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METHODS

Taking timber browsing damage into account: A density dependant matrix model for the optimal harvest of moose in Scandinavia

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ABSTRACT

At present there is a growing optimism in commercializing the moose hunting in Scandinavia. We developed a deterministic, dynamic bio-economic model to examine the optimal management of land with both moose and timber as potential sources of income. We show that most forest owners should target their moose commerce towards increased quality of the hunt rather than quantity. Due to the inherent complexity of moose: forest interactions we ran the model for a wide array of parameter values to check its sensitivity. Although it was the combined production of timber and moose that gave the highest net value in all run scenarios, timber was the major source of income (69% or more). The main single-factors favouring moose over timber was: low timber productivity of the soil and high moose prices in the market. Also factor synergies can strongly increase the relative value of moose. Our model may serve as a decision tool for choosing the economically optimal moose levels in populations with no across-border migration. It highlights the following need for further studies: I. Quantifying the relationship between browse availability (forest state, moose density) and moose condition (weights, fecundity). II. Quantifying the relationship between browse availability and timber browsing damage.

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1. Introduction

There is currently a conclusive need for integrating the management of timber and moose production in Scandinavia. While some forest owners still view the moose as a great threat to their income (Blennow and Sallnäs, 2002), there is also a growing number that highly value it both for recreational and economic reasons (Storaas et al., 2001). Depending on the preferences of forest owners involved, the number of moose is seldom adjusted to neither the ecological nor the economic carrying capacity.

Partly the lack of co-ordination is due to a distinct separation of decision-makers. Although Scandinavian land-

owners hold the right to both trees and wildlife on their property (and may extensively influence its management), traditionally few engage in the active management of both resources. In forestry, landowners individually decide how much timber to cut at any time, given the laws' sustainability criteria are respected. The moose harvest in Norway is decided by a board of county authorities and representatives for the hunting units, the latter typically are elected hunters with or without land property rights. The majority of hunting units involve several properties. Prior to 2002 landowners had considerable less influence on the moose harvest. Hunting quotas were then decided by municipality authorities, while county authorities had some responsibility for deciding the

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quotas' sex- and age structure. The involvement of hunters/landowners varied from absent to dominating in different areas.

Even modelling work on moose and timber production has been kept separate, despite their highly potential inter-relationship. There now exists an extensive literature on forest yield models (for recent reviews, see [Porté and Bartelink, 2002](#); [Sedjo, 2003](#)). Although a lot fewer, also moose yield models are assembling (e.g. [Sylvén, 1995](#); [Moen et al., 1998](#); [Sæther et al., 2001](#)). Models that combine the two, however, stem from a comparatively new practice and are not yet very comprehensive ([Nersten et al., 1999](#); [Kalén, 2004](#); [Skonhoft, 2005](#); [Wam et al., 2005](#)).

Different modelling paradigms between wildlife biologists and forest economists are the major reason for the lack of (comprehensive) moose-timber yield models. With bio-economic modelling, though, the two groups can meet on more common grounds ([Clark, 1976](#)). Here we present a bio-economic model for optimizing the moose and timber harvest when both have potential income value. While the optimization in our model is done mainly from an economic perspective, it also includes biological concerns that are usually viewed as difficult to address in terms of monetary value.

2. Model development

Our model is developed for forest planning over a variable number of years on properties with only one decision-maker (a single owner or several owners joined). We assume that the property is large enough for the across-border migration of moose to be negligible. Consequently, we do not address distribution issues related to the costs and benefits of migratory moose and different right holders (for such a discussion see [Olaussen and Skonhoft, 2002](#)).

