A Simple Individual Based Model of Black Rhinoceros in Africa

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Keywords: *Individual-based model, Black Rhinoceros, South Africa, Translocation, Endangered species*

EXTENDED ABSTRACT

In the last century black rhinoceros numbers declined significantly in Africa. To ensure protection of the species and to also maintain a sustainable population, a national conservation strategy has been established to encourage population growth within South Africa.

Part of this strategy involves translocation of black rhino from a high density source reserve, Hluhluwe-Umfolozi, to several, suitable, low density translocation reserves. This strategy encourages not only growth in the high density source reserve by lowering the population and hence reducing the effects of density but also encourages growth in new reserves. This has the additional benefits of encouraging tourism and economic growth in new areas of the country and also lowers the risk of extinction of the species from disease and poor environmental conditions.

Current population models have supported the idea that the global population of the endangered black rhinoceros will increase faster if animals are translocated from high-density reserves to new suitable reserves of low density. However previous analyses of this problem may have not modelled the new populations appropriately and this may lead to sub-optimal implementation of government translocation policies. To gain a better understanding of this, and the dynamics of small, translocated populations, an IBM of a small rhino population has been developed and tested. This model has then been linked to existing models of the source reserve to get an overall indication of global population dynamics.

The main purpose of this model is to simulate the population growth of the endangered black rhino in South Africa in order to predict the outcomes of different translocation strategies. Firstly the effects of translocating different life stages and sexes in optimising translocation reserve numbers are compared. Secondly, by varying the percentage removed from the source the relative effects on the source, translocated and global populations can be observed. The study investigates strategies that will satisfy two conditions:

i. Populations at the source reserves must be maintained at a reasonable level.

ii. The global population of Black Rhino must be at a maximum, provided the first condition is satisfied.

From the model, different strategies that satisfy the opposing opinions of the park managers, who seek low translocation to preserve income, and the conservation specialists, who seek high translocation rates to many different reserves are developed. Specifically, it is hoped that the outcomes of these simulations enable both park managers and animal conservationist to make balanced, well informed decisions.

The joint IBM – source reserve model gives a good indication of the overall global population dynamics and in particular the relationship between source and translocation reserves. From the simulations it is suggested that translocation of approximately 10 to 15 percent of the source reserve population with a focus on translocating a higher percentage of adults, produce a maximum global population.

1. INTRODUCTION

In the early 20th century black rhinoceros (*Diceros bicornis)* were abundant with an estimated several hundred thousand living in Africa. Towards the end of the 20th century their numbers declined from 65,000 in the late 1960's to an estimated 3,500 in the 1990's (Hearne et al. (1991)). However, poaching, a major cause of the decline is less threatening in South Africa and as a result the black rhino population in this country is sufficiently large to support translocation strategies.

To ensure protection of the species and to also maintain a sustainable population, a national conservation strategy has been established to encourage population growth within South Africa. This strategy involves translocation of rhinos from high density reserves, such as the Hluhluwe-Umfolozi Reserve in South Africa, Figure 1, to new, suitable reserves of low density. Translocation has the benefits of encouraging growth in the high density reserve by lowering population numbers, establishing new populations which will experience growth and spread the risk of extinction from a single catastrophe (Rout et al. (2007)).

Current population models have supported the idea that the global population of the endangered black rhinoceros will increase faster if animals are translocated from high-density reserves to new suitable reserves of low density (Hearne et al. (1991)). Africa has several reserves suitable for translocation including Mkuzi, Ndumu and Itala (Brooks (1989)). We base the source reserve model on the Hluhluwe-Umfolozi game reserve which experiences a high density population of black rhino and consider several generic translocation reserves under different conditions. Previous analyses of this problem have considered only the dynamics of the source reserve population and not specifically modelled the translocated populations. This may lead to sub-optimal implementation of government translocation policies.

Conclusions from population models by Hearne et al. (1991), concluded that translocation of 18 adult rhinos based on a source reserve population of 480, can be translocated per year.

To gain a better understanding of the dynamics of small translocated populations, an IBM of a small rhino population in a translocation reserve will be investigated in this study. This model has been linked to existing models of the source reserve to get an overall indication of global population dynamics. This joint model will provide a more comprehensive analysis of the results of Cromsigt et al. (2002) which focused mainly on the source reserve population.

Figure 1. Hluhluwe-Umfolozi Reserve, South Africa.

2. TERMINOLOGY

The term *global population* refers to the total rhino population including both the population at the source reserve and the population at the translocation reserves. The term *source reserve* indicates the high density reserve where Black Rhino are exported from and *translocation reserve* is used to indicate the reserve receiving Black Rhino. Additionally, *translocation status* is used to indicate the individuals who have been moved from the source reserve.

