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Dehorning African rhinos: a model of optimal frequency and profitability

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SUMMARY

Rhino dehorning is increasingly seen as a method of halting poaching in vulnerable black rhino populations. However, mathematical models suggest that, under current costs and prices, dehorning must be done annually if poaching is to be made unprofitable. As dehorning carries a risk of rhino mortality, it is unsustainable as an anti-poaching measure. A profit-maximizing manager will dehorn at less frequent, but still unsustainable, intervals. Sustainable dehorning produces near-optimal profits but will not deter poachers.

1. INTRODUCTION

The possibility of dehorning rhinos has been discussed for some time, both as an anti-poaching measure and as a means of generating sustainable income from a rhino population. As the black rhino's (*Diceros bicornis*) situation becomes more precarious, crisis anti-poaching measures are being implemented by several African countries. However, as white rhino (*Ceratotherium simum*) numbers on ranches and in National Parks in southern Africa have increased, pressure has increased for the horn trade to be reopened, perhaps using dehorning as a harvesting method. The first attempt at large-scale rhino dehorning was as an anti-poaching measure in Damaraland, Namibia, in 1989. This population was picked because of its isolation from other populations, the open nature of its habitat, so that it would be clear to a poacher that the rhino was dehorned, and the high level of monitoring, allowing a study of the effects of dehorning on social behaviour (Vigne 1989). The scattered population was expensive to protect by patrolling, and adequate resources were not available (Morkel & Geldenhuys 1991). In early 1992, a larger population of white rhinos in Zimbabwe was also dehorned.

As a crisis anti-poaching measure, dehorning should meet certain criteria of cost-effectiveness. In particular, do the costs of dehorning produce the same benefits in terms of reduced rhino mortality as the equivalent amount of money spent on anti-poaching patrols? This depends critically on the regularity with which dehorning must be done for it to be uneconomic for a poacher to kill a rhino. As an income-generating exercise, the optimal rotation time for dehorning will vary with the ratio between the cost of dehorning and the sale price of rhino horn, and with the manager's discount rate. At reasonable parameter values, poachers will kill a rhino before the profit-maximizing manager dehorns it. Using data on current cost–price ratios, it is shown that a rhino should be dehorned annually to ensure its safety from poaching, but it is optimal for a ranched rhino to be dehorned on a 2-year rotation. However, harvesting suboptimally to deter poachers is not feasible, because dehorning is unsustainable at current levels of mortality under anaesthetic.

2. AN EXPRESSION FOR HORN GROWTH

There are virtually no quantitative data on rhino horn growth. However, it is known that horns grow steadily from birth, taking around 3 years to reach full size, although rhinos are not fully mature until the age of 6 years (Mentis 1972). The only sexual dimorphism in horn growth is in the ratio of front-to-back horn length, with females having relatively longer front horns. There appears to be no sexual difference in overall horn mass.

There is even less information on horn regrowth. A few rhinos have been observed regrowing horns that have been removed for some reason, and it is likely that horn regrowth has the same pattern as the original growth, although some horns seem to grow back deformed (Ritchie 1963). Bigalke (1945) cites two contradictory examples of horn regrowth: a 15-year-old zoo-raised female regrew an anterior horn removed through injury very slowly, taking 10 years to regrow it fully. A four-year-old captive male also lost an

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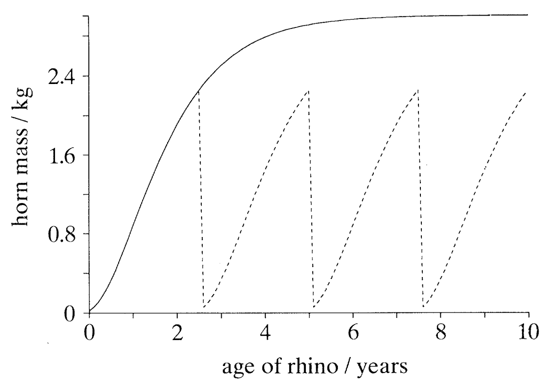

Figure 1. The von Bertalanffy growth curve for rhino horn, for dehorned rhinos (broken line) and rhinos that have not been dehorned (solid line). The function is: $w(t) = \hat{w}(1-a_1\, e^{-a_2 t})^{a_3}$, where $w(t)$ is the mass of horn at time t, $\hat{w}$ is the maximum horn mass, and a_i are constants; a_1 is set at 0.8, determining the y-axis intercept; a_2 is set at 0.87, and determines the horn growth rate; a_3 is set at 3, meaning that growth is the same in all three dimensions. The value chosen for a_2 has the most effect on the model results (see figure 5). Regrowth is assumed to follow the same function as new growth, as is shown for a rhino dehorned every 2.5 years. No decrease in the rate of regrowth occurs with age.

anterior horn through injury, but regrew it within a year. These examples are consistent with the observation that older animals regrow their horns more slowly than younger ones (Morkel & Geldenhuys 1991).

