Wildlife conservation, human welfare and the failure of protected areas

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Abstract
The establishment and expansion of protected areas in Africa have been motivated by the aspiration of increased wildlife abundance. However, the increasing poaching pressure on this continent has led to the perception that protected areas have failed in preserving wildlife. This paper presents a bio-economic model in order to explain the economic factors and mechanisms which may have caused this failure. The analysis focuses on a hunter-agrarian economy where an opportunity cost of habitat protection, due to less land for agricultural cultivation, pasture, and wildlife hunting, is present. An expansion of the protected area restricts the local people’s user rights to land. Depending on the economic conditions in agriculture and wildlife hunting, this policy may reduce the degree of wildlife conservation. This result contrasts the theoretical findings of fishery economics, where a marine reserve increases the aggregate fish stock. In addition to the conservation effect of protected areas, this paper investigates the impact on human welfare of restricting the user rights to wildlife and land.

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1. Introduction

The initial approach to preserve natural resources in Africa had its roots in the Western environmentalist movement of the 20th century. This approach saw the establishment of large areas of national parks and reserves as the foremost priority for African conservation (Marks 1984, Kiss 1990, Swanson and Barbier 1992). The objective of this management system was to protect wild animals and natural habitats through prohibition or restriction of wildlife utilization. Setting aside areas for national parks and game reserves is still the predominating management strategy (Swanson and Barbier 1992). The control and management of protected areas are usually vested in the State, which reaps economic benefits from wildlife tourism. In contrast, gazetting land for wildlife protection has displaced rural communities and curtailed their access to natural resources that they previously had access to. Land for cultivation and pasture has been lost and harvesting of wildlife in these areas has been deemed illegal (Marks 1984, Kiss 1990, Swanson and Barbier 1992, Wells 1992). In addition, local communities bear the costs of living with wildlife through agricultural damage induced by animals roaming on agricultural land. Hence, while the State reaps the benefits of protected areas, the costs are borne at the local level.

The idea of protected areas was motivated by the aspiration of increased wildlife abundance. The continuing expansion of protected areas in Africa reflects that this perception is still prevalent. However, the increasing poaching pressure has led to a growing recognition that protected areas have failed in their goals of preserving wildlife (Kiss 1990, Swanson and Barbier 1992, Martin 1993, Barrett and Arcese 1995, Gibson and Marks 1995, Songorwa 1999). Martin (1993), for instance, discusses protected areas as a tool in wildlife conservation. He claims that Africa has made the mistake of gazetting too many and too large areas to be able to meet the minimum operating costs required in order to conserve and protect wildlife in these areas. He pictures an inevitable situation where budgets are to small to prevent illegal exploitation, leading all areas to deteriorate simultaneously (see also Leader-Williams and Albon 1988, Dixon and Sherman 1991). Instead of focusing on law enforcement and the amount of protected land, Kiss (1990) and Swanson and Barbier (1992), among others, point to the lack of economic compensation to the local people as an explanation of the failure of protected areas. They argue that it is necessary to correct this distortion in order to promote wildlife conservation, and suggest that this is achievable through revenue sharing in wildlife related activities. By providing the local people with such benefits, they believe that the
management authorities will gain the co-operation of the local people and thus reduce their incentives to exploit wildlife.

None of the authors cited above have adopted a model-theoretical framework to explore the conservation-effect of protected terrestrial habitats. In contrast, in fishery economics, marine reserves have been analysed in a bio-economic context by Conrad (1998), Hannesson (1998) Pezzey et al. (2000), and Sanchirico and Wilen (2001), among others. Sanchirico and Wilen (2001) consider two fishing patches, initially characterised as open-access fisheries (entry until zero rents). A marine reserve is created by closing one patch for fishing. The fish stock in the open patch is determined by a fixed cost-price ratio and is not altered by closing the other patch. Based on these assumptions, a marine reserve increases the aggregate biomass of the two patches for every ecological system. Sanchirico and Wilen (2001) also focus on the economic impact of a marine reserve. Because free access to the open patch means zero rent, they define the fishery as better off if a marine reserve increases the total harvest. As the fish stock disperses between the patches, they show that the effect on total harvest of closing one patch is positive if increased dispersal between the reserve and the open patch compensates for the foregone harvest in the reserve. Also Hannesson (1998) shows that marine reserve creation increases the aggregate fish stock when there is open access to the area outside the reserve. However, he demonstrates that a marine reserve of a moderate size will have only a small conservation effect, compared with open access to the entire area inhabited by the stock. In addition, Hannesson (1998) shows that the impact on the aggregate catch depends on the size of the marine reserve.

This paper adds to the research of marine reserves by presenting a bio-economic model of wildlife habitat protection. Terrestrial habitats differ from marine habitats in that there may be, in addition to hunting, an alternative use of protected land. In the present, agricultural crop production is considered the alternative use of protected land. In order to draw a line to marine reserves, this paper makes a distinction between two policies of land protection. The difference between these policies lies in the type of land gazetted. One alternative is to establish a protected area by gazetting non-cultivated land only. In such a case, there is no alternative use of the protected area except hunting. This policy is therefore quite similar to marine reserve creation and the analysis demonstrates that it promotes wildlife conservation. However, rapid human population growth in Africa has forced humans to bring their agricultural activities ever more close to wildlife habitats (see Dixon and Sherman 1991 and Martin 1993). The
second alternative is therefore to expropriate cultivated land for wildlife protection. In this case the protected area does not only close off an area for hunting, it also withdraws land previously used in agriculture. Consequently, an alternative cost of habitat protection is present, namely the foregone return from crop production. The analysis shows, in contrast to marine reserves, that this policy may cause wildlife degradation. Analysing the driving forces behind such an outcome and its impact on human welfare are the main contributions of this paper.

The bio-economic model developed in this paper draws on the biological system presented by Hannesson (1998). See also Armstrong and Reithe (2001). Hannesson looks at a fish stock located in an area of a fixed size and the marine reserve is defined as a subset of this area. In the present paper the biomass is a wildlife stock dispersing over a fixed area or ecosystem. The ecosystem contains two sub-areas, the protected area and the outer area. The protected area is managed by an agency appointed by the State. On the border to the park a group of peasants utilize the outer land for agricultural production and wildlife hunting. Following the fishery analyses cited above, it is assumed that hunting is not allowed within the protected area and that law enforcement is effectively preventing illegal hunting here. However, the local people have legal rights to exploit the land in the outer area and the wildlife roaming outside the park. That is, they have user rights to land and wildlife in the outer area\(^1\).

