Contested Landscapes:

social-ecological interactions between forestry and reindeer husbandry

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"Times change. Would you call this age a good one for unicorns?"

"No, but I wonder if any man before us ever thought his age a good one for unicorns."

P.S. Beagle: *The last unicorn*

Table of Contents

List of papers

This thesis is based on the following four studies, which are referred to in the text by their respective Roman numerals:

I. **Horstkotte T**, Sandström C, Moen J: Exploring the multiple use of boreal landscapes: the importance of social-ecological diversity for mobility and flexibility. *Submitted manuscript*.

II. **Horstkotte T**, Roturier S 2013: Does forest stand structure impact the dynamics of snow on winter grazing grounds of reindeer (*Rangifer t. tarandus*)?
Forest Ecology and Management. **291**: 162–171.

III. **Horstkotte T**, Moen J, Lämås T, Helle T 2011: The Legacy of Logging—Estimating Arboreal Lichen Occurrence in a Boreal Multiple-Use Landscape on a Two Century Scale.
PLoS ONE **6**: e28779. doi:10.1371/journal.pone.0028779.

IV. **Horstkotte T**, Lind T, Moen J: Contested boreal landscapes – consequences of different forest management priorities. *Submitted manuscript*.

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Author contributions

Paper I

TH and JM planned the study. TH, JM and CS performed the interview. TH analyzed the data and wrote the manuscript. JM and CS contributed with comments and text to writing.

Paper II

TH and SR planned and designed the study. TH carried out fieldwork, analyzed the data and wrote the paper. SR contributed with discussions, comments and text to writing.

Paper III

TH, JM and TiHe conceived and planned the study. TH and TiHe conducted field work. TH analyzed the data, TL did the modeling work. TH wrote the paper with all co-authors contributing with comments and text to writing.

Paper IV

TH and JM conceived the study. ToLi carried out the modeling. TH analyzed the data and wrote the paper. JM and ToLi contributed with comments and text to writing.

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1. Background

A framework of social-ecological resilience for multiple-use landscapes

Human choices and actions shape the natural environment according to societal values, needs and desires. Likewise, environmental changes may create new values, needs and desires in people. Nature and people are, therefore, closely coupled in a so called social-ecological system, which involves diverse interdependent feedbacks between the two components (Berkes & Folke 1998, Holling 2001). Such interactions keep the environment and society in a state of constant and dynamic change along a continuum of spatial and temporal scales, ranging from small and fast changes to large and gradual ones. The novel conditions that changes can cause may lead to questioning of current knowledge (Adam & Groves 2007), and can therefore create opportunities, as well as challenges for the social-ecological system.

Coping strategies are often adopted in order to minimize the negative effects of changes at small temporal and spatial scales. To persist successfully during long-term changes however, continuous adaptations are necessary. Herein, diversity that provides a wealth of options to choose from is a major source of flexibility, and thus enhances the resilience of any system to changes (Chapin *et al.* 2009). If a system consists of diverse components that are able to interact so that the system can adapt to changing conditions, it can be described as a complex adaptive system (Levin 1998, Chapin *et al.* 2009).

Social-ecological resilience is, therefore, an essential characteristic enabling a system to withstand shocks and disturbances, and to continue to maintain its functions and identity (Holling & Meffe 1996, Folke 2006). Furthermore, resilient social-ecological systems have the ability to find innovative solutions when disturbances and change create novel conditions. The potential for finding these solutions, as well as implementing decisions to take action and learn to live with uncertainties, constitutes the adaptive capacity of a social-ecological system (Nelson *et al.* 2007, Plummer & Armitage 2010). A low adaptive capacity may increase the vulnerability of a social-ecological system, i.e. the likelihood that changes inflict damage on the system, and the magnitude of these (Turner *et al*. 2003, Adger 2006). This is especially true if changes push conditions beyond the boundaries of social-ecological variations that have been experienced before, because this can create conditions with unforeseen and unknown consequences.

Box 1 summarizes the important concepts that address a system's characteristics and behavior during change.

Box 1: A systems characteristics in the face of change

- **Adaptive capacity**: The ability of a system to find solutions to disturbances or shocks, implementing decisions and learning to live with uncertainties (Nelson *et al.* 2007, Plummer & Armitage 2010).
- **Complex adaptive system:** A system whose diverse and individual components interact, so that the system adapts to changing conditions (Levin 1998, Chapin *et al.* 2009).
- **Resilience**: The capacity of a system to respond to and shape change and still retain its function and identity (Holling 2001, Folke 2006, Chapin *et al.* 2009).
- **Vulnerability**: The degree to which a system is likely to experience harm due to exposure to stressors, depending on the state of the system in relation to a tipping point. Transgressing a tipping point leads to a sudden change in the system (Turner *et al.* 2003, Adger 2006, Eakin & Luers 2006).

To prevent undesired shifts to new circumstances, many strategies for natural resource management have aimed to minimize variation in environmental conditions. Their objective is to maintain predictability of resources in order to minimize fluctuations, e.g. in harvest rates (Holling 2000). The focus of such steady-state resource management falls on control of not more than a few selected ecosystem processes. However, many natural resources represent the livelihood of a wide variety of users. Contrasting values, needs and aims with respect to the management and use of a single set of resources are therefore neither unlikely nor inevitable. Given such a multiple use situation, trade-offs between the resource users are required to balance their diverse needs and resolve conflicts (Lane & McDonald 2002, Lambin & Meyfroidt 2010). This is indispensable to ensure the sustainability of the shared resources by minimizing adverse impacts on each user and on the environmental conditions: another layer of interactions is added to the social-ecological dynamics. Both change and trade-offs between commercial management of natural resources on the one hand and social, cultural and biological values on the other need to be navigated simultaneously (Hytönen 1995, Wiens 2009).

