Managing Reindeer Lichen during Forest Regeneration Procedures: Linking Sámi Herders' Knowledge and Forestry

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Abstract

In northern Sweden, conventional forest regeneration procedures applied in modern commercial forestry can disturb terricolous lichen (*Cladina* spp.) pastures. This has become a source of conflicts with Sámi reindeer herders. The overall aim of this thesis was to investigate forest regeneration strategies that may minimise the disturbance to, and promote the regeneration of, reindeer lichen pastures. The Sámi herders' practices and knowledge related to the lichen resources were also analysed.

Effects of gentle soil preparation methods on the re-establishment of lichen cover, reindeer grazing and establishment of *Pinus sylvestris* planted seedlings were studied in a field experiment. Using the HuMinMix-technique to mix the lichen mat with humus and mineral soil (*humix*-substrate), was found to promote lichen mat recovery more effectively than conventional scarification. Seedling establishment was highest for mounding and tracks with mineral soil. Rates of seedlings mechanically damaged, possibly caused by reindeer trampling in winter, indicates that planting on densely grazed areas should be avoided to minimize sources of conflict and to prefer either direct seeding or natural regeneration instead. According to a survey, complete re-establishment of the lichen mat after soil preparation was estimated to take about one decade on *humix*-substrate, compared to probably more than five decades following conventional harrowing.

Possibilities for artificial dispersal of reindeer lichen, *e.g.* in areas disturbed by conventional soil preparation, were also studied. The substrate was identified as a key factor for lichen establishment. In this regard, mineral soil was identified as a poor substrate for reindeer lichen immobilization, while milled organic materials, such as moss, were suitable substrates for lichen immobilization and growth. All dispersal methods tested resulted in lichen establishment, but transplanted lichen cushions were heavily depleted by reindeer grazing, while fragmented lichen thalli were much less affected.

A study based on ethnolinguistics demonstrated that whereas the Western use of the word 'pasture' is often associated with a specific plant community, Sámi herders' understanding of the word (*guohtun* in Sámi) also incorporates the effect of snow on grazing. Sámi herders use their knowledge of the effects of forest trees and other vegetation on snow conditions, to strategically plan reindeer grazing during winter. Sámi herders' knowledge of winter pastures should therefore be integrated with information on the effects of forest regeneration procedures on stand development to develop strategies that meet the needs of both commercial forestry and the reindeer herders.

Keywords: Artificial dispersal, *Cladina*, *Guohtun*, HuMinMix, Soil scarification, Reindeer pastures

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La gestion des pâtures de lichen au cours de la régénération forestière: Associer les savoirs locaux des éleveurs de rennes Sami et la sylviculture

Résumé

En Suède boréale, les techniques de régénération forestière utilisées par la foresterie moderne, notamment les préparations de sols précédant la plantation, endommagent les pâtures de lichen terricoles (*Cladina* spp.), et sont devenues une source de conflit entre forestiers et éleveurs de rennes Sami. L'objet de cette thèse est d'étudier des stratégies de régénération forestière pouvant réduire les perturbations et promouvoir le ré-établissement du lichen des rennes. Les savoirs et les pratiques des éleveurs Sami sur la ressource en lichen sont également analysés.

Les effets de préparations de sol moins perturbatrices sur le ré-établissement du tapis de lichen, le pâturage des rennes et l'établissement de plants de *Pinus sylvestris* furent étudiés. L'utilisation de l'HuMinMix, technique mélangeant le couvert de lichen avec la couche d'humus et le sol minéral, est favorable à la régénération du tapis de lichen par comparaison aux préparations de sols conventionnelles. Cependant, l'établissement des jeunes pins est supérieur suivant une préparation exposant seulement le sol minéral. L'occurrence de dégâts mécaniques, possiblement causés par le piétinement des rennes, est un argument pour éviter la plantation dans les parcelles fortement fréquentées par les rennes, au profit de la régénération naturelle ou de l'ensemencement afin d'éviter les conflits avec les propriétaires forestiers. La régénération complète du tapis de lichen suivant la préparation de sol HuMinMix est estimée à une dizaine d'année comparé à plus de cinquante ans suivant les techniques conventionnelles.

Les possibilités de dispersion artificielle du lichen, par exemple dans des parcelles fortement endommagées par les préparations de sol, sont également étudiées. La nature du substrat s'avère être un facteur clé pour l'établissement du lichen dispersé. Le sol minéral se révèle être un substrat ne permettant pas l'immobilisation des fragments de lichen, alors que les substrats organiques sont favorables à l'établissement et à la croissance du lichen. Au cours du suivi de 17 parcelles en régénération, toutes les espèces du genre *Cladina* furent observées colonisant naturellement les sols scarifiés. Néanmois la présence d'espèces de lichen pionnières semble favoriser l'établissement des lichens du genre *Cladina*. Toutes les méthodes de dispersion testées résultèrent en un établissement effectif du lichen. Néanmoins l'établissement suivant la transplantation de thalles lichéniques entiers, non-fragmentés, fût sévèrement réduit par le pâturage des rennes, alors que l'établissement à partir de thalles fragmentés le fût beaucoup moins.

Une étude ethnolinguistique permit également de démontrer que, contrairement à son usage dans la culture occidentale où le mot 'pâture' est associé à une communauté végétale spécifique, l'usage par les éleveurs Sami du même mot (*guohtun* en Sami) inclut l'effet de la neige sur les pâtures de lichen et leur pâturage par les rennes. Les éleveurs de rennes Samis utilisent leurs savoirs sur l'influence de la végétation forestière sur les conditions de neige, et donc les conditions de pâturage, pour élaborer des stratégies de pâturage au cours de l'hiver. C'est pourquoi il est nécessaire d'intégrer le savoir des éleveurs Sami sur les pâturages hivernaux en tenant compte des conséquences de la régénération forestière sur le développement et la structure du peuplement, afin d'améliorer la compréhension des effets de la production forestière sur le pâturage hivernal des rennes, et pour développer des stratégies qui satisfassent les gestionnaires forestiers et les éleveurs de rennes.

Mots clés: Cladina, Dispersion artificielle, *Guohtun*, HuMinMix, Pâturage des rennes, Préparation de sol

Skötsel av renlav integrerat med skogsföryngringsåtgärder vid skogsbruk

Sammanfattning

Skogsresursen i norra Sverige används ofta samtidigt av både rennäring och skogsbruk. Det moderna skogsbruket kan medföra störningar i tillgången på renlavar (*Cladina* spp.) för renbete under skogsföryngringsfasen, vilket utgör en källa för konflikter mellan rennäring och skogsbruk. Övergripande mål med denna avhandling var att undersöka skogsföryngrings-strategier som kan minimera störningar och stimulera reproduktion av renlavsbeten. Syftet var att (i) kvantifiera effekter av markberedning, bl. a. avseende HuMinMix-tekniken (Figur 3), på återetablering av renlav, renens betesmönster och etablering av tallplantor (*Pinus sylvestris)*, (ii) undersöka möjligheter till artificiell spridning av renlav, och (iii) analysera hur traditionell kunskap hos renskötande samer används vid val av betesmarker under vintern.

Effekter av skonsam markbehandling på återetablering av renlav, renens betesmönster och etablering av tallplantor studerades i ett fältförsök utlagt på en lavrik tallhed (Studie I). I försöket jämfördes tre varianter av markberedning (humix-spår, högläggning och mineraljordspår, inklusive en kontroll utan markberedning) av olika intensitet, dvs. med olika nivåer av störd markyta. Med en finfördelad blandning av lav-/humustäcke och mineraljord (*humix*-substrat), erhölls snabbare återetablering av renlav jämfört med konventionell markberedning (Figur 4). Studie V, avseende återetablering av renlav för *humix*-spår och konventionell harvning, visade att tiden till fullständig återetablering av renlav kan uppskattas till ca ett decennium för ett *humix*-substrat, jämfört med troligtvis minst fem decennier för konventionell harvning (Figur 6).

I Studie I visade sig plantetableringen vara generellt låg, speciellt för kontrollen, men dock högre för högläggning och mineraljordspår jämfört med *humix*-spår (Figur 8). Förekomsten av mekaniskt skadade plantor, förmodligen orsakat av renens betesgräv under vintern, indikerar att plantering ska undvikas i områden som är speciellt viktiga för renens vinterbete. Istället bör sådd eller naturlig föryngring väljas, som kan ge etablering av ett stort antal stammar till låg kostnad, vilket medför mindre känslighet för att en andel plantor skadas av betesgräv. Därmed minimeras även risken för konflikter. En spillningsinventering i Studie 1 visade på en trend med färre spillningshögar där mer av mineraljorden exponerats och fler spillningshögar där lavtäcket var intakt (Figur 7).

Möjligheter till artificiell spridning av renlav studerades i två fältförsök. I Studie II spreds lavfragment (1- och 3-cm) på fyra olika marksubstrat (mineraljord samt sönderdelad mossa, bärrisvegetation och bark). Marksubstratet identifierades som en nyckelfaktor för lavfragmentens etablering, särskilt för immobilisering av fragmenten. Mineraljord förefaller olämplig medan sönderdelat organiskt material (t ex mossa) erbjuder bra miljö för att lavfragment både ska fästa (Figur 5) och växa (Figur 9), jfr *humix*-substratet ovan. Något fler marklavarter (andra än renlavar) verkar etablera sig i *humix*-spår jämfört med harvning (Studie V, Figur 10). I studie IV undersöktes två spridningssätt, spridning av lavbålar resp. lavfragment. Både spridningssätten

resulterade i lavetablering och tillväxt liknande naturligt etablerad renlav. Spridning av fragment var dock effektivare än spridning av intakta lavbålar eftersom bålarna betades hårt av ren. Spridning av fragmenterad renlav bör alltså vara en möjlighet för restaurering, t ex när onödigt radikal markberedning använts.

I Studie III presenteras resultat från en analys (utförd genom deltagarobservation, intervjuer av renskötare och etnolingvistisk analys) av hur renskötande samer använder sin traditionella kunskap för att välja vinterbetesmarker i Jokkmokksområdet. Samiska ordet *guohtun* (bete) har en vidare betydelse än det svenska ordet *bete*. Medan det svenska ordet ofta är associerat med en specifik art som betas, t ex en marklav, är det samiska ordet även förknippat med snöns effekt på möjligheterna till bete. Renskötarna använder sin kunskap om trädens och annan vegetations inverkan på snöbetingelserna som underlag för strategisk planering av vinterbetet. Därför föreslås i avhandlingen ett schematiskt underlag för diskussion om markanvändning som baseras både på metoder som kan minska skogskötselns negativa inverkan på renlavsbetet och renskötarnas kunskap om beståndsegenskapers och snöns inverkan på renens vinterbete (Figur 11).

Contents

List of Publications

This PhD thesis is based on the following five studies, which will be referred to by their respective Roman numerals.

I Roturier, S., Bergsten, U. (2006). Influence of soil scarification on reindeer foraging and damage to planted *Pinus sylvestris* seedlings. *Scandinavian Journal of Forest Research* 21(3), 209-220.

II Roturier, S., Bäcklund, S., Sundén, M., Bergsten, U. (2007). Influence of ground substrate on establishment of reindeer lichen after artificial dispersal. *Silva Fennica* 41(2), 269-280.

III Roturier, S., Roué, M. (2009). Of forest, snow and lichen: Sámi reindeer herders' knowledge of winter pastures in northern Sweden. *Forest Ecology and Management* 258(9), 1960-1967.

IV Roturier, S., Bergsten, U. (2009). Establishment of *Cladonia stellaris* after artificial dispersal in an unfenced forest in northern Sweden. *Rangifer* 29(1), 39-49.

V Roturier, S., Sundén, M., Bergsten, U. Re-establishment rate of reindeer lichen species following conventional harrowing and HuMinMix soil preparation in *Pinus*-lichen clear-cut stands: a survey in northern Sweden. *Manuscript*.

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1. Introduction

Reindeer husbandry and forestry are by far the most geographically extensive uses of the boreal forests in Fennoscandia, as illustrated by the map showing the reindeer herding areas (47% of which are forested) in northern Sweden in Figure 1. In the last five centuries, semi-domesticated reindeer (*Rangifer tarandus tarandus* L.) herding by Sámi people has required access to pastures in the boreal forest, since reindeer rely on grazing the understorey vegetation, especially terricolous mat-forming lichen (*Cladina*[1] spp.), during wintertime. In addition, for about 100 years, private landowners and forest companies have managed the forest for timber and fibre production in ways, from tree regeneration to final felling, that heavily affect reindeer lichen pastures, particularly during forest regeneration. This dual-use situation has led to frequent conflicts between these two activities, especially in the last 50-60 years (Widmark, 2008). This thesis is intended to provide knowledge to foresters about possible measures to interactively manage reindeer lichen pastures and forest exploitation, taking into account Sámi reindeer herders' knowledge.

Figure 1. Reindeer herding area in Sweden. Forest land for wood production represents about 47% of the reindeer herding area (Norrbotten, Västerbotten, Jämtland). Roman letters refer to Paper numbers indicating the location of the studies presented in the thesis.

[1] Lichen nomenclature follows Moberg and Holmåsen (2000); see Material & Methods (4.2) for brief discussion about the nomenclature of reindeer lichens.

There are numerous sources of conflicts and divergence of interests between forestry and reindeer herding, but ground lichen can be readily identified as pivotal element in this respect for several reasons: ground lichen is the main resource for reindeer during winter, wintertime is the period when access to grazing resources is most critical, and forestry measures impair lichen pastures over both short and/or long-term scales. Hence, most research on reindeer winter grazing has crystallised around issues related to ground lichen.

As a major component of the understorey vegetation in boreal ecosystems, reindeer lichen has been considered in numerous publications by forest ecologists and plant scientists in recent decades. Since it is also the main pasture resource of a large herbivore (reindeer), lichen has also interested zoologists during this time. In addition, since lichen pastures are resources for reindeer herded by indigenous people, with its own culture, practices, language and worldview, reindeer lichens have dimensions that are highly relevant to the social sciences. Recurrent court cases associated with reindeer winter grazing show that the issue has also strong legal aspects, and is highly politically charged (Hahn, 2000). Further, there is unlikely to be any major resolution of the associated problems without the development of clearer institutional frameworks (Sandström *et al.*, 2006).

Forest ecosystems are currently managed in boreal Sweden in ways that are intended to optimise wood production and conserve biodiversity, based on increasing knowledge of forest ecology and management, and experience gained from almost a century of modern forestry. Adapting forest management to reindeer herding should be technically possible, if the only challenges associated with meeting the socio-political requirements were purely related to forest ecology and management. However, knowledge of the effects of forestry on aspects of reindeer herding, such as use of pastures and herding patterns, remain poorly understood or simplistic, as widely acknowledged, *e.g.* in the Swedish Forestry Act (§21 and §31). Indeed, integrating the management of reindeer pastures with forest management requires knowledge and skills that extend beyond those of natural sciences. But neither social nor natural sciences can meet such challenges alone. Therefore, in order to improve knowledge on forest management adapted to reindeer herding and understand the issue in its whole complexity, it must be tackled by an interdisciplinary approach. Thus, this thesis addresses the issues involved in adapting forest regeneration to meet the needs of both forests (optimising forest growth) and Sámi reindeer herding (optimising lichen resources and access) using methodologies rooted in environmental anthropology as well as forest ecology and management.