Throughout this analysis the local people are considered the only active agent. It is assumed that the size of the protected land is determined by the State and, therefore, cannot be altered by the park manager. Hence, expropriation of land will be considered exogenous in the model. In addition, because we neglect illegal hunting, there is no need to focus on law enforcement and consequently, the park manager plays no role in the subsequent model. Instead, the manager is a passive beneficiary of non-consumptive use of the protected stock, for instance tourism\(^2\).

The rest of this paper is organized as follows. Section 2 presents the ecological model, while the behaviour of the local people follows in section 3. The impact on wildlife conservation

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1 In a state property regime individuals or groups may be allowed to make use of the natural resources without having any property rights. Bromley (1991) defines this as usufruct rights.
2 It is therefore assumed that the management of the protected area involves no harvesting or culling. For a critical review of this assumption, see e.g. Wright (1999).
and human welfare of protected area creation is investigated in section 4. A summary and discussion follows in section 5.

2. The ecological model
Consider an area or ecosystem of fixed size divided in two sub-areas; a protected area and an outer area. The ecological modelling is identical to Hannesson (1998) who looks at species dispersing between the sub-areas in a density-dependent way. This means that wildlife migrate to the relatively less dense area (see e.g. Pulliam 1988). The animals roam freely between the sub-areas, because there are no physical obstructions, e.g. fencing, separating the parkland from the open area. It is further assumed, as already mentioned, that wildlife harvesting only takes place when the species are outside the protected area.

In the following, some restrictive assumptions are made about the quality of land. First, land is considered homogenous, i.e. every part of the ecosystem is equally suitable as habitat for wildlife. Secondly, although agricultural production takes place in the outer area, we assume no incompatibility in land use. That is, there is no negative impact on the living conditions of wildlife of adding more land to agricultural production. However, in reality, unexploited land may generate more wildlife than agricultural land as land clearing, fencing and so forth result in poorer conditions and smaller refuges for wildlife (see Norton-Griffiths 2000). This may be captured, as in Huffaker et al. (1992), by assuming a smaller intrinsic growth rate of wildlife in the outer area. Skonhoft (1999) and Bulte and Horan (2000) present an alternative approach where the carrying capacity in the outer area is specified as a decreasing function of the amount of land utilized in agricultural production or other alternative uses. However, in order to capture the main ideas, no incompatibles in land uses are assumed to be present here.

The purpose of this paper is to analyse the conservation effect of altering the size of the protected sub-area. An increase in the size of this area is followed by the same reduction in the outer area. Therefore, the ecological part of the model, which is identical to the system presented by Hannesson (1998), specifies the migration rates between the sub-areas as dependent on the size of the protected area. Technically, the probability of an animal being located in the protected area or the outer area equals the size of the respective areas. Now, assume that the size of the ecosystem is normalized to one. A fraction $w$ of this area is gazetted as protected land and consequently, $(1 - w)$ is the size of the outer area. Let $X(t)$ be the density of the stock in the protected area at time $t$, while $Y(t)$ is the density in the outer
area at time $t$. In the following, the time subscript is omitted. The size of the wildlife stock in the protected area and the outer area is $wX$ and $(1-w)Y$ respectively, so that the aggregate stock equals $S = wX + (1-w)Y$.

Let $z \geq 0$ be the moving rate of wildlife, i.e. the rate at which an animal moves to bring it to the nearest suitable spot for grazing or prey. $z = 0$ means that the animals do not move around at all. The rate of dispersal of the stock in the protected area is then $zwX$. $(1-w)$ is the probability that the moving animal will migrate out of the reserve. The migration out of the reserve is therefore $z(1-w)wX$. To translate this into change in stock density in the outer area, we divide it by the size of that area. Hence, the increase in the density of wildlife in the outer area due to migration from the protected area is $zwX$. Similarly, $zw(1-w)Y$ is the migration from the outer area onto protected land. The reduction in the density of wildlife in the outer area due to migration to the conservation area is then $zwY$. In the same way, the change in the stock density in the conservation area due to migration from the outer area is $z(1-w)Y$, while the stock density in the conservation area is reduced by $z(1-w)X$ due to migration to the outer area.

Because of the non-incomaptibility of land, the carrying capacity per square kilometre is equal in each sub-area and therefore normalized to one. Natural growth is assumed to take place in both sub-areas and is given by a logistic growth function. The rate of change in the density of wildlife in the two sub-areas is given by:

\begin{align}
(1) \quad \frac{dX}{dt} &= rX(1-X) + z(1-w)(Y-X) \\
(2) \quad \frac{dY}{dt} &= rY(1-Y) + zw(X-Y) - h
\end{align}

Here, $h$ is the harvesting rate, while $r$ is the intrinsic growth rate. Note that the rate of change in the aggregate stock is given by $\frac{dS}{dt} = w\frac{dX}{dt} + (1-w)\frac{dY}{dt}$. If the whole ecosystem

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3 The moving rate may also be related to breeding. For instance, animals with slow growing non-precocial young are obliged to stay within a small area to breed. This is the case for carnivores like lions and hyenas. In contrast, ungulates with precocial young do not need to stay in one place because the young can follow the mother within an hour or so of birth (Caughley and Sinclair 1994).

4 The dispersal functions of (1) and (2) are somehow different from those presented by Conrad (1998), Skonhoft (1999) and Sanchirico and Wilen (2001). This is explained and justified in Appendix 1.
is gazetted for wildlife protection \((w=1)\), then \(S = X\) and \(\frac{dS}{dt} = rS(1-S)\). In the same way, with no protection \((w=0)\) \(S = Y\) and \(\frac{dS}{dt} = rS(1-S) - h\). Throughout the analysis it is assumed that \(0 < w < 1\).

In absence of man, \(h = 0\), Figure 1 illustrates the isoclines of (1) and (2). This figure is quite similar to the graphical demonstration of a two-patch density-dependent system in Skonhoft (1999) and Sanchirico and Wilen (2001) (see also Appendix 1). Here, the marginal migration rates are below the maximum specific growth rate so that \(1 - zw/r > 0\) and \(1 - z(1-w)/r > 0\). This makes sense because a system with a migration exceeding the intrinsic growth is likely to fail in sustaining an ecological equilibrium with positive biomass within each patch. The \(X\)-isocline is a strictly convex function of \(X\) and runs through the point \((1,1)\). Above the isocline, the natural growth and dispersion from the outer area exceed the dispersion out of the reserve so that \(\frac{dX}{dt} > 0\). The opposite occurs below the isocline. The \(Y\)-isocline is a strictly concave function of \(X\) and runs through the point \((1,1)\). Below the isocline, \(\frac{dY}{dt}\) is positive, whereas above, \(\frac{dY}{dt}\) is negative.

