CORNELL

91-8

Working Papers in AGRICULTURAL ECONOMICS

September 1991 **91-8**

Economic Strategies for Coevolution: Parks, Buffer Zones and Biodiversity

by

Jon M. Conrad

Department of Agricultural Economics
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853-7801

Economic Strategies for Coevolution:

Parks, Buffer Zones and Biodiversity

by

Jon M. Conrad

Professor of Resource Economics

Department of Agricultural Economics

Cornell University

Ithaca, New York 14853

Economic Strategies for Coevolution: Parks, Buffer Zones and Biodiversity

by

Jon M. Conrad

Abstract

The creation of parks and preserves in less developed countries is seen as an important step in preserving biodiversity and genetic information (Dixon and Sherman 1990). The establishment of a park or preserve, however, is often seen as a threat by rural residents if they are denied access to areas where hunting, gathering or small scale agricultural provided them with food, fuel or marketable products. In a series of papers Norgaard (1981, 1984 and 1985) advocates development strategies that promote coevolution of socioeconomic and ecological systems. In this dynamic context, coevolution might be defined by a set of trajectories describing economic welfare and biodiversity that remain within "acceptable" bounds over some future horizon. (1) What are some possible measures for economic welfare and biodiversity? (2) How might one identify the scale and location of hunting, gathering and agricultural activities within a buffer zone to a park or preserve that would qualify as coevolutionary. (3) How might one optimize over the set of coevolutionary strategies? A methodology is proposed to address these questions and to explore the economic incentives that might support a coevolutionary strategy in the buffer zone to a park or preserve.

Key Words: economics, biodiversity, coevolution, park management.

Economic Strategies for Coevolution:

Parks, Buffer Zones and Biodiversity

I. Introduction and Overview

The past decade has seen heightened awareness of the need to preserve biological diversity. The U. S. Office of Technology Assessment defines biological diversity in the following way.

> Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequency. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance. (Office of Technology Assessment 1987, p. 3)

Strategies to maintain biological diversity include the collection and storage of germplasm *ex situ* and the establishment of parks and preserves that would protect species *in situ*. While there are important and threatened ecosystems in temperate zones, the focus of recent preservation efforts has been in the tropics, where natural areas are highly diverse and under intense development pressure. Dixon and Sherman (1990, p. 11) note that since the 1970s most of the new national parks have been located in developing countries. The opportunity cost of establishing a system of parks or preserves in such countries may be relatively high, particularly when viewed through the eyes of impoverished rural residents who practiced agriculture within the park or harvested resources for subsistence or cash income.

Less developed countries (LDCs) are usually strapped for funds to manage parks and preserves and if the establishment of a park is not seen as beneficial or fair to local residents, "poaching" of plants and animals may become a significant problem and enforcement costs may be substantial. At one extreme, the park or preserve may become a "fortress" guarded by soldiers of the central government. At the other extreme, if enforcement is lax, excessive hunting, gathering and agricultural practices may continue to significantly degrade the park, reduce biological diversity and defeat the objectives of establishing the park in the first place.

In a series of articles Norgaard (1981, 1984 and 1985) extended the biological notion of coevolution, where two or more species may interact and advantageously evolve over time, to the coevolution of a socioeconomic system and its supporting environment. This perspective placed emphasis on finding a set of economic activities and social institutions that could evolve with the natural environment in a nondestructive way.

This paper explores some models and methods which might operationalize the notion of coevolution. To make things concrete we will consider a park and buffer zone recently established in a LDC and will try to answer the following questions.

1. What economic activities might be permitted in the buffer zone surrounding a park?
2. What is the net economic value of various activities to individuals or households living in or adjacent to the buffer zone?
3. How will the scale and duration of such activities affect biodiversity?
4. How can we display the trade-offs between net economic value and biodiversity in a way that is useful to managers and the affected households?

The next section develops a model and some methods that might be used to evaluate economic activities within a buffer zone, in terms of the stream of net revenue they generate over time and their impact on an index of biodiversity. This approach would define coevolution as a set of feasible economic activities that results in acceptable trajectories for both net revenue and the index of biodiversity. The set of coevolutionary strategies might be further narrowed by equity considerations. From the set of activities that are coevolutionary and "economically just" one might recommend those that maximize the present value of net revenues.

The third section examines the institutional and management policies that might be employed to promote the adoption of coevolutionary activities by residents living adjacent to the park. The assignment of exclusive rights for hotel accommodations, food service, guided tours, and the conduct of certain agricultural, hunting and gathering activities within the buffer zone or park is discussed. The fourth section summarizes the major conclusions of the paper and identifies the type of research that will be needed if national and international agencies seek to promote coevolutionary development.

