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Optimising investments from elephant tourist revenues in the Maputo Elephant Reserve, Mozambique

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Summary

Private enterprises are active in conservation initiatives in Africa. Some of these enterprises have long-term licences for the development of conservation areas. The motivation of these organisations to participate in conservation is ultimately determined by the economic output of their activities. An electric fence is being constructed in the Maputo Elephant Reserve, Mozambique. A costs-benefit analysis was carried out, in order to assist in the optimisation of the management activities of the elephant population, based on elephant population size, fence costs, crop raid costs, elephant poaching, and benefits derived from tourism (game-viewing and hunting). Tourist numbers increased with increasing elephant density through a concave utility function. Optimal harvest/hunting strategies were calculated from optimal control theory, using dynamic optimisation (Pontryagin's Maximum Principle). Poaching and raid costs could be compared to fence construction costs at different elephant population sizes. Costs generated through elephant poaching and elephant crop raid costs were higher than fence construction costs at a population size >100. Elephant hunting was a less favourable activity, economically and ecologically, than elephant viewing, due to the large game-viewing profits per elephant. Only if the licence fee increases from US$6500 to 28,500 would hunting become attractive, although ecological and economical constraints would probably prevent the development of hunting activities in the area. The assumed resource price of elephant (US$5000) was lower than the marginal value derived from tourism, indicating that elephants should be bought until the maximum stocking rate is reached.

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Introduction

The continuing human population growth, and the decreasing area of suitable elephant *Loxodonta africana* habitat contribute to an increasing occurrence of elephant crop raiding in Africa and Asia (Campbell, Butler, Mapaure, Vermeulen, & Mashove, 1996; Dey, 1991; Hoare, 1995; Kiiru, 1996; Lahm, 1996; Tchamba, Bauer, & Iongh, 1995). Electric fencing is regarded as a possible long-term solution for crop damage, thereby decreasing people–wildlife conflicts and improving elephant conservation (Hoare, 1995; Thouless & Sakwa, 1995). However, fence construction is relatively expensive, certainly in developing countries. One way to finance these fences is through participation with the private sector. The conservation policy in Mozambique is partly organised in co-operation with the private sector. Tenders for concessions are issued, and management plans written for the different protected areas by the Ministry of Agriculture. The management plan includes guidelines and requirements under which the concession holders can operate in the protected areas, which, in some cases, include specific conservation activities, such as the re-introduction of species or fence construction. Benefits derived from wildlife exploitation are assumed to return entirely to the concession holders, in an effort to compensate them for the high initial development costs. The potential concession holders applying for the tender are purely motivated by economic stimuli, ultimately profits, which validates the application of a cost-benefit analysis. In this paper we try to model the financial costs and benefits (Barnes, Burgess, & Pearce, 1996) of an electric fence currently under construction in the Maputo Elephant Reserve (MER), Mozambique. The fence is aimed at reducing the frequent elephant raids in the surrounding agricultural area (de Boer & Baquete, 1998). The presented model calculates the costs and benefits for the concession holder, associated with the electric fence construction and the diminishing costs of elephant crop raids. The model includes elephant population size, which is assumed to determine both the extent of crop raid costs and the benefits derived from tourism. The objective of the model is to calculate the optimal management strategy, aimed at increasing benefits through tourism, decreasing potential dangerous people–wildlife conflicts, while maintaining a healthy elephant population.

Methods

Study site

The MER is situated in the south of Mozambique (Fig. 1) and was established in 1932, although its current boundaries were redefined in 1960. The MER has not been fenced. The average annual rainfall is 690–1000 mm and the average temperature 20–26° (DNFFB, 1994). The soils are mainly sandy and the vegetation can be classified in six community types: dune vegetation; mangroves; riverine vegetation; forest; woodland; and grassplains (de Boer, Ntumi, Correia, & Mafuca, 2002). A small population of around 180 elephants (de Boer & Ntumi, 2001) can be found in the area. The elephants are distributed relatively close to the human settlements and hide in dense forest patches (de Boer et al., 2002). Elephants are responsible for most crop damage in the area (de Boer & Baquete, 1998). The crop damage influences negatively the attitude of the surrounding local population towards the management of the MER (de Boer & Baquete, 1998).

Two other conservation areas exist in the area, where elephants occur in relatively high densities. These are the Kruger National Park (NP) and the Tembe Elephant Park, both in South Africa. The Kruger National Park is the largest with almost 2 million ha, more than 17 large rest camps, and a population of over 8000 elephants. Elephants have been culled in the Kruger NP until 1995. Tembe National Park comprises 30,000 ha, has one lodge, and an elephant population of about 140 elephants. Bulls have been occasionally hunted in Tembe NP in order to manage the elephant population and benefit from the finances generated by the hunting operation. The proposed Lubombo Transfrontier Conservation Area will link the elephant population of the Tembe NP and the MER through the Futi corridor.

An electric fence has been constructed by Blanchard Mozambique Enterprises (Fig. 1), a private enterprise that obtained a long-term lease for the MER. The Maputo River, acting as natural boundary, is part of the deflecting barrier system (Hoare, 1995). The electric fence aims at enclosing in the agricultural fields between Salamanga and Massuane, along the Futi River (see Fig. 1). The concession holder aims to develop the area for tourism, and would, together with the National Directorate of Forestry and Wildlife, manage the natural resources of the MER.

