THE ECONOMICS OF RHINO CONSERVATION

An economic analysis of policy options for the management of wild rhino populations in Africa

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PREFACE

One of the leading current environmental concerns is that of biodiversity conservation. There is an increasing awareness that biological resources provide economic benefits that, for various reasons, are not being captured by society. As a result, these resources may be perceived to be uncompetitive, and will be removed from the portfolio of social assets, either by active disinvestment or by the passive nonallocation of other resources upon which they depend for survival (Swanson 1990a).

One of the challenges for environmental economists is to identify ways in which economic values of biodiversity can be captured to benefit society. This poses some difficulty - while it is often desirable or even necessary to expropriate value from biological resources in order to conserve them, there are cases where the existence of high commercial values can result in excessive exploitation and even extinction. This issue is the subject of a recent article in **The Economist** (26 June 1993, page 109).

A classic example of this is the issue of rhino conservation. Since 1977 the international trade in products of all rhinoceros species has been prohibited under the Convention on International Trade in Endangered Species (CITES). The objective of this policy is to stop the illegal exploitation of rhinos, yet it has not been successful to date, and the rhino is currently much closer to extinction than in 1977. It is thus worthwhile to question whether a trade ban is an appropriate measure.

An intuitive reason for avoiding any trade restrictions, apart from the fact that they may not achieve the desired objective, is that they may reduce social welfare, since they generally lead to economically inefficient outcomes. At a time when the global benefits of free trade are becoming increasingly obvious, and are being pursued as an objective by major international conventions such as the GATT, the policy directions being advanced by CITES should by regarded with caution.

In this paper I question whether the CITES policy of a trade ban is an appropriate way to address the problem of rhino extinction. To consider this issue, I draw on some recent revisions to the economic theory of extinction proposed by Swanson (1990a). This framework offers a robust means for analyzing the forces driving the extinction of terrestrial species such as the rhino, and I hope that the discussion that follows will stimulate a more constructive debate to this complicated issue.

Numerous people contributed somehow to the work contained in this paper. I would like to mention a few of them. First, I would like to thank Frank and Deborah Vorhies for their consistent support in my work, as well as their useful and stimulating input. Second, I would like to thank my mother for her support and understanding whilst researching and writing up this paper.

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ABSTRACT

The conservation of rhinoceros species is an issue of both biological and economic importance. All five species of rhino have been subjected to considerable levels of human exploitation in the past, and are threatened with extinction. Recently the main reason for exploitation has been to supply the demand for rhino horn on Asian markets. This has caused the numbers of one species, the black rhino, to fall from an estimated 100,000 in 1960 to 2,480 in 1992.

In response to this drastic decline, various international and national restrictions have been placed on the trade in rhino horn. Thus far, these have not been successful in preventing further exploitation. This has prompted certain authors to question whether this strategy is appropriate. A review of the world rhino horn trade by Leader-Williams (1992), a theoretical revision of the economics of extinction by Swanson (1992a) and a detailed discussion of the decline of the black rhino in Zimbabwe by Milliken, Nowell and Thomsen (1993) all suggest that alternative approaches to the problem should be explored.

The theory of natural resource management provides a framework to analyze the economic nature of this problem. Utilising the insights of Swanson (1992a), it is possible to develop a dynamic model of optimal rhino management. This model assumes that the objective of management is consistent with the economic objective of maximising social welfare. One shortcoming of the model is

that it does not deal explicitly with the problem of conflicting objectives between managers and illegal exploiters. This aspect is illustrated by the use of a simple static "two-party" model which predicts that the number of rhinos conserved will be higher if legal exploitation is accepted as a policy option.

A consideration of empirical issues leads to the conclusion that more research is needed to determine the demand for rhino horn, as existing data is unsuitable for detailed analysis. Other data suggests that trade restrictions are unable to prevent illegal exploitation, but the probable effects of trade legalisation are uncertain. It appears that existing management institutions are inadequate in appropriating the full social benefits of rhinos and re-investing these in their protection.

Whilst it is not possible to draw definite policy implications from this analysis because of the lack of sufficient data, a tentative conclusion is that the policy of trade restriction does not appear to be beneficial either to conservation or in economic terms. A regime which allows the full appropriation of rents by the custodians of rhinos would seem to provide greater incentives to conserve whilst simultaneously improving economic efficiency.

1. INTRODUCTION

1.1 Overview

In recent years, sustainable development has become an issue of significant international importance. Among the environmental concerns that have been voiced, one that is of particular global interest is the issue of biodiversity conservation. This issue is especially interesting and complicated, since the majority of those members of society concerned with protecting biodiversity are citizens of affluent, developed countries, whereas the actual targets of conservation tend to occur in less developed countries, where economic growth is usually the main objective. The attempts of the affluent to conserve species in foreign developing countries is frequently perceived as an imposition of alien ethics and a hindrance to development.

This paper examines the conservation of rhinoceros species, an issue which has received considerable attention over the last decade. It is a classic example of "first world" preservation and animal welfare ideologies influencing the destiny of a species in the developing world. Conservationists have noted with alarm that numbers of all rhino species have been dropping drastically during this century, especially the African black rhino. They have identified illegal poaching, driven by the demand for products such as horn, as the cause of the problem. Their reaction has been to tighten control on all illegal activity, and to prohibit the trade in all rhino products.

This paper accepts the notion that it is desirable to conserve biodiversity, and therefore rhinos. Exactly what this means with respect to intraspecific diversity, desirable population levels and appropriate habitat is not that clear, as is discussed in Section 3.1, but it is clear that society should try and prevent the extinction of rhino species for the sake of posterity. The question addressed is whether current policies are the most appropriate way of achieving this objective. Examining the rhino issue in an economic context leads to the conclusion that certain aspects are not being addressed in a sensible way. A debate over appropriate measures is starting to develop, and what follows is an attempt to contribute usefully toward this.

1.2 Taxonomy, numbers and distribution

There are five species of rhinoceros, three of which occur in Asia, and two in Africa. The two African species are the black rhino, *Diceros bicornis,* and the white rhino, *Ceratotherium simum*. According to Owen-Smith (1988), there are two subspecies of the white rhino, the northern and the southern, while seven subspecies of the black have been identified, although the status of some of these is uncertain. For conservation purposes, the black rhino is currently separated into four ecological groupings or "ecotypes" (Brooks 1988; Cumming, Du Toit and Stuart 1990).

Recent estimates of the numbers of all the existing species and subspecific groups are shown below in Table 1. A distinction is made between animals found in zoos (captive) and those occurring under more natural conditions (wild). The total captive population of black rhinos is 205, and the total wild population is estimated at 2,480.

TABLE 1 : Recent estimates of numbers of existing captive and wild populations of all rhino species and subspecies (African Rhino Specialist Group 1992).

	Captive	Wild
INDIAN RHINO, *Rhinoceros unicornis*	120	1,700
JAVAN RHINO, *Rhinoceros sondaicus*	0	100
SUMATRAN RHINO, *Dicerorhinus sumatrensis*	24	850
WHITE RHINO, *Ceratotherium simum*		
Northern race, *C.s. cottoni*	9	31
Southern race, *C.s. simum*	570	5,601
BLACK RHINO, *Diceros bicornis*		
D.b. bicornis	0	559
D.b. longipes	0	35
D.b. michaeli	163	489
D.b. minor	42	1,397

According to Martin (1979) rhinos were far more common and widespread in previous centuries. Their numbers have declined as a consequence of human exploitation for various products, and also possibly as a result of competition for land resources. Milliken, Nowell and Thomsen (1993) discuss the decline of the black rhino. Scientific estimates of rhino numbers were attempted for the first time in 1980, and previous estimates may be inaccurate, but in 1960 the total African population is thought to have numbered 100,000 individuals. This dropped to an estimated 65,000 by 1970 and 14,000-15,000 by 1980. The subsequent trend in numbers is shown in Table 2.

TABLE 2 : The decline in numbers of wild populations of black rhinos in Africa. Two sources are used, Hall-Martin (1988) and Milliken, Nowell and Thomsen (1993).

	Hall-Martin	Milliken
1980	14,795	
1984	8,800	9,500
1985	-	6,000
1986	4,049	-
1987	3,717	3,800
1991	-	3,450
1992	-	2,480

1.3 Human uses of rhino products

A wide variety of uses for rhino products has been documented, with virtually every body part as well as dung and urine being of some perceived value to humans (Martin 1983). Many of these uses are based on traditional Asian medicinal practices, and are gradually disappearing, but some are still currently significant. Martin (1979) indicates that there is still a demand for products such as meat and skin, and especially horn.

There is still a popular misconception about the uses of rhino horn. Martin (1979) finds that rhino horn is not used as an aphrodisiac, as is often claimed, but identifies two primary sources of demand. The first is for medicinal purposes, since it is regarded as having potent fever-reducing qualities by many Chinese people, and the second is for the making of ceremonial dagger handles in Yemen.

The tradition of using rhino horn as a medicine dates back several centuries. It is probable that Asian rhinos initially provided the source of all horn, but as they became scarce, African sources were also used. The Asian horn, often referred to as "fire horn" is regarded as superior to the African "water horn", and commands a considerably higher market price. Martin (1979, 1983) notes that there have also been many ornamental uses for rhino horn in the past, but that this appears to be limited to Yemen at present.

It seems likely that many uses for horn and other rhino products are no longer in evidence because of limited availability. Since all the available horn is probably directed to markets where the highest price can be obtained, it is difficult to determine any latent demand for horn and other products which could emerge in the event of wider availability at lower prices.

1.4 The problem of overexploitation

The ongoing decline in rhino numbers could ultimately lead to the extinction of one or more of the five species, a fact which has become of great concern to conservationists. Only one subspecies (the southern white) is represented by a population large enough to be considered as reasonably safe. This has motivated efforts to reduce or eliminate the exploitation of remaining populations.

Although various conservation agencies had previously attempted anti-poaching measures, the first major international initiative in this direction was the inclusion of all rhino products on the "Appendix A" list of the Convention on International Trade in Endangered Species (CITES) between 1975 and 1977 (Leader-Williams 1992). Subsequent work by Martin (1979, 1983) highlighting the significance and extent of the trade, led to the widespread perception that it had to be stopped.

As is indicated above, the CITES trade ban has not achieved the objective of preventing overexploitation. Supporters of the ban argue that there has been insufficient regulation of internal markets in individual consuming countries, and that additional resources are required for anti-poaching measures to protect remaining populations. If sufficient effort is made and the necessary resources are made available, these measures should succeed (Martin 1979, 1983; Martin and Martin 1991; Lyster 1992; Vigne and Martin 1993).