II. A Model of Coevolution

The model to evaluate coevolutionary strategies, while naive, will illustrate the type of information needed and the analysis that could be conducted. It is based on the following notation.

$A_{i,j,t}$ is the level (or scale) of activity i in sector j in period t, where $i = 1,2,...,I$, $j = 1,2,...,J$, $t = 0,1,...,T$, (see Figure 1),

n_i is the net value per unit, per period derived from activity i,

$X_{k,t}$ is the abundance of "keystone" species k in period t, where $k = 1,2,...,K$,

X_k is the maximum abundance (carrying capacity) of keystone species k,

A_t is an (IxJ) matrix of buffer zone activities in period t,

X_t is a (Kx1) vector of species abundance in period t,

B_t is an index of biodiversity in period t, and

$\rho = 1/(1 + \delta)$ is a discount factor and δ is the periodic discount rate.

The model will assume that the population dynamics of the keystone species can be described by the system of difference equations

$$X_{k,t+1} = F_k(X_t, A_t) \tag{1}$$

Equation (1) says that the abundance of species k in period t+1 will possibly depend on the abundance of all keystone species and on the level of all activities in all sectors of the buffer zone.

The index of biodiversity is assumed to take the following form

$$B_t = B(X_t) = \alpha\left[\left(\frac{X_{1,t}}{X_1}\right)x\left(\frac{X_{2,t}}{X_2}\right)x \ldots x\left(\frac{X_{K,t}}{X_K}\right)\right] = \alpha\prod_{k=1}^{K}\left(\frac{X_{k,t}}{X_k}\right) \tag{2}$$

where α is a scaling parameter. If $\alpha = 1$, then the biodiversity index ranges from 0 to 1, inclusive, and becomes zero if any keystone species goes extinct. (This assumes $X_{k,t} \leq X_k$ for all t.)

The net revenue to households living in or adjacent to the buffer zone in period t may be calculated as

$$N_t = \sum_{i=1}^{I} \sum_{j=1}^{J} n_i A_{i,j,t} \tag{3}$$

The present (or discounted) net revenue from $A_{i,j,t}$ is

$$N = \sum_{t=0}^{T} \rho^t N_t \tag{4}$$

At least three comments are in order. First, the dynamics of keystone species has been limited to a simple system of first-order difference equations. In reality there are likely to be lags between activities $A_{i,j,t}$ and species abundance. This may necessitate the use of delay-difference equations and the adoption of a sufficiently lengthy horizon in order to identify the full, long-run effects of $A_{i,j,t}$ on all keystone species.

Second, estimation and validation system (1) will require time series estimates of the keystone species as they evolve in response to a particular $A_{i,j,t}$. Unless the number of keystone species is small, such annual surveys may be time consuming and expensive.

Third, the biodiversity index requires an estimate of park carrying capacity, X_k, for each keystone species and assumes that carrying capacity is unchanging over the horizon of analysis. As an alternative, we might consider an index proposed by Odem (1963), which takes the form $B_t = K_t/(\ln M_t)$, where K_t is the number of keystone species in existence in period t and $M_t = \sum_k X_{k,t}$ is the total number of keystone individuals in year t.

Pielou (1969) discusses Simpson's measure of diversity, which in our notation may be defined as

$$B_t = \frac{\sum_{k=1}^{K} X_{k,t}\,(X_{k,t} - 1)}{M_t\,(M_t - 1)} \qquad (5)$$

This index can be regarded as the probability of randomly drawing (without replacement) two individuals of the same species. Thus, if B_t is low, diversity is great, if B_t is high, diversity is low. Both of the above indices remain positive in the face of keystone extinction.

If the keystone species have been inventoried so that an estimate of the $X_{k,0}$ is in hand, then the net value and biodiversity implications of $A_{i,j,t}$ might be evaluated as follows.

1. Select a horizon length, $T \approx 1/r$, where r is an estimate of the intrinsic growth rate of the slowest growing keystone species. Then, the horizon of analysis will be $t = 1,2,\ldots,T$.

2. For each $A_{i,j,t}$ calculate the net value N_t in each period according to equation (3) and then the present value according to equation (4). The discount rate might initially be set at $\delta = 0.02$ (Howe 1990).

3. For a particular $A_{i,j,t}$ and initial condition $X_{k,0}$, we can simulate system (1) forward in time and obtain trajectories $X_{k,t}$ for all keystone species.

