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REPORT

Effects of Modern Forest Management on Winter Grazing Resources for Reindeer in Sweden

Sonja Kivinen, Jon Moen, Anna Berg, Åsa Eriksson

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Abstract Boreal forests in Sweden are exploited in a number of ways, including forestry and reindeer husbandry. In the winter, reindeer feed mainly on lichens, and lichen-rich forests are a key resource in the herding system. Commercial forestry has mainly negative effects on reindeer husbandry, and conflicts between these two industries have escalated over the last century. This article reviews the effects of modern forest management practices on the winter resources available for reindeer husbandry. Forestry affects reindeer husbandry at both the stand level and the landscape level and over various time scales. Clear-cutting, site preparation, fertilization, short rotation times, and forest fragmentation have largely resulted in a reduced amount of ground growing and arboreal lichens and restricted access to resource. This article also discusses alternative forestry practices and approaches that could reduce the impacts of forestry on reindeer husbandry, both in the short and long term.

Keywords Reindeer herding · Lichens · Forestry · Boreal forest

INTRODUCTION

Reindeer husbandry and forestry are the two main land uses in boreal forests in northern Sweden. Both reindeer husbandry and forestry have experienced major changes over the last century with subsequent conflicts over land use. These conflicts arise because of the way that the two industries use the forest resources, and the major negative effect that forestry has on the winter resources required for reindeer husbandry (Sandström et al. 2006; Widmark 2006). In northern Sweden (Norrbotten, Västerbotten, Jämtland, Västernorrland), half of the forest land is owned by forest companies, 44% by private non-industrial owners, and the remaining area by communities etc. (Swedish Forest Agency 2009). Reindeer husbandry, in turn, is the meat-producing industry that is an exclusive right of the Sami people (Widmark 2006). The reindeer herding area covers about 40% of Sweden (Fig. 1), and is organized into 51 herding districts that manage grazing resources as a common resource.

The current extensive approach to herding, where large herds graze freely over wide areas and are handled only at strategic times of the year, has been practiced since the early twentieth century. All reindeer (*Rangifer tarandus tarandus)* in Sweden are semi-domesticated. The total number in the size of the winter herd has fluctuated around 225,000 animals throughout the twentieth century (Moen and Danell 2003). A majority of the reindeer herding districts in Sweden is characterized by migrations between summer and winter grazing areas. Summer pastures are located mainly within the western mountain regions. Reindeer forage is normally not limiting during the snow-free period, because reindeer feed on a wide variety of vascular plants, although there is variability, e.g., in forage quality with habitats and seasonality as well as density of reindeer present per unit area. Winter resources, however, create a bottleneck within the reindeer herding system. Winter pastures are located in the boreal forests at lower altitudes, although some herding districts may also practice reindeer husbandry in the forest all year round. In general, the area of suitable winter pastures is significantly more restricted than the extensive summer grazing areas in the mountains (Anon 2006). In winter and early spring, up to 80% of reindeer diet consists of mat-forming terrestrial lichens (mainly *Cladina* spp. and *Cetraria* spp.) and arboreal lichens (mainly *Bryoria* spp. and *Alectoria* spp.) (Heggeberget et al.

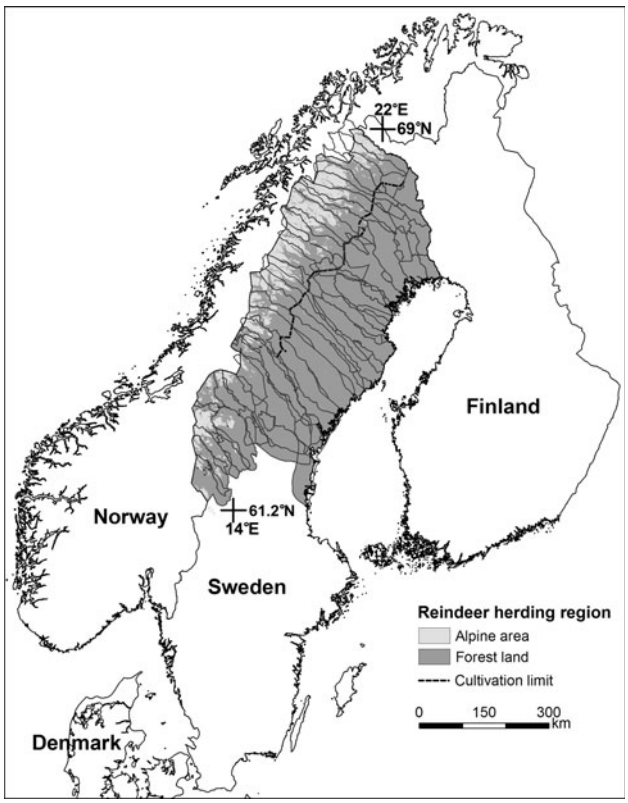

Fig. 1 Location of the reindeer husbandry area in Sweden. The map also shows the 51 herding districts. Year-round reindeer pastures in the northern part of the reindeer husbandry area are found above (to the west) of the so-called cultivation limit (*odlingsgränsen*)

2002). Reindeer mainly feed on ground growing lichens, but arboreal lichens play a critical role on winter survival, particularly when ice-crusts or other harsh snow conditions prevent access to ground lichens (Moen et al. 2006).