The horn growth function that is used in this model is a von Bertalanffy growth curve (Getz & Haight 1989). It is suitable for rhino horn growth because the function increases smoothly with age, rapidly at first, then slowly towards an equilibrium mass. The relations between the growth rate of a new horn, the regrowth rate and the age of the rhino, are uncertain. thus regrowth is assumed to follow the same pattern as new horn growth (figure 1).

3. A MODEL OF OPTIMAL ROTATION TIME

The problem of repeatedly cropping a resource has been most studied in the forestry literature. Mathematically, a horn can be treated as an even-aged forest stand, to be clearcut and allowed to regrow repeatedly over the rhino's lifetime. The present value of such a resource depends crucially on the rotation period as well as on the value of the fully grown stand, because there is an opportunity cost involved in prolonging one rotation in terms of the number of future rotations that can be fitted in (Clark 1990). The analysis of the forestry problem assumes an infinite time horizon, whereas the rhino time period is its 40-year lifespan. However, the mathematical complexity is increased considerably by relaxing the infinite horizon assumption, and the optimum rotation period will not usually exceed 3 years, which is sufficiently far from the horizon for the assumption to have negligible effect.

The forestry model for the optimal rotation of an even-aged stand was first developed by Faustmann in 1850. Faustmann's model differs from the standard maximization of the present value of a resource by having a denominator of $(1-e^{-\delta t})$ on the right-hand side. As $(1-e^{-\delta t}) < 1$, taking rotations into account lowers the optimal harvest time of the resource (Clark 1990). The formula is:

$$V'(T)/(V(T)-c) = \delta/(1-e^{-\delta T}), \qquad (1)$$

where T is the optimal rotation time, $V(t)$ is the value of the crop at time t, c is the cost of harvest, δ is the discount rate, the annual rate at which the present value of future income decreases. This is equivalent to the real interest rate for a private individual. A private individual may have a high discount rate due to the economic instability of most African countries. Discount rates of 0.1–0.3 are used in the model. However, a conservation agency's discount rate may be low because it values the future highly.

The value of a rhino's horn at a particular age, or point of regrowth, is the price per kilogram multiplied by the horn mass, expressed as in figure 1. The optimal rotation for a rhino manager can then be calculated from equation (1). Poachers do not crop but kill the rhino, and, rather than being sole owners, they compete for an open access resource. Only immediate earnings are considered, as the rhino is likely to be killed by others if left to increase in value. The rhino is killed when the value of its horn equals the opportunity cost incurred by hunting it, $V(t)-c = 0$. This corresponds to $\delta \rightarrow \infty$ in equation (1).

Two economic variables, the discount rate and the cost-price ratio, determine the manager's optimal rotation time. The poacher's optimal harvest time is dependent only on his cost–price ratio. A cost–price ratio is the ratio between the cost of dehorning or killing a rhino and the sale price of its horn, and is assumed to be dimensionless and time invariant.

Because the cost of dehorning or killing a rhino does not vary with time, the effects of changes in the rhino population size on the cost of capture are not taken into account. Equally, a constant price does not take into account the effects of changes in the quantity of horns sold on the price of horn. A constant cost–price ratio is a valid assumption for a sole owner of a stable rhino population whose horn output has no effect on the market price of horn. It is also valid for a poacher optimizing in the short run only, so that the decision is simply to harvest rhinos or not at a single point in time.

The model addresses two key questions arising out of a decision to dehorn. Firstly, given that a rhino population is to be dehorned by managers at an interval regular enough to deter poachers, what is that interval? Secondly, given a stable managed rhino population, what is the optimal rotation time for a profit-making manager?

