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Economic Impact Assessment of Sustainable Management Options of the Elephant Population in the Kruger Trans-frontier Park

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Abstract: The elephant population in the Kruger Trans-frontier Park is currently seen by many nature conservationists as beyond sustainable levels. Wild-life supporters are of the view that the elephant population should be sustained. Ecologists warn that over-population of the elephant population is putting too much stress on the environment, which may make it impossible to sustain other plant and wild life forms in the long run. The paper has as its main aim to evaluate Environmental (Ecological), Cultural, Economic and Social dimensions of sustainability using Economic Impact Analysis to appraise different options of managing the elephant population in the Kruger Trans-frontier Park. The authors believe that this research would contribute greatly to the debate in other parts of the world. If not managed properly, an overpopulation of elephants often leads to environmental degradation. Such degradation could lead to a loss in ecosystem function (indirect use value), which not only implies a loss in ecosystem productivity and resilience, but also the need for ecosystem restoration. The sometimes irreversible damage, such as the extinction of other animal and plant species caused as a result of overpopulation of elephant, is a direct cost to the environment and society. This cost is not reflected in, for example, the value an international tourist derives from viewing elephants in the park or protected area where the damage-causing specie lives. Studies undertaken thus far, are mainly based on an economic valuation of the elephant in relation to economic variables that are quantifiable, and also mainly under very limited assumptions. These are but some of the important issues considered in this paper in order to derive Best-Practice appraisal methodology. Although the authors suggest a cost-benefit analysis, it only offers very limited appraisal and the authors therefore argue in favor of a much more rigorous partial equilibrium analysis.

Keywords: Ecological Management, Elephant Management, Partial Equilibrium Model, Linear Programming, Sustainable Ecological Management Options, Environmental Operations Research, Cost-Benefit Analysis, Economic Impact Assessment

Introduction

ACTIONS TAKEN TO manage elephant populations in Africa are subject to intense scrutiny and often political pressure. Legal international trade in elephant products is strictly regulated in terms of the Convention on International Trade in Endangered Species (CITES), of which South Africa is a signatory.

The elephant population density (i.e., the number of elephant per square kilometre of elephant range, for a given period of time) has risen in the southern African states to the point where it raises concern regarding impacts on the environment and people. The key concerns in areas of rising elephant density are the appearance of the landscape, the viability of other species, and the livelihoods and safety of people. There is a vigorous, and often acrimonious, debate about whether elephant numbers need to be curbed or reduced in South Africa, and if so, how.

This research is stimulated by the intense debate surrounding the different factors that impact on

managing the elephant population to the extent that it contributes to the overall goal of preserving both the elephant as important specie in the ecological environment and the environment itself, required by other species for their future existence. The chief visible problem in South Africa is the large-scale destruction of especially large trees, with all of its related consequences to a sustainable ecology.

In the paper, although a daunting¹ task, the authors attempt to cover most of the ecological, environmental and other concerns within the framework largely dependant on economic theory at its roots.

During earlier desk research, the authors were taken aback by the often shallow and ignorant economic view by various authors about the simplistic and often ineffective appraisal techniques. One such example is where the tourism value of the elephant (benefit) is considered along with some over-simplified estimation of the costs to the environment, of which an ignorant estimation of crop damage serves as an example. This type of methodology largely ignores that fact that the environment and ecological

¹ "The authors gratefully acknowledge financial assistance from Economic Research Southern Africa (ERSA)"

system are both experiencing harm as a result of the incorrect management strategies.

The paper sets out to systematically develop and describe an economic model capable of taking a holistic approach to sustainable elephant management. The authors hope that constructive criticism would elucidate the problem at hand and improve the model before any attempt is made to apply the model.

The organisation of the paper is as follows: First, in Section 2, an overview of the current management options of the elephant as specie is given.

In the second major section, the authors review the critique of the current approach to elephant population management.