It is eighteen years since the first anti-trade measures were taken, and subsequently considerable resources have been spent pursuing this strategy (Laurie, 1992), but these do not appear to have been sufficient. Most conservation agencies in Africa are unable to fund the necessary policing and enforcement to protect their populations. As a result, other techniques have been attempted, which include :

1 the introduction of heavier penalties for illegal poaching and smuggling (in Zimbabwe and Kenya poachers are currently shot on sight);

2 the translocation of rhinos to safer areas, including intensively protected "sanctuaries";

3 the removal of horns of live wild rhinos ("dehorning");

4 the imposition of trade bans by countries who are not official signatories to CITES, and

5 the imposition of further internal trade restrictions in certain affected countries.

All these actions have received substantial support from media and fundraising campaigns. Recently certain pressure groups have used political tactics to encourage complete elimination of the trade. An example of this was the attempted campaign to declare trade sanctions against Taiwan unless it banned all local sales of rhino horn products (Katz-Miller 1993; Redmond 1993). Although Taiwan subsequently agreed to take action, it is not yet clear to what extent successful enforcement has taken place.

All recent attempted and suggested techniques have been motivated by the belief that the rhino horn trade is wrong, and therefore has to be stopped. This is to be achieved by eliminating the demand, mainly through restrictions on trade. Advocates of this approach generally either ignore the widespread medicinal use of horn and horn-based products, or acknowledge it, but nevertheless believe it is misguided or even morally wrong. This attitude toward the problem, which is the same as that which motivated the ivory ban in 1989, is referred to as the "conventional approach".

The crucial issue for conservation is whether overexploitation can be stopped in time to save rhinos from extinction. Under the conventional approach this means that the demand for more stocks of rhino horn must be reduced to a point where it is no longer worthwhile to continue illegal exploitation and trade. The economic implications of this approach are dealt with in Section 3.3 of this paper.

As economic analysis of the conventional approach suggests that it may not be possible to prevent the extinction of wild rhino populations this way. This has led to an alternative approach to the whole question of overexploitation. Elements of the alternative argument emanate from several sources, many of which have been discussed in a previous paper ('t Sas-Rolfes 1990).

In essence, the alternative approach questions the assumption that the rhino horn trade is the only cause of overexploitation, and argues that the problem is rather more complicated.

The alternative approach sees the overexploitation of biological resources as the result of underinvestment (Swanson 1992b), and argues that any solutions to the rhino problem must address the underlying economic forces driving this process. Thus the solutions are seen to involve institutional change, and finding ways to increase the economic value of live rhinos. A logical conclusion reached by this approach is that a legal, sustainable trade in rhino products would help to prevent overexploitation.

Many conservationists seem reluctant to accept this proposition, although recently it appears to have gained some support. Also, while some are in agreement with the theory, they present various arguments as to why legalisation is currently an impractical solution. For reasons which are discussed below, this paper subscribes to the alternative approach to overexploitation, but acknowledges that practical issues need to be considered in determining appropriate policy.

1.5 Objectives

This paper examines the current policies aimed at preventing the extinction of rhinos in the wild, in an economic framework. It considers whether the existing strategy of eliminating the trade in rhino horn using bans is appropriate. It also considers the possibility of adopting an alternative approach of phasing in a legal sustainable trade in rhino horn.

These two options will be evaluated by drawing on various elements within the discipline of environmental economics, by using bioeconomic models and applying some broader economic principles. Because of the inherently complicated nature of the problem, it is necessary to make a number of simplifying assumptions about the matters being considered, but these should not detract from the qualitative nature of the conclusions.

2. LITERATURE REVIEW

2.1 Trade literature

A substantial literature on the trade in rhino horn has developed over the last fifteen years, much of which is reviewed by Leader-Williams (1992). The review covers volumes and prices of horn exports and imports of most significant countries, mismatches between records, and data on retail prices. It also attempts to analyze the effect of CITES on the trade.

Unfortunately, much of the data on trade is disjointed and inconsistent, and is therefore not usable for accurate analysis of stock flows or supply and demand. Furthermore, there is very little recent data, and with the often rapid and substantial changes that have taken place over the last few years, much of that which exists has little relevance. A recent survey by Nowell, Chyi and Pei (1992) provides more accurate information on the market in Taiwan, but this information alone does not provide a sufficient base for a rigorous market analysis.

In a more recent paper, Milliken, Nowell and Thomsen (1993) assert that there are currently still markets for horn in China, Taiwan, Korea and Yemen. Attempts are being made at quantifying the annual volume of trade and retail demand, as well as prices, but these efforts are complicated by the fact that most trade has been pushed underground by the various efforts to prevent it. Little of the existing data is useful for any economic analysis.

Table 3 (on the following page) shows data collected on volumes of officially declared imports of rhino horn, measured in kilograms. There is no data for years which have been left blank. It is difficult to ascertain any clear trends from this data, and there are certain complicating issues. For example, it is not clear whether the data sets for Japan, South Korea and Taiwan relate only to African horn, or whether they also contain Asian horn imports. This problem also applies to the import price data in Table 4.

Leader-Williams (1992) questions the extent to which official statistics include the actual amount of imports that took place. For example, in the case of Yemen there were strong incentives to under-declare imports. Furthermore, it is worth noting that the import statistics generally exceed export statistics from African source countries by between five and ten times. However, it is likely that the importing countries have provided the more accurate figures.

The data on import volumes has been used to estimate annual consumption of rhino horn for three of the countries. China is believed to consume an average of between 600 and 700 kilograms per annum, South Korea between 372 and 794 kg p.a, and Taiwan between 186 and 397 kg p.a. Thus the annual consumption for these three countries alone is estimated at between 1,158 and 1,891 kg. This translates roughly to between about 400 and 650 black rhinos or between 290 and 470 white rhinos per annum using average horn weights suggested by Leader-Williams (1992).

TABLE 3 : Declared annual volumes (kg) of imports of rhino horn for five importing nations [from Leader-Williams (1992)].

Year	Importing Nation: China	Japan	S Korea	Taiwan	Yemen*
1970		893	3	211	131
1971		1,270	52	130	1,445
1972		648	248	941	2,139
1973		1,792	253	344	3,544
1974		684	214	1,600	0
1975		181	212	1,098	8,310
1976		823	277	681	6,843
1977		561	307	224	
1978		853	51	905	
1979		357	318	219	
1980		763	217	57	
1981			142	47	
1982	6,651		263	75	
1983	517		300	117	
1984	705			120	
1985	2,274			43	
1986	474				

* Estimated imports for Yemen differ considerably to declared imports. For the period 1970 - 1978, imports are estimated at 3,000 kg per annum; from 1979 - 1984 at 1,675 kg p.a; in 1985 at 1,000 kg p.a, and 1986 at 500 kg p.a (Leader-Williams 1992).

TABLE 4 : Declared import values of rhino horn for five countries quoted in US$/kg [from Leader-Williams (1992)].

Year	Importing Nation China	Japan	S Korea	Taiwan	Yemen
1970		41	30	39	
1971		56	91	50	
1972		50	34	24	
1973		60	37	51	
1974		70	38	37	
1975		84	58	32	
1976		75	49	40	
1977		116	172	17	
1978		308	284	82	
1979		341	355	184	
1980		383	326	477	764
1981			530	476	764
1982	412		516	136	786
1983	696		537	654	891
1984	525			142	796
1985	466			168	1,159
1986	591				1,032

Note : The figures for Japan, South Korea and Taiwan may include Asian horn. Blank spaces indicate an absence of data.

TABLE 5 : Selected retail prices (US$/kg) of African rhino horn ("water horn"), recorded during five different periods [from Leader-Williams (1992)].

Country	Period 1979/80	1982/83	1985/86	1987/88	1990/91
Hong Kong	11,103	15,700	14,282	20,751	16,240
China			18,722	16,304	
Taiwan (a)	1,596		1,532	4,660	4,221
(b)			2,007	3,347	3,737
Singapore	11,615	11,804	14,464	17,327	
Japan (a)	1,620		3,417		
(b)	2,230	2,516	3,771		
S. Korea	1,436	1,797	1,771	4,410	
Malaysia		17,280	11,636	23,810	
Macau	4,127	7,797	8,644	8,407	15,285

Table 4 shows clearly that import prices in Japan, South Korea and Taiwan increased significantly over the period 1975 - 1980, when the CITES ban started coming into effect. Table 5 also shows subsequent general increases in retail prices, although the data is not very consistent between different countries and over time. It is thus somewhat difficult to use this to determine a demand function for horn at the retail level.

The early literature dealing with the trade in rhino horn does not apply any economic analysis. The first substantial survey of the trade is by Martin (1979), who identifies a considerable range of uses for different body parts throughout most of Asia. The most prized part is the horn, used as a fever-reducing drug, followed by skin. The wholesale price of rhino horn is estimated to have increased by 2000% between 1975 and 1979.

In a later survey, Martin (1983) adds to the previous findings. He claims that the quantity of horn reaching the world market fell from an average of eight tonnes per annum between 1972 and 1978, to four tonnes annually from 1979 to 1982. He also argues that prices have kept pace with inflation between 1979 and 1982.

Both these surveys produce varied data concerning the prices and quantity of various imports and exports. Unfortunately the data is somewhat disjointed, the only notably consistent sets being official import statistics for Japan for the periods 1882 - 1903 and 1951 - 1980. Interestingly, the older data set reveals high levels of imports already toward the end of the previous century.

Martin (1979, 1983) concludes both his reports by arguing for the termination of the trade in rhino products. This argument is then pursued in numerous subsequent articles, many of which are referenced in Leader-Williams (1992). Most of these articles update the information on the trade, usually asserting that increased trade restrictions and enforcement measures are having a positive effect, but that more are needed. An article by

Martin and Martin (1987) argues that demand for horn is decreasing, since retail prices appear to be dropping, while the quantity of horn entering the market is also lower than before.

Leader-Williams (1992) cautions against accepting this claim. The report by Nowell, Chyi and Pei (1992), which is based on more reliable survey methods, suggests that Martin's estimates of the extent of the trade in Taiwan are too low, and Song and Milliken (1990) reach similar conclusions for South Korea.

The recent published work on the trade issue reflects an emerging difference in opinion as to appropriate policy on trade. Leader-Williams (1992) and Milliken, Nowell and Thomsen (1993) suggest that a controlled, legalised trade in rhino horn may present a pragmatic solution to the problem of overexploitation, but there is considerable resistance to this proposal (Laurie 1992; Lyster 1992; Vigne and Martin 1992).

2.2 The theory of extinction

The literature in resource economics provides models for the optimal management of renewable resources under various conditions and constraints. Within this literature there are various explanations for the extinction of biological resources.

