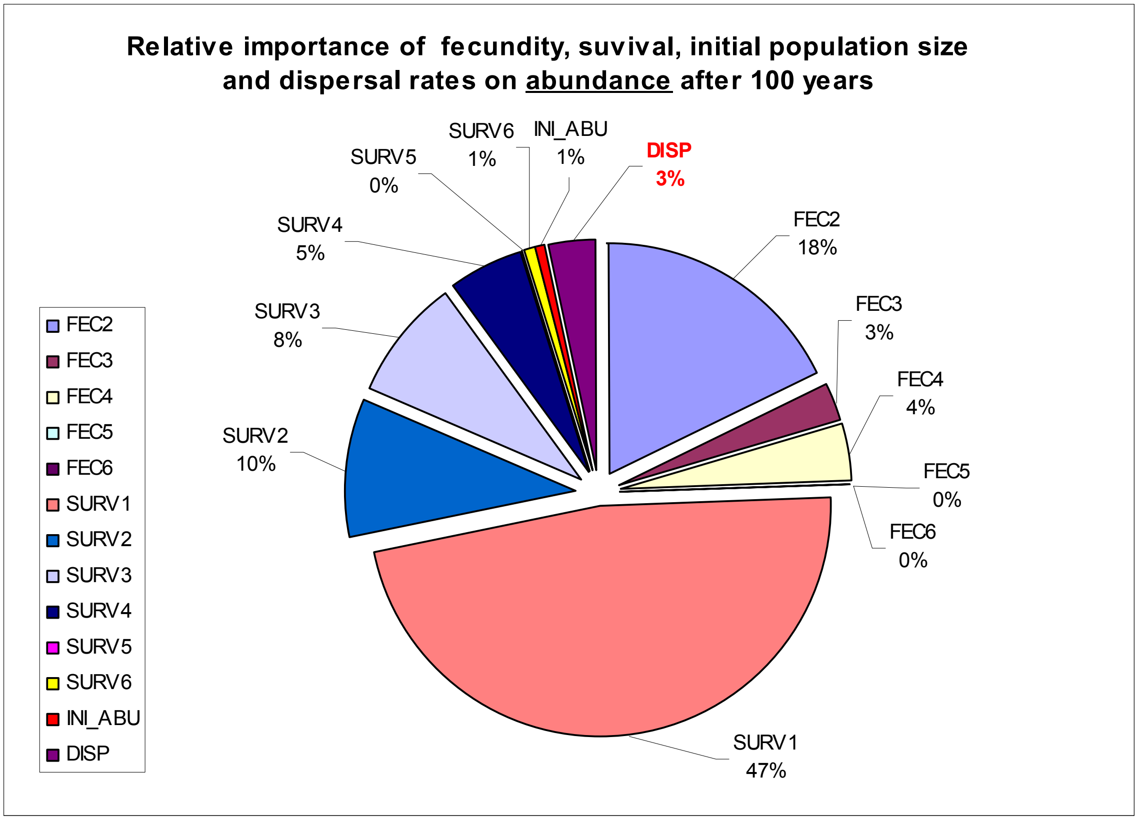


Figure 26: Relative importance of meta-population parameters to abundance after 100 years. Parameter names as described in Figure 14. DISP refers to the average dispersal rate between all 6 populations. Overall, DISP accounts for just 3 percent in variation of population abundance. Survival across all age classes accounts for 71 percent of variation and fecundity for about 25 percent.

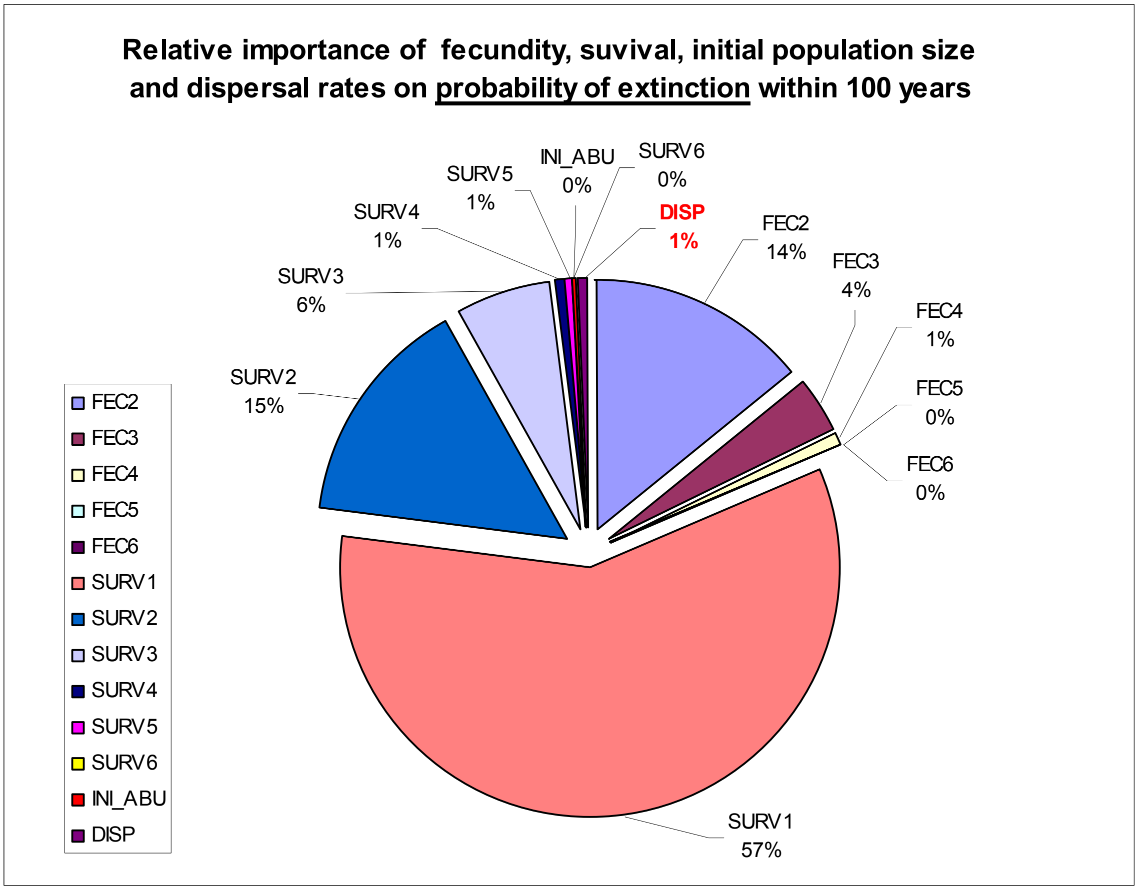


Figure 27: Relative importance of meta-population parameters to extinction probability within 100 years. Results are similar to those shown in Figure 26.