**Figure 1:** Ecological equilibrium in absence of man.

In absence of man and migration below the intrinsic growth, it will therefore be a unique equilibrium with stock densities equal to one. Hence, the aggregate stock equals one in
equilibrium. It can be demonstrated that the equilibrium is stable\textsuperscript{5}. The feasible region for an interior solution of the system is found in the area closed by the isoclines and the axes. The size of this region depends on the biological parameters of the model. If the moving rate \( z \) approaches zero, i.e. a system of closed and independent patches, the individual stocks collapse to zero or the carrying capacity of its area. If the moving rate increases so that \( zw/r \) (or \( z(1-w)/r \) ) approaches one, the feasible region reduces and collapses to a lens with intersection at \((a,0)\) (or \((0,b)\)) and \((1,1)\), where \( a = 1 - z(1-w)/r \) (and \( b = 1 - zw/r \)).

Throughout this analysis it is assumed that the patches are interdependent, i.e. \( z \) is positive. Introducing human activity as a fixed positive harvesting rate in this system shifts the \( Y \)-isocline in Figure 1 down, i.e. human activity reduces the density in the outer area for a given stock density in the game reserve. Consequently, due to a relative dense population in the protected area, wildlife disperses to the outer area, which causes a decline in \( X \). This illustrates that harvesting in the outer area spells over to the protected area. The system settles in a new stable equilibrium where both stock levels are smaller than their respective carrying capacities and \( Y < X \). Throughout the remaining analysis it is assumed that the system is in ecological equilibrium \((dX/dt = dY/dt = 0)\).

### 3. The economy

The ecological steady state above was established for a given harvesting rate. However, the harvesting activity is determined by economic considerations, which are outlined in this section. Before we move to the economic part, it is convenient to establish the different ways in which land is utilized in this model. Recall that land is utilized by two agents. First we have the park manager who utilizes the protected area in production of non-consumptive tourism services (see section 1). Second, we have the local people who have legal rights to utilize the outer area in agricultural production and wildlife hunting.

The State may instruct the park manager, for presumed conservation purposes, to expand the protected area. This can only take place by implementing parts of the outer land into the park area. There are two ways in which the State may accomplish this, and these are related to the type of land as discussed in section 1. First, if present, the State can protect non-cultivated

\footnote{The stability conditions read \( \partial f(1,1)/\partial X + \partial g(1,1)/\partial Y = -(2r+z) < 0 \) and 

\( (\partial f(1,1)/\partial X)(\partial g(1,1)/\partial Y) - (\partial f(1,1)/\partial Y)(\partial g(1,1)/\partial X) = r(r+z) > 0 \).}
land. For the local people living in the outer area, this policy represents limited user rights to wildlife, but no restriction on the rights to exploit land already cultivated for agricultural use. Technically, this will be the case where the constraint on agricultural land is non-binding. Second, in marginal areas, the State must expropriate cultivated land in order to expand the protected area. For the local people, this procedure restricts their user rights to agricultural land as well as their user rights to wildlife. This will be the case when the constraint on agricultural land use is binding. The two scenarios of protected area expansion will be analysed in section 4.1 and 4.2, respectively.

The next step is to present a formal model of the hunting and agricultural decision of the local people. Throughout the analysis the local people are considered a homogenous group of peasants and, in line with traditional reasoning, it is assumed that the elders are in charge of the group’s activities (Marks 1984). The number of animals harvested $H$ is specified as an increasing function of labour effort $E_h$, stock density $Y$, and the size of the outer area $(1-w)$, as $H = H(E_h, Y, 1-w)$. In the following, $H$ is considered linear in $E_h$ and $Y$, but concave in $(1-w)$. The wildlife offtake is specified as

\[ H = f(1-w)E_h Y \]

Here, $f(1-w)$ is interpreted as the catchability coefficient. $f' > 0$ because additional areas are open for hunting as the outer area expands. $f'' < 0$ reflects that the marginal catchability decreases with the size of the hunting ground due increased distance from the home region and because a larger area is likely to include a more diverse and less advantageous

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6 This formulation of $H$ differs from Skonhoft (1999) and Pezzey et al. (2000) who use a Schaefer specification $H = qE_h y / K_y$, where $q$ is the catchability coefficient, $y$ is the stock size, and $K_y$ is the carrying capacity of the outer area. They further assume that $K_y$ is an increasing function of the size of the outer area. That is, in contrast to the present model, and for a given $E_h$, the wildlife offtake decreases with the size of this area due to reduced stock density. However, the ecological system presented by Skonhoft and Pezzey et al. differs from the present system in that they allow for increases in the size of the outer area without altering the size of the protected land (see Appendix 1). Then, by assuming that wildlife roams onto the ‘new’ land, an increase in the habitat size in the outer area has a direct negative effect on stock density $y / K_y$, for a given stock size $y$. Hence, they assume that the impact on wildlife offtake is negative, simply because a less dense population is harder to catch. Here, however, there is no direct effect on stock density $Y$ of increasing the size of the outer area. That is because the outer area increases by altering a non-physical border between the protected land and the outer land.
topography. To translate the offtake into change in the wildlife density in the outer area in (2), we divide $H$ with the size of this area, so that $h = H / (1 - w)$ is the hunting rate.

The next step is to present the agricultural activity, interpreted as crop production, of the local people. The agricultural production is a function of labour $E_A$ and land $L$ as $A(E_A, L)$ (see below). The endowment of labour is normalized to one and, hence, the constraint on labour use reads

\begin{equation}
E_h + E_A \leq 1,
\end{equation}

Throughout the analysis it is assumed that the constraint is binding. A trade-off between wildlife hunting and agricultural production is present in that the opportunity cost of wildlife harvesting equals the foregone return from agricultural production (and vice versa).

As mentioned in section 2, land is homogeneous as habitat for wildlife. It is therefore convenient to consider land as homogeneous for agricultural uses as well. This means that additional land is equally suitable in agriculture as previously exploited land (see also Bulte and Horan 2000). Then, proportional increases in labour effort and land use must cause output to increase by the same proportion. Consequently, the average returns to land $A/L$ and labour $A/E_A$ are left unchanged. The agricultural production function is therefore characterised by constant returns to scale and specified as a Cobb-Douglas type as follows (Hayami and Ruttan 1985).

\begin{equation}
A(E_A, L) = \mu E_A^\alpha L^{1-\alpha},
\end{equation}

Here, $\mu > 0$ is a technology parameter and $0 < \alpha < 1$ is the output elasticity of labour.

