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Reindeer management and winter pastures in the presence of supplementary feeding and government subsidies

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ABSTRACT

We apply an age- and sex-structured reindeer-lichen model to examine the role of winter pastures, pasture rotation, and supplementary feeding on economically optimal reindeer management. The model includes 17 age classes of females, 13 classes of males and a detailed description of winter energy resource utilization by the reindeer population. Reproduction is specified by a modified harmonic mean mating system and the diet choice between different winter energy resources follows the principles of the optimal foraging theory. Wintertime energy intake defines an individual's weight decrease and its consequences on mortality and reproduction. Lichen growth depends on habitat type and lichen biomass. The decision variables are the animals chosen for slaughter from each age and sex class and the amount of supplementary food given. Results show that the availability of arboreal lichens, the growth rate of ground lichens, and pasture rotation all determine the optimal solutions. Reindeer management aiming to maximize long-term net economic revenues leads to very low lichen densities if intensive feeding becomes optimal in the long-term steady state. Government subsidies promote reindeer herders to base management on supplementary feeding leading to lower pasture conditions and to the depletion of lichens.

1. Introduction

Reindeer (*Rangifer tarandus*) is one of the key species in northern Fennoscandia and nearly 40% of the total land area in Fennoscandia is used as reindeer pasture (Pape and Löffler, 2012). The sociocultural and economic impacts of reindeer husbandry are also highly important, especially for the indigenous Sami people (Jernsletten and Klokov, 2002; Sandström et al., 2003). The various ecological, economic, and social aspects as well as the complexity of the grazing system should thus be taken into account when studying the reindeer herding system as a whole.

Fennoscandian reindeer husbandry has experienced major changes since the nineteenth century. Two major transitions have occurred in northern Finland: the traditional intensive herding has shifted toward a free-ranging system and supplementary feeding has become a regular practice in almost every herding district (Helle and Jaakkola, 2008). These changes together with an increase in reindeer numbers and various invasive land-use practices have led to the alarming deterioration of important winter pastures (Kumpula et al., 2014). According to Kumpula et al. (2014), several other factors besides reindeer numbers explain the reduction in ground lichens in the winter reindeer pasture areas. Changes in the grazing system have led to a situation where reindeer are allowed to freely graze on pastures, and only a few northern herding districts separate summer and winter grazing areas using pasture rotation fences (Helle and Jaakkola, 2008; Kumpula et al., 2014). Without seasonal pasture rotation lichen pastures are exposed to grazing and trampling throughout the year (Kumpula et al., 2011). A decrease in old coniferous forest area has also directly and indirectly influenced the reduction of ground lichens (Kumpula et al., 2014). Due to more favorable growth conditions both ground and arboreal lichens are more abundant in old coniferous forests compared to all younger coniferous forest classes.

Winter energy resources are important factors affecting the productivity of reindeer management, and winter pastures are often described as a bottleneck for reindeer numbers (Jernsletten and Klokov, 2002; Moen, 2008). Lichens have been the most important winter reindeer energy resource and when their amounts have reduced, supplementary food has been used to compensate for the lack of natural fodder (Kumpula et al., 1998). Thus the changes in winter pastures, supplementary feeding, and pasture rotation all affect the economics of reindeer herding and optimal reindeer management. The importance of these changes is often pointed out

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(Kumpula et al., 2002; Helle and Jaakkola, 2008; Pape and Löffler, 2012), but the impacts of these factors to economics and the optimality of reindeer management have not been studied.

Kumpula et al. (2002) state that supplementary feeding has increased the productivity of reindeer stocks in Finland, but the costs and other effects of feeding on reindeer management should also be taken into account. Helle and Jaakkola (2008) interviewed 12 reindeer herders and found that interviewees emphasized the importance of arboreal lichens. The interviewees also stated that the lack of both arboreal lichens and old forests were the ultimate reason for the use of supplementary food. They pointed out that the use of supplementary food was costly, but allowed an increase in meat production. Kumpula et al. (2014) found that ground lichen biomass was clearly lower in areas where pasture rotation was not used. A reduction in old forest area and arboreal lichen pastures was also associated with lower ground lichen biomass.

The aim of our study is to examine the role of arboreal lichen pastures, pasture rotation, and supplementary feeding on economically optimal reindeer herding. For this we use the dynamic age- and sex-structured reindeer-lichen optimization model presented by Tahvonen et al. (2014). We expand the model by including arboreal lichens and supplementary food as winter energy resources for reindeer and by taking into account the reduction of lichen outside wintertime due to grazing and trampling by reindeer. We additionally study the effects of ground lichen growth rate on reindeer management. According to our knowledge optimization models with similar features do not exist for reindeers or any similar herbivores.