Where different actors are using a single set of resources, the implementation of property rights can regulate the use of and relationship between natural resources and different users (Dietz *et al.* 2003). These rights can act as institutions, i.e. rules that can be applied when it is necessary to respond to changes in natural resources. Particularly vulnerable are common-pool resources, which can be threatened by overuse and degradation because exclusion of potential users is costly or impossible. Therefore, institutions need to regulate the use of common-pool resources in order to keep the system flexible in the face of changes. Only when explicit and context-specific rules are followed by users and collective decision-making is facilitated can the use of renewable resources be sustainable over the long term (Schlager & Ostrom 1992, Ostrom 2007). Trust between users, the recognition of each other's rights and acceptance of responsibility as well as obligations are essential for the enforcement of well-established property rights (Tole 2010). When the scope and the aims of natural resource management increasingly diverge for the various stakeholders, mutual management of the contested resources becomes more and more difficult. This is especially true in situations where property rights or usufructuary rights are unequally allocated between the parties involved (Dietz *et al.* 2003, Ostrom 2007). When designing strategies for multiple use, Mitchell (2003) points out the importance of power distribution between actors and the ability to shape a landscape whilst taking account of all the stakeholders' interests.

In particular, unbalanced distribution of power in decision-making processes and ownership structures has adversely affected discourses between indigenous peoples and nation states about the management of natural resources (Hibbard *et al.* 2008). To safeguard the survival of the diverse range of indigenous peoples with their specific cultures, including traditions, languages, practices, customs and world views, it is essential to preserve their traditional lands and grant them access to and control of the land and its resources (Wiessner 2011). Rights to land and water, as well as political autonomy and the right to self-determination, have been identified as key aspects that can reduce indigenous vulnerability (Axelsson & Sköld 2006, Lane 2006). One reason for this is the importance of a connection to the land and a "sense of place" in the culture and identity of many indigenous societies, because an attachment to the land enables indigenous peoples to practice resource management that is in accordance with their own moral codes of social-ecological relationships (Davidson-Hunt & Berkes 2003, Berkes 2012, Chapin *et al.* 2012). Political autonomy and cultural self-determination are, therefore, anchored in the sovereignty of natural resources.

Because indigenous claims to land and natural resources have the potential to create conflict with other state interests from political, legal and moral aspects, a different relationship between indigenous peoples and the state compared to other citizens may be required so that the relationship between these actors can be reconciled (Allard 2006). However, Lane (2006) argues that in western post-settler states, where the descendants of former colonizers now form the ‘‘nation’’, the primary challenge of resource sharing is less a problem of supporting indigenous rights and self-determination, but rather the reasonable and realistic way of allocating resources between different claimants in landscape planning and administrative processes. Planning considers not only trade-offs between the interests of different actors, but also between costs and benefits in the long and short term. Yaffee (1997) identified five “nightmares” in decision making that may lead to poor management of natural resources; these include prioritizing short-term goals over long term sustainability and the fragmentation of interest and values, as well as of responsibilities and authorities.

Creating resilient multiple-use landscapes in both social and ecological terms is, therefore, a major task on various spatial, temporal and administrative scales, if diverse human livelihoods with their inherent values are to be sustained by intact ecosystems (Christensen *et al.* 1996, Meffe *et al.* 2002, Millennium Ecosystem Assessment 2005). It is these social-ecological dynamics of contested multiple-use landscapes that form the heart of this thesis.

Multiple use in boreal forests – common land, shared history, different preferences

Forest ecosystems worldwide are particular illustrative examples for social-ecological systems involving multiple uses by a diversity of stakeholders (Bengston 1994, Moen & Keskitalo 2010, Guariguata *et al.* 2012). Forests and the patterns by which they characterize the landscape have been shaped mainly by management practices aimed at increasing timber production. However, the focus on this single provisioning ecosystem service has often lead to substantial changes and simplifications with respect to forest structure, function and biodiversity (Esseen *et al.* 1997, Kuuvulainen 2002, Lambin & Meyfroidt 2010). Forestry that takes an agricultural view of timber production therefore limits the capacity of a forest to act as a complex adaptive system (Puettmann *et al.* 2009).

As a consequence of the simplification of forest ecosystems, living conditions for wildlife and the subsistence livelihoods of resident native peoples have been altered. From an indigenous perspective, forest ecosystems are a “cultural landscape” where native people undertake their daily landscape practices. The transformation of forests therefore challenges indigenous people’s capacity to adapt to rapidly changing conditions (Parlee *et al.* 2005, O'Flaherty *et al.* 2008, Vuojala-Magga *et al.* 2010). These modifications may reduce the ability of forests to provide non-timber forest products, including wildlife and wild plants for subsistence (Ticktin 2004, Guariguata *et al.* 2010).

In northern Sweden, reindeer (*Rangifer t. tarandus*) husbandry is practiced by the indigenous Sámi people[1]. Northern Sweden is a part of Sápmi, the homeland of the Sámi people, which covers the northern parts of Norway, Sweden, Finland and the Kola Peninsula in Russia (fig. 1). The Swedish Reindeer Husbandry Act (1971) gives the Sámi the usufructuary right to "use the land and water for maintenance for themselves and their reindeer" (Reindeer Husbandry Act 1971:§1). These customary rights are based on the undisturbed use of a specific land and its resources since time immemorial ("urminnes hävd") (Allard 2006), but the Sámi do not own the land. The reindeer husbandry area covers approximately 52 % of Sweden and is subdivided into 51 herding districts. A herding district (*sameby*) is an economic and administrative association that represents the interests of its members over a delimited geographic area (www.sametinget.se). Reindeer husbandry today is practiced as an extensive form of land use, focused on meat production and dependent on access to large grazing grounds. In most herding districts, a migratory husbandry system is practiced between the summer grazing grounds in the Scandinavian mountains on the border with Norway and the winter grazing grounds in the forest lowlands east of the mountains (Box 2). Some districts, however, use the forest for year round grazing.

[1] Sweden recognized the Sámi as an indigenous people in 1977.

