ANALYSIS

An assessment of alternative methods of estimating the effect of the ivory trade ban on poaching effort

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Abstract

The ban on international trade in ivory introduced by the international community in 1989 was intended to protect the declining stock of African elephant (*Loxodonta africana*), by providing a barrier between the range state and the principal consuming nations. If there is a residual trade, then the efficiency of the ban is determined by the decline in the price paid to poachers, and the responsiveness of poaching effort to changing prices. This paper concentrates on the latter issue, and provides a review of a number of alternative approaches to modelling poaching effort, with extensions. It is found that even low residual prices would induce a level of effort that would significantly depress elephant numbers. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

In December 1989 the Convention on International Trade in Endangered Species (CITES) voted to place the African elephant (*Loxodonta africana*) on Appendix I of endangered species, effectively banning commercial trade in all elephant products between the signatories of the treaty. Some Southern African states took a reservation, which would allow them to trade with non-signatories or between themselves but the implementation of the ban by domestic legislation within the consuming nations (principally the USA, Japan and the European Union) and many of the range states was an attempt to solve at the international level an environmental management problem using a trade instrument. The problem was a rapidly declining African elephant population, which was estimated to have declined by some 50% at a continental level between 1979 and 1989 (with a point estimate of 609000 in 1989) and even more in some individual countries. Estimates for 1991 give a range of between 549000 and 652000, although
“...these figures should be viewed with extreme caution, as elephant numbers for a number of countries are based on informed guesswork only.” (Douglas-Hamilton et al., 1992, p. 15)

The cause of this decline, particularly in the last 20 years, was seen to be the illegal exploitation of elephant for its ivory (although the decline over the longer run has been attributed to direct competition for habitat between man and elephant: see Parker and Graham, 1989a,b,c). It is tempting to suggest that a review of current population estimates should reveal the impact of the ban. Dublin et al. (1995) give some country level population estimates which can be compared with pre-ban estimates, and these give a very mixed picture of increases and declines (Table 1). Overall, there is a general picture of decline, apart from Zimbabwe, which has had a relatively well funded wildlife protection system, and Kenya which over the period has had a significant increase in funding (Dublin et al., 1995, p. 23). However, such comparisons are fraught with difficulties, not least the problem of accurately estimating populations, and the effect of changes in other factors (e.g. enforcement expenditure, or land use policies).

The decision to place the African elephant on Appendix I was the culmination of a protracted debate on their management. The Southern African states who held relatively large and stable populations wished to retain the right to trade, arguing that the revenues generated would help to fund conservation measures. Other African states which had suffered extreme levels of poaching argued that by shutting off final demand the incentives for poaching would decline to a level that could be contained by law enforcement. In 1997, at the tenth meeting of the conference of the parties to CITES, a limited return to trade in ivory and elephant products was allowed, with the downlisting of the elephant populations in Botswana, Namibia and Zimbabwe to Appendix II. Ivory quotas have been set for each country for 1998 and 1999, subject to the three range states and the proposed sole purchaser of the ivory (Japan) meeting certain requirements relating to monitoring of the trade, and using the revenues generated to support elephant conservation (Gray, 1997). The intention of this limited change is to allow those countries with stable populations and adequate management to realise some economic return, while the controls on the trade are intended to minimise the impact it may have on the other range states. The full implications of the change have yet to be revealed.

The fundamental issues underpinning the over-exploitation (the lack of political will or economic means to enforce the property rights in the resource) are not addressed by a ban, although doubts as to its efficacy were raised in the Ivory Trade Review Groups report to CITES (Ivory Trade Review Group, 1989a,b) and by others (Barbier et al., 1990; Sugg and Kreuter, 1994; Kreuter and Simmons, 1995; Bulte and van Kooten, 1996). A polemical account of the political pressures and lobbying that led to the actual decision is given in Bonner (1993) but there has been little analysis of the relative economic efficiency of the ban as compared to other management options, although Barnes (1996) gives an assessment of the impact of the ban on economic values within Botswana, and Khanna and Harford (1996) indicate, within a theoretical framework, why a trade ban may have to be supplemented by economic incentives if it is to be effective.