Model

The model layout is guided by the work of Skonhoft (1995), with several modifications.

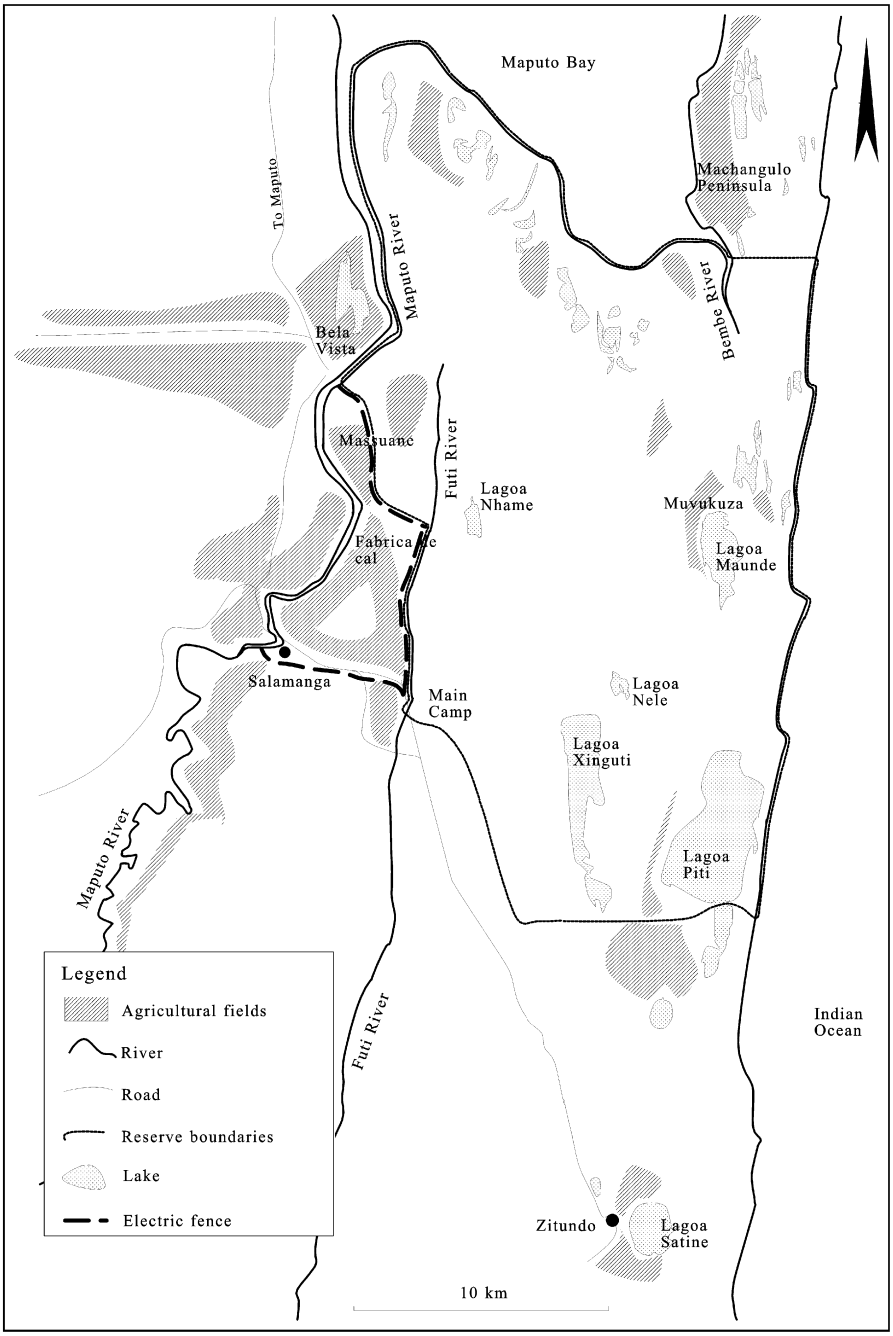

Figure 1. The location of the electric fence, and the agricultural areas around the Maputo Elephant Reserve.

The single species approach (but see Hearne, Lamberson, & Goodman, 1996; van Kooten, Bulte, & Kinyua, 1997) has been used in this case, because the elephants are the main conservation objective of the MER. The benefits derived from the MER are expected to come from both non-consumptive use (game-viewing) and consumptive use (hunting). Wildlife hunting has been proven successful in southern and eastern Africa, contributing significantly to national economies, and could enhance rural development and conservation (Lewis, Kaweche, & Mwenya, 1990). Safari hunting will be allowed in Mozambique in the near future (DNFFB, 1999), and is therefore included in the model. Both costs (fence costs, other investments, and crop damage compensation) and benefits (game-viewing and hunting revenues) are defined from the investors' perspective, the concession holder of the MER. A discount rate *d* of 5% for future earnings (Caughley, 1993) has been incorporated in the model.