The main aim/theme of the paper is to survey current elephant management options, evaluate its effectiveness, and lastly, propose an economic model that may be used devise new and improved elephant management strategies.

Secondary thereto, is to provide a basis for the appraisal of various options and strategies available to stakeholders for sustainable management of the elephant ecology and its external environment - the wider ecology of other live animal and plant species. In Section 3 the authors argue in favour of, and propose a dynamic economic model capable of simulating the dynamic impacts on the total ecology, of different elephant management options. It is meant to assist the analyst in following a holistic approach to ecological management, but with specific reference to the management of elephant populations.

Ecological Management Options

Elephant Ecology

Managing the elephant population of southern Africa, and the world, requires an integrated strategy because they are 'keystone species' (quoted in Elephant Assessment Report, 2007), which is critical for the integrity of the eco system largely because the feeding habits of elephant create habited opportunities for other species. However, sustained, intense disturbance by elephant can change the vegetation and destroy trees.

In the Elephant Assessment Report (Second Draft, 2007), originally commissioned by the department of Environmental Affairs in South Africa, the following strategies are provided in respect of abundant elephant populations (see van Aarde et al, 2007):

Controlling the Distribution of Elephants

It is the density of elephants at certain times of the year and in relation to specific² habitats or areas that results of high levels of elephant impact rather than the absolute number of elephants or their density. Measures for density control include fencing and manipulation of water availability.

Self-Regulation

If left to their own devices, isolated elephant populations within a restricted area will eventually stabilize. As a result of a reduced unavailability of food, which leads to an increase in the average period between successive births, it will increase the average mortality of calves.

Increasing the Size of the Elephant Range

The range of elephants in South Africa has been expanding by addition of land and translocation of elephant into new areas, particularly trans-frontier areas. These measures reduce elephant densities but not the overall elephant growth rate.

Translocation of Elephants

The techniques of capturing, immobilizing, transporting and releasing elephants into new environments have been developed in³ South Africa to the point where elephant mortality is low and the procedure is done safely in respect of elephant.

Reducing the Birth Rate in Elephant Populations

Immune-contraception, particularly of female elephants using vaccine, has proven to be an effective and viable technique in many situations⁴.

Culling of Elephants

Culling and translocation are the only management options for reducing elephant densities and thus local impacts, where interventions are urgent.

What makes the implementation of control strategies over elephant population particularly difficult is that options differ from country to country, particular areas, trans-frontier parks and private game reserves. In this regard the reader is referred to Table 1, which gives a breakdown of the differentiated guidelines for elephants according to size and eco system.

² See also Grant, et al, 2007.

³ See also Grobler, et al, 2007.

⁴ See also Bertschinger, et al, 2007.

Further do the differentiated areas above, what makes implementation of any particular or combination of strategies difficult are:

- societal trends and value systems concerning elephant management
- the economics of elephant in South Africa; the sensitivity of the trade-off between use-values and non-use values of elephants
- the long term psychological and behavioral consequences of contraception in large and distributed elephant populations
- the importance and persistence of stress in elephants induced by culling, hunting, capture translocation and separation from clan members
- the potential to control elephant distribution by behavioral modification
- the feasibility and consequences of achieving elephant population self-regulation by the manipulation of water availability

Table 1: Differentiated Guidelines for the Management of Elephant in South Africa in Protected Areas. 'Large' Reserves Are > 500 000 ha (5000 km²), Medium are 5000 to 500 000 ha (50-5000 km²) and Small < 5000 ha (50 km²)