An assessment of a (totally effective) ban would require the comparison of the economic losses associated with adopting a second best intervention (i.e. at the consumption level to address the effective lack of property rights at the producer

<table>
<thead>
<tr>
<th>Country</th>
<th>Pre-ban</th>
<th>Post-ban</th>
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</thead>
<tbody>
<tr>
<td>Zimbabwe</td>
<td>52 000</td>
<td>61 515</td>
</tr>
<tr>
<td>Kenya</td>
<td>16 000</td>
<td>23 797</td>
</tr>
<tr>
<td>Tanzania</td>
<td>61 000</td>
<td>54 157</td>
</tr>
<tr>
<td>Camaroon</td>
<td>22 000</td>
<td>17 000</td>
</tr>
<tr>
<td>Malawi</td>
<td>2800</td>
<td>2000</td>
</tr>
<tr>
<td>Zambia</td>
<td>32 000</td>
<td>22 785</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1300</td>
<td>1000</td>
</tr>
</tbody>
</table>

level) with the transactions costs associated with enforcing a trade ban as compared to those for enforcing the property rights in the range states. The latter can be extremely high, with estimates in the range of $US 500/km² in 1980 values (Parker and Graham, 1989a; Burton, 1994a) so potentially the transactions costs of monitoring trade may outweigh the deadweight losses associated with a ban.

We do not attempt such an assessment here, but look at a single aspect of the issue: an evaluation of the likely impact of the ban on the activities of elephant poachers. The increase in mortality in the past 20 years has been linked to the concurrent increase in the real price of ivory, but there have been few studies that have formally established that link, nor identified its strength, despite its importance for the pro-ban argument.

In attempting to identify the factors affecting poaching activity there are substantial data problems. If one uses the definition of 'effort' common in fisheries economics as an index of factor inputs, there is obviously no direct measurement of poachers' effort, nor any component of it. There are some indicators of poachers' output, namely the carcass of poached elephants that may be found (minus tusks), but these do not measure effort per se as one needs to correct for the elephant population being hunted, itself subject to large estimation errors. One also needs to account for other changes in the effectiveness of effort, such as changes in anti-poaching activity. The empirical sections of this paper review and extend various studies which have investigated the factors that determine the level of poaching effort, which is a necessary precursor to any assessment of the effects of reduced final demand caused by a trade ban.

2. Direct estimation of poaching effort

This section reviews possible measures of poaching effort which can be inferred directly. The difficulty with this approach is the lack of good data on many of the aspects of the problem (Leader-Williams, 1993). Dublin and Jachmann (1992) report data for five African range states, for a number of national parks in each country. The measure of poaching activity is taken as the carcass ratio (defined as ratio of carcasses to live elephants in an area). Variation in this ratio across parks within a country (estimated for the period 1987–1989) is explained by elephant densities and measures of anti-poaching activity (such as budget/km², scout/km² etc.), using a linear regression based on pre-ban data. Lack of time series data means that there is only one value for each park, so that the regression is based on four to seven data points only, depending on the country. The estimated equation and post-ban estimates of the explanatory variables are then used to generate post-ban forecasts of carcass ratios, which are compared to the actual values (for 1990–1991) using a Wilcoxon matched-pairs rank-sign test. Essentially they are testing for structural change in the relationship between poaching rates and enforcement with the intention of ascribing any such break to a change in the incentive structure caused by the ban. In fact no such structural break is identified. In all cases the post-ban poaching rate is consistent with a stable poaching relationship across the time period when the ban was introduced. This negative assessment of the impact of the ban has to be tempered by the very low power of the tests used, due to the small number of observations. In a follow-up study (Dublin et al., 1995) an alternative modelling methodology is adopted, but with broadly the same objective. Here the dependant variable is the number of carcasses found at sites (usually defined as a national Park or similar area) within a country, for each year in the period 1988–1993. It is hypothesised that the number of carcasses will be predicted by the area of the site, the enforcement budget, the number of scouts employed in the area, the elephant population and a dummy variable that takes a value of zero pre-ban, and one post-ban. The model is estimated for each country separately. The inclusion of the ‘ban’ variable allows for a direct statistical test of the impact of the ban: if it is not significant then, again, the variation in the carcass numbers is explained solely by the other variables. Although the number of countries surveyed is increased (to nine), in only three were the data of sufficient
quality to allow the model to be estimated, and in none of these is the ban variable statistically significant. Although this (negative) result has to be qualified by the poor quality and quantity of the available data, their overall conclusion from this and the more general descriptive data collected (e.g. comparing carcass ratios pre- and post-ban) is that the international ivory trade ban has not halted the illegal offtake of elephants; that, of those considered, only Zambia has had any marked decline in carcass numbers; and that markets for illegal ivory continue to flourish.