Because of its homogeneity, diminishing return to land is not caused by taking inferior land into production, but by reduced labour effort per unit of land. The total area available for

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7 Following Barrett and Arcese (1998), Lopez (1998), Skonhoft (1998), Skonhoft and Solstad (1998), and Bulte and van Soest (1999), the local people are the only agents involved in wildlife hunting in the outer area. That is, we ignore the possibility of outsiders and professional gangs area entering this area for hunting.

8 For linear homogeneous or constant return to scale production functions, the marginal products are independent of scale and depend only on the input proportions.
agricultural production is given by the size of the outer area \((1-w)\). The constraint on land use is therefore given by

\[(6) \quad L \leq (1-w)\]

Investment costs on land, for instance related to clearing and fencing, and costs in cultivation and crop harvesting are ignored in this analysis\(^9\). The only agricultural cost of consideration here is related to damage caused by wildlife roaming on agricultural land. The nuisance stream per unit of land is equal to \(cY\), with \(c > 0\) and fixed\(^10\). Consequently, the total damage of the wildlife roaming on agricultural land is \(cLY\). \(c\) is interpreted as the marginal damage per animal. All else equal, more agricultural land means more nuisances.

When inserting for the effort constraint \((4)\) into the production function in \((5)\), the net benefit function of the local people yields

\[(7) \quad \pi = P_h f(1-w)E_h Y + P_A \mu (1-E_h)^{\alpha} L^{1-\alpha} - P_A cLY,\]

where \(P_h\) and \(P_A\) denote the price of game meat and agricultural output, respectively\(^11\). These prices are assumed fixed throughout the analysis.

As mentioned, the local people have user rights to land and wildlife. This means that they are not granted titles to these resources and, consequently, they face a continuing risk of the State withdrawing their user rights through an expansion of the protected area. The local people have therefore few, if any, incentives to base their wildlife harvesting on long-term considerations. Hence, they do not take the stock of wildlife into account when deciding upon their effort use\(^12\). Technically, this is captured by assuming that the local peasants treat the stock density \(Y\) as exogenous, which is in accordance with one of Smith's models (1975). See

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\(^9\) In reality, however, there will be costs related land clearing, fencing, sowing, fertiliser and pesticide use and so forth. Modelling such costs will not alter the qualitative results of this analysis.

\(^10\) In reality, the local people can perform damage control through fencing, guard patrols and so forth. In the model this would have worked through a changing \(c\). Here, such measures are neglected.

\(^11\) In accordance with the traditions in the past century, it is therefore assumed that no economic compensation is paid to the local people for the loss of access to land and wildlife (Marks 1984, Kiss 1990, Swanson and Barbier 1992, Wells 1992).

\(^12\) Martin (1993) points out how the risk of land expropriation affects landholders. He writes (p. 15): “The influence of the preservationist lobby is a serious disincentive for the landholder contemplating an investment in wildlife as a land use”.  

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also Skenhoft and Solstad (1998). The local people choose the hunting effort $E_h$ and cultivated land $L$ to maximize (7), given the constraint on land use in (6). The Lagrange function reads $V = P_h f(1 - w)E_hY + P_A \mu(1 - E_h)^\alpha L^{1-\alpha} - P_A cLY - \lambda(L - (1 - w))$, where $\lambda$ is the shadow price of land. Equations (8)-(10) yield the first order conditions for maximum when an interior solution for hunting effort is supposed to be present.

\begin{align*}
(8) \quad & P_h f(1 - w)Y = P_A \mu(1 - E_h)^{\alpha - 1} L^{1-\alpha} \\
(9) \quad & P_A \mu(1 - \alpha)(1 - E_h)^{\alpha} L^{-\alpha} = P_A cY + \lambda \\
(10) \quad & \lambda \geq 0; \quad \lambda = 0 \text{ if } L < (1 - w)
\end{align*}

Equation (8) shows that the optimal hunting effort is determined by equality between the marginal product of hunting and the marginal product of labour effort in agricultural production. The decision rule in equation (9) states that the local people will convert land in the outer area to agricultural use until the value of the marginal product of land in crop production equals the marginal cost. The marginal cost consists of the value of the marginal damage per unit cultivated land and the shadow value of land. This value equals zero when the constraint on land use is non-binding, while it is positive for a binding constraint (see (10)).

The economic equilibrium condition in (9) is illustrated graphically in Figure 2. Here, the marginal benefit and costs of land cultivation are measured along the vertical axis. Consider the case of intersection between the marginal cost curve and the marginal benefit curve, which results in $L = L' < (1 - w)$. This means that the local people choose not to utilize the whole outer area for cultivation and, hence, $\lambda = 0$. However, a positive shift in agricultural productivity $\mu$ and/or a downward shift in the marginal crop damage caused by a lower $c$ or $Y$, increase the demand for cultivated land. In Figure 2, this is illustrated by an upward shift in the marginal benefit curve caused by a higher $\mu$. For a given land use at $L'$, the marginal benefit of cultivated land exceeds the marginal crop damage by the positive shadow value of land. The local people respond by converting additional land to agricultural production. In the new equilibrium, $\lambda$ remains positive if the local people utilize the whole outer area for
agricultural production, \( L = (1-w) \), reflecting that land is a scarce factor. This will be the case if \( \mu \) is ‘high’, while \( c \) and \( Y \) are ‘low’. In addition, an increase in the size of the protected area \( w \) shifts the vertical curve denoting the size of the outer area to the left and increases the shadow value of land.

![Figure 2: The maximum condition for the amount of cultivated land \( L \). \( Y \) and \( E_h \) are fixed.](image)

Equation (8)-(10) together with (1) and (2) (with \( dX/dt = dY/dt = 0 \)) determine the optimal hunting effort, optimal use of agricultural land and the aggregate stock in ecological equilibrium. The following section describes the two scenarios of a non-binding and a binding constraint on land use.