The concession holder seeks to maximise the present utility value over a long-term time horizon (the concession period, assumed infinite). By Pontryagin's maximum principle, the maximisation of the benefits derived from tourism (game-viewing and hunting), subject to the constraints mentioned above, is equivalent to the maximisation of the current value Hamiltonian, using co-states or current value multipliers, as auxiliary variables. The theoretical layout of the model is discussed before the parameter estimation, and model results.

Fence construction

The standard electric elephant fence is made out of three strands electric wire mounted on a 2.5 m high game fence, and powered with solar energy. The fence has a length of l, and construction costs are estimated F_f per km. The annual maintenance costs (excluding the costs of solving the problem of fence-breaking animals) are estimated at a proportion r_m of the initial investment. The investment cost will be spread over y years, with an interest rate i and equal annual installments a_{yi}. The total annual fence costs (F_t) are given below:

$$F_a = a_{yi} + r_m F_f l. \tag{1}$$

Elephant population parameters

The annual elephant population growth dN/dt is represented by the logistic growth function:

$$\frac{dN}{dt} = rN_t(1 - N_t/K). \tag{2}$$

The growth rate is maximal at low N_t, and approaches zero when reaching the assumed carrying capacity K. The annual increase in numbers is maximal at half the carrying capacity. The total number of elephants hunted per year, N_h, has a negative effect on the total population size:

$$\frac{dN}{dt} = rN_t(1 - N_t/K) - uN_t. \tag{3}$$

The maximum number of elephants N_{max} is obtained through multiplying K with the total area available to elephants A:

$$N_{max} = KA. \tag{4}$$

Elephant raid costs

Elephant raids involve three different costs. With the existence of the fence these raid costs will be assumed to equal zero. The total costs include compensation paid (C_c) to the surrounding villages for actual crop damage. The costs are assumed to increase linearly with elephant population size (N_t) with a factor c_f (de Boer & Ntumi, 2001):

$$C_c = c_f N_t. \tag{5}$$

The second component (C_{pac}) is the costs related to Problem Animal Control, or the shooting of a certain number (N_{pac}) of problem elephants, which is assumed to increase linearly with elephant population size (N_t). The problem animal hunt will be not be marketed, although this could be considered as an alternative (see Bond, 1994). In the absence of commercial processing facilities, the meat will be distributed to the local villages, and no product profit will be earned from the problem elephant. These costs are given below:

$$C_{pac} = c_r M_{pac} N_t \tag{6}$$

and

$$N_{pac} = M_{pac} N_t. \tag{7}$$

The third component is the fixed annual cost (C_h, Eq. (8)) related to the extra human resources and material necessary for problem animal control and disturbance-shootings. In terms of investment this will require, according to DNFFB (1997), an initial investment (C_i), plus annual running and maintenance costs (C_m) and salaries (C_s) of four game scouts. The control and park protection is assumed to be equal with or without the existence of a fence and is excluded from the equation:

$$C_h = (C_i + C_m + C_s). \tag{8}$$

The total annual raid costs C_{ra}, are therefore

$$C_{ra} = C_c + C_{pac} + C_h \quad \text{or} \quad C_{ra} = (c_f + c_r M_{pac})N_t + C_h. \tag{9}$$

Poaching costs

Elephant poaching is almost impossible to model, because of its stochastic nature. For the sake of model simplicity it is considered to be linearly related to the stocking rate (N_t). The costs of poaching (C_p) are dependent on the resource price (c_r), times the number of elephant killed (N_p), which depends on the poaching mortality rate (M_p). Poaching costs are assumed to equal zero with the existence of the fence:

$$C_p = M_p N c_r \tag{10}$$

and

$$N_p = M_p N. \tag{11}$$

Tourist revenues

Two different types of benefits can be derived from tourist activities (Barbier, 1992; Barnes et al., 1996; Skonhoft, 1995). Firstly, there are the annual profits (P_s) derived from services supplied to tourists: the income minus the costs, which includes infrastructure; staff costs and park protection. Maximum tourist benefits per year ($P_{\max}$) depend on the average occupation rate (R_{occ}), the maximum tourist capacity (K_{T}), the daily lodging rate (H) times the profit rate ($P_{\%}$), minus the total annual costs for the park protection (C_{pp}, comprising both personal and infrastructural costs). These profits are assumed to be dependent on the wildlife-stocking rate (N_{t}). Such benefits are conventionally denoted by a monotone increasing concave utility function that saturates (Regev, Gutierrez, Schreiber, & Zilberman, 1998; Skonhoft, 1995; Skonhoft & Solstad, 1996), with a half-saturation constant m_{t}. The total number of tourists (T) increases asymptotically with increasing elephant population size to a maximum (constraint (14)). The total number of visiting tourists depends on the stocking rate, and increases with elephant stocking rate N_{t} until the elephant carrying capacity K has been reached. The annual profits can be modelled using below:

$$P_{\max} = 365(R_{\mathrm{occ}}K_{\mathrm{T}}P_{\%}H) - (C_{\mathrm{pp}}A), \tag{12}$$

$$P_{\mathrm{s}} = \frac{P_{\max}N_{\mathrm{t}}}{m_{\mathrm{t}} + N_{\mathrm{t}}}, \tag{13}$$

