A Conservation Model for Black Rhino

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Abstract
Over the past thirty years the black rhinoceros (Diceros bicornis) population in Africa has declined from about 30 000 to less than 3 000. In contrast the South African population has increased four-fold to 600 over the same period. The recently developed national conservation strategy for black rhino has as its main goal the increase of the current population to at least 2 000 in as short a period as possible. To achieve this, the growth rate of the population as a whole will have to be maximised. This involves removing animals from areas where the population is approaching the ecological carrying capacity and establishing new viable populations in other suitable reserves.

A model, incorporating what is known about the population biology of black rhino, was developed to give guidance to managers on the most appropriate harvesting stategy to adopt for their populations; in particular, to determine the rate of removals and the age and sex of individuals to be removed to attain a 2 000 strong Southern African population as soon as possible.

Introduction
The population and behavioural biology of black rhinoceros is not well understood. Our current understanding stems from the several different sub-species of black rhino which occur in various localities throughout east and southern Africa. The model we develop, incorporates information on black rhino population characteristics from the published literature and other unpublished sources. Where no specific data for black rhino exists, we substitute with empirically supported generalisations for large mammals from the literature notably Eberhardt (1977),Fowler (1981) and Laws (1981).

Over the past decade, black rhinoceros (Diceros bicornis) have continued to decline in Africa (Cumming,1987). A policy was recently developed for this species in Southern Africa (Brookes,1989) which, it is hoped, will enhance the survival prospects of the black rhino. One of the primary aims stated in this policy is to increase the current population of approximately 600 rhino to at least 2000 in as short a period as possible. To achieve this, the growth rate of the population as a whole will have to be maximised. This involves removing animals from areas where the population is approaching the ecological carrying capacity and establishing new viable populations in other suitable reserves.

A model was developed to give guidance to managers on the most appropriate harvesting stategy to adopt for their populations; in particular, to determine the rate of removals and the age and sex of individuals to be removed to attain a 2000 strong Southern African population as soon as possible.

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Formulation of the Model
Black rhinos available for translocation are found in the following game reserves: Hluhluwe – Umfolozi, Mkuzi, Ndumu and Itala [Brooks 1989]. To keep the model simple, the populations from these reserves will be regarded as constituting a single group, referred to as the Founder Population. In the same way tanslocated black rhinos will be regarded as a single group referred to as the Translocated Population.

In order to preserve genetic diversity the Founder Population will be kept close to the estimated ecological carrying capacity and a removal policy will only be regarded as feasible if the adult female and male population numbers do not decline to less than 60% of their initial values at any time. Genetic diversity will be further managed when selecting animals for translocation and in selecting their destination.

The Founder population is divided into 8 groups according to age and sex. The various female groups, their initial values and the rates determining their levels are shown in table 1. The male groups M1 – M4 are divided in a similar way.

Group	Initial Value	Age (yrs)	Flows IN	Flows OUT
F_1	10	0 – 1	Births	Maturation, death, predation
F_2	8	1 – 2	Maturation	Maturation, death, predation
F_3	22	2 – 8	Maturation	Maturation, death, removal
F_4	160	8 +	Maturation	Death, removal

Table 1

From the table it can be noted that migration does not take place and that predation is confined to the younger groups. Calves stay with the cows until at least age 2 and removal (translocation) is restricted to the groups F_3 and F_4 (as well as M_3, M_4).

A juvenile black rhino exerts less pressure on resources than an adult and we therefore define the adult equivalent population (AEP) as

$$AEP = a_1(F_1 + M_1) + a_2(F_2 + M_2) + a_3(F_3 + M_3) + F_4 + M_4$$

where $0 \leq a_i \leq 1$ $(i = 1, 2, 3)$.

Population density is measured as the ratio $\frac{AEP}{ECC}$ where ECC is the estimated ecological carrying capacity.

Observations indicate that births in Umfolozi Game Reserve have occurred as early as 6 years (Goddard 1967) and in the high density extreme in Hluhluwe Game Reserve first calves are dropped at around 10 years and 6 months. (Hitchins and Anderson 1983). In this model it is assumed that births occur only amongst the group F_4 (which is true on average).

