R. LOON & D. POLAKOW

no 5

A conceptual model for assessing the economic feasibility of harvesting African rhinoceros horn

There have been recent calls for the rhinoceros industry to be privatised. A Leslie matrix modelling approach based on population parameters of rhino and the most current economic indicators available provide useful insights into the viability of harvesting rhinoceros horn. Assuming no poaching risks allows one to explore the potential internal rates of return and hence total revenue which may be expected to be generated for a varying initial population density of rhinos at different time horizons. An appraisal of this model as a heuristic analytical tool reveals that rhino horn harvesting is likely to be profitable under liberal market demands and especially at high initial stocking densities. Conversely, the time taken to achieve a positive balance at low stocking densities and at conservative market demands would likely take too long to be profitable.

There have been recent calls for the CITES ban to be lifted so that a controlled trade in rhino horn (particularly white rhino) can be allowed to take place.[1–6] These arguments range from claims that the ban has simply been ineffective in controlling poaching in Africa,[1] to others that argue that privatisation of the rhino horn industry would be more effective in conserving this species than through state protection.[2–6] These latter arguments believe that the greater the property rights in rhinos, the smaller would be the impetus for over-exploitation. Precedent for commercially harvesting wild animals successfully without threatening them with extinction is evidenced in both the ostrich and the crocodile product industries.[4]

Rhino horn is used primarily in the medicinal market in Taiwan and China and in the ornamental market in Yemen and Oman.[5–8] t' Sas-Rolfes[5] contends that the nature of the demand for rhino horn is price-inelastic in the higher price range of the market. The affluence of certain users of rhino horn in these Eastern and Middle Eastern countries and their obvious reluctance to accept substitutes due to cultural preferences imply that increases in the price of horn will lead to proportionately smaller declines in consumption.[5] For this reason a ban may be ineffective and lead merely to a black market and increased poaching levels. Trends in black rhino numbers over the past three decades (from an estimated 65 000 in 1970 to approximately 2500 today) suggest that this analysis is valid.

What would happen if an entirely free trade in rhino horn could take place? Given a substantial but varying market demand for rhino horn, it would be valuable to gain insight into what a 'profit maximising' manager's situation would entail under different demand scenarios. Is harvesting rhino horn potentially a sustainable business?

The only attempt to model aspects of harvesting rhinos for profit has been performed by Milner-Gulland *et al.*, who suggest that dehorning must be done annually if it is to be made unprofitable for poachers.[9] Furthermore, since dehorning carries a risk of rhino mortality, they suggest that it is unsustainable as an anti-poaching measure, although they acknowledge that as anaesthetic technology improves, dehorning mortality rates will be reduced. These authors also foresee the ability to generate revenue which could be used to offset the costs of poaching, but regard the question as academic in light of the existing ban.

Milner-Gulland *et al.*'s model focused primarily on the derivation of the optimal rotation time of dehorning. As an income generating exercise, the optimal rotation time for dehorning will vary with the ratio of the costs of dehorning and the sale price of rhino horn (cost-price ratio), according to the manager's discount rate.[9] Milner-Gulland *et al.* assumed a dimensionless, time invariant cost-price ratio in applying Faustman's forestry model in deriving the optimal rotation time.[9] This assumption is invalid. The ratio between the cost of dehorning/maintenance and the price of horn will vary considerably due to unpredictable changes in the price of the horn.

The aim of this research is to incorporate the abovementioned variables into a simple conceptual model based on known rhino demography. Using the most current economic indicators available, notably the fluctuating range of potential wholesale market demands for rhino horn, the viability of harvesting this horn as a sustainable profit-making endeavour is analytically explored.

Our objective is not to provide a single heuristic answer to the problem facing rhino conservation, but instead, to provide insight into the potential economic parameters involved in approaching the rhino problem from an economic perspective. A generalised age–class transition matrix model is adopted, and the effect of covariation between the two varying parameters (market demand and stocking density) on financial outcome is investigated in a series of model simulations.