Lichens are composite organisms consisting of a symbiotic relationship between a fungus (the mycobiont) and a phycobiont (a green alga in the case of reindeer lichens). Lichens can tolerate extended periods of desiccation, but are photosynthetically active only when they receive enough water from moisture in the atmosphere or from precipitation. The growth of the lichens is strongly related to the amount of light they receive during their wet active periods. Palmqvist and Sundberg (2000) have reported the growth amounting to 30–70 g/m^2/year for ground living lichen and 1–4 g/m^2/year for arboreal lichen. The distribution and abundance of lichens in boreal forests is connected to the characteristics of forest stands and the soil. Forest characteristics affect the growth and abundance of lichens through effects on microclimate (light, moisture, and temperature), available nutrients and substrates which, in turn, influence competition with mosses and vascular plants. Reindeer lichens are particularly abundant on dry oligotrophic soils in pine (*Pinus sylvestris* L.) heaths where they can successfully compete with vascular plants and bryophytes (Ahti 1961). A high biomass of arboreal lichens tends to be found mainly in old-growth coniferous forests, usually dominated by Norway spruce (*Picea abies*) (Esseen et al. 1996). Ideal winter grazing areas have a high abundance of both ground growing and arboreal lichens that are easily accessible to reindeer.

The requirements of reindeer husbandry, namely, relatively undisturbed lichen-rich forests, are not supported by current forestry management practices. During the pre-industrial period, forest fires played a major role in creating a mosaic of vegetation types and floristic composition in forest ecosystems in northern Sweden (Zackrisson 1977). The effects of human activities on boreal forests were largely restricted to spatially broad, but low intensity use by the Sami people (Östlund et al. 1997) who have practiced reindeer herding since at least the seventeenth century (Lundmark 1982).

Rapid developments in the forestry industry took place in Sweden in the late nineteenth century, following the establishment of the sawmill industry and large-scale forest companies. Repeated selective loggings, where the largest trees were harvested, opened up forests and probably improved the conditions for lichen growth (Berg et al. 2008). Mechanization during the 1950s transformed the labor-dependent small-scale forestry industry to a modern large-scale operation, and resulted in increasing exploitation of the boreal forests. Selective logging was replaced by clear-cutting, often followed by soil scarification, planting, and fertilization. Nowadays most forest land in Sweden is used for the production of saw-timber and pulp wood (Esseen et al. 1997).

Modern forestry has produced dramatic changes in the structure and function of boreal forest ecosystems and the consequent impacts on biological diversity have been widely studied and reviewed (Esseen et al. 1997). The effects of forestry on reindeer husbandry have not been studied in a wider context, although there are some case studies and traditional knowledge pertaining to the conflict between the two industries. Understanding the impacts of forestry methods on reindeer husbandry is crucial for the future of reindeer herding. For instance, one study suggest that up to 30–50% of the winter grazing grounds may have been lost in the study area during the last century as a result of intensified forestry (Berg et al. 2008). The aim of this review is to collate the available information on the effects of modern forestry on the winter resources for reindeer husbandry (both mountain and forest herding districts) and to identify specific areas where further research is needed. Furthermore, this article discusses alternative silvicultural methods that could minimize the negative impacts of forestry on reindeer husbandry.

EFFECTS OF FORESTRY ON WINTER RESOURCES FOR REINDEER

General Landscape Structure

Forestry determines the physical structure of the boreal forest landscape to a significant degree, and consequently it also affects the quality of winter pastures. Forestry and reindeer husbandry use different resources, but also operate on different spatial scales. Forest management is carried out at the stand level, whereas reindeer husbandry operates at a wider landscape level. Thus, in addition to the changes in single stands at a local level, reindeer husbandry is also affected by any changes in the landscape mosaic, which is made up of the different types of forest stands. From the reindeer herding viewpoint, the forest landscape structure needs to be considered in terms of both the amount and availability of lichen resources as well as practical aspects of reindeer herding, such as moving and gathering the herds.

Modern forest practices have resulted in an increasing proportion of even-aged young stands and a scarcity of old-growth forests (Berg et al. 2008; Fig. 2). The remaining stands of old coniferous forests are relatively small and they are becoming increasingly isolated as forests are harvested (Kivinen 2009, Submitted manuscript). Reindeer utilize various habitat types during specific seasons and weather conditions, but the general concern with respect to reindeer husbandry is the maintenance of an appropriate amount of old-growth forest in the landscape (Danell 2005). Studies of semi-domesticated reindeer with collars fitted with GPS in Finland and radio-tracked woodland caribou (*Rangifer tarandus caribou*) in Canada have shown a high preference for old-growth forests and an avoidance of clear-cuts and young stands (Kumpula et al. 2007; Apps et al. 2001). However, these kinds of studies are generally lacking in winter-grazing areas in Sweden. Relatively undisturbed old-growth forests are usually good winter pastures and are important habitats, especially for arboreal lichens. The effects of a reduction in the age of stands, forest fragmentation and different forest practices on lichens and reindeer herding is discussed in detail below.

In addition to changes in the age structure of the forest, construction of new logging roads disrupts the continuity of winter pastures. Reindeer and caribou have been found to avoid areas with infrastructure and human activities to a varied degree depending on, e.g., type of disturbance, sex, and season (Vistnes and Nellemann 2008). However, there is not much traffic on logging roads and disturbances are usually limited to logging events. Thus, logging roads can be used by reindeer to travel more easily through the forest, and this can make it difficult for herders to keep reindeer in one place. On the other hand, logging roads can also facilitate searching for reindeer (Huusko 2008). As with roads, ditching results in more fragmented winter pastures.