2. Background

2.1. Forest management in reindeer grazing land

2.1.1. History of forests use for logging in northern Sweden

The present use of the boreal forest for commercial forestry has developed via a series of historical changes. Human impact on the forest remained of low intensity until the 19th century, following the establishment of settlements, the beginning of industrialization and the introduction of commercial forestry (Tirén, 1937). During the 19th century the two northern counties of Sweden (Västerbotten and Norrbotten) were reached by the *timber frontier* that moved across the country targeting the largest Scots pine (*Pinus sylvestris* L.) trees (Östlund, 1993). During the first half of the 20th century, selective logging (or high-grading) was still the principal logging system, and together with fire prevention, forest exploitation provided a sparser forest which was more suitable for the growth of terricolous lichens, and thus for reindeer herding (Berg *et al.*, 2008). Changes occurred progressively during this period towards more intensive and productive forest management (Östlund & Roturier, in press). The use of forestland for producing wood presented a dramatic shift in the middle of the 20th century with the introduction of mechanization and rationalized practices. During the second half of the 20th century, clear-cutting, soil scarification and fertilisation became dominant practices (Östlund *et al.*, 1997; Berg *et al.*, 2008). As a result of this high-yielding strategy forestry is an important contributor to the economy of the lightly populated northern counties of the country.

2.1.2. Effects of forest management on reindeer lichen pastures

Terricolous mat-forming lichen, together with epiphytic species (*Alectoria* spp. and *Bryoria* spp.), represent 50-80% of the reindeer's winter diet (Bergerud & Nolan, 1970; Kojola *et al.*, 1995; Heggberget *et al.*, 2002; Storeheier *et al.*, 2003; Jaakkola *et al.*, 2006), and thus are of critical importance for reindeer herding. During winter reindeer have to dig through the snow to feed on lichen. Temperatures are generally milder, and the snow conditions more suitable for digging reindeer in coniferous forests than in bare mountain areas. Therefore, *Pinus*-lichen stands (also called pine-heaths) in the winter grazing area (Fig. 1) constitute the principal pastures for reindeer during winter. *Pinus*-lichen forests are dominated by Scots pine, which accounts for the largest part of the standing volume, and the ground vegetation is dominated by lichens, feather mosses (*Hylocomium splendens* Hedw. and *Pleurozium schreberi* Bridd.) and ericaceous dwarf shrubs. In two types of vegetation, designated *lichen-rich* and *lichen-dominated types*, the lichen cover amounts to ≥25 to < 50% or ≥50%, respectively, according to Hägglund and Lundmark (1982), and these types jointly account for about 13% of the forest land in Sweden (data from 1999; Sandström *et al.*, 2006).

Forest management is mainly based on clear-cutting and artificial regeneration. *Pinus*-lichen forests are generally considered to have low productivity, and thus are harvested after longer periods (100-120 years) than more productive forests (SKSFS 1993:2). However, prior to regeneration, the first step in a rotation in most (87%) forest stands is soil preparation by scarification (Swedish Forest Agency, 2007). For *Pinus*-lichen stands established on dry and mesic soils the most common practice is to scarify by harrowing before planting and/or natural regeneration (Karlsson *et al.*, 2009). However, in some cases mounding may be preferred to more severe harrowing. The regeneration strategies applied generally depend on the degree of moisture of the soil and thickness of the humus layer. On dry soils, with thin humus layers, natural regeneration without soil scarification may be chosen since Scots pine seeds readily germinate on lichen mats (cf. Steijlen *et al.*, 1995). However, this strategy is only usually recommended for areas where the temperature sum is higher than 1 000°C, otherwise there are substantial risks that it will not result in sufficiently high stem densities (Karlsson *et al.*, 2009). In the reindeer husbandry area of northern Sweden, this corresponds only to a narrow belt of land along the coast.

Most current forestry practices applied to *Pinus*-lichen stands have negative effects on reindeer winter pastures since they decrease the biomass of lichen forage. Measures that have a direct effect on lichen abundance include: conventional scarification methods like harrowing, which partly destroy the vegetation cover; and leaving logging residues in clear-cut areas, which affects lichen growth and access to it (Eriksson, 1976a; Helle *et al.*, 1990; Webb, 1998).

By changing abiotic conditions, notably light and moisture levels, other practices may also favour vascular plants at the expense of ground reindeer lichen. Both fertilisation and clear-cutting on sites with high nitrogen supplies, promote the growth of dwarf shrubs or pioneer species such as *Deschampsia flexuosa* (L.) (*e.g.* Hannerz & Hånell, 1997; Kellner & Mårshagen, 1991; Eriksson & Raunistola, 1993). However, on drier sites, dwarf shrubs such as

Vaccinum myrtillus (L.) and feather mosses are adversely affected by the higher irradiance that follows clear-cutting, consequently decreasing the competition for *Cladina* lichens (Kardell, 1980; Bråkenhielm & Persson, 1980). There will also be between-*Cladina* species differences in such responses, for instance Webb (1998) observed a decline in *C. stellaris* cover after logging, but an increase in cover of other ground lichen species, possibly due to an increased access to light.

Recent production practices, such as the planting of densely ramified *Pinus contorta* (Dougl.), since the 1960s, and high stem density, often due to owners neglecting pre-commercial thinning, also favour mosses at the expense of ground lichen (Kardell & Eriksson, 1992; Berg *et al.*, 2008). Another effect of high stem density related to reindeer herding is that it is very difficult to drive snowmobiles through stands with high stem density and consequently almost impossible to gather animals in dense forests.

Before the end of the 19th century, when forest fires were prevented to maximise wood production (Tirén, 1937), coniferous forest burnt at a mean interval of 80 years in northern Sweden (Zackrisson, 1977), an extremely high frequency compared with today. This change has led to a decrease in *Pinus*-lichen stands at the landscape level, and it may be the most important effect of forestry on lichen cover at the landscape level (Zackrisson, 1977; Berg *et al.*, 2008). On mesic sites, this favours litter accumulation and late successional species at the expense of reindeer lichen (Ebeling, 1978). Thus although the absence of fire is beneficial for reindeer lichen in the short term at stand level, in the long term ground lichen benefits from frequent forest fires relative to vascular plants (Zackrisson, 1977; Ebeling, 1978; Foster, 1985; Hörnberg *et al.*, 1999; Berg *et al.*, 2008).

Finally, since reindeer have to dig through the snow to reach the lichen, snow density and snow depth are key factors that influence reindeer grazing (Eriksson, 1976b; Pruitt, 1979; Collins & Smith, 1991; Kumpula & Colpaert, 2007; Helle & Kojola, 2008). The effects of forest management on the degree and extent of snow cover are therefore of great importance to Sámi herders, but they have not been thoroughly studied because of the complexities of the interactive factors involved.

It should also be noted that the shift from the longer natural cycles that predominate in old growth forests to a clear-cutting system with shorter rotation cycles has also reduced the amount of arboreal lichens, which are mostly confined to old-growth forests (Holien, 1996; Jaakkola *et al.*, 2006). Today approximately 72% of the forest land in Sweden is occupied by stands younger than 100 years (Swedish Forest Agency, 2007). The poor dispersal potential of epiphytic lichen in general, and the fragmented habitats due to the absence of old-growth forests, has isolated arboreal lichen populations and prevented their development (Dettki & Esseen, 1998). In addition to causing concerns regarding biodiversity (Hörnberg *et al.*, 1998), this causes problems for reindeer herding (Jaakkola *et al.*, 2006), since epiphytic lichens provide useful alternative sources of forage. This has increased the grazing pressure on ground lichen.

2.1.3. Effects of soil preparation on seedling establishment and lichen cover

For forest owners, the aim of soil preparation is to facilitate forest regeneration by improving soil and microclimate conditions for seeds and seedlings. It is commonly used to improve survival rates and early growth of forest plantations and natural regenerations (Karlsson *et al.*, 2009). Conventional practices involve soil scarification, in which the organic layer is either removed, leaving the mineral soil surface exposed (harrowing) or inverted (mounding).

When the organic layer is removed and mineral soil is exposed germinating seeds have direct access to the mineral soil, which improves the establishment of seedlings (Winsa & Bergsten, 1994; Wennström *et al.*, 1999; Hille & den Ouden, 2004), partly because they are less dependent on the highly variable moisture regime of the humus layer (Oleskog & Sahlén, 2000), as illustrated by sharp drops in mortality when seedlings have established their roots in mineral soil (Nilsson *et al.*, 2002). In addition, removing the vegetation layer increases the availability of suitable microsites for seeds, and reduces the competition young seedlings face for water and nutrients. It also decreases the allelopathic effects of dwarf shrubs (*e.g. Empetrum nigrum* L.), which can inhibit the germination of Scots pine (Zackrisson & Nilsson, 1992).

In a naturally grown forest, wildfire is a primary determinant of the composition and biomass of understory vegetation, and hence a major driver of forest community and ecosystem properties. To a certain degree, disturbing the humus layer by scarification can mimic some effects of fire, by removing the understorey, increasing rates of mineralization (Johansson, 1994) and consequently increasing rates of nitrogen uptake by conifer seedlings (Nilsson & Örlander, 1999). Moreover, mounding increases the thickness of the fertile zone by inverting the humus layer. Soil structure is also improved by associated increases in soil porosity, which, *e.g.*, promoting gas exchange (de Chantal *et al.*, 2004).

Low soil temperature may inhibit root growth as well as water uptake, and thus affect seedlings' water absorption and nutrient uptake rates (Mellander *et al.*, 2004). A further positive effect of scarification on seedling establishment is to remove the insulating effect of the vegetation layer, thereby increasing solar radiation and raising soil temperatures in the root zone. The increases in solar radiation, together with the reflectance and conductivity of mineral soil, may also increase the temperature of the air surrounding the above-ground parts of the seedlings. This can enhance their rates of photosynthesis and keep them warmer than they would otherwise be during cold summer nights (Lundmark *et al.*, 1978; Kubin & Kemppainen, 1994). Increased temperatures in seedlings' surroundings may also reduce the risks of fungal diseases and damage by insects such as *Hylobius abietis* (L.) (Örlander & Nilsson, 1999). However, scarification may also have negative effects on seedlings, notably it may increase their transpiration and, consequently, water requirements.

Scarification also has profound effects on reindeer grazing, since it can affect as much as 35-55% of the vegetation cover grazed by reindeer when applied in lichen-rich stands (Eriksson & Raunistola, 1990). It reduces a substantial proportion of the forage biomass, and may also have indirect effects since herders report that reindeer generally avoid grazing in scarified stands because they are repelled by the smell of exposed mineral soil. Thus, during the consultations that forest companies are obliged to hold with reindeer herders prior to clear-cutting according to Forest Stewardship Council regulations (FSC, 1998), soil preparation is one of the main focus of negotiations and sources of conflicts (see also Sandström & Widmark, 2007). For these reasons, scarification techniques with as little impact as possible on vegetation cover should be selected, especially since harsh scarification may give no better results than mild treatments. For instance, Mattsson (2002) showed that (on sites with intermediate fertility at least), 20 years after mounding and harrowing, which resulted in disturbance to 35 and 54% of the soil area, respectively, stem volume yields were similar.

2.2. Sámi reindeer herders: the other users of the boreal forest

2.2.1. Reindeer herding in Sweden today

The Sámi herding society in Sweden has been organized in 1886 in 51 *reindeer herding communities* in the three northernmost counties. Today, a reindeer herding community is commonly defined as a geographic entity delimiting the grazing areas and an economic organization representing its members' interests (Gustavsson, 1989; Sametinget, 2008). In addition, a herding community also refers to a community in the more commonly used sense, *i.e.* the herders and their families, who share the land and collaborate during many essential activities. Since reindeer husbandry is an exclusive right of the Sámi people, all members of a herding community are Sámi. There are about

4 500 reindeer owners in Sweden and about 250 000 reindeer (Sametinget, 2008). Reindeer herding communities are differentiated between *mountain* and *forest*[2] communities. The principal difference is that summer pastures of the former are located in the mountains and those of the latter are located in the inland forests. Hence, migration distances are longer for mountain herding communities, but winter pastures, which are the main foci of this thesis, are invariably located in the forestland at lower altitudes for both mountain and forest herding communities.

At the beginning of the 20th century, there were major changes in reindeer herding in northern Sweden, with a transition towards the reindeer being gathered in larger herds solely for slaughtering. These changes had multiple causes, including the spread of the extensive herding practiced by Karesuando Sámi, who were relocated to various places throughout northern Sweden after the border closure with Norway in 1919. In addition, modernization and motorization of herding tasks during the second half of the 20th century eased some of the herders' work and lifestyle. Finally, the rationalization encouraged by Scandinavian states also contributed to the switch to the current form of reindeer herding (Beach, 1981; Bjørklund, 1990; Müller-Wille *et al.*, 2006).

Reindeer herding is based on an annual cycle that can be outlined as follows. From calving in May until the end of the growing season, the herds graze freely and their diet consists of protein-rich deciduous shrubs, herbs and grasses, allowing them to build reserves for winter, during which they rely mostly on energy-rich lichen (*e.g.* Eilersten *et al.*, 2001; Heggberget *et al.*, 2002). At the turn of June-July, reindeer herds are gathered by foot and motorized vehicles, including helicopters, for earmarking the yearlings (Fig. 2), after which they are released for free grazing until the slaughter of the males. Males are slaughtered in autumn, before the rut, to obtain meat for both private consumption and sale. After the rut, in November-December, the first herds are gathered by herders of the whole community to be sorted and separated into smaller herds belonging to specific families, or groups of families, called winter-groups or *siida* (Fig. 2). At that time of the year, herders stop working for the whole community, and concentrate their labour on reindeer belonging to their respective winter-groups. Depending on the location of winter-groups' territory and weather conditions, reindeer herds either migrate by foot or are taken in vehicles to their winter territory. Due to the extensive form of summer grazing, with extremely loose guarding, it is very rare that all reindeer belonging to a herding community are gathered together. For the same reason, reindeer belonging to adjacent communities often mix and herders also have to participate in neighbours' separations to

[2] *Concession* communities can be regarded as "forest" communities with respect to their land use strategies, see Gustavsson (1989).