Model description

Population dynamics. Rhino population dynamics are described by the age class vector $\mathbf{X}_i = (X_1, X_2, \ldots X_{40})$, where X_i is the number of individuals in age class i, and age classes range from 1 year to 40 years of age for a particular t (time in years). For each cell, the transitions of rhinos from one year to the next can be described by a Leslie matrix approach:

$$\mathbf{X}(t+1) = \mathbf{PX}(t) \tag{1}$$

or

$$\begin{bmatrix} X_1(t+1) \\ X_2(t+1) \\ \vdots \\ \vdots \\ X_{40}(t+1) \end{bmatrix} = \begin{bmatrix} f_1 & f_2 & \cdots & \cdots & f_{40} \\ P_{2,1} & 0 & \cdots & \cdots & 0 \\ 0 & P_{3,2} & \ddots & & \vdots \\ \vdots & & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & P_{40,39} & 0 \end{bmatrix} \begin{bmatrix} X_1(t) \\ X_2(t) \\ \vdots \\ \vdots \\ X_{40}(t) \end{bmatrix} \tag{2}$$

where $P_{i+1,i}$ is the probability of any one rhino transferring from one age class to the next, and f_i is the average number of offspring produced by a mature rhino female in age class i. The gross percentage increase in the population over each generation (recruitment rate) is set at a constant of 7%. This value is used to incorporate both black and white rhinoceros recruitment rates. For simplicity, the number of new recruits each year $X_{1(t-1)}$ is computed as

$$(0.07)\sum_{2}^{40} X_i(t) = \sum_{2}^{40} f_i X_i(t) \; .$$

The initial age class vector $\mathbf{X}_{i(\text{ini})}$ of rhinos is modelled by a normal age distribution

$$f(\mathbf{X}_{i(\text{ini})}) \cong \frac{1}{\sigma\sqrt{2\pi}} e^{-(x_i-\mu)^2/(2\sigma^2)} \; , \tag{3}$$

with the standard deviation (σ) being set at 6 and the mean (μ) at 20. This gives a coefficient of variation in the initial age structure of 30%. Longevity never exceeds 40 years of age ($P_{41,40} = 0$).

Economic parameters. Two economic variables, the cost-price ratio and the discount rate, determine a manager's optimal

(4721)

rotation time.[9] Optimal rotation time of dehorning is set here as constant at a period of 2 years with initial dehorning taking place when animals are 5 years old. Although an older dehorned rhino's horn appears to grow at a slower rate than a younger rhino's, there is evidence to suggest that there is an appreciable amount of horn regrowth after initial dehorning of older animals.[10] Growth patterns in white rhino horn have recently been better refined.[11] However, the stochastic nature of the market value of horn means that modelling the exact nature of horn growth is superfluous. Instead, reliance is placed on varying estimates of the return value of horn to incorporate this uncertainty about horn regrowth rates. The results of this model should still be of interest to the profit maximising manager and conservation authorities.

Prices of rhino horn vary enormously.[5] Wholesale prices appear to be primarily in the range of \$500–\$3000 per kilogram,[11-13] however, figures of up to \$7750 per kilogram one year after dehorning have been reported.[14] For the purposes of this model, amounts of R2000, R4000, R8000, R12 000 and R30 000 are used as estimates of the full range of potential returns for a horn (based on R4.60 to 1 US\$). It is, however, acknowledged that the upper limit used would be approaching retail values not expected to be procured by the 'profit maximising manager' (M. t' Sas-Rolfes, pers. comm.). Dehorning costs have been estimated at R165 per horn[15] on foot, but may vary according to the particular dehorning operation.[9,11] These costs would remain more or less constant. Annual maintenance costs have been estimated at R84 per hectare for natural habitat (G. Creemers, pers. comm.). A maintenance cost of R20 000 per year is considered reasonable to sustain a 200-hectare plot of land/pasture within such habitat.

Neither land costs nor the initial expenditure on rhino stocks have been taken into account. These figures will vary according to such factors as property prices, fencing material, game guard salaries and the opportunity cost of the land used to support the animals. Models on the translocation of rhinos have been dealt with elsewhere.[16,17] Notwithstanding the translocation policies of conservation agencies, it is acknowledged that the transaction costs of acquiring animals will vary according to several factors. Possible eco-tourism effects have likewise not been considered. Annual income (I_t) is calculated as:

$$I_t = \left(\sum_{2}^{19} X_{2i+1} \times \text{return on a horn}\right) - \left(\sum_{2}^{19} X_{2i+1} \times \text{dehorning cost}\right) - (\text{maintenance cost per year}). \quad (4)$$

Balance at time $t+1$ ($B_{(t+1)}$) is calculated as:

$$B_{(t+1)} = B_{(t)} + I_{(t)}. \quad (5)$$

The index, years to positive balance (YTPB), is used as an indicator of when $B_{(t+1)}$ becomes positive overall. A_{10} is the projected balance 10 years after reaching the first year of YTPB.

