Hunting and exploitation of terrestrial animal species

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1.Introduction

The bioeconomic analysis of exploitation of animal species was initially developed in the context of marine resources. The first studies published in the mid 1950's were concerned with the uncontrolled, or 'open access', aspect of the marine harvesting activity. Some twenty years later the analysis was extended to account for the optimal harvesting, or fishing, activity over time and where fish was considered as capital. Within this capital theoretic framework, the fish could either be kept in the ocean, or it could harvested and stored in 'the bank' as capital. It was shown that three factors played an important role determining the degree of exploitation; the price-cost ratio of the yield, the natural growth rate of the fish stock and the opportunity cost of the natural capital, i.e., the rate of interest. It was also shown that extinction could be an optimal option for marine species if the price-cost ratio of the yield was 'high', if the natural growth rate of the resource was 'low' and if the opportunity cost of the capital was 'high'. For a fishery, or marine resources in general, these economic and ecological factors, in addition to a management regime of the 'open-access' type, will therefore work in the direction of resource depletion.

These factors may also cause biological overexploitation, and even possibly extinction, of terrestrial animal species. However, there are some differences compared to the management of marine resources. First, the harvesting of terrestrial resources is more likely to be controlled because land, in contrast to oceans, more frequently has a well-defined ownership. Secondly, there are generally a number of competing uses of the habitats of terrestrial species. While the main avenues in which humans interact with oceanic species is through harvesting and pollution, the interactions with terrestrial species are much more multi-faceted. Humans may consider making the use of the habitat for purposes of agricultural production or for purposes completely unrelated to the biosphere (e.g., residences and factories). The land-use of terrestrial resources, as opposed to marine resources, has therefore usually an opportunity cost. Thirdly, and also generally in contrast to marine resources, there are more value components related to terrestrial animal species. Such values include non-use values as existence value and biodiversity value. When present, these values will typically be the public good nature of the animals. There may also be other cost and benefit components, like capturing a market value depending on the stock of the species, say, through production of tourism services. On the other hand, terrestrial animal species may also cause damage, like rodents and other types of pest species, but also large herbivores and predators, causing different types of agricultural damages, including eating crops and pastures and preying on livestock.

These differences compared to marine resources are more of the stylized-facts type than absolute. For example, whales have clearly a noticeable existence value and there are eco-tourist opportunities allowing for non-consumptive uses. There may also be alternative uses of marine habitats, particularly for the coastal zone (fish - farming, marinas, ocean wind farms, oil drilling, etc.). There may also be 'open-access' exploitation of terrestrial species, even when there are well-defined property rights, due

to lack of enforcement capacity, or lack of investments in management services. The fugitive nature of many terrestrial animal species, like many fish stocks, may also cause unclear property rights and overexploitation.

In this chapter, I will take a closer look at a small sample of these issues. In section 2, I start to analyze a simple model of competing land uses where habitat land for wildlife competes with other type of land uses. This model is framed in a developing country setting, where the alternative use of habitat land typically then is agricultural land. The crucial issue raised here is in which direction a 'high' value of the wild animals may work. While this first model is analyzed within a social planner framework, I next in section 3 present a model, also framed within in a developing country context, where the conflicting interests of conservation and hunting of wildlife is highlighted through different groups that claims the rights to the wildlife values. This is a two agent model with a conservation agency (i.e., a national park owner) and a group of local people, and where illegal hunting, or poaching, is the central issue. Land use is here assumed fixed. In section 4, I look at a more 'fine tuned' harvesting model. While the biological models in section two and three are biomass models where 'an animal is an animal', the different age and sex categories of the animals play the important role here. The crucial question raised is how to compose an efficient harvest among the different stages. This model also consider big game hunting and is formulated is for a moose population. The institutional setting framing this model is Scandinavia where the landowners obtain the harvesting benefits, but where they also bear the browsing damage cost, and there is no illegal hunting.

2.Harvesting and competing use of habitat land

Wildlife is today threatened in many developing countries. In Africa, as well as other places, this is particularly so in regions with dense and fast-growing human populations where expanding settlements, crops and livestock are displacing wildlife at an ever-increasing rate. In these as in other areas, local people often find only trouble in having an abundant wildlife community in their neighborhood. Often this is a result of government policies which have alienated the wildlife from the local people. The establishment of national parks and game reserves has displaced rural communities (pastoralists and peasants) from the land which traditionally was theirs. Land for cultivation and pasture has been lost and anti-poaching laws have criminalized subsistence hunting.

This conflict between wildlife conservation and agricultural production is here analyzed as a *land use* conflict where a fixed amount of land either can be used as habitat land or agricultural land. On habitat land H designed to protect wildlife, hunting and non-consumptive use of the wildlife (i.e., tourism) are practiced while agricultural land A is assumed to be exploited through pastoralism and agro-pastoral schemes. When the total area of land is fixed as L, the land-use constraint is hence given as:

(1) $H + A \leq L$.

Because the very nature of the problem is that land is a scarce factor, the constraint should hold as equality at every point of time.

The population growth of the wild species is next given by:

(2) $dX / dt = F(X, H) - y$

where one stock X represents the whole wildlife population at time t, measured in biomass ('an animal is an animal') and y is the harvesting at the same time. $F(X, H)$ is a density dependent natural growth function depending on the stock X. In addition, the natural environment for the population is not constant and more habitat land H boosts animal growth, $\partial F / \partial H = F_H > 0$. I will here think of a logistic natural growth function, $F(X, H) = rX[1 - X / K(H)]$, with r as the maximum specific growth rate and $K = K(H)$ as the carrying capacity depending on the size of the habitat. More land means a higher carrying capacity, $K(0) = 0$ and $K' > 0$.

Equation (3) describes the current net social benefit SB related to the various land use activities. The first term $B(X, H)y = py - ce(X, H)y$ is the net benefit from harvesting where $B(X, H)$ is the unit harvesting profit, comprising harvesting income with p as the hunt price and c as the unit harvesting effort cost, both assumed fixed. Effort, measured in, say, hunting days, is given by $e = e(X, H)y$, depending on the wildlife stock, the size of the habitat as well as the harvest. A Schaefer-type harvesting function is assumed, $y = y(e, X, H) = \theta eX / H$, where θ is the productivity ('catchability') coefficient. Therefore, I have $e = (H / \theta X)y = e(X, H)y$. A higher wildlife stock for a fixed size of the habitat means lower harvesting costs and thus, more profit $B_X > 0$. On the other hand, a larger size of the habitat for a given stock size means higher hunting costs, and thus lower profit $B_H < 0$.

(3) $SB = B(X, H)y + W(X) + G(A) - D(X)$.