Management Issue		Ecosystem		
		Deciduous Savannas (broad- and fin- leafed) and their included riparian forests 400-800mm/y	Succulent thicket, Dune forests	Arid shrub land (Karoo) 200-400mm/y
Minimum area for viable elephant population		600 km ²	400 km ²	3000 km ²
Maximum recommended sustained elephant density (landscape average, kgLW/km ²)		1.2	0.6	0.3
Population Control method	Large	None urgently Required at Present, may be needed within a decade. Water restriction and mass contraception may begin as experiments.	Not applicable, no areas of this size exist.	None needed if water points are restricted.
	Medium	Culling may be only current viable option in areas that exceed maximum density or will do so in next five years. Contraception may be viable in other areas.	Area expansion and translocation currently suffice. Culling may soon be unavoidable.	Contraception.
	Small	Contraception		Should not have wild elephant.
Fencing		Western and Southern boundary fence should move to W and S extreme of the habitat and upgraded to 'highly resistant'.	Elephant-exclusion fencing for areas with key populations of threatened plants. Perimeter fencing 'elephant-proof'.	Perimeter fencing 'elephant-resistant'

Capture and translocation		Full immediate family groups only. Pre-assessment of suitability of receiving habitat and post-assessment of impacts.		
Hunting (non-state areas only)				
Water provision	Large	Close artificial water points more than 10km from permanent natural water in dry season	Not applicable	Restrict to 1/ 1200 km ²
	<i>Medium & small</i>			
Source: Scholes, et al. (2007)				

Critique of Elephant Management Options and the Wider Ecology

There is general agreement among different stakeholders and experts that there is an unsustainable overpopulation of elephant in South Africa. Yet, the very same stakeholders and experts are restricted by the management options outlined above. The complex ecological and human systems at stake are completely misunderstood; therefore the approach currently followed is that of 'active-adaptive' management. This approach is current best practice; it is applied as deliberate experiments, based on trial-and-error.

There is conflict between ecological and human objectives which may vary from one area to another. There is variation in the type and condition of vegetation according to habitat, elephant density, the presence of other more endangered species (animals and plants), human objectives, the proximity of other land users and economic and technical specifications to undertake actions.

Controlling the distribution of elephants. The effectiveness of fencing to control elephant varies greatly according to design, location and costs. This strategy is also only effective to the extent that it can control for short run impacts limited to small areas, and only when the correct fencing is constructed. This is then normally very costly. Distribution has also been limited by non-physical barriers like repellants, sound or disturbance, but the control impacts of these nonphysical barriers were found to be limited.

Restricting water availability decreases elephant density in water scarce areas and increases density in water abundant areas. Some exponents are of the view that elephant population numbers may be self-regulatory in the long run (decades to centuries). This is only plausible over areas of thousands of square kilometers where a rough balance between habitat condition and elephant numbers may be reached. The criticism of this view is that it is only based on the ecology of the elephant, remaining ig-

norant of the ecology required for human and other animal and plant specie survival.

The world renowned naturalist and wild-life photographer, Lord Thomas Pakenham (2007:910) opposes this view strongly, especially with regard to the destruction of trees by elephants: "too many elephants are now trying to find a living in the bushveld along the line of the Limpopo on the boarder of South Africa, Botswana and Zimbabwe. Culling was suspended for good humanitarian reasons in 1995, but the result is an environmental disaster. Trees and other animals are now paying the price for a huge surge in the number of elephants - a rise of a third in a decade".

According to Pakenham (2007), "the Limpopo Valley of today is like a battle field. Fever trees, Shepards Trees, Sesame bushes, all the smaller and more vulnerable trees of the bushveld in this area are being upended by hungry elephants".

He is in favor of sensible, humane culling before the place becomes "a desert of smashed trees and starving elephants..... a man-made catastrophe for the environment". His other concerns for nature are the excessive culling of alien trees and global warming.