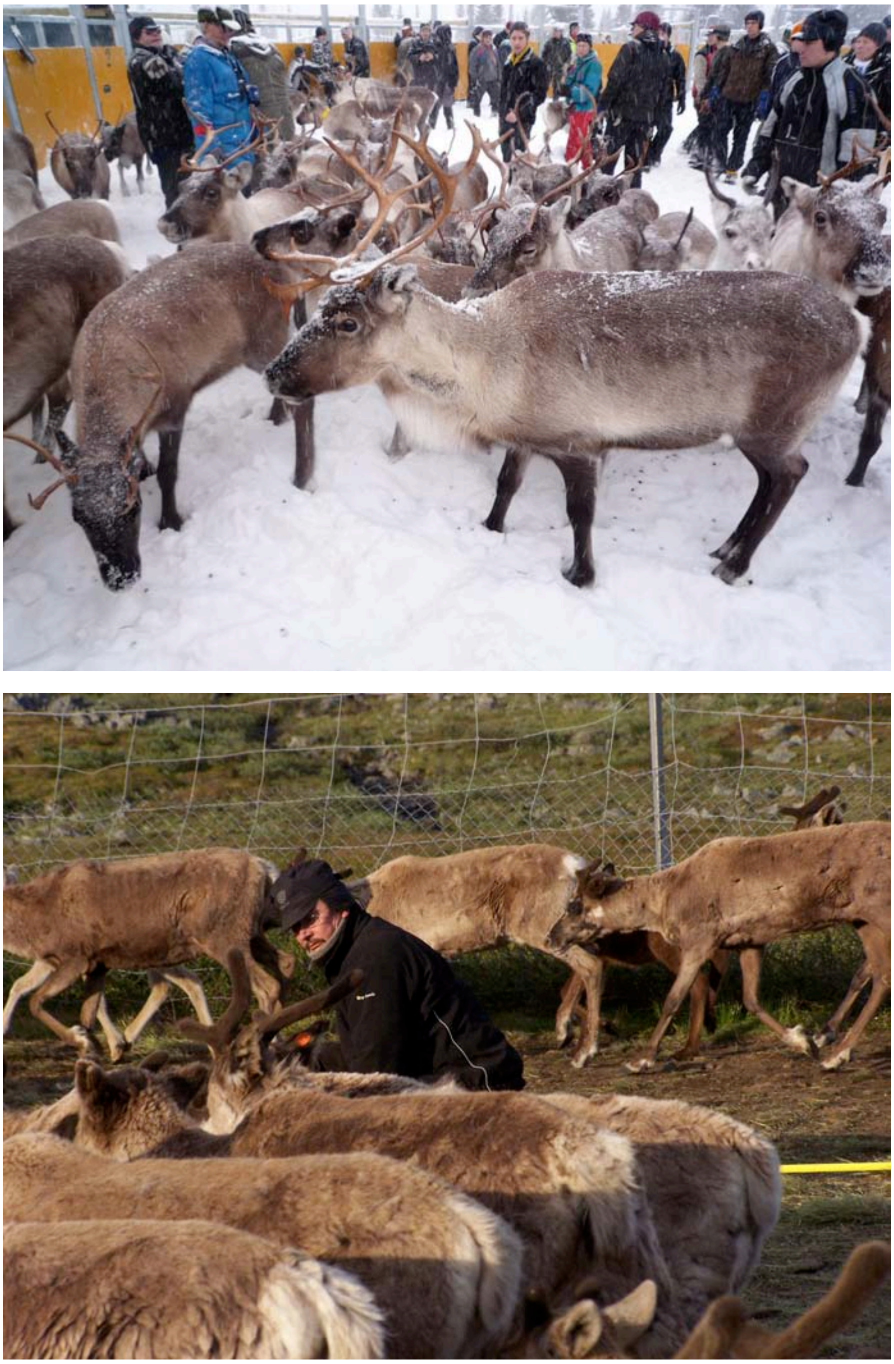

Figure 2. (Top) Reindeer separation: after identifying the owner of the reindeer by their earmarks, reindeer belonging to the winter-group are gathered in an adjacent coral before the migration to the winter grazing land. (Bottom) Earmarking of yearlings in July. Photos: S. Roturier.

collect their own reindeer and transport them to their winter land. New herds of reindeer can thus be gathered and moved to winter land until the end of January. Adverse climatic conditions, especially for mountain communities, which are frequently confronted with bad weather, can reduce the efficiency of the gathering and some reindeer commonly spend the winter in the mountain area. Winter separations are also the time when herders can sell yearlings to slaughterers. Wintertime is a period of intense guarding to avoid reindeer scattering. This is especially true when a crust of ice covers the snow cover and reindeer scatter to find epiphytic lichen. Thereafter the spring migration takes place and reindeer herds are then released in the community's common pasture, when they are heading toward calving land.

Winter is often considered to be the bottleneck for reindeer survival and reindeer herding in general, since the quantity and quality of winter ranges strongly influence the body weight, calf production and mortality of reindeer (Skogland, 1986; Kojola *et al.*, 1995; Kumpula *et al.*, 1998). As well as trying to ensure the survival of the reindeer, herders have to prevent them scattering beyond their grazing area at that time. As explained above, winter grazing for each winter-group takes place in a particular area. Thus, the grazing territory of each winter-group is limited in space and surrounded by the territories of other winter-groups. Keeping reindeer within their respective winter-group's territories avoids the need for extra labour to collect the scattered reindeer, and helps to maintain good relations between neighbouring groups. In addition, maintaining control of the herd, which is mostly composed of pregnant female during winter, is also the only way to ensure that the yearlings will be earmarked next summer.

> After the winter separation, our task is to control our reindeer. To make sure that our reindeer spend the winter as well as possible, and that they give birth to nice and healthy calves in May. (P.-J. Parffa, March 2008)

This is an important factor to consider when studying reindeer herding in winter, since reindeer continuously move when grazing (see also III).

2.2.2. Contribution of indigenous knowledge to resource management

As often mentioned, there is no universally accepted definition of traditional ecological knowledge (Berkes, 1999) and the understanding of the term, as widely used since its official emergence in Article 8(j) of the Convention of Biological Diversity (CBD, 1992), may even be misleading when studying such knowledge (see Nakashima & Roué, 2002). Thus, in this thesis when referring to current knowledge of Sámi herders about forest grazing areas, the term of indigenous ecological knowledge is preferred and understood as:

> (…) the complex arrays of knowledge, know-how, practices and representations that guide human societies in their innumerable interactions with the natural milieu: agriculture and animal husbandry; hunting, fishing and gathering; struggles against disease and injury; naming and explaining natural phenomena; and strategies for coping with changing environments. (Nakashima & Roué, 2002)

In his seminal work on *The Savage Mind*, Lévi-Strauss (1962) reflected on the distinctive nature and process of what he called *the science of the concrete*, *i.e.* the results of the accumulation of individuals' and societies' interactions, observations and efforts to comprehend and organize their surrounding environment.

Reindeer herding concerns as much the material environment as the spiritual environment, since both are undoubtedly combined in indigenous knowledge. Centuries of acculturation of Sámi people have made this dimension less obvious to outsiders, but dismissing it would be an error (cf. Oskal, 1999; Ruotsala, 2004), since it remains a cornerstone of the worldview that Sámi societies have of their environment. Authors commonly agree that indigenous knowledge has a number of distinctive features, among which the following are of particular interest in the context of this thesis: (i) indigenous knowledge has an holistic approach; (ii) it has a strong empirical knowledge component; (iii) it is cumulative and open to change; (iv) it has a management practice component; hence (v) it is always embedded in a specific socio-cultural context (Berkes, 1999; Posey, 1999).

Language often embodies such knowledge, frequently in unwritten forms. Naming and classifying things enable people to "*understand and make more intelligible the relationships between beings*" (author's translation from Durkheim & Mauss, 1901-1902). For that reason the study of indigenous knowledge is deeply rooted in ethnoscience, or *new ethnography*, which can be defined as the study of a culture's system of classification and taxonomy to describe its surrounding environment. Key objectives of this discipline are to understand indigenous people's view from within and obtain insights into the very nature of indigenous knowledge (cf. Nakashima & Roué, 2002). Current interest in indigenous knowledge regarding resource management is motivated by both ethical concerns and desires to increase the effectiveness of management measures (*e.g.* Fernandez-Gimenez, 2000; Hunn *et al.*, 2003; Foale, 2006). In that sense, understanding Sámi reindeer herders' knowledge is highly relevant to attempts to improve the management of both reindeer lichen pastures and boreal forests.

2.3. Restoring reindeer lichen: how and why?

2.3.1. Lichen recovery after disturbances

The "National goals for the forestry sector" guidelines recommend that forest managers should pay particular attention to reindeer herding, especially regarding soil preparation in *Pinus*-lichen forest (Swedish Forest Agency, 2005). However, in order to progress beyond good intentions to concrete action in this respect, one should acknowledge the complexities involved in meeting such a goal. Ideally, reindeer lichen should be managed during regeneration procedures in ways that satisfy both the needs of forest managers, as stipulated by the Swedish Forestry Act for production purposes (SKSFS 1993:2), and the needs of Sámi reindeer herders, which are not solely determined by profit (Riseth, 2006). The latter cannot be identified without a thorough understanding of herders' worldviews regarding winter pastures.

It is technically challenging to prepare soils for tree regeneration while affecting reindeer lichen supply as little as possible. These dual objectives conflict, to some degree (as shown above), and meeting them requires both knowledge about the potential rates of reindeer lichen re-establishment, and measures that may promote it. Valuable insights regarding measures that could be applied can be obtained from knowledge of lichen re-establishment following natural and anthropogenic disturbances, such as the well-documented information that is available on post-fire succession. Fires may consume virtually all of the ground cover and important changes in vegetation composition occur during the following 100 years, *i.e.* it takes at least a century for lichen cover to peak again (Kershaw, 1977; Morneau & Payette, 1989). The succession stages have been thoroughly described (Maikawa & Kershaw, 1976; Ahti & Oksanen, 1990). In boreal regions, the first colonizers of bare soils are fast-growing crustose lichens and some bryophyte species, as well as some vascular plants that can peak at this time. Then cup lichens (*Cladonia* spp.) become abundant and the first fruticose lichens may also appear. Later, fruticose lichens, and usually reindeer lichens (*Cladina rangiferina* L., *C. arbuscula* Wallr.) become dominant. *Cladina stellaris* (Opiz) is usually the last to establish. In the absence of grazing, reindeer lichen mats can attain their maximum thickness (*ca.* 13 cm) and maximum biomass after 125 years (Morneau & Payette, 1989). It is noteworthy that Sámi people knew about the succession of different lichen florae. Nissen (1921, p. 243) noted that Sámi herders in Norway in the early 20th century seemed to recognize different stages corresponding to the dominance of different lichen species or groups of species.

In contrast to fire, soil preparation (like over-grazing and trampling) does not remove all of the lichen ground cover. Instead, it initiates a new succession on exposed ground, beginning with settlements of crustose lichens or other pioneer species (Helle & Aspi, 1983; Boudreau & Payette, 2004a). This differs from post-fire succession because species from different successional stages are already present following the disturbance and, according to Boudreau and Payette (2004a), *C. stellaris* may directly recolonize via the spread of fragmented thalli. After nearly complete removal of lichen cover by over-grazing, in the absence of further grazing, at least 20 years are needed for the lichen cover to fully recover (Henry & Gunn, 1991). Conventional scarification can have more prolonged consequences (Sundén, 2003).

On the other hand, the total absence of disturbance can have adverse effects for lichen cover, including the following. On more mesic sites, canopy closure leads to the establishment of feather mosses that can compete with terricolous lichen (Foster, 1985; Sulyma & Coxson, 2001). Gaare (1997) also hypothesized that by grazing reindeer may decrease the thickness of the lichen mat that would otherwise promote the establishment of vascular plants, and thus maintain lichen dominance.

2.3.2. Elements of lichen biology

Lichens are symbiotic organisms, composed of a fungal partner (mycobiont) and photosynthetic partners (photobionts) that may be cyanobacteria and/or green algae. However, all of the most common mat-forming lichens in boreal forests – including *Cladina* spp. – are associated with algae from the genus *Trebouxia* (Ahmadjian, 1993).

Lichenized ascomycetes can reproduce either asexually or sexually. A general characteristic of reindeer lichens (*Cladina* spp.) is that they mainly propagate through the dispersal of fragmented thalli (Honegger, 1996). The extreme brittleness of the thalli at water contents below 25% (Bayfield *et al.*, 1981) facilitates dispersal, which is mediated by wind and animals (Bailey, 1976; Heinken, 1999).

Lichens are poikilohydric organisms that lack water-transport organs and depend on passive physical processes of water uptake and loss (Blum, 1973). Thus, their moisture status varies to a large extent with surrounding atmospheric conditions, and both their metabolism and growth are periodically inactive when conditions are dry, and activated when they are hydrated by precipitation, dew or atmospheric water (Péch, 1991; Hyvärinen & Crittenden, 1998; Sundberg *et al.*, 1999; Palmqvist & Sundberg, 2000; Jonsson *et al.* 2008).

Nevertheless, despite being subject to passive regulation, desiccation and rehydration rates of lichen thalli vary between species. The morphological structure and the growing habits of the lichen play an important role in these processes (Larson & Kershaw, 1976; Gauslaa & Solhaug, 1998). As reindeer lichens are all fruticose species, *i.e.* species with highly ramified morphology, they have a high surface area exposed to the air relative to their volume. For that reason reindeer lichen are more sensitive to desiccation than foliose lichen species, for instance (Larson & Kershaw, 1976). On the other hand, their mat-forming growth habit is often considered to help reduce evaporation, potentially prolonging their growing period (Kershaw & Rouse, 1971; Larson & Kershaw, 1976; Helle *et al.*, 1983; Jonsson *et al.*, 2008). However, this has been recently challenged by Gaio-Oliveira *et al.* (2006) who found that the wet active time of *C. stellaris* was not affected by either the density or the thickness of the mat. Nevertheless, isolated thallus fragments, especially smaller ones, may desiccate more rapidly than dense mats or larger fragments (Kershaw & Field, 1975; Gauslaa & Solhaug, 1998; Kytöviita & Crittenden, 2002).

In reindeer lichen most of the photobionts are concentrated in the apical part of the thalli (Nash *et al.*, 1980). Several experiments have shown that the relative growth rate of the apical parts is higher than that of the lower basal parts, which are constituted of fungal, sometimes senescent, tissues (Kärenlampi, 1971; Kytöviita & Crittenden, 2002; Gaio Oliveira *et al.* 2006). Recent studies have shown that the combined effects of hydration periods and the irradiance intercepted by lichen during these wet periods (I_{wet}) are key determinants of thallus growth that explain much of the variation observed between species and habitats (Palmqvist & Sundberg, 2000; Gaio Oliveira *et al.*, 2006). Consequently, microclimatic conditions at lichen establishment sites strongly influence rates of lichen growth.