4. The impact of protected areas on wildlife conservation and local welfare

Above we established the first order conditions maximizing the local people’s benefit from wildlife harvesting and agricultural production. In addition, we studied the conditions under which the system settles in a solution where the constraint on land use is binding. The next step is to investigate the impact on wildlife conservation and the welfare of the local people of protected areas. It turns out that the effects are strictly dependent on whether the state gazettes non-cultivated land or expropriates cultivated land, i.e. whether the constraint on land use is non-binding or binding. Section 4.1 considers the case of a non-binding constraint on land use, while the constraint is binding in section 4.2.
4.1 The constraint on land use is non-binding

Assume that the protected area is relatively small, so that land is not a scarce factor in the outer area. Then, the local people settle with an interior solution for cultivated land, \( L < (1 - w) \), where the marginal return from land equals the marginal damage in (9) and \( \lambda = 0 \). Combining (8) and (9) (with \( \lambda = 0 \)) and solving for \( Y \) gives

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(11) \quad Y = \mu \left[ \frac{P_x}{P_k} \frac{\alpha}{\mu} f(1 - w) \right]^{\frac{\alpha}{1 - \alpha}} \left[ \frac{1 - \alpha}{c} \right]^{-\alpha}
\]

Equation (11) alone determines the equilibrium stock density in the outer area \( Y \). This means that \( Y \) is determined by the (fixed) economic parameters and the park size only. The result stems on the constant return to scale in the agricultural production function. Accordingly, the input proportion \( (1 - E_k) / L \) is constant and independent of the scale of crop production for fixed model parameters. This means that we cannot solve the optimal input combination and the resulting crop output from the economic first order conditions. Instead the stock density in the outer area is determined by the economic conditions, while the hunting effort and the stock density in the protected area \( X \) are solved from the ecological equilibrium in (1) and (2) (with \( dX / dt = dY / dt = 0 \)). Although the systems are quite different, the same result occurs in Sanchirico and Wilen’s model (2001). The aggregate stock follows from \( dS / dt = 0 \). Finally, the amount of cultivated land \( L \) is determined through the fixed input proportion.

The economic and ecological effects of an expansion of the protected area is found by taking the total differential of (11) and (1) and (2) (with \( dX / dt = dY / dt = 0 \)) (for details, see Appendix 2). With a non-binding constraint on land use, the state gazettes non-cultivated land when expanding the protected area. This means that more habitat protection displaces the local people from pre-hunting areas without restricting their rights to utilize land in agricultural production. The effect on hunting effort and land use is unclear. However, equation (11) demonstrates that an expansion of the protected area increases the stock density in the outer area. This gives more dispersal into the protected area and leads to a more dense population here. Because of increased stock densities, there must be a positive effect on the

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\[\text{13 In addition, an expansion of the protected area is feasible through expropriation of agricultural land in the outer area. In this case, the local people are displaced from both pre-hunting areas and pre-cultivated land. However, because land is homogeneous and there is no investment cost in land, the local people simply move their agricultural production to the pre non-cultivated areas. Therefore, as long as the constraint on land use is non-binding, the conservation-effect of gazetting non-cultivated or pre-cultivated land is identical.}\]
aggregate stock of gazetting non-cultivated land for wildlife protection. The conclusion is therefore that more protection gives more wildlife even if the local people increase their hunting effort.

The next step is to investigate how this intervention affects the economic conditions of the local people. Recall from fishery economics that Sanchirico and Wilen (2001) claim that a marine reserve may benefit the fishermen through increased aggregate catch, if increased dispersal from the marine reserve compensates for the foregone harvest in the reserve. In the present model, however, the effect on the wildlife harvest is not an adequate measure of the impact on the economic conditions of the local people. Instead we need to investigate the effect on the net income in (7) in optimum. This is done by taking the differential of (7) with respect to \( w \), when accounting for the effect working through a changing stock density (see Appendix 2). In contrast to marine reserves, it turns out that there is no potential for improved human welfare of expanding a protected area. There is a direct negative effect working through the reduced income from hunting due to restricted hunting rights. While the expansion of the protected area increases the stock density in the outer area, this cannot offset the direct negative effect. This means that positive effect on the wildlife density cannot compensate the local people for the foregone hunting ground. This negative income effect is strengthened by the fact that a more dense wildlife population imposes further damage to agricultural crops. Gazetting non-cultivated land for habitat protection will therefore promote wildlife conservation at the expense of human welfare. See also Table 1 in section 4.2.

4.2 The constraint on land use is binding

Assume that land is a scarce factor to the local people living in the outer area. This is the case if, relatively speaking, the protected area is widespread, the agricultural productivity is high, and/or the marginal wildlife-induced damage to crops is low. In such a scenario, the local people settle in a corner solution for cultivated land, i.e. \( L = (1 - w) \) and \( \lambda > 0 \) from (10). Hence, the marginal return on land cultivation exceeds the marginal damage in (9). See also Figure 2. Inserting \( L = (1 - w) \) in (8) gives

\[
(12) \quad P_h f(1 - w)Y = P_A \mu_\alpha (1 - E_h)^{\alpha - 1} (1 - w)^{1-\alpha}
\]
Equation (12) states that the local people will divert effort to hunting until the marginal benefit of hunting equals the marginal cost. The marginal cost reflects the alternative cost of hunting, namely the foregone return on agricultural production. In contrast to the non-binding scenario, the hunting effort $E_h$ is now determined from the economic first order condition for a given wildlife density $Y$. This is because the amount of cultivated land $L$ is fixed at $(1 - w)$ and, hence, the hunting effort follows from the fixed input proportion 

$$(1 - E_h)/(1 - w) = \left[ P_A \mu \alpha / (P_h f(1 - w)Y) \right]^{1/\alpha}. $$

The economic equilibrium for a given wildlife density in the outer area is illustrated in Figure 3. Here, the marginal benefit from hunting (MBH) is measured along the left-hand vertical axis, while the marginal benefit from agricultural production (MBA) is measured along the right-hand axis. The optimal hunting effort is determined by the intersection between the two curves.

![Figure 3:](image)

**Figure 3:** The maximum condition for the hunting effort $E_h$. The constraint on land is binding. $Y$ is fixed, $w_0 < w_f$.

Equation (12) shows that an expansion of the protected area, i.e. an increase in $w$, has a direct negative effect on the marginal return on labour in agriculture. This is because the State must expropriate cultivated land in order to expand the protected area and this is new compared to the non-binding case. Consequently, the MBA curve in Figure 3 shifts down, which works in the direction of increased hunting effort. However, restricted hunting rights reduce the
marginal return on hunting, which shifts the MBH curve down. This leads the local people to
direct less effort towards hunting. The total effect on hunting effort is therefore unclear. If
restricted hunting rights affect the local people less than reduced cultivated land, i.e.

$$\left| \frac{\partial^2 H}{\partial E_h \partial w} \right| < \left| \frac{\partial^2 A}{\partial (1 - E_a) \partial w} \right|,$$

they will reply to habitat protection by directing more
effort to hunting. This is illustrated in Figure 3 by a stronger downward shift in the MBA
curve.