It is difficult to define what constitutes sufficient suitable winter pastures in the landscape. Furthermore, there have been no scientific studies on the impact of fragmentation of winter grazing grounds on the use of the remaining resources. However, it is likely that small patches of high quality pastures with abundant lichen resources may be more difficult and time-consuming to reach and are thus used less than large continuous patches of suitable pastures. A study of the distribution of winter habitats of woodland caribou (O'Brien et al. 2006) suggested that the spatial configuration of suitable habitats within the landscape and the intervening land cover types should be taken into account when assessing range quality. A better understanding of the landscape level effects of forestry on the availability, and accessibility of winter resources is thus

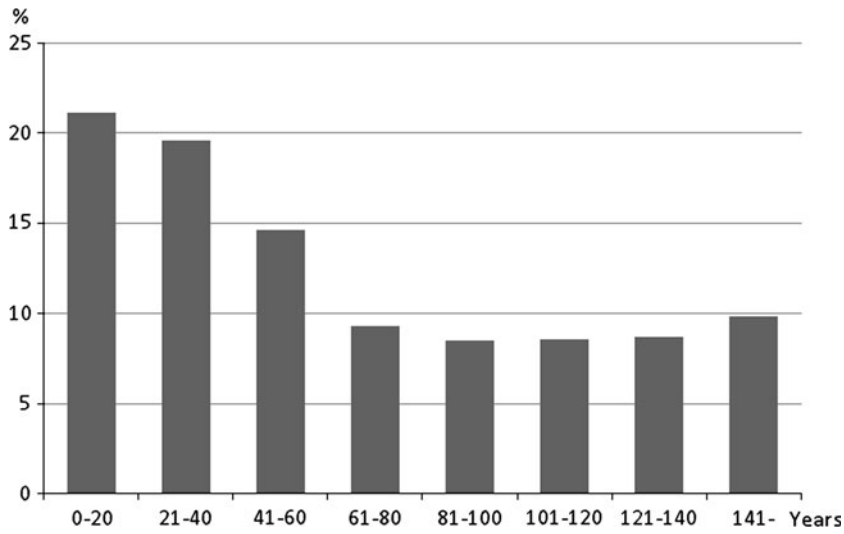

Fig. 2 Productive forest land by age class in northern Sweden (Norrland, Västerbotten, Jämtland, Västernorrland) in 2004–2008 (excluding protected productive forest land). *Source*: Skogsstyrelsen—Swedish Forest Agency. Forestry statistics (www.skogstyrelsen.se)

required to manage effectively a suitable mosaic of forest stands that can support reindeer husbandry. This calls for more research into how reindeer and reindeer herders perceive the forest landscape structure.

Clear-Cutting

Clear-cutting (removal of all trees in a single harvest) has been the predominant logging practice since the 1950s in Sweden. Clear-cutting is a major disturbance that has a great impact on, e.g., microclimate, the availability of nutrients, and hydrological processes. It initiates succession in the forest and thus temporally increases early-successional habitats in the landscape (Esseen et al. 1997). The general effects of clear-cutting on winter resources include habitat loss (e.g., old forest), and habitat alteration (e.g., forest structure and composition), resulting in changes in growing conditions for lichens and reindeer access to them. Consequently, winter grazing grounds become fragmented and less suitable for grazing.

The impact of clear-cutting on ground growing lichens depends on the original composition of the ground vegetation, the forest type and the logging practices employed on the clear-cut site. In boreal forests, ground vegetation dynamics and patterns arise from the competitive interactions between lichens, vascular plants (particularly *Vaccinium* spp., *Calluna vulgaris*, and *Empetrum nigrum*), and bryophytes. Clear-cutting affects competition success among species through changes in microclimate, including light conditions, temperature, soil moisture, and nutrients. It has been observed that the cover of most of the vascular plants and bryophytes decreases significantly after clear-cutting in dry and sub-dry sites, whereas ground-growing lichens, such as *Cladina* spp., can benefit from the improved light conditions. However, clear-cutting only favors ground lichens if shading is prevented by the removal of logging residues and if soil scarification does not take place (Bråkenhielm and Persson 1980; Bråkenhielm and Liu 1998; Olsson and Staaf 1995). Logging residues are usually left on the ground to prevent loss of nutrients from the site as a result of removing the trees. The release of nutrients after clear-cutting can particularly enhance the growth of the grass *Deschampsia flexuosa* in more productive sites (Hannerz and Hånell 1997). In contrast to ground lichens, arboreal lichens disappear immediately as a result of clear-cutting. Arboreal lichens grow slowly and the loss of biomass is the greatest when old forests are cut (Esseen et al. 1996).

In addition to affecting the abundance of lichens, clear-cutting also has an impact on reindeer access to lichens. Reindeer seem to avoid clear-cuts where large volumes of logging residues hinder digging through the snow to reach ground lichens (Helle et al. 1990). Furthermore, removal of trees may also have an impact on snow conditions. Snow depth and snow melt are determined by the forest stand characteristics. In general, snow cover has been found to be deeper in clear-cuts than in forests (Golding and Swanson 1986; Ottosson-Löfvenius et al. 2003). Sámi reindeer herders interviewed for the study of Roturier and Roué (2009) all agreed that clear-cutting has a negative effect on winter grazing as snow becomes too hard to be dug by the reindeer.

Instead, the suitability of different forest stands for grazing can vary between winters or even between two climatic events within one winter according to the herders (Roturier and Roué 2009). For example, snow melting and dropping from the tree crowns in dense mature forests during a warmer period can result in hard-packed snow on the ground compared to sparser stands with softer snow between the trees. As young trees trap less snow than older ones, younger stands can be good grazing grounds during thawing–freezing periods in the winter. On the other hand, melting and freezing of an early snow in young forests, where most of the snow will reach the ground, can result in ice-crust formation and make lichens inaccessible to reindeer. These findings call for more research about the effects of different silvicultural methods on snow conditions in different types of forests.