Box 2: Characterization of a herding year in a migratory district

The herding year, reflecting the distinct seasonality of northern Sweden, begins with the birth of reindeer calves in May. Summer is spent grazing freely in the mountains, where reindeer selectively feed on highly palatable good quality forage, such as herbs, shrubs and grasses, to maximize their growth and build up reserves for the winter (Eskelinen & Oksanen 2006, Moen *et al.* 2006). After mid-summer, reindeer herds are gathered for individual ear-marking of the calves by their respective owners. Towards autumn, selected reindeer bulls are slaughtered before the beginning of the rutting season. In late November, the herds are gathered and spilt up into smaller winter groups (*siidas*) cared for by a varying number of families that share the effort of herding the reindeer during the winter, when herding is more intensive than during summer. The winter grazing grounds are reached either by migration on foot or the animals are transported in trucks. During winter, reindeer primarily forage on terrestrial lichens (*Cladonia* spp., *Cetraria* spp.) in dry, oligotrophic pine forests. Lichen availability and the impact of snow cover on reindeer foraging are critical variables during the winter (Helle 1984, Kumpula & Colpaert 2007). If snow conditions hinder reindeer digging, e.g. due to hard snow or ice crusts, the availability of arboreal lichens, such as *Bryoria fuscescens* and *Alectoria sarmentosa* is essential for survival (Rominger *et al.* 1996, Helle & Jaakkola 2008). The availability of winter grazing grounds, therefore, constitutes the critical bottleneck in the herding year, because they strongly impact winter survival and calving success of reindeer (Kumpula & Colpaert 2003, Helle & Kojola 2008). Around March, migration or transportation starts back to the calving grounds.

Reindeer husbandry has been practiced since at least the 17th century, although at that time it took a different form than it does today (Lundmark 1982). Since then, reindeer husbandry has adapted to changes in social and ecological drivers (Helle & Jaakkola 2008, Moen & Keskitalo 2010). These have influenced the settings in which transhumance, a rotational grazing practice, is conducted. Despite the many adaptations and transformations that reindeer husbandry has gone through, it remains a keystone in the Sámi culture, though it is practiced by only a small percentage of the Sámi population as an exclusive source of income (SSR 2012). The population of reindeer in Sweden underwent considerable fluctuations during the 20th century, though the long term average numbers have been quite stable at 225 000 animals (Moen & Danell 2003).

From the early 20th century onwards, river damming for the generation of hydroelectric power, mining operations, wind farms and especially forestry all have become more common and have changed the landscape used for reindeer husbandry (Berg *et al.* 2008, Helle & Jaakkola 2008, Össbo & Lantto 2012). These cumulative pressures have resulted in losses of particularly important landscape elements, such as migration routes between summer and winter pastures, good calving grounds or winter pastures with usually favorable snow conditions. The silvicultural intensification that accompanied the introduction of clear-cutting in the 1950s, and made mandatory by the Forestry Act of 1979, along with a focus on increasing the profitability of timber production, has decreased ecological variation in boreal forests within forest stands, leading to a preponderance of even-aged monocultures. In contrast, heterogeneity has increased at a landscape scale, characterized by a mosaic of highly fragmented forest stands of different age classes. Importantly, the extent of continuous old-growth forests, rich in biodiversity, has been greatly reduced (Esseen *et al.* 1997, Kuuvulainen 2002).

This intensification of silvicultural methods has led to a decrease in the abundance of terrestrial and arboreal lichens and thus has reduced the carrying capacity of winter grazing grounds for reindeer (Kivinen *et al.* 2010). For instance, the area of forests classified as rich in terrestrial lichens has decreased by about 50 % during the last 50 years (Sandström *et al.* 2006).

Furthermore, harvesting strategies have changed the structure of forest stands from mainly multi-layered canopies to a dominance of single-layered monocultures with trees of similar age classes. Due to the impact of the forest canopy, e.g. its effect on regulating the through-fall of precipitation and the radiation regime, snow accumulation and properties on the ground can be expected to differ between forests with different canopy characteristics and open areas, such as clear cuts (Gelfan *et al.* 2004, Talbot *et al.* 2006). This may have consequences for the foraging efficiency of reindeer when they dig for terrestrial lichens through the snow cover. In combination with timing and duration, the physical characteristics of the snow cover, i.e. depth and hardness, are important variables that impact the foraging of reindeer by affecting lichen availability (Helle 1984, Skogland 1978, Nellemann 1996). Deep and/or hard snow, e.g. as a result of climatic drivers such as freeze-thaw cycles (Bartsch *et al.* 2011) or rain-on-snow (Putkonen & Roe 2003, Hansen *et al.* 2011) can make it difficult for the reindeer to dig for terrestrial lichens. In these situations, the availability of arboreal lichens (*Alectoria sarmentosa, Bryoria fuscescens*) is an important asset that allows the herding system to remain resilient to the challenges of reduced forage accessibility. Historically, arboreal lichens could support reindeer herds during years of adverse snow conditions (Helle & Jaakkola 2008). A past herding strategy was, therefore, to cut down trees rich in arboreal lichens to provide forage for starving reindeer and to keep the herds together (Berg *et al*. 2011). However, as old-growth forests with abundant arboreal lichens have become significantly less common in northern Sweden, the resultant decrease in the abundance of arboreal lichens has resulted in an increased need for supplementary feeding and/or a reduction in herd sizes (Helle & Saastamoinen 1979).

Historical landscape transformations create “path dependency”, i.e. future options and changes depend on decisions taken both in the past and at present. As consequence of landscape transformations and a decrease in essential grazing resources, the adaptive capacity of reindeer husbandry and its resilience to disturbances, e.g. extreme winter events, have diminished (Danell 2005).

2. Aims of the thesis

Building on this brief historical overview, I describe and analyze the interactions between reindeer husbandry and forestry that are taking place in the multiple-use landscape that we can see today and I examine how these interactions impact the use of winter grazing grounds. This thesis is framed by an understanding of the interactions between reindeer husbandry and forestry in various dimensions of "landscape diversity" that originate from the landscape's range of structural and functional attributes in space and time. Although I mainly explore the ecological foundations of reindeer husbandry, this thesis also considers the institutional characteristics of the landscape that are of social, economic or administrative origin and that affect reindeer husbandry.

Thus, my thesis aims to improve our understanding of the challenges with respect to the management of winter grazing grounds and their resources, and to identify possible options for increasing the adaptive capacity in order to address these challenges.