If the harvesting effort changes, however, both the wildlife densities and the aggregate stock
will change, since they all depend on $E_h$. The first order condition in (12) and the ecological
equilibrium in (1) and (2) (with $dX/dt = dY/dt = 0$), determine simultaneously the optimal
hunting effort and the stock densities. Again, the aggregate stock follows from $dS/dt = 0$.
Differentiation of these equations with respect to $w$ gives the impact of a protected area
expansion (for details, see Appendix 2). In contrast to section 4.1, it turns out that the effect
on wildlife conservation is ambiguous. The mechanism works as follows. Consider first the
direct effect. Because more animals are protected from hunting for a given hunting effort, the
aggregate stock $S$ increases. Second, we have the indirect effect working through the hunting
decision of the local people. As discussed above, restricted user rights to wildlife reduce the
marginal return from labour in hunting, while restricted user rights in agriculture reduce the
marginal return from labour in crop production. These have opposite effects on the hunting
effort. As argued, if the local people respond less to the closed hunting ground than the loss of
cultivated land, they will divert more labour effort towards wildlife exploitation. This will be
the case in areas where the local people rely heavily on agriculture as a land use so that
expropriation of cultivated land represents a considerable income loss. In this case, the
indirect effect on wildlife conservation implies less wildlife in the outer area and a smaller
aggregate stock. The total effect on wildlife conservation is therefore unclear. Contrary to the
non-binding scenario, this demonstrates that protected areas which restrict the user rights to
wildlife and cultivated land may reduce the degree of wildlife conservation. This obscure
result occurs because the constraint on land use in agriculture is binding, meaning that there is
an alternative use of the protected land in agricultural production.

The final part of this analysis is to investigate how expropriation of cultivated land affects the
economic conditions of the local people living with wildlife. Again, differentiation of (7) with
respect to $w$, when taking into account the effect working via a changing wildlife stock, gives
the effect on local income in optimum. There are three possible outcomes regarding wildlife conservation and local welfare, and these are summarised in the second column of Table 1. Assume first that an expansion of the protected area fails and results in a smaller degree of wildlife conservation. As reported in the table, this results in poorer economic conditions for the local people. Therefore, this model predicts that where protected areas have failed in promoting wildlife conservation, they have also caused a degradation of human welfare

Table 1: The welfare effect of an increase in \( w \) in equilibrium.

<table>
<thead>
<tr>
<th></th>
<th>Non-binding constraint on land use</th>
<th>Binding constraint on land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>( + )</td>
<td>( + )</td>
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<tr>
<td>( \pi )</td>
<td>( + )</td>
<td>( + )</td>
</tr>
<tr>
<td></td>
<td>( z \text{ low} ) or ( z \text{ high} )</td>
<td>( z \text{ high; } c \text{ low, } P_h \text{ high} )</td>
</tr>
</tbody>
</table>

* The welfare effect is conditioned by the impact on wildlife conservation.

** Here, it is assumed that the wildlife stock in the outer area increases, \( d(1-w)Y/dw > 0 \). The magnitude of \( dY/dw \) increases with \( z \). \( z \text{ 'high' is interpreted as the case where increased dispersal from the protected area compensates for the foregone hunting ground. } z \text{ 'low' means that dispersal from the protected area cannot compensate for the foregone hunting ground.}

An expansion of the protected area promotes wildlife conservation if the local people respond to restricted user rights by devoting more effort to agricultural production. As shown in Table 1, the resulting effect on local welfare is ambiguous and dependent on the moving rate of wildlife and the benefit and cost of living with wildlife. First, the income from hunting is reduced if increased dispersal from the protected area cannot compensate for the foregone return from the pre-hunting ground. This will be the case if the moving rate \( z \) is ‘low’. Then, an expansion of the protected area promotes wildlife conservation at the expense of human welfare. Although the systems are quite different, the same conclusion is drawn by Sanchirico and Wilen (2001). Second, the income from hunting increases if increased dispersal from the protected area exceeds the foregone return from the pre-hunting ground. As for marine reserves, this requires a ‘high’ moving rate \( z \). Still, and in contrast to marine reserves, there is a negative impact on human welfare as more animals in the outer area cause

14 Obviously, protected areas cannot promote local welfare at the expense of wildlife conservation. In the case of a binding constraint on land use and \( dS/dw<0 \), \( d\pi/dw<0 \) must indicate that the local people were utilizing ‘too much’ land for agricultural production prior to the expansion of the protected area. In this case, profit-maximization requires that the local people choose an interior solution for cultivated land (i.e. a non-binding constraint on land use).

15 Here, the effect on local welfare stems from the assumption that more wildlife in the entire area is a result of higher densities and stock sizes in both sub-areas. See Table 1.
more damage to agricultural crops. If the cost of living with wildlife is sufficient above the benefit (i.e. \( c \) ‘high’ and \( P_h \) ‘low’), wildlife conservation is promoted at the expense of human welfare. On the other hand, the welfare effect is positive if the benefit of living with wildlife exceeds the cost.

The results summarised in Table 1 demonstrate that there is a potential for a double payoff to emerge where both wildlife and the local people benefit from an expropriation of cultivated land. On the other hand, while the degree of wildlife conservation increases, the welfare of the local people reduces when the State gazettes non-cultivated land. The reason for these adverse effects on human welfare lies in the assumed constant return to scale in the agricultural production function in (5). In presence of this formulation, the equilibrium stock density in the outer area is determined by the size of the protected area and the fixed economic parameter values when the constraint on agricultural land is non-binding. Hence, in this case, the stock density in the outer area is independent of the hunting effort and the stock density in the protected area. The implication of this is that the welfare of the local people in optimum is only influenced by the direct effect of a changing \( w \) and the following effect working through a changing \( Y \). That is, the welfare in optimum is independent of how a changing \( w \) affects \( E_h \) and \( X \) and, thereby, the dispersal from the protected area. The mechanism at work is quite different when the constraint on agricultural land is binding. Then, the equilibrium stock density in the outer area is affected by the hunting effort, the density in the protected area and the dispersal from this area onto the open land. In presence of this interdependency in equilibrium, the local people will benefit from any increased dispersal from the protected area. Precisely this effect gives the potential for a double payoff to emerge from expropriation of cultivated land.

5. Discussion and concluding remarks

Establishing national parks and other types of protected areas have been the traditional approach to natural resource conservation in Africa. However, protected areas have during the past decade been viewed as having failed to preserve wildlife on that continent (Kiss 1990, Barrett and Arcese 1995, Gibson and Marks 1995). Martin (1993) explains this failure by claiming that the budgets and funds are too small to finance the activities necessary to combat illegal hunting on protected land. This paper gives an alternative explanation of what may have caused the failure of protected areas. In contrast to Martin, the analysis demonstrates that
protected areas may cause wildlife degradation, even when anti-poaching law enforcement succeeds in eliminating illegal hunting in the gazetted area.