The value of trees to society, which seems to show the 'other side of the coin', i.e. looking a bit at trees' species and their importance in the ecology and to society, is quoted by Arbor Day (2007) as follows:

"If you plant a tree today on the west side of your home, in 5 years your energy bills should be 3% less. In 15 years the savings will be nearly 12%." —*Dr. E. Greg McPherson, Center for Urban Forest Research*

"A mature tree can often have an appraised value of between \$1,000 and \$10,000." —*Council of Tree and Landscape Appraisers*

"One acre of forest absorbs six tons of carbon dioxide and puts out four tons of oxygen. This is enough to meet the annual needs of 18 people." —*U.S. Department of Agriculture*

"There are about 60-to 200- million spaces along our city streets where trees could be planted. This translates to the potential to absorb

33 million more tons of CO₂ every year, and saving \$4 billion in energy costs.”—*National Wildlife Federation*

“Trees properly placed around buildings can reduce air conditioning needs by 30 percent and can save 20 - 50 percent in energy used for heating.”—*USDA Forest Service*

“The planting of trees means improved water quality, resulting in less runoff and erosion. This allows more recharging of the ground water supply. Wooded areas help prevent the transport of sediment and chemicals into streams.”—*USDA Forest Service*

FAO (2007) describe the livelihood effects of trees. According to FAO: “Like irrigation, they have a counter seasonal quality and role in livelihoods. Their deep roots tap soil moisture or groundwater long after rain-fed surface crops dry up, and they can photosynthesize and be productive and useful in various ways. They are less vulnerable than ground crops to bad years of rainfall. Trees are perennials but some produce seasonal crops, and all trees accumulate biomass year by year until they die. They are thus partly drought-proofed, and many can provide both crops and assets”.

Kerley, et al. (2007), is of the opinion that the role of elephant in ecosystems and biodiversity is self-regulating and that elephant is just part of ecosystems, contributing to biodiversity. They take the view that no real damage is done by elephant and mostly advocate a hands-off approach to managing the elephant population. This finding is based on a detailed study of the contribution that elephant make to sustain other wild-life and animal species.

Economic Impact Analysis

Introduction

It is important to understand elephant biology and ecology. Kruger elephant is fenced in by the intervention of man resulting in a smaller home range surrounded by transformed land and the biodiversity is very likely to be degraded if elephant population management is not practiced. Biodiversity losses are likely to be increasingly irreversible with the increasing transformation of surrounding land and isolation of protected areas (Mabunda, 2005). This therefore puts insurmountable pressure on the natural resource environment and could lead to environmental degradation and a loss in ecosystem function.

The current focus in the economic measurement of the ecology is on the total economic value (TEV), where TEV measurement captures only a small part of total ecosystem value – mainly the commercial side. This approach underestimates ecosystem value. In turn, this gives rise to the rejection of management

options to preserve and restore the ecological balance, mostly because costs, when compared to the current low TEV, outweighs the benefit of such policies. The economic returns (both current and inter-temporal), to the ecosystem and investment to sustain and preserve, is largely underestimated. The real returns to the ecosystem are therefore being destructed systematically.

In recent years the direct consumptive use of elephant was reduced dramatically with the CITES ban on culling. It stands to reason that elephant could become an important generator of income in the future, especially if culling is re-introduced. Elephants are important generators of income both nationally and internationally. However, they also generate costs in the form of damage to crops and infrastructure where communities need to be compensated.

Confinement strategies often fail. Direct costs involved in erecting appropriate fencing and maintaining it is prohibitively high and not effective. Indirect costs may include cases where e.g. buffalo exit the park where elephant destroyed fences, transmitting diseases such as foot and mouth and bovine tuberculosis, which infect livestock and have a negative economic impact (Mabinda, 2005). There are also concerns of population extinction of other species resulting from habitat degradation and starvation, seen in some instances to accelerate ecological regression of more species. The species that are particularly vulnerable to elephant comprise the bulk of the regional endemic Red Data Book species (Lombard et al., 2001).

On the Methodology of Economic Impact Assessment

One of the methods most often used to analyze economic impacts of public projects and environmental projects is cost-benefit analysis (CBA). The CBA is a systematic attempt to measure and weigh together all costs and benefits from a project, with respect to whether the project is profitable or not, in the socio-economic sense. In this paper, socio-economic means to include environmental and ecological impacts.