Fecundity, which is reflected by the interval between calving is suggested to be a declining function of density (Eberhardt 1977, Laws 1981). Hitchins and Anderson (1983) summarised calving interval statistics from a variety of areas and recorded a minimum between calving of 26 months (0.46 calves/year) and a maximum of 63 months (0.19 calves/year). The exact shape of the fecundity function FF is not known for rhino and we have assumed a smooth decreasing curve between the recorded maximum and minimum values as shown in figure 1.

There is a delay involved in the fecundity response to changes in density. The effect of changes on the conception rate is modelled as a first order delay with delay time DEL and that of the gestation period as a third order delay with delay time DEL3. The birth rate is therefore given by

$$F_4 . FF_4 \quad \text{(calves/yr)}$$

where

$$\frac{d}{dt}FF_1 = (FF - FF_1)/DEL$$

and

$$\frac{d}{dt}FF_i = (FF_{i-1} - FF_i)/DEL3, \quad i = 2, 3, 4.$$

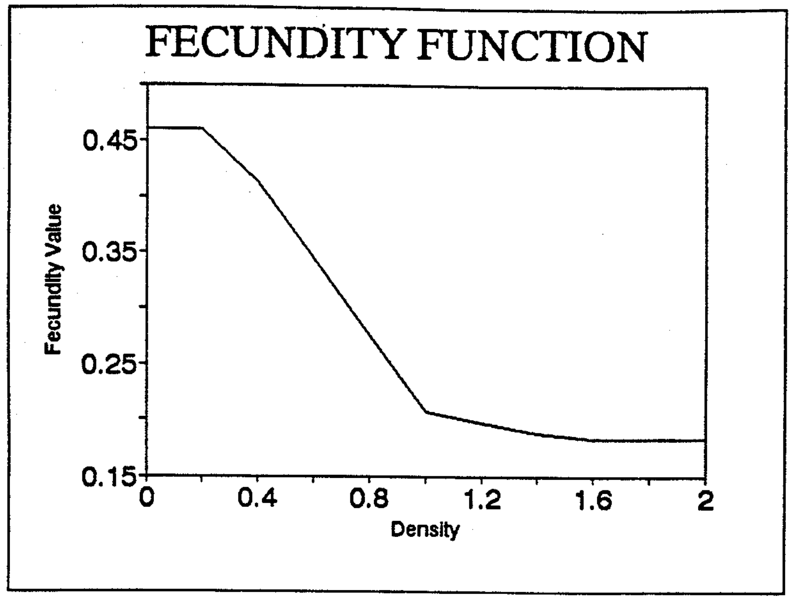

Fig. 1
Fecundity as a function of density

Mortality is a function of age (Goddard 1970) and density (Eberhardt 1977, Fowler 1981). Eberhardt (1977) proposed that one of the first signs of density dependent stress was an increase in juvenile mortality. At the other extreme Fowler (1981) states that in many large mammal populations, adult survival is insensitive to changes in density. Observations indicate that for rhino, subadults have higher mortality rates than adults because they are subject to more social stress than adults, particularly when they are trying to establish their home ranges for the first time. Animals in the two youngest age groups are also subject to nutritional stress. Yearlings (age group 2) are weaned and so must depend on vegetation for food. They therefore have a higher mortality rate and are more susceptible to density stress than unweaned calves. There is insufficient information available for a precise definition of the mortality functions but based on the above discussion and field experience the functions shown in figure 2 were considered plausible. In addition to natural mortality, deaths due to predation occur amongst the two younger groups.

The population is assumed to be uniformly distributed over each age group and ageing is assumed proportional to the number of animals in each group (excluding the adult groups).

The female sector of the Founder Population is described by the following model equations:

$$\frac{d}{dt}F_1 = 0.5(F_4 . FF_4) - F_1 . F_1AN - F_1 . mort_1 - F_1 . F_1PN$$

$$\frac{d}{dt}F_2 = F_1 . F_1\,AN - F_2 . F_2\,AN - F_2 . mort_2 - F_2 . F_2\,PN$$

$$\frac{d}{dt}F_3 = F_2 . F_2\,AN - F_3 . F_3\,AN - F_3 . mort_3 - Rem\,(F_3)$$

$$\frac{d}{dt}F_4 = F_3 . F_3\,AN - F_3 . mort_4 - Rem\,(F_4)$$

where $F_i\,AN$ = ageing normal of group F_i (yr^{-1})

$mort_i$ = mortality function of group F_i (yr^{-1})

$F_i\,PN$ = predation normal of group F_i (yr^{-1})

The removal rates for groups 3 and 4 are exogenously specified.