Clark (1990) argues that under certain conditions extinction is economically optimal. He discusses these in detail referring to the case of the fishery, and asserts that rates of resource depletion are affected by the price-cost ratio, the rate of discount and the rate of growth of the resource. Conditions leading to possible extinction include a high price-cost ratio, high discount rate, low biological growth rate, and a growth function displaying critical depensation. These aspects are discussed in more detail in Section 3.2.

An implicit assumption in Clark's work is that overexploitation (overfishing) is the only cause of extinction, but as Pearce and Turner (1990) point out, species extinction may occur not only through direct overexploitation, but also as a result of the destruction or modification of habitat. Swanson (1992a) develops this argument further, asserting that extinction is a consequence of niche competition between species (including humans). Society may decide not to maintain specific biological assets - this would affect their stock levels via three routes, these being:

1 stock disinvestments,
2 base resource allocations, and
3 management service allocations.

Stock disinvestments refers to actual harvesting or direct elimination of species. This takes place when a species is not considered to be delivering a competitive return. Base resource allocations refer to the investment in land, water or natural habitat of a species. Where the a base resource is not providing a competitive return, it may be converted to another use, and this conversion may result in the indirect elimination of the species dependent on it.

Management services are required to maintain certain species, particularly those with high commercial value. Frequently wild species are treated as open access or public resources, but if they are perceived to provide a highly valued harvest, it is necessary to invest in institutions to protect them. The rhino is clearly an example of such a species. Chapter 3 deals with this issue in greater detail, including implications for policy.

2.3 Economic analysis of elephants and the ivory trade

Some detailed work has been done on the economics of elephant exploitation and the ivory trade. Much of the work is summarised in Barbier et al (1990). The work includes extensive data on trade flows - exports and imports, ivory prices and consumption figures. The data is used to determine geographical flow patterns and to estimate final demand. The analysis is then used to discuss policy implications.

The authors conclude that elephants provide a substantial source of income to African countries, but that much of this is not channelled into their protection. This results in the type of underinvestment in management resources referred to by Swanson (1992a). The reasons for this underinvestment are considered, and three possibilities are examined. The first is that extinction is optimal, the second is that local institutions are deficient in providing appropriate incentives, and the third is that international intervention is hampering the ability of range states to appropriate rents.

The first argument is not seen to be very compelling. A survey by Brown and Henry (1989) in Kenya suggests that elephants have considerable value in attracting tourists to that country, which indicates a substantial demand for live elephants. The other two arguments are seen as more significant. The authors recommend that local institutions are modified to allow for greater local rent appropriation, and that a carefully regulated international trading regime be established.

The economic work on elephants has been criticised, because it suggests that an ivory ban is inappropriate, yet conservationists claim that the ivory ban of 1989 has in fact been successful in lowering demand for ivory as well as prices. This conclusion should be regarded with caution, as it is likely that the global media campaign surrounding the ban was highly effective in reducing demand. Furthermore, it is possible that considerable stockpiles had developed prior to the ban, and these are now being released, further depressing the price.

It is inadvisable to draw an analogy between the regulation of the ivory trade and the trade in rhino horn, because the two differ in two important respects. First, ivory is a luxury good, consumed mainly by people with Western values and ready access to the media. Rhino horn is used as a primary pharmaceutical remedy for serious illness, and has a well established tradition of use by Chinese peoples throughout Asia, many of whom do not have ready access to the media, and who do not possess Western cultural values. It is therefore most likely that the demand functions for the two products are quite different, with the demand for rhino horn being far more persistent and less price elastic than the demand for ivory.

The second important difference between ivory and rhino horn is that it is necessary to kill an elephant to obtain ivory, whereas rhino horn can be harvested renewably without harming the animal. This fact is extremely important, because it suggests that rhinos could be farmed for their horn, without significant adverse effects to the total population. It also suggests that rhino horn has a potentially much faster growth rate than ivory, and rhinos should therefore be a less likely candidate for stock disinvestment.

2.4 The privatisation proposal

Fiske (1988) argues that unless rhinos are farmed, they are likely to become extinct outside zoos over the next few decades. This argument is explored in detail in a paper examining possible roles for the private sector in rhino conservation ('t Sas-Rolfes 1990). Rhinos are found to be regarded as open access property under the law, providing a strong disincentive for individuals to regard them as a long term investment. Furthermore, the state is found to have sold live animals at heavily subsidised prices, well below their market trophy price, which is thought to have created a perverse incentive resulting in excessive harvesting.

The paper concludes that existing policy measures are failing to achieve the goal of conservation, and need to be modified. The recognition and enforcement of private property rights, and the legalisation of markets in horn and other products are seen as possible solutions to provide appropriate incentives leading to increased conservation effort.

2.5 Illegal exploitation

In recent years, some work has been done on the economics of illegal exploitation and law enforcement. Leader-Williams and Albon (1988) show that the rates of decline of black rhinos and elephants in certain areas are related directly to conservation effort and spending. They suggest that certain expenditure per square kilometre per year is necessary to achieve a zero decline of rhinos and elephants. Using regression, they propose a figure of US$ 230/km^2/year based on data collected for 1980. This translates to an expenditure of $ 575 per rhino per year.

A later paper by Leader-Williams, Albon and Perry (1990) examines poaching of black rhinos and elephants in the Luangwa Valley in Zambia, and provides much data concerning the relationship between poaching, law enforcement and effects on the populations of these two species. The paper concludes that a solution to the poaching problem must address the issues of world trade regimes, incentives faced by local people, appropriate disincentives to poaching and conservation funding.

In a more recent paper, Milner-Gulland and Leader-Williams (1992) attempt to model economic incentives for illegal exploitation. They conclude that a penalty which varies with the output of a poacher is likely to be more effective as a deterrent, and they argue that different strategies are needed to deal with two different types of poachers. Local poachers may respond to local investment schemes, but organized gangs can only be deterred by improved law enforcement operations.

In another paper, Milner-Gulland, Beddington and Leader-Williams (1992) consider whether dehorning acts as a suitable deterrent to poachers. Using a model of optimal harvest frequency, they conclude that a profit-maximising manager will not dehorn rhinos frequently enough to deter a poaching. Milliken, Nowell and Thomsen (1993) also record that 14 dehorned rhinos have been poached between 1992 and early 1993.

The literature on illegal exploitation provides some interesting insights into the nature of the rhino conservation issue. In particular it highlights institutional deficiencies which amount to the underinvestment in management service allocations alluded to by Swanson (1992a).

3. A THEORY OF RHINO MANAGEMENT

3.1 The management objective

Establishing a clear objective for rhino management is not as simple as it may seem. The perspective of conservationists differs considerably to that of economists, and stated rhino conservation objectives are thus somewhat difficult to interpret economically. Furthermore, conservation objectives tend to be rather complex and multi-faceted, and this makes it difficult to apply the rigorous techniques used in microeconomic analysis.

Although the apparent objective addressed by this paper is to "save the rhino from extinction in the wild", there are a number of issues which require clarification. First, although it is obvious that complete extinction is undesirable, there is no indication as to what a desirable population size would be. Second, a closer examination of conservation objectives reveals that the issue is not simply one of protecting one or more species, but that intraspecific variation is also an important factor. Third, the phrase "in the wild" has no clear meaning, which raises further complicating issues.

Brooks (1988) indicates that the conservation objective is to maintain a "genetically viable" population of rhinos in their "natural habitat". He points out that there is some disagreement over the classification of black rhino subspecies, but that for current management purposes, the objective is to maintain completely separate populations of the four different ecotypes.

The issue of genetic viability is discussed by Cumming, Du Toit and Stuart (1990). Since interbreeding and loss of genetic diversity increase risks of extinction, an attempt is made to determine biologically important population sizes. The concept of a "minimum effective population size" N_e is used, where this should be at least 500 individuals for "long term evolutionary potential", and 50 for "short term fitness". Brooks (1988) asserts that the number 50 represents a critical threshold, below which genetic diversity loss exceeds 1% per annum, but recommends that captive populations should be based on a minimum of 20 individuals.

These criteria appear to apply to individual populations in specific areas. The total population size considered to be genetically viable for a subspecies or ecotype is 2,000 individuals, which Cumming, Du Toit and Stuart (1990) consider to be a "minimum viable population" (MVP). This concept is discussed by Clark (1990), who indicates that a drop in numbers below a certain level K_0 results in critical depensation, leading to certain extinction of the species. However, it is not clear that 2,000 individuals represents a level beyond which critical depensation will occur with certainty.

All varieties of rhino, except the southern white, are currently represented by total populations of less than 2,000 individuals. The population size of northern white rhinos was thought to be

22 in 1990, the same level the southern population is supposed to have dropped to in the 1920's ('t Sas-Rolfes, 1990). The latter population has recovered to reach a global level of over 6,000 individuals (after a substantial input of conservation management effort by the Natal Parks Board), suggesting that critical minimum sizes may not be as high as those put forward by conservationists. Nevertheless, the longer term implications of drastic drops in numbers are less certain, and it is clear that conservationists prefer to err on the side of conservatism.

Establishing a precise minimum level K_0 for rhinos is probably inappropriate, since aspects such as spatial distribution, population age profiles and male-female ratios also have to be taken into account. The literature on rhino conservation strategies is unclear as to what extent these factors need to be included in determining MVP sizes. Assuming that these factors could be included, the question of a relevant time frame still remains. A small population of rhinos may be perfectly capable of surviving in the short term, but interbreeding could eventually result in extinction in the longer term. It is thus necessary to add this time dimension in setting objectives.

If the population level of 2,000 can be considered as safe in the long term, it could be argued that this is the appropriate level to maintain, and that any excess numbers of a particular variety could be ignored, or at least should not incur any additional expenditure of resources. Conservationists are unlikely to agree with this point of view. An examination of the conservation strategy for African elephants (Cumming, Du Toit and Stuart, 1990) reveals an objective to maintain "baseline" populations in each country where they occur, using a scoring system to determine "biological importance".

It is interesting to note that the total suggested baseline elephant population for southern Africa alone is 95,500, close to the current level. This implies that conservationists attempt to secure populations at whatever levels they can. It is likely therefore, that many conservationists would like to see rhino populations at much higher levels than the 2,000 indicated in conservation strategies. A maximum limit on total population size would seem to be dictated by land availability and budgetary constraints, as argued by Swanson (1992a).

The conservationists' objective of maintaining populations in their "natural habitat" presents some difficulty, since there appears to be no absolute definition of this concept. It seems obvious that populations occurring indigenously in wilderness areas where they are never subjected to any sort of human contact or interference, can be regarded as truly "wild". Unfortunately, such instances are extremely rare if not nonexistent, since all conservation areas tend to be subjected to some degree of human interference or management.