My thesis, therefore, has a multidisciplinary perspective that is necessary to examine this broad context. The framework consists of three parts:

1) Perception of the structures, functions and their dynamics in the landscape from a reindeer husbandry perspective (paper I).
2) In-depth analysis of the basic ecological prerequisites for reindeer husbandry identified in paper I: the influence of forest structure on characteristics of the snow cover that affect reindeer foraging (paper II) and the occurrence of arboreal lichens from a long term perspective (paper III).
3) Integration of the results from papers I-III into a simulation study examining different forest management strategies to compare the resulting consequences for forest characteristics and the economics of forestry practices (paper IV).

3. Materials and methods

As my thesis takes a multidisciplinary approach to exploring the social-ecological system in the Swedish boreal forests, a variety of methods has been used. They range from interviews to ecological field work and computational modeling. Figure 1 shows the location of the study sites where field work was conducted or that were included in the theoretical modeling.

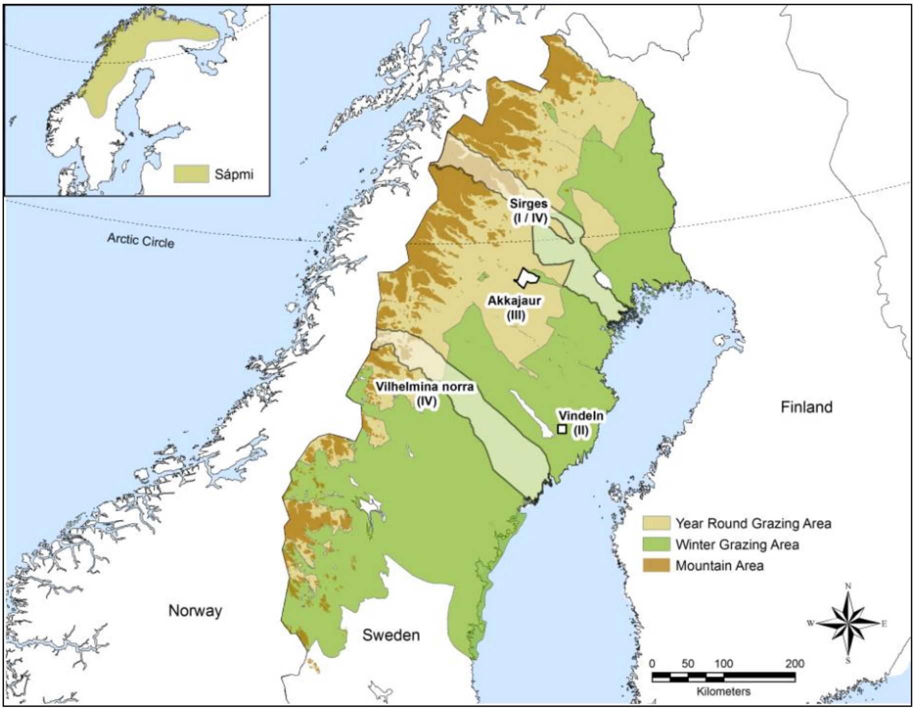

Figure 1: Location of the study sites, their roman numbers indicating the individual paper where they are considered.

Study area

All the study sites considered in the individual papers are situated in mid- to northern boreal forests, these represent the dominant vegetation type in Fennoscandia. The vegetation of lowland forests is characterized by Scots pine (*Pinus sylvestris*) on glacio-fluvial soils, with Norway spruce (*Picea abies*) occurring more frequently on mesic sites, as well as deciduous trees (*Betula pubescens*, *B. pendula*, *Salix* spp.). The understory vegetation is mainly composed of dwarf shrubs (*Vaccinium vitis-idaea*, *Vaccinium myrtillus, Calluna vulgaris*), mosses and ground lichens (*Cladonia* spp., *Cetraria* spp.). In the past, fire was an important agent of disturbance in these forests, with the intervals between fires ranging from 52 to 160 years, depending on soil moisture (Östlund *et al.* 1997). The topography is characterized by moraine hills, with elevations increasing from the eastern coastal plains towards the mountain chain in the west. Snow covers the ground for more than half of the year (175 days to 225 days moving to the west), usually forming in late November and disappearing in May. Therefore, the short vegetation period ranges between 100 – 150 days (www.smhi.se) and results in low forest productivity.

Semi-structured interview (Paper I)

The knowledge of reindeer herders, originating from practical experience, offers a holistic, qualitative perspective on the complexities of social-ecological systems that differs from scientific reductionist ways of acquiring knowledge (Peloquin & Berkes 2009, Berkes 2012).

As the strategies for using the land and its resources originate from the herders' daily experiences of the interactions between reindeer, their environment and the factors that influence these, the practices connected to herding of reindeer are a way of perceiving, understanding and interpreting the environment, as well as the interactions between different land users.

Because an understanding of such landscape functions and structures is fundamental for successful implementation of the management of multiple-use resources, we conducted a study based on an interview with a representative of the Sirges herding district (fig. 1) to document the Sámi knowledge of these dynamics, structures and functions in the landscape and the interactions between the different users that are taking place. The interview was semi-structured, as we used only a general outline for the questions, allowing other topics to be addressed as they came up during the conversation (Kvale 1997, Huntington 2000). The study site on which we focused our analysis is the winter grazing grounds of one of the *siidas* in the Sirges herding district.

Snow cover characteristics in relation to forest stand variables (Paper II)

We tested the hypothesis that the development of snow cover characteristics is affected by the features of forest stands. During the winters of 2010-11 and 2011-12, we investigated snow cover in three landscape elements that are common in the Swedish boreal forest: i) forest stands with trees of different age classes and species, creating a multi-layered canopy, ii) even-aged stands with a single canopy layer and iii) clear cuts. These three forest types were each represented by three individual stands.

A sampling scheme with triangular plots nested at different distances was adopted to account for the spatial variability of snow (Watson *et al.* 2006). In every forest stand, four triangular plots each with nine snow sampling points were laid out; the samples were 1 m, 10 m or 100 m from each other. For every sampling point, snow depth and hardness were measured, the latter using a Swiss Ramsond penetrometer (Institute for Snow and Avalanche Research SLF), which measures the force necessary to penetrate the snow cover (Gray & Male 1981, McClung & Schaerer 1993).