Given the low power of the tests used in these studies, an obvious extension is to conduct the test for structural change using a longer time series of data. Data exists for Zimbabwe at a park level for a wide range of data on poaching activity, including elephants shot, poachers arrested, incursions, etc. for the period 1980–1992. There is not good data on anti-poaching activity at the park level, although there is some at regional level. However, the author could find no relation-ship between levels of poaching activity (however defined) and enforcement. This may be because of the degree of aggregation of the data, but Fig. 1, which reports incursions in four regions, also indicates a spatial aspect to exploitation. Prior to 1984 there are relatively few incursions, except in Gonarezhou. There is then a sequencing of incursions, starting in the Zambezi region and moving through Hwange and Sebungwe, and this pattern is despite a relative constancy in wildlife populations and anti-poaching operations prior to the start of poaching activities. What appears to occur is not a simultaneous exploitation in all areas, but the exploitation of the ‘low-cost’ areas first (on the borders in the north and south east of the country) and as populations decline, effort has to be extended into areas with higher costs, or lower initial population densities. Thus the effort expended at the park level depends not only on the marginal returns to poaching in that park, but also returns elsewhere. Making inferences about the determinants of effort based on regional or
even park level data is then very problematic. It has been suggested that the process of sequential exploitation of populations has occurred at a continental level, with exploitation moving from country to country as marginal returns decline, and the general increase in poaching in Zimbabwe as a whole in the mid-1980s was not due to changes in the internal position at the park level, but because of the total collapse in elephant populations in East Africa (Martin, R., personal communication, 1991).

An analysis of the Zimbabwe data highlights two other issues. The first is multi-species exploitation by poachers: associated with the increase in incursions in Fig. 1 is an initial increase in poaching of rhino, and only as rhino numbers decline does elephant poaching increase, suggesting a further, local-level, evaluation of relative returns. Secondly, there may be an apparent perverse relationship between observed poaching effort and enforcement. The immediate victims of poaching do not report the crime, this will generally be identified by anti-poaching patrols, either on the ground or from the air. As one increases enforcement one may record an increase in illegal activity, even though actual illegal activity is declining. At some point the effect of increased enforcement on activity will overwhelm the effect on detection, and the expected negative relationship will emerge. This problem is less likely to emerge if the periodicity is short, so that one can express poaching effort as a function of lagged enforcement as poachers may reduce effort as they experience previous high levels of enforcement, but it places high demands on data collection.

Jachmann and Billiouw (1997) undertake an analysis based on a much more complete data set, derived from the Luangwa Integrated Resource Development Project in Zambia, which has maintained detailed information on law-enforcement and illegal activities for the period 1988–1995. They explain the annual variation in the number of elephant illegally killed in the area as a function of the level of manpower and budget available, measured using nine different variables. Because of the very small number of observations (eight), the analysis was restricted to using only two explanatory variables in any one model: the number of bonuses paid and each of the other eight available explanatory variables, giving eight possible models. Bonuses are paid if members of a patrol make an arrest, or confiscate a firearm or trophy, or if information is provided which leads to such outcomes. As such it reflects the level of overall enforcement activity, and is the variable which is most highly correlated with illegal off-take. Only two of the models are deemed adequate, on the basis of the overall significance of the equations: those that augment bonuses with the number of effective investigation days (i.e. days spent investigating reports of illegal activity, usually in villages and towns rather than on patrol in the study area), and the number of carriers employed to assist scouts when on patrol. However, the latter was negatively related, which is counter-intuitive, and the authors use the former specification (i.e. bonuses paid and effective investigation days, both of which are negatively correlated with kills) in estimating the budgetary cost of achieving acceptable levels of elephant losses.

There are two comments that should be made about the results. Firstly, although the number of bonuses paid “incorporates the influence of the number of scouts and carriers employed as well as the number of effective patrol days (i.e. the entire manpower input).” (p. 240) it must also reflect the propensity to poach. Thus one could imagine a situation where the incentives to poach decrease because of a change in the external conditions, which leads to a decrease in bonuses paid (as there is less activity to counter) while at the same time illegal killings decrease. The extent to which this endogeneity may be affecting the results is unclear. Secondly, although the data period includes both pre- and post-ban periods, there is no formal attempt to test if this may be statistically significant. Instead, on the basis of the overall significance of their preferred equation, they conclude that “...the variation observed in the numbers of elephants found killed illegally between 1988 and 1995 can be explained by resource allocation, without any contribution of external factors including the international ivory ban.” (p. 243). They therefore discount the possibility that allowing the ban to have some impact may
potentially increase the extent to which that variation can be explained.

Direct estimation of the responsiveness of poaching activity to economic incentives and enforcement activity is fraught with difficulties, both in terms of data and methodology. It has to be said that none of the data reviewed above give a great deal of guidance on the impacts of the ban on poaching effort.