4.2.4 Summary

The results of the meta-population model suggest that connectivity between the six identified breeding grounds is most likely of lesser concern compared to the intrinsic imbalance of the demographic rates and the resulting negative growth rate of the population.

4.3 Scenarios and decision support

Evaluation of the first version of this report revealed a lack of appropriate scenarios in support of deriving conservation targets and recovery goals. It was generally acknowledged that the negative growth rate of the rather small Ontario population of the Eastern Loggerhead Shrike and the lack of a significant positive impact of the captive breeding program until now cannot be used for deriving meaningful population targets. It was therefore decided by the project authority to consider various scenarios and relationships based on assumptions such as inflated survival rates, inflated and perhaps more realistic standard deviations around those and inconsistency in population productivity between consecutive years. Specific tasks were assigned to the contractor, the results of which are represented in the following sections.

"This exercise will inform what a minimum population size, based purely on demographic rates and their variability, might be under a variety of scenarios. This exercise will not consider any genetic consequences of small populations, such as loss of allelic diversity." (SOW)

4.3.1 Inflated survival rates

"Simulate populations where vital rates are inflated from those in the current PVA, to reflect a stable population. Since fecundity is well quantified, and appears to be within reasonable norms, this exercise should focus on the 2 survival rates (juveniles and adults). Each survival rate should be adjusted independently, leading to 2 different models. This approach assumes that whatever factor is depressing survival rates can be mitigated or that survival rates may be actually better than the rate estimated from the little data available." (SOW)

Survival rates for juveniles and adults (age classes adult_1 to adult_4) of the population model as presented in chapter 3 were modified. The growth rate for each survival rate was calculated as the difference between the average population size at the end of a 20 year simulation run and the initial population size divided by 20. The results are shown in figures 28 and 29.

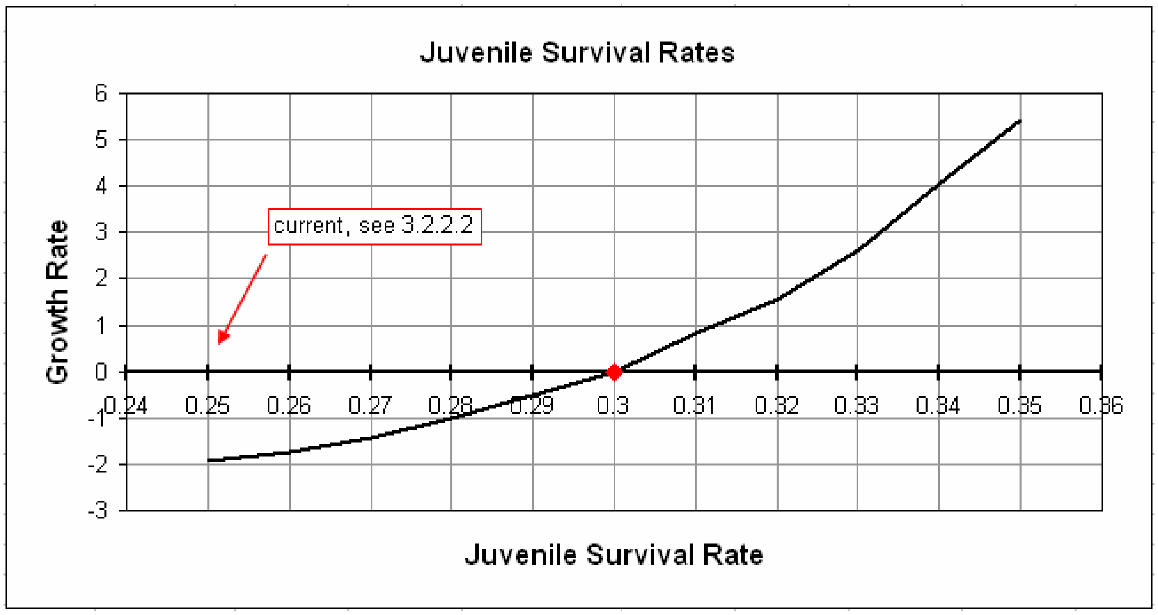


Figure 28: Relationship between juvenile survival rate and population growth rate. A 40 percent increase in juvenile survival would change population growth rate by more than 300 percent.

Figure 28 shows that a 20 percent inflation of the currently assumed juvenile survival rate (0.25 to 0.3) would result in a neutral population growth, i.e. a stable average population size over 20 years. Likewise, a 20 percent inflation of the currently assumed adult survival rate (0.5 to 0.6) would lead to a neutral population growth over 20 years. Two hypothetical population models can be derived from this exercise. The first model with a changed juvenile survival rate of 0.301 and the second model with a changed adult survival rate of 0.501. Both models independently result in a neutral population growth with all other model parameters and assumptions – as outlined in chapter 3 - unchanged.