To relate snow cover characteristics to the forest structure of multi-layered and single-layered stands, the distance from every snow sample to the nearest tree, as well as the tree diameters at breast height and the species were recorded.

Estimation of arboreal lichen occurrence (Paper III)

The biomass of arboreal lichens was estimated visually in the field by defining four abundance classes based on the findings of Jaakkola *et al.* (2006). These classes represent mean values of arboreal lichen biomass: none (0), sparse (< 35 kg/ha), moderate (35–120 kg/ha) and abundant (> 120 kg/ha). The occurrence of arboreal lichens was related to stand age, derived from the forest owner's inventories. Building on the relationship between forest age and arboreal lichen occurrence at present, we used historical forests inventories for the years 1926, 1936, and 1960 to estimate past arboreal lichen occurrence and document the changes that resulted from the progressive impact of commercial forestry in our study area. In addition, we used the computer program Heureka for long-term planning and analyses of forest management strategies (Wikström *et al.* 2011) to compare the effects on habitat supply of arboreal lichens of three different management strategies over the next 120 years.

Simulation of different forest management strategies (Paper IV)

The results from papers I – III were integrated to develop a scenario for forest management adapted to the requirements of reindeer husbandry; this was combined with earlier work on forestry impacts on winter grazing resources and a forest policy document published by the National Association of Swedish Sami (www.sapmi.se/skogspolicy.pdf). Management practices in the scenario are mainly focused on developing forest structures and functions that favor the establishment of grazing resources, e.g. by implementing longer rotation times, higher levels of pre-commercial thinning, lower levels of forest harvest and avoiding soil preparation activities (the "reindeer scenario"). To develop this scenario, we used the Heureka program (Wikström *et al.* 2011), and then compared it with a scenario simulating forestry based on the principles required for timber production as practiced today within the guidelines of environmental consideration as given in the Swedish Forestry Act of 1993 and certification rules by FSC (the "timber scenario"). In this study, we tracked the development of landscape characteristics and economics that result from the implementation of the two management strategies over 100 years. Specific winter grazing grounds in the herding districts of Sirges and Norra Vilhelmina were used as study sites (fig. 1).

4. Major results and discussion

The multi-dimensional landscape

A landscape is a multi-dimensional construct incorporating a number of processes, resulting from a variety of driving forces at several scales. These drivers can be, *inter alia*, of ecological, social or economic origin (Cash *et al.* 2006, Brunetta & Voghera 2008). There is value in the landscape because people use its resources and these may differ according to the aim of resource management; in contrast, landscape functions are independent of people (Termorshuizem & Opdam 2009). The exploitation that has caused transformations of the landscape is a result of the needs and practices of multiple users of forest resources. These needs and practices both *shape* and *are shaped* by interests competing over how and for what landscapes should be managed. The social-ecological forest system, therefore, is fragmented in physical, administrative as well as social ways. Because landscape patterns and the processes they create strongly influence the flow of ecosystem services that the landscape can provide to people (Turner *et al.* 2001), these patterns affect the adaptive capacity of actors to react to disturbances in the landscape.

The composition of the managed landscape of boreal Sweden is mainly the result of forest management practices. Because the distribution of landscape elements, with their particular structures and functions in space and time, reflect social driving forces (Leach *et al.* 1999), they are inseparable from the power of decision making and the implementation of decisions. The financial superiority of forestry in comparison to reindeer herding results in decisions about land use and planning being primarily driven by economics (Widmark 2006, Keskitalo 2008a), rather than based on ecological and social-cultural values, such as the grazing practices associated with the Sámi cultural landscape (**papers I**, **III**). How forests and the services and values linked to them are perceived by reindeer herders differs from the understanding of forests from a silvicultural perspective. Forests can be seen as “habitats”, i.e. grazing grounds with different functions and suitability. Therefore, it is the *supporting values* of the forests that matter to herders, while from a silvicultural perspective it is *final values*, i.e. wood products, that are the focus of interest (Chan *et al.* 2012, **paper IV**). Negotiations about forests and their inherent values therefore take place from the perspective of different evaluations (**paper IV**).

Herd size, mobility between the elements within the existing diversity of the landscape, the availability of grazing resources as well as the regeneration of pasture lands are critical for viable pastoral cultures (**paper I**). The major environmental drivers of landscape diversity that affect reindeer herding on the winter grounds are the interactions between topography and weather variables. These determine movement patterns, timing of herding activities and the ability of reindeer to access grazing resources (Kumpula & Colpaert 2007, **papers I**, **III**). Weather variation in particular can act as a constant driver of change of landscape functions and thus require responsive action (**papers I**, **II**). Therefore, conditions in different winters require herders to make different choices. Key elements in making these choices are snow conditions (**paper II**) and the availability of arboreal lichens (**paper III**).

Snow cover characteristics and their interaction with the landscape

Snow is a major driver, changing the availability of forage on winter grazing grounds. In consequence, there are numerous classifications of snow by Sami reindeer herders (Ryd 2007, Riseth *et al.* 2011, Gaup Eira *et al.* 2012). The characteristics of snow affect the functional response of reindeer, i.e. the consumption rate in response to food abundance (Fancy & White 1985, Robinson & Merrill 2012). Reindeer, as “classic Ice Age mammals” (Geist 1999), adjust their feeding behavior and cratering strategies according to the predominant snow conditions (Helle 1984, Pruitt 1992). Adaptive behavior to specific snow conditions includes mutual foraging (*fies’ki* in Sámi language) as well as varying habitat selection in search for sites with easier foraging, e.g. when hard and/or deep snow makes terrestrial lichens inaccessible (Johnson *et al.* 2000). The adaptability of animals to harsh environmental conditions is thus an important characteristic that links the pastoral culture to its environment (Li & Li 2012). In the Sámi language, the dynamic, multi-dimensional character of “good grazing grounds” is described as *guohtun*, which refers to the abundance of forage, the behavior of reindeer mediated by several factors and snow conditions in relation to their suitability for reindeer digging (Roturier & Roué 2009).