In addition to harvesting benefits, there will also be costs associated with the use of habitat land and non-consumptive uses. The second term $W(X)$ with $W(0) = 0$ and $W' > 0$, represents the non-consumptive benefits. It can capture a market value depending of the size of the population, for example through production of tourism services (traditional wildlife viewing and safari tourism). In addition, there may also be non-use values of the species such as biodiversity, existence value and so forth, not taken care of by the market. This will be the public good nature of the animals and can particularly be so if they belong to relatively rare and threatened species. The third term in equation (3), $G(A)$ with $G(0) = 0$ and $G' > 0$, yields profit from the land-use made up for alternative

activities, here as agricultural production. Finally, a cost factor depending on the stock size of the species as given by $D(X)$ with $D(0)=0$ and $D'>0$ is included. This is the nuisance costs where the wildlife, e.g., large mammals, destroys agricultural production of the agropastoralists living in the proximity of wildlife habitats. As mentioned, the agricultural damage may take place in a variety of ways such as eating up crops and destroying pastures. All cost and benefit functions are assumed to be fixed through time.

The social planner goal is to maximize the present-value net benefit,

$\max_{y,H} = \int_{t=0}^{T=\infty} [B(X,H)y + W(X) + G(A) - D(X)]e^{-\delta t}dt$, subject to land-use constraint (1), all the time assumed to bind, and population growth (2). $\delta \geq 0$ is the (social) rate of discount. The current value Hamiltonian of this problem is described by

$\Psi = B(X,H)y + W(X) + G(L-H) - D(X) + \mu[F(X,H) - y]$ with μ as the wildlife shadow price. The first order necessary conditions are $\partial\Psi / \partial y = 0$, $\partial\Psi / \partial H = 0$ and $d\mu / dt = \delta\mu - \partial\Psi / \partial X$ for the singular solution and habitat use in the domain $(0, L)$.

After some small rearrangements where the shadow price is eliminated, I find the equations:

(4) $$F_X(X,H) + [B_X(X,H)/B(X,H)]F(X,H) + [1/B(X,H)][W'(X) - D'(X)] = \delta$$

and

(5) $$B(X,H)F_H(X,H) + B_H(X,H)F(X,H) = G'(L-H)$$

to describe the reduced form necessary long-term equilibrium (steady state) conditions. These equations hence jointly determine the equilibrium stock X^* and equilibrium land-use H^*. In addition, the steady-state harvest y^* follows from equation (1) when $dX/dt = 0$. For the definition of the various functional forms and the sufficient conditions for maximum, the solution will be unique and the dynamics leading to the steady-state will be of the Most-Rapid-Approach-Path (*MRAP*-dynamics) type, but necessarily exact a *MRAP*-path.

Equation (4) is the present version of the Clark-Munro rule (or Golden rule) where the equilibrium condition of an optimal harvesting strategy is extended with the term reflecting the marginal non-consumptive value of the species and the marginal nuisance costs. Therefore, the left hand side of equation (4) is the internal rate of return of keeping the wild species as an asset. It will slope downwards due to the sufficient conditions for maximum. In optimum it should be equal to the external rate of return, i.e., the opportunity cost of capital δ. See upper panel Figure 1. It is seen that if

D' does not dominate $(B_X F + W')$, the equilibrium stock will be at a point with $(\delta - F_X) > 0$ for a given land use. That is to say, if the marginal negative damage effect does not exceed the marginal non-consumptive benefit effect plus the marginal profitability effect due to increasing costs as the stock becomes smaller, the natural growth of the species should be below that of the rate of discount. This will be referred to as the 'normal case'. On the other hand, I have the 'nuisance-case' when the marginal external damage cost is high so D' dominates the solution and $(\delta - F_X) < 0$ holds.

<Figure 1 about here>

Equation (5) is the equilibrium condition of land-use with $(BF_H + B_H F)$ as the marginal benefit of the habitat area. For a given stock of wildlife, it will also be downward sloping due to the sufficient conditions. This reflects the assumption of decreasing natural growth of the species as well as the fact that the unit harvesting cost increases as the habitat become larger. In the optimal steady state it should be equal to the marginal profit of the alternative use of the land which will be downward sloping from the right under the assumption of $G'' < 0$. See Figure 1, lower panel.

The effects of how the various economic forces influence the steady state are found by total differentiation of equations (4) and (5). First, it is possible to show that an increased opportunity cost of the habitat will shrink both the stock size and the habitat. The same occurs for a higher rate of discount. The negative animal effect is the same that we find in the traditional bioeconomic models. In addition, as here, it is also beneficial for the social planner to reduce the size of the habitat area. On the other hand, a permanent increase in the existence value of the species will work in the direction of a larger stock and more habitats. More nuisances from the species work in the opposite direction.

The effects of a permanent change in the market price of the hunting p are, however, not clear. The intuition is that an increased price, for a given land-use, motives for stock disinvestment according to the traditional bioeconomic model. On the other hand, an increased harvesting price makes habitat investments more attractive as the marginal benefit ratio p / G' increases. The effect on the stock size is found as $\partial X^* / \partial p = [\partial B / \partial p) / \Omega)[(\delta - F_X)(BF_{HH} + 2B_H F_H + B_{HH} F + G'') +$ $F_H (B_X F_H + BF_{XH} + B_{XH} F + B_H F_X - \delta B_H)]$ where $\Omega > 0$ according to the sufficient conditions. In the 'normal case' when $(\delta - F_X) > 0$ holds, the first term is negative because of the downward sloping marginal benefit schedules for land, $(BF_{HH} + 2B_H F_H + B_{HH} F) < 0$ and $G'' \leq 0$. The second term is positive under the assumption that $(B_X F_H + BF_{XH} + B_{XH} F + B_H F_X - \delta B_H) > 0$ which means that the marginal benefit of the species shifts up when the habitat increases. The sign of $\partial X^* / \partial p$ is therefore ambiguous. However, a negative sign seems most likely to occur because the absolute value of the

term $(B_X F_H + BF_{XH} + B_{XH} F + B_H F_X - \delta B_H)$ should be small according to the sufficient conditions. On the other hand, in the 'nuisance case', I get $\partial X^* / \partial p > 0$. $\partial H^* / \partial p$ will also be ambiguous in the 'normal case' and unambiguous positive in the 'nuisance case'. The conditions for obtaining a positive effect on the habitat land is, however, less restrictive than for obtaining a positive effect on the species. This is seen directly from Figure 1 and equation (5) since a price increase will shift up the demand schedule for habitat land through an increased B even if the stock size remains unchanged.

Summing up, I therefore find that the price effect of the harvesting generally works different compared to the traditional bioeconomic model of marine resources. There are two reasons for this. First, marginal stock dependent values are included as a part of the social evaluation of the species. Second, the species have to compete with an alternative use of the land. The *disinvestment* process, i.e. the competition for natural habitats, is identified as the basic driving force behind terrestrial species decline and the threat of extinction. Thus, rather than being overexploited, species are undercut according to this mechanism. The general conclusion from this exercise is therefore in line with the reasoning of the ecologists which for a long time have argued that habitat degrading is the most serious threat to biodiversity loss and species extinction. However, the above analysis says possible something more, namely that habitat land converts into other uses because wild species does not pay its way.