Model I

Using the above parameters, values for YTPB and A_{10} are estimated under several different initial stocking densities (ranging from 5–50) and under different assumptions of horn returns (R2000, R4000, R8000, R12 000 and R30 000).

Model II

Values for YTPB and A_{10} are estimated under the same ranges of initial stocking densities and different assumptions regarding horn returns; mortality resulting from dehorning is set at a conservative estimate of 3%. $P_{i+1,i}$ at the beginning of every two-year period is set at 0.97 for any rhino $\geq X_5$. Furthermore, a natural mortality rate of 3% is incorporated in the model by setting $P_{i+1,i}$ at 0.97. The cumulative transition probability $P_{i+1,i}$ of a rhino $\geq X_5$ at the beginning of every two-year period is therefore 0.94.

The simulation model was run under the conditions of both model I and model II. The results are represented by: (1) a log-smoothed graph showing YTPB on the initial stocking density for each approximation on horn return, and (2) a linear plot of A_{10} on initial stocking density for each assumption regarding horn return.

Results

This model enables one potentially to calculate the internal rates of return on a dehorning venture under various conditions at different times. Results indicate that the greater the market demand for rhino horn the sooner one would achieve a positive balance (see Fig. 1*a*). Similarly, a greater initial stocking density of harvestable rhino would lead to a quicker attainment of such a balance for a range of potential market demands. This is because more animals would provide a greater quantity of horn in the face of a constant maintenance expense in addition to contributing appreciably to recruitment in the founder population. The consequences of mortality act to delay the time taken to reach a positive balance but do not affect potential profitability under conditions of average wholesale market demand (Fig. 2a).

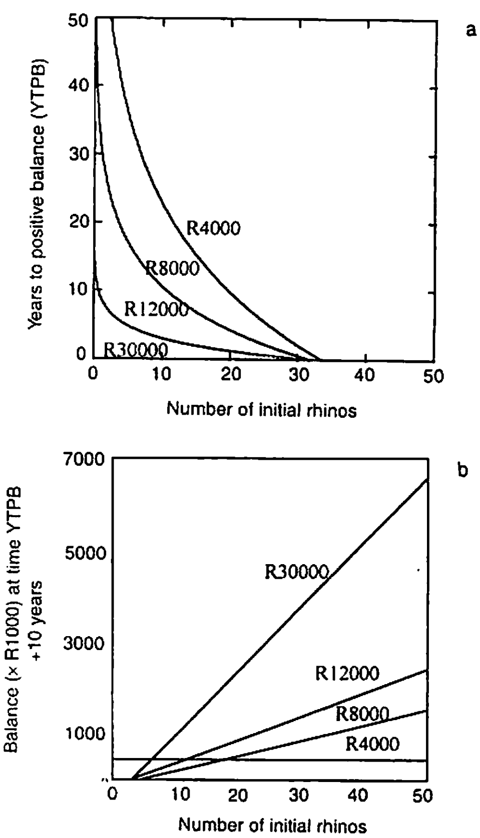

Fig. 1. The output from model I. Figures indicate the range of potential economic return scenarios on a dehorning venture where mortality resulting from dehorning and natural mortality are ignored: (*a*) Years to positive balance (YTPB) on initial stocking density for each approximation on horn return, and (*b*) A_{10} on initial stocking density for each approximation on horn return.

In the short term, the initial costs loom large and the growth potential in the series is disguised. Once a positive balance is achieved, however, revenue grows exponentially. For example, for an initial stocking density of 50 rhinos, income may range potentially from R5.2 million, 10 years after a positive balance is achieved (i.e. after 10 years), given the effect of mortality on the stock (Fig. 2), to R6.5 million given no mortality (Fig. 1). A projection at 30 years points to potential income of between R16 million and R35 million under similar conditions due to such compound growth. For lower market demands the proportional increase is lower. Thus, tangents to the curves at differing densities for different market demands provide a crude index of relative discount rates at different time intervals. Growth in the founder population will eventually be expected to be affected by density-dependent factors, which will clearly curtail exponential profit in later years. However, surplus stock would be expected to be sold then to maintain the productivity of the population.