3. Micro-simulation models

An alternative approach has been to develop micro-simulation models of poaching behaviour, based on detailed data collected at a single point in time. An example of this is given in Milner-Gulland and Leader-Williams (1992) (hereafter MGLW), where various models of poaching activity are constructed. Here we concentrate on their open access model of elephant hunting. Individual gangs are assumed to maximise short-run profits subject to a production function, which relates harvest levels to levels of effort and density of elephants, and a cost function, which not only includes direct costs of effort, but also the expected fine level given a probability of capture. Four models are developed, depending on the form of the production function (linear or non-linear) and the form of the penalty function (a flat fine if caught, or one that varies with amounts of poached ivory taken). The models can be represented by:

\[
\text{max. } \text{Profit} = pq - wx - F
\]

Subject to: a production function:

\[
q = aBx \text{ (linear) or } q = a'Bx^{0.5} \text{ (non-linear)}
\]

and a penalty (fine) function:

\[
F = bx(r + p) \text{ (constant fine) or } F = bx(rq + p) \text{ (variable fine)}
\]

where \( p \) is the price per unit of output; \( q \) is the quantity of output; \( x \) is the quantity of input (number of poaching trips); \( w \) is the price per unit of input; \( B \) is the elephant population; \( r \) is the fine rate; \( F \) is the expected fine; and \( a,a',b \) are the technical parameters.

The probability of being caught is given by \( bx \), and in the variable fine case the fine is given by \( r \) times \( q \), the output level, plus the value of one confiscated trophy \( (p) \); in the constant fine case it is simply \( r + p \).

Using this model, it is possible to identify the optimal level of input for the firm, \( x^* \), under the different assumptions about the nature of the production and penalty functions. For the case of the variable fine and linear production function this is given by:

\[
x^* = \frac{paB - w - rp}{2braB} \text{ if } paB - w - rp > 0
\]

\[
x^* = 0 \text{ otherwise}
\]

MGLW report extensive data obtained in the field from which the parameters and economic variables can be derived (Milner-Gulland and Leader-Williams (1992), Appendix 1 and 2), and which allow one to translate this expression into a numerical estimate of poaching activity. Using data based on 1985 values (and in particular 1985 elephant population levels) the optimum is 12 expeditions, which generates 42.4 units of output. This gives an estimate of the hunting mortality (defined as the proportion of the population that it is optimal to kill) of 0.003, as reported in Table 1 of MGLW. This is the short-run firm-level response. The industry-level short-run response is simply the aggregate of the (fixed number) of individual gangs. However, in the context of the current paper, what is of more interest is the long-run industry equilibrium response, and its responsiveness to the ivory price, and this is not dealt with in MGLW.

At the short-run level of exploitation each firm is generating profits, and in an open access system one would expect to see additional firms entering the industry until all profits have been driven out of the system. The mechanism by which this occurs is falling population numbers: as more firms enter and harvest their optimal 42.4 units, total population will fall. This will reduce the optimal level of input \( x^* \) and the optimal level of output \( q^* \) for each firm but the process of adjust-
ment will continue until an equilibrium level of elephant numbers is identified. This will occur where the average profit earned by each firm is zero. This can be identified by substituting the expression for the optimal level of input, Eq. (2), into the definition of profit (Eq. (3)):

$$\pi = paxB - wx - bx(raxB + p)$$  \hspace{1cm} (3)

Given that all gangs are assumed to be identical, and there is no short-run interaction between the firm-level profit and the number of firms, one can identify the long-run equilibrium population level by setting the profit function equal to zero and solving for $B$, i.e. identifying the level of population at which firm-level profits will be driven to zero when the firm uses the optimal level of input (if one has identified all of the costs correctly then firms will still be prepared to operate at this level, as there will be no better alternative use of their resources). The solution for $B^e$ in this case is:

$$B^e = \frac{bp + w}{pa}$$  \hspace{1cm} (4)

Thus, in principle, one can identify the level to which the open access exploitation of the resource will drive the population level in its search for profit.

However, in the case of a linear production function and variable fine, the analysis runs into conceptual difficulties. The system will only reach an equilibrium when the level of the elephant population has been reduced to such a low level that the optimal level of input for the individual gang is zero (this can be seen by substituting Eq. (4) into Eq. (2)). This occurs because at population levels higher than $B^e$ it is possible for firms to identify a level of input that generates a profit for the individual, and hence attract further effort into the system, and so further reduce the population level.

This leads to the internally consistent result that at the industry equilibrium there will be a positive level of output produced by an infinite number of producers, each producing an infinitely small level of output. This is an analogue to the conventional long-run analysis of a perfectly competitive industry where individual firms face decreasing returns to scale at all output levels, and hence the minimum of the average cost curve occurs at an infinitely small level of output. At prices above this level, firms enter in response to profit, increasing industry level output and hence pushing prices down towards the minimum average cost. In the current model, entry causes elephant numbers to decline rather than the price of output, and hence costs to increase, but the basis of the analysis is identical.