3.Conflicting views on species values and conservation

The above model is formulated within a social, or unified, planner framework. Therefore, possible conflicting land use options and wildlife exploitation schemes between the conservation agency and the local people are not explicitly taken into account here. In this section, I will highlight such conflicts by using a simple two agent model, still framed within a developing (e.g., African) country context. Land use is now, however, assumed fixed so conflicting land uses is neglected. The crucial question raised is to say something about the motives steering the wildlife harvest, or poaching, of the local people. To keep the analysis relatively simple, I just study a biological equilibrium situation meaning that the wildlife natural growth is exactly balanced by the total harvest all the time. The economic equilibrium is assumed to be of the Nash type.

Therefore, the conflicting interests between an agency managing a wildlife habitat, or protected area, and a group of people living in the vicinity of this area is considered. The park agency benefits from wildlife through safari hunting and non-consumptive tourism services, such as wildlife viewing. The local people, agro pastoralists and small scale farmers, also hunt wildlife, but this hunting is illegal. However, because of small fund for policing and large protected area, poaching cannot be prevented by

the park manager. Hence, the actual property rights structure is endogeneous as illegal hunting will depend on economic and biological conditions; that is, de jure and de facto property rights differ.

The two production activities practised by the conservation agency, non-consumptive tourism and hunting, and illegal hunting by the local people are constrained by wildlife abundance. Again, one stock of wildlife X represents the whole wildlife population with natural growth as $F(X)$. The hunting of the park manager (agent 1) y_1, depending on effort use and number of animals $y_1 = y_1(e_1, X)$, and the hunting of the local people (agent 2) y_2, depending on the same factors $y_2(e_2, X)$, means that population growth is described by $dX / dt = F(X) - y_1(e_1, X) - y_2(e_2, X)$. Notice that I now find it more convenient to use effort as the control variable (see also section 2 above) and that the size of the habitat land is not explicitly included because land-use is assumed fixed. Notice also that the notation is changed slightly compared to previous section. Now, subscript denotes agents, and not partial derivates. In biological equilibrium where total harvest equals natural growth, I have

$F(X) = y_1(e_1, X) + y_2(e_2, X)$, or :

(6) $X = X(e_1, e_2)$.

Increased hunting effort reduces the (equilibrium) stock, $\partial X / \partial e_i < 0$, $i = 1, 2$, and for a given stock level equation (1) is hence downward- sloping in the (e_1, e_2) space. See Figure 2. The biological equilibrium condition (6) may therefore be considered as an iso-conservation line, and where lines closer to the origin imply more animals as it represents less harvesting effort.

As indicated, the park manager obtains income from hunting wildlife, by selling hunting licences, and from non-consumptive tourism. The net benefit of hunting is now expressed as $B_1(e_1, X) = p_1 y_1(e_1, X) - c_1 e_1$ where, just as in the previous section, both the safari hunting licence price p_1 and the unit cost of organizing the hunting, c_1 are assumed fixed. When $W(X)$ again represents the benefit from non-consumptive tourism the current profit of the park manager is:

(7) $\pi = B_1(e_1, X) + W(X)$.

The local people derive utility from hunting wildlife illegally. The poaching benefit may also be written as $B_2(e_2, X) = p_2 y_2(e_2, X) - c_2 e_2$, and where the price and unit cost generally differ from those of the park manager. Because the wildlife knows no boundaries and moves freely in and out of the protected area, the game also destroys agricultural crops and competes with livestock when outside the protected area. Just as above, the wildlife therefore also represents a nuisance, and accordingly the net benefit to the local people is given by:

(8) $U = B_2(e_2, X) - D(X)$.

In the absence of a unified resource policy, there are several externalities. Just as in the standard harvesting (fishery) model, reciprocal harvesting externalities work through the hunting benefit functions. In addition, there are reciprocal stock externalities related to the stock values: more hunting effort by the park manager, ceteris paribus, induces a positive externality on the local people through a reduction in $D(X)$. On the other hand, more hunting effort by the local people induces a negative external effect on the park manager through a reduction in $W(X)$.

The economic problem of the park agency is to determine the profit-maximizing hunting effort under the ecological constraint (6), given the effort of the local people. The necessary condition for a maximum (when having an interior solution) is:

(9) $\partial B_1(e_1, X)/\partial e_1 + [\partial B_1(e_1, X)/\partial X](\partial X/\partial e_1) + W'(X)(\partial X/\partial e_1) = 0$.

This represents also the park manager's best-response function, denoted by $e_1 = R_1(e_2)$ in Figure 2. Along the best-response curve, profit depends on the effort of the local people, $\pi = \pi(e_2)$. In Figure 2, π^0 and π^1 yield two iso-profit curves, where $\pi^1 > \pi^0$.

<Figure 2 about here>

The economic problem of the local people is to determine the utility-maximizing harvesting effort e_2, subject to the ecological constraint (1) and the effort of the park manager. The necessary condition for maximum is:

(10) $\partial B_2(e_2, X)/\partial e_2 + [\partial B_2(e_2, X)/\partial X](\partial X/\partial e_2) - D'(X)(\partial X/\partial e_2) = 0$,

and is the local people's best-response function, denoted by $e_2 = R_2(e_1)$ in Figure 2. Along the best-response curve, utility depends on the effort of the park manager, $U = U(e_1)$, and implicit differentiation (the envelope theorem) implies $dU(e_1)/de_1 = (\partial B_2/\partial X - D')(\partial X/\partial e_1)$. Accordingly, greater effort by the park manager reduces the optimal utility of the local people if the marginal harvesting benefit dominates the marginal damage effect; i.e., if $(\partial B_2/\partial X - D') > 0$. Hence, under this condition, the iso-utility curves, U^0 and U^1, in Figure 2 are such that $U^0 > U^1$. Otherwise, in the 'nuisance case', when $(\partial B_2/\partial X - D') < 0$, greater effort by the park manager is beneficial because reduced damage dominates the reduced harvesting benefit. This is illustrated by the two iso-utility

curves $U^3 > U^2$. These iso-utility curves bend in the opposite direction to that of U^0 and U^1. The Nash equilibrium is given by the effort levels $e_1^* > 0$ and $e_2^* > 0$ in Figure 2. In addition, the iso-conservation schedule through the Nash equilibrium $X^* = X(e_1^*, e_2^*)$ yields the stock size.

Within this simple model the degree of species conservation is determined by several forces that work in a relatively complex way. It is also generally not clear how the utility, or welfare, of the local people is influenced. Welfare and conservation may go hand in hand, or in the opposite direction, as the comparative static results in Table 1 indicates. The stock value functions are here assumed to be linear; i.e., $W(X) = wX$ and $D(X) = dX$ while the harvesting functions, just as in the previous section, are specified as Schäfer functions $y_i(e_i, X) = \theta_i e_i X$, but now without explicitly stating the size of the habitat, under which $B_i(e_i, X) = p_i \theta_i e_i, -c_i e_i$ ($i = 1, 2$). In addition, I also now assume logistic natural growth, $F(X) = rX(1 - X/K)$.

