Bioeconomic Modelling of Endangered Species Conservation

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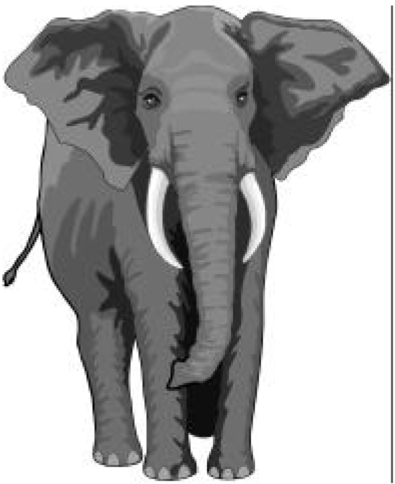

Massey University

Centre for Applied Economics and Policy Studies

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Foreword

Endangered species conservation is a serious global problem, with species facing increasing pressure from competition for land, from direct exploitation, and from a lack of effective management. It is virtually certain that we will continue to lose large numbers of species in the next century, but we do have the ability to choose particular species and ecosystems to be targeted for preservation. If we are to save these endangered species, it is important to understand the key causes of extinction as well as the incentives that cause human behaviour to induce extinction of some species.

In this research, a model is developed highlighting the key economic factors that are influential in determining the fate of an endangered species. Particular emphasis is placed on the role of non-consumptive values as a key component of species' survival. The authors demonstrate that, in many cases, some existence value must be appropriated to the resource in order for extinction to be avoided. Although the authors use the specific case of the African elephant in this paper, the results are applicable to a wide variety of species worldwide.

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Part 1. Introduction

The modelling of endangered species has principally grown out of the literature of fisheries economics. Clark (1973) based his model of species extinction on Gordon's (1954) seminal fisheries model in order to examine the conditions under which extermination of a species may appear to be the most attractive policy to a resource owner. This forms the foundation for most of the work on species extinction that has followed. More recently, Swanson (1994) examined ways of adapting this model to terrestrial species by generalising the model in a similar conceptual structure.

Swanson (1994) also provides a conceptual framework for the economics of extinction that considers the elimination of species as a product of human choice. He points out that mankind has a portfolio, as it were, of productive assets and that we substitute between those assets through a process of investment and disinvestment. Extinction is seen as a complete disinvestment of a wildlife resource which occurs because it is perceived as not being worthy of investment. (See also Swanson and Barbier 1992.)

Both the Clark and Swanson models address consumptive use of the endangered species, but provide no means by which non-consumptive values may act to the benefit of the species. Yet non-consumptive values are large and may even exceed consumptive values (Swanson and Barbier 1992; Barnes 1996). The general objective of this research is to develop a model of endangered species management, based on the objectives of the various interested agents, in order to examine the impacts of their decisions on the decline of populations.

More specifically, the objectives are first, to examine the causes of a species' decline toward extinction in the general framework of Clark and Swanson. Second, to reconcile the nature of the differences between the values received by the resource owner as reflected in those models, and the total value placed on the resource by the global society. And third, to develop a model to examine the magnitude of the unappropriated values that would be necessary to make long-term sustainable populations of a given endangered species bioeconomically viable. Although the African elephant is used as the basis for this model, the concepts contained herein are fully transferable to other species of similar characteristics.

In Part 2, we examine the Clark and Swanson models, particularly the policy implications of the results. In Part 3, we develop a conceptual model with which to illustrate the existence and character of the values to be developed. In Part 4, we discuss the implications of the new model extensions for policies of endangered species management. Finally, in Part 5, we offer some final remarks and conclusions.

Part 2. Models of the economics of extinction

The Clark Model

The Clark model explains the possible extinction of species as resulting from three factors: 1) open access to the resource, which results in overexploitation and driving economic rents to zero; 2) the relationship between price and marginal cost of harvesting the resource; and 3) the growth rate of the resource relative to the discount rate (Clark 1973). (See also, Clark 1976; Clark and Munro 1978; Clark *et al*. 1979.) If either the first condition or the last two conditions are met, then resource extinction may result. The first condition is not further considered here, but is discussed in both Clark (1973) and Swanson (1994). Regarding the last two conditions, Clark states, "if price always exceeds unit cost, and if the discount rate…is sufficiently large, then maximization of present value results in extermination of the resource". Clark's 'large discount rate' is equivalent to a resource's 'low growth rate' as the terms are relative to each other. It is the latter interpretation that we shall focus on in this paper.