4. Calculate the biodiversity index in each period t.

The first obvious piece of analysis would be to plot the trajectories N_t and B_t associated with each $A_{i,j,t}$. Suppose there is consensus that the index of biodiversity should not drop below some level $B \geq 0$. Such a criterion may reduce the set of candidate $A_{i,j,t}$. This situation is depicted in Figure 2 where the $A_{i,j,t}$ associated with N'_t and B'_t would be removed from consideration since B'_t drops below B at $t = t'$.

A second criterion might be invoked to further reduce the set of admissible strategies. Suppose in each period that the net revenue from buffer zone activities is distributed among H households. Let $N_{h,t}$

denote the net revenue earned (or net value of food and resources consumed) by household h from buffer zone activities in period t. Define $s_{h,t} = N_{h,t}/N_t$ to be the share of household h in the net revenues from buffer zone activities in period t, where $1 \geq s_{h,t} \geq 0$. A Lorenz curve can be constructed which would plot the cumulative share of income held by the lower p^{th} proportion of households. The Lorenz "curve" for a four-household case where $s_{h,t} = 0.05$ for h = 1,2,3 and $s_{4,t} = 0.85$ is shown in Figure 3. In general, we will denote this curve by L(p), where $p = \phi(s_{1,t},\ldots,s_{H,t})$. The Gini ratio (Gastwirth 1972) is defined as the ratio of the area between the Lorenz curve and the 45° line and the area under the 45° line. In every period a Gini ratio could be calculated as

$$G_t = 1 - 2\int_0^1 L(p)\, dp \tag{6}$$

This ratio measures the degree of income inequality. If buffer zone income is equally distributed in period t, then $G_t = 0$. If buffer zone income is perfectly inequitable in distribution (one person receives it all), then $G_t = 1$. For each activity matrix A_t it would be possible to calculate G_t, and if the Gini ratio is too high, that activity matrix would be eliminated for being inequitable or "economically unjust." In our example in Figure 3 the Gini ratio is $G_t = 0.6$. This might be regarded as too inequitable a distribution.

By restricting choice to those activities where the index of biodiversity stays above some lower bound and the Gini ratio stays below some upper bound it may be acceptable to maximize the present value of net revenue. Mathematically we wish to

$$\text{Maximize} \quad \sum_{t=0}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J} \rho^t n_i A_{i,j,t}$$

$$\text{Subject to} \quad X_{k,t+1} = F_k(X_t, A_t)$$

$$\alpha \prod_{k=1}^{K} \left(\frac{X_{k,t}}{X_k} \right) \geq B$$

$$1 - 2\int_0^1 L(p)\, dp \leq G$$

$$p = \phi(s_{1,t}, \ldots, s_{H,t})$$

$$s_{h,t} = N_{h,t}/N_t \quad (\text{either } N_{h,t} \text{ or } s_{h,t} \text{ given})$$

The above approach is similar to multiobjective programing (Cohon and Marks 1975), where all but one objective is treated as a constraint. The unconstrained objective is then maximized. By sequentially varying the constraint levels (in our case the lower bound on B or the upper bound on G) one could numerically identify the

Pareto-efficient trade-offs between N and B or G. When the Pareto-efficient points are connected in N-B or N-G space, one would expect a frontier comprised of a series of line segments (facets) collectively forming a surface that is concave to the origin. A hypothetical frontier, displaying the maximum N for various values of B and fixed G, is shown in Figure 4.

III. Park Management and Incentives for Conservation

The designation of land as a park or preserve might be relatively easy to accomplish, particularly if the government already owns the land. The protection and maintenance of biodiversity within a park or preserve may not be so easily accomplished. As noted in the introduction to this paper, the the ability to stop encroachment and degradation within a park might critically depend on the cooperation of local residents.

While economists have long called for the use of economic incentives in resource management and pollution control, there now appears to be a greater appreciation of such policies by wildlife managers and development sociologists. If local residents can be given a financial stake in conservation, then the probability of maintaining a park and slowing the loss of biodiversity can be increased (Dixon and Sherman p. 70). The economic incentives that might be provided could include jobs within the park (serving as rangers or guides), jobs within hotel, restaurant or resort facilities used by visitors to the park, or exclusive rights to harvest certain resources within the park.

The first strategy has been referred to as "eco-tourism." If ecosystems supporting interesting flora and fauna can be maintained within a park for tourists staying in comfortable facilities adjacent to the park, jobs and revenue can be generated which can support both local residents and park maintenance.