Atmospheric deposits are believed to be the main sources of nutrients for *Cladina* lichens (Ellis *et al.*, 2004), although Crittenden (1991) also suggested that reindeer lichen may recycle nutrients from their decaying basal areas to their upper parts. The optimal growth temperature for reindeer lichens is known to be between 15-25°C, but in summer the temperature at the surface of lichen mats can reach 35-40°C without affecting their vitality (Tegler & Kershaw, 1980; Coxson & Wilson, 2004). Since lichens are dependent on wet active periods their growth rates vary between seasons and years. On an annual basis biomass increments up to 17-26% have been measured (Crittenden *et al.*, 1994; den Herder *et al.*, 2003), which is substantially higher than those reported by Kumpula *et al.* (2002) for an intensively grazed mat (*ca.* 7%). The elongation rate of reindeer lichen has been measured, and found to be *ca.* 4 mm y^{-1}, in several studies (Scotter, 1963; Helle *et al.*, 1983; Boudreau & Payette, 2004b).

3. Objectives

The overall aim of the studies underlying this thesis was to acquire knowledge regarding possible measures to decrease the disturbance and negative consequences caused by soil preparation during forest regeneration procedures on reindeer winter pastures, and to promote integration of lichen management with the regeneration of forest trees. The work focused on reindeer lichen (*Cladina* spp.) pastures and their use by Sámi herders. The first overall hypothesis tested was that since reindeer lichen naturally disperse by thalli fragmentation, it should be possible to accelerate the recovery of lichen mats after disturbance by artificial dispersal and/or by creating suitable establishment conditions during soil preparation. The second overall hypothesis examined was that since reindeer herders belong to the Sámi community, herders' indigenous knowledge of forest winter pastures should provide valuable insights regarding the management of reindeer lichen pastures. A more detailed understanding of Sámi herders' knowledge and means to restore lichen grounds is necessary to integrate reindeer lichen management, as a resource for reindeer herding, with forestry practices, patterns and paradigms. Therefore, the approach presented in this thesis, and applied in the underlying studies, is of interdisciplinary nature, involving forest ecology and management as well as social and cultural anthropology. More specifically, the objectives were to:

(i) Evaluate the effects of scarification treatments that disturb the soil less than conventional scarification (I, V) using recently developed equipment that can create various types of planting substrates, with varying intensity, on both the re-establishment of lichen mats in disturbed areas and the regeneration of *Pinus sylvestris* seedlings (considering also interactive effects of reindeer);

(ii) Test the scope for artificially dispersing reindeer lichen (*Cladina* spp.) (II, IV, V) in pine forests by assessing the ability of lichen thalli, dispersed by several methods, to restore areas disturbed by forest soil preparation;

(iii) Improve the understanding, through participant observations and interviews, of Sámi reindeer herders' ecological knowledge with regard to lichen-rich pastures and their use of managed forests during winter time (III).

4. Material & Methods

4.1. Study areas

The studies this thesis is based upon were carried out at places actively used for both forestry and reindeer herding in winter (Fig. 1), in typical boreal forest areas in the middle-north boreal zone of Sweden (Ahti *et al.*, 1968). All of the studies were located in productive, young to middle-aged, Scots pine forests. The field layer of the ground vegetation at each site was dominated by dwarf shrubs, mainly *Vaccinum vitis-idaea* (L.), *Calluna vulgaris* (L.), *Empetrum nigrum* and some *V. myrtillus*, while the bottom layer was dominated by terricolous lichen (*Cladina* spp. and *Cladonia* spp.) and feather mosses. More specifically, studies presented in Papers I, II and V were carried out on dry sites supporting a lichen cover >25% of the bottom layer; the experiment described in Paper IV was established on a mesic site supporting a moss vegetation type with spots of reindeer lichen; and the study reported in Paper III concentrated on the winter grazing areas of reindeer herding communities around Jokkmokk, extending along the valley of River Lule where *Pinus*-lichen stands are frequent. The study sites are more precisely described in the cited papers.

The monthly mean temperature in the study region ranges between −15 °C in January and +19 °C in June, with mean annual precipitation ranging between 500-700 mm. The average numbers of days with snow, and snow depth, generally vary along a gradient from the coast of the Gulf of Bothnia inland, 150 days with a mean maximal depth of 70 cm near the coast, to up to 225 days with a mean maximal depth of 90 cm close to the mountain areas (data from 1961-1990; SMHI, 2008).

4.2. Lichen cover measurements

Reindeer lichen cover was one of the main variables measured in the experiments (I, II, IV and V). According to the nomenclature proposed by Moberg and Holmåsen (2000), reindeer lichen is the general term for species belonging to the genus *Cladina*. Recent phylogenic studies have argued that there is no reason to distinguish the genus *Cladina* from the genus *Cladonia*, to which its members were previously assigned (Stenroos *et al*., 2002; Santesson *et al*., 2004). In the papers underlying this thesis, the nomenclature follows Moberg and Holmåsen (2000), except in Paper IV for editorial reasons. To be consistent throughout the thesis this distinction has thus been kept.

Lichen cover measurements were performed following different methods depending on the experiments. Where surveys of ground vegetation cover were carried out, a 50 cm x 50 cm frame, divided into 25 squares, was used to estimate the cover of terricolous lichens, in conjunction with both visual estimation (I) and point intercept methods (V). The height of lichen thalli was measured using a graduated rod (∅ 1 mm) lowered vertically to the ground without penetrating into the litter and humus layer (I,V).

Where permanent quadrats (1 m x 1 m) were established to monitor the lichen cover over time (II, IV), measurements were made by photo inventory (Dietz & Steinlein, 1996; Vanha-Majamaa *et al*., 2000). For this purpose, photographs of quadrats were taken, from vertically overhead, using a tripod-mounted camera. The photographs were then automatically processed using image analysis software. In these analyses the following precautions were routinely taken in the field to minimise errors due to the nature and colour of reindeer lichen and reduce the time required to obtain high-quality data. Debris of similar colour to the reindeer lichen was cleared from the ground surface, and photographs were taken when the ground vegetation was dry to avoid moisture (*e.g.* raindrops or dew) reflecting the light and being confounded with the white colour of lichen. In addition, each series of photographs was taken when air moisture conditions were as similar as possible. Lichen was photographed when moist, where possible, since colour nuances of dry lichen are less easy to distinguish. Finally, photographs were consistently taken on overcast days since direct sunlight could have masked the contrast between reindeer lichen and the vegetation, and above all created shadows in the lichen mat that would have decreased the apparent lichen cover. For these analyses WinCAM™ (Regent Instr., 2007) was used, which enables features in images to be analysed according to colour and to group colours. It should be noted that this program provides attractive possibilities for extending previous studies. For instance, it could be used to complement lichen biomass data presented in Moen *et al*. (2007) by non-destructive methods. Biomass measurements were used to compare different methods of estimating reindeer lichen cover, including visual estimation, presence/absence and point intercepts. Comparing results obtained using these methods with estimates of cover obtained by image analysis would be very useful for large-scale inventories of reindeer lichen biomass in grazing areas.

4.3. Ethnographic fieldwork

The ethnographic fieldwork included about six months of participant observation spent, between July 2007 and July 2009, in the area of Jokkmokk (chosen because of its importance as a centre for reindeer herding communities and Sámi cultural institutions). Jokkmokk is known as a pioneering area with respect to initiating dialogue between foresters and reindeer herders (Gustavsson, 1989).

Repeated stays gave possibilities to assist (and experience to some degree) different phases of herders' work such as gathering reindeer, separations in winter, keeping reindeer in winter, checking the grazing conditions, marking yearlings and slaughtering male reindeer, as well as visiting winter grazing areas with herders during the snow-free season.

In addition to the participant observations, the fieldwork included semi-directed interviews with Sámi reindeer herders. Twenty-four herders belonging to the herding communities of Báste, Jåhkågasska, Sirges, Sörkaitum, Tuorpon and Udtja were interviewed, often with the help of field maps to support the discussions. Although most of the Sámi herders use the Sámi language as their mother tongue, the interviews were performed in Swedish, in which they are all fluent, except for Sámi words and expressions that are culturally specific.

The interviews were recorded and most of them were transcribed. This approach prevents the loss or neglect of data that initially seems to be uninformative, but later, during the progress of the fieldwork, may become highly relevant for the analysis, or raise new hypotheses. The topics discussed during the interviews were largely related to the nature and use of winter pastures, including ground lichen, herding management approaches, forestry techniques and Sámi relationships with forest companies. Forest managers from the four forestry companies based in Jokkmokk and representatives from the National Forest Agency were also interviewed on various occasions during this period.

5. Results & discussion

5.1. Gentle forest soil preparation and ground lichen re-establishment

5.1.1. Effects of gentle scarification on ground lichen

The overall objective of mechanized scarification is to increase seedling establishment after clear-cutting by improving soil and microclimatic conditions. It involves removal of the ground vegetation and exposure of humus or mineral soil in which seeds or seedlings can germinate and establish more easily. Ground lichen cover is destroyed by this process, to a degree that depends on the extent of the scarification (see section 2.1.3). There is a need, therefore, to identify soil preparation techniques, and the optimal intensities to apply them, in order to ensure both satisfactory forest regeneration and satisfactory lichen cover re-establishment.

In 2000, a field experiment was established in a *Pinus*-lichen stand, on dry soil, to evaluate the effects of gentle scarification techniques on ground lichen cover and seedling establishment (Paper I). Three different scarification techniques creating different substrates were tested using recently developed equipment, a flexible HuMinMix scarification apparatus. The scarification techniques were each applied at various intensities of soil disturbance, resulting in six treatments, including Mounding (14 and 21% of soil disturbed by intermittent mounds); Min-track (28% of soil disturbed by 0.3 m-wide tracks exposing mineral soil); Humix-track (14 and 28% of soil disturbed by 0.3 m-wide tracks consisting of mixed lichen cover, humus material and mineral soil, called *humix*), and controls (no treatment) (Fig. 3). Scarification was followed by planting 1-year-old pine seedlings at a density corresponding to 2 000 plants ha^{-1}. The scarification treatments applied in this experiment differed from conventional treatments in: the low intensity of initial soil disturbance (from 14 to 28% of ground cover); the nature of the Humix-track substrate, which does not expose exclusively mineral soil, but leaves a mixture of different materials, including reindeer lichen, on the surface; and in the fact that a single machine was used to apply all the treatments.

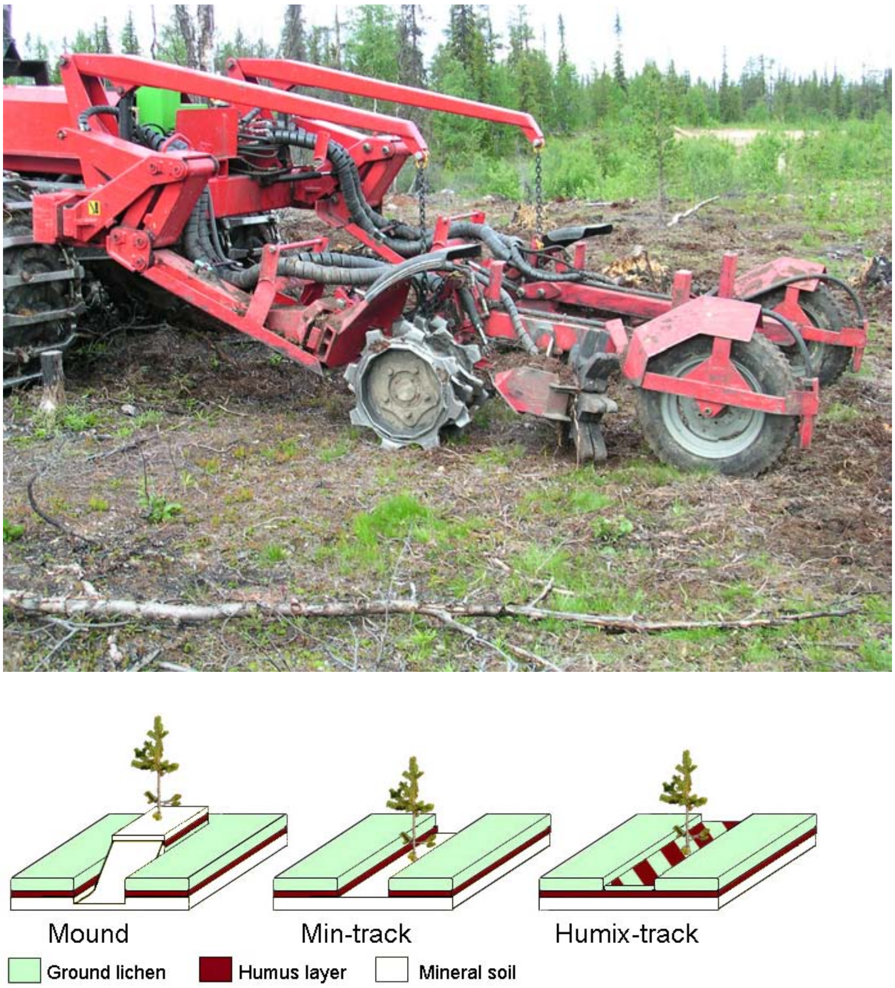

Figure 3. Different substrates created by the HuMinMix scarification apparatus in Studies I and V. Photo: U. Bergsten.

Five years after soil preparation, the ground cover in the areas disturbed by scarification was surveyed to obtain information on the effects of the scarification techniques (Fig. 4a). In control plots there was *ca*. 90% cover of ground lichen (*Cladina* and *Cladonia*) and no exposed mineral soil. By contrast, in plots where the Mounding treatment had been applied 15% of the ground cover was covered by lichen and 65% by mineral soil, due to the creation of the mounds. The ground cover in plots disturbed by the Min-track and Humix-track treatments presented intermediate values, with a significantly larger cover of ground lichen and a lower cover of mineral soil following Humix-track treatment (56% and 36%, respectively) than Min-track

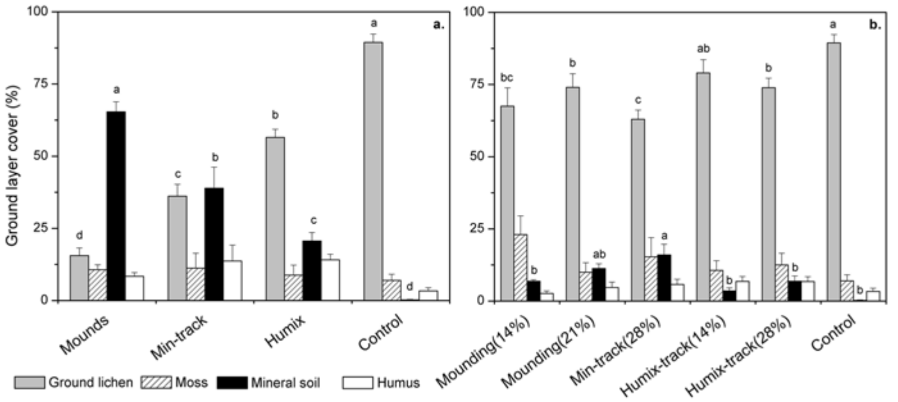

Figure 4. Mean ground layer coverage five years after soil preparation (a) in areas where the soil was disturbed by different scarification techniques resulting in the indicated substrates, and (b) weighted plot-level averages of cover observed following different techniques and different intensities of initial soil disturbance. Different letters indicate significant between-treatment differences (Tukey's test: $p \leq 0.05$). Error bars =SE.

treatment (36% and 39%, respectively). The differences between scarification techniques can be explained by the presence/absence of fragmented lichen in disturbed areas, the substrate and the micro-topography created.