Conningarth (2007: 9), Describe the difference between CBA and economic impact assessment (EIA) as follows: “Whereas CBA is concerned exclusively with comparisons of direct benefits and costs to society created by an investment project, economic impact analysis examines the distribution of many secondary economic impacts and outcomes that traditionally fall outside the scope of CBA”. Economic Impact Assessment may thus include a variety of economic tools to analyze wider economic impacts, e.g. econometric models, partial equilibrium models, Input-Output models, etc.

In regard to CBA, the authors recommend the application of CBA as an addition to a partial equilibrium model. The authors, being mindful of attempts to value natural resources in economic terms, hypothesize that given the nature of the total ecology and environment of the Kruger Trans-frontier Park, the most efficient ecological and environmental management strategy, not only with respect to the elephant, but in relation to the whole ecology, would be the one that will ensure long run sustainability of the ecology, the environment and the elephant as invaluable resources.

Therefore, the authors take the view that before attempting to value the economic impacts of different projects or strategies, the most ecologically efficient options should be identified. Further thereto, the most ecologically efficient options should be equated to the most economically efficient, or Pareto efficient condition. In alternative modern CBA analysis the Pareto efficient criterion is replaced by the Kaldor-Hicks criterion. Boardman et al. (2006:31) explains Kaldor-Hicks efficiency as "A policy should be adopted if and only if those who will gain could fully compensate those who will lose and still be better off". From this it is clear that only policies with positive net benefits should be accepted.

Unlike normal economic efficiency, which is based on societal welfare, it is accepted here that ecological welfare cannot be measured in terms of human preference revelation or society's willingness to pay for the ecology to be brought into equilibrium so that future generations may enjoy the benefit of that ecology and a healthy environment accompanying it.

The basic condition that needs to be satisfied may therefore be stated as follows:

$$NEB = B - C; B > C$$

Where NEB = Net Ecological Benefit; B = benefits derived from bringing the ecology from its current state of degeneration due to over population of elephant to the optimal point of ecological efficiency where the total ecology is in harmonious equilibrium and C = Cost of the management strategy selected plus the cost of restoration.

This remainder of the paper is limited to the discussion of a proposed partial equilibrium model using linear programming (LP) with which to analyze the economic impact of various elephant management options within a holistic ecological sense.

Structure of a LP Model

Linear programming (LP) is one of the most practical planning tools to simulate systems where there are scarce resources and many alternative ways of utilizing these resources to attain a specific objective. LP is a mathematical technique, which can be employed by management to determine the optimal utilization of limited resources i.e. to optimize the value of the system. It comprises the formulation of a model, which is solved mathematically to provide an optimal solution (Hazell et al., 1986).

In order to analyze a problem using LP, the problem is systematically described and molded into a particular structure that should contain the following components:

- Objective – the best or optimal solution
- Activities or decision variables which defines what to do
- Constraints or restrictions on the availability of a resource (functions' limit)

The structure of the model contains the following elements:

- A description of the economic management of elephants in protected areas
- A description of off-take of various species in respect of growth rates and potential revenues
- A description of economic models to calculate economic costs and benefits
- A description of economic opportunities to maximize benefits associated with elephant products or hunting opportunities
- A definition of the resource endowments and carrying capacity
- A specification of the market environment in which the game reserve operates
- A specification of the policy environment of the sector

In order to illustrate the basic principles of LP model a typical conceptual outlay of a National Park or private game reserve is presented in figure 1 below. Any attempt to simulate the typical game ranch or reserve system would include the objectives of the game reserve, the resources available to reach these objectives as well as alternative activities available to reach them.

Figure 1: Typical LP Model Structure

In order to simulate the impact of consumptive behavior of game on vegetation and veld types two additions to the basic LP model are required:

- A game minimum feed requirement component (this specifies the minimum nutritional requirements of each specie); and
- A feed availability component per vegetation type, including the nutritional value of each type and the quantity of dry matter.