The Clark model posits a societal objective of maximising the appropriable income from its natural assets as follows.

$$(1) \quad \max_{h} \int_{0}^{\infty} e^{-dt}\left[p\big(h(t)\big)h(t) - c\big(x(t)\big)h(t)\right]dt$$

$$\text{s.t.} \quad \dot{x} = F\big(x(t)\big) - h(t),$$

where $x(t)$ is the population of the endangered species in time t, $h(t)$ is the harvest of the species in time t, $p(h(t))$ is the inverse demand curve defined as a function of harvest, $c(x(t))$ is the unit cost of harvest as a function of the stock level, $F(x(t))$ is the growth function of the resource as a function of stock, and d is the marginal returns to capital in the society. For notational convenience, the time notation will subsequently be omitted, but will be understood to be implicit in all control and state variables. We follow Swanson's (1994) interpretation of the Clark model, rather than Clark's original, as the form is better suited for comparison with the model developed in this paper.

To maximise its investment in this resource as well as in the other resources available, society will wish to maintain an asset portfolio that balances the level of each resource against other productive opportunities. The condition associated with optimal harvest (*h**) is shown in equation (2) and that associated with optimal stock levels (*x**) is shown in equation (3).

(2) $$l = p\left[\frac{1}{e_d} + 1\right] - c,$$

(3) $$d = F'(x) - \frac{c'(x)h}{l} + \frac{\dot{l}}{l},$$

where l is the shadow value of the resource, and e_d is the elasticity of demand for the resource.

Equation (3) represents a modified form of the *golden rule* equation common in renewable resource models. Without modification, this *golden rule* would indicate that the resource must be maintained at a stock level such that the marginal productivity of the renewable resource stock, *F*¢(*x*), equates to the returns to capital available to the resource owner, *d*.

This relationship may be viewed in terms of the Clark model as suggesting that if *F*¢(*x*)< δ for all population levels, *x*, then extinction will result as the model’s optimum strategy for the resource owner. Only if $F¢(x)=d$ at some positive population level do incentives exist for a positive equilibrium population to survive. This relationship makes clear the dilemma of slow-growth species competing in developing countries against fast-growth investment opportunities. Modifications to the *golden rule* equation may hinder or help the slow-growth species as it is required to ‘pay its way’ as a competitive resource.

The modifications to that relationship in equation (3) take into account the stock-dependency of the harvest, indicating that costs increase as stocks decline. This acts to further lower the effective marginal productivity of the stock relative to the discount rate. A species’ *adjusted* growth must then achieve a rate of growth equal to the discount rate, placing even more pressure on the trend toward extinction.

The policy implications of the Clark model are clear. Since we cannot change the resource growth rate, and since artificial discount rate distortions are an infeasible tool for resource management, changes must be initiated through adjustments to either the unit price received for the resource, the unit cost of harvesting the resource, or both. Specifically, to preserve a species for which the optimal financial solution is extinction, some combination must be enacted of lowering the unit price and raising the unit cost. Clark expresses this in terms of the cost/price ratio, with a ratio greater than 1.0 resulting in non-harvest, and therefore non-extinction, even when the resource growth rates are less than the rate of return on capital in the society (Clark, 1976).

Swanson (1994) points out that this is the basis for the 'rent destruction' policies exacted in response to the rapid decline of African elephant populations in the 1980s. It was estimated that between 1979 and 1989 the population of African elephants declined from 1,343,340 to 609,000, a loss of more than half the entire population (Douglas-Hamilton 1989). During a similar timeframe, from the early 1970s to the early 1980s, the volume of the ivory trade nearly doubled from 550 tonnes to 1,000 tons annually (Barbier *et al*. 1990). It was predicted that if those trends continued, extinction of the species would result within 20 years (Renewable Resources Assessment Group, 1989).