Snow cover characteristics are affected by numerous environmental factors and consequently they evolve during the winter. Winter weather and its variability influence the formation and duration of the snow cover, as well as the metamorphosis of its physical characteristics (Sturm & Holmgren 1995, Lehning *et al.* 2002). Within a forest stand, the structure, e.g. density and spatial distribution of trees, as well as the architectural composition of the canopy influence the pattern of snow accumulation on the forest floor. The processes involved are interception of snow in the canopy and its subsequent unloading at snowmelt or during warm spells (Storck *et al.* 2002, Varhola *et al*. 2010). The combination of the weather and forests stands with different structures results in different areas having particular functions as grazing grounds. As a consequence of factors such as the timing of snowfall and warm spells during the winter, the snow blanket on the forest floor may differ considerably between forests of different ages or as a result of the architectural structure of the canopy (**paper I**, **II**). As modern forestry practices have shifted forests from comprising mainly multi-layered stands to a higher abundance of single-layered stands, the dynamic mosaic of snow cover has changed. In **paper II**, we described our finding that variability in snow hardness, but not for snow depth, is affected by canopy structure. Forest stands with a multi-layered canopy had more variable snow hardness due to the patchy distribution of hard snow clumps on the forest floor that had dropped out of the canopy. This patchy distribution is favorable for reindeer foraging, as pastures that are completely inaccessible because of unvaryingly compacted snow are unlikely in such stands. In contrast, the single-layered stands had a comparatively even distribution of snow hardness. The relatively uniform snow hardness under single-layered canopies compared to the higher variability of snow hardness in multi-layered stands thus potentially creates a risk of there being snow conditions that are uniformly adverse for reindeer digging.

However, this effect was only observed in the winter of 2010-11, when a warm spell in early February caused a major canopy drop-off event, followed by refreezing. The notably different climatic conditions and occurrences of warm spells between the two years of our study had different effects on the development of the snow intercepted by the canopy, as well as that on the forest floor.

This illustrates how important weather variations are, i.e. the timing and severity of discrete events, in combination with forest structure, in determining the development of a particular stand as a suitable grazing area during the course of the winter. It is, consequently, difficult to rank habitats in terms of pasture quality, as this together with the occurrence of forage depends on the dynamics of weather variables. In particular, because there is an observed tendency towards increasing weather variation, it is important to understand the disproportionately large impacts that these variations have (Krupnik & Jolly 2002, Berkes 2012).

Therefore, to maintain resilience of the husbandry system within a season and between years, a diversity of forest types is needed to enable reindeer herders to choose the best available grazing conditions (Roturier & Roué 2009, **paper I**). However, modern forestry practices have reduced the diversity of forest age classes at the landscape level (Östlund *et al.* 1997). A necessary balance of different forest types with their inherent structures and functions is, therefore, no longer available, especially due to the lack of old-growth forests (**paper I**). The variability that forestry methods create is thus not unfavorable *per se*. Rather, there is uneven distribution in the spatial extent of these different functional types.

Thus, for reindeer husbandry, an increase in the diversity of landscape elements at the stand level, as well as fostering a higher abundance of older forests at the landscape scale, would favor adaptation to changes in snow conditions (**paper I**, **II**). This is of particular significance with regard to the loss of arboreal lichens for use as emergency forage.

Arboreal lichens and their interaction with landscape patterns

Due to the slow growth of arboreal lichens, the accumulation of high arboreal lichen biomass is highly dependent on forest age, but forest volume seems to be of importance as well (Dettki & Esseen 2003, Jaakkola *et al*. 2006). Our study area, in which we investigated the relationship between forest age and arboreal lichens, is dominated by young (1 – 39 yrs) and mature (40 – 120 yrs) forests stands, comprising 25 % and 42 % of the sampled stands, respectively. Nearly half of the sampled stands (45 %) lacked arboreal lichens (**paper III**). In our study area, with its particular history of timber harvesting, we found a threshold forest age of 63 years, above which stands are more likely than not to contain at least an abundance class 1 (< 35 kg/ha) of arboreal lichens. However, as only a few older forest stands especially rich in arboreal lichens were present in the landscape, we could not identify a reliable age threshold between classes of higher abundance.

During the past 80 years, forestry has reduced the number and extent of forest stands associated with a high probability of lichen occurrence (**paper III**). In other words, “source habitats” for lichen dispersal have been reduced and the fragmentation of the landscape has increased. Therefore, the contribution of old forest stands to the probability of arboreal lichens being present at the landscape level in 2006 is much lower in comparison to the first inventory in 1926. Since arboreal lichens have only limited dispersal abilities, the spatial structure of their habitat is essential for both survival and their ability to colonize new patches (Dettki *et al*. 2000). Increased fragmentation therefore prevents lichen dispersal units available to colonize new suitable habitats. Thus, the temporal and spatial continuity of forest stands rich in arboreal lichens is a particularly important landscape pattern, as the availability of suitable forest stands alone cannot guarantee the presence of arboreal lichens (Nilsson *et al*. 2001).

Because the probability of lichen occurrence increases with the age of forest stands, an extension of the relatively short rotation times of approximately 80 – 100 years applied in forestry today would contribute to increasing the abundance of arboreal lichens (**paper III**). Sustaining both the spatial and temporal cover of a key habitat that represents “ecological memory”, i.e. forest older than 63 years, would increase the likelihood of the presence of arboreal lichens. This change would enhance the grazing resource for reindeer and thus would increase the resilience of reindeer husbandry in times of adverse winter conditions (**paper I**).