These components are embodied in the basic LP planning structure to create an integrated model. Each national park or private game reserve would have its own unique characteristics built into the model to simulate the real world situation as closely as possible.

Objective Function

The research problem presents a typical optimization problem where an attempt is made to maximize the economic benefits of maintaining a sustainable elephant and wildlife population within the limitations posed by the natural environment. The aim of the LP model is to optimize the consumptive use of game and economic returns to society and the game parks.

An *objective function* {XE “Objective function”} is introduced to drive the model’s solution to a market-equilibrium outcome, i.e. to maximize profit of the game ranch or reserve under different scenarios.

Other dual objective functions such as the minimization of management costs may also be considered.

Algebraically the objective function in its simplest form is stated as follows (Hazell et al. (1986) :

$$(1) \quad \sum_{j=1}^n P_j Q_j - C_j X_j = \text{MAX!}$$

where :

P_j = the price per elephant and elephant products and other species per unit of “j”

Q_j = the selling activity of elephant and elephant products and other species per unit “j”

C_j = the management and operational cost of maintaining an elephant population and products and other species per unit “j”

Equation (1), the maximand, calculates total revenue ($P_j Q_j$) and then subtracts total costs ($C_j X_j$).

Decision Variables/Activities

Points of view on the management of elephants tend to be polarized between pro- and anti-culling lobbies. There is however, consensus that elephant density, distribution and population structure may need to be managed locally to meet biodiversity and other ecological objectives. This requires an integrated strategy that includes a range of options as discussed in Section 2.

Total Economic Value

Ecosystems' secondary values also called Total

Economic Value (TEV) of ecosystems comprise direct, indirect, option, existence and bequest values. See figure 2.

Figure 2: Values for the Environment, *Source: Adapted from Turner, R.K. et al. (1994)*

The model is proposed to focus on the direct use values that include the consumptive and non-consumptive use values.

Consumptive use values include:

- Hunting – trophy or meat
- Culling
- Elephant products such ivory and skins

Non-consumptive use values include:

- Game viewing
- Elephant rides
- Tourism including accommodation, food sales etc.

Decision variables/activities typically include the following:

- Production of natural vegetation (area)
- Production of supplement vegetation (area) (increasing the range)
- Game production (numbers) – live sales
- Sell game
- Cull game – fresh or dried meat
- Culling – meat processing
- Culling – dry salted hides
- Culling – hide tanning
- Sell ivory
- Buy game
- Natural mortality of game
- Transfer of naturally produced and supplement vegetation to game

- Buy feed for game consumption
- Initial stock of feed (this is the current state of the natural vegetation)
- Feedbank transfer to period $j+1$
- Fencing
- Own labor use
- Rent inputs
- Monthly water use
- Short term production loans
- Overhead costs
- Other income (this is income from accommodation, restaurant, game drives etc.)
- Tourism – viewing
- Tourism – trophy hunting
- Investment of surplus funds
- End balance after redemption of loans
- Calculated annual cash flow

Different strategies to manage the game numbers could, according to Mabinda (2005), be modeled as follows:

- Do nothing (*laissez faire*)
- Expand elephant habitat
- Restrict elephant habitat by closing water points
- Introduce biological control
- Exclude elephants from sensitive areas
- Increase mortality to reduce population. The main options are:
 - Culling (full culling or selective)
 - Allowing hunting and
 - Failing to control poaching
 - Reduce birth rate by contraception
 - Translocation of elephants to less populated areas

The LP Model considers all cost-effective options for population management. These also form the basis of a cost-benefit analysis in the short and long run to test the feasibility of these options.