Within the park or preserve it may be possible to allow regulated harvest of certain resources that would not threaten, and in some cases might enhance, the balance and resilience of park ecosystems. Mackinnon *et al.* (1986) discuss systems in the Chitwan National Park in Nepal and the Matobo National Park in Zimbabwe where local villagers are allowed to harvest a certain amount of grass for thatching of roofs. In the rainforest of Peru, Peters, Gentry and Mendelsohn (1989) estimate that periodic and selective cutting of timber, combined with annual fruit and latex collection has a present value of $6,820 per hectare. This compares to a one-shot net revenue of about $1,000 for standing timber and a subsequent present net value, if the hectare is converted to pasture, that is unlikely to exceed $2,960. The authors conclude that selective harvest of timber and the annual harvest of minor forest products results in a present value that significantly exceeds a one-shot timber harvest and conversion to pasture.

In parts of Zimbabwe, the right to cull elephant and other abundant wildlife has been transferred to villages, who are in turn able to transfer that right to foreign hunters. Proceeds from the trophy fee are divided among village members, used to purchase communally-owned agricultural equipment or provide other "local public goods." Table 1 lists a few of the species in Zimbabwe, their abundance, the trophy fee and the revenues obtainable from a safari.

By giving villagers in communal lands a financial stake in conserving these animals, Zimbabwe is in the envious position of having relatively abundant wildlife populations. The investiture of culling rights to a village creates two strong incentives. First, there is a desire to maintain the herds at a relatively high level so culling is allowed, and second, villagers have a financial stake in preventing poaching, which is a serious problem in other parts of Africa.

The Zimbabwe experiment has been so successful that some villages have voluntarily removed all cattle from communal grazing land, thereby reducing the competition with wildlife for grass and water. In the May, 1991 *National Geographic* Douglas Chadwick recounts the comments of a Hwange tribal chief.

> For a long time the government told us that wildlife was their resource. But I see how live animals can be our resource. *Our* wealth. *Our* way to improve the standard of living without waiting for the government to decide things. A poacher is only stealing from us. If our forefathers guide me, my task now is to bring this message to the people (Chadwick 1991, p. 42).

The Zimbabwe model of game management may strike some as simply catering to an elitist group of "great white hunters," who wish to act out a fantasy in an Africa that no longer exists. Some would argue that the killing of all wildlife should stop. In an imperfect world, however, perhaps the profitable harvest of a few may contribute to the survival of many. And it's not just the survival of elephant, Cape buffalo, kudu and zebra. By removing fences and joining communal lands with existing game ranches, there is a potential to "reawaken" an immense regional ecosystem bordering on Zimbabwe, Botswana and Zambia.

IV. Conclusions

This paper has attempted to extend the notion of coevolution to the management of parks and buffer zones in less developed countries. Coevolutionary strategies might be defined as a set of economic activities that allows a socioeconomic system and its supporting ecosystem to evolve nondestructively. The definition of "nondestructive" might be operationally found by imposing lower bounds on an index of biodiversity and upper bounds on an index of income inequality. From the (hopefully nonempty) set of activities that maintain biodiversity and satisfy economic justice, one might choose those which maximize the present value of net revenues. The opportunity cost of biodiversity or equity might be analyzed by varying their constrained levels and seeing how the maximum present value of net revenue changes.

There is evidence from southeast Asia, South America and Africa that parks and preserves are more likely to achieve their goals of biological conservation if they can give local residents a financial stake in their operation and maintenance. Strategies where local residents are given jobs in facilities that support park tourism or exclusive (but transferable) rights to harvest park resources may reduce enforcement costs and may be more effective in the long-run.

Determining which activities are acceptable from a coevolutionary perspective and which of the acceptable activities is "best" will require an interdisciplinary research effort involving agricultural, biological and social scientists. Agronomists would be needed to examine the suitability of soils in the buffer zone for various types of crops and agricultural practices. Ecologists would attempt to link the location and scale of agricultural activities with the dynamics of keystone species. They would also be involved with the analysis of hunting and gathering activities within the buffer zone or park for plants and animals consumed by households or sold for cash. As in the study of minor forest products in the Amazonas, the emphasis would be on the level of sustainable yield and its impact on forest ecosystems.

Economists would work on the evaluation of net benefits to households from small scale agriculture, hunting and gathering and attempt to evaluate the externalities that might arise within the buffer zone and park in later periods. Development sociologists could play a role in examining the factors affecting population growth and migration and the establishment of local institutions that might implement economic policies for promoting biological conservation.

Interdisciplinary research is easy to propose but difficult to achieve. The diverse set of applied scientists needed to identify and promote coevolutionary strategies requires a shared understanding of the role that each might play within the broad dynamic scheme of things. It also requires a humility and cooperative spirit that is sometimes lacking in academics who are programmed to operate in a more narrowly focused, competitive discipline. Biological conservation may depend not only on our ability to understand and model the relevant physical, biological and social systems, but on the implementation of policies that give individuals a financial stake in maintaining the biological "capital" on which current and future generations depend.