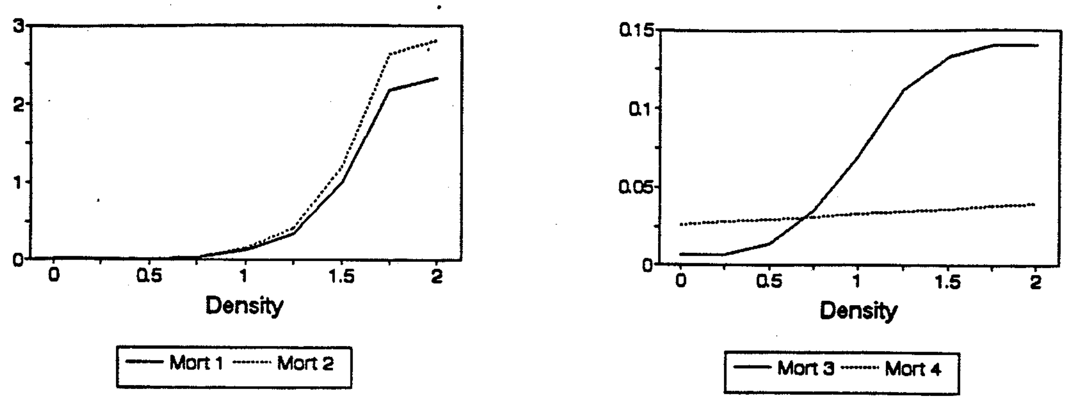

Fig. 2
The mortality functions for the different groups

The male sector is modelled in a similar way as is the translocated population. The removals from the founder groups F_3, F_4, M_3 and M_4 are additional flows into the translocated population.

Until now removals have been conservative and aimed only at dropping the founder population level below the estimated ecological carrying capacity in order to stimulate breeding and survival. Initial values for the translocated population are specified as follows:
$F_1 = 0$, $F_2 = 0$, $F_3 = 5$, $F_4 = 20$, $M_1 = 0$, $M_2 = 0$, $M_3 = 5$ and $M_4 = 20$.

Results
For this set of results constant removals take place once per year. A policy is considered feasible if after removal at any time during the 30 year simulation $F_3 \geq 1$, $M_3 \geq 1$, $F_4 \geq 100$, $M_4 \geq 100$. The adult founder groups need to be kept reasonably high to preserve genetic diversity. The vector (f_3 f_4 m_3 m_4) describes a removal strategy where once a year f_i animals are removed from founder group F_i and m_i animals are removed from founder group M_i ($i = 3, 4$). It is assumed that the ecological carrying capacity of the translocated population is 1600 as opposed to the 400 of the founder population.

In table 2 a comparison of some feasible removal strategies is shown. For low removals (2 – 8) best results are obtained by relatively high F_3 and F_4 removals. For medium removals (10 – 16) best results are obtained by relatively high F_4 and M_4 removals and for high removals (18 – 26) relatively high F_3 and M_3 removals are indicated. In the case of 24 and 26 removals there are few feasible strategies and it becomes meaningless to differentiate between good and poor strategies.

Figure 3 shows the total population after 30 years corresponding to the best removal strategy for each constant total annual removal, while figure 4 shows the minimum number of years to reach a target population of 2000 as a function of the number of removals per year. In Figure 5 the population dynamics of the total black rhino population is compared under various removal strategies. Figure 6 shows the population structure of the female sector of the founder population under the removal strategy (2 6 0 8).