Clearly by mixing the lichen mat with the upper layer of the soil, Humix-track scarification promoted lichen re-establishment in disturbed areas; since fragmentation is the main dispersal form for *Cladina* species (Honegger, 1996), the lichen mat began to regenerate immediately after this form of disturbance as observed in surveys one and two years after Humix-track scarification in Study V. Heinken (1999) reported that fragmented thalli spread rapidly by wind, within a radius of 20 cm, within only 15 days. Thus, areas disturbed by Min-track and Mounding were also probably settled by lichen fragments to some degree. However, the establishment of the lichen fragments was enhanced following the Humix-track scarification, presumably because it also created a more suitable substrate.

The results presented in Paper II highlighted the importance of the substrate for lichen displacement, since the displacement rate of lichen fragments was higher on sandy mineral soil than on coarser substrates. This was particularly obvious in an environment exposed to wind (Clear-cut) compared to a more closed one (Forest) (Fig. 5). Further, the results showed that lichen establishment was poorer on mineral soil, firstly because it provides an unstable substrate for lichen, and secondly because of its poor water-holding capacity. Other substrates, such as moss, probably created a micro-climate that could have prolonged the wet active period of thalli (*e.g.* Kershaw & Rouse, 1971; Jonsson *et al.*, 2008). In this respect, the micro-topography created by the Min-track and Humix-track treatments most likely contributed to a favourable micro-climate, by protecting lichen from too rapid desiccation by wind. In contrast, Mounding did not favour lichen establishment because it resulted in the creation of hollows about 0.3 m deep adjacent to mounds on which only mineral soil was exposed. If they fell in hollows, fragments could be periodically flooded and somewhat covered by mineral soil due to micro-erosion. But falling on mounds resulted in exposure to higher solar radiation and wind.

Results from study V corroborated the finding that re-establishment of reindeer lichen was faster in the areas scarified by Humix-track than in areas where techniques that only exposed mineral soil were applied (such as Mounding, Min-track or harrowing). According to regressions between the rates of biomass and cover re-establishment and time (V), the total recovery of the lichen mat was estimated to take about one decade after Humix-track scarification compared to probably more than five decades after harrowing exposing mineral soil (Fig. 6;V).

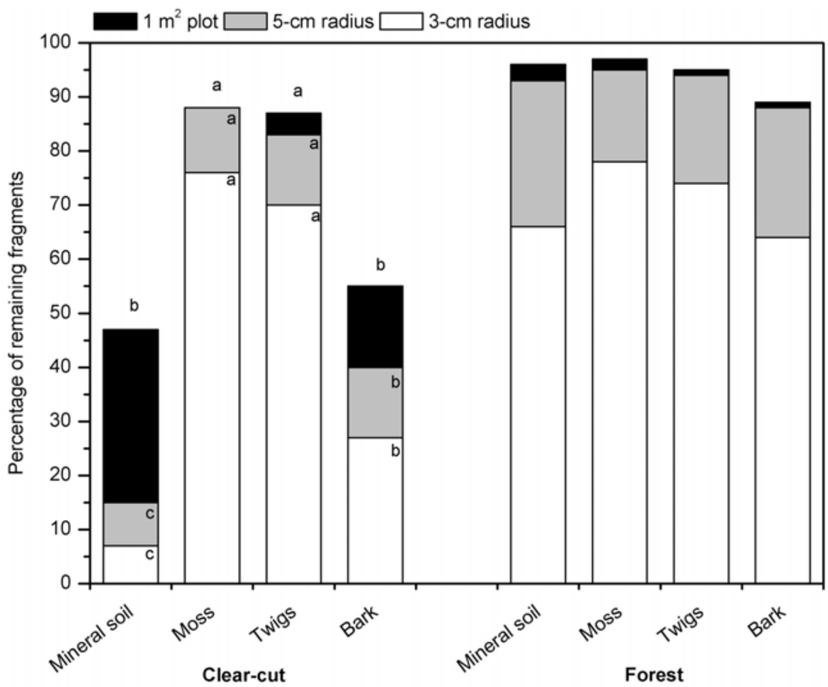

Figure 5. Immobilisation capacity of different substrates measured by the mean percentage of fragments remaining within 3-cm and 5-cm radii from their establishment points, and within 1 m^2-plots, on indicated substrates and sites one year after establishment. Different letters within columns indicate significant between-substrate differences (Tukey's test: $p \leq 0.05$).

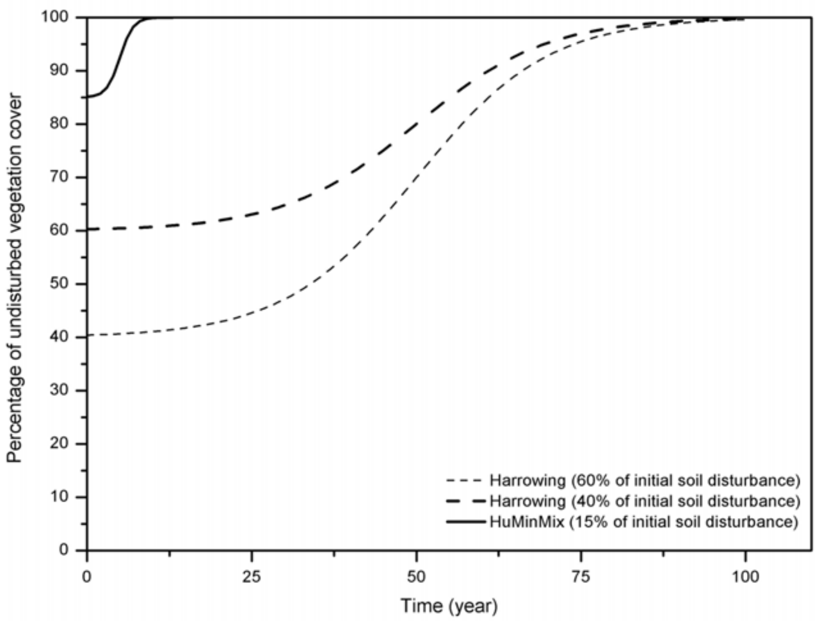

Figure 6. Theoretical re-establishment rate of reindeer lichen over time at stand level depending on the scarification technique and the initial soil disturbance. The HuMinMix-technique is assumed to create a humix-substrate.

5.1.2. Effects of gentle scarification on reindeer grazing

Paper I also presented data from a yearly inventory of reindeer droppings following each of the scarification treatments (Fig. 7). The numbers of pellet-groups recorded in experimental plots indicated that the scarification treatments had significant, but irregular, effects on the density of pellet-groups in the plots. These results can be related to the ground vegetation cover at plot scale, measured in 2005 (Fig. 4b). Significant differences between treated and control plots were detected in 2002 and 2005, when control plots (0% mineral soil exposed) were the most frequently visited by reindeer, and plots scarified by the Min-track treatment (16% mineral soil exposed) the least frequently visited. In the same years, the numbers of reindeer droppings recorded in Humix-track and Mounding plots did not significantly differ, in spite of the differences in intensities of soil disturbance and substrates created. The results suggest that high soil disturbance intensity, combined with exposure of mineral soil, affects reindeer behaviour. Exposed mineral soil has often been hypothesized by reindeer herders to deter reindeer grazing, and the results from Study I tend to support this hypothesis. However, it is difficult to tell from these data whether the decrease in reindeer lichen cover or the increase in mineral soil cover, or both, affected reindeer behaviour, and thus potentially reindeer grazing. On the other hand, the effects of snow conditions should not be ignored, or underestimated, since it is well known that snow conditions affect reindeer digging strategies (Helle, 1984; III). Assuming there were significant between-year differences in snow conditions, and similar numbers of reindeer each year (I), harsher or unfavourable snow conditions in 2002 and 2005 could very well have prompted the reindeer to spend most time in plots with more reindeer lichen, or less mineral soil, in which according to a herder: they would "*feel that it is worthwhile digging the snow*". In contrast, during winters with softer snow conditions, as they may have been in 2003 and 2004, reindeer may not be as sensitive to these variables, possibly explaining the absence of significant between-treatments differences in those years.

Previous studies have described effects of soil scarification treatments in which about 50% of the vegetation cover was disturbed with mineral soil exposed and recovery took several decades (Eriksson & Raunistola, 1990). Such treatments would heavily affect reindeer winter pastures since the initial high disturbance persists in a longer time period. In contrast, Papers I and V show that gentler scarification techniques producing humix-substrate have a low initial disturbance and promote faster reestablishment of reindeer lichen by fragmenting the lichen mat.

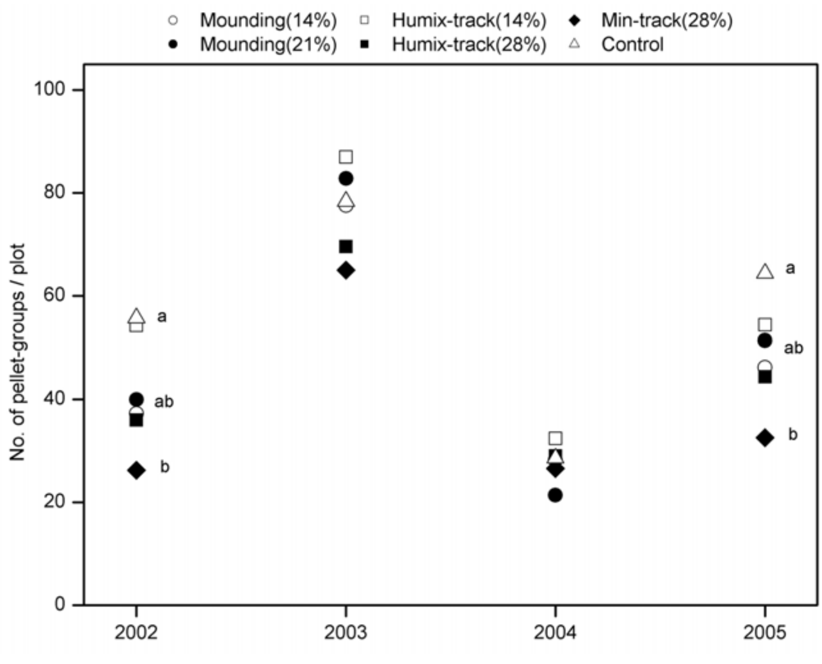

Figure 7. Mean numbers of pellet-groups per plot in which each of the indicated scarification techniques (and intensities of initial disturbances) was applied in 2000. Different letters indicate significant between-technique differences (Tukey's test: $p \leq 0.05$).

5.1.3. Seedling establishment on mixed substrates

It should be noted when considering the effects of scarification on pine regeneration that recorded mortality rates of seedlings were generally high in the field experiment presented in Paper I – 46% on average in 2005 (I) and 56% on average in 2009 (Fig. 8) (cf. Åström, 2006). However, there were significant differences in this respect between treatments. Regeneration was poorer following Humix-track scarification, compared to other techniques, six growing seasons after planting, but much higher than in control plots. Examination of the causes of damage to seedlings provided no clear reasons for this. But exposure of the mineral soil probably improved establishment conditions for seedlings, compared to the creation of humix-substrate, by fostering a soil microclimate that promoted nutrient uptake (Lundmark *et al.*, 1978; Kubin & Kemppainen, 1994), while mounding also formed a thicker fertile layer. The poor seedling survival rates observed following all tested treatments confirm reported difficulties of planting in lichen-dominated ground to reach a satisfying regeneration (Mattsson, 2002). According to the guidelines set out in the Swedish Forestry Act (SKSFS 1993:2), forest regeneration on such sites is considered satisfactory when 1100-1200 seedling ha^{-1} are present at the last time of supplementary planting, *i.e.* about ten years after planting. Seedling establishment after the Mounding and Min-track treatments showed satisfactory results in this respect nine growing seasons after planting, while it did not after Humix-track treatment (Fig. 8a). On the other hand, the poor success of planted seedling was compensated to a substantial degree by natural regeneration, which contributed more than 3200 plants ha^{-1} according to a survey in 2009, after removal of seed trees in 1991 (Fig. 8b). As an alternative to planting, direct seeding should also be mentioned here since it enables regeneration with even larger number of stems per ha, particularly on poor, lichen-rich sites (Wennström *et al.*, 1999). This could be applied

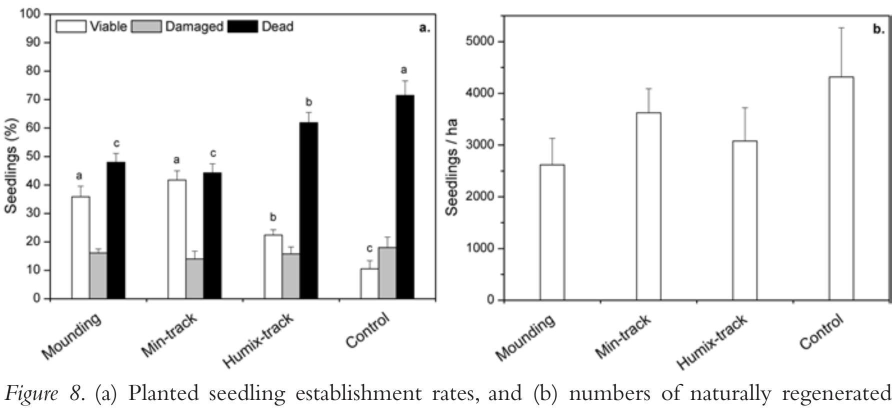

Figure 8. (a) Planted seedling establishment rates, and (b) numbers of naturally regenerated seedlings per ha nine growing seasons after application of the indicated scarification techniques. Different letters indicate significant between-treatment differences (Tukey's test: $p \leq 0.05$). Error bars =SE.

in association with gentle scarification on such sites, resulting in a substrate composed not only of mineral soil, but also lichen fragments, since lichen does not impede seed germination (Steijlen *et al.*, 1995; Wennström *et al.*, 1999).

It should be noted that rates of seedling mechanically damaged, possibly caused by reindeer trampling in winter (about 8%, I), were of similar magnitude to those recorded by Helle and Moilanen (1993). However, in terms of interactions between reindeer herding and forestry, this is a reason to avoid planting on such densely grazed areas to minimize sources of conflict and to prefer either direct seeding or natural regeneration instead (which are also much less costly options for the forest owner). In this regard, observations that removal of the lichen mat may have positive long-term effects on Scots pine growth should not be ignored neither (Macias Fauria *et al.*, 2008).