<Table 1 about here>

Consider first the effect of an increase in the price of safari hunting licences p_1. The relative profitability of consumptive and non-consumptive activities of the park manager is affected, and the price increase results in greater hunting effort, given the effort levels of the local people. This causes an outward shift in $R_1(e_2)$, and hence, $\partial e_1^* / \partial p_1 > 0$ and $\partial e_2^* / \partial p_1 < 0$ It can be shown that the increased effort of the park manager dominates the indirect effect relating to the local people. I therefore find $\partial X^* / \partial p_1 < 0$ and the new economic equilibrium intersects with an iso-conservation schedule further from the origin. The profit of the park manager increases, $\partial \pi^* / \partial p_1 > 0$, while the utility effect for the local people depends on the sign of $(\partial B_2 / \partial X - D')$. If the marginal harvesting benefit dominates, then $\partial U^* / \partial p_1 < 0$. In the opposite 'nuisance case', when $(\partial B_2 / \partial X - D') < 0$, I find $\partial U^* / \partial p_1 > 0$, in which case, increased profit for the park manager is associated with improved welfare for the local people.

Increased profitability in non-consumptive tourism through a positive shift in w has the opposite effect of an increase in p_1 as $R_1(e_2)$ shifts downwards. Increased wildlife-induced damage motivates the local people to expend more harvesting effort and $R_2(e_1)$ shifts upwards. Therefore, $\partial e_1^* / \partial d < 0$ and $\partial e_2^* / \partial d > 0$. I also find $\partial X^* / \partial d < 0$. In addition, more nuisance reduces the welfare of the local

people. An increase in p_2 increases the net harvesting benefit and motivates the local people to expend greater hunting effort. On the other hand, the increase in p_2 also reduces the value of wildlife damage relative to the value of wildlife meat, which has the opposite effect. Hence, the result from the standard bioeconomic model , $\partial e_2^* / \partial p_2 > 0$, only arises if the nuisance is low relative to the harvesting cost. If the nuisance is relatively high, the price increase leads to reduced harvesting effort by the local people and to more wildlife. As shown in Table 1 more productive wildlife conditions through higher intrinsic growth rate r and biological carrying capacity K not necessarily mean more conservation. The welfare effects of the local people are also unclear.

The above analysis demonstrates that wildlife conservation may work directly against the interests of the local people, but the overall picture is far from clear. One important message is that reduced nuisance works beneficial for conservation as well as welfare improving of the local people. Hence, measures taken to reduce nuisance may therefore pay well off. Recently, however, the main approach to wildlife management and conservation has been to include the local people to gain their cooperation and support, which has eventually resulted in so-called integrated conservation and development projects (ICDPs). These projects involve varying levels of local participation, ranging from pure benefit sharing, such as transfers from wildlife-related activities, to a more far-reaching design of community based management. Pure benefit-sharing strategies may also be analysed within the present model. The general findings of such an analysis are that while more conservation may be obtained, the effect on the welfare of the local people is ambiguous.

The fact that transfers to the local people may reduce their welfare is obviously a strange result, but can be explained that such transfers take place within a general equilibrium type framework where the harvesting effort of both agents as well as degree of species conservation are influenced by shifting prices and income. If, say, the local people obtain a fixed proportion of the total park income, the relative valuation of the two activities of the park manager (hunting and tourism) is not influenced. The best-response function of the park manager $R_1(e_2)$ stays therefore unchanged. On the other hand, $R_2(e_1)$ shifts inwards because the transfer increases the marginal cost of hunting and reduces the hunting effort. The new Nash equilibrium is thus characterised by more harvesting effort by the park manager and reduced harvesting effort of the local people. The indirect transfer effect, working through increased harvesting effort of the park manager and less harvesting of the local people, may be negative. Therefore, if this indirect effect is strong enough, the net result can be negative. An uncertain, or even negative, welfare effect of the local people is just what may follow as a possible outcome following the logic of the classical theory of the second best.

In the above model the local people has been treated as a homogeneous group and hence, any possible conflicting interests among them have been neglected. Utility maximisation is assumed as well. Whether utility maximization is an adequate representation of the behaviour of smallholder farmers living under complex and often harsh conditions can clearly be questioned. Alternatively, assuming poaching to be of the pure 'open-access' type, we may find that the species abundance is determined by the zero-profit (or zero-rent) harvesting condition. This arises given the standard Schäfer harvesting assumption where $B_2(e_2, X) = (p_2\theta_2 X - c_2)e_2 = 0$ (see also above). The degree of conservation is then determined only by the price and cost parameters together with the harvesting productivity of the local people, $X^{\infty} = c_2 / p_2\theta_2$. This zero rent stock size yields at the same time the iso-conservation line through equation (6). Together with the profit maximisation condition of the conservation agency (9), or $e_1 = R_1(e_2)$, the harvesting effort of the two agents are found. The only factors affecting the welfare of the local people under these assumptions are the prices. The effect of an increased p_2 will hence lead to less wildlife and damage and higher welfare as there is zero-profit harvesting.

The assumption that the park manager maximises profit from both park activities may also be questioned. In many protected areas there is no commercial hunting, and hunting activity is simply culling to maintain the ecological system. Therefore, the goal of the park manager is typically to maintain a large and 'sustainable' stock of wildlife while keeping the ecosystem in shape. Under such a management scheme, the best-response function of the conservation agency coincides with the iso-conservation schedule representing the target stock size. Hence, this condition together with the best-response function of the local people determines the harvesting effort of the two agents. Suggested that an interior solution exists for the effort use, we then find that factors improving the harvesting profitability of the local people at the same time will increase welfare as the nuisance is unchanged.

4.From biomass models to a stage structured hunting model

The previous analysis, both in section two and three, have been carried out within a biomass context; that is, 'an animal is an animal' and hence no distinction between the different age and sex classes of the wildlife populations has been made. This represents the traditional modeling concept within natural resource economics, and works often well when one aims to examine the basic driving forces behind hunting, wildlife exploitation and conservation. However, when a more 'fine tuned' analysis is necessary, say, if the hunting selection between groups of animals in a wildlife population is a crucial issue, it is necessary to make a distinction between the different year classes, or stages, of the actual wildlife population.

Stage structured models, i.e., models where the species are grouped in different classes according to age and sex, has a long tradition within biology. However, until recently, quite few studies have been carried out within an optimizing economic framework. In this section a stage structured model of a moose population is studied. The setting is therefore now a more northern country context, where I am basically thinking about Scandinavia where the landowners obtain the harvesting value of the animals while they at the same time bear the timber browsing damage cost. The crucial issue is to find the harvesting composition of the different age and sex classes that maximizes the present value net benefit, comprising harvesting benefit and browsing damage cost.