Loss of functionality in space and time

Herding communities traditionally reflect the variability and unpredictability of the ecosystem in which they operate, e.g. by migrations following seasonal vegetation changes through the year or leaving “reserve areas” with abundant forage for emergency use during catastrophic years and environmental shocks (Niamir-Fuller 1998). The availability of grazing resources and key habitats with specific structures and functions can thus reduce the vulnerability of reindeer herding communities to such shocks (**paper I**). However, to be available in the long term, these habitats also need to be connected spatially and temporally**,** and to be accessible to migrating reindeer herds in order to prevent dispersal of the animals in search of forage, e.g. when difficult snow conditions make foraging on terrestrial species impossible (**paper I**). Thus, there is a demand for spatial flexibility and mobility in the landscape. Some stressors can occur rapidly, such as sudden inaccessibility of grazing grounds due to changes in snow conditions (**paper II**). Other stressors may accumulate slowly over the years, such as progressively declining numbers of forest patches rich in lichens (Sandström *et al.* 2006, **paper III**). Temporal connectivity can be understood as the continuous access to grazing resources to sustain reindeer herds, e.g. under any snow conditions. Because industrial forestry methods have reduced the amount of certain forest age classes in the landscape (**paper I**) and adversely affected the availability of arboreal lichens (**paper III**), the cultural landscape of Sámi reindeer husbandry has experienced a loss of functionality that has decreased its resilience. Lifting the scale of forest management from the stand level to the landscape level (Puettmann *et al*. 2009), which is capable of "embracing change" (Holling 2001), could deliver a diversity of landscape functions. Such an approach to the management of multiple-use commons could potentially foster essential sources of mobility between landscape elements, as well as decrease the negative impacts of fragmentation (**paper I**, **III**).

Vulnerability of reindeer husbandry as a result of the loss of functionality due to increasing industrialization of the landscape, however, cannot be evaluated fully without considering the increasing uncertainty due to as yet unexperienced variations in climatic conditions and their effects on human–animal relations within herding communities (Cassidy 2012). Therefore, critical thresholds may shift both within a season and between years as a result of weather conditions interacting with the effects of industrialization of the boreal landscape (**paper I**). When the diversity of functional elements in the landscape is reduced, the buffering capacity may be reduced, and other coping strategies have to be found. For example, in the past, inaccessible grazing grounds were counterbalanced by a supply of abundant arboreal lichens (Berg *et al.* 2011, Helle & Jaakkola 2008), but today costly supplementary feeding is necessary because relying on arboreal lichens is no longer an option (**paper I**). In consequence, the distance from the resilience threshold, below which there is an increased risk of collapse, is not easy to evaluate, as variations in weather do not follow a linear trend. However, this distance may be decreasing due to the cumulative effects of continuing resource exploitation reducing landscape services, a high predation pressure in some parts of the Swedish reindeer husbandry area and the uncertain effects of climate change (fig. 2, Moen 2008, Furberg *et al.* 2011, Hobbs *et al*. 2012).

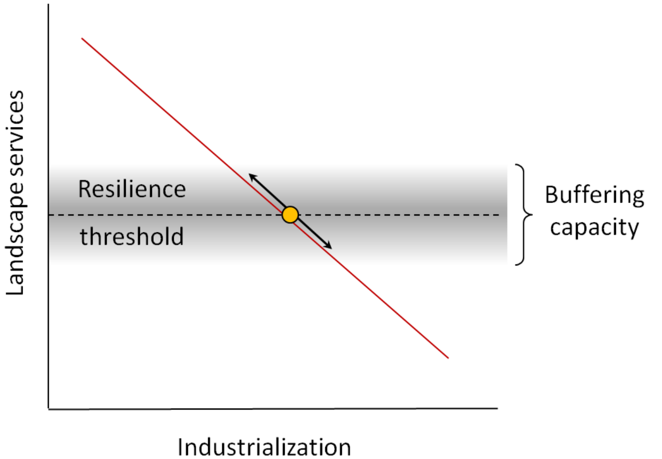

Figure 2: Decreasing resilience of reindeer husbandry as a result of industrialization reducing the availability of landscape services on winter grazing grounds. The location of the husbandry system (yellow dot) to the resilience threshold can be modulated by weather dynamics.

Throughout its history, reindeer husbandry has had to adapt to changes in climate (Tyler *et al*. 2007). It has therefore been argued that the adaptive capacity of reindeer husbandry is constrained more by socio-economic development of the landscape than by climate change *per se* (Rees *et al.* 2008, Forbes *et al.* 2009).

Management strategies following different priorities in forest services

The socio-economic development of the winter grazing grounds has been primarily shaped by the demands of forestry (**paper I**, **III**). The drivers behind these landscape transformations depend, *inter alia*, on external variables including globalization and the market economy (Keskitalo 2008b). Therefore, a social-ecological system, such as the boreal forest, is closely coupled to socio-economic systems at larger scales and there is a risk of decoupling between the two components at the local scale, thus eroding sustainability in the long term (Li & Li 2012). Consequently, planning for long term sustainability requires trade-offs with short-term goals, as well as between the different stakeholders in the local multiple-use system.

Simulating two different management strategies resulted in different forest characteristics and net income from forestry (**paper IV**). Relative to the "timber scenario", the "reindeer scenario" resulted in less dense forests with larger trees, and only 80 % of the area being cut compared to the timber scenario. However, the larger tree sizes do not compensate for the less dense stands, and lead to a net income of approximately 80 % that generated if the timber scenario is implemented. In order to support both terrestrial and arboreal grazing resources, rotation times under the reindeer scenario would increase from approximately 110 years to 130 years at both study sites (**paper III**). Consequently, age composition and landscape patterns clearly developed into different states at the end of the 100-year simulation period. Forests older than 120 years would expand from very small areas to cover 11 % of the study area in Norra Vilhelmina, and 18 % in Sirges under the reindeer scenario, compared to 8 % under the timber scenario. A high abundance of old forest types is not necessary for the forestry sector, because high harvest volumes can be sustained by younger forests with a higher stem density. However, the skewed abundance of forest age classes towards younger stands does not offer the services necessary to keep reindeer husbandry resilient to changes in grazing conditions that result from unpredictable weather dynamics (**paper I**, **paper II**). These dynamics, which in some years necessitate the function of old forests as grazing grounds more than in others, complicate predictions of habitat requirements by reindeer. Therefore, estimating the value of old forest for reindeer husbandry in monetary terms is difficult, although it is possible to relate their presence within a particular area to the income generated, for example, from reindeer meat.