5.2. Scope for artificially dispersing reindeer lichen and restoring disturbed areas

5.2.1. Determinant factors for reindeer lichen establishment

Aspects of the restoration of reindeer lichen pastures have been considered for many years, mainly in attempts to find ways to remedy overgrazing problems (Barashkova, 1964). Like many fruticose lichen species, reindeer lichens naturally disperse by thallus fragmentation, but few studies have examined the effects of spreading lichen fragments (Christensen, 1988; Gaare & Wilmann, 1998; Polezhaev & Berkutenko, 2003), although many experiments have focused on dispersal through other propagules (see Bailey, 1976). An interesting trial, in which different terricolous lichen species were dispersed, was carried out in the second half of the 20th century (see Prof. P. Kallio's experiment mentioned in Crittenden, 2000, p. 133), but unfortunately no data acquired in the trial were published. Furthermore, no field experiments dealing with the possibilities of restoring reindeer lichen after forest soil scarification were published prior to the studies this thesis is based upon, despite its importance as a source of conflict between reindeer herding and forestry in northern Fennoscandia. In order to evaluate the feasibility of such restoration, a certain number of parameters that may influence the establishment of fragments had to be tested.

Substrate:

It is not uncommon to observe exposed mineral soil that has been barely colonized by lichen several decades after scarification, in spite of the presence of lichen in close vicinity. This long-term effect of scarification clearly illustrates that an unsuitable substrate can strongly impede lichen re-establishment. Since reindeer lichens reproduce and propagate exclusively by fragmentation (2.3.2), fragmented thalli need to find and attach to a suitable substrate before starting to grow. In this context it is noteworthy that Galløe (1954) and Webb (1998) observed that new lichen "branches" formed between internodes on the surfaces that received most insulation, and that undifferentiated thallus spread from the point of contact of older thalli with the substrate. In both cases these observations imply that fragments must first be immobilized in a stable position.

In Study II, fragments of *Cladina mitis* (Sandst.) were dispersed on different substrates in both a middle-aged forest and a former clear-cut, then the distances they had spread from their point of dispersal was measured a year later. In the clear-cut, substrates made of milled feather mosses and milled twigs of dwarf shrubs appeared to have the highest capacities to immobilise lichen fragments, since about 70% of the fragments dispersed on these substrates remained within 3 cm from their dispersal points (Fig. 5, II). Bare mineral soil (70% sand, 28% silt, 2% clay) did not favour fragments' immobilisation since only 7% of those dispersed on this substrate remained within 3 cm from their dispersal points, and only half remained within their respective 1 m^2-plots. Pine bark presented intermediate results. In the forest, no significant between-substrate differences were found. This was explained by the effect of falling litter from the trees, which probably homogenized the surfaces of initial substrates. The weaker winds in closed forests compared to those in open areas also reduce the dispersal of lichen fragments, according to Heinken (1999).

Three years after the establishment, a photo inventory was carried out, which showed that there were significant differences in lichen cover between substrates in the open clear-cut, but not in the forest. The lichen cover measured then included natural dispersal from the surrounding of the experimental plots. The moss substrate appeared to be the most efficient of the tested substrates for immobilizing lichen fragments coming from the surroundings and reaching the inner-part of the plots (Fig. 9a). In an early experiment (Fink, 1917), a similar observation was made after small fragments of *Cladonia unicialis* dispersed in a moss plot developed to normal size after only four years.

In addition, the lichen cover measured in the outer-parts of the plots showed that moss substrate also favoured the expansion of the whole lichen mat from the edges of the plots. Mineral soil also seemed to favour this expansion (Fig. 9b). Expansion of the lichen mat from the side was also observed following different scarification treatments, resulting in substrates composed of bare

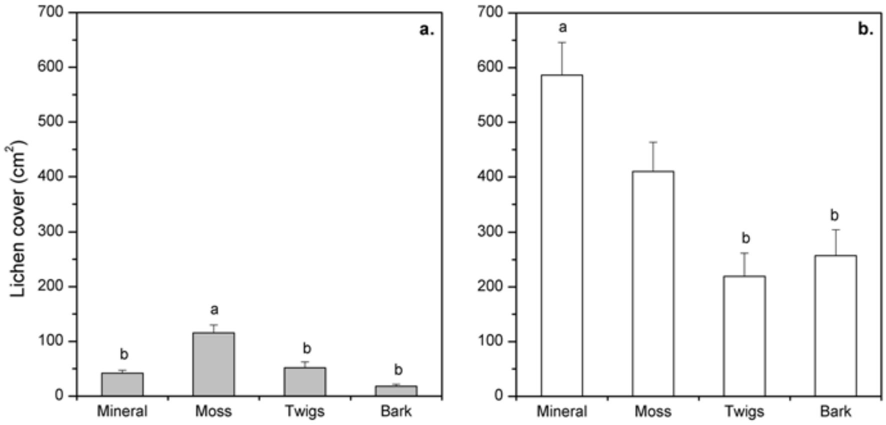

Figure 9. Mean lichen cover measured on different substrates in (a) the inner- and (b) outer-parts of the plots established in the clear-cut, three years after complete removal of vegetation cover and substrate establishment. Different letters indicate significant between-substrate differences (Tukey's test: $p \leq 0.05$). Error bars =SE.

mineral soil or humix-substrate (I). The recorded expansions on bark and twig substrates were small, even in the outer-parts of the plots, possibly because of unsuitable pH value for lichen (although this hypothesis was not tested) since it might be an important factor, *e.g.* for the establishment of epiphytic lichens on bark (Lidén & Hilmo, 2005). These results from Paper II clearly showed the importance of the substrate for lichen immobilisation and further establishment, *i.e.* when attached fragments started to grow and colonize the plots.

In addition to the capacity to immobilize lichen fragments, the water-holding capacity of a substrate is clearly of great importance since lichens are poikilohydric organisms. Their wet active time may thus be partly regulated by their immediate environment (Kershaw & Rouse, 1971; Jonsson *et al.*, 2008). A potentially important factor in this context is that dry mineral soil generally have higher albedo than vegetation cover, hence lichen fragments on this substrate will receive more radiation and be more prone to desiccation, which is likely to affect fragments of *Cladina* especially strongly since they are particularly sensitive to hydric variation. Another pertinent feature of mineral soil is that its heat conductivity will be low when dry. The temperature will generally increase much faster at the surface of sandy mineral soil exposed to solar radiation than at the surface of vegetation. This difference will have substantial effects within timeframes of hours, and the wet active time of lichen fragments lying on mineral soil will decrease accordingly. The host substrate and the microclimate are also determinant factors for epiphytic lichens (Esseen *et al.*, 1996; Esseen & Renhorn, 1998). In this respect, organic materials, such as moss, promote their establishment much more effectively than sandy mineral soil. As previously observed by Lidén *et al.* (2004) for epiphytic lichen, the creation of a microenvironment that reduces wind and desiccation at the surface of the substrate also appeared to be beneficial for isolated lichen fragments in experiments in which the effects of different scarification treatments (I) and different ground substrates (II) were examined.

Dispersal method:

The apical part of the thalli is the most exposed to drying, hence this part is most likely to fragment. This is also where most of the photobionts are concentrated and thus where the photosynthetic capacity is highest (Kärenlempi, 1971; Nash *et al.*, 1980). Little is known about the colonization rates of *Cladina* species on bare soil, although it can easily be hypothesised that it occurs by the accumulation of small individual fragments, several mm long, transported by animals, wind and (possibly) water (Bailey, 1976). Once established, the mat-forming habit of reindeer lichen gives them a competitive advantage over vascular plant (Crittenden, 1991).

In Study IV, two dispersal methods were tested, one involving translocation of intact reindeer lichen cushions to reconstitute a lichen mat and one in which fragments 0.5-5 cm long were scattered over the plots (referred as *Patch* and *Scatter*, respectively, IV). Both methods resulted in a severe decrease in lichen cover as measured by image analysis two years after dispersal. The main reason for the decrease in lichen cover was probably grazing by reindeer. After this major disturbance, lichen cover increased during the two following years at the same rate (1.79 cm^2 cm^{-2}) without significant differences either between the initial dispersal treatments, or with between the treatments and the controls (1.69 cm^2 cm^{-2}). Hyvärinen and Crittenden (1998) found that transplanted cushions of *Cladonia portentosa* (Duf.) grew more slowly a year after transplantation southwards in Great Britain, apparently due to their adaptation to higher N deposition. Transplanting reindeer lichen to sites within boreal latitudes did not seem to reduce their growth rates in the short term (IV). However, *Patch* dispersal increased the lichen cover in the plots significantly (following an important initial loss due to reindeer grazing), relative to the cover in control plots, while *Scatter* dispersal resulted in non-significant increases. The findings indicate that although the dispersal method may have an effect on lichen establishment and growth, the most important factor to take into account for artificial dispersal seems to be the effect of reindeer grazing on the dispersed lichen.

In Study II, fragments of two sizes were dispersed. The upper part of fragments of *Cladina mitis* were sectioned at 1 and 3 cm, after removing the senescent part of the thalli, and transplanted into different plots to assess the effects of fragment size on their establishment. A significant difference was found in the number of remaining fragments one year after dispersal in the (1 m^2) plots, in which 87% of 3 cm-fragments remained and 77% of 1 cm-fragments. It is possible (but impossible to discern from available data) that smaller, lighter fragments may be more easily blown (Bayfield *et al*., 1981) or larger, more ramified ones may more easily catch the wind (Christensen, 1988). However, considering the generally similar shape of fragments of both tested sizes in Study II, the larger load of water when wet, and consequently higher weight, of larger fragments may probably explain this difference. The total lichen cover in plots established in the clear-cut did not show any effect of size, which is not surprising since naturally colonizing lichen fragments of varying sizes were included in the measurements. In contrast, in the forest, where the rate of natural colonization from the surroundings was very low, the total lichen cover was significantly higher in plots where 3 cm-fragments were dispersed rather than 1 cm-fragments (II). This difference cannot be explained solely by their larger size, but most likely by litter fall covering small fragments more easily than larger ones.

The results from papers II and IV, as well as observations from paper I, showed that dispersal of reindeer lichen by fragments seems to be the most appropriate method.

Species:

According to the post-fire succession commonly described for boreal forest, reindeer lichen species are not pioneer species and mat-forming *Cladina* lichens become dominant in ultimate stages (Oksanen, 1986; Ahti & Oksanen, 1990). However, reindeer lichen establishment on mineral soil substrates has been observed in several other studies (Christensen, 1988; Boudreau & Payette, 2004a; II). Furthermore in Kallio's experiment described by Crittenden (2000), in which the initial substrate was not recorded, monocultures of non-pioneer species such as *Cladina stellaris*, *C. rangiferina* and *Stereocaulon paschale* (L.) were obtained following dispersal of crushed thalli 20 years after complete removal of vegetation. In addition, Gaare *et al*. (2003) dispersed fragments, which apparently established, of non-pioneer species in overgrazed sites. However, since reindeer lichens disperse by fragmentation and need to anchor to a suitable substrate before growing (Webb, 1998; II), it could be hypothesized that they are not the most-well adapted species to disperse after disturbances caused by soil scarification treatments that leave virtually only mineral soil. This is an important issue to address since dispersal of "alien" fragments is dependent on collection possibilities, and due to their growing habits reindeer lichens are definitely the easiest to gather.

In Study V, the diversity of lichen flora on soils disturbed by scarification, following harrowing, leaving virtually only bare mineral soil, and Humix-track treatment, leaving a mixed substrate of mineral soil and organic materials, was compared to the lichen diversity on adjacent intact ground (V). Both scarification treatments had significant effects on lichen species diversity. A significant decrease in lichen diversity was observed following harrowing, but a significant increase was observed following the Humix-track treatment (Fig. 10). In the latter, the increase in lichen diversity is typical of young intermediate stages, which are richer in term of species diversity than both very early and later stages (Helle & Aspi, 1983; Oksanen, 1986). In this respect, harrowing technique may be considered as creating conditions more similar to those of earlier succession stages than Humix-track technique does.

However, both scarification treatments had no significant effects on the occurrence of *Cladina* lichen, including *C. stellaris*, *C. arbuscula* and *C. rangiferina*, although the number of *Cladina* species was higher in Humix-track plots than in harrowed plots (Fig. 10). The lichen cover on the undisturbed surfaces was largely dominated by *Cladina* species. This probably represented an important source for dispersal of fragmented thalli that established in a relatively short period of time (V). Considering data on the abundance of *Cladina stellaris* in more detail, scarification had no significant effect on the occurrence of this species, which was found at low frequencies following all treatments (V). Results presented in Paper V support the hypothesis that fragments of *Cladina* spp., including *Cladina stellaris*, established on relatively "young" mineral soil substrate (10 years after scarification on average). Nevertheless, the changes in lichen diversity observed following both scarification treatments also indicate that the presence of other ground lichen species may be beneficial for the establishment of *Cladina* species.

5.2.2. Practical and economic issues

Harvesting reindeer lichen, especially *Cladina stellaris*, has been a common practice in Sámi society for a long time. According to Lynge (1921) reindeer lichen was collected in large quantities by Sámi people for feeding reindeer, and also by Norwegian farmers for their cattle. However, Lynge considered the farmers' practices (removing about two thirds of the lichen mat in harvested areas) to be less sustainable than those of the Sámi (who removed no more than a quarter). Such large-scale practices do not occur anymore in the Jokkmokk area. Ground lichen is occasionally collected, but rarely in large quantities. Instead, silage and pellets have become the most common fodder in case of emergency. Reindeer lichen is, however, commonly gathered in small quantities by herders who have tamed reindeer males, or to feed injured or weakened reindeer in corral.

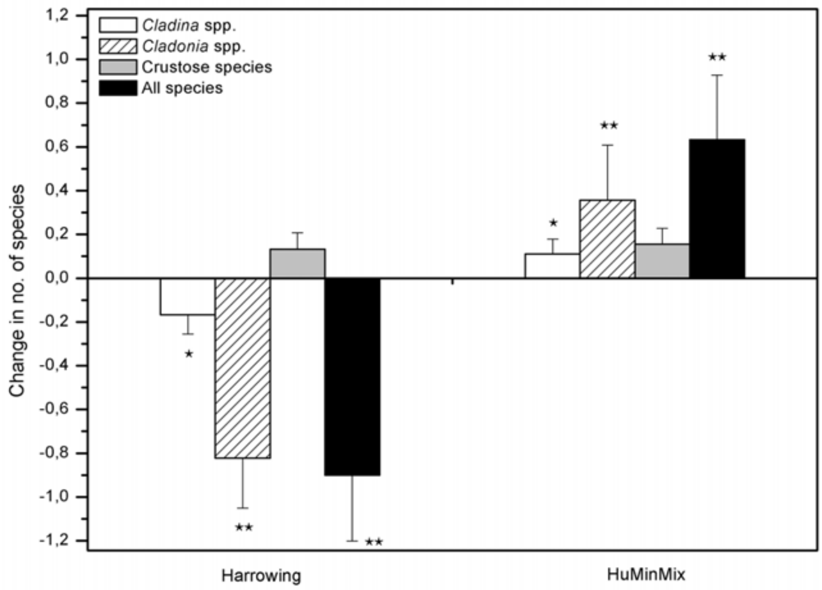

Figure 10. Change in the total number of species, and in groups of ground lichen species, in the scarified areas compared to the adjacent intact lichen-mat following the harrowing and the HuMinMix scarification treatments (Mean ± SE; ⋆ p ≤0.05; ⋆⋆ p ≤0.01).