3. PURPOSE

The IBM considers two regimes in order to optimise the endangered black rhino in South Africa. *Regime I* explores the question: What age and sex should be translocated? *Regime II* looks at how many rhinos to translocate. In both of these regimes the following criteria need to be satisfied:

i. Populations at the source reserves must be maintained at a reasonable rate.

ii. The global population of Black Rhino must be at a maximum provided the first condition is satisfied.

4. STATE VARIABLES AND SCALES

In this IBM, each individual is tracked over successive years and is categorised by the state variables: sex, life stage, age and translocation status. Additional traits for each adult female are years since last birth, and whether or not her last calf has matured.

Traits for the overall population include translocation percent (removal and introduction), sex and life stage of each translocated individual, and density effects on the source reserve.

The individuals have been classified into the following life stages based on the age divisions given by Hearne et al. (1991):

- Unweaned: Represent new born calves in their first year of life.
- Juvenile: Represent calves that are still with their mothers but have been weaned.
- Sub-Adult: Represent individuals that have left their mothers but cannot reproduce.
- Adult: Reproductive members of the community.

Each individual's age in the translocation reserve is defined by their age when they were translocated, which is a result of the translocation strategy. Otherwise, age is determined from birth in the translocation reserve.

5. PROCESS OVERVIEW AND SCHEDULING

Individual processes in the translocation reserve include death from translocation, birth, stage progression from aging, survivability and reproduction, where survivability relates to an individuals chance of living until the nest year.

Regime I

To begin simulation the model introduces a number of black rhino into a single translocation reserve which is considered to have zero population initially. Each of these individuals is categorised by their sex, which is determined by the translocation strategy selected, and life stage. At each new time step the same percentage of black rhino is translocated.

Regime II

Based on the results from *Regime I*, the number of the optimal sex and age of black rhino translocated from the source reserve each year is varied. This percentage is dispersed evenly between three translocation reserves. If an individual does not survive translocation, population numbers at the source reserve are decreased. The number of black rhino translocated will be dependant on the percentage of black rhino at the source reserve during the previous year.

In both regimes once translocation has taken place, the translocation reserves are updated for the next time step. Survivability is calculated and deceased rhinos removed from the population. Remaining individuals can then progress life - stages, which is dependant on their age. All individuals in the unweaned life stage progress to juvenile. Juvenile transition is linked to the mother's calving interval. If juvenile individuals do progress, the mother is then free to participate in the reproduction stage if she is within the given time period. Along with these females, transitioning sub-adults will also be able to participate in reproduction.

Mating probabilities occur as a percentage of available females compared to males who are able to reproduce. It has been observed that mating can occur all year round with males mating with several females per year.

Births are included at the beginning of the next time step and individuals are classified into the unweaned age class. For more on age classes see Section 7. Figure 2 gives a flow diagram of the process.

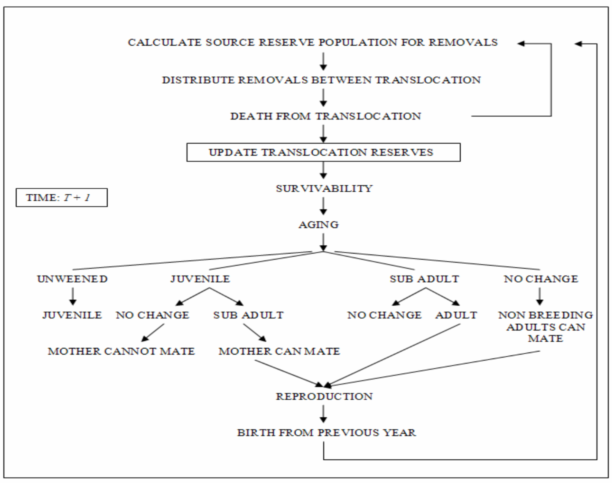

Figure 3. Flow Chart – Process Overview and Scheduling.

6. DESIGN CONCEPTS

Adaptation and Fitness: Individual life cycles are governed by probabilities and thus fitness seeking and adaptation are not modelled. However the adaptation of individuals to the new reserves is indicated during the translocation process and it's overall influence is on the source reserve population.

Interaction: Adult individuals interact only during the reproduction cycle. Female adults have the additional interaction with their calf after birth and until the calf progresses to the sub-adult life stage.

Sensing: Individuals are assumed to know their sex, age, life stage and translocation status. Additionally, females are aware of their reproductive capabilities.

Stochasticity: All life events are given by probabilities or are drawn from probability distributions. Translocation percentages are governed by the source reserve sub-model and therefore not generated in this manner.