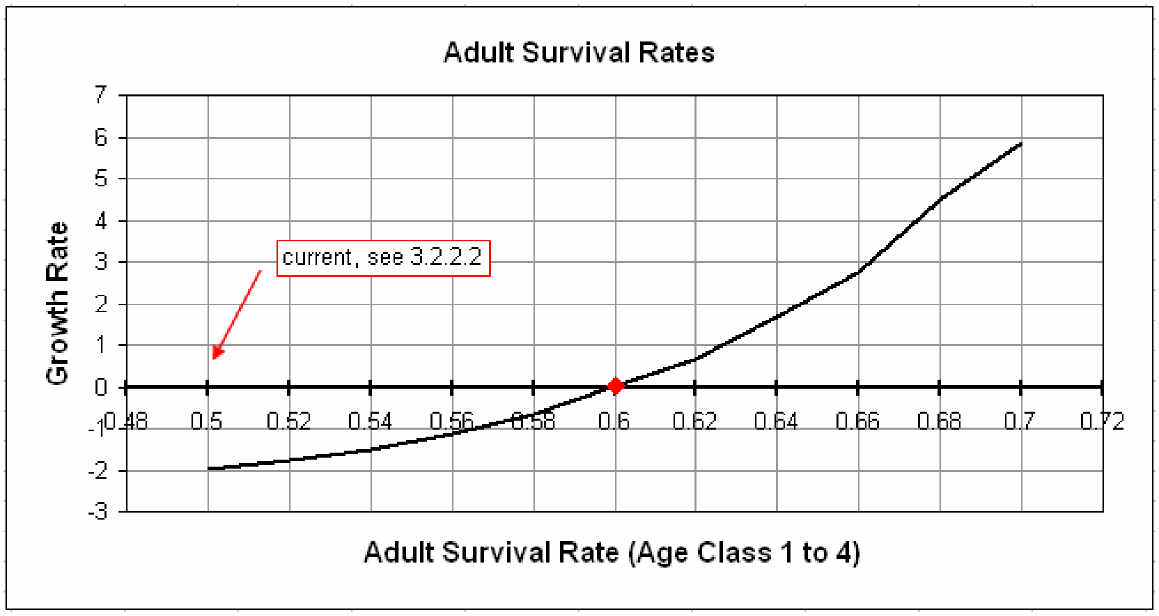


Figure 29: Relationship between adult survival rates and population growth rate. Similar to figure 28, a 40 percent increase in adult survival would change population growth rate by more than 300 percent.

4.3.2 MVP based on inflated survival rates

"Using these 2 populations with inflated survival rates, calculate minimum viable population sizes under a variety of scenarios of temporal variation in survival. The current model uses 10% as the SD in the survival rates. In addition, calculate MVPs, using 5%, 20% and 40% SD in survival." (SOW)

The two modified population models with inflated survival rates for juveniles and adults where subjected to different standard deviation around survival rates. The results are shown in figures 30 and 31. The model predicts a minimum viable population size of about 200 female adults (equivalent to breeding pairs) over a time span of 100 years and a maximum extinction risk of 5 percent. Higher standard deviations increase the risk of extinction and therefore result in larger minimum viable population sizes.

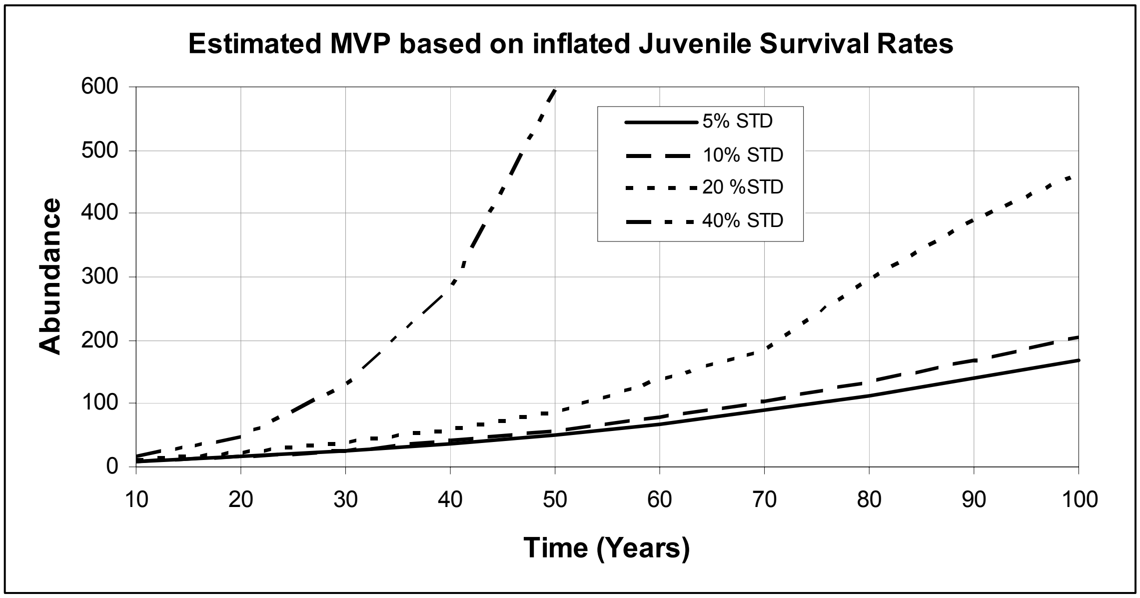


Figure 30: Simulated Minimum Viable Population sizes based on population model with inflated juvenile survival rate of 0.301 with different standard deviations around juvenile survival rate. A 10% STD in inflated juvenile survival would require about 200 breeding pairs for a viable population with an extinction risk lower or equal 5 percent over 100 years.