The policy response was that the Convention on International Trade in Endangered Species (CITES) moved the African elephant from Appendix II to Appendix I, effectively prohibiting all international trade in ivory. This response is entirely consistent with the Clark model. The ban reduces the unit price of ivory to near zero by eliminating demand and simultaneously increases the unit cost of supplying ivory due to the legal barriers it imposes. Conceptually, the move of the African elephant to Appendix I may be viewed as an attempt to drive the cost/price ratio over 1.0. It has been generally successful in achieving the goals of no ivory trade and short-term cessation of rapid population decline (Barnes 1996).

This type of policy has some problems, however. Dependence on the cost/price ratio, where the discount rate exceeds the resource growth rate, limits policies to an all-or-nothing option. That is, any cost/price ratio less than 1.0 results in an outcome of optimal extinction, while any cost/price ratio greater than 1.0 results in no trade in the resource. Thus, positive sustainable trade is not an option.

In some respects, this may not seem like a bad idea. Many conservationists and biologists, like Douglas-Hamilton, argue strongly that the only way to preserve the African elephant from extinction brought on by overexploitation in support of the ivory trade, is to ban the trade altogether (Douglas-Hamilton and Douglas-Hamilton 1992). This argument overlooks the slower, but equally certain, decline of elephants—in fact, of all endangered species—due to unsuccessful competition for the limited land resources controlled by humans. This issue is addressed at greater length below.

Further, as ivory is the principal valuable harvest resource of the elephant, eliminating all markets for ivory also acts to remove one of the major incentives for protecting the species. Desperately needed revenues that were formerly used for the protection of elephants are no longer available. This reduces the value of the stock and renders it less able to compete against alternative uses of the land. This is demonstrated in Part 3. Swanson (1993) also discusses this issue at some length. (See also, Swanson and Barbier 1992.)

The Swanson Model

In his 1994 paper, Swanson proposes generalisations to Clark's fishery-based model by including terrestrial resources required for endangered species survival. Swanson points out that while humans do not compete for many of the ocean resources used by marine species, they do compete for the same land-based resources used by terrestrial endangered species. Thus, he argues that terrestrial species must not only generate growth in value to compete with other capital opportunities, they must also generate growth in value to compete with the opportunity costs of the resources they need for survival.

To address this, Swanson adds another control variable to the problem, which represents the land resources allocated to a species as shown in equation (4) below.

(4) $$\max_{h} \int_0^{\infty} e^{-dt}\left[p(h)h - c(x)h - dr_R R\right]dt$$

$$\text{s.t. } \dot{x} = F(x;R) - h\,,$$

where R is a unit of terrestrial resources upon which the species depends for survival, and r_R is the price of a base unit of that land resource. This formulation removes the implicit assumption in fisheries-based models that required resources are free goods that do not require investment. This generates one of Swanson's 'alternative routes to extinction' through the addition of another first-order condition.

(5) $$d = \frac{lH_R}{r_R}$$

Similar in concept to the *golden rule* equilibrium discussed above, this condition requires that land-based resources be allocated to a species only in proportion to its ability to generate a competitive return. Note that this condition is in addition to the ones shown in equations (2) and (3) above. When taken together, these conditions offer some further insight into the issues surrounding species extinction. In particular, through this new condition, we note that, even when Clark's conditions are not met—that is either when growth rates are greater than the discount rate or when unit price is less than unit cost—we can still see a species move toward extinction if it does not provide a competitive return to the natural resources it requires for survival.[1]

Most compelling, for our purposes, is one of Swanson's general conclusions. Referring back to the policy of rent destruction, he argues that those policies cannot save a species from extinction; they can only shift the species onto a different path to extinction. He adds, "the only policies that can alter the ultimate fate accorded by human society to any particular species are those that address the fundamental cause of decline: perceived investment-unworthiness" (Swanson 1994, p. 819).

[1] Swanson also introduced a similar condition requiring returns to management services, which is not considered here.

Part 3. Evaluating non-consumptive values

A key characteristic of both the Clark and Swanson models is that each considers only the consumptive value of the endangered species.[2] That is, the stock must be harvested for any benefits to be realised. Yet some of the largest potential and realised benefits of the African elephant are non-consumptive. In Kenya alone, tourism generates revenues of about US$400 million per year (Pierce 1995), mostly related to wildlife and wilderness experiences. The consumers' surplus of tourists visiting Kenya's wildlife reserves has been estimated at between US$46 million and US$450 million per year (Pearce 1995).