However, this analytical possibility assumes that inputs are completely divisible. In the current case the input (expeditions) should strictly take integer values only. This will not lead to large errors if the number of expeditions is large, but at small numbers, and in particular at values close to unity, the constraint imposed by the indivisible nature of the input has to be reflected in the model solution. Thus, one can replace the optimality condition Eq. (2) for the level of input by the corner solution of a single expedition per gang. One can follow the same logic as above, and identify the population level at which the profit per gang falls to zero by setting $x = 1$ in Eq. (2) above, and solving for $B^e$:

$$B^e = \frac{w + bp}{pa - bra}$$  \hspace{1cm} (5)

This gives an equilibrium elephant population under open access of 998, or a 93% mortality rate compared to the 1985 population.

It is not possible to identify the aggregate level of input in the industry needed to maintain this population level, nor the aggregate output, without knowing the growth function of the elephant, but the form of the growth function does not affect the equilibrium level of the population which is determined solely by the profitability of the individual firms at different levels of population, not by the rate of growth of the population.

If one changes the form of the function governing fines so that a constant fine is charged, then even the firm-level analysis runs into difficulties. Because there is no decreasing marginal productivity in the use of input, nor increasing marginal cost component, in the short-run, if the individual firm finds it profitable to use a single unit of input then there is no limit as to the level of input that
will generate marginal profits. Thus the results of the short-run firm-level analysis is indeterminant. MGLW recognise this (p. 391) and suggest that the population size is varied until the profit earned in the industry is zero.

The equilibrium level of the population is given by (Eq. (6)):

$$B^e = \frac{w + bp + br}{pa}$$

and this yields the hunting mortality of 91.9% reported in Table 1 of MGLW.

The model is also solved when the non-linear production function is used. For both fine structures, for the single firm, there exists a positive level of input (however small) that will generate a positive level of profit ‘for any set of prices, costs, fines and population level’. This may seem counterintuitive, but it derives from the form of the production function: as input tends to zero, the marginal productivity of the input tends to infinity. This means that as elephant numbers fall in response to effort entering the industry, the individual firms will adjust their input downwards but will always be earning positive profits. This leads to similar difficulties at the industry-level as before: the search for profit will force population levels down as long as there are positive profits to be earned, and this will only stop when the firm’s inputs have been driven to very small levels.

However, because of the indivisibility of the input, it is not possible for input levels to fall below unity. Thus, again, one can identify the long-run industry-level equilibrium level of population by identifying that level of population that generates zero profits when one unit of input is used. For the variable fine case the definition of profit is (Eq. (7)):

$$\pi = \; pa’ Bx^{0.5} - wx - bx(ra’ Bx^{0.5} + p)$$

which yields (Eq. (8)):

$$B^e = \frac{w + bp}{pa’ - bra}$$

which gives an equilibrium population of 258 (or 98.1% mortality). Note that this differs from the population derived from Eq. (5) because the parameters of the production function differ.

The constant fine case gives (Eq. (9)):

$$\pi = \; pa’ Bx^{0.5} - wx - bx(r + p)$$

which yields:

$$B^e = \frac{w + bp + br}{pa’}$$

which gives an equilibrium population of 288 (or 97.9% mortality).

The higher mortality rates when using the non-linear production function arise because the parameters used imply a higher level of productivity at low levels of input compared to the linear function. What this analysis indicates is that using a variable fine structure has little impact on the equilibrium population towards which the open access system will converge, whereas the representation of the technology has a greater effect.

It is also possible to identify the responsiveness of the system to changes in the economic parameters by calculating the appropriate elasticities. These are reported in Table 2, for the case of the linear production function only. The first column reports the elasticity of output for the individual firm, for the variable fine case, based on the 1985 data. It indicates that the firm’s output is relatively responsive to the price of output and the level of the fine, but not to the level of the wage. At the firm-level poachers are also responsive to the probability of detection. However, a different picture emerges at the industry-level. Column 2 reports the elasticities of the ‘industry’ equilibrium population level. These are measured close to the equilibrium population identified by Eqs. (4) and (5) (i.e. 1000 elephant). The signs are reversed as compared with the firm-level analysis (here the dependent variable is the residual population rather than the firm’s offtake), but what is notable is the change in the effect of the wage rate and fine level. These results are not inconsistent: one reports the responsiveness of an individual firm, the other the effect on the number of firms which can profitably operate in the system. The final column reports the elasticities for the equilibrium population level under a constant fine system, which can be directly compared to the estimates in Column 2. As required by theory, the sum of the monetary elasticities (for wage, price and fine) is zero.
Table 2
Elasticities of firm output and industry open access equilibrium populations, for variable and constant fine structures