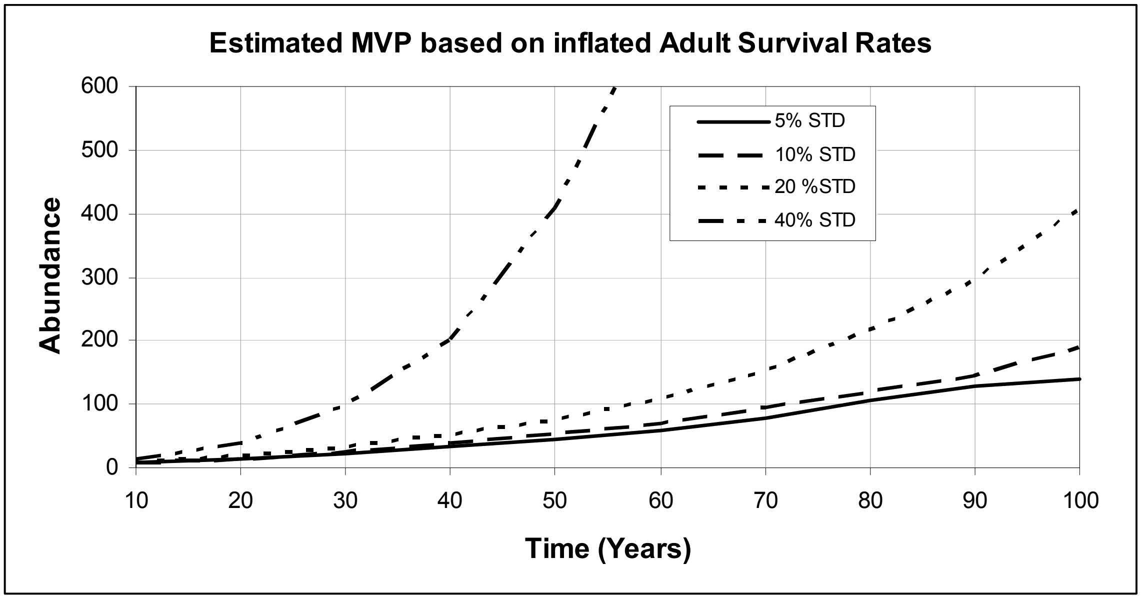


Figure 31: Simulated Minimum Viable Population sizes based on population model with inflated adult survival rate of 0.501 with different standard deviations around adult survival rate.

4.3.3 Juvenile vs. adult survival rates

“To better understand the relationship between the survival rates and population stability, plot a figure showing the combinations of juvenile and adult survival rates than will lead to a stable population, assuming fecundity values at the observed mean. Examine this relationship with increasing amounts of temporal variability in survival rates.” (SOW)

Combinations across a meaningful range of juvenile and adult survival rates were simulated. The results are shown in figure 32.

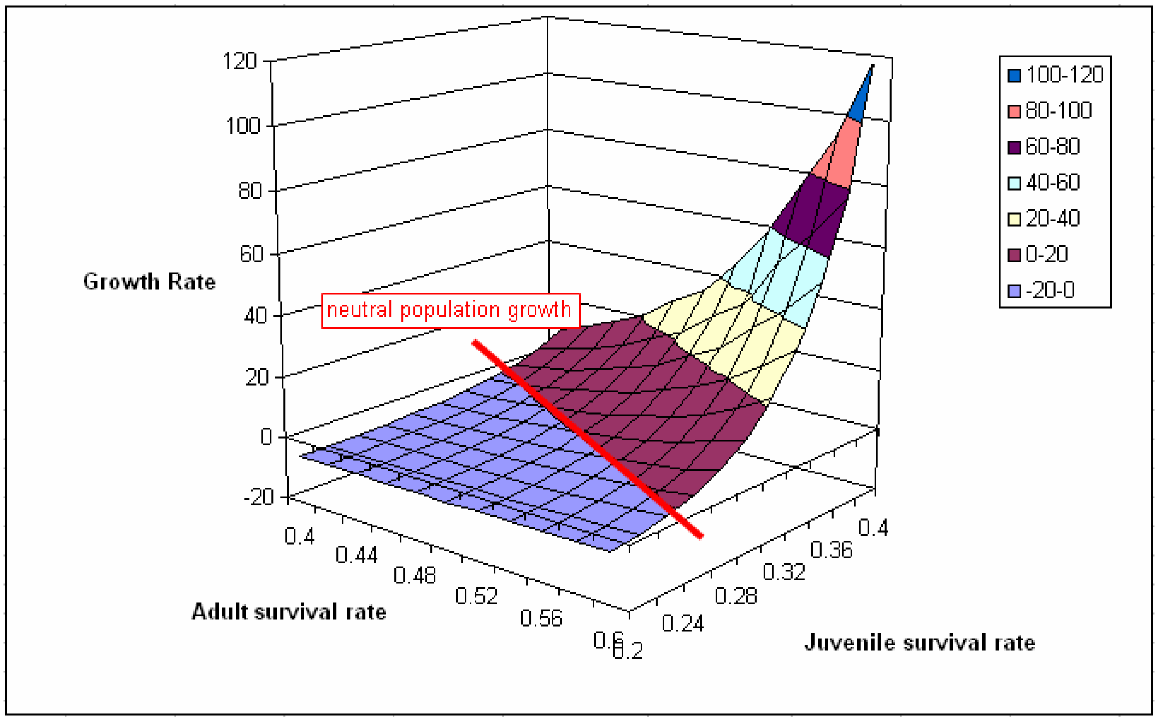


Figure 32: Combination matrix of juvenile and adult survival rates at 10% STD.

The neutral population growth line in figure 32 corresponds to parameter combinations as shown in figure 33. An increasing adult survival rate requires a lower juvenile survival rate and vice versa to support a neutral population growth.

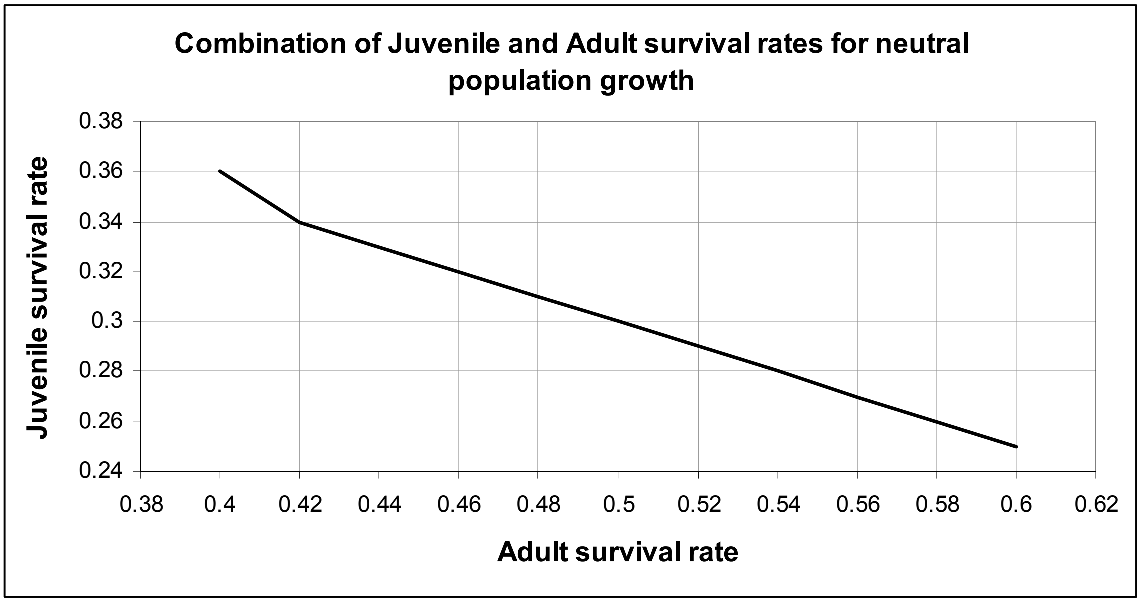


Figure 33: Combination of juvenile and adult survival rates resulting in neutral population growth.