Annual Removals	Good Strategies	Poor Strategies	Best	Target	Worst	Ave
2	0 2 0 0 2 0 0 0	0 0 0 2 0 0 2 0	1856	∞	1415	1600
4	0 4 0 0 2 2 0 0	0 0 0 4 0 0 2 2	2135	29	1441	1767
6	2 4 0 0 4 2 0 0	0 0 0 6 0 0 2 4	2231	27	1468	1877
8	2 4 0 2 2 4 2 0	0 0 2 6 0 0 4 4	2235	27	1496	1949
10	0 6 0 4 0 6 2 2	0 0 6 4 0 0 8 2	2272	26	1525	2047
12	4 4 0 4 4 4 2 2	0 0 12 0 2 0 10 0	2292	26	1555	2123
14	2 6 0 6 4 4 0 6	2 0 12 0 2 0 10 2	2315	25	1826	2190
16	0 8 0 8 2 6 0 8	4 0 12 0 4 0 10 2	2333	24	2032	2250
18	0 8 6 4 0 8 6 4	4 0 14 0 2 2 14 0	2333	24	2046	2277
20	6 4 4 6 0 8 12 0	6 0 14 0 4 2 14 0	2334	24	2177	2303
22	6 4 8 4 12 0 2 8	8 0 14 0 8 0 12 2	2339	24	2261	2319
24	6 4 14 0 12 0 6 6	10 0 14 0 10 0 12 2	2340	24	2313	2279
26	12 0 12 2 12 0 14 0		2340	24	2334	2337
28	14 0 14 0		2318	23	2318	2318

Table 2

Analysis of translocation strategies

Column 1 shows the total number of animals translocated, columns 2 and 3 list some good and poor strategies respectively. The last four columns give respectively the highest population total, the first time the population exceed 2000, the lowest population total and the average population total corresponding to the number of animals translocated (column 1).

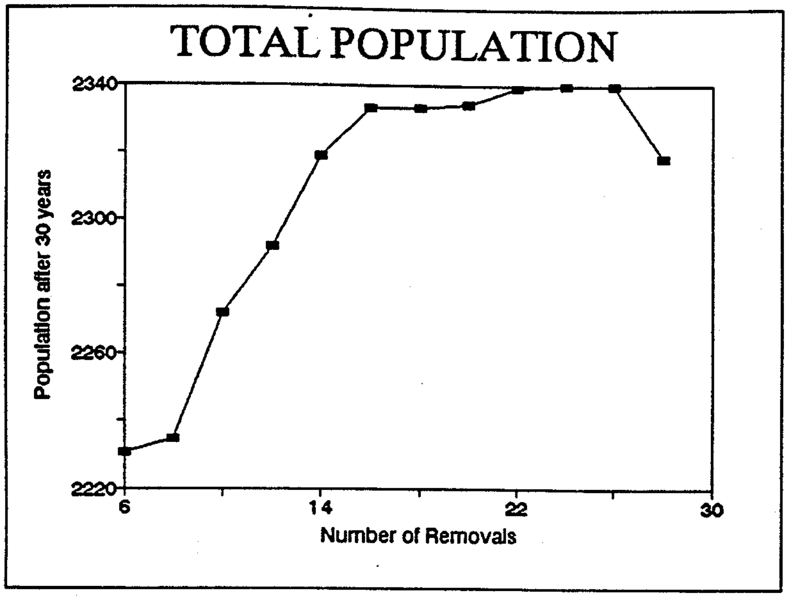

Fig. 3
Total population after 30 years corresponding to the best removal strategy for each constant total annual removal.

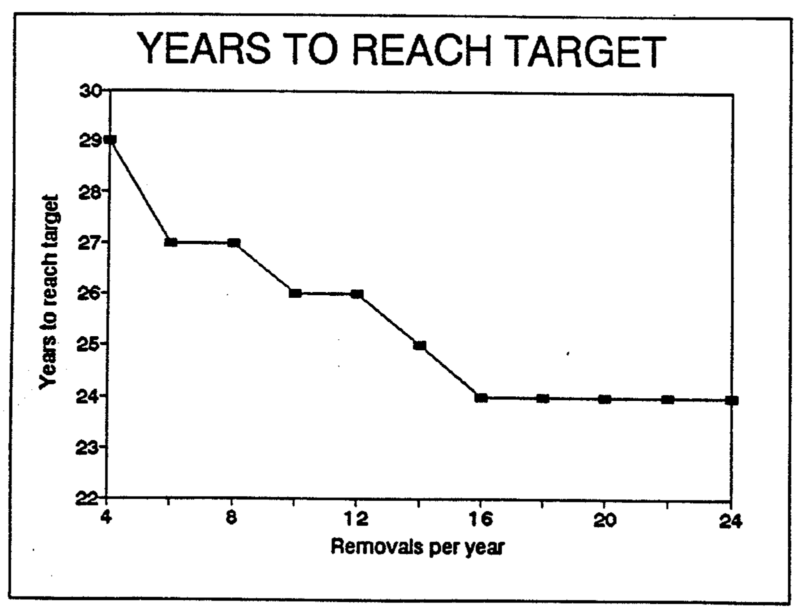

Fig. 4
Minimum number of years to reach a target population of 2000 plotted against the number of removals per year.