From this model, the potential value of harvesting the horn of the 1500 white rhinos presently in private hands in South Africa is estimated to be between R14 million and R195 million over 10 years, depending on market demand, other factors being equal or constant. It is important to note that the time taken to achieve a positive balance is longer for low initial stocking densities (see Figs 1 and 2). For particularly low market demands (i.e. R2000) a positive balance will never be achieved under the conditions used in this model.

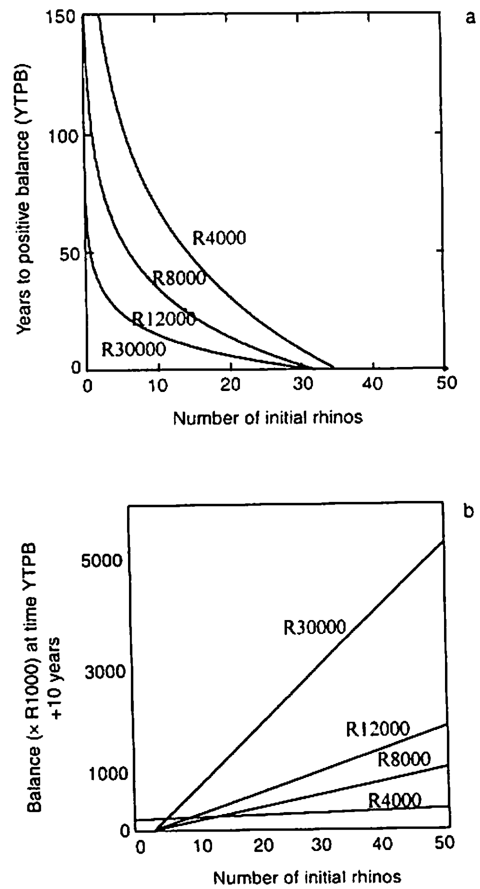

Fig. 2. The output from model II. Figures indicate the range of potential economic return scenarios on a dehorning venture where both dehorning and natural mortality are included: (*a*) Years to positive balance (YTPB) on initial stocking density for each approximation on horn return, and (*b*) A_{10} on initial stocking density for each approximation on horn return.

Discussion

Lindeque[18] stated at the start of the dehorning campaign that old accepted conservation practices have clearly failed to protect the rhino in many African countries and that imaginative alternatives deserve a fair trial. Irresponsible public pressure of the wrong kind could stifle innovation when we need it most. Dehorning rhinos will not necessarily deter poaching.[14] However, such a policy can potentially generate revenue which can contribute to greater anti-poaching measures. Leader Williams has shown that at least in the Luangwa Valley in Zambia, extinction rates are directly related to protection effort.[19] He argued that all available resources should have been concentrated in a core area in order to prevent a decline in the local rhino population. Instead, resources were spread too thinly and the whole population suffered. Deciding how much conservation is enough given limited budgets requires making selective and sometimes unpalatable decisions instead of bowing to particular interest groups guided by emotional and preservationist notions.

We share these sentiments and suggest that harvesting rhino horn should be looked at as a serious policy option by conservation authorities as well as the private sector as a means of earning revenue, possibly to be ploughed back into anti-poaching measures. Our model provides some indication of the magnitude of revenue that can be generated under certain conditions. Several of the assumptions of this model are likely to be violated in certain situations. For example, continued pressure from poaching could significantly increase mortality levels and lead to population decline.[19,20] Also, increases in the overall supply of horn by flooding the market with existing stockpiles, although this is not being proposed by conservation agencies, will lower the overall price of the horn below the levels indicated in this model.

It should be noted that the model presented is likely to be restricted to one set of realistic estimates in a potential horn harvesting scenario, primarily a cost-benefit type analysis of private industry investing in a dehorning venture. We acknowledge that such estimates will vary according to the maintenance scenarios, that may range from farming on natural habitat to a captive-breeding situation. An appraisal of this model as a heuristic tool, however, reveals that rhino horn harvesting is likely to be profitable even under conservative market estimates, and especially at high initial stocking densities. Conversely, the model shows that a positive balance at low stocking densities would likely take too long to be profitable.