It would seem logical that for habitat to be natural, human interference should be kept to a minimum. Despite this, Brooks (1988) suggests that captive breeding programmes should be supported, and considers "habitat manipulation" as part of a conservation strategy. The extent of the threat to rhinos recently has been so great that several populations in Africa have been subjected to management practices which entail high levels of interference, such as dehorning, translocation to smaller sanctuaries and close monitoring by armed guards.

As rhinos become increasingly threatened, increasing levels of human intervention are required to protect them. It is not clear when these levels become sufficiently high as to detract from the "natural" or "wild" status of rhino populations. Presumably a combination of factors such as proximity or exposure to humans (habituation), and the size of the relevant land area or enclosure would count toward an assessment of this goal, but there is no single objective criterion. In the absence of any definitive guideline to the concept of "wild" rhinos in a "natural habitat", it must be assumed that the objective of conservationists is to conserve a minimum viable population which is as "wild" as possible under the circumstances.

The conservationist objective for rhino management is difficult to interpret economically. An objective function (population size) is to be maximised, subject to certain ecological constraints (e.g. habitat types, genetic variability) which do not appear to be readily and unambiguously determinable. While economic factors such as allocation of base resources and management services are not expressly mentioned, they represent additional implicit constraints.

To what extent does the conservationist objective represent the view of society as a whole? First it is necessary to define "society". This paper ignores issues of national sovereignty, and treats rhino conservation as a global objective. Thus "society" is taken to represent all global citizens, including future generations. The standard economic objective is to maximise social welfare W over time t. Conserving rhinos clearly has an opportunity cost, so the social welfare derived from rhino conservation $W[A(t)]$ needs to be weighed up against the welfare derived from all other social needs and wants $W[B(t)]$. The objective is to maximise total welfare $W(t)$ where

$$W(t) = W[A(t),B(t)]$$

It is certainly not desirable to fill the world with rhinos, so there must be diminishing marginal returns to rhino conservation, and a trade-off with other goods and services. This implies that there must be an economically optimal level of $W(t)$, where the marginal $W[A(t)]$ equals the marginal $W[B(t)]$[1], determined by the production possibilities frontier and the social indifference curve. Thus, even at maximum efficiency, there is an economic constraint on the level of rhino conservation that society wants.

$W[A(t)]$ can also be interpreted as the social value or "total economic value" (TEV) of rhinos. This value is likely to bear a positive functional relationship to the live population size, $X(t)$. Intuitively, a higher TEV for rhinos implies a larger live

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[1] i.e. $W'[A(t)] = - W'[B(t)]$

population, *ceteris paribus*, so that if TEV is maximised, an optimal level of $X(t)$ should also be reached. This will not be the case, however, when the TEV of dead rhinos is consistently higher than that of live rhinos.

This paper assumes that rhinos have certain values not related to any direct consumptive use. These values represent society's willingness to pay for viewing rhinos as tourists as well as via certain media, in addition to option, bequest and other potential "existence" values. There is clear evidence that such values do exist, reflected by tourist visits to wildlife reserves, consumer purchases of media products, and memberships of various non-profit conservation organisations, some of which are devoted exclusively to rhinos. (This paper does not consider "intrinsic" and other completely non-use related existence values which have ambiguous economic meanings.)

The fact that positive non-consumptive use values exist, implies that society is willing to forego other goods and services for rhino conservation. The maximum amount that society is willing to pay for rhino conservation is the opportunity cost to be incurred out of $W[B(t)]$, and can be interpreted as a conservation budget constraint $\beta(t)$. This budget constraint limits the level of investment in base resources and rhino management services, thereby acting as an implicit constraint on total population size. Thus the values of $\beta(t)$ and the relevant social discount rate δ will influence the allocation of resources between rhinos and all other goods and services over time.

An economic objective for rhino conservation would be to maximise the total economic value of rhinos over time, relative to all other goods and services. This differs considerably to the conservationist objective of maximising live population size. How can these two objectives be reconciled? This paper argues that the failure of conservationists to recognize the economic objective is a principal source of the problem under discussion, but it is nonetheless important to include conservationists' concerns in the economic objective.

These concerns can be accommodated in several ways (some possible techniques are discussed in Section 4.1), but for the purposes of the analysis about to follow, some simplifying assumptions are made. First, the issue of different species and ecotypes is ignored - the model assumes a single species of rhino. Second, in the absence of a clear indication of a critical minimum size, a single level K_0 is assumed to exist, below which critical depensation occurs within a relevant time period.

Finally, the issue of "natural habitat" is ignored. Since conservationists are likely to treat this objective as secondary to that of maintaining a MVP, it is assumed that the only objective is to conserve population size. The effects of relaxing these assumptions are discussed in Section 4.1.

3.2 A simple rhino management model

This section discusses a simple bioeconomic rhino management model, based on the conventional approach used by Clark (1990). For this model, it is assumed that harvesting is acceptable, and takes place. The objective is to maximise the social value (TEV) of rhinos $W[A(t)]$, which will depend on both the harvest $y(t)$ and the live population of rhinos $X(t)$. Thus

$$W[A(t)] = W[y(t), X(t)]$$

The benefits from the harvest are derived from rhino products, and also possibly from the utility derived from the actual process of harvesting, as in the case of sport hunting. The benefits from the live population may derive from its ability to produce a harvest, as well as from direct and indirect non-consumptive use values ("preservation value"). Maximising TEV should have the effect of balancing the various demands for consumptive and non-consumptive uses, provided the correct social values are used (if all externalities are taken into account).

To determine the appropriate levels of $y(t)$ and $X(t)$ which maximise TEV, it is necessary to solve for their time paths in a dynamic optimisation problem,

$$max \quad \int_0^T \; W[y(t), X(t)] \; e^{-\delta t} \, dt$$

which assumes that discounting at a (social) rate $\delta > 0$ is appropriate (Conrad and Clark 1987). The nature of the social value function $W(\cdot)$ depends on various factors. For this model, some simplifying assumptions are made.

First, an infinite time horizon $T = \infty$, is assumed. Second, the total value per harvested rhino p is assumed to be constant, as is the cost of a unit of effort c. Lost preservation value is assumed to be included in the cost of harvesting, at a similarly constant rate per unit. A simple production function of the standard form is used, such that

$$y(t) = qE(t)X(t) \qquad [1]$$

where $E(t)$ represents harvesting effort, and q is a constant. The rate of biological growth is represented by the function $G(X)$, which acts as a constraint in the problem. Based on these assumptions the objective takes the form

$$\max_{y(t)} \int_0^\infty [p - c(X)]\, y(t)\, e^{-\delta t}\, dt \qquad [2]$$

$$\text{s.t. } \dot{X}(t) = G(X) - y(t)$$

$$X(t) \geq 0$$

$$y(t) \geq 0$$

This problem can be solved using the Euler equation (Clark 1990) to obtain the expression for optimal stock size X^*

$$G'(X) - [c'(X)G(X)]/[p - c(X)] = \delta \qquad [3]$$

Equation [3] provides a number of important insights as to the effects of changing various parameters in the problem. First, it is obvious that X^* is a function of the discount rate δ as well as the economic and biological parameters. The relationship between the marginal rate of population growth $G'(X)$ and δ will determine X^*, although this is affected by the value of the marginal stock.

The numerator of the second term represents the marginal stock effect; that is, the increase in harvesting costs due to stock reductions. The denominator represents the marginal value of the population. The value of X^* must lie somewhere between the points where rent is maximised (X_0: $\delta = 0$) and where rent is completely dissipated (X_∞: $\delta \rightarrow +\infty$). It is clear that extinction will occur if $X^* < K_0$.

Equation [3] was derived assuming that costs, prices and the discount rate remain constant over time. If this assumption is relaxed, the value of X^* may change. For example, prices may change independently of $G(X)$. The equation becomes

$$G'(X) - [c'(X)G(X)]/[p - c(X)] = \delta - \{\dot{p}(t)/[p(t) - c(X)]\} \qquad [4]$$

where the last term represents the relative growth of the marginal value of X (Barbier et al 1990). From this equation it is clear that changing prices may affect the value of X^*. The same is true for changing costs and discount rates.

With reference to equation [3], Clark (1990) discusses conditions under which extinction would be economically optimal. He argues that the nature of the production function (equation [1]), taken with the assumption that harvesting cost is proportional to effort, implies that $X^* > 0$, even when rents are completely dissipated. Extinction is only possible here, when $X^* < K_0$.

There are two senses in which this conclusion may not be correct. First, as Clark (1990) acknowledges, the cost of harvesting the last individual may not be infinitely large, and it is possible that the value of harvesting the last unit may exceed the cost. Second, as Swanson (1992a) points out, the Clark model ignores the additional opportunity costs of base resource and management inputs. These effectively reduce the price-cost margin, implying a lower value for X^*. Thus it may be feasible for the economic optimum to be at $X^* = 0$.

Equation [3] implies that extinction may occur when $p > c(K_0)$, if the discount rate is high. For example, if $c(X) = c$ for all X, then the marginal stock effect reduces to zero, and the equation becomes

$$G'(X^*) = \delta$$

which may have no solution for large values of δ. Equation [4] implies that increases in the marginal value of X reduce the effective value of δ, thereby decreasing the possibility of extinction. Equations [3] and [4] demonstrate the importance of rents, since X^* is likely to be highest when rents are maximised and lowest when they are dissipated. This has implications for appropriate property right regimes, since rent dissipation is caused by open access conditions.

If applied to the case of rhino management, the above model has various implications. First, there is an economically optimal population level of rhinos, X^*, which cannot be exceeded without reducing total social welfare. Then, given the conservationist's objective of maximising the level of X, the following issues are of significance :

a) Higher discount rates favour higher rates of harvesting, so the lowest possible discount rate will be preferred. Using social rates of discount, rather than private rates, would appear to be beneficial to conservation. If discount rates exceed the biological growth rate, there is a high risk of extinction.

b) Property right regimes are important in influencing the rate of harvesting. Open access conditions lead to high individual discount rates which lead to rent dissipation, which in turn could result in extinction. Higher rents encourage conservation, so secure private property rights would seem to be a desirable objective.

c) Higher prices and lower costs of harvesting favour more rapid exploitation, so from the conservationist's point of view it seems desirable to increase harvesting costs, and reduce the benefits of harvesting. The existence of preservation value can be interpreted as an opportunity cost of harvesting, and it is therefore also desirable to appropriate the highest preservation value possible.

This model does not appear to offer a good explanation of the current situation with respect to rhino management. The issues relating to discount rates and property rights are complicated by the fact that there is a conflict between conservationists and illegal exploiters, and attempts to reduce the net benefits of harvesting do not appear to be having the desired affect of reducing the rate of exploitation.