References

Chadwick, D. H. 1991. "Elephants - Out of Time, Out of Space," *National Geographic*, May: 2-49.

Cohon, J. L. and D. H. Marks. 1975. "A Review and Evaluation of Multiobjective Programing Techniques," *Water Resources Research*, 11(2): 208-220.

Dixon, J. A. and P. B. Sherman. 1990. *Economics of Protected Areas: A New Look at Benefits and Costs*, Washington, D. C., Island Press.

Gastwirth, J. 1972. "The Estimation of the Lorenz Curve and Gini Index," *The Review of Economics and Statistics*, 54: 306-316.

Howe, C. W. 1990. "The Social Discount Rate." *Journal of Environmental Economics and Management*, 18(2 of 2): S-1-2.

MacKinnon, J., K. MacKinnon, G. Child and J. Thorsell. 1986. *Managing Protected Areas in the Tropics*, International Union for the Conservation of Nature and Natural Resources, Gland, Switzerland.

Norgaard, R. B. 1981. "Sociosystem and Ecosystem Coevolution in the Amazon," *Journal of Environmental Economics and Management*, 8(3): 238-254.

Norgaard, R. B. 1984. "Coevolutionary Development Potential," *Land Economics*, 60(2): 160-173.

Norgaard, R. B. 1985. "Environmental Economics: An Evolutionary Critique and Plea for Pluralism," *Journal of Environmental Economics and Management*, 12(4): 382-394.

Odem, E. P. 1963. *Ecology*, Holt Rinehart and Winston, New York.

Office of Technology Assessment. 1987. *Technologies to Maintain Biological Diversity*, Washington, D. C., U. S. Government Printing Office.

Peters, C. M., A. H. Gentry and R. O. Mendelsohn. 1989. "Valuation of an Amazonian Rainforest," *Nature*, 339(29): 655-656.

Pielou, E. C. 1969. *An Introduction to Mathematical Ecology*, Wiley Interscience, New York.

Figure 1. A hypothetical park with j=7 sectors in the buffer zone.