$$\text{constraint}: \quad T < R_{\mathrm{occ}}K_{\mathrm{T}}. \tag{14}$$

The second potential source of profits derived from tourism is the selling of hunting licences (P_{H}, Eq. (15)), which is linearly related to the number of elephants hunted (N_{h}). Elephant hunting will only be allowed for the bulls in the population under the condition (Armbruster & Lande, 1993) that the population size is at least half of the maximum number at maximum stocking rate. The hunting licence fee per elephant (P_{f}; Bond, 1994; Campbell et al., 1996; Child, 1990) times the number of elephant bulls killed determines the total profits. Apart from the licences, no profits will be derived from the processing of the animal (such as hides, ivory and meat), because of the low numbers of hunted elephants, and the low ivory market prices in Mozambique (at present in Mozambique, 2005, about US$ 10/kg, see also Burton, 1999). The safari hunting operations will be paid for via the normal tourist expenditures, included in Eq. (12). The licence fees therefore only generate extra profits:

$$P_{\mathrm{h}} = P_{\mathrm{f}}N_{\mathrm{h}}. \tag{15}$$

Parameter estimation

Parameter estimates were obtained from literature sources and expert opinions (Table 1). The total fence costs F_{t} were US$ 228,000. The annual maintenance costs (excluding the costs of solving the problem of fence-breaking animals) are estimated at 10% of the initial investment. Spreading the investment cost over 20 years, with equal annual installments a_{yi} (Eq. (1)), total fence construction and maintenance costs are US$ 41.100/yr.

At present at least 180 elephants can be found in the area (de Boer & Ntumi, 2001). The carrying capacity of the MER has never been determined, but the nearby, ecologically similar Tembe Elephant Park in South Africa has a maximum stocking rate of 0.4 elephants per km^2 (Hall-Martin, 1992; Ostrosky, 1988), similar to the estimated maximum stocking rate of the Kruger National Park (Trollope, Trollope, Biggs, Pienaar, & Potgieter, 1998). The total available habitat of the elephants is estimated at 800 km^2 (de Boer et al., 2002), which means that the population at maximum stocking rate (K) could total 320 elephants.

The three elephant raid cost components are crop damage compensation, problem animal control, and annual fixed costs. At present, annual compensation paid to farmers to compensate for crop damage is estimated at US$ 8800 (de Boer & Ntumi, 2001) at a population size of 180 elephants or US$50 per elephant. The second component (C_{pac}) is the costs related to problem animal control. Two elephants have been shot in the last four years. This is an annual mortality rate (M_{pac}) of 0.3% representing a total annual cost of US$ 2500, at an average resource price, c_{r}, of US$ 5000. The latter price is based on the possibility of obtaining relatively cheap surplus animals from the nearby Kruger National Park, South Africa, and includes transport. The third component is the fixed annual cost (C_{h}) for salaries and material for problem animal control and disturbance-shootings. This investment requires, according to DNFFB (1997), an initial investment (C_{i}) of two motorcycles and other material (equipment, binoculars, rifles, etc.) estimated at US$ 20,000, with a depreciation and renewal period of four years, plus annual running and maintenance costs (C_{m}, 50% of the resource price) and the salaries (C_{s}) of four game scouts (US$ 600/yr each). These three cost components, the total elephant raid costs, add up to (Fig. 2):

$$C_{\mathrm{ra}} = (c_{\mathrm{f}} + c_{\mathrm{r}}M_{\mathrm{pac}})N + C_{\mathrm{h}} \quad \text{or} \quad 65N + 17{,}400. \tag{16}$$

Elephant poaching depends on the stocking rate (N_{t}), the elephant resource price (c_{r}), and the poaching rate (M_{p}). The resource price of an elephant is estimated at US$ 5000 (see above). Hall-Martin (1988) estimated an annual poaching percentage of 8.5% in 1988 for the Tembe Park.

Table 1. Alphabetical listing of parameters, their interpretation, estimated values and sources