4. RESULTS OF THE MODEL

A manager's optimal rotation time is more sensitive to the cost–price ratio than to the discount rate (figure 2). At all cost–price ratios, the poacher's optimal harvest time is much lower than the manager's optimal rotation time. If both parties are hunting the same

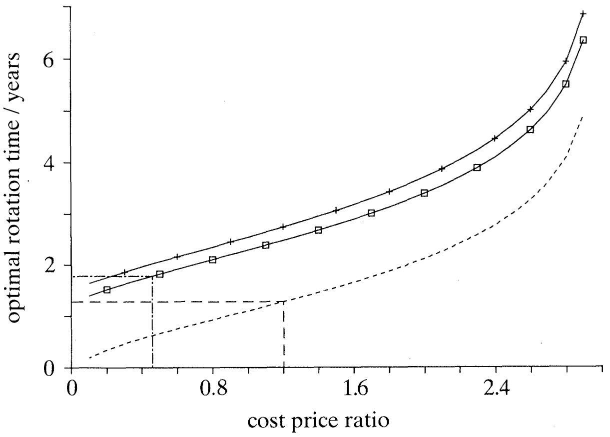

Figure 2. The optimal rotation time for a manager (solid curve) and the optimal harvest time for a poacher (broken curve) at various cost–price ratios. The manager's cost–price ratio is insensitive to discount rate, as shown by the similarity of the curves under discount rates of 0.1 (crosses) and 0.3 (squares). The optimal harvest time for a poacher is considerably less than the optimal rotation time for a manager at all cost-price ratios. The curves reach an asymptote at a cost–price ratio of 3 because, at this point, the cost of killing a rhino equals the revenue from its 3 kg horn. The optimal rotation time for a manager with a cost–price ratio of 0.43, as estimated for the Namibian dehorning exercise, is shown along with the optimal harvest time for a Luangwa Valley poacher with a cost–price ratio of 1.2. Data shown for manager (dot-dash line) and poacher (dashed line).

rhinos solely for profit, the rhino will be killed by the poacher before its horn is cropped by the manager. This conclusion holds for most realistic combinations of cost–price ratios. To explore the implications of the model for a real-life situation, data on cost–price ratios are necessary. However, the available data are scanty, and can provide only an approximate idea of the orders of magnitude involved.

5. COST-PRICE DATA FOR RHINO HARVESTING

(*a*) *The profit-maximizing manager*

The discussion of the profitability of dehorning is rather academic at present, as trade in rhino horn is illegal. However, there has been strong pressure for limited trade to be reopened. To predict the optimal behaviour of a manager in a real-life situation, some idea of the likely cost–price ratio is needed. The dehorning exercise in Namibia cost R2400 per rhino ($1 = 2.5 Rand).The wholesale price of rhino horn in eastern Asia in 1987 was $600–750 per kilogram (Martin 1989). If $750 per kilogram, or R1875, is taken as the rhino horn price in 1989, a rough calculation of the optimal rotation time for a manager in 1989 can be made. The cost–price ratio is 2400/5625 (= 0.43), giving an optimal rotation time of 1.8 years.

At present, any commercial dehorning would be done on white rhinos, which are well established in private hands in southern Africa. On a private ranch, the costs of keeping rhinos need to be weighed up against the revenue from horn sales for a full picture of the profitability of ranching. However, only the variable costs of dehorning need be considered for the calculation of the optimal rotation time. If dehorning is done the manager also incurs the opportunity cost of the risk of a rhino dying under anaesthetic. This deprives him of future income, depending on the rhino's age and the rotation period, and thus acts to lengthen the optimal rotation time. Rhino mortality under anaesthetic is around 9% (Roth & Child 1968), which is large enough to create a significant opportunity cost for the manager, and even to lead to population decline (Milner-Gulland 1991).

(*b*) *The poacher*

At the time of the dehorning, there was a large amount of horn in circulation in the Caprivi Strip area of Namibia because of the military presence. Prices were very variable, and there was a lot of speculatory buying. Poachers received R50–R500 for a 2.6 kg horn, whereas middlemen selling to South Africa received R200–R660000. There are no data on poacher costs in Namibia. Zambian poachers in 1985 (Milner-Gulland & Leader-Williams 1992) had a cost–price ratio of 1.2. Although this is very much higher than the cost–price ratio calculated for managers, it still leads to the poachers killing rhinos after 1.3 years, before the profit-maximizing manager would dehorn.