The moose (Alces alces) is the world's largest member of the deer family and is found in the northern forests of North America, Europe and Russia. The mean slaughter body weight (about 55% of live weight) for adult moose in Scandinavia of about 170 kg for males and 150 kg for females. It is the most important game species in this area, and in Norway and Sweden about 35,000 and 100,000 animals, respectively, are shot every year. The hunting takes place in September and October. The non-harvest mortality rates are generally low due to lack of predators, and there is no evidence of density-dependent mortality. On the other hand, fecundity has proven to be affected by the female density while the number of males seems to be of negligible importance within the range of moose densities in Scandinavia. However, it may play a role if the sex composition is very skew.

In the model to be studied here, the population at time (year) t is structured in four stages; calves $X_{c,t}$ ($yr < 1$), yearlings $X_{y,t}$ ($1 \leq yr < 2$), adult females $X_{f,t}$ ($yr \geq 2$) and adult males $X_{m,t}$ ($yr \geq 2$) so that the total moose population is $(X_{c,t} + X_{y,t} + X_{f,t} + X_{m,t})$. Notice that I am now using discrete time and using time subscript, where the time step is one year. Natural mortality is assumed to take place during the winter, after the hunting season, as the natural mortality throughout summer and fall is small and negligible. The same natural mortality rate is imposed for males and females and the same sex ratio is assumed for the yearlings when they enter the adult stages. The number of calves (recruitment) is first governed by $X_{c,t} = r_t X_{f,t}$ with $r_t = r(X_{f,t}, X_{m,t})$ as the fertility rate (number of calves per female). The fertility rate generally depends on both female density (number of females) and male density. It decreases in the female density $\partial r / \partial X_{f,t} = r'_f < 0$, and may also be reduced when the number of males become low, $r'_m \geq 0$. Therefore, the recruitment function yields:

(11) $$X_{c,t} = r(X_{f,t}, X_{m,t}) X_{f,t}.$$

The number of yearlings follows next as:

(12) $$X_{y,t+1} = s_c (1 - h_{c,t}) X_{c,t}$$

where s_c is the fixed calf natural survival rate (fraction) and $0 \le h_{c,t} < 1$ is the calf harvesting rate. Finally, the abundance of (adult) females and (adult) males become:

(13) $$X_{f,t+1} = 0.5 s_y (1 - h_{y,t}) X_{y,t} + s(1 - h_{f,t}) X_{f,t}$$

and

(14) $$X_{m,t+1} = 0.5 s_y (1 - h_{y,t}) X_{y,t} + s(1 - h_{m,t}) X_{m,t},$$

respectively, and where the same sex ratio is assumed for the yearlings when they enter the adult stages. s is the fixed natural survival rate, identical for females and males while s_y is the yearling survival rate. $h_{y,t}$, $h_{f,t}$ and $h_{m,t}$ are the harvesting rates of yearlings, females and males, respectively. These harvesting rates are also assumed to be less than one, $0 \le h_{i,t} < 1$ ($i = y, f, m$). The population model (11) – (14) has a recursive structure, and when combining (11) and (12) I find:

(15) $$X_{y,t+1} = s_c (1 - h_{c,t}) r(X_{f,t}, X_{m,t}) X_{f,t}.$$

Therefore, equations (13) – (15) is a reduced form model in three stages and where all equations are first order difference equations. This form is used when studying exploitation below.

As mentioned, the situation where the landowner, or landowner association, maximizes the meat value while taking the browsing damage into account is considered. Because natural mortality basically occurs during the winter, after the hunting season (see above), the number of animals removed in the different categories in year t are defined by $h_{i,t} X_{i,t}$ ($i = c, y, f, m$). The current hunting value is accordingly $Q_t = p(w_c h_{c,t} X_{c,t} + w_y h_{y,t} X_{y,t} + w_f h_{f,t} X_{f,t} + w_m h_{m,t} X_{m,t})$ where $w_c < w_y < w_f < w_m$ are the (average) body slaughter weights and p is the hunting price, similar for all stages. The unit hunting price is supposed to be independent of the amount harvested and the stock sizes. When further assuming that the marginal cost of the landowners of organizing this hunting is stock independent, the harvest price p is a 'net' price assumed to be fixed.

The forest browsing damage on pine trees occur basically during the winter when other food sources are restricted. Therefore, I relate the damage costs to the population sizes after the hunting, and hence, just before the winter; that is, $D_i((1 - h_{i,t}) X_{i,t})$ with $D_i(0) = 0$ and $D_i' > 0$. The damage function may be concave or convex, or even concave-convex, but just as in the previous section I use linear functions, $D_t = d_c (1 - h_{c,t}) X_{c,t} + d_y (1 - h_{y,t}) X_{y,t} + d_f (1 - h_{f,t}) X_{f,t} + d_m (1 - h_{m,t}) X_{m,t}$, and where

$d_c < d_y < d_f = d_m$ are the per animal cost which differ among the stages due to (basically) size. As no more cost and benefit components are included for the landowner, the current landowner profit is described by $\pi_t = (Q_t - D_t)$.

The present-value landowner profit is to be maximized subject to the above biological constraints. The problem is hence to $\max_{h_{c,t}, h_{y,t}, h_{f,t}, h_{m,t}} \sum_{t=0}^{t=\infty} \rho^t (Q_t - D_t)$ given the biological growth equations (13) – (15) and where $\rho = 1/(1+\delta)$ is the (discrete time) discount factor. The Lagrangian of this problem may be written as

$$\begin{aligned}\Psi = \sum_{t=0}^{\infty} \rho^t \Big\{ & \Big[p\Big(w_c h_{c,t} r(X_{f,t}, X_{m,t}) X_{f,t} + w_y h_{y,t} X_{y,t} + w_f h_{f,t} X_{f,t} + w_m h_{m,t} X_{m,t} \Big) \Big] \\ & - [d_c (1-h_{c,t}) r(X_{f,t}, X_{m,t}) X_{f,t} + d_y (1-h_{y,t}) X_{y,t} + d_f (1-h_{f,t}) X_{f,t} + d_m (1-h_{m,t}) X_{m,t}] \\ & - \rho \eta_{t+1} \Big[X_{y,t+1} - s_c (1-h_{c,t}) r(X_{f,t}, X_{m,t}) X_{f,t} \Big] \\ & - \rho \lambda_{t+1} \Big[X_{f,t+1} - 0.5 s_y (1-h_{y,t}) X_{y,t} - s(1-h_{f,t}) X_{f,t} \Big] \\ & - \rho \mu_{t+1} \Big[X_{m,t+1} - 0.5 s_y (1-h_{y,t}) X_{y,t} - s(1-h_{m,t}) X_{m,t} \Big] \Big\}\end{aligned}$$

and where $\eta_t > 0$, $\lambda_t > 0$ and $\mu_t > 0$ are the shadow prices of the yearling, female and male populations, respectively.