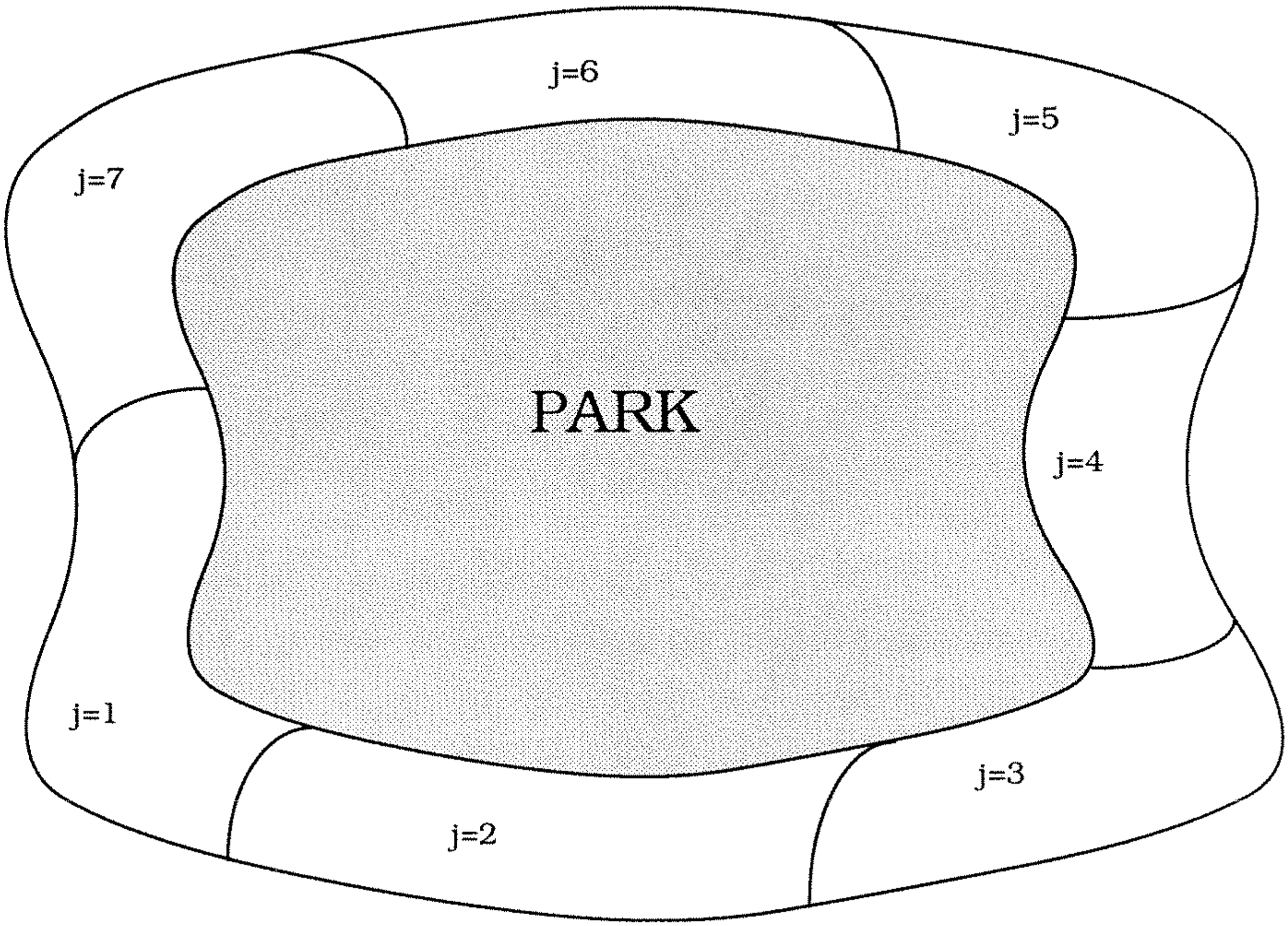

Figure 2. Time paths for net revenue and biodiversity. The activities generating N_t and B_t are admissable while those generating N_t' and B_t' are inadmissable.

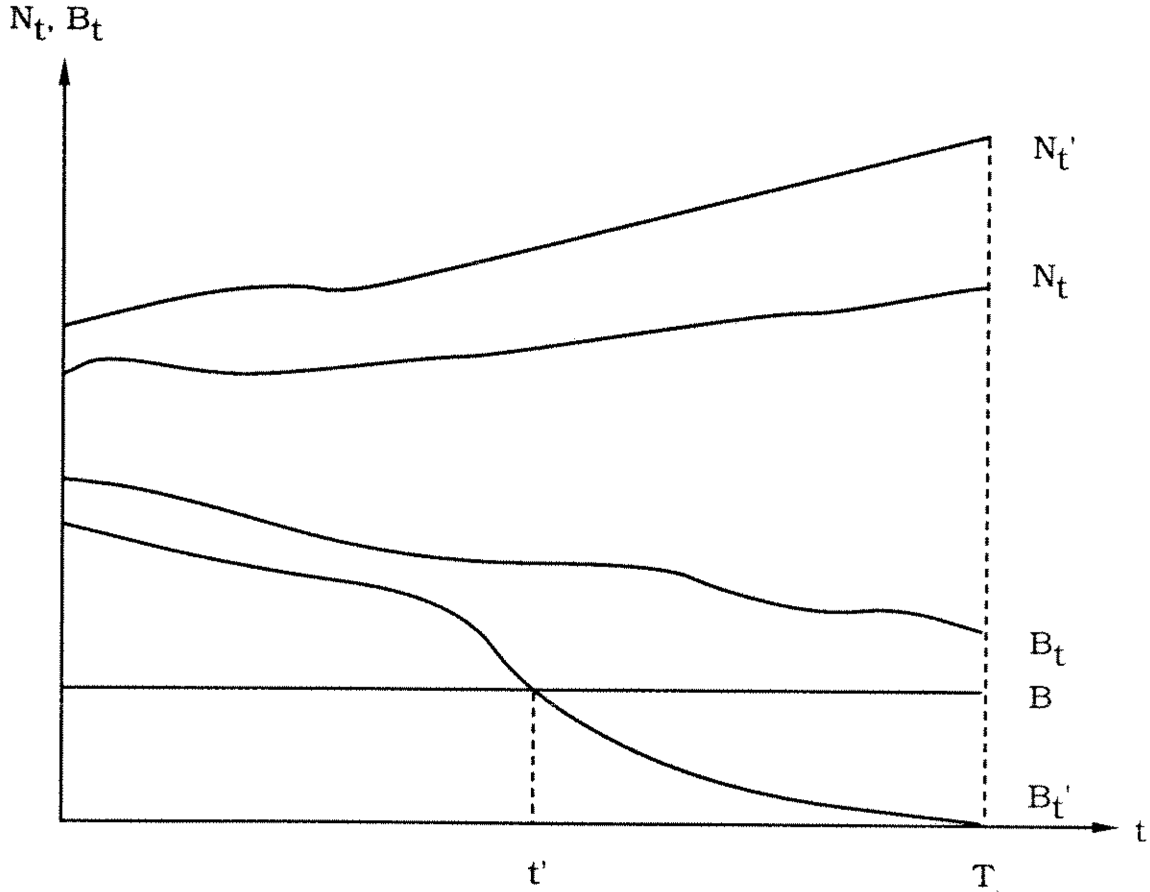

Figure 3. The Lorenz Curve and Gini Ratio for the case where H=4, $S_{h,t}$=0.05, h=1,2,3 and $S_{4,t}$=0.85. The Gini Ratio is G=2A=0.60.