4.3.4 Poor productivity

"Fledging rates have been one of the best estimated parameter in the actual population and they vary between years from 1 to nearly 5 fledglings/pair. The actual series of data is too short to adequately reflect the frequency of good vs. bad years. Assuming that there is no relationship between number of fledglings produced and survival, model, using survival parameters assuring a stable population, the impact of 1 to 4 years in 5 year showing poor productivity on the population. Ideally this should be done using as initial population size: A) half the actual number of pairs in the population B) the actual number of pairs; C) twice the actual number of pairs and 4 times the actual number of pairs."

Poor productivity was defined as either 90% (poor) or 80% (very poor) of fecundity values of the original population model. The frequency of "poor productivity" years was changed from none to 5 out of 5 years. The effect on the population was measured as extinction risk over 100 years. The results are shown in figures 34 and 35. The results show an increasing risk of extinction with an increasing frequency of "poor productivity" years. There seems to be a minor threshold or a significant shift in extinction risk when poor productivity years occur more frequently then 3/5 years. Initial population size also shows a significant effect on this relationship with smaller populations resulting in higher extinction risks. Very poor population productivity (figure 35) resulted in a similar pattern but with overall higher extinction risks.

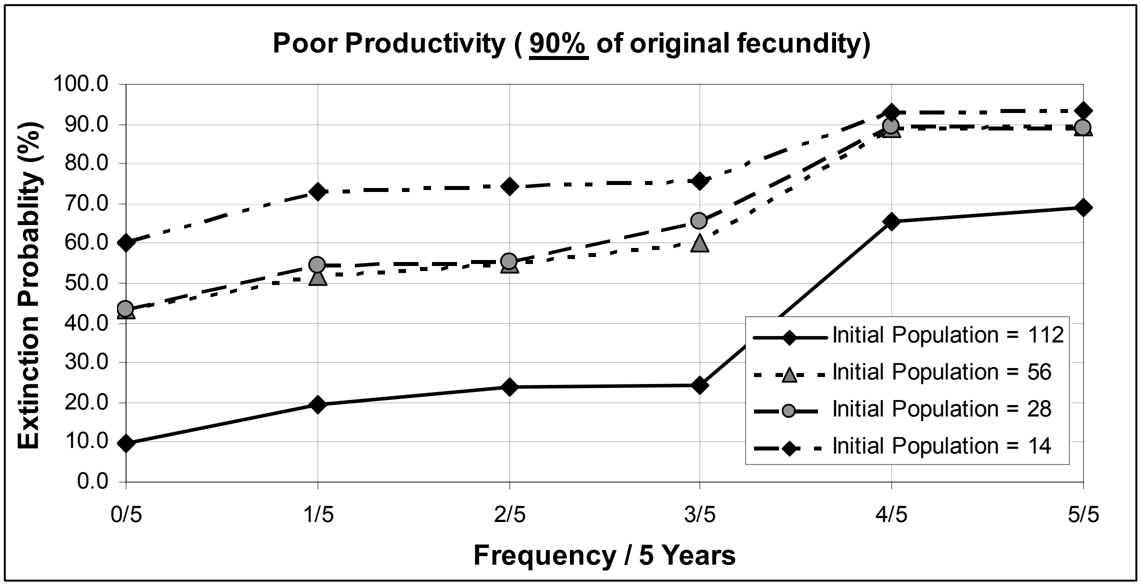


Figure 34: Relationships between frequency of years with 90% of original fecundity and extinction risk based on population model with inflated adult survival rates.

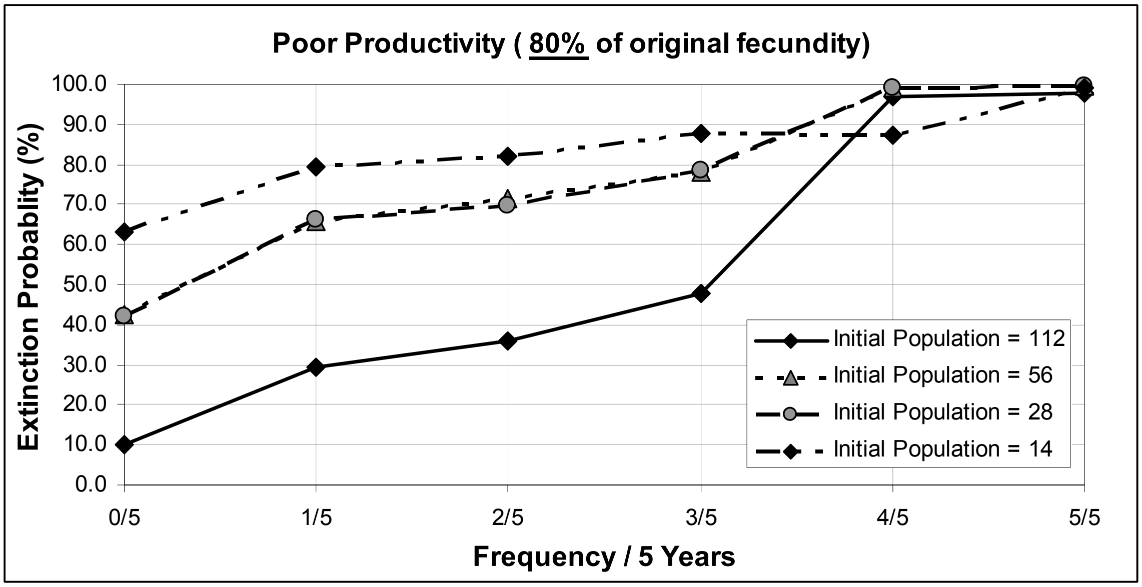


Figure 35: Relationships between frequency of years with 80% of original fecundity and extinction risk based on population model with inflated adult survival rates.