All the first-order control conditions of this maximizing problem are stated with the actual complementary slackness conditions and where the possibility for keeping each of the stages unexploited is considered while harvesting whole sub populations are assumed not to be an option. These control conditions then read:

(16) $$\frac{\partial \Psi}{\partial h_{c,t}} = r X_{f,t} (p w_c + d_c - \rho \eta_{t+1} s_c) \le 0 \;;\; 0 \le h_{c,t} < 1,$$

(17) $$\frac{\partial \Psi}{\partial h_{y,t}} = X_{y,t} (p w_y + d_y - \rho \lambda_{t+1} 0.5 s_y - \rho \mu_{t+1} 0.5 s_y) \le 0 \;;\; 0 \le h_{y,t} < 1,$$

(18) $$\frac{\partial \Psi}{\partial h_{f,t}} = X_{f,t} (p w_f + d_f - \rho \lambda_{t+1} s) \le 0;\; 0 \le h_{f,t} < 1$$

and

(19) $$\frac{\partial \Psi}{\partial h_{m,t}} = X_{m,t} (p w_m + d_m - \rho \mu_{t+1} s) \le 0 \;;\; 0 \le h_{m,t} < 1.$$

The state, or portfolio conditions, with $X_{y,t} > 0$, $X_{f,t} > 0$ and $X_{m,t} > 0$, are:

$$(20) \qquad \frac{\partial \Psi}{\partial X_{y,t}} = pw_y h_{y,t} - d_y(1-h_{y,t}) - \eta_t + \rho\lambda_{t+1} 0.5 s_y (1-h_{y,t}) + \rho\mu_{t+1} 0.5 s_y (1-h_{y,t}) = 0,$$

$$(21) \qquad \frac{\partial \Psi}{\partial X_{f,t}} = pw_c h_{c,t}(r + r'_f X_{f,t}) + pw_f h_{f,t} - d_f(1-h_{f,t}) + \rho\eta_{t+1} s_c (1-h_{c,t})(r + r'_f X_{f,t}) - \lambda_t$$

$$+\rho\lambda_{t+1} s(1-h_{f,t})] = 0$$

and

$$(22) \qquad \frac{\partial \Psi}{\partial X_{m,t}} = pw_c h_{c,t} r'_m X_{f,t} + pw_m h_{m,t} - d_m(1-h_{m,t}) + \rho\eta_{t+1} s_c (1-h_{c,t}) r'_m X_{f,t}$$

$$-\mu_t + \rho\mu_{t+1} s(1-h_{m,t}) = 0.$$

Condition (16) says that calf harvest should take up to the point where marginal harvest income plus the benefit of reduced browsing damage is equal to, or below, the cost in term of reduced yearling growth evaluated at its shadow price while also taking the discount rent into account. When this condition holds as an inequality, the marginal benefit is below its marginal cost and harvesting of this stage is thus not profitable, $h_{c,t} = 0$. In a similar manner, condition (17) indicates that harvesting of the yearlings should take place up to the point where the marginal benefit is equal to, or below, the cost in terms of reduced population of males and females. The female condition (18) is simpler as reduced stock growth works only through its own stage. The male condition (19) is analogous to the female harvesting condition. The yearling stock portfolio condition (20) may also be written as $\eta_t = pw_y h_{y,t} - d_y(1-h_{y,t}) + \rho\lambda_{t+1} 0.5 s_y (1-h_{y,t}) + \rho\mu_{t+1} 0.5 s_y (1-h_{y,t})$. It hence indicates that the number of yearlings should be maintained so that its shadow price equalizes the meat value minus the browsing damage of one more animal on the margin plus its growth contribution to the adult stages evaluated at their shadow prices and when discounting is taken into account as well. The other stock portfolio conditions (21) and (22) can be given similar interpretations.

These first order conditions together with the biological constraints comprise a complex dynamic system. However, because of the linear cost and benefit functions, some important tradeoffs that occur when composing the harvest can be found analytically. I first ask whether it is more likely to harvest only yearlings, females or males, two of these stages, or all stages, and I find that yearling harvest will contradict the optimality conditions. To see this, suppose as a starting point that yearling, but also

female and male harvest, take place; that is, $h_{y,t} > 0$, $h_{f,t} > 0$ and $h_{m,t} > 0$. The three control conditions (17) – (19) then holds as equations, and combining (with positive stock sizes) yields $pw_y + d_y = 0.5(s_y / s)(pw_f + d_f + pw_m + d_m)$. As only parameters are included, this equation holds only by accident. Therefore, harvesting all these three stages at the same time can not represent an optimal solution.

Suppose next that I have positive yearling harvest together with zero female and positive male harvest, i.e., $h_{y,t} > 0$, $h_{f,t} = 0$ and $h_{m,t} > 0$. Condition (18) then holds as an inequality and combination of conditions (17) – (19) yields therefore $pw_y + d_y > 0.5(s_y / s)(pw_f + d_f + pw_m + d_m)$. Since the adult and yearling survival rates s and s_y ('biological discount' rates) are more or less identical and the yearling weight is below that of the females which again is below that of males, $w_y < w_f < w_m$, and the marginal browsing damage of adults typically is above that of the yearlings, $d_y < d_f \approx d_m$, this inequality represents a contradiction. Therefore, positive yearling harvest together with zero female and positive male harvest is not a possible optimal option.

In a similar manner, I find that positive yearling harvest together with zero male and positive female harvest yields the same inequality as above and hence also contradict the optimality conditions for the given structure of parameter values. The assumption of positive yearling harvest together with zero male and zero female harvest contradicts the optimality conditions as well. I can therefore conclude that positive yearling harvest is not optimal under the present assumptions of constant harvest price and constant marginal browsing damage for all categories of animals. On the other hand, I find that zero yearling harvest together with positive harvest of one, or both, of the adult categories do not contradict the optimality conditions. The reason for this outcome is simply that the per animal values (meat value plus omitted damage value due to harvesting) are higher for the adults than the yearling category while the survival rates do not differ too much.

It is also possible to show that positive calf harvest can not be optimal suggested that there is no yearling harvest. With zero yearling harvest, $h_{y,t} = 0$, the yearling state condition (20) reads $\eta_t + d_y = \rho\lambda_{t+1} 0.5 s_y + \rho\mu_{t+1} 0.5 s_y$, while the yearling control condition (17) reads $pw_y + d_y < \rho\lambda_{t+1} 0.5 s_y + \rho\mu_{t+1} 0.5 s_y$. These two conditions yield $\eta_t > pw_y$. When combining the calf control condition (16) under the assumption of positive calf harvest with the above inequality, I further find $(1/\rho s_c)(pw_c + d_c) > pw_y$, or $(pw_c + d_c)/s_c > \rho pw_y$. That is, a higher 'biological discounted' meat plus omitted damage value of the calf age class than the economic discounted meat value of the yearlings. However, because of the substantial more valuable harvest of the yearling than

the calf category together with the small calf damage cost and the high calf survival rate this outcome is not likely. Suggested that there is no harvest of the yearling stage and if the discount factor is not too low, i.e., the discount rate δ is not too high, it can not be beneficial to harvest the calf population. Therefore, the general conclusion is that adult harvesting only will maximize the landowner present-value net benefit. Notice that this is not merely a steady state condition, it holds for all t.

