Ulvelg0604

PRELIMINARILY AND UNCOMPLETED

The cost, or benefit, of predation. An analysis of the recent wolf re-colonisation in Scandinavia.

by

Anders Skonhoft
Department of Economics
Norwegian University of Science and Technology
N-7491 Trondheim, Norway

Abstract

After close to being extinct, the wolf (*Canis lupus*) has re-colonised in Scandinavia during the last two decades. The population counts today about 120 individuals, and is distributed in small packs along the border between Sweden and Norway. The re-colonisation has caused several conflicts. One conflict is due to predation on livestock (sheep, reindeer). Another conflict is predation on wild ungulates, and where the wolf shows a particularly strong selection for moose (*Alces alces*). As a consequence, a smaller population is available for moose hunting, the far most important game in Scandinavia. The costs of moose predation are studied in two steps. First, we analyse the costs of the landowners. They are made up of two components; loss of animals potentially for hunting minus reduced browsing damage due to a smaller moose population. Next, we look at the problem from a more overall point of view, as costs, external for the landowners and the local communities, are included. Far most important here is the damage costs related to moose-vehicle collisions which may even exceed the meat value of the moose.

1.Introduction

After close to being extinct in Scandinavia during the 1960's, the wolf (*Canis lupus*) was protected by law in the beginning of the 1970's. As a result, it has re-colonised during the last two decades, and the population now counts about 120 individuals (Environmental Department 2003, Wabakken *et al.* 2002). The wolf in Sweden and Norway is distributed in small packs, and most of the packs are found in the border areas between these countries in the Hedemark county (Norway) and Jämtland county (Sweden).

While small in number, the re-colonisation of the wolf has caused several conflicts. One conflict is due to predation on livestock (sheep, reindeer). Measured in total loss this predation is not very severe, but farmers in some few areas have been seriously hit (Environmental Department 2003). Another important conflict is predation on wild ungulates, and where the wolf shows a particularly strong selection for moose (*Alces alces*). As a consequence, a smaller moose population is available for hunting. Moose predation has also taken place only in some few areas, but these being areas with high moose density and strong and old hunting traditions. However, while considered as a direct pest and nuisance only in some few areas, the wolf predation on moose has caused great concern in most of the rural Scandinavia, as moose hunting is the far most important game. Yearly, about 40.000 and 100,000 animals are shot in Norway and Sweden, respectively (Saether *et al.* 1992). In addition, the hunting in September/October is an important, not to say *the* important, yearly social and cultural event, taking place in a large number of rural communities.

In what follows, the cost of this recent wolf re-colonisation due to predation of moose is analysed. The problem is studied in two steps. First, the costs of the landowner are analysed. According to the wildlife laws in Scandinavia, the landowners are given the hunting value of the moose. At the same time the landowners bear the cost of the browsing damage and hence reduced forestry income, of the moose. The browsing damage takes basically place during the winter when young pine trees are the important food source (Storaas *et al*. 2001). The economic loss of the landowners due to wolf predation is therefore made up of two components; loss of animals potentially for hunting minus reduced browsing damage due to a smaller moose population. The loss, however, depends on the management goal, and altogether we consider four management options. As will be shown, and contrary to intuitive reasoning, the loss may be negative under some of the scenarios, meaning that predation, or increased predation pressure, increases the profit of the landowners. Next, we look at the problem from a more overall point of view, as the costs due to moose-vehicle collisions are included. These costs are considerable, and recent estimates indicate that they may be even higher than the meat value of the moose (Storaas *et al*. 2001).

The relationship between the wolf and the moose is generally highly interactive, determined by the growth rate of the moose population and the functional and numerical response of the wolf population. The wolf-moose ecology has been studied in North America, and to some extent, in Scandinavia (Nilsen *at al.* 2004). However, very few studies are published including any economic considerations. One analysis is Tu and Wilman (1992) who studied the dynamics of the wolf and moose relationship using a Lotka-Volterra model. The scope of their analysis was basically to study how various predator control programs affect the dynamics of the ecological system when uncertainty is included. Another study is Boman *et al*. (2003) who analysed bio-economic aspects of the dispersal pattern of the recent wolf expansion in Sweden. No predation of moose was, however, included in this study. The following analysis is therefore more related to some recent bio-economic pest and nuisance studies (see, e.g., Zivin *et al.* 2000 and Huffaker *et al.* 1992). It has also links to the Flaaten and Stollery (1996) paper analysing the economic loss of the cod-fishery along the Norwegian coast due mink whale predation. Just as in this fishery study, we apply a reduced form predator-prey model because the size of the Scandinavian wolf population is strongly controlled by human management. The ecological model includes therefore only the ecological link from wolf to moose, and not the vice versa, and utilises a stylised biomass framework.