4.3.5 Released birds and population growth

"Finally, it would be useful to have a graph of population growth rate versus number of fledgling released, for a) at survival rates providing a stable population, and b) survival rates currently used in the model leading to a declining population."

The relationship between population growth rate and number of introduced (released) juveniles and one year adults was evaluated against the base model, the population model with inflated juvenile survival and the population model with inflated adult survival rates. Population growth was calculated based on the difference of the average population size after 20 years and the initial population size divided by 20. The results are shown in figures 36 to 38. This experiment revealed a fairly linear relationship between the number of released juveniles or adults and population growth rate. There seems to be a minor advantage of the population model with inflated juvenile survival rates.

It should be of interest that the model predicts a much stronger increase in growth rate when one year adult individuals are introduced into the population (see figure 38).

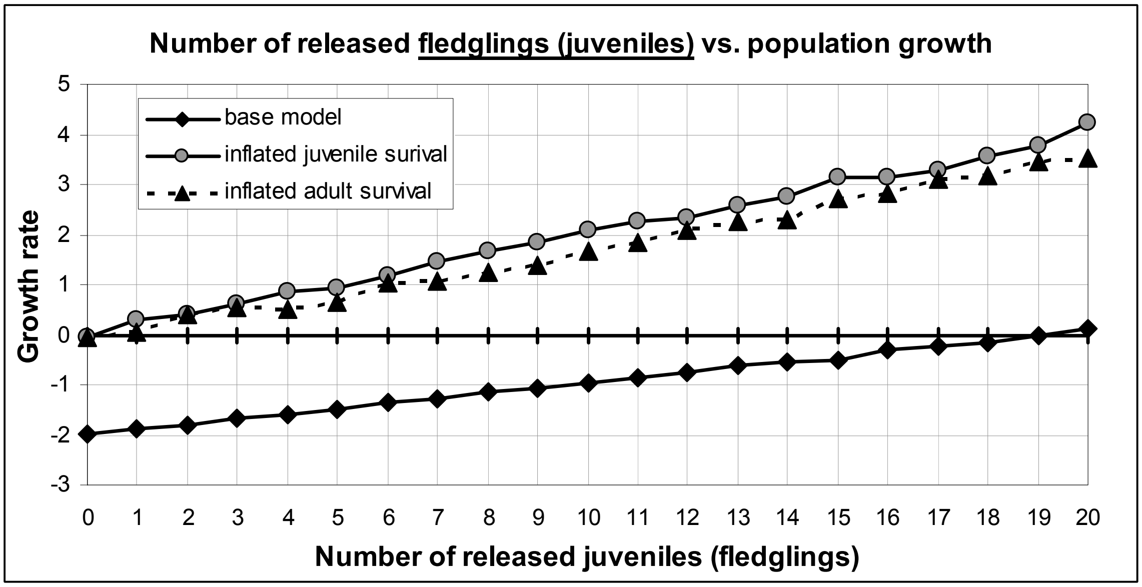


Figure 36: Relationship between number of introduced juveniles and population growth rate for base model, inflated juvenile and inflated adult survival rates.

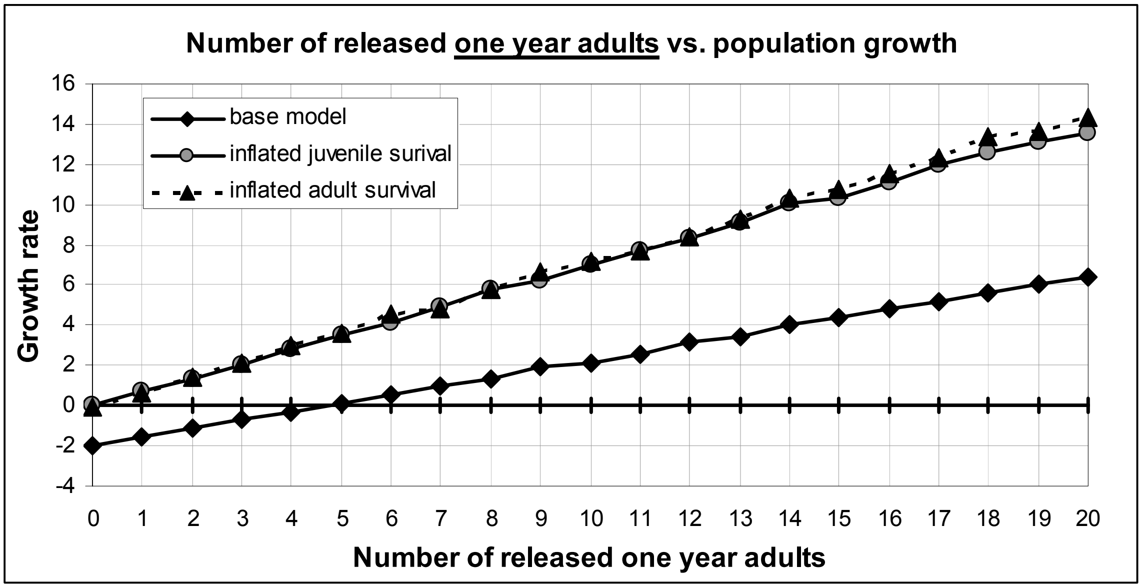


Figure 37: Relationship between number of introduced one year adults and population growth rate for base model, inflated juvenile and inflated adult survival rates.