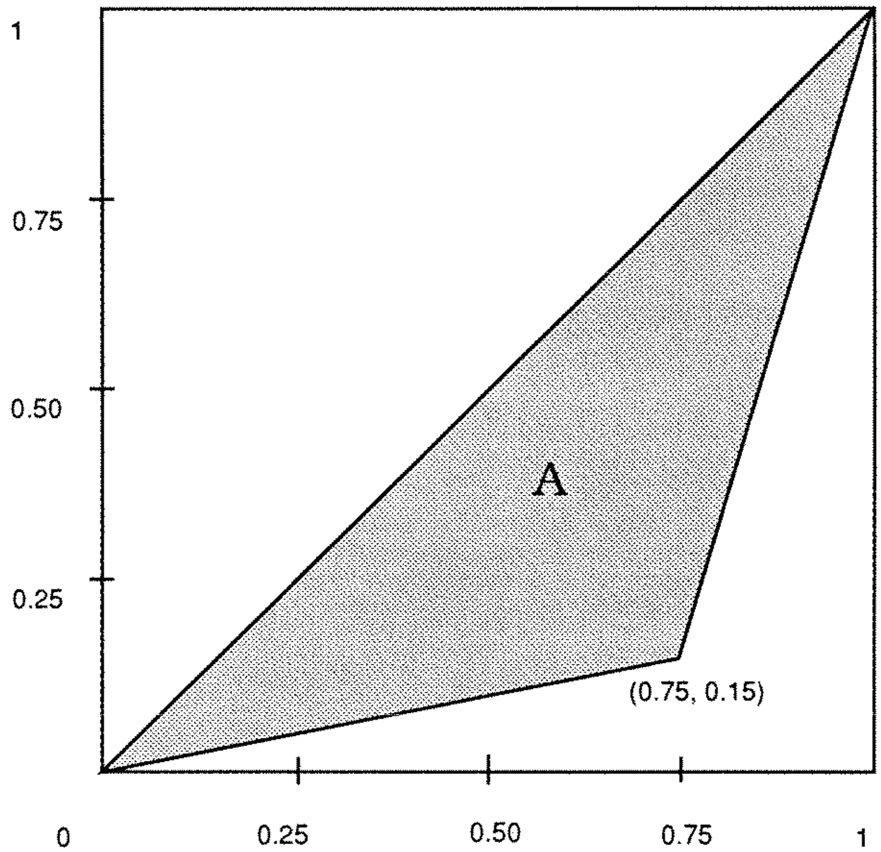

Figure 4. The Pareto-Efficient Trade-off Curve between the present value of net revenes, N and the lower bound on biodiversity, B, for a fixed upper bound on the Gini Ratio, G.