Site Preparation

Site preparation is carried out after clear-cutting to improve the establishment and growth of seeds and seedlings, particularly on more fertile sites. The most common treatment is soil scarification, where the top soil is turned over to expose the mineral soil (Fig. 3). This influences a number of environmental factors, such as soil temperature and moisture, nutrient cycling, light

Fig. 3 Soil scarification conducted on a clear-cut (Photo: Sonja Kivinen)

availability, and competition between species, and consequently affects the development and growth of plants. Disc trenching, harrowing, and mounding are the most frequent methods (Örlander and Gemmel 1989; Eriksson and Raunistola 1990; Roturier and Bergsten 2006). Prescribed burning was a commonly used site preparation method until the 1960s, when it was gradually replaced by mechanical scarification. It has similar effects on ground vegetation as the uncontrolled forest fires that were common in northern Sweden until fire suppression was initiated in the early twentieth century. Today, prescribed burning is used mainly to conserve the biologic diversity of boreal forests (Zackrisson 1977; Fries et al. 1997).

Scarification has immediate negative effects on reindeer husbandry, as the coverage and volume of ground lichens are greatly decreased. The degree of soil disturbance and the effects on ground lichens and their re-colonization depends on the scarification methods used. For example, the proportion of disturbed vegetation and mineral soil exposed is 45–55% as a result of harrowing (Eriksson and Raunistola 1990; Roturier and Bergsten 2006). It has been observed that reindeer graze at the sites with the greatest lichen cover (Roturier and Bergsten 2006) and, thus, such disturbances have negative effects on foraging. The long-term effects of soil scarification on ground lichens are largely unknown. Eriksson and Raunistola (1990) found that about 20% of the ground remained free of vegetation 10 years after ploughing or harrowing. This suggests that at least the more radical scarification methods may result in long-lasting reductions in lichen resources in winter grazing grounds. Moreover, tracks and mounds in the treated ground can hinder movement of reindeer and reindeer herders through the landscape, but studies of the effects of site preparation on practical reindeer herding are lacking.

Fire greatly decreases the ground lichen cover in the short term (Morneau and Payette 1989; Thomas et al. 1996), but the long term effects depend on the forest type. Burning of lichen-rich ground benefits shrubs and has thus significant negative effects on reindeer herding. On the other hand, burning of shrub-type forests with a thick humus layer and relatively little lichen cover benefits lichens (Boström 2004). There is strong evidence that lichen-rich pine heaths originate from repeated forest fires, because the accumulation of organic material and resultant water retention in the absence of fire disturbance results in vascular plants out-competing lichens (Ahti 1961; Zackrisson 1977). The final successional phase in a plant community dominated by reindeer lichens is reached ca. 100 years after complete burning (Morneau and Payette 1989; Thomas et al. 1996). However, burned areas may be used for reindeer foraging much earlier, depending on the distance to dispersal sources. One study found that the cover of lichens returned to pre-fire levels 40–70 years after burning (Helle and Aspi 1984).

Forest Regeneration and Young Forests

The length of the rotation period for managed forests in northern Sweden is ca. 100–130 years. This is in contrast to the highly variable disturbance cycles that occurred in unmanaged forests in the past. In general, modern forest management has greatly reduced the age of forest stands (Esseen et al. 1997). For example, a study from northern Sweden suggests that the mean age of stands has decreased from more than 200 years to ca. 70 years over the last hundred years in the study area (Berg et al. 2008). In the northern part of the country, forests are regenerated either by planting or natural processes; sowing is rarely used. In addition to the native conifer species Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies*), North American lodgepole pine (*Pinus contorta*) has been planted and, today, covers ca. 600,000 ha in Sweden. *Pinus contorta* grows faster than *P. sylvestris* and was introduced into northern Sweden on a large scale as a consequence of an anticipated timber shortage resulting from over-exploitation of the old forests (Elfving et al. 2001).

The possible effects of different regeneration methods on reindeer husbandry have not been studied. However, young forests are known to be problematic for reindeer husbandry in terms of the amount and accessibility of winter resources (Thomas Stenlund, pers. comm.). Lack of light often limits lichen growth in forests. Forests with a canopy cover of more than ca. 60% have been found to provide suboptimal light conditions for mat-forming lichens (Jonsson Čabrajić 2009). Furthermore, low light restricts the growth of arboreal lichens particularly in young dense forests (Gauslaa et al. 2007). The biomass of arboreal lichens is strongly related to the age of the forest stand. Forestry has reduced the availability of arboreal lichens, since forests with abundant arboreal lichens are usually older than forests at the end of the rotation period currently favored. For example, old spruce forests can contain up to six times more arboreal lichen biomass than mature managed spruce forest (Esseen et al. 1996). Arboreal lichens disperse at the stand level in the form of large fragments or whole thalli. Dispersal by wind to new sites is relatively slow and depends greatly on the distance to the nearest source of propagules. *Bryoria* is a common genus of arboreal lichen and its fragments have been shown to disperse effectively only up to 100 m (Dettki 1998). A study by Stevenson (1990) suggests that early lichen colonization is limited to about 350 m from mature stands with highly abundant lichens. These findings indicate that the increasing fragmentation of old forest stands means that

long-term persistence of arboreal lichens in the landscape is not sustainable.

No clear relationship exists between the cover or thickness of the lichen mat and the age of the forest stand (Bråkenhielm and Persson 1980; Helle et al. 1990). This is probably because the amount of light and other stand characteristics, rather than age per se, affect lichen growth. The cover of reindeer lichens has been found to increase during the first 10–20 years (Bråkenhielm and Persson 1980) or even 30 years after clear-cutting (Nieppola 1992) in Scots pine stands, probably because of increased light reaching the ground combined with decreased competition. As the crown closes, reindeer lichens are more likely to be out-competed by mosses (Sulyma and Coxson 2001). *P. contorta* stands tend to have a denser canopy and thus a more shaded environment than *P. sylvestris* stands (Elfving et al. 2001). Nilsson et al. (2008) did not find differences in understorey species composition between *P. contorta* and *P. sylvestris* stands. However, *P. contorta* stands had more than three times more needle litter cover on the ground, which can suppress the growth of lichens there. More research is needed particularly on the long-term effects of dense second-growth forests on ground lichen abundance.