Parameter	Interpretation	Units	Value	Source
A	Elephant distribution area	km	800	de Boer et al. (2002), this study
a_{yi}	Annual installments over y years at interest i	US$	Eq. (1)	This study
C_c	Total annual compensation costs	US$/yr	Eq. (5)	This study
c_f	Elephant raid costs	US$	50	de Boer and Ntumi (2001)
C_h	Total annual personnel costs	US$/yr	Eq. (8)	This study
C_i	Material investment for problem animal control	US$/yr	5000	DNFFB (1997)
C_m	Running costs	US$/yr	10,000	DNFFB (1997)
C_p	Total annual poaching costs	US$/yr	Eq. (10)	This study
C_{pac}	Total problem animal control costs	US$/yr	Eq. (6)	This study
C_{pp}	Park protection costs	US$/km^2	200	Leader-Williams (1996)
c_r	Elephant resource price	US$	5000	Child (1990); Barnes (1996); E. Gous, personal communication 1998
C_{ra}	Total annual raid costs	US$/yr	Eq. (9)	This study
C_s	Annual salary costs	US$/4 game scout/yr	2400	DNFFB (1997)
F_a	Total annual fence costs	US$/yr	Eq. (1)	This study
F_f	Total fence construction costs	US$/km	6000	E. Gouws, personal communication 1998
H	Daily lodging rate	US$/day	100	E. Gouws, personal communication 1998
h_b	Maximum proportion of elephant bulls hunted	–	0.02	Bond (1994)
I	Interest rate	Per year	0.05	This study
K	Carrying capacity	Elephants/km^2	0.4	Hall-Martin (1992), Ostrosky (1988) and Trollope et al. (1998)
K_T	Maximum tourist capacity	Total number of beds	2000	DNFFB (1994); www.uthungulu.org.za
L	Total fence length	km	38	de Boer et al. (2000)
M_p	Poaching mortality rate	–	3.4	de Boer et al. (2000), this study
M_{pac}	Mortality rate for problem animal control	–	0.003	This study
m_t	Half saturation constant	–	50	This study
N_h	Total number of bulls hunted	Elephants	Eq. (15)	This study
N_{max}	Elephant population size at carrying capacity	Elephants	Eq. (18)	This study
N_{pac}	Number of problem animals	Elephants	Eq. (7)	This study
$P_{\%}$	Tourist profit rate	–	10%	This study
p_b	Sex ratio (proportion of bulls)	–	0.4	de Boer et al. (2002), this study
P_f	Hunting licence fee	US$/elephant	6500	Child (1990), Bond (1994) and Campbell et al. (1996)
P_h	Total annual hunting profits	US$/yr	Eq. (15)	This study
P_{max}	Maximum tourist benefit	US$/yr	Eq. (12)	This study
P_s	Total annual game-viewing profits	US$/yr	Eq. (13)	This study
r	Maximum growth rate	–	0.07	Calef (1988) and Owen-Smith (1988)
r_m	Fence maintenance cost as proportion of $F_f l$	–	0.10	This study
R_{occ}	Average occupancy are	–	50%	This study
T	Total tourist numbers	Tourists/day	Eq. (14)	This study
y	Installment period	Years	20	This study

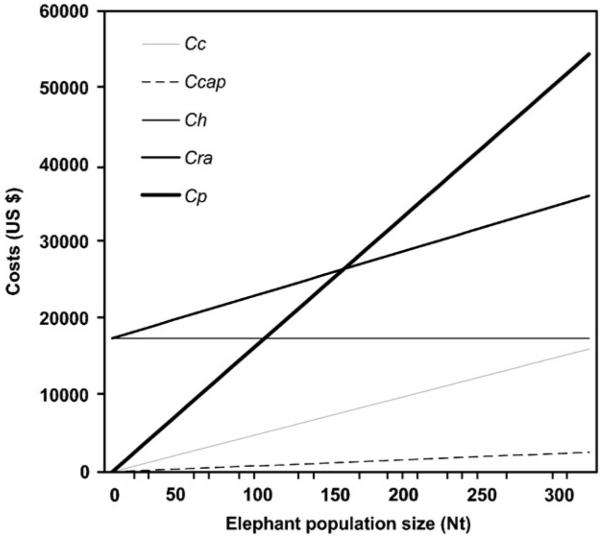

Figure 2. The linearly increasing total elephant raid costs (C_{ra}, in US$), composed of the three components: compensation payment (C_{c}); problem animal control (C_{pac}); and fixed costs (C_{h}), dependent on elephant population size. The poaching costs (C_{p}) are depicted in the same figure.

At least three animals were poached in 1996 in the MER, and unconfirmed information reported more cases. The population has declined between 1973 and 1998 from 350 to 180 elephants (de Boer et al., 2002), indicating a mortality rate higher than the reproductive rate. The mean annual growth of a population of 180–350 elephants is estimated at 2.6 calves/yr. This means that between 1973 and 1998 a total of 68 elephants would have been produced. Adding this total to the population decrease (350–180), a calculated total of 238 elephants would have been killed in 26 years, equal to an annual mortality rate (M_{p}) of 3.4% due to poaching. Annual poaching costs, C_{p}, are estimated at 170*N* (Fig. 2).

The profits (P_{s}) derived from game-viewing depend on the tourist capacity (K_{T}) of the area, estimated at 2000 tourist beds, and the average occupation rate (R_{occ}) of 50%. The profits ($P_{\%}$) are estimated at 10% of the daily rate (*H*) of US$ 100, with a mean daily occupancy of 1000 tourists. Park protection costs are estimated at US$ 200/km^2. The half-saturation constant has been estimated as to follow the concave utility function (Regev et al., 1998).

The second tourist income source is generated by the hunting operation (P_{h}), depending linearly on the elephant numbers. Approximately 2% of the total number of bulls are expected to be hunted (see Bond, 1994), under the condition (Armbruster & Lande, 1993) that the population size is at least 50% of the maximum number at maximum stocking rate, in this example 0.5 K = 160 animals. The sex ratio is estimated at 40% bulls. The average hunting licence fee (P_{f}) is estimated at US$ 6500/elephant for Mozambique, but the effect of an increasing licence fee is simulated in the model.