The range of potential returns used in the model is thought to provide some broad indication of the long-term sustainability of such a venture if a no-ban policy were to be adopted. Although not taken into account in this model, the first generation of adult rhinos will obviously yield a greater quantity of horn on their first dehorning, possibly worth up to R120 000.[6] Moreover, white rhinos, which have horns approximately twice as heavy as those of black rhinos,[10] would be expected to fetch a relatively higher market price for their horns. In addition, male white rhinos are expected to provide a greater yield of horn than females.[11]

Discount rates were not explicitly accounted for in this model; harvesting rhinos for their horn is intuitively viable only if discount rates are low.[21] The exponential growth of revenue in a sustainable venture suggests, however, that rhino horn harvesting will be profitable even under relatively high discount rates. The growth of revenue will also be enhanced by a general depreciation of African currencies against the US dollar. A conservation agency's discount rate will be lower than that of a private individual, which may experience a high discount rate due to the economic instability that prevails in certain African countries.[9]

Privatisation of the rhino industry, with the prospect of owners expanding product markets, may help to lower private discount rates and encourage breeding rather than exploitation.[5] In South Africa; harvesting rhinos privately would be viable only for the white rhino (rather than the black) at present, given that relatively few black rhinos are in private hands.

Milner-Gulland *et al.*'s[9] independent calculation of the optimal rotation time of dehorning as 1.8 years for the profit maximising individual lends support to the value of 2 years used in our model. The model assumes that harvesting should be performed every 2 years. This is optimal for the first growth but does not necessarily apply to the second or third regrowths of the horn.[10]

Although mortality risks due to the use of anaesthetics to subdue the animals have been reported to be as high as 9%,[22] current initiatives in dehorning rhino indicate that it is much lower than this (H. Ebedes, pers. comm.). *In situ* capture and release, if done professionally, can result in smaller if not negligible mortality risks (about 1%). A mortality risk of 3% was used in this model to account for natural deaths due to predation and disease. In addition, every individual above the age of four suffers an increased mortality risk of 3% due to dehorning. We have chosen to err possibly on the conservative side both in light of the controversy surrounding the dehorning issue as well as to our contention that this is a conceptual rather than a definitive model.

Security from poaching will remain a priority in rhino conservation for the foreseeable future and revenue is needed to offset the costs of poaching. Our model lends support to the South African initiative to allow for a legalised controlled trade in existing stockpiles of rhino horn and more flexible management of populations of rhinoceros currently in private and government hands.

Although the views expressed in this paper are solely those of the authors, we would like to acknowledge the following for valuable input, comments and discussion: Mike t' Sas-Rolfes for his substantial comments on an earlier draft of this manuscript, also Martin Brooks, Geert Creemers, Richard Davies, Hymie Ebedes, Kobus du Toit, Tony Leiman, Clive Walker and an anonymous referee.

RAEL LOON[1] and DANIEL POLAKOW[2*]

Department of Zoology,
University of Cape Town,
Rondebosch, 7700 South Africa.

Present addresses: [1]School of Economics, and [2]Department of Statistical Sciences, University of Cape Town, 7700 Rondebosch (e-mail: polakow@ maths.uct.ac.za).
*Author for correspondence.

Received 7 January; accepted 4 April 1997.