As already indicated, it is difficult, if not impossible, to say something analytically about the dynamics of the harvest and stock evolvement. However, due to the strong degree of linearity in the model together with density dependent regulating through the recruitment function, the model is suspected to approach a stable equilibrium quite fast. This is confirmed by numerical examples where the recruitment function (11) is specified in a fairly standard manner. The dynamics have similarities with the Most Rapid Approach Path (MRAP) (see also above), but with some degree of undershooting and overshooting depending on the initial stock values, parameter values and management regime (not reported here).

Table 2 demonstrates some typical numerical steady state results. The first line of the table shows the hunting rates and adult sex ratio. In line with the theoretical reasoning, there is no yearling and calf harvest. The adult male hunting rate is substantial higher than that of the female hunting rate. There are two reasons for this. First of all, and in line with the above discussion, the male hunt is more valuable as both the meat value (higher weight, but similar meat price) and the omitted damage value due to harvest is higher for the male category. Second, females are more important for the recruitment. For both these reasons, we hence find that male harvest is more aggressive than female harvest and the optimal harvest is characterized by a highly skewed male – female sex ratio.

<Table 2 about here>

In this table, I have also calculated harvest rates and profit when the optimal harvest pattern is replaced by an ‘optimal’ uniform hunting pattern. This uniform pattern describes an exploitation scheme where the present value net befit is maximized under the same biological constraints as above, but with the additional constraint of similar harvest rates of all stages. This scheme may thus indicate a harvest pattern where ‘an animal is an animal’; that is, just as in the traditional bieconomic models studied in sections 2 and 3 above. The ’optimal’ uniform steady state harvest rate becomes 0.18. The economic benefit reduces dramatically (last column); from the scaled value of 100 with optimal selective hunt to 67 with uniform hunting rates; that is, 33 % reduction,

Irrespectively of the fact that this model indeed is quite complicated, I have demonstrated that it is possible say something crucially about the efficient harvest composition without relying on numerical solutions. The basic reason is that the population variables are not included in the above control

conditions (16) – (19). These variables are not included because the hunting benefits as well as the browsing damage are represented by linear functions. The 'biological discounted' meat value plus the omitted browsing damage value due to harvesting are then instrumental in determining the efficient harvest composition. More stages included in the model will complicate the picture, but with linear control conditions I still will find that differences in the 'biological discounted' values among the stages will be of crucial importance. More cost and benefit components can be included as well. For example, it is well known that the cost related to traffic damages is an important problem related to the present high moose and deer populations in Scandinavia as well as in North America. Including such costs, which typically are external to the landowners, and optimizing the hunt will represent an overall solution to the management problem. Not surprisingly, I find that this leads to more aggressive hunting, but still only adult hunting as long as the damage functions are linear.

5.Further readings

Clark (1990) gives a coherent and excellent capital theoretic analysis of renewable natural resources. In addition, both open-access harvest and some basics of cohort models (age, or stage structured models) are presented in this milestone book. However, any analysis of land-use and terrestrial animal species are not covered as this book basically is related to fish and other marine resources. Conrad and Clark (1987) is another advanced text related to the economics of renewable (as well as non-renewable) natural resource exploitation. The overview paper by Brown (2000) is also useful.

Swanson (1994) is one of the first texts that studied exploitation of terrestrial animal species within an economic framework. See also Swallow (1990), and Schulz and Skonhoft (1996). In this last paper various in situ (stock) values, like tourist value, are introduced. Part of section 2 builds on this article. Several topics in the utilization of terrestrial animal species are studied further by Bulte and van Kooten, see, e.g., van Kooten and Bulte (2000). In the collection of articles edited by Barbier and Swanson (1992) several important issues analyzing the economics of wild terrestrial animal in a developing economy, i.e., African context, are studied.

The analysis of the conflicting wildlife utilization model in section 3 builds on Johannesen and Skonhoft (2005). Because de jure and de facto property rights differ, this is an example of an analytical model where property rights are determined endogenously. It is now a rather large literature on this issue, see e.g., Engel and Lopez (2008). I still feel that Bromley (1990) is a good general text on property rights issues. See also Baland and Platteau (1996) and the classical Ostrom (1990) analyzing common property issues.

Caswell (2001) gives an in-depth overview of age structured, or cohort, models. Getz and Haigh (1989) is also a useful text. However, economic analysis plays a minor role in these books. Economic reasoning is taken up in the seminal article by Tahvonen (2009), but this analysis is for a fishery. Few economic models are published analyzing exploitation of terrestrial animal species within a stage structured framework. One of this is Olaussen and Skonhoft (2011) in which the analysis presented in section 4 draws on.