Results

Tourist profits increased with an increasing elephant population (Fig. 3). At an elephant population of 320, total profits comprise US$ 2.7 million, based on a maximum tourist capacity of 2000 beds. Total profits are always higher in the presence of an elephant fence. A lower tourist capacity reduces of course the maximum profits, as can be seen from the three scenarios depicted in Fig. 3. These scenario's simulate the default case ($P_{\max} = 3.5$ million US$), the effect of decreasing the maximum tourist capacity K_{t} to 1000 beds ($P_{\max} = 1.7$ million US$), and a luxury lodge with a K_{t} of 100 beds, a lodging rate *H* of US$ 200 and profit rate ($P_{\%}$) of 0.20 ($P_{\max} = 0.6$ million US$). However, for all three scenario's maximum profits are obtained at maximum stocking rate of 320 elephants, and, for all cases, in the absence of hunting. The form of the concave utility function, determined by the half-saturation constant m_{t}, does not have a large effect on the predicted total profits. Decreasing m_{t} from 100 to 50, or increasing

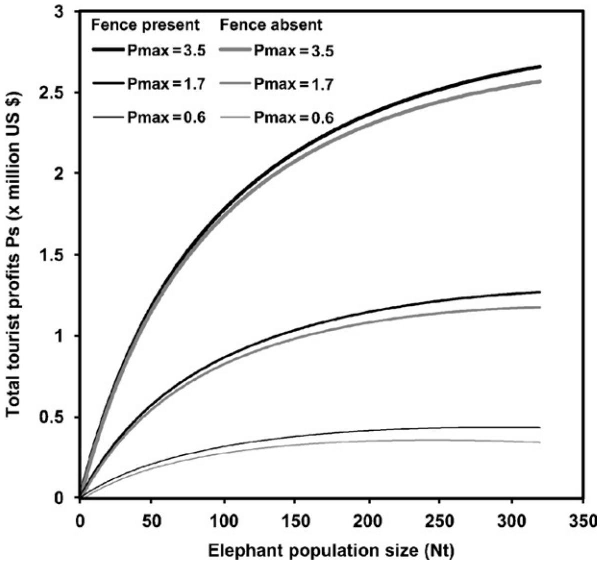

Figure 3. The increasing total tourist profits (in million US$) in relation to an increasing elephant population. Three different scenario's are depicted, for different $P_{\max}$ values (in million US$). Black lines give the impact of fence construction on total profits, whereas the lower grey lines depict profits in the absence of an elephant fence.

it to half the maximum stocking rate (160), changes the total profits with respectively +14% or −13%.

Fence construction in Mozambique is more expensive than in other areas (compare with Hoare, 1995; Thouless & Sakwa, 1995). The fence construction costs could be compensated for by both the decrease in crop damage and poaching. The break-even point depends on the number of elephants. Assuming that no crop damage or poaching will occur with the existence of the fence, the fence costs will be totally compensated if

$$F_a \leqslant C_{ra} + C_p \quad \text{or} \quad 41{,}100 \leqslant 65N + 17{,}400 + 170N. \tag{17}$$

This equation holds if $N \geqslant 101$, which is smaller than the actual elephant population size.

The marginal profits derived from game-viewing are relatively high at low stocking rates and increase at a diminishing rate with increasing stocking rate. These marginal game-viewing profits are always larger than the US$ 6500 trophy fee per elephant derived from hunting (Fig. 4), indicating that game-viewing is the activity with the highest financial returns. Marginal returns are about US$ 8309 at maximum stocking rate of 320 elephants. Hunting becomes economically interesting at a stocking rate below 320 elephants, if the licence fee increases (Fig. 5). However, the effect of the increasing trophy price is relatively low, as total profits derived from both hunting and game-viewing will increase less than 10% when the trophy fee increases to US$ 100,000.

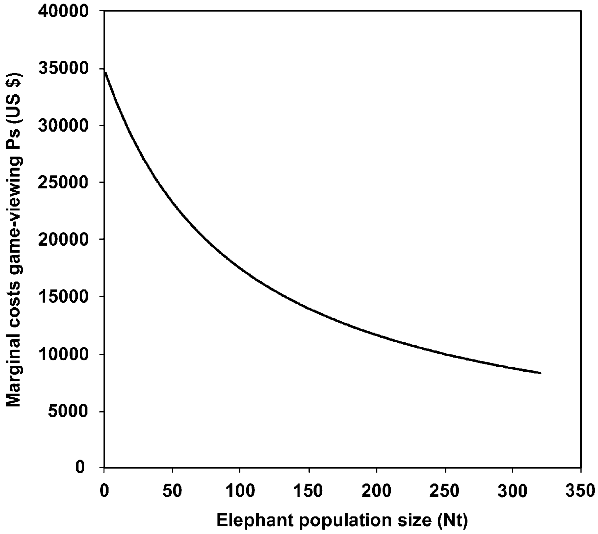

Figure 4. The decreasing marginal profits for game-viewing (P_s') at increasing elephant population size.

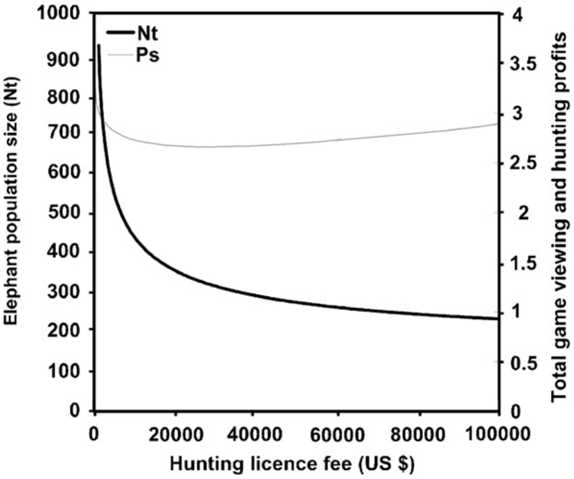

Figure 5. The elephant population size (N_t) at which hunting becomes economically profitable for different hunting licence fees. The corresponding effect on total profits is depicted on the second y-axis.