Barnes (1996) demonstrated that the non-consumptive value of the elephant is becoming increasingly important. Prior to the ban on ivory trade, 44 percent of the potential use value of elephants

[2] Swanson does, at one point, identify the benefits as a more general 'flow of social benefits', but they are still expressed as a function of harvest.

in Botswana was derived from non-consumptive uses, but that the figure has risen to 77 percent following the ban.

Appropriability of these values is a problem, however. Of the $400 million in Kenyan tourism revenues, only $13 million, or 3 percent, is appropriated by the Kenyan Wildlife Service for management of the wildlife (Pearce 1995). It has been suggested that considerable additional appropriations could be achieved simply through increased gate fees at reserves. However such increased appropriations might be achieved, it is sufficient for our purposes to note that wildlife appropriates a very small proportion of the tourism use value it generates.

In addition to non-consumptive use values expressed through tourism, significant existence values of the elephant are demonstrated through memberships in various conservation societies. Actual studies on existence values of elephants are scarce,[3] and the worldwide existence value of the elephant is unknown, but it is probably safe to suggest that it is considerable, and that it would provide additional incentives to include elephants in the asset portfolio of the human species if it were

[3] Some isolated studies do exist, however. For example, Dixon and Sherman (1990) estimated total economic value of elephants and other wildlife in Thailand at US$4.7 million per year.

appropriated by the resource owners. The lack of existence value appropriation may well be the principle reason we see the decline of many species, such as the African elephant, that are highly regarded and valued by people around the world.

There are many structural reasons why existence values are not appropriated, and they are not easy to overcome. Existence values are non-rival in consumption and non-excludable, and thus are classified economically as public goods. By ‘non-rival in consumption’, we mean that the enjoyment one person receives from the existence of elephants does nothing to diminish the enjoyment of another; that is, the good is not ‘used up’ through consumption. By ‘non-excludable’, we mean the level of an endangered species’ existence at any given time is the same for all people. Thus, you cannot exclude a non-paying person from experiencing the knowledge that elephants exist. As with all public goods, there is no incentive for any given individual to pay the value they receive and such a good is typically under-supplied without government intervention.

If the good in question, and those benefiting from it, were all contained within a single government jurisdiction, this problem could be solved in the traditional way. The government would tax all of its members, perhaps weighted by some criterion such as the ability to pay, and then the government itself would provide the good. This works for such traditional examples of public goods as lighthouses, police protection and national defence.

The problem of species extinction, however, is complicated by its global nature. Most of the world's biological diversity is concentrated in a small number of states (McNeely *et al*. 1990). Those countries are generally poor and are in dire need of appropriable income, while the bulk of the non-consumptive values of endangered species arise out of the relatively wealthy developed nations. There is no mechanism in place to transfer income from those who benefit to those who are asked to bear the costs.[4]

Of the two non-consumptive values we have identified—tourism use values and non-use existence values—clearly the latter is the more difficult to appropriate in practice. Although a closer examination of policy alternatives is beyond the scope of this paper, it may be instructive to examine the impacts inclusion of

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[4] Some programmes exist which attempt to 'tax' wealthy nations to support wildlife and biodiversity conservation, such as the United Nations' World Heritage Convention, but the level of support provided is minuscule when compared to the world's conservation needs (Swanson and Barbier 1992).

these values may have on the trend of a species toward extinction. Although we may not be able to solve the appropriation problem immediately, we may be able to design a framework within which it is possible to determine the appropriation necessary to make a particular species ‘pay for itself’.

Consider the specific case of the African elephant in a particular jurisdiction. The objective of society in terms of value appropriated may be expressed with the following objective and constraint.

(6) $$\max_h \int_0^\infty e^{-dt}\left[\left(P_M(h)g_M + P_I(h)g_I + P_S(h) - C(x)\right)h + P_U U(x)\ldots\right.$$
$$\left.\ldots + N(x) - P_R Rx\right]dt$$

s.t.

$\dot{x} = F(x) - h$, $P_M'(h) < 0$, $P_M''(h) < 0$, $P_I'(h) < 0$, $P_I''(h) < 0$,

$C'(x) < 0$, $C''(x) < 0$ $U'(x) > 0$, $U''(x) < 0$, $N'(x) > 0$,

$N''(x) < 0$,

and the usual transversality and boundary conditions.