Observation: The IBM was tested using observed data from the Hluhluwe-Umfolozi reserve in South Africa given an initial population with no translocation. Decisions relating to translocation strategies were determined from existing policies.

7. INITIALISATION

Initially, all translocation reserves are considered empty. The initial population in the source reserve is 300 with a previous year translocation of 10 black rhinos, taken from observed data, for simulations involving translocation percentages. When considering translocation sex and life - stage a single translocation reserve is considered and the effects observed, whereas when observing the results of different translocation percentages 3 separate translocation reserves relying on a single source reserve are considered.

8. INPUT

Density effects at the translocation reserves were not included in the IBM so simulation probabilities were set to match given probabilities from previous models by Goodman (1989) and Hearne (1991) rather than from comparison to the density dependant source reserve, although some comparison is provided in the results section.

Table 1 gives the life - stage structure and probabilities for males and females and Table 2 gives the annual survivability probabilities.

The time horizon is set to 20 years; this allows for the translocation reserve population to remain small enough for density effects to be negligible. It also allows for significant forecasting to enable appropriate decisions are made for short term and long term gain.

9. SUB MODELS

Source reserve model: The source reserve is modelled so that it includes the effects of density, the growth rate and the percentage of removals. The model of the source reserve at time T+1 is given by:

$$source(T+1) = source(T) + r * source(T) * (1 - (\frac{source(T)}{K})^n) - removals \quad (1)$$

where,

r = the specific growth rate

K = carrying capacity at the reserve

n = the density effect, n<7

removals = the number of animals translocated from the reserve

Specific data on the dynamics of the source reserve is not available and hence an accurate IBM of this reserve is not possible. The model also allows for population census errors of up to 30% which occur in the statistics taken by park managers. Table 3 provides the specific parameter values for this model.

Translocation reserve model: The reproduction probability is modelled from the ratio of males to females where a 1:4 ratio relates to a 25% chance of reproduction.

Life - stage change probabilities will govern the calving interval for juveniles with the interval between female claves to be less than that of males. This also allows sexual maturity to occur at different ages for male and female adult black rhino. In this case it is suggested that this is approximately 4 to 7 years for females and 7 to 10 years for females (Cromsigt et al. (2002)). Mean birth intervals are set at 5 years with a standard deviation of .33 or 4 months.

Translocation Strategies: Three translocation models are considered in the first stage of the model. The first is translocation of six adults per year. The second is translocation of six sub adults per year and the third considers translocation of two adult male and two mother calf pairs, with one male and one female calf. These three strategies are considered to provide suitable alternatives during poor environmental conditions when translocation of certain life stages is not a viable option.

Using the results of these simulations we consider translocation from the source reserve into three translocation reserves with equal dispersion between them. For these simulations the source reserve population influences the amount of rhinos receive at the translocation reserve. Three reserves are considered so density effects at the translocation reserve can be ignored by keeping the population sizes small. Realistically it is expected that black rhino would be dispersed to several reserves rather than filling a single reserve at a time.

10. PARAMETERS

The following tables provide the life - stage change probabilities, the survival probabilities and the parameters for the source reserve model. The parameters in table 1 and 2 govern the individual's life cycle and are compared to a randomly generated number between 0 and 1. Table 3 gives the parameters for the source reserve model.

Table 1. Life - stage structure for males and females.

LIFE STAGE	STAGE CHANGE PROBABILITIES	
	MALE	*FEMALE*
Unweaned	1.00	1.00
Juvenile	0.25	0.50
Sub Adult	0.33	0.33
Adult	-	-

Table 2. Annual survivability probabilities.

LIFE STAGE	SURVIVABILITY PROBABILITIES
Unweaned	0.99
Juvenile	0.99
Sub Adult	0.99
Adult	0.965

Table 3. Source reserve parameters.

r	*K*	*n*	*Initial Population*	*error*
0.08	400	5	300	0.3

11. RESULTS

Simulations are calculated with a 20 year time horizon. Firstly considered is the effect of translocating different sexes and life stages on the translocation reserves, *Regime II*. The optimal outcomes from these simulations determine the specific strategy used to calculate the optimal percentage of removals. To compare these three strategies one translocation reserve is considered with 100 simulations. The mean population is then compared to the results of the other translocation strategies considered. Note that the term *group* is used to mean two adult males, two mother calf pairs with one calf female and the other male. Table 4 gives the results of these simulations.

From these results we conclude that translocation of adult rhinos will provide the optimal global population. If it is not viable to translocate adult rhinos sub adults should be translocated instead. This is a real possibility during environmental conditions such as drought or times of poor population growth at the source reserve.

Table 4. Translocation Strategy Results.