Reindeer have been found to avoid young forests, and Helle et al. (1990) found a negative correlation between stand density and grazing pressure. This may be because poor visibility in young dense stands can increase predation risk, or because logging residues prevent digging for lichens beneath the snow. Furthermore, dense forests, logging residues and stumps can hinder practical reindeer herding activities, such as gathering herds (Huusko 2008). In general, there is not much information available on the effects of stand characteristics on reindeer herding practices.

Forest Fertilization

The aim of forest fertilization is to increase the production of timber and pulp-wood. In boreal forests, the availability of nitrogen normally limits the growth of trees and nitrogen fertilization has been used in Swedish forestry since the 1960s. Forests were first fertilized with urea, and later with ammonium nitrate. Fertilization is usually carried out two to four times during a rotation, at intervals of approximately 10 years (Nohrstedt 2001).

The effects of fertilization on the field and ground layers depend generally on the individual species, the composition of the plant community, and the fertilizer type and practice (Nohrstedt 2001). The abundance of lichens has been reported to decrease significantly as a result of nitrogen fertilization. The effects of nitrogen fertilization tend to be most pronounced on nutrient-poor sites, and reductions in lichen cover can be long-lasting (Kellner 1993; Olsson and Kellner 2006; Eriksson and Raunistola 1993). Studies of lichen physiology have shown that changes in the availability of key macronutrients can alter the growth of the algae and the fungus and thus disrupt the symbiotic interaction (Makkonen et al. 2007). In addition to immediate damage, the abundance of lichens can also be decreased because of competition from bryophytes, and shading from the field and tree layers (Kellner 1993).

Fertilization also affects reindeer foraging preferences. Eriksson (1980) found grazing intensity to decrease significantly in the first winter after nitrogen fertilization. Reindeer avoidance of lichens in fertilized forest stands may be caused by the presence of breakdown products of fertilizers in the ground, in the air close to the ground, or in air diffusing through the snow pack. Furthermore, nitrogen fertilization affects the amounts of the lichen compounds usnic and perlatolic acid (Hyvärinen et al. 2003), and this can alter the taste of lichens and make them less palatable to reindeer. The results of fertilization trials by Åhman and Åhman (1984) have, however, shown that the concentrations of nitrate in fertilized lichens are significantly below the level that could be considered injurious to reindeer.

REDUCING THE EFFECTS OF FORESTRY ON WINTER RESOURCES

In order to minimize the adverse effects of forestry on reindeer husbandry, the availability of lichens as well as reindeer access to them should be considered as part of a sustainable forest management strategy. Ownership and the right to use forest land in northern Sweden are mainly regulated by two laws: the Swedish Forestry Act and the Swedish Reindeer Husbandry Act. According to these regulations, forestry practitioners and reindeer herders have to consider the effects of their activities on the other sector. For example, large forestry companies have to take into account essential reindeer husbandry requirements when planning forest management measures, such as tree harvests in areas that are grazed throughout the year. This could be interpreted to mean that the herding district should be given annual access to sufficiently large and cohesive grazing areas and ample vegetation resources in areas used for reindeer corralling, migration and resting. However, the nature of the consideration is not defined in detail, which leaves implementation of the law to consultation between the two industries with, in general, unsatisfactory results from a reindeer husbandry perspective (Sandström et al. 2006; Widmark 2006).

Several alternative forestry measures could mitigate the negative effects of forestry on reindeer husbandry (Table 1). At the landscape level, attention should be paid to the age structure and spatial configuration of forest

Table 1 A summary of the observed effects of forestry on winter resources and recommendations for reducing the negative impacts of forestry on reindeer husbandry

	Ground lichens	Arboreal lichens	Reindeer (herding)	Recommendations
Clear-cutting	• Shading caused by logging residues	• Loss of habitat	• Loss of forage	• Removing logging residues
			• Logging residues hinder digging and moving	• Leaving individual trees or groups of trees
Soil scarification	• Decrease of coverage		• Loss of forage	• Lower level of soil disturbance
			• Tracks and mounds hinder movement	
Prescribed burning	• Decrease of coverage		• Loss of forage	• No burning in lichen-rich forests
	• Long-term effect:		• Burning logging residues facilitates digging and moving	• Burning in more productive sites
	+ In shrub-type			
	− In lichen-type			
Fertilization	• Decrease of coverage		• Avoidance of fertilized stands (off-putting taste or smell?)	• No nitrogen fertilization in lichen-rich forests
	• Disrupted fungus-algae symbiosis			
	• Outcompeted			
Young forest	• Lack of light	• Lack of light	• Less forage	• More vigorous early thinning
			• Poor visibility	• Increasing rotation time
			•Hinder reindeer herding	• Avoiding *Pinus contorta*
Fragmentation of old forest		• Loss of habitat	• Loss of good pastures	• Maintenance of large continuous old forest patches
		• Limited dispersal		• Consideration of efficient dispersal distances

stands. Reindeer have to move over vast areas during winter to find accessible forage. Small isolated patches of suitable winter pastures are probably more difficult to utilize for reindeer herding than large patches in close proximity. The maintenance of large continuous stands of lichen-rich forests is likely to improve the suitability of winter ranges and enhance the movement of reindeer in the landscape. Landscape structure also has a significant effect on dispersal of arboreal lichens. The long-term availability of arboreal lichens in the landscape could be enhanced by considering efficient dispersal distances when planning the size and spatial configuration of clear-cuttings. Geographic Information Systems (GIS) provide useful tools for land use planning over wide geographical areas. However, landscape-level planning can be a challenging task, particularly in regions with many different land owners.