Trade-offs and power relationships in the landscape

The implementation of management activities in space and time, and the path dependencies they create, ideally are equally directed at maintaining ecosystem services, economic interest and societal services (Bettinger *et al.* 2009). Given a multiple-use situation, agreement about a given management strategy requires trade-offs between opposing interests and different valuations of specific services at particular times and places, as well as sociopolitical factors (Arponen *et al*. 2010, Hauera *et al*. 2010). For example, the ecological significance or extent of certain valuable areas has to be traded off against maximizing financial profit resulting from resource extraction (Robards *et al.* 2011, **paper IV**). The extent, timing and location of landscape changes thus depend on the aims specified by the management authorities. Harvest levels of both timber and non-timber forest products are largely determined by forest ecology and the structure of property rights (Nelson *et al.* 2011). Thus, taking account of such rights adds a social and political dimension to the interaction between natural and economic systems. Property rights and the power of decision making are a part of the adaptive capacity of land users. The power to implement decisions is likely to differ between stakeholders, but cannot be ignored in the management of natural resources. It is also important to acknowledge different ways of knowing, e.g. the inclusion of indigenous ecological knowledge (Hirsch *et al.* 2010, **paper I**). Cultural diversity can, therefore, create more challenges than opportunities for adaptation to stressors. However, the different perspectives and types of knowledge that may be expressed in the different cultures and their different management strategies add multiplicity to experiences of how to address challenges and make changes (Chapin *et al.* 2009). In making this knowledge understandable to other land users, there is a chance that trade-offs in the management of common pool resources can be achieved. Nevertheless, merely recognizing indigenous peoples' knowledge in resource management is not sufficient. Rather, it is necessary to comprehend indigenous peoples' knowledge in its specific context as a mutualism of empirical knowledge, practice and belief systems (Berkes 2012). Brody (1982) cautions that to "disconnect the variables, to compartmentalize the thinking, is to fail to acknowledge its sophistication and completeness". Therefore, the initiation of a "bottom-up" process that fosters co-production of knowledge is a key to success: it offers the opportunity for social learning by transcending narrow contexts of conventional decision-making processes (Ellis 2005, Davidson-Hunt & O'Flaherty 2007).

Frequently however, it is the stronger competitor who has the power to ensure that his benefits are guaranteed by the management system (Jentoft 2006), such as keeping a landscape structure shaped by the demands of forestry rather than specific Sámi grazing practices (**papers I - IV**). As a consequence, reindeer herders perceive their influence on the outcome of consultations with forestry companies to be limited (Sandström & Widmark 2007). In boreal Sweden, this issue is also colored by the Swedish colonization of Sápmi and the loss of Sámi property rights (Allard 2006, Lantto & Mörkenstam 2008).

Governance approaches that stimulate collective action could assist in tackling these social legacies. As a possible solution, authority could be transferred from a centralized government to local cooperative decision-making, fostering power sharing and social learning to negotiate trade-offs between the interests of the stakeholders (Folke *et al.* 2005). By not recognizing that current forest management is only one of many possible options, negotiations become locked in an inflexible "rigidity trap" (Gunderson & Holling 2002, Allison & Hobbs 2006): the management regime is unwilling to adapt to new conditions and resists change *a priori.* However, to accomplish long-term sustainability in the multiple-use management of natural resources, the cultural dimensions of land use need to be integrated (**paper IV**). This can be achieved through flexibility in decision-making and courage to experiment with creating landscapes that are complex adaptive systems incorporating structural and functional complexity that allows the users to adapt and recover from disturbances. Raising the cultural and biological significance of boreal forests is fundamental to ensuring the cultural survival of Swedish reindeer husbandry, a keystone of Swedish Sámihood.

5. Concluding remarks

Landscape diversity acts as a source for resilience and adaptation during times of change or crisis. Because anthropogenic action has reduced this diversity and thus caused a loss of functionality in Swedish boreal forests, their capacity to act as an intact social-ecological system supporting multiple stakeholders with different values and needs has been curtailed.

In this thesis, therefore, I have emphasized the stewardship of multiple-use commons by recognizing the need for diversity in the structure and function of landscape elements, as well as understanding the links between many variables. These variables - such as ecological, economic and social drivers and the interactions between them - shape the relationship between people and their environment.

I have shown how and why diversity in landscape functions and structure in space and time are essential for increasing the resilience of reindeer husbandry, i.e. to keep the relationship between people, animals and landscapes “fluid and responsive” (Cassidy 2012). This is merely the tip of an iceberg. There is a melting pot of administrative and multidisciplinary scientific challenges that is liable to explode. This potential conflict can be understood as a product of the uncertainties in the wake of the decisions we make, especially during times of rapid change when uncertainty is increased. In the Swedish reindeer husbandry area, these changes manifest as increasing resource exploitation, resulting in landscape changes and losses of grazing grounds. In addition, there is the threat of climate change, with its still largely unknown consequences. These challenges, not specific to reindeer husbandry, make it more difficult for the pastoral people to realize fully their humanity through their animals (Cassidy 2012).

Because the vulnerability of reindeer husbandry to forestry actions has increased as grazing resources have declined, a shared future for the two land users could be initiated by fostering the social-ecological co-evolution of multiple-use landscapes. Social attitudes, needs and desires control the way that natural resources are managed. We therefore need to reflect on the social values of ecosystem services

(Daily *et al*. 2009), such as keeping alive different cultures. Where changes in decision-making are necessary for the stewardship of natural resources, we need to understand the motivation and actions necessary to initiate these changes.

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Epilogue

This thesis is about diversity and changes in the landscape – and therewith closely related to how my personal landscape changed and developed during the bygone years. Of course, I could not have ventured out into the intellectual landscape with all its summits and abysses without the help, assistance and encouragement of many people.

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I conclude - with the words by Tolkien composed for such a ceremonial occasion - that *I don't know half of you half as well as I should like, and I like less than half of you half as well as you deserve*.

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And Beate – there are no words as yet to say what there should be said. And if so, they would require another thesis and not belong here. May our road go ever on and on, to meet further paths and errands!