In the subsequent analysis, we are all the time thinking of an area of fixed size with a moose population together with a wolf population. There is no dispersal in and out of the area affecting the natural growth. It may be one of more landowners of the area, but in sum they are assumed to behave like a single agent. We start by formulating the ecological model in section two. The cost and benefit functions of the landowners follow in section three. Next, in section four, we formulate and analyse the various moose management goals of the landowners and find the economic loss of the wolf predation. The management options studied are; a) keeping a constant stock level of the moose population, b) harvesting a fixed fraction of the population, c) harvesting a fixed quota, and finally, d) maximising the profit of the moose population. Section five illustrates the various management schemes numerically by a real life example from one of the areas where a wolf pack has re-colonised, the Koppang area, located some 300 km north of Oslo. In section six, the cost of moose-vehicle collisions, external for the landowners, is included, and we hence analyse the economics of moose-wolf interaction from a more overall perspective.

2. The ecology

While the recent re-colonisation of the Scandinavian wolf is of low density and patchily distributed, the density of the moose population is, on the other hand, high. The main reasons being the previous absence of predators, a highly selective harvesting scheme and good growth conditions due to shifting practices in the forestry. The population size has hence increased significantly during the last 30 years or so in both Sweden and Norway (Saether *et al.* 1992, Gundersen 2003).

The moose-wolf ecology has been subject to intensive studies in North America. From these studies it seems clear that wolves, when present, influence moose populations to a large extent, while it is somewhat unclear whether the wolf only limit, or regulate, the populations. (Nilsen *et al.* 2004 gives more details). The Scandinavian ecosystem is, however, somewhat different than the North American system. First, the moose density is generally higher in Scandinavia. Second, the age and sex structure is different due to a high degree of hunting selection with a high proportion harvesting of calves and young males. Third, the wolf density in Scandinavia is much lower, and more patchily distributed (Gundersen 2003, Nilsen *et al.* 2004). The moose- wolf ratio is thus higher in Scandinavia, and the impact of wolf predation is likely to be of more local nature. The predation is basically focused on calves, yearlings and older females, with calves as the main food source. The predation rates reported from Scandinavia seem to be higher than those found in North America, which may indicate that, the predation, for a given size of the wolf pack, increases with the moose density (Nilsen *et al.* 2004).

Based on the above reported studies, it will be assumed that the wolf predation represents an addition source of mortality for calves, yearlings and older females. In our biomass framework, the natural growth of the moose population then translates into two terms; growth in absence of wolf minus mortality through predation. The predation is determined by the size of the wolf pack and where a larger pack means more predation. While most likely increasing in the size of the moose population as well (see above), it is, however, somewhat unclear how this functional response may look like. Following the Lotka-Volterra biomass model (see, e.g., Tu and Wilman 1992) the predation increases linearly in the number of prey. In what follows, we use a more general functional form which may include a decreasing effect as well.

While the predation is determined by the size of the wolf pack together with the size of the moose population, any functional response the other way around is not taken into account; that is, the number of wolf is not influenced by the size of the moose population. The reason for this is that the wolf population, at least in Norway, is managed with strictly target levels for the various packs (Environmental Department 2003, REF Sweden..). Accordingly, as the size of the wolf population, or equivalently, the predation pressure, is determined outside the model, there is only a one-way interaction between the predator and the prey in our ecological model. The ecology has hence the same structure as the cod - mink whale model of Flaaten and Stollery (1996), albeit their argument for omitting the functional response of the predator is somewhat different.