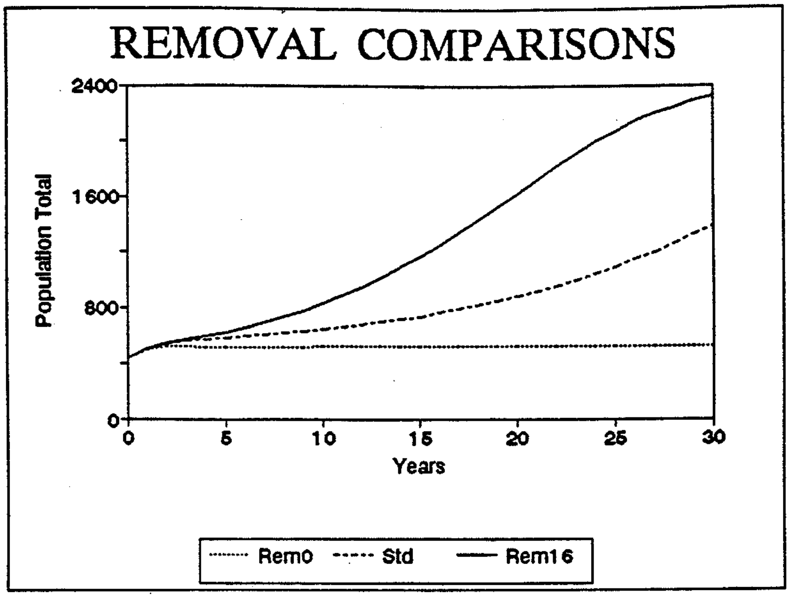

Fig. 5
The population dynamics of the total black rhino population is compared under three removal strategies. The standard graph shows the population dynamics if no further removals take place; the graph Rem 16 shows the dynamics of the constant removal strategy (2 6 0 8) is applied. The graph Rem 0 shows the hypothetical result in the absence of removals.

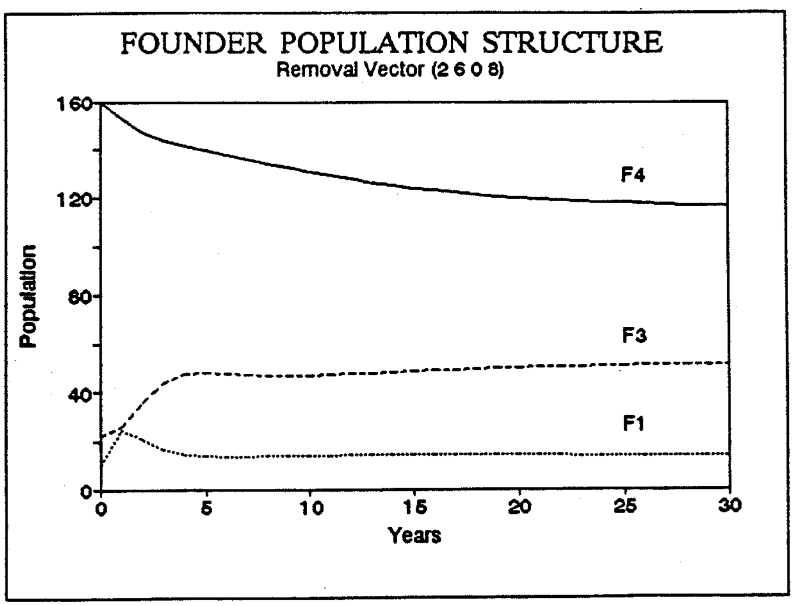

Fig. 6
The population structure of the female sector of the founder population under the removal strategy (2 6 0 8). The graph for F_2 is almost identical to that for F_1 and is not shown.

In obtaining the above results it was assumed that no removal deaths occured. In practice some removal deaths are likely to occur and in figure 7 the effect of a somewhat high 10% removal death rate is illustrated. As expected the total population is lower, but as before there is little to gain from increasing the annual removal rate beyond 16.