<table>
<thead>
<tr>
<th></th>
<th>Variable fine</th>
<th>Constant fine: open access population ($B^*$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm-level output ($q^*$)</td>
<td>Open access population ($B^*$)</td>
<td></td>
</tr>
<tr>
<td>With respect to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wage ($w$)</td>
<td>−0.060</td>
<td>0.796</td>
</tr>
<tr>
<td>Price ($p$)</td>
<td>1.069</td>
<td>−0.837</td>
</tr>
<tr>
<td>Fine ($r$)</td>
<td>−1.099</td>
<td>0.040</td>
</tr>
<tr>
<td>Detection ($b$)</td>
<td>−1.024</td>
<td>0.244</td>
</tr>
</tbody>
</table>

Source: author’s calculations.

These models use the theory of the firm to utilise a considerable amount of primary data on the economic conditions facing poachers. Although the results from the long-run analysis have to be taken with some degree of caution, they do suggest that the variables would have to change considerably for any significant change in equilibrium elephant numbers to occur, despite the apparently large elasticities reported in Table 2. This is because these values are measured at the (very low) long-run equilibrium population level. Even if prices were to be halved, implying a 40–50% increase in population, this would still give a very low population when compared to the 1985 level. MGLW also estimate the implications of sole-ownership of the resource, as they suggest that it is possible for there to be some potential for control and exclusion of effort. Using the linear fine and linear production function in an intertemporal optimisation framework leads to similar conclusions as those for the open access model at long-run equilibrium: the population level of elephant is forced down to a very low level, and there have to be considerable changes in the ivory price before there are significant changes in that equilibrium level.

4. Aggregate simulation models

An alternative approach to the issue of poaching effort is to develop aggregate simulation models of elephant population numbers. There have been a number of models used (Pilgrim and Western, 1986; Milner-Gulland and Mace, 1990; Milner-Gulland and Beddington, 1993) but here we concentrate on an extension to the model presented in Burton (1994b), which in turn is a development of Caughley et al. (1990).

At the continent level, one of the few pieces of data that is available is an estimate of the total harvest of ivory. Caughley et al. (1990) present a model which consists of three equations, which determine population levels (measured as tonnes of ‘live’ ivory), ivory harvest and hunting effort. The population dynamics are governed by a logistic equation (Eq. (11)):

$$N_{t+1} = (N_t - Y_t) \exp[r_m (1 - N_t/K)]$$

(11)

where $Y_t$ is the harvest in year $t$, $r_m$ is the intrinsic rate of increase and $K$ is the environmental carrying capacity. Harvest yield is a linear function of effort ($E$) and population level ($N$), with effort normalised so that the ‘catchability coefficient’ is unity (Eq. (12)), i.e.

$$Y_t = E_t N_t$$

(12)

The level of effort is assumed to increase exponentially, at a rate $f$, from an initial level:

$$E_t = (Y_{1950}/N_{1950}) \exp(f t)$$

(13)

where $t$ is a time index with a value of 0 in 1950. The value of $r_m$ is taken to be equal to 0.06, (Hall-Martin, 1980; Calef, 1988) and the initial population level $N_0$ (i.e. in 1950) is assumed to be equal to $K$, the environmental carrying capacity.
The time series data on ivory production is derived from Parker (1979, 1989). There is no consistent time series data available on effort or population levels. In order to overcome this difficulty, key parameters of the model are calibrated so that the historical simulation performance of the model with respect to the harvest level meets certain criteria. However, the model of effort has no behavioural content, and guarantees that extinction will occur. Burton (1994b) proposes an alternative representation of the factors governing effort levels, and here we continue that development.

The effort Eq. (13) can be replaced by the following effort equation (Eq. (14)), which is based in the theory of open access exploitation of resources (see Hartwick and Olewiler (1986) for a discussion in the context of fisheries).