At the stand level, the abundance and accessibility of lichens can be enhanced in several ways. The removal of logging residues that shade the ground is likely to improve the growth of ground lichens in clear-cuts. Prescribed burning decreases the amount of logging residues and facilitates reindeer movement in the landscape (Helle and Aspi 1984). However, burning should not take place in lichen-rich forests, where the loss of good pastures both in the short and long term is greatest. Prescribed burning of more productive sites can enhance the growth of lichens and, thus, have a positive impact on reindeer husbandry. Soil scarification and particularly conventional mechanical techniques reduce the quality of winter pastures. In lichen-rich stands, a lower level of soil disturbance that still yields satisfactory forest regeneration should be selected. The positive effects on both seedling growth and lichen recovery can be achieved by exploiting the flexibility of equipment. For example, a special method called HuMin-Mix has been developed to be used on drier areas to minimize disturbance to the lichen cover (Roturier and Bergsten 2006).

Nitrogen fertilization is avoided in lichen-rich forests with >25% lichen cover due to the significant negative effect on lichens. However, forests with less lichen cover can be fertilized even though they may be important pastures for reindeer husbandry. A clearer definition of forest

types, specifically including grazing value, could reduce the negative effects of fertilization on lichens. Removal of logging residues from the forests results in a decrease in nutrients, but this can be compensated for by using wood ash as a forest fertilizer. Wood ash is generated as a by-product of combustion and it includes most of the macro and micronutrients from the biomass except nitrogen. The use of wood ash for forest fertilization is a relatively new technique that is likely to become more common in the future because of increasing interest in using logging residues for the production of biofuels (Pitman 2006). More information is needed on the effects of different forms and doses of ash on ground vegetation as well as the long-term effects of ash fertilization.

Longer rotation times and the preservation of old-growth forests have positive effects on the availability of arboreal lichens in forests. Leaving individual old trees, or groups of trees, in clear-cuts can aid the natural colonization of arboreal lichens. More open forest stands can improve the growth of lichens as a result of increases in light and precipitation. Thinning is carried out in young forests to improve the growing conditions of the remaining trees. Early thinning could provide better conditions for lichen development in second-growth stands. Furthermore, thinning can also benefit reindeer herding in the young forests (Huusko 2008). The effects of *P. contorta* forests on reindeer husbandry are poorly known. However, the denser structure of the forest, shorter rotation time and more abundant needle litter compared to native *P. sylvestris* suggest that *P. contorta* stands are likely to provide poorer winter pastures.

Re-establishment of lichens after forestry can also be facilitated by artificial distribution of lichen fragments. A study by Lidén et al. (2005) showed that new populations of arboreal lichens can be successfully established, and that existing lichen populations can be enlarged, by transplanting small fragments into suitable habitats. Furthermore, Roturier et al. (2007) suggest that artificial dispersal of reindeer lichen on an appropriate substrate could be a successful strategy for promoting lichen recovery. In addition, natural colonization of reindeer lichens can be enhanced by providing substrates onto which lichen fragments can attach. However, the viability and economic aspects of artificial distribution on a large scale are unclear. Landscape-level planning should thus form the basis for the sustainable availability of winter resources in the long term.

Climate change is likely to further aggravate the impacts of forestry on reindeer husbandry through increased productivity that can result in denser forests with shorter rotation times. Better growing conditions can also increase tree harvesting in previously less-utilized regions and introduce more disturbances in the reindeer herding region. Furthermore, warming climate can increase uncertain environmental variation, such as the frequency of ice-crust formation that further decreases the availability of forage (Moen 2008).

SUMMARY OF FINDINGS

The challenge of understanding and mitigating the effects of modern forestry on reindeer husbandry arises from the fact that the two industries operate over a wide range of spatial and temporal scales. The impacts of forestry activities on winter resources for reindeer have generally been examined at the stand level over relatively short time periods. Such studies show that site preparation, fertilization, reduced rotation times, and decreasing cover of old-growth forests can strongly reduce the quality of winter pastures. One important step toward more sustainable reindeer husbandry would be a more comprehensive approach using alternative forestry methods that have less harmful effects on winter resources but still yield sufficient timber. Second, the spatial and temporal scales at which impacts are monitored and decisions made should be expanded. The ability of the landscape to sustain the varying needs of reindeer husbandry at different times of the year, as well as in the long term, need to be evaluated. The maintenance of landscape mosaics that increase the resilience of reindeer husbandry to adverse changes requires more dynamic management approaches to be implemented and co-operation between all relevant parties.

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REFERENCES

Åhman, G., and B. Åhman. 1984. Effects of forest fertilization on nitrate and crude protein content in some important reindeer forage species. *Rangifer* 4: 43–53.

Ahti, T. 1961. Taxonomic studies on reindeer lichens (*Cladonia*, subgenus *Cladina*). *Annales Botanici Societatis'Vanamo'* 32: 1–160.

Anon. 2006. Samernas sedvanemarker - Sami customary lands. SOU 2006:14, Stockholm (in Swedish).

Apps, C., B.N. McLellan, T.A. Kinley, and J.P. Flaa. 2001. Scale-dependent habitat selection by Mountain Caribou, Columbia Mountains, British Columbia. *The Journal of Wildlife Management* 65: 65–77.

Berg, A., L. Östlund, J. Moen, and J. Olofsson. 2008. A century of logging and forestry in a reindeer herding area in northern Sweden. *Forest Ecology and Management* 256: 1009–1020.

Boström, M. 2004. Available reindeer pasture on Myrtillus-, Calluna/Empetrum- and lichen land approx 50 years after a fire/prescribed burning. Master's Thesis, Swedish University of Agricultural Sciences, Department of Silviculture, 23 pp. (in Swedish).

Bråkenhielm, S., and Q. Liu. 1998. Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. *Biodiversity and Conservation* 7: 207–220.

Bråkenhielm, S., and H. Persson. 1980. Vegetation dynamics in developing Scots pine stands in central Sweden. *Ecological Bulletins* 32: 139–152.