Several papers reported the harvest of reindeer lichen for decorative or cosmetic purposes, particularly in Finland where it represents a larger "industry" south of the reindeer herding area (Llano, 1948; Kauppi, 1979; 1993; Søchting, 1984). Kauppi (1979) recommended that no more than 20% of the lichen cover should be picked in harvested area, with 5-6 years intervals between collections, to maintain good production. During the 1980s, about 1 000-1 500 tons of reindeer lichen was exported from Fennoscandia annually. In 2008, the price for a bag of lichen (60 litres) imported from Finland into northern Sweden was about 60 SEK (personal observations).

Clearly, since fresh, bare mineral soil represents a serious hindrance to lichen attachment, lichen should be dispersed a few years later (see V) or with an accompanying substrate (see II). Although it was not examined in the studies this thesis is based upon, it would also be of great interest to assess the possibility of dispersing *Cladonia* cup-lichens that reproduce by other means than fragment dispersal (see Fink, 1917; Bailey, 1976). Dispersal of fragmented reindeer lichen thalli should be preferred to translocating lichen-mats, since reindeer appear to be less strongly attracted to fragmented lichen than to entire lichen cushions (see IV). There are no doubts about the ability of fragmented or crushed lichen to survive and start to grow (Fink, 1917; Gaare & Wilmann, 1998; Polezhaev & Berkutenko, 2003; II and IV). However, there are still uncertainties regarding the best ways to increase the rate of establishment of dispersed lichen. For that reason the size and species of fragments dispersed are important factors to consider, and already established experiments in Norway and Sweden should give interesting results in these respects in a near future. A fragmentation process that detaches the fast-growing apical parts from the basal parts appears to be a potential means for increasing the relative growth rate of dispersed fragments, although this could likely lead to faster desiccation (Kytöviita & Crittenden, 2002; Gaio Oliveira *et al.*, 2006). This procedure could be applied with commonly available machinery at reasonable cost (personal observations; see also Krekula, 2007).

5.3. Sámi reindeer herding: knowledge rooted in language and culture

5.3.1. *Guohtun*, a holistic definition of pastures

Ground reindeer lichen has become a source of greatly increased concern and conflict since the widespread application of clear-cutting and mechanized scarification. Attempts have been made to harmonise forest vegetation classifications that are relevant to reindeer grazing, in order to improve the understanding of reindeer herders' needs from a forestry perspective (Skuncke, 1958; Gustavsson, 1989; Thun, 2005). The classification system used today by forest managers follows Hägglund and Lundmark (1982). According to this system, on *Pinus*-lichen stands, when terricolous lichens cover more than 25% of the ground, the ground vegetation is classified as *lichen-rich type*, and as *lichen-dominated type* when lichen cover exceeds 50%. Below this threshold, it is classified as *dwarf shrubs type*. In contrast, the prime practical characteristic of vegetation for reindeer herders is its quality as feeding resource.

Kitti *et al.* (2006) have listed a number of factors that have a direct influence on the quality of reindeer pastures in two herding communities in Finland and Sweden. They showed that vegetation is only one of many factors (*e.g.* diverse herd management, geographic, socioeconomic and climatic variables) that are considered by herders when assessing the quality of pastures. This is particularly true during winter when climate and snow properties play key roles in determining the quality of the pasture (Eriksson, 1976b; Pruitt, 1979; Kumpula & Colpaert, 2007). Identifying these factors can help attempts to understand parameters taken into account by Sámi herders when considering the suitability of land for reindeer grazing, but it will not provide understanding of their views of reindeer grazing. This can only be approached with an ethnolinguistic study.

However, as described in Paper III, in discussions with herders it became apparent that when Sámi use the Swedish word for pasture (*bete*) it has additional dimensions to those commonly ascribed to *bete* by Swedes, or 'pasture' in English. Sometimes *bete* very clearly meant the snow conditions, while on other occasions it referred to reindeer lichen with no possible doubt. This is because the word *guohtun*[3] is at the heart of herders' classification of reindeer pastures. Although it is translated as *bete* in Swedish in specialized literature (Ruong, 1964; Nielsen & Nesheim, 1979 [1932-1962]; Svonni, 1990), and by herders themselves, it embodies the interactions between snow, pastures and reindeer. Herders' definition of *guohtun* is not restricted to the presence of a suitable plant community for grazing, *e.g.* ground lichens, but it relates to the accessibility of the plant community for the reindeer under the prevailing snow and ice conditions, at different locations and at specific moments in time. For Sámi reindeer herders, the snow cover is as important as the abundance of lichen. When the reindeer cannot access the lichen through the snow, the *guohtun* disappears; there are no reindeer pastures anymore even though the ground might be covered with reindeer lichen. Therefore effective management of lichen pastures for winter grazing, *i.e.* as *guohtun*, requires understanding of herders' knowledge of snow as well as the vegetation.

5.3.2. Grazing in winter: the science of the snow

When looking at snow cover, Sámi herders pay great attention to several aspects: the depth of the snow, the different layers of snow and the "bottom", or *bodni* in Sámi (III). In the context of grazing, the *bodni* has a clear meaning: it defines the lowermost snow layer, or to be more precise, the space where the vegetation makes contact with the first layer of snow.

> The *bodni* is not the soil… Where the snow ends and the soil begins: this is the *bodni* for me. Where there is the reindeer lichen. (L. Åstot, Aug 2009)

The fundamental aspect of *bodni* is that the snow or the ice should not fasten to the vegetation or "*lock it in*". That is what happens when there is *skilži* (pieces of ice on lichen or vegetation) or *skárta* (an ice layer that encapsulates lichen or vegetation). The presence (and nature) of different layers of snow and its depth are also important aspects of snow cover, which may prevent reindeer digging, smelling the lichen, and thus accessing it. Sámi herders recognize many different categories of ice and snow, which have been previously compiled and displayed (Ruong, 1964; Jernsletten, 1997; Ryd, 2001).

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[3] The spelling of Sámi words follows the North Sámi dictionary (Svonni, 1990).

All these properties – snow depth, the formation of different layers and state of the *bodni* – depend on the first snow that falls in the winter, temperature variations, further snow accumulation and wind, which are the causes of snow metamorphism (Gray & Male, 1981).

This is well known by herders. They say for instance that *ceavvi* (a compacted, hard layer of snow) can turn to *seaŋáš* (a granular, loose layer of snow that is easy to dig) with time. Similarly when herders affirm that old forests are better for reindeer grazing compared to clear-cuts, they always imply that in clear-cuts the snow cover is different due to the absence of trees trapping the snow, *e.g.* deeper. They also add that hardening of the snow is induced by stronger winds (III). Measurements by meteorologists and forest scientists have confirmed that snow density varies with forest types (Eriksson, 1976a; Gray & Male, 1981; Ottosson-Löfvenius *et al.*, 2003). But how consistent are these observations when unpredictable and sudden climatic events occur, and what are the consequences for reindeer grazing? Far from being an inert description of different properties of snow, reindeer herders' knowledge includes a dynamic understanding of snow changes and factors that regulate the processes.

5.3.3. Snow changes and herders' use of pastures

Winters with perfect grazing conditions are rare, and there are generally frequent changes in the weather during winter, such as episodes of thawing and re-freezing, or more rare (but more dramatically) rain may fall on snow. Consequently, reindeer herders are always dependent on identifying places where "*there is* guohtun", *i.e.* places where it is possible for reindeer to access forage. By contrast to Western science, in indigenous knowledge exceptional events are not considered as aberrant observations, but as experiences that contribute to the corpus of knowledge in a similar fashion to systematic experiments. Therefore, in such empirical knowledge systems, the longer one lives, the more skilled one becomes through repeated experience of "exceptional" climatic events and consequent changes in grazing conditions in different forest types. In this respect Sámi reindeer herders' knowledge is thoroughly developed whereas academic literature has so far overlooked this aspect. Furthermore, one of the most dramatic predicted effects of global climate change in the region is an increase in frequency of such "extraordinary" phenomena (*e.g.* Moen, 2008), hence understanding their consequences for reindeer herding may become increasingly important.

Use of forest structure to adapt to snow change:

In winter, thawing-freezing induces a partial melting of snow cover that subsequently freezes when temperatures decrease again. This phenomenon can form a crust of ice, of varying thickness and hardness, and compact the snow. Another effect is that snow clears from tree crowns, resulting in water dropping from the canopy or falling in clumps. Herders have complex knowledge of the effects of these climatic events on the state of the snow and ice, which depend upon the suddenness and length of the thawing periods, temperature amplitudes, and the period in the winter when they occur. These effects can result in completely different grazing situations.

According to herders, large trees in old forests trap part of snowfalls, thereby reducing the depth of the snow on the ground. In younger stands, with only small seedlings, most of the snow accumulates on the ground, resulting in a deeper snow cover. When a strong thawing event occurs, in young stands the thick snow cover melts partially and decreases in depth, but the snow that remains freezes and turns to ice. In older stands, the thinner snow cover may completely melt, leaving the ground free from ice. Therefore when the new snow comes, herders use older stands for grazing because the younger stands are "locked in" by ice.

Conversely, a later thaw-freeze in the winter season can result in opposite effects on herders' use of the pastures. In old, mature forests, all the snow trapped in the higher canopy falls in clumps under tree crowns. This is not the case in younger stands where trees are smaller. When all the snow that has accumulated in the canopy of a dense even-aged stand melts and falls down, the snow cover is compacted over the whole stand. In such cases, reindeer herders can only use stands with low stem density, or stands in which younger trees with smaller crowns had not trapped as much snow. As illustrated with these examples, stands with certain characteristics can be used for grazing in particular conditions, but in other conditions the same stands become completely unsuitable for reindeer grazing.

"Humus thickness" and frozen bodni:

The ground vegetation also plays a key role in thawing-freezing events (III). Sámi reindeer herders generally distinguish between two main vegetation types: lichen-heath vegetation with extensive ground lichen cover, and ericaceous dwarf shrub vegetation with feather mosses and some patches of ground lichen. Sámi herders differentiate these two categories of vegetation according to the thickness of the humus when speaking in Swedish, as "*thin humus*" for the lichen-heath vegetation, and "*thick humus*" for the dwarf shrub vegetation. However, the key aspect that herders express when using these terms is whether water released from the thawing snow flows through the vegetation before re-freezing, or pools on the ground and subsequently forms an ice layer, encapsulating the lichen at the *bodni* level. According to herders, in forests with "thick humus" the water flows down through the generally thick moss layer, leaving the lichen accessible for the reindeer to graze. In contrast, in lichen-dominated vegetation, often with "thinner humus", the water soaks into the lichen mat, forming a crust of ice which freezes, and thus limits its availability as reindeer fodder.

It would be tempting to make a comparison with the widespread classification of forest ground vegetation by Hägglund and Lundmark (1982). However, in this classification the criterion used to differentiate between *lichen type* and other vegetation types is based on the percentage of lichen cover. Sámi categories, in addition to describing categories of humus thickness (which often do coincide with vegetation types), inform us about the possibility for the *bodni* and the lichen to escape freezing. Consequently, they tell us much more about the possibilities for grazing in the forest after a snow change.

The above examples of different grazing situations merely provide hints of herders' extensive knowledge of forest winter pastures. The effects of forest vegetation, including tree cover and understorey vegetation, combined with climatic variations, are fully integrated by herders when they consider the snow conditions. This knowledge, based on experience, allows herders to formulate strategies to find, in a specific snow and climatic context, the best *guohtun*. The real science of the snow of Sámi reindeer herders is in applying their knowledge to reindeer herding, in order to adapt to changing grazing conditions.

5.3.4. Strategies for grazing in a managed forest landscape

The locations of *guohtun* continuously change during the winter season, as well as it varies between years. Due to their knowledge of the nature of snow, and the influence of forest vegetation on its properties, Sámi herders can adapt to snow changes, but grazing conditions still remain subject to a large degree of uncertainty during the winter owing to the suddenness of climatic events.

To cope with this uncertainty, herders constantly consider where their reindeer should be taken to graze and make constant adjustments to short- and mid-term plans. That is why they are reluctant to provide straightforward answers when asked about the grazing conditions. This reflects constant planning and adjustments, rather than, as ignorant observers believe, a lack of knowledge. From the first snowfall until the migration back to the summer land, Sámi reindeer herders consider a multitude of factors and numerous possible scenarios to enable reindeer to feed until the end of the winter. Such considerations include where reindeer will graze if the snow conditions remain the same; which areas will be locked in by ice; which areas will remain accessible to grazing after a thaw-freeze; and how to save a pasture for later use, *etc.* This constant planning allows herders to react to rapid and unexpected changes in grazing conditions. Such anticipation would be impossible without a thorough understanding of all potential interactions between forest vegetation, snow cover and weather, which enables them to take appropriate decisions and find *guohtun* for their reindeer.

In this regard, forest management increases the degree of uncertainty regarding reindeer winter pastures. In a managed forest landscape, most of the factors that influence the *guohtun* are strongly controlled by forest management, particularly during forest regeneration. Thus, creation of these somewhat artificial forest ecosystems has been added to the already high degree of uncertainty due to natural variables. A major cause of forestry-related uncertainty is soil preparation following clear-cutting, which has highly variable (but unfavourable) effects on snow and reindeer lichen cover for many years. Reindeer herders cannot rely on land subjected to such practices when planning reindeer grazing.

For herders, grazing conditions are thus dependent on numerous interacting factors including (*inter alia*): tree density (ranging from zero in open clear-cuts to very high in dense forest), tree height (ranging from zero in clear cuts to uniformly high in mature stands), the size of trees' crowns, and the understorey vegetation (which may influence the nature of the *bodni*). One can easily contemplate the huge numbers of possible interactions and permutations involved, and hence, the huge variety of possible snow conditions and grazing alternatives. A positive aspect of this variability in snow conditions that can occur between forest stands is that it provides Sámi herders with multiple options to cope with climatic variations. In this respect, the shift in forest structure that occurred during the second half of the 20th century towards a more uniform forest landscape with removal of certain forest types (Östlund *et al.*, 1997), has reduced the number of possible snow conditions, and hence the possibilities to find *guohtun*. The decrease in pasture types (understood by herders, as discussed above, not solely as different types of vegetation but as different permutations of forest vegetation and snow cover) considerably hinders reindeer herders' management of climatic uncertainty.

Sámi reindeer herders' use their knowledge of forest vegetation for managing the grazing of their herd, and consequently have detailed understanding of the effects of forest measures on reindeer pastures. In contrast, the complex ecological consequences of disturbances caused by commercial forestry in boreal forest ecosystems during winter remain largely unknown by forest managers. Hence, for a forest management that is willing to manage the forest in ways that facilitate its use by Sámi reindeer herders, it is essential to understand the effects of their practices on winter pastures, and thus to integrate Sámi reindeer herders' knowledge in their planning.