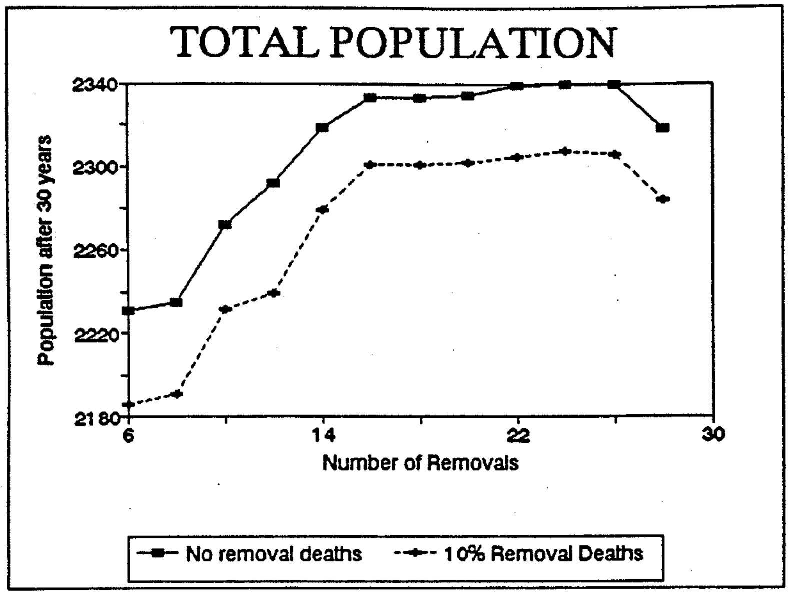

Fig. 7
The effect of translocation deaths.

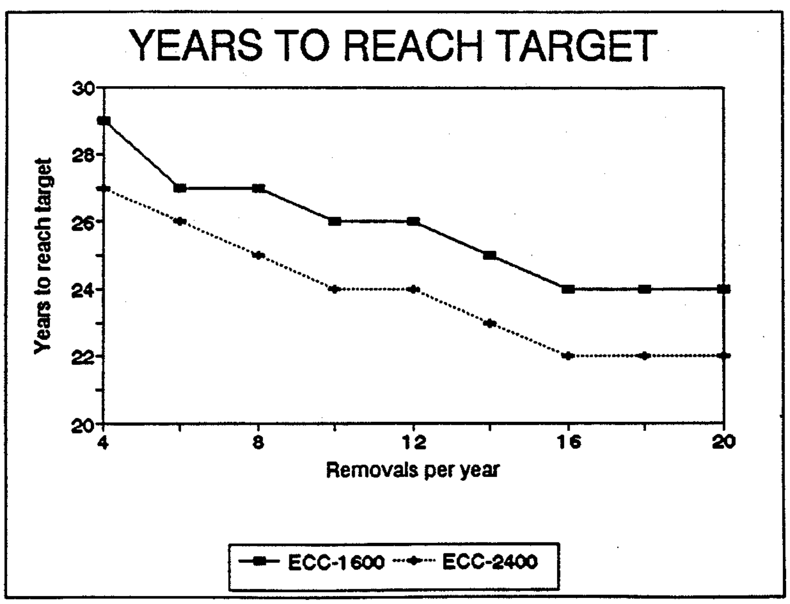

Fig. 8
The effect of carrying capacity on the time to reach the target population.

Mortality and fecundity are functions of density and hence depend on the specified ecological carrying capacities. The carrying capacity of the founder population is fixed but that of the translocated population depends on the amount of suitable habitat made available. In figure 8 the number of years to reach the target population of 2000 is compared under ECC specifications of 1600 and 2400 respectively for the translocated population. The target is reached 2 years earliear and once again a removal rate of 16 animals per year is the lowest removal rate to achieve this result.

Conclusion

The model confirms that a policy of translocation is essential if the total population of black rhino modelled is to increase from 400 to a genetically viable population of well over 2000 in 25 years.

No appreciably better total population results are obtained by increasing the annual removal rate from 16 to 26 (after which a constant removal strategy is no longer feasible).

As expected the translocated population will benefit from more suitable habitat made available. The population numbers will be higher and the target population will be reached sooner. Only a slight improvement in overall numbers result from increasing the annual removal rate from 16 to 28 and in view of the additional disburbance to the rhino as well as additional costs, a constant removal strategy of 16 is indicated, with the animals selected from appropriate groups to maximise the total population.

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