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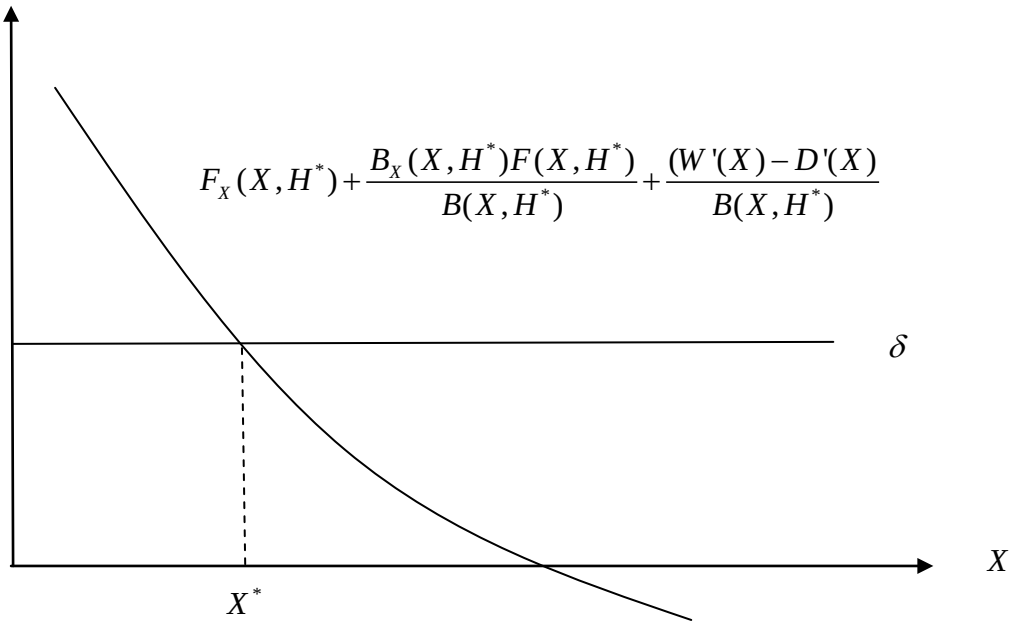
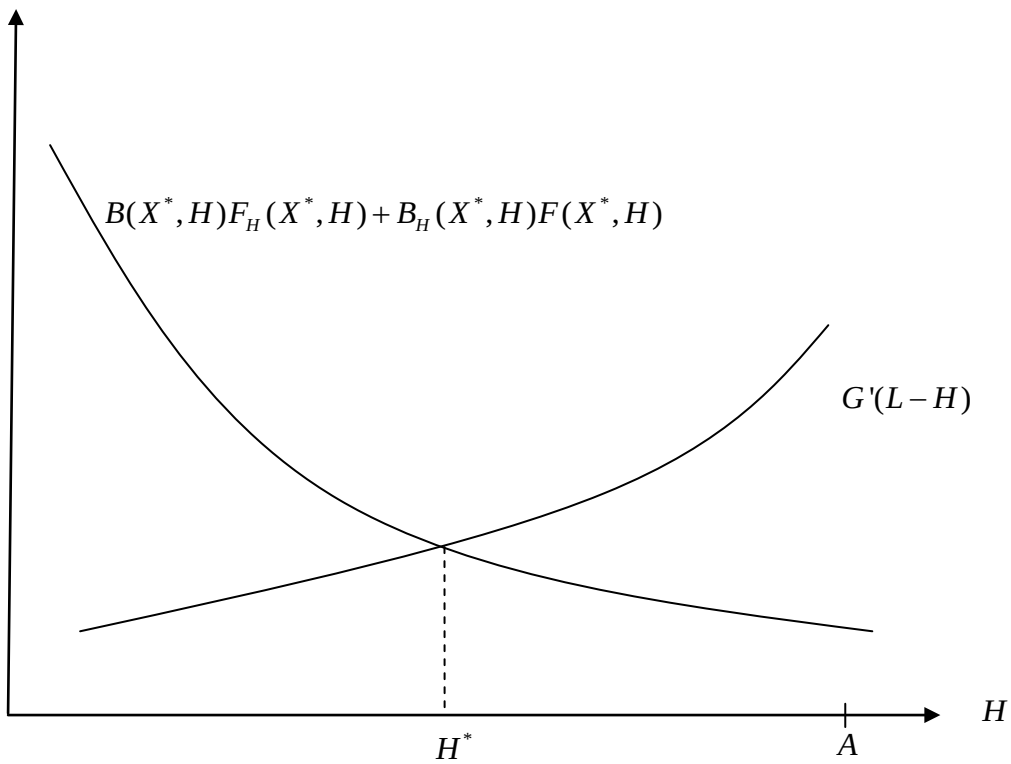
Tables and Figures

Figure 1. The equilibrium (steady state) conditions for the wildlife stock and land use social planner model



Panel a): The equilibrium wildlife stock (Eq. 4).



Panel b) the land-use equilibrium (Eq. 5)

Figure 2. The Nash equilibrium the two agent conflict model

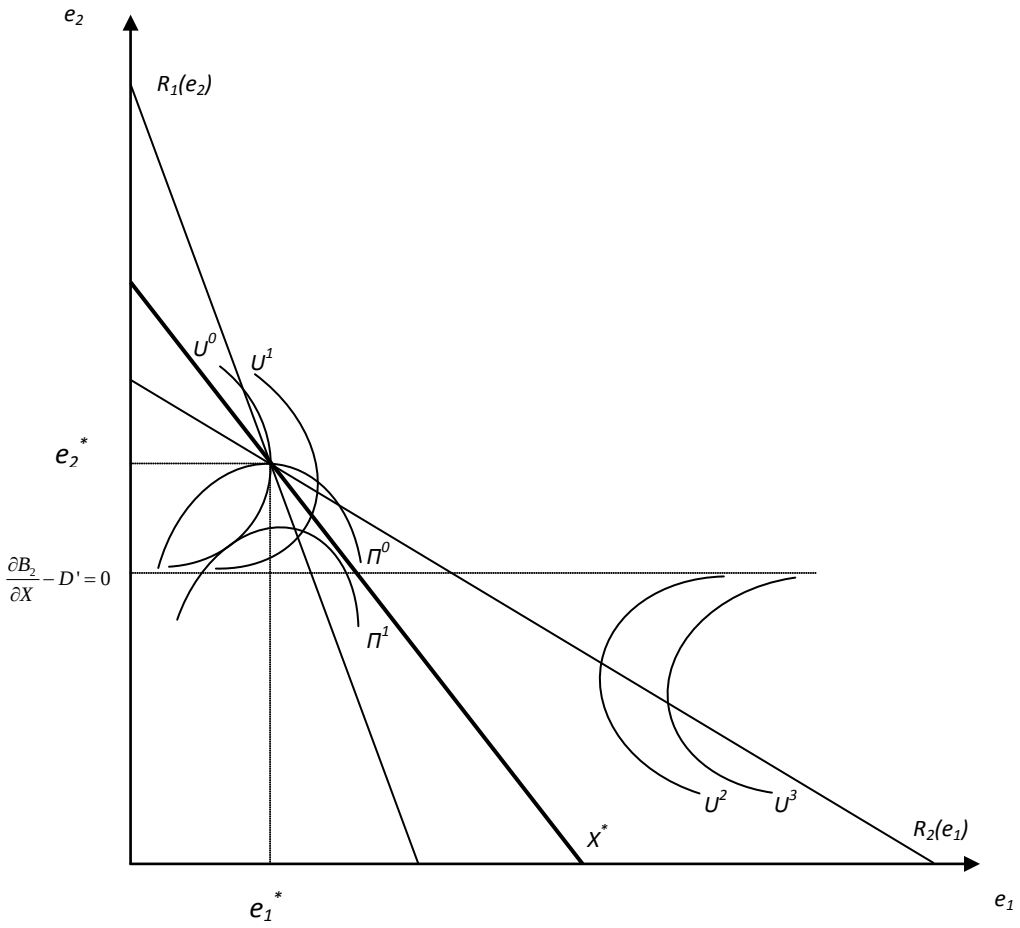


Table 1. The two agent conflict model. Comparative-static results

	e_1^*	e_2^*	X^*	π^*	U^*
p_1	+	–	–	+	?
w	–	+	+	+	?
d	–	+	–	–	–
p_2	–	+/–	–/+	–/+	?
c_1	–	+	+	–	?
c_2	+	–	+	+	?
r	?	?	?	?	?
K	?	?	?	?	?

Note: +/– implies different sign effects e_2^* and X^* (and π^*). ? implies ambiguous sign effect.

Table 2. Steady state selective hunting and uniform hunting.

	h_c^*	h_y^*	h_f^*	h_m^*	X_m^* / X_f^*	π^*
Selective hunting	0	0	0.25	0.90	0.29	100
Uniform hunting	0.18	0.18	0.18	0.18	1.00	67