When neglecting any stochastic variations in environment and biology, the equation:

(1) $$X_{t+1} - X_t = F(X_t) - G(W, X_t) - h_t$$

gives therefore the growth of the moose population. X_t is the population size year t measured as biomass (or number of 'normalised' animals), $h_t \geq 0$ is the harvest same year and $F(X_t)$ is the density dependent natural growth function in absence of wolf predation, assumed to be of the standard logistic type with $\partial F / \partial X_t = F' > 0$ for a 'small' population and $F' < 0$ when the size becomes larger (more details below). $G(W, X_t)$ is the predation term where W is the size of the wolf pack, being exogenous throughout the analysis, with $G(0, X_t) = 0$ and $\partial G / \partial W = G_W > 0$. The size of the moose stock generally influences the predation as well, $G(W, 0) = 0$ and $G_X > 0$, while this effect might be reduced when the moose density becomes higher (see above), $G_{XX} \leq 0$. Finally, $G_{WX} \geq 0$ is also assumed to hold. See Figure 1.

Figure 1 about here

In ecological equilibrium we have $F(X) - G(W, X) - h = 0$ which implicitly defines the prey isocline. For a given amount of harvesting, the slope reads $dX / dW = G_W /(F' - G_X)$. Accordingly, when $(F' - G_X) < 0$, $G(W, X) + h$ intersects with $F(X)$ from below and the isocline slopes downward. In the opposite case it slopes upward. However, in what follows, only the decreasing part of it will be considered as this implies dynamic stability (see also below).

3. The cost and benefit of the landowners

The landowner's net benefit of the moose population is made up of two components; hunting income and browsing costs due to damage on young pine. The hunting income is given as ph_t where p is the hunting licence price. Mattson (1994) observed a positive stock dependent willingness to pay for hunting licences in Sweden while an ambiguous affect was observed between the price and the number of animals hunted. However, here it is assumed that p is fixed and independent of the amount harvested and the stock size which may be justified by the presence of competition among different suppliers of hunting licences. Following the practice in Norway (and Sweden), one licence allows the buyer to kill one animal, which is paid only if the animal is killed.

The damage on young pine happens basically throughout the winter and varies due to the quality of the timber stand and the productivity of the forest. The damage may take place immediately and damaged young pine trees may be replaced directly, but quite frequently there is a time lag between the occurrence of browsing and the economic loss of the damage. In such instances, however, discounting is not taken explicitly into account in the present exposition. A simple, but realistic way, to account for the browsing damage is to relate it to the size of the moose population (see also Zivin *et al*. 2000). The damage function reads then $D_t = D(X_t)$ with $D(0) = 0$ and $D' > 0$. In addition it is assumed to be convex, $D'' \geq 0$ (Storaas *et al*. 2001). The yearly net benefit, or profit, of the landowners year t reads accordingly:

(2) $$\pi_t = ph_t - D(X_t).$$

The potential economic loss of the landowners year t due to the wolf predation is therefore the profit (2) in absence of wolf predation minus the profit (2) with wolf predation. The loss is hence made up of two components; a change in the harvestable population and a change in the stock size causing browsing damage. To account for the loss, however, the management strategy of the landowners has to be specified as harvest and stock size, and hence the profit, are related to the harvesting practice.

4. The various management scenarios of the landowners

According to Norwegian wildlife law, the State through the Directorate for Wildlife and Nature Management ('Direktoratet for Naturforvaltning') determines the number and composition (calves, juveniles, adult female and adult male) of moose to be hunted within each management area. The management goal is usually to maximise the meat value in ecological equilibrium (Saether *et al.* 1992). Browsing damage may be taken into account, but often in ad-hoc manner. The management goal in Sweden is more or less the same (REF). However, due to uncertainty of various types, lack of information, and so forth, the landowners usually implement the above management goal in a pragmatic manner, which in most instances, if not always, boils down to formulating simple goals for the population size and/or the harvest. One such goal may be to keep a fixed stock size over time; meaning that the whole population over a certain threshold should be harvested. Another goal may be to harvest a fixed fraction of the population every year. These management goals are accordingly very much the same as in the fisheries (see e.g., Flaaten and Stollery 1996).