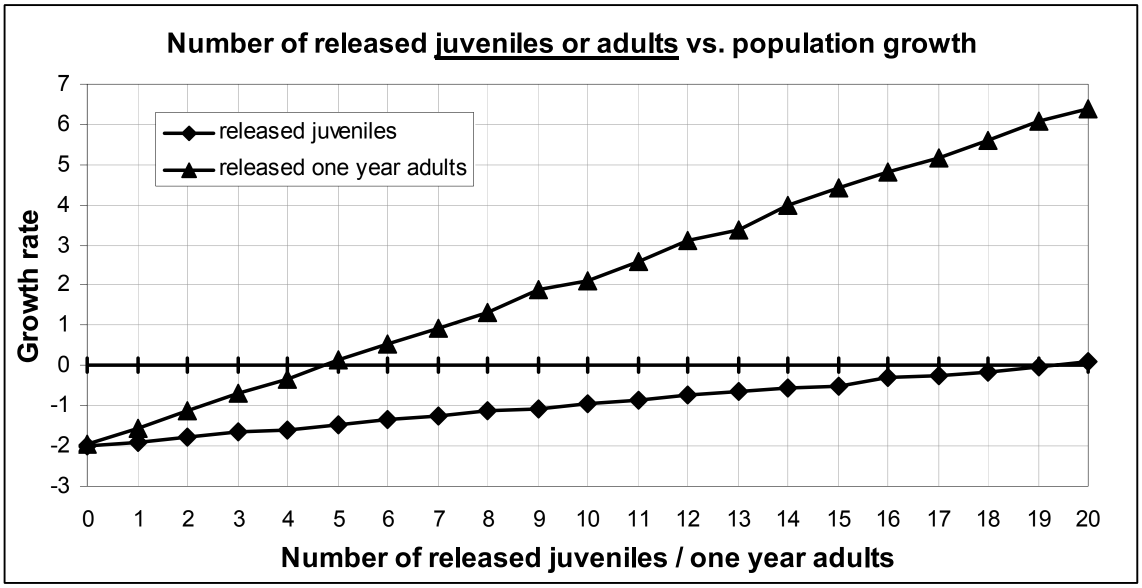


Figure 38: Difference in population growth rate between juvenile and one year old adult introductions. (based on base population model)

4.3.6 Summary

The results of these scenarios suggest that a 20 percent improvement of juvenile and/or adult survival rate would be necessary to achieve a neutral population growth. If factors depressing survival rates could be mitigated by conservation efforts, a minimum viable population of about 200 breeding pairs would be necessary based on 95% viability over 100 years. Furthermore, poor productivity years are likely to increase extinction risk over time. Larger populations will result in lower overall extinction risks and are better suited to mitigate detrimental effects of poor productivity years. Finally, a linear relationship between number of released birds and population growth rate should be expected based on the simulated results. Releasing one year adult birds may result in a much stronger effect on population growth, although this may not be feasible either for the captive breeding program itself or due to behavioural implications of the birds (i.e. belated migration etc.).

5 Conclusions

The following conclusion can be derived from the results of the presented PVA:

- the Loggerhead Shrike population in Ontario faces a serious if not certain risk of extinction within a projected time frame of 100 years
- the negative growth rate of minus 2 breeding pairs every year seems much likely caused by insufficient over-winter survival of juveniles and adults
- survival of juveniles and young adults consistently are the most sensitive model parameters and are therefore most important for population viability
- polygynous mating activities may be beneficial for population viability by compensating a potential lack of male adults
- the effects of the released 419 HY from the captive breeding program between 2000 and 2008 are visible in a reversed population trend, but seem to remain far below theoretical expectations

- in the absence of evidence for an Allee effect or of any lasting effect of the captive breeding program on demographic rates in the wild population, it seems rather unlikely that a self-sustaining wild population will emerge – the captive breeding program alone may not be sufficient in re-storing a self-sustaining wild population in Ontario
- the spatial arrangement of the six identified breeding grounds in Ontario and associated potential dispersal seem to have a marginal effect on the viability of the Ontario Loggerhead Shrike population.
- exploration of various scenarios revealed that a 20% increase in juvenile or adult survival might result in neutral population growth
- scenario results suggest a linear relationship between number of fledglings or one year adults released and population growth
- poor productivity years are likely to have a positive effect on extinction risk

6 References

Akçakaya, H.R. and W. Root. 2002. RAMAS Metapop: Viability Analysis for Stage-structured Metapopulations (version 4.0). Applied Biomathematics, Setauket, New York.

Brooks, B.L. and Temple, S.A. 1990. Dynamics of a Loggerhead Shrike population in Minnesota. Wilson Bull., 102(3), 1990, pp. 441-450

Collister, D.M. and De Smet, K. 1997. Breeding and natal dispersal in the Loggerhead Shrike. Journal of Field Ornithology, 68(2):273-282.

Curtis, J. M, and I. Naujokaitis-Lewis. 2008. Sensitivity of population viability to spatial and non-spatial parameters using GRIP. Ecological Applications, 18(4):1002-13.

Heath, S.R. et al. 2008. Rodent control and food supplementation increase productivity of endangered San Clemente Loggerhead Shrikes (Lanius ludovicianus mearnsi). Biological Conservation, 141:2506-2515.

SAS Institute. 1990. SAS Version 9., Cary, NC, USA.

7 Appendix

7.1 List of documents attached to this report

- 2003 Ontario Field Report by Merilee Temple
- 2004 Ontario Field Report by Rina Nichols
- 2005 Ontario Field Report by Rina Nichols
- 2006 Shrike Field Report 2006 by Jessica Steiner
- Eastern Loggerhead Shrike 2007 Season Update – Author unknown
- Eastern Loggerhead Shrike 2008 Season Update by Jessica Steiner and Elaine Williams
- ON_LOSH_banding_summaries_PVA_3feb09.xls - by Angela Darwin and Amy Chabot
- ON_LOSH_nesting_FY_summaries_PVA_3feb09.xls – by Angela Darwin and Amy Chabot
- ON_LOSH_population_estimate_PVA_3feb09.xls – by Angela Darwin and Amy Chabot
- US LOSH age structure summary.xls – by Angela Darwin and Amy Chabot
- Fecundity summary_LOSH-US pops.xls – by Angela Darwin and Amy Chabot
- transitionprobabilities_bycorearea.xls – by Rich Russell