Resource Restrictions

It should be borne in mind that animal species could be divided into browsers, selective grazers and non-selective grazers. Within each of the classes, species are assumed to compete for the same resource. Scientific evidence shows that interrelationships between elephants and other species of large herbivores and biodiversity are complex and population management of elephants would be applied to avert risks to biodiversity. The total food requirements of each class must be equal or less to food resources available to that class. The finite resources in each food class constrain the number of animals in that group.

Quality Differences in Resources

Difference in the quality of resources can be incorporated in the LP model by treating each resource e.g. area of land per vegetation type separately within a spatial context.

Seasonality and Influx

Plant growth is seasonal and differs between summer and winter. The authors therefore see seasonal patterns in resource use, and carrying capacity of different vegetation and veld types. This also impacts on the management of the resources. The dynamic LP model needs to incorporate elephant conservation flux as part of ecosystem dynamics. Spatial variability is important in maintaining a diversity of plants. However, heterogeneity that formerly prevailed becomes restricted in fenced-in protected areas.

Carrying Capacity

According to Macnab (1985) concepts such as “carrying capacity” is a mathematical abstraction rather than a measurement of sustainable population size. This is especially true when measured within variable environments where carrying capacity can fluctuate between extreme seasons or years. The application of the ecological concept of “carrying capacity” to environmental management has its historical roots in commercial livestock husbandry (Gillson et al., 2002). A distinction should be made between “economic carrying capacity” and “ecological carrying capacity”. The former refers to the density of stock that provides maximum sustained yield to farmers. The latter is the average density a population assumes over a long period and at which the net population growth rate becomes zero. Since density is higher in ecological than economic carrying capacity, the pressure of grazing and browsing is heaving and the long-term composition of vegetation is very different (Caughley, 1983).

In the LP model the conservation and health of the elephant herd is directly dependant on the ability of the park management to keep the herd population below the carrying capacity of the land. A *laissez faire* approach and too many elephants will result in long-term damage to the park’s feed production capacity, a depletion of food reserves and ultimately reduce the number of elephants that can be sustained.

One of the primary herd control leverage points in this system is to change the rate at which elephants are harvested by increasing or decreasing culling and trophy hunting. It is assumed that the elephant population level is a function of the elephant net birth rate and the harvest rate. The death rate would also be incorporated in the model and is a function of the average lifespan which is affected by the carrying

capacity. The net growth rate of the herd is defined by the number of elephant births minus the number of elephant deaths.

The LP model is capable of simulating a dynamic system that changes over time. The system may *overshoot* its limit, causing the carrying capacity itself to change. In such cases, three outcomes are possible depending upon the specific structure of the system. The system may:

- oscillate about its carrying capacity;
- overshoot and collapse in which case the carrying capacity is destroyed and the system crashes; or
- reverse direction and approach its carrying capacity in an s-shaped declining fashion.

Figure 3 shows the results of a simulation run from time=0 to time=100 with an initial herd population of 50 elephants. At around time = 20, the herd has expanded to exceed the initial carrying capacity. After some delay, this excess number of elephants begins to erode the carrying capacity. Since the carrying capacity serves as the target in this negative feedback system, the elephant population responds by reversing its exponential growth and follows the carrying capacity downward. Note that even when the population drops to 200 animals, the initial carrying capacity, it remains greater than the now decreasing carrying capacity, thus the process continues until the system crashes and the carrying capacity of the land becomes zero.

Figure 3: Results from Elephant Population Overshoot Scenario,
Source: Internet: <http://www.systemdynamics.org/DL-IntroSysDyn/sshp.htm>

According to Owen-Smith et al. (2006), a demographic model indicates that reducing the continuing growth of Kruger Park's elephant population to zero could be brought about by a change of about 60% in specific vital rates, e.g. lengthening of the interval between calving from 3.8 to 6 years, delaying the age of first parturition from 11 to 18 years, and reducing calve survival between birth and 5 years from 91% – 55%, without any change in age-specific survival among adults. Elephant population growth seems particularly sensitive to changes in inter-calving periods.