Danell, Ö. 2005. Renskötselns robusthet - behov av nytt synsätt för att tydliggöra rennäringens förutsättningar och hållbarhet i dess socioekologiska sammanhang—The robustness of reindeer husbandry—need for a new approach to elucidate opportunities and sustainability of the reindeer industry in its socio-ecological context. *Rangifer Report* 10: 39–49 (in Swedish).

Dettki, H. 1998. Dispersal of fragments of two pendulous lichen species. *Sauteria* 9: 123–132.

Elfving, B., T. Ericsson, and O. Rosvall. 2001. The introduction of lodgepole pine for wood production in Sweden—a review. *Forest Ecology and Management* 141: 15–29.

Eriksson, O. 1980. Effects of forest fertilization on the cratering intensity of reindeer. In *Proceedings of the 2nd international reindeer/caribou symposium, Röros, Norway, 1979*, 26–40.

Eriksson, O., and T. Raunistola. 1990. Impact of soil scarification on reindeer pastures. *Rangifer Special Issue* 3: 99–106.

Eriksson, O., and T. Raunistola. 1993. Impact of forest fertilizers on winter pastures of semi-domesticated reindeer. *Rangifer* 13: 203–214.

Esseen, P.-A., B. Ehnström, L. Ericson, and K. Sjöberg. 1997. Boreal forests. *Ecological Bulletins* 46: 16–47.

Esseen, P.-A., K.-E. Renhom, and R. Pettersson. 1996. Epiphytic lichen biomass in managed and old-growth boreal forests: Effect of branch quality. *Ecological Applications* 6: 228–238.

Fries, C., O. Johansson, B. Pettersson, and P. Simonsson. 1997. Silvicultural models to maintain and restore natural stand structures in Swedish boreal forests. *Forest Ecology and Management* 94: 89–103.

Gauslaa, Y., K. Palmqvist, K.A. Solhaug, H. Holien, O. Hilmo, L. Nybakken, L.C. Myhre, and M. Ohlson. 2007. Growth of epiphytic old forest lichens across climatic and successional gradients. *Canadian Journal of Forest Research* 37: 1832–1845.

Golding, D.L., and R.H. Swanson. 1986. Snow distribution patterns in clearings and adjacent forest. *Water Resources Research* 22: 1931–1940.

Hannerz, M., and B. Hånell. 1997. Effects on the flora in Norway spruce forests following clearcutting and shelterwood cutting. *Forest Ecology and Management* 90: 29–49.

Heggeberget, T., E.M. Gaare, and J.P. Ball. 2002. Reindeer (*Rangifer tarandus*) and climate change: Importance of winter forage. *Rangifer* 22: 13–32.

Helle, T., and J. Aspi. 1984. Prescribed burning from the viewpoint of reindeer husbandry. *Communicationes Instituti Forestalis Fenniae* 120: 97–101.

Helle, T., J. Aspi, and S.-S. Kilpelä. 1990. The effects of stand characteristics on reindeer lichens and range use by semi-domesticated reindeer. *Rangifer Special Issue* 3: 107–114.

Huusko, U. 2008. *Poro ja poronhoito talousmetsissä – Reindeer and reindeer husbandry in managed forests*, 31. Rovaniemi: Lapin Metsäkeskus (in Finnish).

Hyvärinen, M., B. Walter, and R. Koopmann. 2003. Impact of fertilisation on phenol content and growth rate of *Cladina stellaris*: A test of the carbon-nutrient balance hypothesis. *Oecologia* 134: 176–181.

Jonsson Čabrajić, A. 2009. Modeling lichen performance in relation to climate: scaling from thalli to landscapes. PhD Thesis, Department of Ecology and Environmental Science, Umeå University, Umeå, 38 pp.

Kellner, O. 1993. Effects on associated flora of sylvicultural nitrogen fertilization repeated at long intervals. *Journal of Applied Ecology* 30: 563–574.

Kivinen, S., A. Berg, J. Moen, L. Östlund, and J. Olofsson. 2009. Fragmentation and landscape transformation in a reindeer husbandry area in Sweden. Submitted manuscript.

Kumpula, J., A. Colpaert, and M. Anttonen. 2007. Does forest harvesting and linear infrastructure change the usability value of pastureland for semi-domesticated reindeer (*Rangifer tarandus tarandus*)? *Annales Zoologici Fennici* 44: 161–178.

Lidén, M., M. Pettersson, U. Bergsten, and T. Lundmark. 2005. Artificial dispersal of endangered epiphytic lichens: A tool for conservation in boreal forest. *Biological Conservation* 118: 431–442.

Lundmark, L. 1982. *Uppbörd, utarmning, utveckling. Det samiska fångstsamhällets övergång till rennomadism i Lule lappmark - Levies, impoverishment, development. The transition of the Sami hunter community to reindeer nomadism in Lule Lappmark. Arkiv för studier i arbetarrörelsens historia*. Lund (in Swedish).

Makkonen, S., R.S.K. Hurri, and M. Hyvärinen. 2007. Differential responses of lichen symbionts to enhanced nitrogen and phosphorus availability: An experiment with *Cladina stellaris*. *Annals of Botany* 99: 877–884.

Moen, J. 2008. Climate change: Effects of the ecological basis for reindeer husbandry in Sweden. *Ambio* 37: 304–311.

Moen, J., R. Andersen, and A.W. Illius. 2006. Living in a seasonal environment. In *Large herbivore ecology, ecosystem dynamics and conservation*, ed. K. Danell, P. Duncan, R. Bergström, and J. Pastor, 50–70. Cambridge: Cambridge University Press.

Moen, J., and Ö. Danell. 2003. Reindeer in the Swedish mountains: An assessment of grazing impacts. *Ambio* 32: 397–402.