$P_M(h)$ is an inverse demand function for the non-ivory products of harvest, g_M is the average yield of non-ivory products per animal, $P_I(h)$ is an inverse demand function for ivory, g_I is the average yield of ivory per animal, $P_S(h)$ is an inverse demand function for safari hunting, P_U is the unit price of one tourist-day, $U(x)$ is tourist-days as a function of population, $N(x)$ is the non-market existence value of elephants as a function of population, P_R is the unit value of land resources used by elephants, Rx is quantity of land resources used by elephants as a constant proportion of population, and all other terms are as previously defined in Part 2.

Note that, unlike Swanson, we do not characterise land resources given to elephants as a control variable as we find it unlikely that resource managers will have sufficient control of those resources to act on the results of these models. Rather, we suggest that if the correct incentives are put in place in society, including the appropriations that are the focus of this model, such transfers of land resources from alternative uses will arise through the market.

For the purposes of this exposition, we offer some simplifications to the model to aid the transparency of the result. We assume that $P_M(h) = P_M$ (constant), that $P_I(h) = P_I$ (constant), that $P_S(h) = P_S$ (constant), and that $g_M = g_I = 1$. This removes some terms that are not needed for understanding the features of the model, but which would be useful for developing a numerical solution.

With the simplifications in place, the societal objective with regard to elephants is shown in equation (7).

(7) $$\max_h \int_0^\infty e^{-dt}\left[\left(P_M + P_I + P_S - C(x)\right)h + P_U U(x) + N(x) - P_R Rx\right]dt$$

s.t. $\dot{x} = F(x) - h$ and other conditions as noted above.

Using the Pontryagin necessary conditions for maximisation of this problem, we derive the new version of the *golden rule* equation, analogous to that shown in equation (3). This condition shown in equation (8) below must be met when this system is optimised.

(8) $$d = F'(x) + \frac{-C'(x)F(x) - P_R R + P_U U'(x) + N'(x)}{P_M + P_I + P_S - C(x)}$$

Recall that the LHS and the first term on the RHS indicate that the resource must be maintained at a stock level such that the marginal productivity of the renewable resource stock, *F¢*(*x*), equates to the returns to capital available to the resource owner, δ, and that all other terms on the RHS modify that relationship.

The modifications take into account the stock-dependent terms of the original objective function, all expressed proportionately to the unit net revenue of harvesting the resource. The negative terms on the right side of equation (8) act to further lower the effective marginal productivity of the stock and the positive terms act to increase it. As in Clark's model, the first term, $-C'(x)F'(x)$, represents the stock-dependent harvest costs. A species' growth must then accommodate a rate of growth equal to the discount rate *after* this adjustment is made, placing even more pressure on the trend toward extinction.

Similarly, the second term on the RHS shows the return for the foregone land required to sustain the elephant. This is one of the key points offered by Swanson in his generalisation of Clark's extinction model; that is, the elephant must compete for the land resource that sustains it against the next best opportunity available for that land. The returns from the harvest must also cover these costs.

The two positive terms in equation (8) reflect the non-consumptive values of the elephant. These terms act to increase the effective returns from the population of elephants, but both terms are non-consumptive in that they do not require the harvest of an animal to be realised. The third term on the RHS is the marginal revenue from tourism. This is one way in which the total value people place on elephants is expressed in the market. These revenues act to support the existence of the elephant as it competes against other opportunities in society.

The fourth term on the RHS is the marginal existence value, aside from any use value (either harvest or tourism) that people place on knowing that the elephant species continues. As used in this model, it actually represents the marginal existence value that is appropriated by the resource owner.

Part 4. Implications for species extinction

A closer examination of the modification terms may be instructive in understanding the implications of this model. The ban on ivory trade has created a value of P_I that is effectively zero. The impact of that change is to increase the net impact of the modification whether negative or positive; that is, the value of each modification is proportionately more important. If the combined values of stock-dependent costs and returns to land resource use outweigh those of tourism and existence value revenues—a condition that is almost certainly the case in many populations, as will be addressed below—then the loss of ivory revenues acts to the detriment of elephant conservation. This is a point that economists have attempted to make throughout the debate on the CITES ban.