In what follows, the cost of predation is evaluated in light of such pragmatic harvesting strategies, and three such management options are studied; a) keeping a constant stock level, or threshold harvesting, b) harvesting a fixed fraction of the population every year, and c) harvesting a fixed quota every year. These three goals are then compared to the strategy of finding the value of the moose population that maximises the economic outcome of the landowners. This is formulated as, d) maximising present-value profit. All these schemes are evaluated at ecological equilibrium (but see the concluding section).

a) Keeping a constant stock level, or threshold harvesting

Threshold harvesting, or keeping a constant stock level X^a, may typically be related to the maximum sustainable yield level, or other 'sustainable' levels of the population. In ecological equilibrium we accordingly have $F(X^a) - G(W, X^a) - h^a = 0$ where $h^a \geq 0$ indicates the threshold harvesting. When $h^a > 0$, differentiating yields $dh^a / dW = -G_W < 0$, which means that increased predation consumption is exactly balanced by reduced harvesting. The ecological equilibrium economic loss due to wolf predation under this harvesting rule follows then simply as reduced harvesting income:

(3) $$\frac{d\pi^a}{dW} = -pG_W(W, X^a) < 0 .$$

b) Harvesting a fixed fraction of the population

According to this management rule, the harvest year t is governed by $h_t = \gamma X_t$ where $0 \le \gamma < 1$ is the fixed harvesting fraction. Inserted into the population equation (1) in ecological equilibrium we have $F(X^b) - G(W, X^b) - \gamma X^b = 0$ and where X^b indicates the equilibrium stock level under this management rule. Differentiation yields $dX^b / dW = G_W / (F' - G_X - \gamma)$, being negative when demanding dynamic stability (see also above). Accordingly, under this condition the moose stock is unambiguously lower under the presence of wolf predation than without predation. The equilibrium harvest $h^b = \gamma X^b$ will therefore be lower as well.

As both the number of animals harvested and the number of browsing animals decrease, the harvesting income as well as the browsing damage decrease. Hence, the profit effect is ambiguous:

(4) $$\frac{d\pi^b}{dW} = \frac{(p\gamma - D'(X^b))G_W(W, X^b)}{(F'(X^b) - G_X(W, X^b) - \gamma)},$$

and we find that the presence of wolf predation, or equivalently, a higher wolf predation, reduces the profit of the landowners only if the marginal harvesting income dominates the marginal browsing damage; that is, $(p\gamma - D') > 0$. For these parameter values the size of the moose population is below the static profit maximising condition $(p\gamma - D') = 0$, and hence an additional moose consumed by the wolf pack leads to an allocation even farer from this maximum. In the opposite case with $(p\gamma - D') < 0$, a larger predation pressure increases accordingly the profit of the landowners as reduced marginal damage dominates reduced harvesting income following a smaller moose population.

c) Harvesting a fixed quota

Following this management rule the ecological equilibrium condition reads $F(X^c) - G(W, X^c) - h^c = 0$ with $h^c \geq 0$ indicating the fixed quota and X^c the accompanying stock level. Differentiating yields $dX^c / dW = G_W / (F' - G_X)$, being negative when demanding dynamic stability. The presence of wolf, or higher wolf predation pressure, will under this condition unambiguously increase the profit:

(5) $$\frac{d\pi^c}{dW} = -\frac{D'(X^c)G_W(W, X^c)}{(F'(X^c) - G_X(W, X^c))} > 0$$

The reason for this result is obvious, as the harvesting income stays unchanged while the browsing damage decreases following a smaller moose population. At the price of a smaller and less 'sustainable' moose population (but see the numerical results below), the landowners will hence benefit from wolf predation. For obvious reasons, however, the harvesting quota cannot be too large if the predation pressure is substantial; it is then simply not enough moose for harvesting.

d) Maximising present-value profit

The above management rules are now contrasted with the scenario of present-value profit maximising of the landowners. This harvesting strategy follows accordingly by maximising $\sum_0^{T-1} \rho^t [ph_t - D(X_t)]$ subject to the ecological growth condition (1), and where T is the planning period and $\rho = 1/(1+\delta)$ is the discount factor with $\delta \geq 0$ as the (yearly) discount rate. The planning horizon is presumably long, or infinite, meaning that no scrap value is included in the objective function.