Morneau, C., and S. Payette. 1989. Postfire lichen-spruce woodland recovery at the limit of the boreal forest in northern Quebec. *Canadian Journal of Botany* 67: 2770–2782.

Nieppola, J. 1992. Long-term vegetation changes in stands of *Pinus sylvestris* in southern Finland. *Journal of Vegetation Science* 3: 475–484.

Nilsson, C., O. Engelmark, J. Cory, A. Forsslund, and E. Carlborg. 2008. Differences in litter cover and understorey flora between stands of introduced lodgepole pine and native Scots pine in Sweden. *Forest Ecology and Management* 255: 1900–1905.

Nohrstedt, H.-Ö. 2001. Response of coniferous forest ecosystems on mineral soils to nutrient additions: A review of Swedish experiences. *Scandinavian Journal of Forest Research* 16: 555–573.

O'Brien, D., M. Manseau, A. Fall, and M.-J. Fortin. 2006. Testing the importance of spatial configuration of winter habitat for woodland caribou: An application of graph theory. *Biological Conservation* 130: 70–83.

Olsson, B.A., and O. Kellner. 2006. Long-term effects of nitrogen fertilization on ground vegetation in coniferous forests. *Forest Ecology and Management* 237: 458–470.

Olsson, B.A., and H. Staaf. 1995. Influence of harvesting intensity of logging residues on ground vegetation in coniferous forests. *Journal of Applied Ecology* 32: 640–654.

Örlander, G., and A. Gemmel. 1989. Markberedning – Soil preparation. *Sveriges Skogsvårdsförbunds Tidskrift* 3: 1–53 (in Swedish).

Östlund, L., O. Zackrisson, and A.L. Axelsson. 1997. The history and transformation of a Scandinavian boreal forest landscape since the 19th century. *Canadian Journal of Forest Research* 27: 1198–1206.

Ottosson-Löfvenius, M., M. Kluge, and T. Lundmark. 2003. Snow and soil frost depth in two types of shelterwood and clear-cut area. *Scandinavian Journal of Forest Research* 18: 54–63.

Palmqvist, K., and B. Sundberg. 2000. Light use efficiency of dry matter gain in five macro-lichens: Relative impact of microclimate and species-specific traits. *Plant, Cell & Environment* 23: 1–14.

Pitman, R.M. 2006. Wood ash use in forestry—a review of the environmental impacts. *Forestry* 79: 563–588.

Roturier, S., S. Bäcklund, M. Sundén, and U. Bergsten. 2007. Influence of ground substrate on establishment of reindeer lichen after artificial dispersal. *Silva Fennica* 41: 269–280.

Roturier, S., and U. Bergsten. 2006. Influence of soil scarification on reindeer foraging and damage to planted *Pinus sylvestris* seedlings. *Scandinavian Journal of Forest Research* 21: 209–220.

Roturier, S., and M. Roué. 2009. Of forest, snow and lichen: Sámi reindeer herders' knowledge of winter pastures in northern Sweden. *Forest Ecology and Management* 258: 1960–1967.

Sandström, C., J. Moen, C. Widmark, and Ö. Danell. 2006. Progressing toward co-management through collaborative learning: Forestry and reindeer husbandry in dialogue. *International Journal of Biodiversity Science and Management* 2: 326–333.

Stevenson, S. 1990. Managing second-growth forests as caribou habitat. *Rangifer* 3: 139–144.

Sulyma, R., and D.S. Coxson. 2001. Microsite displacement of terrestrial lichens by feather moss mats in late seral pine-lichen woodlands of North-central British Columbia. *The Bryologist* 4: 505–516.

Swedish Forest Agency. 2009. *Swedish statistical yearbook of forestry*. *Official statistics of Sweden*, 392. Jönköping.

Thomas, D.C., S.J. Barry, and G. Alaie. 1996. Fire–caribou–winter range relationships in northern Canada. *Rangifer* 16: 57–67.

Vistnes, I., and C. Nellemann. 2008. The matter of spatial and temporal scales: A review of reindeer and caribou response to human activity. *Polar Biology* 31: 399–407.

Widmark, C. 2006. Forestry and reindeer husbandry in Sweden—the development of a land use conflict. *Rangifer* 26: 43–53.

Zackrisson, O. 1977. Influence of forest fire on the North Swedish boreal forest. *Oikos* 29: 22–32.

AUTHOR BIOGRAPHIES

Sonja Kivinen (✉) is a post-doc researcher at University of Oulu. Her research interests are in the fields of landscape ecology and biogeography, and her current project focuses on the impacts of land use and climate change on reindeer husbandry.
Address: Department of Geography, University of Oulu, 90014 Oulu, Finland.
Department of Ecology and Environmental Science, Umeå University, 90187 Umeå, Sweden.
e-mail: sonja.kivinen@oulu.fi

Jon Moen is a professor in ecology at Umeå University. His research focuses on sustainable uses of natural resources, especially for reindeer husbandry and forestry.
Address: Department of Ecology and Environmental Science, Umeå University, 90187 Umeå, Sweden.
e-mail: jon.moen@emg.umu.se

Anna Berg is a Ph.D. student at the Swedish University of Agricultural Sciences. She studies how modern forestry and reindeer herding have affected the forests in northern Sweden during the last two centuries.
Address: Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, 90183 Umeå, Sweden.
e-mail: anna.berg@svek.slu.se

Åsa Eriksson has a Ph.D. in animal ecology from Umeå University. At present, she works as an analyst at the Swedish University of Agricultural Sciences. Her main task is to analyze data from the Swedish environmental monitoring programme National Inventory of Landscapes in Sweden (NILS).
Address: Department of Forest Resource Management, Swedish University of Agricultural Sciences, 90183 Umeå, Sweden.
e-mail: asa.eriksson@srh.slu.se