What has been analysed in this paper is a wildlife management system where land is gazetted as a protected area in order to conserve wildlife. The ecosystem of consideration is of fixed size and consists of two sub-areas – the protected area and the outer area – over which the wildlife stock disperses. The outer area is settled by humans who utilize this area for wildlife hunting and agricultural production. The local people have user rights to wildlife and land for cultivation in the outer area, but they do not have the property rights. Related to the land use in the outer area, this paper distinguishes between two ways of gazetting land. First, the state gazettes non-cultivated land. This policy restricts the local people’s user rights to wildlife by withdrawing former hunting grounds without interfering with their rights to cultivate land. Technically, this is the case where the constraint on land use is non-binding. Second, the state expropriates cultivated land, a policy which restricts the local people’s user rights to both wildlife and land for cultivation. In this scenario, the constraint on land use is binding.

The main point of the analysis is to find out under which conditions protected areas may fail in conserving wildlife. In addition, the analysis focuses on the economic impact of protected areas by investigating the effect on human welfare. It is shown that the actual outcome of habitat protection depends critically on whether the constraint on land use is binding. Only when the constraint is non-binding will protected areas with certainty increase the wildlife stock. This scenario is quite similar to a marine reserve creation with no alternative use of the marine habitat. However, in contrast to marine reserves, there is no potential for improved human welfare of gazetting non-cultivated land.

Protected areas work quite differently from marine reserves when the constraint on land use is binding and the State expropriates cultivated land for wildlife protection. This discrepancy stems from the alternative use of protected land as land for agricultural production. The model demonstrates that an expansion of the protected area causes a degradation of wildlife if the impact of lost cultivated land is high relative to the impact of lost hunting grounds. If this is the case, the local people will compensate themselves by devoting more time on hunting. In contrast, if the impact of less cultivated land is low relative to the impact of restricted hunting grounds, the local people respond to land expropriation by devoting more time on agricultural production and, thereby, reduce the time spent hunting. In this case, an expansion of the
protected area promotes wildlife conservation. Then, a double payoff will emerge if the wildlife-induced damage to agricultural crops is small and the increased dispersal from the protected area compensates for the foregone wildlife harvest on the pre-hunting grounds.

It is important to note, however, that this model simplifies the interaction between the wildlife population dynamics and the human activities. In the ecological part of the model, the quality of land as habitat for wildlife is considered constant and independent of the agricultural use in the outer area. In reality, however, unexploited areas may generate more wildlife than cultivated land. Therefore, the analysis overlooks a positive effect on wildlife conservation as protected areas displace agricultural activities in the wildlife habitat. However, the weakness of omitting this connection becomes less apparent as there is assumed to be no cost in converting land to agricultural use in the economic part of the model. In reality, investing in land is costly and time consuming. This strengthens the negative impact on the local people of an expansion of the protected area and may therefore lead to wildlife degradation. Implementing investment costs may even cause failure when the constraint on land use is non-binding.

It is also important to notice the lack of economic compensation to the local people of restricted user rights to wildlife and land. With the growing recognition of the failure of protected areas, international conservation organizations and African governments have developed a new approach to wildlife conservation, namely the Integrated Conservation and Development Project (ICDP) (see Kiss 1990, Barbier 1992, Wells and Brandon 1992, Barrett and Arcese 1995, Barrett and Arcese 1998, Songorwa 1999). The central issue in ICDPs is benefit sharing, or compensation for restricted user rights, for instance through income transfers from the tourism sector. Neglecting such compensation schemes may suppress a potential positive effect on local welfare of protected areas. Still, because there is no broad-based evidence in the literature suggesting that existing ICDPs can fully compensate the local people for the loss of user rights, such benefit-sharing schemes have not been taken into account in this paper (see also Barrett and Arcese 1995, Gibson and Marks 1995, Emerton 1998, Songorwa 1999).
References


Appendix 1

Migration between a protected area (or marine reserve) and an outer area is also of focus in Conrad (1998), Skonhoft (1999), and Sanchirico and Wilen (2001). The point of departure for these analyses is that the migration is density dependent, i.e. the net in/out migration of the protected area depends on the ratio of the stock size to the carrying capacity within each sub-area. This means that increased carrying capacity in one sub-area, which reduces its stock density, leads to reduced migration out of this particular area. Skonhoft (1999) interprets the carrying capacity of each sub-area as proportional to the size of the respective area (see also Pezzey et al. 2000). In addition, the size of the ecosystem is not fixed, meaning that it is possible to increase the size of one sub-area without altering the size of the other area. This is illustrated in the figure below, where the size of the protected area increases as indicated by the left-pointing arrows. In this system, more protected land means more space for the animals, which has a direct negative effect on the stock density in the protected area. Consequently, the migration into the protected area increases due to a relatively low density here.

In the present analysis, the ecosystem is of a fixed size. This means that an increment in the protected area takes place by altering the (non-physical) border between the park and the outer area. Consequently, more protected land is followed by an equal reduction of the open area, as illustrated by the right-pointing arrows in the figure below.
In this system, the effect on wildlife migration of altering the size of the protected area is somehow different from Skonhoft’s model (1999). Here, there is no direct effect on the stock densities. Instead, expanding the protected area reduces the probability of an animal in the pre-protected area moving into the outer area. Recall that this probability is given by \((1 - w)\).

For a given stock density \(X\), this effect works in the direction of reduced migration out of the protected area. At the same time, for a given stock density \(Y\), the probability \(w\) that an animal in the pre-outer area is included in the protected area increases. However, when the outer area shrinks, its stock size \((1 - w)Y\) is reduced for a given \(Y\). Translated into a changing stock density in the protected area (i.e. \(zw(1 - w)Y/w = z(1 - w)Y\), see the main text), these latter effects work in the direction of reduced migration into the protected area. A fixed positive harvesting rate in the outer area gives \(X > Y\) (see main text), and, consequently, the total effect on net migration into the protected area is positive.