The current-value Hamiltonian of this problem reads (see, e.g., Conrad and Clark 1995) $H = ph_t - D(X_t) + \rho\lambda_{t+1}[F(X_t) - G(W, X_t) - h_t]$ where λ_{t+1} is the resource shadow price. The first order conditions for maximum yield $p - \rho\lambda_{t+1} = 0$

and $\rho\lambda_{t+1} - \lambda_t = D' - \rho\lambda_{t+1}(F' - G_X)$ when an interior solution is assumed (harvesting takes place at the steady-state). The interpretation of these conditions is standard. Suppose that the steady-state is reachable from the initial position X_0 (see also the concluding section below) and substituting away the shadow price, the reduced form first order condition, the so-called golden rule condition, may be written as:

(6) $$F'(X^*) - \frac{D'(X^*)}{p} - G_X(W, X^*) = \delta .$$

This condition indicates that the 'net' internal rate of return of the moose population should be equal the external rate of return δ. Multiplying with p and rearranging, the golden rule condition also says that net marginal value of the moose population 'in the forest', $p(F' - G_X) - D'$, should be equal the marginal harvesting revenue invested at the interest rate δ, $p\delta$. Following condition (6), the stock size will always be below the maximum sustainable harvest level $F'(X^*) > 0$, or $X^* < X_{msy}$. Discounting, browsing damage as well as predation works all in that direction. When the rate of discount is zero, $\delta = 0$, it can be shown that the solution (6) coincides with the problem of maximising current profit (2) in ecological equilibrium (see, e.g., Scott and Munro 1985).

Differentiation of (6) yields $dX^* / dW = G_{WX} / (F'' - D''/p - G_{XX}) \leq 0$, as the numerator is negative due to the second order conditions for maximum. As already indicated, the profit maximising steady-state stock size of the landowners is therefore lower in the presence of wolf predation. The steady-state harvest follows as $h^* = F(X^*) - G(W, X^*)$, and higher predation pressure reduces the harvest as well, $dh^* / dW = (F' - G_X)(dX^* / dW) - G_W < 0$. The effect on the steady-state profit $\pi^* = ph^* - D(X^*)$ becomes accordingly:

(7) $$\frac{d\pi^*}{dW} = \{p[F'(X^*) - G_X(W, X^*)] - D'(X^*)\}\frac{dX^*}{dW} - pG_W(W, X^*) < 0$$

which is also is negative as $[p(F' - G_X) - D'] \geq 0$ holds from the golden rule condition (6). The presence of predation lowers therefore unambiguously the profitability of the moose population when harvesting takes place under the strategy of present-value profit maximising. As both the harvesting income and the browsing damage decrease under a higher predation pressure, reduced harvesting income therefore dominates reduced browsing damage. When

$\delta = 0$ and having the situation of current profit maximising, condition (7) reduces to $d\pi^* / dW = -pG_W$; that is, just the same effect as in the threshold harvesting case a).

Summing up the four managing practices evaluated at steady-state, we may therefore conclude that two of the schemes mean reduced profit due to wolf predation, one yield unambiguous higher profit while the fixed harvesting fraction scenario b) yields no clear conclusion. The outcome of the last one depends on the value of the harvesting fraction, in addition to the cost - price ratio, and when the harvesting fraction is large, a higher predation pressure is likely to reduce the profit of the landowners. It is also clear that a higher quota under the fixed quota scheme c), generally will increase the profitability of predation (SJEKK:::::::::::?)

5. Numerical illustrations

Data and specific functional forms

The above analysis will now be illustrated numerically with data from the Koppang area, some 300 km north of Oslo. In this region a wolf pack settled in 1997 utilising an area of about 600 square km, with a moose population of somewhat below 1000. A new pack settled later, and since 1997 the number of wolves has been between 5 and 12. The yearly moose consumption is estimated to have been in the range xx- xx animals, basically calves and older females (see Gundersen 2003 for more details). As mentioned, the wolf population in Scandinavia is strictly controlled by human management. This is also so for the Koppang area, and during the winter 2002 one of the two existing packs was erected by use of helicopter, snowmobiles and a large squad of government paid hunters while being watched by various NGO's and the world press (see, e.g., New York Times xx).