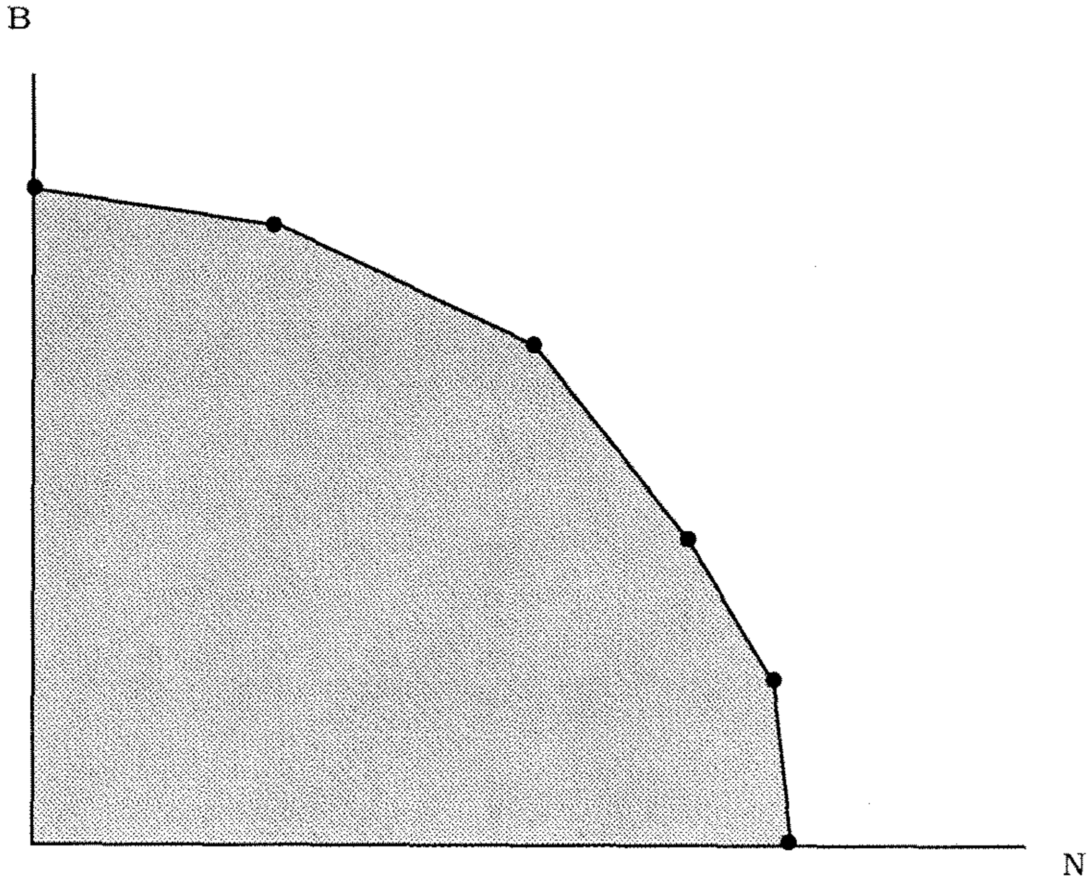

Table 1. Estimated population of selected game species in Zimbabwe, proposed trophy fee (US$), duration of hunt (days), allowable kill (per 1,000 km^2/year) and total revenue (US$)[a].

Species	Estimate of Total[b] Population	Trophy Fee Per Animal	Duration of Hunt	Allowable Kill	Total Annual[d] Revenue
Elephant	66,438	$15,000[c]	10.0	7	$175,000
Zebra	22,396	$700	1.0	20	$34,000
White Rhino	389	$30,000	10.0	1	$40,000
Buffalo	71,298	$1,000[c]	5.0	40	$240,000
Kudu	53,369	$500[c]	1.0	60	$90,000
Sable	11,764	$1,250	1.5	50	$137,500
Wildebeest	8,036	$500	0.5	12	$12,000
Lion	3,843	$2,500[c]	5.0	10	$75,000
Leopard	9,737	$2,000	5.0	16	$112,000
Crocodile	8,389	$1,500	2.0	3	$10,500

(a) Source: Modified from handouts at a seminar by Rowen Martin at Cornell University 5/2/91.
(b) Estimate as of 1 January 1991.
(c) Trophy fee for male of species.
(d) Total annual revenue assumes a safari rate of $1,000 US/day.

Other Agricultural Economics Working Papers

No. 90-14	A Bioeconomic Model of the Pacific Whiting	Jon M. Conrad
No. 90-15	Optimal Depletion of Non-Renewable Resources under Linear Homogeneous Stock-Dependent Cost	Robert W. Jefferson
No. 90-16	The Economics of a Stock Pollutant: Aldicarb on Long Island	Jon M. Conrad Lars J. Olson
No. 90-17	Productive and Predatory Public Policies: Research Expenditures and Producer Subsidies in Agriculture	Harry de Gorter David J. Nielson Gordon C. Rausser
No. 91-1	Departmental Rankings by AJAE Publication Rates	Deborah H. Streeter Harry M. Kaiser
No. 91-2	Stock Pollutants and Risky Accumulation	Jon Conrad
No. 91-3	Influence of Agricultural Lending Policies on Commercial Bank Loan Volume	Eddy L. LaDue John Thurgood
No. 91-4	Variability in Soybean Futures Prices Economic and Econometric Issues	Deborah H. Streeter William G. Tomek
No. 91-5	A Critical Analysis of Climate Change Policy Research	Dale S. Rothman Duane Chapman
No. 91-6	Global Properties of Well-Behaved Demand Systems: A Generalized Logit Specification	Jess Dumagan Tim Mount
No. 91-7	Measuring the Consumer Welfare Effects of Carbon Penalties: Theory and Applications to Household Energy Demand	Jesus C. Dumagan Timothy D. Mount