5.4. Managing reindeer lichen: towards social and ecological engineering

From the studies presented in this thesis and current literature, it is possible to outline several strategies to manage reindeer lichen for grazing purposes in *Pinus*-lichen forests, *i.e.* (i) to minimize disturbance of the existing lichen mat, (ii) to foster suitable conditions for the growth of reindeer lichen, and (iii) to enable access to pasture for reindeer in winter.

For these purposes, it is necessary to consider dry and mesic soils separately. Both types of soil can generally support (to varying degrees) high lichen cover (Ebeling, 1978) and are almost always capable of providing important grazing land for herders. It is also necessary to consider the ground vegetation, not solely in terms of the proportion of lichen cover (see Hägglund & Lundmark, 1982), but also according to the quality attributed to different vegetation categories by Sámi reindeer herders themselves (see section 5.3). For simplicity, "thin humus" will refer here to soil supporting frequently grazed vegetation that is dominated by reindeer lichen and sensitive to ice formation, while "thick humus" will refer to soil supporting less frequently grazed vegetation with lower cover of reindeer lichen and larger cover of moss and dwarf-shrubs, but above all that is much less sensitive to ice formation (III).

The use of the land by reindeer herders should also be considered. Certain forests may be essential grazing areas for a winter-group, while other grazing lands may be less often used owing to some adverse factor. The "Land Use Plans for Reindeer Husbandry", drafted by reindeer herders, provide indications about the areas used for grazing (Sandström *et al.*, 2003), which can give some indications to non-herders, *e.g.* forest managers.

The options for managing reindeer lichen should be considered according to possible current regeneration practices (Fig. 11). In all cases, rapid forest regeneration should be ensured because it minimizes the risk of snow being hardened by the wind and potentially reduces snow accumulation on the ground. Abiotic variables, notably light conditions and moisture levels, should also be considered when deciding subsequent stand management measures, *e.g.* pre-commercial thinning and thinning. Too high tree density and consequent canopy enclosure favour moss at the expense of reindeer lichen (Sulyma & Coxson, 2001). In this respect Jonsson Čabrajic (2009) recommended a canopy cover <60%, or basal tree areas <15 m^2 ha^{-1}. Such density is far too low for commercial forestry to be systematically applied. On the other hand this could be targeted through an early timber stocking close to such density to promote lichen growth, during the 10-20 years before final felling for instance.

- Natural regeneration enables the regeneration of stands without disturbing ground vegetation cover, when harvested in winter, and thus leaves ground lichens largely intact. A possible mistake from both lichen cover and tree regeneration perspectives, especially on dry sites, may be to apply conventional scarification under seed trees, since the consequent risks of moisture deficits in the soil can lead to regeneration failure in the scarified areas. Then the disturbance to the lichen mat is totally unjustified.

- Direct seeding after gentle scarification with microsite preparation has a short-term, low impact on ground lichen cover (cf I). This can be a successful means to regenerate *Pinus*-lichen stands on both dry and mesic sites (Winsa & Bergsten, 1994).

- Planting after mounding is a more expensive forest regeneration method than direct seeding and natural regeneration. In stands with high grazing pressures, such as those in areas essential for grazing, risks of damage due to trampling could potentially increase these costs. Regarding lichen cover, mounding does not promote rapid lichen re-establishment (I).

- Prescribed burning on sites where understorey vegetation begins to be dominated by late successional species, such as feather mosses and *Empetrum nigrum*, can remove the moss and humus layer and promote lichen re-colonization in stand in the long-term. It may also promote soil processes that enhance site productivity and, thus, tree growth (Nilsson & Wardle, 2005).

- Clear-cutting has varying effects on lichen cover depending on soil types. It may decrease competition with vascular plants on dry sites, but increase it on mesic soil (2.1.2). However, it is accompanied by the inconvenience of reducing access to lichen under harder and deeper snow cover (III). Timber stocking could be applied before clear-cutting to reduce the effects of clear-cutting on snow and promote lichen growth during some decades.

- Continuous cover forestry involves no clear-felling of areas >0.25 ha, instead felling of scattered single trees or group of trees (Pommerening & Murphy, 2004; Axelsson, 2008). One possibility is to apply partial cutting, *e.g.* in chequered gap-shelterwood patterns, which allows regeneration by planting or direct seeding in the gaps (Erefur, 2007; Steen *et al.*, 2007). Other options are to use various selection-felling systems, in which trees are harvested without any clearcutting and (hence) planted or naturally regenerated seedlings establish under shelterwood (Fries *et al.*, 1997; Nilsson *et al.*, 2002; Strand *et al.*, 2006). Both techniques present interesting results; increasing lichen cover (Steen *et al.*, 2007; Coxson & Marsh, 2001), and above all creating potentially more favourable snow conditions by producing multi-layered uneven-aged forest stands. Unfortunately, however, there are only few studies regarding forest regeneration under continuous tree cover due to the high-yielding clear-cut orientation of Swedish forestry since the 1950s (see section 2.1.1).

- Artificial dispersal of lichen may be a suitable method to restore areas that have been locally disturbed by mounding or harrowing (V). It may need to be accompanied by the creation of a suitable substrate for the lichen to establish on (II). Gentle scarification procedures, such as Humix-track, enable some dispersal of reindeer lichen in disturbed areas during the soil preparation itself (I, V), and creates a suitable substrate for natural lichen spreading from surroundings. On dry sites, this could even increase the lichen cover by removing vascular plants from the tracks and disperse lichen into them. Lichen dispersal following overgrazing and burning may also provide a means to assist lichen colonization, especially on dry soils where there is only weak competition from pioneer vascular plants (Polezhaev & Berkutenko, 2003).

In northern Sweden, all of the large forest companies are now certified by the Forest Stewardship Council, which obliges them to "*give consideration to the Sámi people's reindeer husbandry*" (FSC, 1998, p. 9). The main effect of certification by the Forest Stewardship Council has been to increase the numbers of consultations of reindeer herders by forest companies. Communication and dialogue between forestry managers and Sámi herders have increased in prominence and importance in recent years (Sandström & Widmark, 2007). Even though the influence of reindeer herders remains uncertain, forest regeneration and soil preparation are frequently discussed. The results presented in this thesis could be used by forest managers and Sámi reindeer herders as a basis for discussing possible strategies to manage reindeer lichen and forest regeneration jointly (Fig. 11).

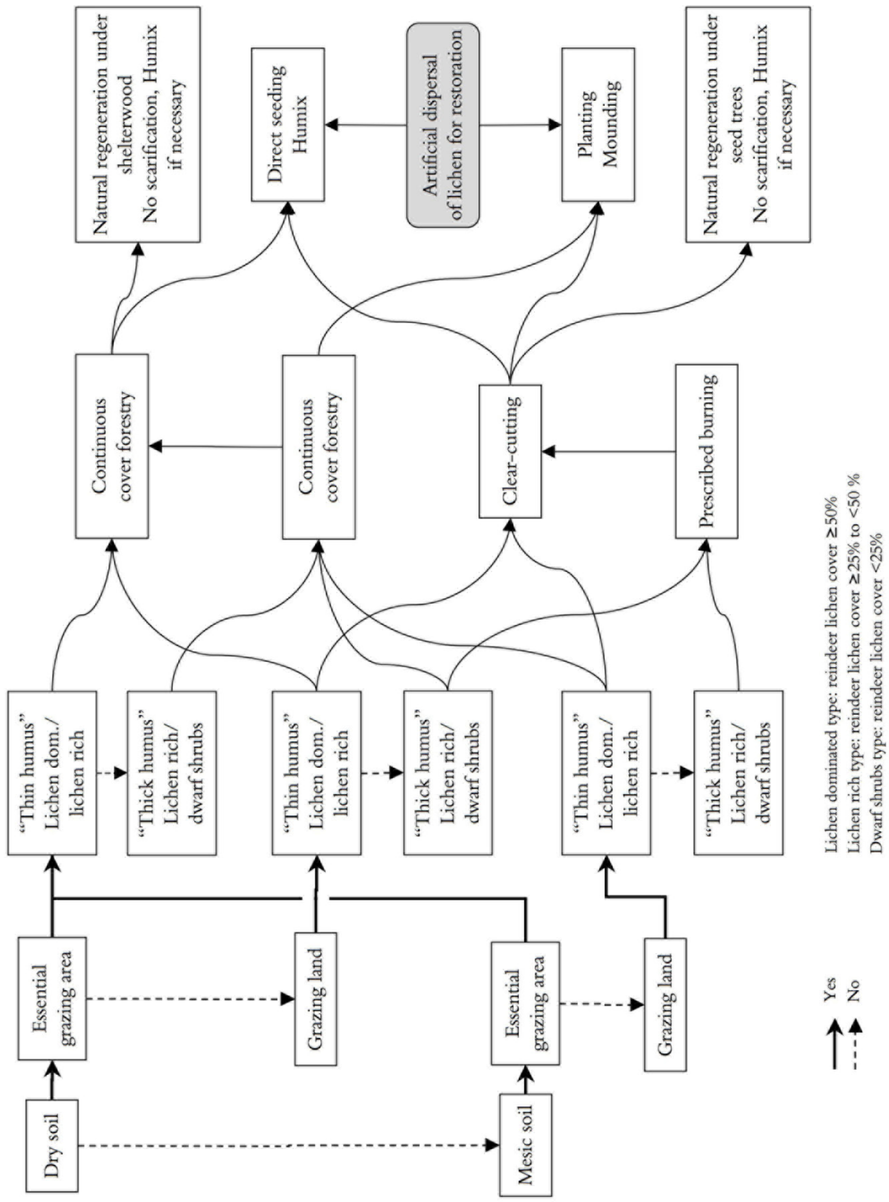

Figure. 11. Proposed guidelines for regenerating *Pinus*-lichen forest stands, including management of reindeer lichen, *i.e.* minimizing effects on lichen cover and hindrance to reindeer grazing, as well as possible restoration measures. These guidelines are intended to provide a basis for forestry planning or for consultation procedures between Sámi reindeer herders and forest managers prior to final logging and regeneration.

6. Conclusions

6.1 Major findings

The following conclusions can be drawn from the studies this thesis is based upon.

(1) Gentle soil scarification methods, such as using the HuMinMix-technique to produce Humix-substrate, reduce the disturbance to lichen cover and promote rapid re-establishment of *Cladina* lichens in the disturbed soil. The time required for complete re-establishment of the lichen mat following scarification can be reduced to about one decade by using HuMinMix techniques, instead of probably more than five decades following conventional harrowing. Both degree of initial soil/lichen disturbance and lichen re-establishment rate must be considered when estimating effects of scarification on lichen loss over time.

(2) Soil preparation, even with relatively low intensity soil disturbance, tends to affect reindeer behaviour during winter grazing, and the risk of possible damage to seedlings by reindeer indicates a clear need for regeneration methods at intensively grazed areas that provide high seedling densities, *e.g.* natural regeneration or direct seeding, which can be applied following gentle soil scarification.

(3) Dispersed fragments of *Cladina* lichen can readily establish following soil disturbances and in intact vegetation. Thus, artificial dispersal of reindeer lichen provides a potential means for restoring areas disturbed by, for instance, conventional soil preparation techniques. The dispersal of fragmented lichen thalli has advantages over the transplantation of intact lichen cushions, since they are less likely to be grazed by reindeer before they have established and re-formed a mat. To improve the immobilization and growing conditions of lichen fragments, the dispersal should be accompanied by adding organic material, *e.g.* fragmented feather mosses, when carried out on a substrate of pure sandy mineral soil.

(4) Sámi herders' understanding of winter pastures includes knowledge of the effects of snow on reindeer grazing, in addition to the presence and abundance of ground reindeer lichen. This is embedded in Sámi culture and language, as shown by the word *guohtun*, translated as 'pasture', but incorporating the possibility for reindeer to access pasture under the snow cover. Sámi herders' knowledge about winter pastures encompasses understanding of the interactions between forest vegetation and snow conditions for reindeer

grazing. They use this knowledge to face climatic uncertainty during winter and to plan reindeer grazing accordingly.

The work presented in this thesis demonstrates that the development of effective forest management strategies to ensure satisfactory maintenance of reindeer lichen (*Cladina* spp.) resources for reindeer grazing, together with adequate forest regeneration, requires the integrated application of knowledge of all the pertinent forestry, ecological and anthropological (social and cultural) dimensions, as well as indigenous Sámi knowledge. Thus, further research to deal with the complex issues related to reindeer forest pastures should have an interdisciplinary approach and include an ethnoscientific research.

6.2 Needs for further research

Artificial dispersal appears to be a potential means to re-establish reindeer lichen in disturbed areas. It could also be applied to areas where the vegetation cover (especially the lichen) and/or soil has been heavily damaged by overgrazing or radical degradation by activities such as mining, or to accelerate the re-establishment of lichen cover following forest fire or prescribed burning on dry sites. For such large-scale strategies to succeed further research is needed to improve the establishment of dispersed fragments and thus the cost effectiveness of dispersing them. To do this, several practical questions regarding the optimum methods of collecting, fragmenting and dispersing large quantities of reindeer lichen need to be addressed. The optimal methods to create a suitable substrate for large-scale dispersal, especially on damaged ground in quarries, also need to be identified. Whether reindeer lichen should be dispersed after pioneer species have naturally colonized the substrate, or the establishment process should be accelerated by first dispersing pioneer species could also be considered. The dispersal pattern is also an important topic to examine. Establishing sources from which the lichen could disperse under the action of wind or other factors may be preferable to uniform dispersal over the area to be restored. Finally, the scope for improving artificial dispersal by the creation of a suitable micro-climate, *e.g.* by planting vascular plants, should be studied since the micro-site conditions appear to strongly affect the immobilization, establishment and growth of lichen fragments.

The herders' understanding of *guohtun* introduces a holistic perspective by incorporating the effects of the depth and nature of snow cover on reindeer grazing in addition to the nature of the vegetation. This should be further considered in forest management strategies. Therefore, there is a need to develop alternatives to current forest management practices, based almost exclusively on high-yielding clear-cuts. Developing strategies that can deliver satisfactory forest regeneration under shelterwoods or in continuous cover forestry systems is a challenge for forestry researchers. For reindeer herding, an additional positive effect of continuous tree cover would be to create conditions that promote the establishment of epiphytic lichen, which represent an essential grazing alternative when snow locks in the ground pasture. The areas required for grazing would consequently decrease. Developing forest management strategies that avoid clear-cutting large areas could provide compromises that would be favourable not only to reindeer herding, but also to biodiversity, while allowing the maintenance of satisfactory levels of wood production.

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Figurehead. Thanks to Ulla Nylander for laying out the thesis.

Fishing rod. I would like to warmly thank Elsa, Morgan and family, for their hospitality on many occasions.

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Navigation. To helping avoid linguistic hazards, Sees-Editing Ltd. corrected the written English.

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