As indicated, the natural growth of the moose population in absence of predation is assumed to be of the standard logistic type; $F(X_t) = rX_t(1 - X_t / K)$ with r as the maximum specific growth rate and K as the carrying capacity. The functional response due to predation is specified as a Cobb-Douglas function, $G(W, X) = \alpha WX^{\beta}$ with $\alpha > 0$ and $0 < \beta \leq 1$. Hence, for $\beta = 1$ the functional response of the moose population is governed as in the Lotka-Volterra model, and the predation rate (as a fraction of yearly growth) is constant and equal to αW. Finally, we use a linear browsing damage function; $D(X) = aX$ with $a > 0$ as the fixed damage cost per moose. For these functional forms, routine calculations yield ecological equilibrium profit under the various management schemes as

$\pi^a = pX^a[r(1 - X^a / K) - \alpha W] - aX^a$, $\pi^b = (K/r)(p\gamma - a)(r - \alpha W - \gamma)$,

$\pi^c = ph^c - a(K/2r)[(r - \alpha W) + \sqrt{(r - \alpha W)^2 - 4rh^c / K}$ and

$\pi^* = p(K/4r)[r^2 - \delta^2 - 2(r - \delta)\alpha W - (a/p)^2 + (\alpha W)^2] + a(K/2r)[r - \delta - (a/p) - \alpha W]$.

Under the fixed harvesting quota scenario c), there will generally be two values for the stock size, but only the largest is in accordance with dynamic stability (again, see above). Hence, π^c is for this root.

The parameter values are based on Skonhoft and Olaussen (2004). The maximum specific growth rate is given as $r = 0.47$ while the carrying capacity is assumed to be $K = 3500$ (number of moose) which implies about 5.8 moose per square km. In the calculations reported below, $\beta = 1$ is used in the functional response function. We study three alternatives of predation pressure; with $\alpha W = 0.05$ as the baseline value, meaning that 5 per cent of the moose population growth is consumed by the wolf pack. This represents more or less the recent wolf consumption when calves and older females (see above) are translated into biomass, or 'normalised' number of animals (SJEKK). This value is contrasted with the 'high' pressure of $\alpha W = 0.10$, and no predation at all. The price of the hunting license is fixed as $p = 8000$ (NOK per moose, 2003 prices), while the marginal damage cost is given as $a = 1500$ (NOK per moose, 2003 prices). In the baseline calculations, we assume a zero discount rent, $\delta = 0.00$, meaning that the steady-state of the present-value maximising scenario coincides with equilibrium harvesting profit maximising (see above).

Results

Table 1 gives the results under the baseline predation scenario of $\alpha W = 0.05$, and where the stock size under the threshold harvesting scenario a) is $X^a = X_{msy} = 1750$ (number of moose), the harvesting fraction under the fixed harvesting fraction scenario b) is $\gamma = 0.3$, and the harvesting quota under the fixed harvesting quota scenario c) is $h^c = 200$ (number of moose).

Table 1 about here

The fixed harvesting fraction scheme b) yields results quite close to the profit maximising scenario d), while the outcome of the fixed quota scheme c) is a very high stock. As a result the browsing damage strongly dominates the harvesting income, and the profit becomes negative. However, it should be noted that this is a calculated loss, as the forest damage, in most instances, represents future profit loss (cf. section three above).

Table 2 about here

Tables 2 and 3 shows the results when predation is absent (Table 2) and when the pressure is high (Table 3). The cost of predation becomes quite high under the threshold scheme a), while being more modest under the fixed harvesting fractioning scenario b). As shown in the above section four, the effect of predation under this scheme is generally unclear. However, because $(p\gamma - D') = (p\gamma - a) > 0$ holds, a higher pressure means lower profit (cf. also the above profit function). On the contrary, and in line with the analytical exposition, the profitability improves with more predation under the fixed quota scenario c).