There are two reasons why the Clark model may not provide a realistic representation of the current issues facing rhino conservationists. The first is discussed by Swanson (1992a) who argues that the objective of increasing harvesting costs and reducing harvesting benefits is inappropriate. This model leads to the wrong conclusion because it is based on a fishery, where there is no opportunity cost associated with the base resource, and management input is negligible. This is not the case for terrestrial species, especially large herbivores, which require base resources (land or "natural habitat") and active management input to survive.

Since base resources and management services have an opportunity cost, equation [2] misrepresents the current situation and needs to be modified to account for this. Swanson (1992a) proposes the following revised social objective function[2]:

$$\max_{y,R,M} \int_0^\infty [S(y;R,M) - c(X)y - \delta\rho_R R - \delta\rho_M M]\, e^{-\delta t}\, dt \qquad [5]$$

$$s.t.\ \dot{X} = G(X) - y$$

where R represents the base resource, ρ_R is the price per unit of R, M represents management resources, and ρ_M is the price per unit of M. S is the flow of social benefits from y, given the quality of the other inputs.

The inclusion of the two additional control variables adds a complicating factor to the management model, although their interpretation is quite straightforward. The model requires the addition of two further first order conditions, equating the rates of return from these resources with those offered by alternative investments. Thus the decision to invest in base resources and management institutions depends on whether these will yield a competitive return.

As before, it is clear that lower discount rates and higher rents will favour higher levels of R^* and M^*, but it is also intuitive that poor returns to harvesting may inhibit investment in both these, implying lower levels. Thus by adding this dimension, it is clear that a reduction in net benefits from harvesting may

[2] To avoid cluttered equations, the notation $\cdot(t)$ is not used for the remainder of this paper. Where time-functional relationships are not immediately obvious, these are explicitly referred to.

have an indirect perverse effect on the level of X^*. This would seem to offer a more plausible explanation for the extinction of terrestrial species with low commercial value.

The second reason why the conventional model does not provide a realistic analysis of the rhino issue, relates to the assumption that there is a single decision-making party, acting on behalf of "society" in a socially optimal way. In the case of rhino management, the existing situation is quite different. There is no single decision-maker, but rather two broad groups acting in conflicting ways. One is attempting to appropriate preservation value only, and the other is only concerned with harvesting. This situation leads to some unique problems, which cannot be dealt with by the single-party models used above. To gain a better understanding of the forces at work, a two-party model would seem more appropriate.

In the analysis that follows, an attempt is made to develop a framework to describe the existing situation more accurately. Further assumptions need to be made at this point. First, the situation described will utilize information mainly concerning the exploitation of black rhino populations in Southern Africa. For this reason, some of the specific assertions may not apply in all cases of rhino management. For example, the analysis will ignore the issue of base resources R, since there is no shortage of conservation land for African rhino species, although this may not be the case for Asian rhinos. Despite this, the overall conclusions from this section should still hold for all rhinos.

The second assumption to be made concerns the relationship between the parties involved. Milliken, Nowell and Thomsen (1993) have identified an extremely complex network of parties involved in the exploitation process. However, for the purposes of this analysis, an abstraction is made, and only three parties are assumed to exist.

The legitimate owners or guardians of existing rhino populations are referred to as "custodians". Illegal players involved in the process of poaching, smuggling, trading and speculating in horn investment are collectively referred to as "exploiters". These two parties are assumed to have the conflicting objectives of conservation and illegal exploitation. The demand for rhino horn is determined by "consumers", being pharmaceutical producers, retail pharmacies and the end consumers of rhino horn products. For the purposes of the analysis about to follow, this demand is treated as an exogenous constant.

3.3 A two-party model

In this model, it is assumed that the custodian's objective is to maximise the social value of rhinos $W(A)$, and that the exploiter's objective is to maximise private profits Π. To explain the economic nature of the interaction between the two parties, each is first examined separately.

The custodian has a choice of two approaches to harvesting; if harvesting is accepted as a legitimate conservation practice, the custodian's objective function essentially remains the same as in equation [5][3]. There is, however, one fundamental difference relating to the harvesting of horn. Although it is theoretically possible for an illegal exploiter to extract horn without killing the rhino (by tranquillising it), in practice there is no incentive to do this[4]. On the other hand, it is perfectly possible for the custodian to cut off the rhino's horns once they have reached a certain size, and repeat this process a number of times, since the horn grows back again.

This process of renewable harvesting, which can be likened to the shearing of sheep for wool, implies that the growth rate of the resource (horn) is actually higher than the actual growth rate of the rhino population. It is thus possible to model the optimal harvest cycle for horn, independently of harvesting the actual rhino. To do this, a model similar to the Faustmann forest model could be used. Intuitively, the custodian who extracts a renewable harvest of horn will delay the process of harvesting the rhino itself, if the rate of horn growth exceeds the growth of the actual rhino population. The overall effect of being able to renewably harvest rhino horn, is to raise the rent value of the population to the custodian.

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[3] It may be appropriate to modify this equation by including preservation value as a separate term $V(X)$ (Clark 1990) such that

$$W(A) = S(y;R,M) - c(X)y - \delta\rho_R R - \delta\rho_M M + V(X)$$

[4] Tranquillisation is far more costly than shooting, and it is not possible to extract all the horn from a rhino without killing it - about one third of a full grown horn is embedded in the skull.

If the custodian decides not to harvest, but only to appropriate preservation value, as is presently the case, the nature of the objective function changes[5]. For this case, it is assumed that the supply of base resources (conservation land) way exceeds the requirements of the existing population (this is currently the case with the surviving African population, which only occupies a fraction of the available suitable habitat). Accordingly, the variables *R* and *y* do not apply to the custodian's objective function, which becomes

$$\max_{X,M} \int_0^\infty \{S[V(X);M] - \delta\rho M\}\, e^{-\delta t}\, dt \qquad [6]$$

$$s.t.\ \dot{X} = G(X)$$

where *S* now represents the social benefits flowing from the preservation value of rhinos *V(X)*, given the quality of resource management generated by the level of investment in management *M*. The optimal investment in management institutions is given by

$$M^*:\ S_M/\rho = \delta$$

as proposed by Swanson (1992a). It is clear that there is an opportunity cost of management even when the conservationist's only goal is to maximise preservation value.

Equation [6] implies that the only effective constraint on

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[5] Strictly speaking, this strategy does not satisfy the objective of maximising social welfare *W(A)*, because denying a supply of rhino horn to members of society who demand it is not Pareto efficient.

population size X is the rate of population growth $G(X)$ over time, if there is no exploitation[6]. The constraint on investment in management does not necessarily affect X directly, but it does matter because it has an effect on the level of illegal poaching that is taking place, an aspect which is missing from this model. This can be taken into account by considering the exploiter's objective function, which may take the form

$$\max_{y} \int_0^T (p - c)\, y - \Theta F\, e^{-rt}\, dt \qquad [7]$$

$$s.t.\ \dot{X} = G(X) - y$$

where p represents the average price of the horn from a single rhino, c is the cost of obtaining the horn, and y is the number of rhinos harvested. The new term ΘF represents an additional cost to the illegal exploiter, being the potential cost of arrest and conviction. The punishment or fine is indicated by F, and Θ represents the probability of being caught and punished. Note that because the exploiter's decisions are not based on social considerations, a private time frame ($T \neq \infty$) and a private rate of discount r, are used.

The illegal exploiter's function differs in several ways to that of a legal harvester, and there are certain implications arising from equation [7]. These can be related to aspects concerning equations [3] and [4] discussed in the previous section :

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[6] In the absence of any exploitation, population growth would continue until some point where the inevitable effect of the constraint on base resources R would start to play a role.

a) The private rate of discount used by the illegal exploiter is likely to be much higher than the social discount rate, which implies that the rate of harvest will be higher than the socially optimal rate. The illegal exploiter adopts a shorter time frame, and it is far more likely that the discount rate will exceed the biological growth rate.

b) Illegal exploiters compete with one another in the process of harvesting. Since they have no legitimate property rights over the rhinos, they operate in an effective open access situation. Since all rents are dissipated, they have no incentive to delay the decision to exploit.

c) Given that illegal exploiters face high private rates of discount and have an incentive to act sooner rather than later, the chief influence on their level of activity is the price-cost ratio. Four factors may affect this : the price of horn, the costs of exploitation, the probability of getting convicted and the cost of the penalty. The lower the price, and the higher the latter three factors, the less incentive there will be for illegal exploitation.

An additional point worth noting is the effect of changing prices in rhino horn, as indicated by equation [4] above. Where prices are increasing at a rate higher than the rate of discount, there is an incentive to stockpile horn as an investment. Thus rapidly rising prices may create additional illegal speculative demand.

A question of considerable interest to conservationists concerns the relationship between the objective functions of the custodian and the illegal exploiter. The interaction of these functions will determine the live population level X^*. To demonstrate how this interaction may occur, a simple static analysis is used[7]. X^* is the population level of rhinos at which the marginal net benefits of conservation W_c equal the marginal net benefits of illegal exploitation W_e.

To illustrate this, it is necessary to modify the previous analysis slightly. Equation [6] can be considered in a static context, by utilising the concept of the conservation budget constraint β discussed above in Section 3.1. Assuming that the entire amount is applied to management services, it is possible to determine a marginal net preservation value per rhino $\mu(X)$. If all rhinos are considered to be of equal value, this value would simply be

$$\mu(X) = \beta/X$$

This equation is likely to hold true for the minimum viable population of rhinos - since the loss of any one rhino leads to extinction, all should be considered equally valuable. Beyond the level K_0, however, there are likely to be diminishing marginal net benefits, and the value of μ will decline to a point K_{MAX} where additional rhinos start to have a negative value (this

[7] For this analysis let $W'(A) \equiv W_c$, the custodian's marginal net benefit function, and $\Pi' \equiv W_e$, the exploiter's marginal net benefit function. Both are indirect functions of X.

could be thought of as a "maximum economic population"). This relationship determines a demand curve for live rhinos as shown in Figure 1. The demand equation is simply

$$W_c = \mu(X) \qquad [8]$$

When viewed in the static context, the illegal exploiter's function (equation [7]) can be modified to derive a demand for "dead rhinos". The equation becomes

$$W_e = p - c'(X) - \Theta'(X)\ F \qquad [9]$$

Intuitively, W_e should be a decreasing function of X if the both the total population level and price are fixed. This is because both the cost of exploitation $c(X)$ and the probability of getting fined $\Theta(X)$ are likely to increase as the rhino numbers diminish and more time and effort is required to harvest them.

Now if the population at a particular time is fixed at a level $\bar{X}$ (assume that $\bar{X} < K_{MAX}$), it is likely that some rhinos would be allocated to preservation, and some would be harvested illegally. Figure 2 shows that the probable outcome would be that X^* rhinos would be conserved, determined by the point of intersection between the two demand curves[8].