Discussion

The results indicate that the fence construction is an economically viable activity at the present elephant population size. The real value of the parameters used in the model could be different from the values adopted here. For instance the price of the elephants may be considered low, as an average resource price of US$ 22,000 has been calculated from Child (1990) and Barnes (1996). But higher elephant prices would put the balance even more in favour of the fence. The proposed fence does not enclose the MER totally, as only a small section, where crop damage is highest, will be fenced out. The MER benefits from its natural boundaries (rivers and sea), which minimise the amount of fencing required. Hence, in other situations the fences could be longer, fence construction could be cheaper, and elephant population size could presumably be larger, the latter increasing the raid costs. These will all have their impact on the balance of the equation.

The continuing payments of compensation can, in the long-term, stimulate people to cultivate in areas with a high elephant crop damage record, because compensation payments do not exclude production risks. According to Hoare (1995) compensation schemes are therefore not successful. The negative attitude of people towards the MER is mainly influenced by elephant crop damage (de Boer & Baquete, 1998). Although the fence will also decrease the raid frequency of bush pigs and hippo from the Futi River, other damage from nearby antelopes and from hippos from the Maputo River will continue.

Poaching could however continue with the existence of an electric fence. In that case, the costs of not erecting a fence would depend entirely on the compensation paid to the farmers and the costs of the disturbance-shooting patrols. Under these assumptions the fence costs will be equivalent to the elephant raid costs at a elephant population >364, larger than the maximum elephant stocking rate of the area. An extra advantage of the fence is better protection of the other herbivores in the MER and other species scheduled for re-introduction. It could enhance the control of people exploiting other natural resources (see de Boer & Baquete, 1998), and the spread of agricultural activities. These extra benefits are not included in the model. The model could also be improved by including the cost of fence-breaking elephants (Thouless & Sakwa, 1995).

Another option would be to abandon the fence and pay for the elephant raid costs (C_{ra}) and poaching costs. At maximum stocking rate this would mean an annual total payment of US$ 93,000, equivalent to the price of 18 elephants or more than two years of fence costs.

The model indicates that the costs of elephants lost to poachers ($170N$) are about three times the compensation costs ($50N$). Total elephant raid costs (compensation payments, problem animal control and annual fixed costs) equal poaching costs at 156 elephants (crossing point of C_{ra} and C_p in Fig. 2), after which poaching costs will be superior. At maximum stocking rate this difference between C_p and C_{ra} will increase to an amount of US$ 18,440, which means that at larger elephant population size relatively more effort should be dedicated to anti-poaching activities as compared to crop damage reduction. This imbalance would increase further (larger C_p) if the price of the elephants increased, because compensation payment and annual fixed costs are independent of the resource price.

The marginal profits derived from game-viewing decrease with an increasing stocking rate, but are always larger than the US$ 6500 trophy fee per elephant derived from hunting (Fig. 4). Hence, game-viewing is a sound economic activity under the actual circumstances. Hunting becomes economically interesting if the licence fee increases (Fig. 5). The effect of an increasing hunting fee is not large, as the total profits derived from both hunting and game-viewing will increase less than 10% when the trophy fee increases to US$ 100,000. However, hunting elephants in the area should also be controlled by ecological constraints. The elephant population comprises a known proportion of bulls, p_b. Elephant hunting is normally only allowed for a maximum proportion (h_b) of the bulls in the population (constraint (15), see Bond, 1994), under the condition (Armbruster & Lande, 1993) that the population size is at least half of the maximum stocking rate (constraint (18)):

$$\text{Constraint}: \quad h_b \times p_b \times K/2 < N_h < h_b \times p_b \times K. \tag{18}$$

Solving this constraint indicates that only 1–2 elephants can be hunted every year, which is probably too few for the development of hunting activities. The initial investments for game hunting operations in Mozambique will also be larger than in neighbouring countries, which means that they will not be profitable at the small hunting quotas. Moreover, the maximum population size (320) is smaller than the minimum (500, Belovsky, 1987) for long-term survival of the population. Weighing up these factors, the conclusion must be drawn that, in the MER, elephant hunting is a less favourable activity, economically and ecologically, than elephant viewing.

However, trophy hunting is a lucrative wildlife use in other areas (Lewis & Alpert, 1997). Moreover, Barnes and de Jager (1996) showed that both species diversity and total numbers can be increased as a consequence of economically sound wildlife exploitation strategies. Bond (1994) has calculated that the CAMPFIRE project in Zimbabwe earned the community at least US$ 7 million between 1989 and 1992, of which 90% was derived from sport hunting activities. Barnes (1996) estimates the potential contribution to the national Botswana economy at US$ 70–141 million, of which non-consumptive game-viewing might contribute 44–71%. Cumming (1989), Barnes and de Jager (1996) and Hosking (1996) showed that safari hunting could substantially benefit the other national economies in the region and Lewis et al. (1990) and Lewis and Alpert (1997) calculated that trophy hunting contributed significantly to rural development. Mozambique is the only country in southern Africa that does not (yet) benefit to such an extent from wildlife exploitation. However, this is likely to change, when the concession holders have the necessary infrastructure in place, and when DNFFB permits conditional safari hunting operations (DNFFB, 1999).