Both Conrad (1998) and Skonhoft (1999) consider the rate of change in biomass \(x\) and \(y\) in two areas with different carrying capacities \(K_x\) and \(K_y\) and with a dispersal function given as \(s(x/K_x - y/K_y)\). Skonhoft extends this dispersal function by taking into account the fact that dispersion due to different sex and age composition of the two sub-populations can be skew. The function is therefore given by \(s(\beta x/K_x - y/K_y)\). Sanchirico and Wilen (2001) define the stock densities as \(X = x/K_x\) and \(Y = y/K_y\) and specify the dispersal function as \(s(X - Y)\). In the present analysis, the carrying capacities per square kilometre equal unity so that \(X = x/w\) and \(Y = y/(1 - w)\), \(\beta\) equals 1, and the migration rate \(s\) equals \(zw(1-w)\).
Appendix 2

1. Non-binding constraint on land use

Taking the total differential of the ecological equilibrium \( dX / dt = dY / dt = 0 \) in (1) and (2) yields

\[
\begin{bmatrix}
    r(1-2X) - z(1-w) & z(1-w) \\
    zw & r(1-2Y) - zw - f(1-w)E_h/(1-w)
\end{bmatrix}
\begin{bmatrix}
    dX \\
    dY
\end{bmatrix}
\]

\( (A1) \)

\[
+\begin{bmatrix}
    0 \\
    f(1-w)Y/(1-w)
\end{bmatrix}
\]

\[dE_h\]

The determinant

\[D = [r(1-2X) - z(1-w)] [r(1-2Y) - zw - f(1-w)E_h/(1-w)] - z^2w(1-w)\]

is positive from the condition of ecological stability. Figure 1 shows that a given positive harvesting effort shifts the Y-isocline down for a fixed positive wildlife density in the protected area. Consequently,

\[\frac{dY}{dE_h}\bigg|_{dX=0} = \left( \frac{f(1-w)Y/(1-w))}{r(1-2Y) - zw - f(1-w)E_h/(1-w)} \right) < 0,\]

meaning that the denominator is negative. The system settles in a new ecological equilibrium with reduced densities. It follows from \((A1)\) that

\[\frac{dY}{dE_h} = [r(1-2X) - z(1-w)] f(1-w)Y / D(1-w) < 0\].

The differential of \((11)\) together with \((A1)\) gives the comparative static results in the case of a non-binding constraint on land use as

\[
\begin{bmatrix}
    r(1-2X) - z(1-w) & 0 \\
    zw & - f(1-w)Y/(1-w)
\end{bmatrix}
\begin{bmatrix}
    dX \\
    dE_h
\end{bmatrix}
\]

\( (A2) \)

\[
= \begin{bmatrix}
    z(Y-X) - z(1-w)\alpha f'(1-w)Y/f'(1-w) \\
    \rho
\end{bmatrix}
\]

\[dw\]

where the determinant of the system \([-r(1-2X) - z(1-w)] f(1-w)Y/(1-w)\) is positive.
The sign of \( \rho = -\left[r(1 - 2Y) - zw - f(1 - w)E_h / (1 - w)\right]g'(1 - w)Y / f(1 - w) + z(Y - X) - \left[f'(1 - w) - f(1 - w) / (1 - w)\right]E_h Y / (1 - w) \) is unclear. The corresponding change in the aggregate stock density equals \( dS = wdX + (1 - w)dY - (Y - X)dw \) where \( dY \) is given from the differentiation of \( (11) \) and \( dX \) is given from \( (A2) \).

The input proportion in agricultural production is found by inserting \( (11) \) in \( (8) \) (or \( (9) \)) and equals \( (1 - E_h) / L = P_\alpha c / [P_h f(1 - w)(1 - \alpha)] \). Differentiation of this with respect to \( L, E_h, \) and \( w \) gives

\[
(A3) \quad dL = -[L / (1 - E_h)]dE_h - [Lf'(1 - w) / f(1 - w)]dw
\]

Taking the differentiation of \( (7) \) with respect to \( w \), and taking into account the effect working through \( Y \), gives the effect on local welfare of expanding the protected area.

\[
(A4) \quad \partial \pi / \partial w = P_h E_h \left[f(1 - w)dY / dw - f'(1 - w)Y\right] - P_\alpha cLdY / dw
\]

Here, the term \( f(1 - w)dY / dw \) reflects that the income from hunting increases due to increased stock density, while \( f'(1 - w)Y \) reflects reduced income from hunting due to the foregone return from the pre-hunting ground. It is easy to show that the net effect on the income of the local people is negative. Inserting for \( dY / dw = \alpha f'(1 - w)Y / f(1 - w) > 0 \) from the differentiation of \( (11) \) with respect to \( w \) gives

\[
d\pi / dw = -f'(1 - w)Y[P_h E_h(1 - \alpha) + \alpha P_\alpha cL / f(1 - w)] < 0.
\]

2. Binding constraint on land use

Recall that \( dS = wdX + (1 - w)dY - (Y - X)dw \), where \( dX \) and \( dY \) are given from \( (A1) \).

With a binding constraint on land use, the comparative static results are derived from differentiation of this and \( (12) \) with respect to \( w \)

\[
(A5) \quad \begin{bmatrix} 0 & \delta^* \\ 1 & \sigma \end{bmatrix} \begin{bmatrix} dS \\ dE_h \end{bmatrix} = \begin{bmatrix} \tau \\ \theta \end{bmatrix} dw
\]
The sign of
\[
\delta = -P_d\alpha(1-\alpha)\mu(1-E_h)^{-\alpha-2}(1-w)^{1-\alpha} + P_hf(1-w)^2 Y[r(1-2X) - z(1-w)] / D(1-w)
\]
is negative so that the determinant is positive. The sign of
\[
\sigma = -f(1-w)Y[r(1-2X) - z(1-w) - Zw] / D
\]
is positive, while the signs of
\[
\theta = (X-Y) - [z(1-w)(X-Y) + E_hY(f'(1-w) - f(1-w)/(1-w))]r(1-2X) - z(1-w) - Zw] / D
\]
\[
\tau = P_hf'(1-w)Y - P_d\alpha(1-\alpha)\mu(1-E_h)^{-\alpha-1}(1-w)^{-\alpha} + P_hf(1-w)z^2w(Y-X) / D
\]
are unclear.

Again, differentiation of (7) with respect to \(w\), and taking into account the effect working through \(Y\), gives the effect on local welfare of expanding the protected area.

\[
\frac{\partial \pi}{\partial w} = P_hE_h[f(1-w)dY / dw - f'(1-w)Y] - P_h\mu(1-\alpha)(1-E_h)^{\alpha}(1-w)^{-\alpha}
\]
\[
(A6)
- P_dE[f(1-w)dY / dw - Y]
\]

Here, \(dY / dw\) is determined in \((A1)\) when accounting for the effect working through the hunting effort in \((12)\).