Table 3 about here

The management schemes a), b) and c) are also studied under different values for the stock threshold level, harvesting fraction and quota, respectively. Due to less browsing damage, the economic viability under the threshold scheme a) improves when the fixed stock level is lowered. Moreover, the cost of predation becomes less significant as well. With $X = X_{msy}/2 = 875$ (number of moose), we find $\pi^a = 1155$ (1,000 NOK) without predation, which reduces to 455 when $\alpha W = 0.10$. The baseline scenario of $\alpha W = 0.05$ yields $\pi^a = 805$. When the harvesting fraction under scenario b) reduces, more or less the same picture emerges. Under the fixed harvesting quota scheme c), we find that XXXXXXXXXX XXXXXX

6. The social planner solution and the social benefit of predation

The above analysis reflects an institutional situation where the landowners determine the harvest and the size of the moose population while taken the cost (or benefit) of the wolf predation as given. This may hence be considered as a market solution where the landowners have the property rights of the moose population while correcting for one externality, the public good value of the wolf population (see, e.g., Bromley 1991). The social benefit of predation may then hence be calculated as the landowner profit with predation together with the social benefit of the wolf population, minus the landowners profit in absence of predation. There are, however, other externalities present following such a property rights scheme; the single most important is the damage costs related to moose-vehicle collisions. These costs are considerable, and in Norway as a whole they may even exceed the meat value of the hunting (Storaas *et al*. 2001). People living outside the various 'moose-areas' generally cover these costs (insurance fee). For the landowners and the local communities these costs are therefore external.

A simple, yet realistic, way to account for the moose-vehicle damage is just as for the browsing damage, to relate it to the population size as more moose, *ceteris paribus*, means more damage; that is, $T_t = T(X_t)$ with $T(0) = 0$ and $T' > 0$. When neglecting other potential cost and benefit components, the yearly net social benefit of the moose population in the given area then writes $[ph_t - D(X_t) - T(X_t)]$ [1]. When further assuming that the size of the wolf population W in the population dynamics (1) reflects the social desirable stock, the present-value profit maximising solution of the social planner yields the golden rule condition[2]:

$$(8) \qquad F'(X^s) - \frac{D'(X^s) + T'(X^s)}{p} - G_X(W, X^s) = \delta ,$$

where sub-script 's' indicates the social planner solution. Compared to the steady-state of the present-value profit maximisation scheme of the landowners (6) with the same size of the wolf pack, we find $X^s < X^*$, and hence also $h^s < h^*$ because X^* as well as X^s are below that of X_{msy}. When no predation is included in the management of the landowners, the gaps become even larger. Compared to the other management options of the landowners, not very much

[1] A positive non-consumptive stock value of the moose population (viewing value, etc.) should generally been added to the social value. However, due to the healthy state of the Scandinavian moose population, this value is likely to be small, if not negligible, on the margin. In a more general model one could also imagine that the costs of effort use to reduce traffic damages should be included. However, this would have demanded a more fully model where the mortality of the moose population due to traffic incidences explicitly had to be introduced as well.

[2] To determine the size of the social desirable wolf population (if possible), however, a more fully model had to been constructed as well.

can be said about the differences as they generally depend on the parameterisation of the models.

The social gain of predation will now be illustrated more closely by using the same functional forms and data as above. In addition, and in line with the linear browsing damage function, we also introduce a linear traffic damage function, $T(X_t) = tX_t$ with $t > 0$ as the fixed damage cost per moose. Based on Gundersen (2003) we assume $t = 1,000$ (NOK per moose). Moreover, we use the baseline predation pressure $\alpha W = 0.05$ as an illustration of the social desirable predation pressure, with the accompanying social value of the wolf pack as VW (NOK). Table 4 shows the outcome when comparing with the landowner management options b) and d).

We first look at the profit maximisation scheme d). This scheme implemented as the market solution, meaning that neither the external cost of the wolf population nor the external traffic damage are taken into account, yields a landowner profit of 1,189 (1,000 NOK) (see also Table 2). The social surplus becomes 137. If this market solution is implemented while correcting for the external cost of traffic damage, but still not accounting for the public good value of the wolf pack, the landowner profit reduces to 956. The social surplus increases then to 370. Finally, when comparing this outcome with the social planner solution, it is seen that the landowner profit is further reduced while the social surplus reads $(172 + VW)$. The social benefit of predation is therefore this amount minus 370 under this management scheme.

Table 4 about here

The fixed fraction harvesting scheme b) gives a social surplus of -127 (1,000 NOK) when there is no wolf population, and hence no predation pressure, and the traffic damage is neither taken into account (again, see also Table 2). The 'pure' market solution under this scheme hence yields an even higher traffic damage cost than the profit of the landowners. The social gain of correcting this market solution for both externalities is now $(172 + VW + 127)$.