It is possible that the two curves may not intersect, or may

[8] Note that Fig 2 is a simplistic representation of the demand functions, and assumes smooth linear relationships.

intersect at a point below the level K_0, in which case extinction would result. Examples of such situations are illustrated in Figure 3. This could happen if the value placed on horn is consistently higher than the preservation value of rhinos[9]. It is also possible that increases in the costs of exploitation may be offset by even greater increases in the price of horn, which would lead to an upward sloping curve. This could be the case if illegal investors thought that the rhino was definitely about to become extinct, and speculation caused the price of horn to rise exponentially, in the same way as an exhaustible resource being mined to depletion as described by Solow (1974).

What would happen if the custodian also engaged in harvesting? It is most likely that there are positive rents to be gained. If the added marginal rent per rhino $\lambda(X)$ is assumed to be constant, equation [8] becomes

$$W_c = \mu(X) + \lambda(X)$$

which implies that the demand curve would move to the right as indicated in Figure 4. If the additional rents are re-invested in rhino management services, this would also raise the total costs of illegal exploitation, and the illegal exploiter's demand curve would move to the left (to the right in Figure 4). The new level of rhinos would be X^{**}, which is greater than X^{*}.

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[9] The reverse could also happen - the preservation value of all rhinos could be consistently higher than the value of their horns. Since this is not the case at present, this possibility is ignored.

This static analysis using the two-party model leads to a fairly straightforward conclusion : the size of the live population of rhinos is likely to be greater if legal harvesting is permitted, than if only illegal harvesting takes place, provided certain assumptions are satisfied. Furthermore, it is clear that the legal harvesting option is Pareto efficient whereas declaring harvesting illegal is not.

Theoretically, banning the legal harvesting of rhino horn does not appear to be beneficial either in economic or conservation terms. It is thus surprising that this policy is being pursued with such vigour. There is a possibility, however, that the assumptions made in this model are incorrect, and materially affect the probable outcome. To ascertain whether this may be the case, it is necessary to consider the likely effects of relaxing the assumptions as well as some other empirical issues that have been raised.

4. EMPIRICAL ISSUES

4.1 Assumptions reconsidered

In the previous chapter, numerous assumptions were made to develop the rhino management model. It is important to consider whether empirical matters may affect the conclusions reached by this model. Three main categories of assumptions were made, concerning 1) the management objective, 2) the economic nature of the problem, and 3) specific issues relating to the rhino management issue.

Three simplifying assumptions were made concerning the management objective. First, the model assumed a single species of rhino and ignored the issue of different species and subspecific groups. Second, a single and determinable minimum viable population size was assumed to exist, and third, the issue of appropriate habitat was ignored. How might these issues affect the results obtained in the previous chapter?

It is argued that while certain policies may be appropriate for the African rhino species, they may not apply for the Asian species. This issue is considered in more detail in Chapter 5, but in general the principles should apply equally to all species and subspecies. It may be the case, however, that society does not value all individual varieties of rhino as much as rhinos *per se*. Thus, the four ecotypes of black rhino may be relatively unimportant as compared to the black rhino as a single species.

Since different varieties do comprise diversity in genetic resources, and diversity is known to be of economic value to society, it should be theoretically possible to measure this diversity and therefore its value. Some preliminary work in this area has been done by Weitzman (1992) and Solow, Polasky and Broachus (1993). This approach could also be used to deal with the second problem of minimum viable size. If it is possible to establish criteria relating population size to the risk of extinction, then it should be possible to determine "diversity safety values" for population size.

A similar approach could be adopted for the issue of natural habitat. If pristine wilderness is the most highly valued type of habitat, with diminishing values as human intervention and habituation increase, then it should be possible to place an economic value on the relevant habitat - a shadow price for habitat quality.

If the above factors could be valued and incorporated into the objective function, this would probably not have a significant effect on the demand for live rhinos. This is because there are diminishing marginal returns to all three factors, just as there are diminishing returns to the value of population size alone. Thus it is worthwhile to preserve diversity and natural habitat up to a point, but as the number of rhinos increases, these objectives become less economically important. The overall conclusions of the model are thus unlikely to be affected materially by these assumptions.

The second set of assumptions made concern the economic nature of the problem. Since the issue of rhino conservation concerns the allocation of scarce resources, it is clearly an economic problem, and for this reason is examined in a neoclassical economic framework. All the usual assumptions that apply to such a framework are implicit in the analysis used here - for example, a general equilibrium framework is assumed, based on the standard assumptions of microeconomic theory. It is beyond the scope of this paper to defend these assumptions.

The third set of assumptions relate specifically to the issue of rhino management. In the analysis, simple production functions and constant parameters are used. While non-constant parameters will lead to different results, the overall nature of the results should remain the same. This would only be properly established by thorough empirical analysis. The assumptions relating to the relationship between various parties are a simplification of the issue, based on the example of black rhino exploitation. It is necessary to analyze these empirical issues in more detail.

4.2 Empirical evidence

As indicated in Chapter 2, empirical data on the rhino horn trade and illegal exploitation does exist, but is disjointed and therefore impossible to use in any rigorous analysis. For this reason, the following discussion considers more general empirical aspects of the rhino management issue.

Although inadequate and possibly inaccurate, the data contained in Tables 3, 4 and 5 does suggest that the CITES ban has not had the desired impact of eliminating the trade in rhino horn. In addition, there is a definite general increase in both import and retail prices over the periods observed, with substantial increases in certain cases. Unfortunately, the ban has led to the termination of official record keeping, making recent trade monitoring very difficult.

The high variation in prices complicates any analysis of demand and objective functions. Clearly the earlier assumption that prices are constant does not hold, but it is also not clear that prices are rising constantly in real terms. The data suggests that prices fluctuate, possibly in response to changes in supply (demand is thought to be reasonably consistent) influenced by conditions in supplying, entrepôt and receiving countries. As Leader-Williams (1992) shows, additional regulations were being imposed in various countries throughout the period examined.

Perhaps the most useful approach to an empirical analysis is to consider the assumption of three parties acting in specific ways as modelled in the previous chapter. As Milliken, Nowell and Thomsen (1993) have indicated, there are in fact numerous different parties all facing different incentives. In broad terms, however, several observations can be made.

Custodians of rhinos include government conservation agencies and private landowners. It has been shown that these parties may face different incentives ('t Sas-Rolfes 1990), and this is not clear from the management model presented. For example Laurie (1992) notes that there are numerous incidents where government officials are involved in illegal exploitation, including several cases where employees of conservation agencies themselves are responsible for poaching. In practice it is necessary to examine closely the individual incentives faced by all those involved under the category of rhino custodians.

If harvesting were legalised, would custodians have an incentive to harvest horn without killing the actual rhino? This depends on several factors: the profitability of harvesting, the ability to appropriate rents, and the discount rate. The discount rate used in developing countries tends to be higher than that applied in developed countries - a figure of 10 % is often recommended. This may have an adverse affect on rhino investment. Populations of black rhinos are known to grow at rates of between 8 and 9 % per annum (Brooks 1988) and those of white rhinos at up to 10 % per annum (Laurie 1992).

If renewable harvesting takes place, the returns on horn are accelerated. Research is being conducted on the rate of horn regrowth of dehorned rhinos (Dobb 1993), and an initial rate of 9 % growth per annum has been suggested. This translates to a compounded horn growth of 18.81 % per annum in a population growing at 9 % p.a, which appears to be an attractive real rate of return. Clearly the ability to appropriate and re-invest rents resulting from the asset's growth is also of great importance.

If it is possible for the custodian to appropriate rents, the issue of profitability will determine the level of investment. Table 5 shows that retail prices in certain countries appear to be sufficiently high to warrant investment. However it is unclear what effect legalisation would have on these prices, and it is also unclear what wholesale prices could be obtained by the custodian selling horn.

There is better information on the costs of horn extraction. According to Milliken, Nowell and Thomsen (1993), average dehorning costs per rhino were US$ 960 for Namibian black rhinos in 1989, $ 1,100 for Zimbabwean black rhinos in 1992 and $ 426 for Zimbabwean white rhinos in 1991. This indicates that the cost of harvesting horn from wild rhinos is considerable, but this could probably be reduced greatly in a ranching situation.

Another implicit assumption in the previous chapter was that rhino horn provides the only source of consumptive use value. This is clearly not the case, as there are many additional potential benefits such as the value of trophy hunting, skin, meat and all other body parts for which there is a demand. In the case of trophy hunting, it is usually ageing bulls which are harvested, having little to no impact on the breeding potential of the population. Thus additional consumptive use values are likely to provide an added incentive to invest in rhinos.

If harvesting is not legalised, custodians will need to invest considerable resources in protection and enforcement, and finance these by appropriating any non-consumptive use values that rhinos may have. There is likely to be some demand for tourism services and vicarious uses, but other value will have to be appropriated from the general public. This raises the complex issue of how this is to be done. Individual countries finance conservation activity by taxing their citizens, but many African countries cannot afford to spend large amounts on rhinos. It is therefore necessary to appropriate value from other countries whose citizens are concerned with rhino conservation.

The World Bank's Global Environment Facility is a vehicle that has been created to address the above problem. Others include aid agencies and non-profit organisations such as the World Wide Fund for Nature (WWF). Unfortunately, all such organisations are burdened with numerous demands on their funds. Milliken, Nowell and Thomsen (1993) claim that the Zimbabwe Department of National Parks and Wild Life Management currently requires about US$ 20 million annually for rhino conservation alone, which is double it's entire budget for all activities in 1991. It seems unlikely that such considerable shortfalls would be supplemented by the international community on an ongoing basis.

As indicated above, illegal exploitation is a complicated process which has been greatly simplified in the rhino management model. It is useful to distinguish between three separate functions: 1) poaching, 2) smuggling and 3) speculative investment. The exploiter's objective function addresses a composite of all of these, but in reality separate parties face different incentives.

The extensive work by Leader-Williams and Milner-Gulland (1992) analyses the incentives faced by poachers. The poacher's objective function is essentially the same as equation [7] in Section 3.3. Since prices and harvesting costs are relatively constant, the only factor that can significantly influence the level of poaching is the level of enforcement which determines the cost ΘF. If the penalty F remains constant, it is necessary to increase the probability of punishment Θ, but this can only be done through increased investment in management institutions.

Milliken, Nowell and Thomsen (1993) present data concerning poaching in Zimbabwe. In this country, the effective penalty for poaching has been death since 1984. It could be argued that this constitutes a maximum penalty, yet it has not been effective in deterring poachers. Thus it appears that Zimbabwe's only option is to invest in increased policing. The Appendix on page 64 shows how data from Zimbabwe can be used in a simplified analysis of poaching incentives. It also shows how the data could be used to obtain a crude estimate of the value of a poacher's life.