\[ E_{t+1} = E_t + g \pi_t \quad (14) \]

where \( \pi_t \) is the profit per kilo of ivory harvested. Thus, if profits are positive, effort increases in the sector (at a rate governed by \( g \), a parameter to be estimated), whereas negative profits cause it to decrease. Profit is defined as \( (IP_t, Y_t - c_t, E_t) / Y_t \), where \( IP_t \) is the price of ivory, and \( c_t \) the per unit cost of effort. Empirically the measurement of this profit variable is problematic, with little available data. However, Milner-Gulland and Leader-Williams (1992) give data that can be used to estimate the profit per kilo in Zambia for 1985, with an estimate of the price of 285 kwacha kg\(^{-1} \), and a cost of 22.3 kwacha kg\(^{-1} \) (equivalent to $50 and $3.9, respectively). This information is used to calibrate the level of profit simulated in the current model. \( IP_t \) is defined as the real price of imports of raw ivory into Japan (based on the data reported by Barbier and Burgess (1989) and deflated by the Japanese consumer price index), normalised to have a value of 285 in 1985. The real unit cost of effort, \( c_t \), is assumed to be a constant and becomes a parameter to be estimated. However, the cost per kilogram of ivory harvested is given by \( c_t / N_t \), and hence will change inversely as elephant numbers change. Within the calibration \( c_t \) is constrained to equal 22.3*\( N_{1985} \), and hence the simulated cost per kilo generated by the model in 1985 is constrained to equal 22.3 kwacha ($3.9), so that the level of profit simulated by the model is consistent with the 1985 Zambia data. The level of profit simulated by the model in other periods will obviously vary, increasing as the real price of ivory rises, falling as elephant numbers fall and costs per kilo rise. This model of profit will only represent a crude proxy for the incentives that have motivated effort over the period 1950–1986, but given the magnitude of the changes in the real price of ivory, it is probably a good enough indicator of general trends. It should be emphasised that the purpose here is to investigate the implications of an alternative specification for the equation describing effort, rather than present a definitive model of it.

There are then two unknown parameters in the system: the initial population level, \( N_{1950} \), and \( g \), the response of effort to profit. By utilising GAMS, a non-linear programming package (Brooke et al., 1988), it is possible to identify the values of these parameters which minimise an objective function defined as (Eq. (15)):

\[ \sum_{t=1950}^{1987} (Y_t^* - Y_t)^2 + \beta (N_{1981}^* - N_{1981})^2 \quad (15) \]

The first term is the sum of squared deviations of the simulated yield from the actual yield over the period, and is the criteria used in Burton (1994b). But, as was noted there, the calibration can result in simulated live ivory stocks that are considerably in excess of field estimates. If time series data on population levels were available they could be included, but generally this is not the case. However IUCN/WWF/UNEP (1982) does provide an estimate of 1.2 million elephant for 1981, and this information is used. Here the population level is converted into live ivory by using an estimate of 1 tonne of ivory per 100 elephant, and the coefficient \( \beta \) is chosen so that a 10% error in the simulated population in 1981 has the same impact on the objective function as a 10% error in the yield in 1981. On this basis, the single observation on population levels is given the same weight as any single observation on yield. Given the high margin of error in the original population estimate and the poor estimate of the translation from population to live ivory, this is probably appropriate.\(^1\)

\(^1\) The model was also solved with \( \beta \) increased by a factor of 10, and this had relatively little impact on the results.
When calibrated on this basis the estimate of \( N_{1950} \) is 29754 tonnes, and \( g = 1.0693 \times 10^{-5} \). The implicit value of \( c \) is 3.1 \( \times 10^5 \). The simulated value of the population level (of live ivory) in 1981 is 16391 tonnes, above the point estimate of 12000 tonnes but well within the margin of error.

The increase in effort between 1950 and 1987 is equivalent to a 5.9% growth rate, not dissimilar to the 5.73% growth rate estimated by Caughley et al. (1990), but obviously the long-run behaviour implied by the two systems is quite dissimilar. Here, as population levels fall then the cost per unit of ivory harvested rises, profits fall and effort leaves the industry. At 1987 ivory prices the equilibrium population level is 1121 tonnes of ivory (equivalent to approximately 112000 elephant). Simulation of the model post-1987, holding the price of ivory at its 1987 value, indicates that the system converges on that equilibrium but the dynamics are such that the population falls to very low levels in the interim. One cause of this is the relatively slow response of effort to profit, so that there is a very gradual exit of effort as profits become negative, and hence populations continue to decline. This may be purely an artifact of the model, however, as it has been calibrated entirely over a period when profits are positive: the situation of negative profits is completely outside of the historical experience.

Fig. 2 gives the estimated phase diagram for the model. The vertical line indicates the locus of points where economic equilibrium is achieved (i.e. the change in effort is zero), while the second line indicates the locus for biological equilibrium (i.e. where there is no change in population levels). The vectors in each quadrant indicate the direction of change of the system when out of equilibrium, and reveal that the equilibrium point is stable.