The model indicates that in the MER, elephant hunting is not an economically justifiable activity at low, intermediate or even high elephant densities. This discrepancy between some regional examples and the MER can be understood by studying the model design. Profits derived from hunting are assumed to be fixed and not influenced by tourist numbers, whilst profits derived from game-viewing are dependent on tourist capacity and tourist expenditure, and influenced by elephant numbers. In the case of the MER, elephant numbers are quite low (maximum 320), and tourist capacity assumed by us is relatively high (2000 beds), which could even decrease the attractivity of the MER for tourism if for instance no appropriate measures are taken to decrease tourist impact on the area. This means that the game-viewing value of elephants (US$ per elephant) is consequently high. In other areas, with a lower tourist:elephant ratio, hunting will be more profitable at lower stocking rates. The maximum tourist capacity of 2000 beds is regarded as high. Barnes et al. (1996) estimated that a (high price, low quantity) lodge would need an average of 700 ha/bed, corresponding to 114 beds in the 800 km^2 of the MER. Another game area, with a lodge of 100 beds, would have a different balance between the marginal values derived from game-viewing and hunting, as can be seen from Fig. 3.

The marginal game-viewing value increases through a concave utility function with increasing stocking rate (Regev et al., 1998; Skonhoft, 1995; Skonhoft & Solstad, 1996). Comparing P_s' with the elephant resource price (c_r), the decision should be made to buy elephants on the market as long as $P_s' > c_r$. In fact, c_r should be spread evenly over the average elephant's lifetime, which makes it even more lucrative to buy elephants on the market. In the latter case, the costs of the elephant (US$ 5000 here, but regarded as low) will always be $< P_s'$, which means that elephants should be bought until the maximum stocking rate has been reached. The low resource price of elephants, could, from an economic point of view, increase consumptive use. The actual situation in the Kruger National Park is such that elephants have reached the maximum stocking rate and international pressure has forced the park management to reconsider their culling operations. Elephants are therefore now offered for low prices, lower than the hunting fees paid in other areas (see Bond, 1994; Campbell et al., 1996; Child, 1990). This means that it would make sense to buy elephants in the Kruger Park and shoot them elsewhere!

Elephant population growth and elephant carrying capacity is a current source of much debate (Hall-Martin, 1992; Hanks & McIntosh, 1973; Page, 1996) and some authors doubt if the logistic growth function is suitable to model elephant population growth. High growth rates, equal to the maximum intrinsic growth of 7%, will not have any influence on the model's outcome other than the time path. Hence maximum stocking rate will be reached sooner, which will increase annual raid costs, poaching costs and benefits derived from tourism. It is expected that if elephant density in the MER equals the allowed maximum stocking rates of the Kruger National Park and of the Tembe Park, management measures will be taken to prevent further growth of the population. One of the options for the concession holder is to issue extra elephant hunting licences for elephants that need culling in order to stay below the maximum stocking rate. This option has recently generated considerable revenues for the Tembe Elephant Park.

One important precondition is included explicitly in the model, namely that the model only works assuming a prior investment in tourist facilities, which will be repaid by benefits derived from game-viewing. Investments will probably be made gradually over time, to track the expected increase in elephant numbers. Tourist profit rates (P_s) will depend upon occupancy levels, and can be negative at low tourist numbers. However, for the simplicity of the model P_s was fixed at 10%, represented the profits minus the costs (including mortgage costs and investments). In the absence of this infrastructure, the largest short-term profits can be obtained by concentrating on safari hunting, which gives a profit of at least US$ 6500/elephant. African countries, like Mozambique, have insecure investment conditions. It is unclear, but likely, that the actual pressure of safari companies in Mozambique on the Ministry of Agriculture, to re-open elephant hunting, is linked to unwillingness to invest in non-consumptive activities. Long-term leases with clearly defined conditions for development should therefore be worked out for the different conservation areas.

The proximity of the Kruger National Park, which makes the largest contribution to elephants available on the market, together with regional expertise and the interest of concession holders willing to invest in Mozambique, certainly hold promise for the future. Even with the existence of an electric fence, people in the vicinity bear the costs of living with wildlife without benefiting from the profits being earned through the wildlife in the Reserve. Hence, illegal exploitation of wildlife resources is expected to continue (see also Burton, 1994; Lewis et al., 1990; Milner-Gulland & Leader-Williams, 1992; Schulz & Skonhoft, 1996; Skonhoft & Solstad, 1996) until ways are found to compensate for these lost opportunity costs. The rural communities should, through a system of profit sharing, benefit from the revenues gained from wildlife (Alpert, 1996; Durbin & Ralambo, 1994; Happold, 1995; Heinen, 1996; Kiss, 1990; Lewis et al., 1990; Rihoy, 1995) in an effort to compensate them for lost opportunity costs.

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