The following basic resources should be included in the model:

- Total available land (area)
- Total surface area by natural vegetation type
- Minimum and maximum inclusion levels of food sources (this specifies the minimum and maximum levels of intake in terms of the relative contribution to dry matter intake)
- Minimum and maximum levels of specific nutrients (eg. Fibre, energy, protein, starch, bulk etc.)
- Labor
- Water resources
- Operational capital

Data Requirements

The data requirements of the model and the actual data collection are quite formidable especially regarding the following aspects:

- The actual game numbers or estimates thereof
- The nutritional requirements of various game species by age class
- The spatial composition of natural vegetation types and the nutritional value of vegetation during different times of the year
- The availability of natural vegetation in terms of dry matter per ha per month or estimates thereof

The calculation of the off-take of elephant according to Hearne (1999) is a challenge and would entail two steps viz:

- Develop a deterministic model for elephants to find an age structure to maximize off-take
- Dynamic stochastic modeling that uses the age structure as targets in an off-take strategy.

The principle of “garbage in - garbage out” certainly applies in this case. Although it will probably be difficult to collate this data, the authors believe

that calibration methods could be used to calibrate the model to a base situation/year which simulates an observed state of the system fairly accurately. This could be done by appointing a panel of environmental and conservation experts to share expert knowledge on a specific region.

Model Output

It is expected that the model will be able to calculate the following:

- Benchmark assumptions and “what if” scenarios
- Test assumptions and underlying ecological principles and guidelines
- Maximum conservative carrying capacity for a game farm/park.
- How one could manipulate the balance of species in order to optimize surplus animals
- The optimal population number for each specie. Are there too many elephants?
- The impact of different culling levels and possibly ways of culling
- The economic impact of alternative management options or plans.

Validation of the Model

The first step in the validation is the development of a test model for a specific game farm or park, testing the mathematical soundness of the model. The final phase is to validate the model by running several scenarios and to test the results with experts in the game industry.

Validation of the model is a process that leads to:

- a numerical report of the model’s fidelity to the historical data set;
- improvements of the model as a consequence of imperfect validation;
- a qualitative judgement on how reliable the model is for its stated purposes; and
- a conclusion (preferably explicit) for the kinds of uses that it should not be used for (Hazell and Norton, 1986).

On a last note, researchers with the likes of Hearne (1999), have used a similar approach to the one pro-

posed by the authors, to show that the highest (most optimal) economic returns are obtained from harvesting the surplus of all animal species within a particular park or game ranch, which are in excess of the ecological equilibrium. An example that serves to illustrate this point is that the income derived from hunting one elephant is equivalent to the income derived from 100 tourists.

Conclusions

The wide-ranging arguments from different interest groups and stakeholders in regard to elephant management, seen to have reached a critical state, have been surveyed in this paper. It is clearly evident that the issue is politically largely sensitive and complex. Using an appropriate economic model, this issue may be addressed in a scientific manner and reduced to manageable proportions.

There is sufficient international support to develop markets for ecosystem goods and services. The authors propose that a partial equilibrium Linear Programming model be developed for the purpose of simulating the dynamic impacts of various elephant management options. The model may also be developed in respect of all other species or inclusive thereof. The main aim of the model should be to pursue ecological balance, simultaneously optimizing the economic returns from managing any surplus species.

The authors emphasize that constructing the proposed model would require a collaborative effort by scientists from different disciplines. Man interfered with nature by limiting the natural habitat of various animal species. Then, instead of continually monitoring and managing the ecological impact thereof, allowed for the ecology to move out of balance. The effects were especially harmful in the case of the elephant, which in its state of over-population, denies other plant and animal species an equal chance of survival by destroying large parts of the natural habitat within the Kruger Trans-frontier Park. Urgent action is required. However, if not scientifically managed, restoration efforts may lead to more harm. The model outlined in this paper, provides a holistic and well-balanced approach to finding sustainable elephant (and ecological) solutions.

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