1. Walker C. (1991). Legalize the horn of Africa? *Rhino & Elephant J.* 21–23.
2. Fiske S. (1988). Rhinos: By the horn? *Effective Farming* January 21.
3. t' Sas-Rolfes M. (1990). The economics of rhino extinction. *Endangered Wildlife Trust* 2, 5–9.
4. t' Sas-Rolfes M. (1990). Privatizing the rhino industry. Free Market Foundation paper 900501, Johannesburg.
5. t' Sas-Rolfes M. (1995). Rhinos: conservation, economics and trade-offs. I.E.A. Environmental Unit, London.
6. Koch E. (1996). Farmers want to harvest rhino horn. *Mail & Guardian* November 8–14.
7. Martin E. (1985). Rhinos and daggers: a major conservation problem. *Oryx* **19**, 198–201.
8. Martin E.B. and Martin C.B. (1987). Combating the illegal trade in rhinoceros products. *Oryx* **21**, 143–148.
9. Milner-Gulland E.J., Beddington J.R. and Leader-Williams N. (1992). Dehorning African rhinos: a model of optimal frequency and profitability. *Proc. roy. Soc. Lond. B* **249**, 83–87.
10. Pienaar D.J., Hall-Martin A.J. and Hitchins P.M. (1991). Horn growth rates of free-ranging white and black rhinoceros. *Koedoe* **34**(2), 97–105.
11. Rachlow J.L. and Berger J. (1997). Conservation implications of patterns of horn regeneration in dehorned white rhinos. *Conserv. Biol.* **11**(1), 84–91.
12. Nowell K., Wei-Lien C. and Chia-Jai P. (1992). The horns of a dilemma: the market for rhino in Taiwan. *TRAFFIC Bull.*, Cambridge.
13. Miliken T., Nowell K. and Thomsen J.B. (1993). The decline of the black rhino in Zimbabwe. *TRAFFIC Bull.*, Cambridge.
14. Berger J. (1993). Rhino conservation tactics. *Nature* **361**, 121.
15. Galli N.S. and Flamand J.R.B. (1995). Darting and marking black rhinoceros on foot: part of a monitoring and population estimation technique in Hluhluwe-Umfolozi park, South Africa. *Pachyderm* **20**, 33–38.
16. Hearn J.W. and Swart J. (1991). Optimal translocation strategies for saving the black rhino. *Ecol. Model.* **59**, 279–292.
17. Dorndorf N. (1993). *Translocation strategies for the conservation of the black rhino.* MSc thesis, University of Cape Town.
18. Lindeque M. (1990). The case for dehorning the black rhinoceros in Namibia. *S. Afr. J. Sci.* **86**, 226–227.
19. Leader Williams N. (1990). Black rhinos and African elephants: lessons for conservation funding. *Oryx* **24**, 23–29.
20. Tudge C. (1991). Can we end rhino poaching? *New Scientist*, 5 October, 36–39.
21. Pearce D.W. (1983). *Cost Benefit Analysis.* St Martin's Press, New York.
22. Roth H.H. and Child G. (1968). Distribution and population structure of black rhinoceros in the Lake Kariba basin. *Z. Saugetierk.* **33**, 214–226.

Trace zinc and copper in roadside vegetation and soil in Alice, Eastern Cape, as monitor of atmospheric pollution

The concentrations of zinc and copper were determined in 180 grass and associated soil samples. The zinc levels ranged from 7 ± 1 – 135 ± 6 µg/g dry weight in grass and from 1 ± 0.2 – 120 ± 4 µg/g dry weight in soil. Zinc concentrations declined with distance from road traffic. Similar studies on copper gave levels which varied between 2 ± 1 – 19 ± 2 µg/g dry weight in soil and 2 ± 1 – 23 ± 11 µg/g dry weight in grass samples. There was no correlation between sample concentrations and distance from road traffic. A quality assurance study with standard soil reference material gave results (Zn, 6636 ± 44 µg/g; Cu, 2725 ± 49 µg/g) which compared closely with certified literature values (Zn, 6952 ± 91 µg/g; Cu, 2950 ± 130 µg/g). Results of addition experiments with standard metals and grass samples gave high recoveries (Zn, 97 ± 1%; Cu, 96 ± 1%). The degree of pollution measured does not constitute a threat to livestock. Motor traffic appears to be the main source of zinc; copper probably has a different source.

Determining the nature and then deducing the sources of chemical species in the atmosphere are of primary importance in the study of heavy metals. Many of these elements are associated with natural background aerosols but certain species such as zinc and copper are mostly of anthropogenic origin. Many biological materials have been used as sensitive indicators of heavy metal pollution including mosses, shrubs, bryophytes, grasses, tree barks and leaves.[1–6] The usefulness of soil and vegetation in detecting atmospheric metals has been reported.[7–9]

Motor vehicles introduce a number of toxic chemicals into the atmosphere and elevated concentrations of lead from vehicle emissions have been reported in roadside vegetation.[3–7,10,11] Likewise, elevated concentrations of zinc have been shown in roadside plants.[7,11–13] This form of zinc contamination is considered to arise from vehicular tyre wear and emissions due to zinc additives