7.2 Ramas@Metapop - Model Summaries

7.2.1 Non-spatial, single population model

Program: RAMAS Metapop version 4.0
Title: Eastern Loggerhead Shrike PVA
Comments: nonspatial, single population base model, uses fecundity calculated for wild birds only... calibrated on population trend between 1991 and 2008 without captive bred birds...
Replications: 1000
Duration: 18 time steps (18.0 years)

Stage structure
There are 6 stages

Stage-specific parameters

Stage	***Exclude***
juvenile	True
adult_1	False
adult_2	False
adult_3	False
adult_4	False
adult_5	False

Stage matrix

default	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	1.6965	1.6965	1.6965	1.6965	1.6965
adult_1	0.25	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.501	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.501	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.501	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.501	0.24

Constraints
Proportion of each stage matrix element that is survival (as opposed to fecundity)

	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.0	0.0	0.0	0.0	0.0
adult_1	1.0	1.0	1.0	1.0	1.0	1.0
adult_2	1.0	1.0	1.0	1.0	1.0	1.0
adult_3	1.0	1.0	1.0	1.0	1.0	1.0
adult_4	1.0	1.0	1.0	1.0	1.0	1.0
adult_5	1.0	1.0	1.0	1.0	1.0	1.0

Stochasticity
Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal
Extinction threshold for metapopulation = 0
Explosion threshold for metapopulation = 0
When abundance is below local threshold: count in total
Within-population correlation: All uncorrelated (F, S, K)
(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

default	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.61074	0.61074	0.61074	0.61074	0.61074
adult_1	0.025	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.0499	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.0499	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.0499	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.0499	0.024

Catastrophes
There are no catastrophes.

Initial abundances

	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
Pop 1	99	26	14	8	4	3

Populations

General
Population is Pop 1
Initial abundance is 154
Local threshold is 0.0
The population is included in the summation

Density dependence

Density dependence type is Exponential

Population management

Population management is not used

7.2.2 Meta-population model

Program: RAMAS Metapop version 4.0
Title: Eastern Loggerhead Shrike PVA

Replications: 1000
Duration: 18 time steps (18.0 years)

Stage structure

There are 6 stages

Stage-specific parameters

Stage	***Relative Dispersal***	***Exclude***
juvenile	1	True
adult_1	0.5	False
adult_2	0	False
adult_3	0	False
adult_4	0	False
adult_5	0	False

Stage matrix

default	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	1.6965	1.6965	1.6965	1.6965	1.6965
adult_1	0.25	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.501	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.501	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.501	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.501	0.24

napanee	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	1.6995	1.6995	1.6995	1.6995	1.6995
adult_1	0.25	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.501	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.501	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.501	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.501	0.25

carden	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	1.742	1.742	1.742	1.742	1.742
adult_1	0.25	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.501	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.501	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.501	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.501	0.24

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.0	0.0	0.0	0.0	0.0
adult_1	1.0	1.0	1.0	1.0	1.0	1.0
adult_2	1.0	1.0	1.0	1.0	1.0	1.0

adult_3	1.0	1.0	1.0	1.0	1.0	1.0
adult_4	1.0	1.0	1.0	1.0	1.0	1.0
adult_5	1.0	1.0	1.0	1.0	1.0	1.0

Stochasticity

Demographic stochasticity is used
Environmental stochasticity distribution: Lognormal
Extinction threshold for metapopulation = 0
Explosion threshold for metapopulation = 0
When abundance is below local threshold: count in total
Within-population correlation: All uncorrelated (F, S, K)
(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

default	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.61074	0.61074	0.61074	0.61074	0.61074
adult_1	0.025	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.0499	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.0499	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.0499	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.0499	0.024

carden	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.74906	0.74906	0.74906	0.74906	0.74906
adult_1	0.025	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.0499	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.0499	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.0499	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.0499	0.024

napanee	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5
juvenile	0.0	0.628815	0.628815	0.628815	0.628815	0.628815
adult_1	0.025	0.0	0.0	0.0	0.0	0.0
adult_2	0.0	0.0499	0.0	0.0	0.0	0.0
adult_3	0.0	0.0	0.0499	0.0	0.0	0.0
adult_4	0.0	0.0	0.0	0.0499	0.0	0.0
adult_5	0.0	0.0	0.0	0.0	0.0499	0.025

Catastrophes

There are no catastrophes.

Initial abundances

	juvenile	adult_1	adult_2	adult_3	adult_4	adult_5

Carden	22	6	3	2	1	1
Napanee	59	16	8	4	2	2
Pembroke	4	1	0	0	0	0
Smiths-Falls	13	3	2	1	0	0
Grey-Bruce	4	1	0	0	0	0
Manitoulin	4	1	0	0	0	0

Spatial structure

There are 6 populations (see "Populations" below for coordinates)

Dispersal

There are 30 migratory/dispersal connections among the 6 populations
(100 % of the 30 possible connections).
The dispersal rates range from 0.01 to 0.2

	Carden	Napanee	Pembroke	Smiths-Falls	Grey-Bruce	Manitoulin
Carden	0.0	0.2	0.1	0.15	0.2	0.15
Napanee	0.1	0.0	0.05	0.15	0.05	0.01
Pembroke	0.01	0.05	0.0	0.1	0.01	0.01
Smiths-Falls	0.1	0.1	0.1	0.0	0.05	0.01
Grey-Bruce	0.15	0.08	0.01	0.02	0.0	0.1
Manitoulin	0.05	0.01	0.01	0.01	0.1	0.0

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.990 to 0.990

Populations

General

Local threshold is 0.0
All populations are included in the summation

Density dependence

Density dependence type is Exponential
Density-dependent dispersal as a function of source pop. size (slope) is 0.0

Population	X-coordinate	Y-coordinate	Initial abundance	Stage matrix	Std. dev. matrix
Carden	3.5	2.0	35	carden	carden
Napanee	6.0	3.0	91	napanee	napanee
Pembroke	6.0	1.0	5	default	default
Smiths-Falls	7.0	1.5	19	default	default
Grey-Bruce	1.5	2.0	5	default	default
Manitoulin	1.0	1.0	5	default	default
Total			160		

Population management

Population management is not used