6. IMPLICATIONS FOR DEHORNING PROGRAMMES

Two major considerations are involved in the decision to dehorn; the economic benefits, and the effects on rhino mortality. The latter may result either from poaching or from the dehorning process itself. In this study, two very different decision-making situ-

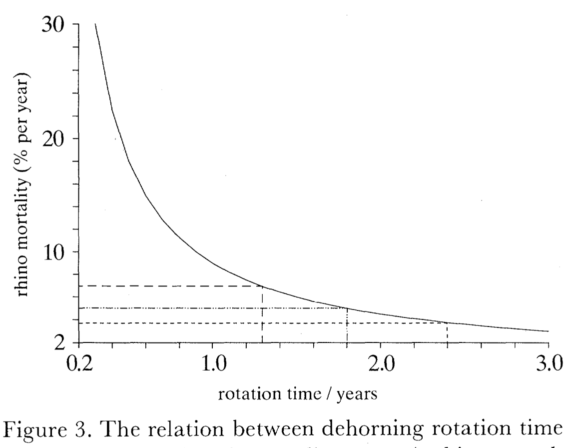

Figure 3. The relation between dehorning rotation time and the dehorning-induced mortality rate. A rhino population can sustain a human-induced mortality rate of 3.7% per annum without declining (–––). A rotation time of 2.4 years produces this mortality rate, under the assumption of 9% mortality at each dehorning exercise. The mortality rates of both the optimal rotation time (– · ·) and the rotation time to deter poaches (———) are higher than the sustainable rate. Mortality increases exponentially with decreasing rotation time, so that it rapidly becomes very high at rotations of less than 1 year.

ations are considered. In the case of a manager dehorning ranched rhinos for profit, poaching can be ruled out as a source of mortality. However, the mortality caused by the dehorning process is sufficient to make the optimal rotation period unsustainable (figure 3). A sustainable rotation period would have a profit of around 90% of the maximum (figure 4). However, as anaesthetic technology improves, dehorning mortality rates will be reduced, shortening the sustainable rotation period towards the optimum.

Data are needed on the growth function for rhino horn, and in particular on the relation between horn regrowth and the age of the rhino. From the anecdotal evidence presented, it seems likely that, as a rhino ages, the rate of horn regrowth slows. However, only if a horn takes 20 years to regrow does the poacher's optimal harvest time exceed the manager's optimal rotation time. If regrowth took 10 years, the longest time recorded, dehorning at the profit-maximizing optimum would be sustainable, although dehorning for poaching prevention would still be unsustainable (figure 5). If regrowth took 1 year, the shortest time recorded, both the profit-maximizing and anti-poaching rotation times would be considerably less sustainable than suggested here (figures 3 and 5).

Although a manager attempting to deter poaching is primarily concerned with the reduction of rhino mortality rates, the economic advantages of dehorning could be great. The use of dehorning alone to control poaching would lead to profits of 89% of the maximum, but would be unsustainable at present dehorning mortality rates, because of the short rotation time needed to deter poachers (figures 3 and 4). However, if the profits from dehorning accrued directly to the Wildlife Department and were re-invested in anti-poaching patrols, a mixed strategy could be possible. A common rule of thumb is that $200 per square kilometre (Bell & McShane-Caluzi 1986) is needed to halt poaching in National Parks using anti-poaching patrols. At a rhino density of 0.4 per kilometre (Leader-Williams 1985), this translates into about $500, or R1250, per rhino. Sustainable dehorning could supply over 90% of this investment requirement.

As yet, there have been few practical indications of the success of dehorning. The rhinos dehorned in 1989 have not been poached, although, because there has been little poaching throughout Namibia since the dehorning, this is not necessarily a direct consequence of the programme (Morkel & Geldenhuys 1991). The model presented here suggests that dehorning alone is unlikely to be a feasible method of preventing poaching because of the mortality associated with the dehorning process. It is useful only as a method of earning revenue, and so would only be worthwhile if the international trade in rhino horn were restarted. It could then be done on a sustainable rotation, which, although suboptimal, gives profits very close to the maximum. These profits could then be used to offset the costs of other forms of poaching prevention. These costs would be considerable because rhino mortality from poaching would have to be reduced virtually to zero to ensure that the population did not decline.