STRATEGY	NUMBER (mean, n=100)
6 Adults	270
6 Sub-Adults	249
"Groups"	224

Secondly considered, using these results, is the effect of different translocation percentages on the source reserve and the global population, *Regime II*. We now refer to the two specific aims of the model. Each year a percentage of adult black rhino, with even dispersion of sexes, are translocated into the new reserves. The percentage of removals is maintained throughout the 20 year simulation in order to obtain an idea of the effect on the source reserve. Firstly presented are the results of translocation percent on the source reserve population. Figure 4 and Table 5 gives the results from simulation.

Translocation percents of over 20 percent produce a source reserve population that is unstable and eventually, the population decays to zero with high translocation percents. We therefore only consider percentages below 25 percent.

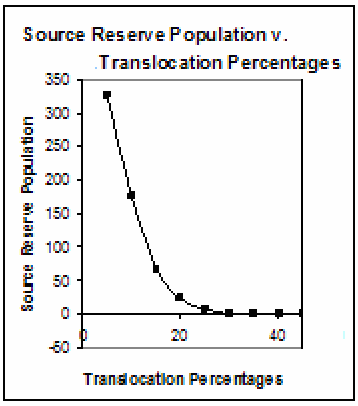

Figure 4. Source reserve v. Translocated Population.

Figure 5 and 6 present the results of the translocation percentages on the translocation reserves and the source reserve against the global population respectively.

Eliminating results that don't maintain populations at the source reserve translocation percentages close to 10% produce optimal translocation reserve numbers. When observing the effects on the global population this can be increased to approximately 15 percent.

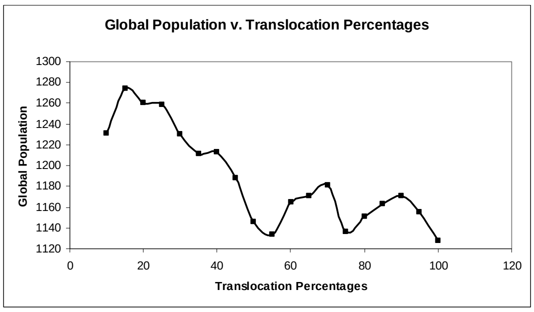

Figure 5. Global Population v. Translocated Percentages.

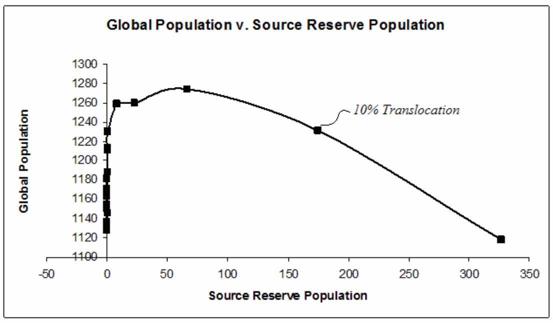

Figure 6. Global Population v. Source Reserve Population.

Table 5 presents the results of these simulations. When observing these results a translocation strategy that will maintain the population at the source reserves at a reasonable rate and maximise the global population is sought. From these results it is conclude that translocation percentages between 10 and 20 satisfy the two conditions set out by the study. More specifically, translocation percentages at approximately 10 percent produce a result that maintains a reasonable source reserve population of 175 black rhinos.

12. DISCUSSION AND CONCLUSION

We have presented the results of different translocation strategies using an individual-based model which describes the population growth of black rhino in South Africa. The model algorithm used information on life structure, sex, mating habits and survivability of the species. The model was based on reserves in South Africa and considered the effects of translocation on the source reserve, the translocation reserve and the global population. The results indicate that translocation of adult, reproducing, members of the source population, at a rate of ten percent will produce optimal global population numbers while sustaining a source population at approximately half of its carrying capacity. It is suggested that further study could incorporate the environmental fluctuations that often govern population growth in these reserves.

Translocation of adults provides the opportunity for immediate population growth from reproduction. It is suggested that this is the reason for higher population numbers as compared to other strategies. Also emerging from the simulations is that high numbers of deaths in the adult life stage significantly decreased the translocation reserve population at the end of the 20 year time horizon.

The trade off between options for *Regime I* present possible variations in translocation when the population at the source reserve is unstable. If this is the case it could be considered that translocation of Sub-Adults would be a reasonable translocation strategy.

In comparison with previous studies it can be concluded that a slightly higher translocation from current strategies could be considered. This strategy would sustain a reasonable population at the source reserve but produce a significantly higher global population.

Table 5. Results of translocated percentage on the source, translocation and global population.

TRANSLOCATION PERCENT	SOURCE RESERVE POPULATION	TRANSLOCATION POPULATION	GLOBAL POPULATION
5	327	791	1118
10	175	1056	1231
15	67	1207	1274
20	23	1237	1260
25	8	1251	1259

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