7. Discussion

References

Bromley, D. 1991: *Environment and Ecology*: Blackwell, Oxford

Conrad, J. and C. Clark 1987. “Natural Resource Economics. Notes and Problems”. Cambridge U.P., Cambridge

Environmental Department 2003. “Rovdyrmeldingen”

Flaaten, O. and K. Stollery 1996. “The economic costs of biological predation”. *Environment and Resource economics* 8: 75-95

Gundersen, H. 2003: …Ph.D Thesis. Dep. of Biology, University of Oslo

Huffaker, R. G., M. G. Bhat and S.M. Lenhart. 1992. “Optimal trapping strategies for diffusing nuisance-beaver populations.” *Natural Resource Modeling* 6: 71-97.

Mattsson L. 1994. ”Att kvantifisera viltets jaktvärde.” *Arbetsrapport* nr. 192 Sveriges Lantbruksuniversitet, Umeå.

Munro, G. and A. Scott. 1985. “The economics of fishery management.” In Kneese og Sweeney, *Handbook of natural resource and energy economics*, *vol. II,* Elsevier Science, Amsterdam.

Nilsen, E., T. Pettersen, H. Gundersen, J. Milner, A. Mysterud, H. Andreassen and N. Stenseth 2004. “Moose harvesting in the presence of wolves. Submitted

Saether, B-E., K. Solbraa, D. P. Sødal and O. Hjeljord. 1992. ”Sluttrapport Elg-Skog-Samfunn.” *Forskningsrapport nr. 28 NINA*, Trondheim.

Skonhoft, A. and J.O. Olaussen 2004: Managing a migratory species that is both a value and pest. *Land Economics* (in press)

Storaas, T., H. Gundersen, H. Henriksen and H. Andreassen. 2001. “The economic value of moose in Norway.” *Alces* 37: 97-107.

Tu, P. and E. Wilman 1992: “A generalised predator-prey model: Uncertainty and management”. *Journal of Environmental Economics and Management* 23: 123-138

Zivin, J., B. M. Hueth and D. Zilberman. 2000. “Managing a multiple-use resource: The case of feral pig management in California rangeland.” *Journal of Environmental Economics and Management* 39: 189-204.

Wabakken,

Table 1
Baseline predation $\alpha W = 0.05$. *Population size (number of moose), harvesting (number of moose) and profit (1,000 NOK)*

Management scheme	Population size X	Harvesting h	Profit π
a) Threshold harvesting	1,750	324	-35
b) Fixed fraction harvesting	894	268	804
c)Fixed quota harvesting	2,542	200	-2,213
d) Maximising present-value profit	866	263	805

Table 2.
No predation $\alpha W = 0$. *Population size (number of moose), harvesting (number of moose) and profit (1,000 NOK)*

Management scheme	Population size X	Harvesting h	Profit π
a) Threshold harvesting	1,750	411	665
b) Fixed fraction harvesting	1,266	380	1,139
c)Fixed quota harvesting	3,004	200	-2,906
d) Maximising present-value profit	1,052	346	1,189

Table 3.
Predation $\alpha W = 0.10$. *Population size (number of moose), harvesting (number of moose) and profit (1,000 NOK)*

Management scheme	Population size X	Harvesting h	Profit π
a) Threshold harvesting	1,750	236	-735
b) Fixed fraction harvesting	521	156	469
c)Fixed quota harvesting	2,017	200	-1,425
d) Maximising present-value profit	680	189	496

Table 4

Social planner solution and market solutions. Population size (number of moose), harvesting (number of moose) profit (1,000 NOK), traffic damage (1,000 NOK), social value wolf population and social surplus (1,000 NOK)

	Population size X	Harvesting h	Landowner profit π	Traffic damage T	Social value wolf population	Social surplus
b)Fixed fraction harvesting	1,266	380	1,139	1,266	0	-127
d) Profit maximising	1,052	346	1,189	1.052	0	137
d) Profit maximising, taking traffic damage into account	586	229	956	586	0	370
Social planner solution	400	147	572	400	VW	172+VW