Empirical evidence on poaching suggests that this activity is a consequence of poverty and limited alternative opportunity. It is thus unlikely that anything other than a substantial decrease in the price of horn would reduce poaching in extreme cases like Zimbabwe. Thus the only effective way of dealing with this problem would seem to be increased investment in enforcement. A legal trade may only act to deter poaching in such areas if the proceeds from the legal sale of rhino products is invested in protection. In other areas, such as parts of South Africa, the opportunity cost to poachers may be significantly higher, so a legal trade may have the additional effect of reducing the profit incentive by lowering prices.

Illegal smugglers will operate as long as the benefits of smuggling exceed the costs. The latter would include the cost ΘF. It is very difficult to determine what the actual value of Θ might be. Smuggling is an activity which certain people are well placed to do. There is certainly a lot of corruption in this area, and thus smuggling is the most difficult activity to eliminate through enforcement. The best way to address this problem would be for custodians to supply legal horn directly to wholesalers and retailers, thus undercutting smugglers profits.

Speculative investment will take place when the real rate of increase in the value of horn exceeds the discount rate. The data presented in Tables 4 and 5 suggests that there may have been substantial returns to investors over certain periods, but is insufficient to reach any concrete conclusions. There are reports in the literature of individuals claiming to have bought horn for investment purposes. This type of speculation probably arises from the assumption that rhinos will become extinct, and the last remaining horn will become extremely valuable.

A legal and sustainable trade in horn would reduce or even eliminate speculation, first by changing future expectations, and second by allowing rhino custodians to appropriate the benefits of possible price rises through increased rent value. This is the result shown in equation [4] in Section 3.2.

The previous chapter assumed that consumers constituted a single entity, and that demand was an exogenous constant. According to the literature there are a number of different parties involved: wholesalers, pharmaceutical companies, retailers and individual consumers, as well as the dagger handle manufacturers in Yemen. These elements have only been researched superficially, and it is hard to determine demand. Although Martin (1983) and Leader-Williams (1992) suggest overall consumption figures for nations, they do not indicate how this might be distributed.

The lack of sufficient accurate demand data does not allow for a demand analysis, however it is possible to postulate that the medicinal demand for rhino horn is relatively price inelastic. This must be true if the assertion by Leader-Williams (1992), that the demand for rhino horn medicine has remained fairly constant, is correct. This makes intuitive sense, because the demand for a medicine believed to have significant effects for serious illness would certainly display a low measure of price elasticity.

It would be useful to measure both the price elasticity of demand for African rhino horn, as well as the cross-price elasticity of demand with Asian horn. The latter would indicate the degree of substitutability between the two types of horn. Intuitively, the two types of horn must be substitutes to some extent, as they are both used for the same purpose, even though Asian horn is considered to be superior. This implies that an increase in the supply of African horn would reduce the demand for Asian horn. This point is not established, however, and many conservationists fear that the reverse effect may take place.

As noted in Section 2.1, the current estimated demand for horn used for medicinal purposes may be satisfied by a certain number of rhinos per year. Leader-Williams (1992) indicates that there are also substantial stockpiles of horn, so it would be feasible to reintroduce horn into a legal market while building up a further supply of horn. Rhino farming could be phased in gradually to supply the entire needs of the existing market.

5. CONCLUSION

5.1 Policy implications

Leader-Williams (1992) argues that a legal trade in rhino horn could generate revenues to fund anti-poaching measures and may reduce pressure on unprotected rhino populations. However, he expresses concern over certain issues: 1) the effect of such a policy on Asian rhino populations, 2) the lack of information on the volume of horn demanded and traded, 3) future demand for horn, and 4) the role of legalisation in reducing speculation.

None of these concerns can be addressed thoroughly without further empirical research. The issues of Asian rhinos and speculation have been briefly discussed above. Future demand could be ascertained by analyzing the demographic profile of consumers, but it is seems more important to address the existing demand which is still evident - it is probably safe to assume that this will persist in the short term.

The management model suggests that a legal trade would benefit the custodians of rhinos, provided that appropriate institutional structures exist. It is preferable to either establish private property rights, or allow agencies to retain earnings from harvesting to re-invest in protection. If rents are dissipated, a legal trade would be of little benefit to rhino conservation. Thus a key policy objective should be to create incentives to conserve through the establishment of appropriate institutions.

The model also suggests that illegal exploitation may be reduced through a reduction in price brought about by a legal and sustainable trade. However, there would be little to no effect in areas where the opportunity cost to poachers is low. The effect would be felt to a greater extent by smugglers and by speculative investors. Thus even if the trade is legalised, a high level of enforcement would remain necessary, as illegal activity would persist wherever economic incentives remain.

Milliken, Nowell and Thomsen (1993) explore the possibility of selling horn directly to wholesalers and retailers at very low prices, so as to undercut illegal dealers. This strategy does not seem advisable for two reasons. First, it defeats the objective of rent capture by the custodian for re-investment in enforcement. Second, it is likely that horn priced below market rates will be bought up and stockpiled for investment, thus the effect of depressing prices would only be temporary, and this would not eliminate the fundamental demand dictating market price levels. It would seem preferable to sell all horn at market prices, possibly through an auction system.

It may seem advisable to establish a strict regulatory framework in which trade could take place, but it is important to avoid market distortions which may have perverse effects. The idea of a monopoly producer or cartel is theoretically appealing, because the resource economics literature suggests that such producers will extract at slower rates, but there are possible adverse consequences of establishing such a regime. This is because of the potential for corruption, rent seeking and overpricing, which may lead to further overexploitation. The establishment of any new regulatory regime has to be carefully considered.

The existing policy of the CITES ban on the trade in horn certainly does not appear to be effective in preventing the overexploitation of rhinos. It is also economically inefficient, because it denies the possibility of mutually beneficial trade between rhino custodians and consumers of rhino products. It is inequitable, because the potential beneficiaries are mostly citizens of developed countries where rhinos do not occur, while the costs are borne by the developing countries where the rhinos occur and where the products are in demand.

Finally, the policy of a ban on any consumptive uses is likely to be unsustainable. At present, it is not possible to raise sufficient funds to support the preservationist approach in all areas where rhinos occur, and it is most unlikely that it will be in the future. It is only by establishing a regime where maximum rents can be captured and re-invested by the agents concerned with rhino conservation that an efficient, equitable and sustainable outcome is likely.

5.2 Suggestions for future research

The shortage of robust and reliable data on the rhino horn trade is a hindrance to any rigorous economic analysis. Further detailed and methodologically sound research on the extent of the demand in Asia, such as that conducted by Nowell, Chyi and Pei (1992), would be extremely useful. If volumes of retail sales and prices could be determined for major consuming countries over a period of time, it may be possible to estimate demand functions and determine price elasticity of demand. Unfortunately, the covert nature of the remaining market will seriously hamper any future attempts at such research.

An analysis of cross-price elasticity of demand between African and Asian horn would help to address the concern that re-opening the trade in African horn would adversely affect Asian rhinos. A demographic analysis of consumers of horn products would also be useful in establishing whether demand is likely to continue, or whether it is restricted mainly to older generations.

There is also scope for further research on the economic values of genetic variability within and between species, as well as the value of natural habitat. This is an area where the apparent gap between conservation and economic objectives could be narrowed considerably. Such research would require additional scientific input on the exact role of these factors in conservation.

Finally, it may be useful to extend the analysis used here to issues concerning other species faced with extinction. CITES policy affects a considerable number of species, and there are likely to be other examples which merit investigation.

APPENDIX

Milliken, Nowell and Thomsen (1993) provide some information on poaching of black rhinos in Zimbabwe. This information can be used to illustrate the types of incentives faced by a poacher.

Most poachers are Zambians. The average annual income in Zambia is less than US$ 290 per annum. Poachers form gangs of between four and six people. They frequently use automatic weapons, which are probably supplied to them by middlemen. They are paid between US$ 100 and $ 360 for a horn. In addition, they may be paid $ 0.5 a day, and a further $ 5 on delivery of the horn. Incursions into Zimbabwe may last between three days and two weeks; recently the time has increased as rhinos have become harder to locate.

The following data is also presented:

Total recorded number of incursions (1984-1993)	873
Number of poachers killed	167
Number of poachers captured	84
Number of poachers wounded	48
Recorded number of rhinos killed	1,130

The above data can be substituted into the static time version of the poacher's objective function:

$$\Pi = (p - c)\ y - \Theta F$$

Now, assuming that the average number of members in a gang is five, 873 x 5 individuals entered Zimbabwe over a certain period, and 167 of these were killed. The probability of death is thus equal to 167/(873 x 5) which is ≈ 0.038, close to 4%. Ignoring the possibility of being captured or wounded, how is this likely to affect the incentives of a poacher?

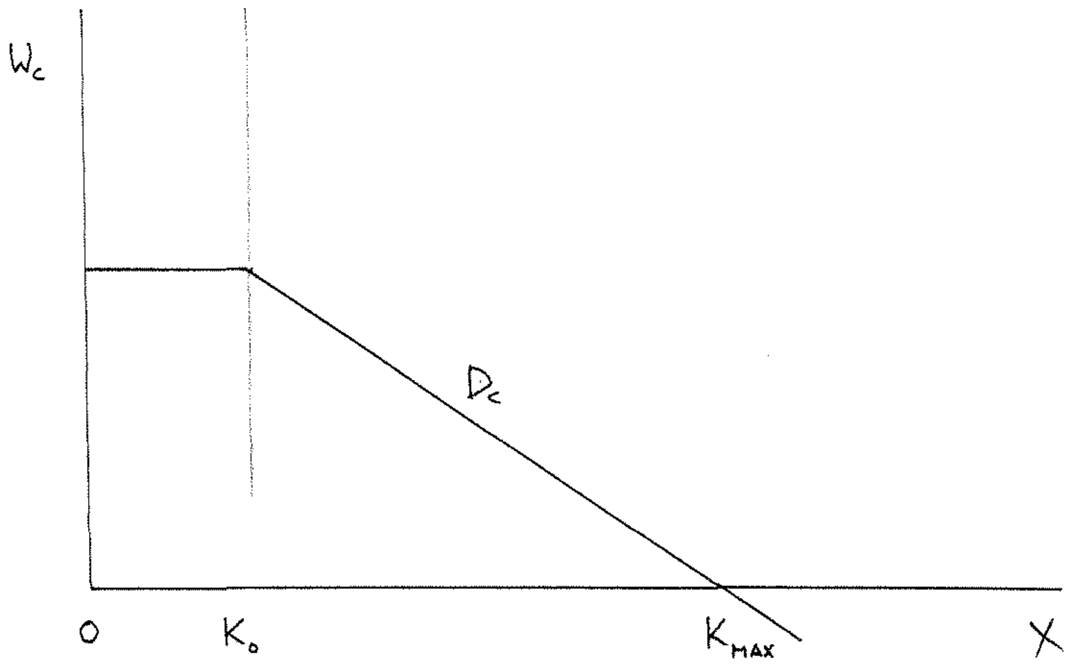
Suppose there is a six day incursion by a five member gang. Two rhinos are killed, and the gang receives US$ 600 for the horns. In addition they receive $ 8 in wages. Assume that costs are negligible and all weapons and ammunition are supplied by the middleman. If the $ 8 in wages is sufficient to cover costs, and the profit is split five ways, each individual receives $ 120. If the poaching option had been forgone, the poacher could have received roughly a six day share of the annual income, being close to $ 5. This is the opportunity cost. For poaching to be worthwhile, Π must be greater than or equal to $ 5. Thus:

$$5 \leq 120 - .038\ F$$

Since the penalty is death, F must equal the value of life to the poacher. Solving the equation gives $F \leq 3{,}026$. This suggests that in the above scenario, the poacher either places a value of around US$ 3,000 on his own life, or is acting irrationally. In economic terms, however, this value could arguably represent the value of a statistical life of a Zambian poacher. This example leads to the alarming conclusion that poverty levels are so high in Zambia, that there can be virtually no deterrent to poaching.