2.1. Model structure

Trees and moose are projected at one-year intervals, assuming discrete reproduction and mortality. The number of individuals is counted after harvest, immediately before reproduction. A suitable model for the growth of both trees and moose is a modified stage-version ([Usher, 1966, 1969](#)) of the basic Leslie matrix model ([Leslie, 1945](#)). If \mathbf{M}_t is the number of moose present in the forest at time t , then:

$$\vec{\mathbf{M}}_{t+1} = \mathbf{M} \cdot \vec{\mathbf{M}}_t - \vec{\mathbf{H}}_t \tag{1}$$

where $\vec{\mathbf{M}}_t$ is the vector of population stage structure at time t , $\vec{\mathbf{H}}_t$ is hunting stage structure and \mathbf{M} is the population projection matrix, which is given as:

$$\mathbf{M} = \begin{bmatrix} 0 & 0 & 0 & f_4 & 0 \\ \frac{s_1}{2} & 0 & 0 & 0 & 0 \\ \frac{s_1}{2} & 0 & 0 & 0 & 0 \\ 0 & s_2 & 0 & s_4 & 0 \\ 0 & 0 & s_3 & 0 & s_5 \end{bmatrix} \tag{2}$$

where f is calves produced per cow per annum (primary fecundity, not influenced by density, see later for density effects), and s is the probability for animals in one stage to

survive until next year. Reflecting what is recognizable for the hunters, we have five stages of moose: 1=calves (0–1 years), 2 and 3=female and male yearlings (1–2 years), 4 and 5=older cows and bulls (2+ years). Only cows 2+ years may reproduce. For simplicity we assume that calves contribute 50:50 to the male and female yearling segment, although in reality this ratio may be skewed (see [Andersen and Sæther, 1996](#) for a discussion).

Likewise, though slightly more complicated, we can make an Usher–Leslie matrix for the trees. Let $F_{t,s}$ be the number of trees in stratum s at time t . A stratum is composed of two variables: tree species and soil productivity. Hence, one particular stratum is made up of all trees of a certain tree species growing on land with the same level of soil productivity. The development of each stratum is modelled as:

$$\vec{\mathbf{F}}_{t+1,s} = \mathbf{F} \cdot \vec{\mathbf{F}}_{t,s} - \vec{\mathbf{U}}_{t,s} + \vec{\mathbf{R}}_{t,s} \tag{3}$$

where $\vec{\mathbf{F}}_{t,s}$ is the vector of stratum stage structure at time t , $\vec{\mathbf{U}}_{t,s}$ is harvesting stage structure and $\vec{\mathbf{R}}_{t,s}$ is recruitment stage structure (stemming from timber harvest, recruitment only to stage I, no recruitment across strata). The stratum projection matrix \mathbf{F} is given as:

$$\mathbf{F} = \begin{bmatrix} (1-g_1)q_1 & 0 & \dots & 0 \\ g_1q_1 & (1-g_2)q_2 & \dots & 0 \\ 0 & g_2q_2 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & (1-g_i)q_i \\ 0 & 0 & \dots & g_iq_i \end{bmatrix} \tag{4}$$

where q_i is the probability for trees in stage i to survive until next year and g_i is their probability to grow into the next stage. Trees are allowed to move a maximum of one stage at each projection interval. We have ten different stages of trees, I–X. Stage I are trees fully covered by snow in winter and not available to moose (0.0–0.5 m). Stages II and III are trees within all-year moose browsing height (0.5–3.0 m). The remaining stages are trees with their crown fully above moose browsing height.

Note that in our model the volume growth of individual trees is not density dependant, i.e. our forest matrix is stationary. A stratum follows a pre-scheduled development through the growth stages, where natural and selective thinning is included in the mortality factor (as a set constant for each stage). A tree is considered mature (it no longer increases in volume) when it reaches stage X. Harvest may take place in all stages but the first three.

Most interactions between moose and its forage are largely density dependant, so we want to introduce non-linearity to our basic Leslie models, although matrix models with non-linearity are less flexible for deterministic optimization ([Buongiorno et al., 1995](#)). In order to retain as much of the linearity as possible, we include density dependance through functions of aggregation variables, i.e. the weighted sum of all individuals in all stages. The general form for including such functions to our moose projection is:

$$\vec{\mathbf{M}}_{t+1} = \vec{\mathbf{M}}_t + D(M_t) \cdot (\mathbf{M} - \mathbf{I}) \cdot \vec{\mathbf{M}}_t - \vec{\mathbf{H}}_t \tag{5}$$

where \mathbf{I} is the identity matrix of \mathbf{M} , and $D(M_t)$ is the density dependant function we want to include. In our model moose

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