A further extension of the model is to consider the change in technology over the period. As Douglas-Hamilton (1987) notes, there has been a substantial increase in the availability of modern firearms in the range states, and Milner-Gulland and Leader-Williams (1992, p. 399) suggest that these increase the number of kills of a gang of poachers by a factor of 16. We accommodate this possibility by introducing a time varying catchability factor, so that the yield equation becomes:

\[
Y_t = (0.1 + 0.9 \exp(-dt))^{-1}E_tN_t
\]

The time trend \( t \) takes a value of zero in 1950, so the catchability coefficient is equal to 1 in 1950, and then increases up to a limit of 10. This is a conservative upper limit, and it allows for an incomplete diffusion of the new technology by 1987. The change in catchability coefficient is given by the coefficient \( d \), which is constrained to be positive. When the model is calibrated using this yield equation the initial population is estimated at 27168, \( g = 2.599 \times 10^{-6} \), with an implicit value of \( c \) of 1.046 \( \times 10^6 \). \( d \) is 0.055, which results in the catchability coefficient increasing to 4.46 by 1987. The level of effort also increases, but at a much lower rate than before (equivalent to 2.66% per year: see Fig. 3 ). This distinction between changes in effort and advances in technology may not appear to be a significant one, especially as the simulated time path of yields is quite similar (Fig. 4), but it does have implications for the long-run equilibrium population. If one holds both the ivory price and the technology at 1987 values then the equilibrium value is 848 tonnes of live ivory, some 25% lower than the previous estimate. If one allows the catchability coefficient to rise to a value of 10, then it falls to 378 tonnes. What is also notable is that the estimated change in effort over the period is altered by the representation of technology, and the response of effort to the presence of profit is re-
The purpose of the ban on trade was to reduce incentives to poach by restricting final demand. The price of ivory has to fall by some 90% if the simulated 1987 population is to be maintained in the constant and variable technology models (if the latter is held at 1987 technology levels: an even larger decline is needed in the variable technology model if the catchability coefficient is increased to a value of 10). This is not very encouraging, in that it implies that the effectiveness of the ban at the level of final demand has to be high if it is to have the required effect on the poachers.

5. Discussion

Any analysis of the economics of ivory poaching is going to be constrained by the paucity of good data available, and in particular, time series data. This paper has looked at various approaches to the question of the relationship between poaching and economic incentives. With few direct measures of poaching effort one is reduced to indirect measurement of the links between economic incentives, enforcement activity and levels of poaching, and then inferring the responsiveness of the underlying poaching effort.

Those studies that look directly at the determinants of poaching activity (i.e. those in Section 2) all conclude that there is little evidence of any impact of the ivory ban in 1989, given the data they have to work with. The simulation models (Sections 3 and 4), by construction, contain a positive relationship between poaching effort and prices, and hence one has a prima facia case for the ban having a positive effect on elephant conservation. However, what those models do reveal is that significant poaching effort will remain even if the ivory price is reduced substantially, and hence suggest that if the ban is to be effective, the link between final consumer and poacher has to be practically absolute: any slippage may be sufficient to give sufficient incentives to poachers to prevent recovery in elephant populations. In this context, the comment reported in Dublin et al. (1995) that “...donor countries in the north seem to feel that the problem of elephant poaching has been ‘taken care of’ by the ban and that there is..."
Although the structure of the ivory market may be known in general terms there is relatively little work on quantifying the structure, and this information is needed if the economic activity of poaching is to be controlled. The determinants of poaching effort is perhaps the most developed area, but as we have seen, the limitation of poor data places extreme restrictions on what can be achieved. Without that information, identifying the effects of the trade ban (both 'ex ante' and 'ex post') is fraught with difficulties and runs the risk of “...equating association and correlation with causality, failing to identify and cut through confounding factors, failing to replicate, failing to balance, failing to control” (Caughley, op cit p. 239). Given that the African elephant listing is often viewed as one of the more successful examples of the CITES listing mechanism, the difficulty in showing its effect is of concern. Without establishing this link the objective development of policy is severely hampered, and evaluating even incremental management, such as the recent CITES downlisting of local elephant populations, and the associated requirement to assess any negative impacts of the resumption in trade on other range states will be problematic. The adoption by the parties in 1997 of a Resolution to establish “a comprehensive, international monitoring system... with the objective of measuring and recording current levels and trends of poaching and illegal trade in ivory in African and Asian range states, and in trade entrepots” and assessment as to “whether, and to what extent, observed trends are the result of changes in the listing of elephant populations in the CITES Appendices and/or the resumption of legal international trade in ivory” (Conf.10.10, cited in Gray, 1997), may go some way to filling this gap, but without an understanding of the historical patterns of exploitation (and the associated data) such an analysis will be incomplete.

Given that the management of elephants, and the ivory trade ban, have probably received more attention from the social scientists than any other species, the implications of this paper for the management of other species which are under threat are not hopeful.
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References