Increasing marginal tourism revenues, $P_U U'(x)$, acts unambiguously to the benefit of elephant conservation. Unfortunately it is unlikely that such revenues are sufficient to encourage additional investment in the elephant resource. Norton-Griffiths and Southey (1995) found that non-consumptive use values in Kenya are not sufficient to equal the opportunity costs of the land. In a similar result, Barnes (1996) found that non-consumptive use values are not sufficient to justify further investment in the elephant resources of Botswana. Within the context of this model, these results suggest that tourism revenues are less than the opportunity cost of land, $P_U U¢(x)<P_R R$.

Despite its prominent place in this model, marginal existence value appropriated by the resource owners is virtually zero.[5] Foregoing any consideration of the stock-dependent costs, if this is the case, then the negative terms of the RHS of equation (8) must outweigh the positive, and the loss of ivory revenues must be considered to be detrimental to elephant conservation.

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[5] Several conservation organisations, such as the WorldWide Fund for Nature, do contribute funds to projects in support of elephant conservation. As the sources of these funds are from voluntary contributions from members who may never see an elephant, it may be argued that this is an appropriation of existence values. Unfortunately, such resources are so small relative to the other values involved that the magnitude may be considered close to zero for our purposes.

More important for our purpose, this highlights the critical nature of existence values being appropriated to the resource owner on behalf of those who enjoy the public good of the elephants' existence. This value can be characterised by manipulating equation (8) to isolate $N'(x)$ then solving the resulting differential equation for $N(x)$.

To summarise the argument, recall that the equation *must* balance at some positive stock level for the elephant to avoid extinction. Now consider the variables we have to work with.

The basic relationship is that the elephant growth rate must equal the rate of return on capital at some positive population level. With a particularly slow growing species like the elephant, this is unlikely. We cannot change the growth rate of the elephant and we cannot unilaterally force the discount rate lower, especially for the long term over which this problem is defined. Stock-dependent costs act to the detriment of the elephant, but are based on biology and technology and are not something we can dramatically lower. Even if we were to bring this term to zero, which we could achieve by setting harvest to zero, it wouldn't remove the competition for land resources.

Competition for land resources acts to the detriment of elephant conservation and is substantial in magnitude. It is estimated that human populations will more than double in Africa over the next decade (Concar and Cole 1992), and this will only increase the opportunity cost of the land for which the elephant must compete. Not only can this not be changed, it poses the greatest long-term threat to the survival of the elephant.

Price and cost policies cannot alter the basic relationship, although they can speed up or slow down the process of extinction. As Swanson (1994) expresses it, this can 'shift the path' of extinction but not prevent it. So we are left only with non-consumptive values as possible tools with which to balance the equation. We have already discussed how tourism values alone are insufficient to offset the opportunity cost of land resources, and this leaves only one option for preserving the African elephant: the appropriation of existence values. Extinction is inevitable if some means for such appropriation to occur is not found. This conclusion may well be generalised to many endangered species.

Part 5. Conclusions

This paper has attempted to highlight the key economic factors which influence the fate of the elephant and to provide a theoretical basis for estimating the non-consumptive values required to be appropriated in order for the elephant to 'pay its own way' in our asset portfolio.

All species of animals and all wilderness areas are now economic goods in the sense that they must compete for a place in mankind's asset portfolio. It is estimated that global human populations will double over the next century (Perman *et al.* 1996). This will significantly increase pressures to convert wildlands into food-producing areas and make it even harder for endangered species to compete. This continuing loss of habitat is probably the greatest threat facing endangered species. The African elephant is particularly threatened by these trends, as it requires a tremendous volume of land to sustain viable populations.

Non-consumptive use values of the elephant are becoming increasingly important in acting to slow the population decline. However, tourism alone is insufficient to support increased investments in elephant conservation, so it is critical to the survival of the species that a way is found to appropriate the non-consumptive, non-use existence value held by members of the wealthy industrialised societies. The relationship of these values to the other elements in the elephant conservation problem has been identified and the theoretical foundation provided for numerically approximating their magnitude.

It is clear that the continued survival of the African elephant, and of many other endangered species, depends upon the ability of our global society to develop a mechanism for the transfer of value from those who desire the benefits of continuing existence to those who bear the cost of maintaining the species.

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