FIGURE 1

The demand for live rhinos



Key:

X : Number of live rhinos

W_c : Marginal net benefits of rhino conservation

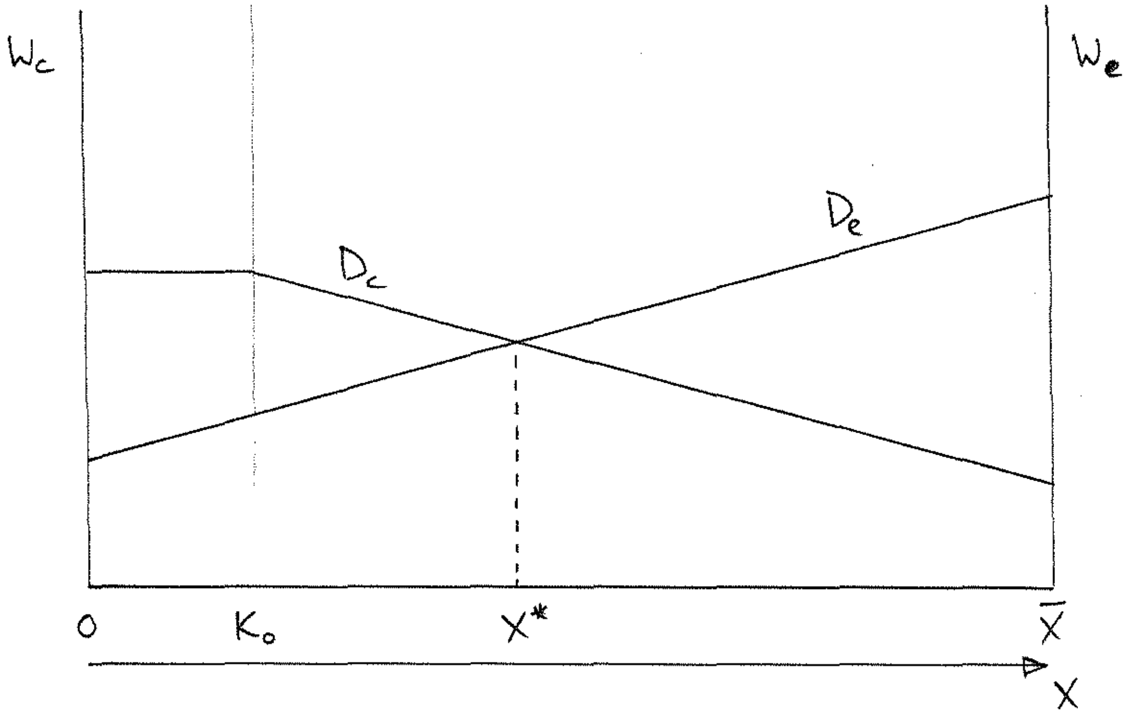
K_0 : Minimum viable population

K_{MAX} : Maximum economic population

D_c : Custodian's demand curve

FIGURE 2

The equilibrium live population level

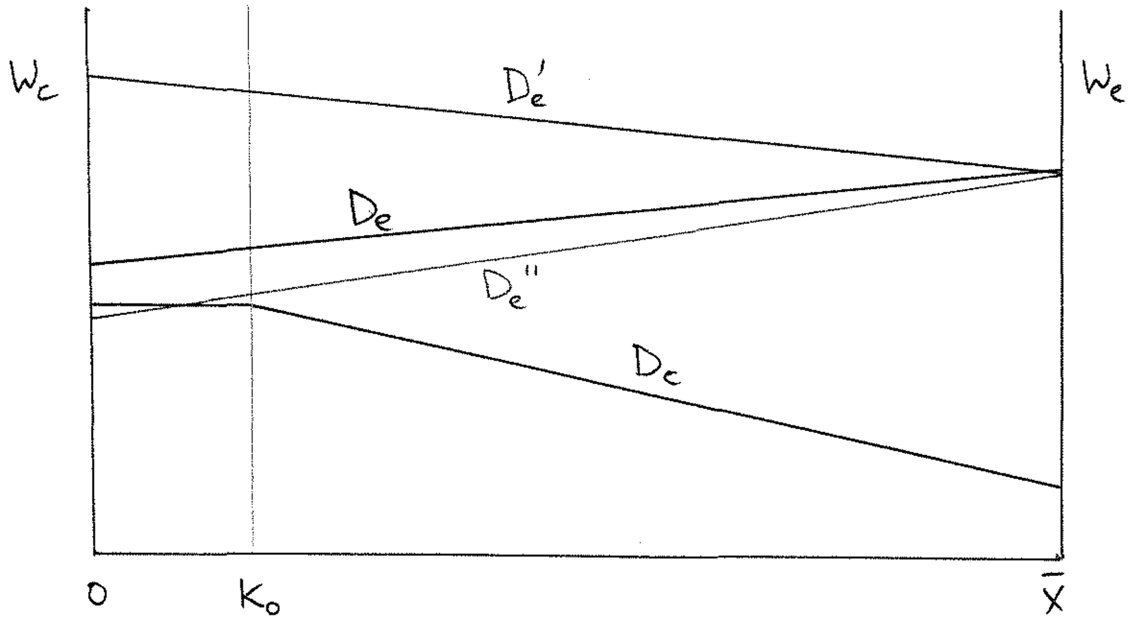


Key:

X	:	Number of live rhinos
W_c	:	Marginal net benefits of rhino conservation
W_e	:	Marginal net benefits of illegal rhino exploitation
K_0	:	Minimum viable population
D_c	:	Custodian's demand curve
D_e	:	Illegal exploiter's demand curve
X^*	:	Equilibrium live population level
$\bar{X}$	:	Total number of rhinos available

FIGURE 3

Non-intersecting demand functions

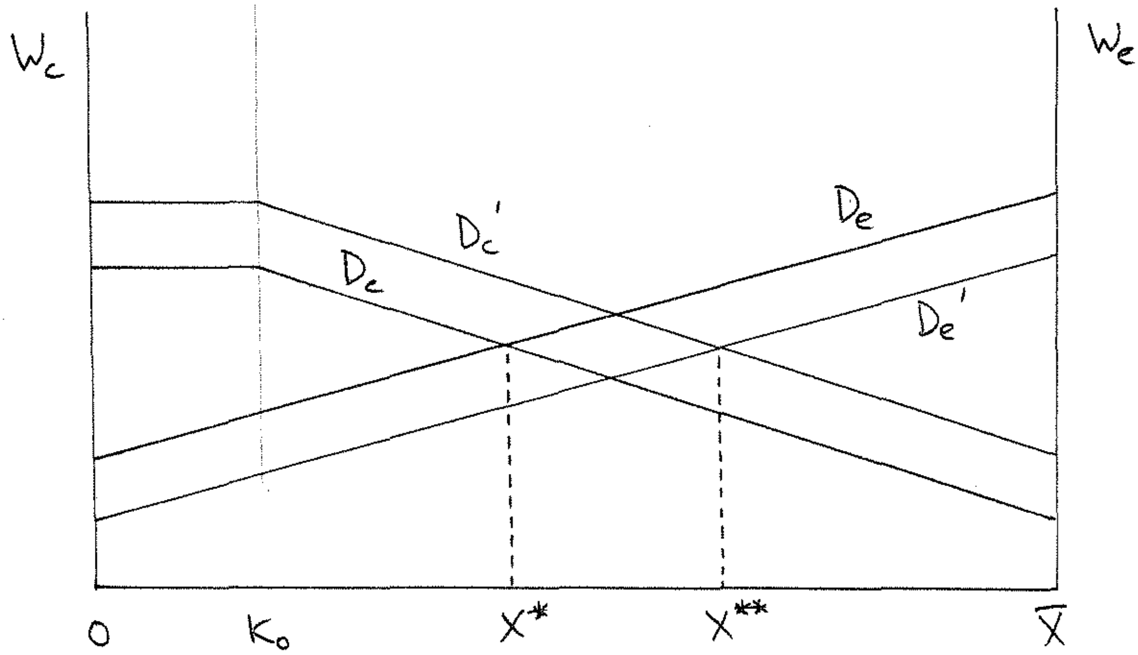


<u>Key:</u>

W_c	:	Marginal net benefits of rhino conservation
W_e	:	Marginal net benefits of illegal rhino exploitation
K_0	:	Minimum viable population
D_c	:	Custodian's demand curve
D_e	:	Illegal exploiter's demand curve This curve is downward sloping (from right to left), but does not intersect with the custodian's demand function - extinction will result
D_e'	:	This curve is upward sloping and therefore cannot intersect with the custodian's demand function
D_e''	:	This curve does intersect with the custodian's demand function, but at a point below the MVP, so extinction will still result
$\overline{X}$	:	Total number of rhinos available

FIGURE 4

The equilibrium population level with legal harvesting



Key:

W_c : Marginal net benefits of rhino conservation

W_e : Marginal net benefits of illegal rhino exploitation

K_0 : Minimum viable population

D_c : Custodian's demand curve without legal harvesting

D_c' : Custodian's demand curve with legal harvesting

D_e : Illegal exploiter's demand curve without legal harvesting

D_e' : Illegal exploiter's demand curve with legal harvesting

X^* : Equilibrium live population level without legal harvesting

X^{**} : Equilibrium live population level with legal harvesting

$\overline{X}$: Total number of rhinos available

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