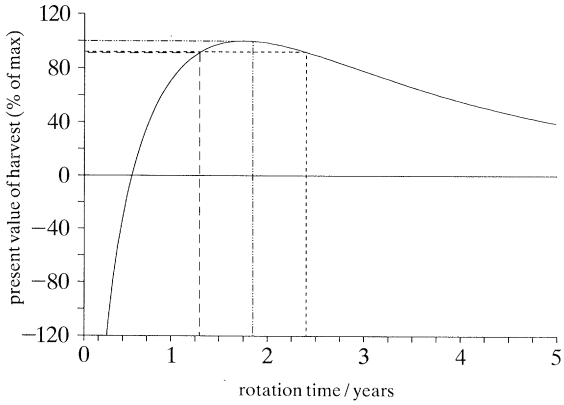

Figure 4. The value at birth to a manager of the horn supplied by a rhino throughout its lifetime (present value), varying with the rotation time. A constant cost–price ratio of 0.43 is assumed, from the data presented in the text, together with a discount rate of 0.3. At the optimal rotation time of 1.8 years (–··), the rhino has a present value of R1300 at birth. If the rotation time is increased to the sustainable level of 2.4 years (-----), the present value only drops to 90% of the optimal value. If it is decreased to the Luangwa Valley poacher's optimum of 1.3 years (———), the present value is 89% of the optimum. Any rotation time between 1 year and 3 years provides at least 75% of the maximum value, although the value drops off sharply below 1 year.

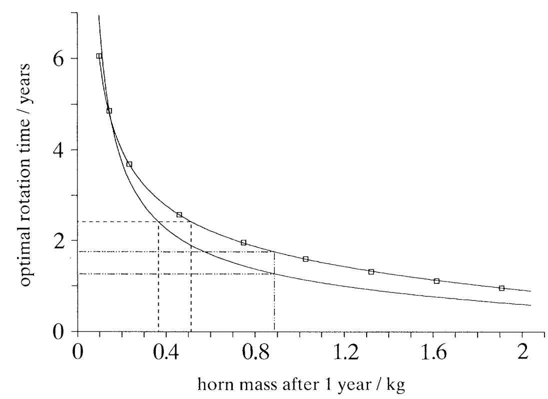

Figure 5. The effect of changes in the rate of horn growth on model results, shown for the cost–price ratios estimated in the text. As the horn mass attained after 1 year of growth declines, both the manager's optimal rotation time (squares) and the poacher's optimal harvest time (curve without symbols) increase. The optimal rotation times to deter poaching and to maximize profits are shown for the rate of horn regrowth assumed in the model (–··). For the profit-maximizing rotation time to be sustainable, horn mass after 1 year must decrease to 59% of the assumed value, whereas for the rotation time that deters poaching to be sustainable, the mass after 1 year must decrease to 41% of the assumed value (———). A horn taking 10 years to regrow, the longest anecdotally recorded regrowth time, would have reached a mass of 0.43 kg, 49% of the chosen value, after 1 year. This graph can be interpreted as a sensitivity analysis of the effect of the growth rate parameter in the von Bertalanffy function on the model's results (see figure 1). It also demonstrates the effect of changes in horn regrowth rate as the rhino ages on the model results.

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REFERENCES

Bell, R. H. V. & McShane-Caluzi, E. (ed.) 1986 *Conservation and wildlife management in Africa*. Washington, D.C.: Peace corps.

Bigalke, R. 1945 The regeneration of the anterior horn of the black rhinoceros. *Proc. zool. Soc. Lond.* **115**, 323–326.

Clark, C. W. 1990 *Mathematical bioeconomics*. New York: John Wiley.

Getz, W. M. & Haight, R. G. 1989 *Population harvesting*. Princeton University Press.

Leader-Williams, N. 1985 Black rhino in South Luangwa National Park: Their distribution and future protection. *Oryx* **19**, 27–33.

Martin, E. B. 1989 Report on the trade in rhino products in Eastern Asia and India. *Pachyderm* **11**, 13–22.

Mentis, M. T. 1972 A review of some life history features of the large herbivores of Africa. *The Lammergeyer* **16**, 1–89.

Milner-Gulland, E. J. 1991 The exploitation of certain large mammals for trade: The implications for management. Ph.D. thesis, University of London.

Milner-Gulland, E. J. & Leader-Williams, N. 1992 A model of incentives for the illegal exploitation of black rhinos and elephants: poaching pays in Luangwa Valley, Zambia. *J. appl. Ecol.* **29**. (In the press.)

Morkel, P. vd. B. & Geldenhuys, L. J. 1991 *Dehorning of black rhinoceros in Namibia*. Paper to the International Rhino Conference, San Diego.

Ritchie, A. T. A. 1963 The black rhinoceros. *E. Afr. Wildl. J.* **1**, 54–62.

Roth, H. H. & Child, G. 1968 Distribution and population structure of Black rhinoceros in the Lake Kariba basin. *Z. Säugetierk.* **33**, 214–226.

Vigne, L. 1989 Dehorning rhinos in Damaraland – a controversial issue. *Pachyderm* **12**, 47–48.

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