Other earlier optimization models for reindeer include the two state-variable lichen-reindeer models by Virtala (1992, 1996) and Moxnes et al. (2001). The control variable in these models is harvesting, which is chosen for maximizing the harvesting income over a long time period, and their results include optimal steady-state levels for lichen and reindeer densities. Both Moxnes et al. (2001) and Tahvonen et al. (2014) also include other cratered food resources besides ground lichens as winter fodder, but none of the previous studies consider the effects of arboreal lichens or supplementary feeding. All previous studies also assume that pasture rotation is used and winter pastures are consumed only during winter. Other age- and sex-structured reindeer models include Petersson and Danell (1992), Danell and Petersson (1994) and Olofsson et al. (2011), but none include supplementary feeding, arboreal lichen pastures, or optimized harvesting. Walters et al. (1975) specify an age-structured model for Canadian caribou. They include arboreal lichens in their model, but its use is combined with ground lichens and thus no compensatory use of arboreal lichens to preserve ground lichen pastures is possible.

Our model includes 17 age classes of females and 13 classes of males and the mating system is specified by a modified harmonic mean mating function. Lichen resources develop over time but arboreal lichen availability is constant. This is because most ground lichens are available to reindeer, but over 95% of arboreal lichens grow on trees too high for reindeers to reach and every winter a certain percentage of these arboreal lichens fall onto the snow and can be used by reindeer (Esseen, 1985; Stevenson and Coxson, 2003). The energy available from arboreal lichens depends on the area of arboreal lichen pastures as well as on the arboreal lichen biomass available to reindeer (arboreal lichens both growing on trees at a height of under 2 m or falling from the upper parts of trees down onto the snow). The amount of supplementary food offered to reindeer is optimized. The wintertime diet choices of reindeer follow the principles of the optimal foraging theory and the winter energy intake defines individuals' overwinter weight decrease and its consequences on mortality, the number of calves per female, and the birth weight of calves. Lichen is consumed in winter and, if pasture rotation is not in use, also in spring, summer, and autumn.

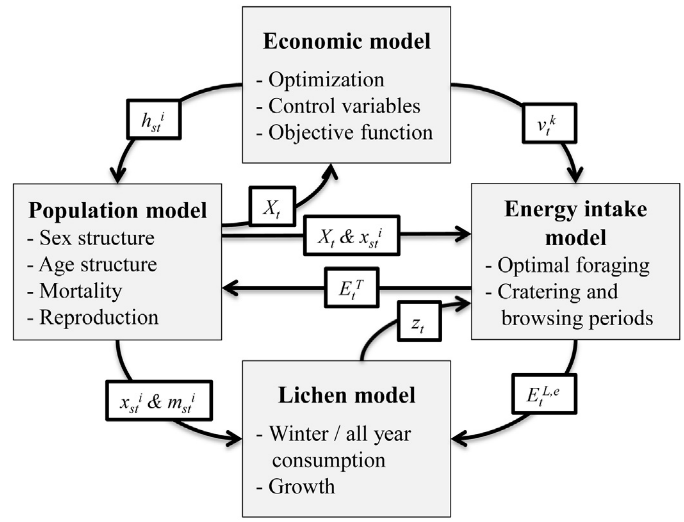

Fig. 1. Interactions between the four submodels.

Lichen growth depends on lichen biomass after winter and spring consumption and also on the habitat type of the lichen pastures. The decision variables are the animals chosen for slaughter from the age and sex classes and the amount of supplementary food given. The results describe the development of a reindeer-lichen system over time, optimal harvesting strategies, and whether or not supplementary feeding is part of the economically optimal solution.

2. The model and methods

In our study we further develop the reindeer-lichen optimization model presented in Tahvonen et al. (2014). We expand the model with multiple winter energy resources, supplementary feeding, over-year lichen consumption, and two different lichen growth rates. The optimization model used in our study can be divided into four submodels shown in Fig. 1. These submodels interact via variables shown in the figure. The population model includes the description of the state and development of the age- and sex-structured reindeer population. It uses the energy intake of a reindeer and the harvesting levels of each age and sex class to compute the mortality and reproduction of the population. The energy intake model describes the diet choices and energy intake of an individual reindeer. It uses population size and structure as well as lichen and supplementary food biomasses to compute the total energy intake and the energy intake from lichen. The lichen model describes the growth and consumption of lichen throughout the year. Finally the economic model includes an objective function and an optimization algorithm for computing the optimal harvesting and supplementary feeding levels needed to gain the highest present value of the net revenues over an infinite time horizon.

2.1. Winter period lengths

Fig. 2 shows the yearly cycle of reindeer husbandry as it is described in the model. The yearly cycle begins after autumn slaughtering. The winter is divided into a cratering period denoted by *a* and a browsing period denoted by *b*. Cratering is easier in early winter (here 121 days) and reindeer use cratered food and, if available, supplementary food as an energy resource. In late winter (60 days) when snow is hard, cratering is more time- and energy-consuming, and where arboreal lichen pastures are present reindeers turn to a mixed diet and the browsing period begins. The cratering period continues after the arboreal lichen pastures have