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REINDEER HUSBANDRY UNDER GLOBAL CHANGE IN THE TUNDRA REGION OF NORTHERN FENNOSCANDIA

Editors:
Jukka Käyhkö & Tim Horstkotte

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University of Turku
Department of Geography and Geology
Division of Geography

The TUNDRA author team:

Antti Aikio
Sámi Parliament in Finland, Rovaniemi, Finland

Bruce Forbes
Arctic Centre, University of Lapland, Rovaniemi, Finland

Tim Horstkotte
Department of Ecology and Environmental Sciences, Umeå University, Sweden

Jane Uhd Jepsen
Norwegian Institute for Nature Research, Tromsø, Norway

Bernt Johansen
NORUT-Tromsø, Norway

Sonja Kivinen
Department of Geographical and Historical Studies, University of Eastern Finland, Joensuu, Finland

Jukka Käyhkö
Department of Geography and Geology, University of Turku, Finland

Lauri Oksanen
Department of Arctic and Marine Biology, UiT The Arctic University of Norway, Alta, Norway

Johan Olofsson
Department of Ecology and Environmental Sciences, Umeå University, Sweden

Tove Aagnes Utsi
Department of Arctic and Marine Biology, UiT The Arctic University of Norway, Alta, Norway

Jarmo Vehmas
Finland Futures Research Centre, University of Turku, Finland

Chapter contributions:
Chapter 1: Jukka Käyhkö
Chapter 2: Tim Horstkotte & Antti Aikio
Chapter 3: Sonja Kivinen, Bernt Johansen & Jukka Käyhkö
Chapter 4: Lauri Oksanen, Tim Horstkotte, Johan Olofsson & Jane Jepsen
Chapter 5: Tim Horstkotte, Bruce Forbes, Tove Aagnes Utsi, Sonja Kivinen & Jukka Käyhkö
Chapter 6: Jukka Käyhkö, Jarmo Vehmas, Tim Horstkotte & Lauri Oksanen

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Tim Horstkotte

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Executive summary

The Nordic Centre of Excellence (NCoE) TUNDRA ("*How to preserve the tundra in a changing climate*") has been a 5-year project (2011–15) within the Top-Level Research Initiative (TRI) by NordForsk. This report combines the key results and a synthesis of the NCoE TUNDRA with earlier research to provide a comprehensive picture of the interplay between the tundra ecosystem, climate change and reindeer husbandry to relevant stakeholders.

Most recent climate projections suggest that by the 2070s, temperature conditions that are warm enough for tree growth (> 10 °C average temperature during summer months) will cover almost all of northern Fennoscandia, excluding only the highest-altitude areas of the Scandinavian mountains. A warming climate will promote growth of shrubs and trees, a process that decreases the area of the tundra biome remarkably. The projected increase in spring temperatures will enhance snow melting. Together with the expansion and densification of shrub vegetation, this can significantly decrease surface reflectance (albedo), and have an amplifying feedback on global climate warming. Therefore, hindering shrub expansion and preserving the circumpolar high albedo tundra biome would serve as climate change mitigation.

Herbivores (animals feeding on plants) have a strong impact on vegetation communities. The most important herbivores in Northern Fennoscandia include large mammals (reindeer), small mammals (rodents), and insects (geometrid moths). Their exact effect, however, varies between the animal groups and their population dynamics, seasons, weather conditions, and vegetation communities, and is dependent also on the combined impact of these animal groups. Reindeer grazing in particular has the potential to counter-impact the climate-induced shrubification. The maximum grazing impact on woody plants is obtained if reindeer are present in a region during early growing season in June and early July. In addition, grazing has an impact on plant biodiversity. By preventing the invasion of trees, tall shrubs and forbs, reindeer maintain the openness of the tundra, which is a precondition for the survival of many small-sized arctic plant species. Although grazing may disturb also these plant species, the net impact of intense summer grazing can be positive at the population level.

From a transdisciplinary perspective, tundra is not only a biome, but also a social-ecological system (SES) incorporating humans and their activities, including reindeer husbandry. Decision-making involves various aspects of this complex social-ecological system and is, therefore, always a compromise and a matter of values and opinions. Reindeer husbandry exhibits major legal and administrative differences in local, regional, and state governance between Finland, Norway and Sweden. Anticipated changes in climate and within the societies require reindeer husbandry to adapt to these transformations. Future is not

pre-determined but unveils itself as a chain of decisions and actions. Therefore, various scenarios of the future of the social-ecological system in Northern Fennoscandia – including reindeer husbandry – can be foresighted depending on the circumstances, decisions and actions.

Current tensions between stakeholders – including reindeer herders, other land users, Sámi and non-Sámi individuals, and the governance system – stem from different values regarding ecological, cultural, social, and economic matters. These tensions may inhibit fruitful discussion and feasible decisions, and may lead to a future that is undesirable for many, if not all parties. At present, there is too little interaction, and inadequate, unequal discussion between the stakeholders. From the herders' perspective, unclear legislation and lack of self-determination are considered as threats for the livelihood. To improve the quality of decision making, planning and actions regarding future land use and livelihoods should be co-designed by different stakeholders. To overcome the historical apprehension between the parties, a neutral boundary organisation might serve as an appreciated mediator.

Preface

In the autumn of 2008, the Nordic countries established a large joint research and innovation scheme, the *Top-level Research Initiative* (TRI), involving various Nordic organizations and national institutions. The five-year initiative consisted of six sub-programmes, one of them being *Effect Studies and Adaptation to Climate Change* (ADAPT). The overarching objectives of the ADAPT programme were to improve awareness about:

- the effects of climate change,
- the adaptation capacities of society,
- the risks and opportunities that the effects of climate change may bring to the Nordic region.

Three Nordic Centres of Excellence (NCoE) within the ADAPT sub-programme were funded for a five-year period in 2011–2015 with a total of 100 million NOK (ca. 11 million €). The NCoE TUNDRA "How to preserve the tundra in a warming climate" was one of them. In this report, the key results and a synthesis of the NCoE TUNDRA have been merged with earlier research to provide a comprehensive picture of the interplay between the tundra ecosystem and reindeer husbandry to relevant stakeholders. To keep the report concise and easy to access, we have left out many details, which, however, can be accessed through the selected list of scientific literature at the end of the report.

Although the key focus of the ADAPT sub-programme has been climate change, we have adopted a broader approach to change, including also other types of transformations such as societal and governance changes, which may impose even stronger impact on people's lives than climate alone.

In combination, these transformations form potential future development paths, scenarios. How the future unveils itself depends on the decisions to be made by stakeholders. We wish that the science-based knowledge and understanding would serve as a tool for stakeholders when considering the preferred course of development.

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norden

Top-level Research Initiative

NCoE TUNDRA

http://ncoetundra.utu.fi

Managing team and administration:

Scientific leader: Lauri Oksanen

Project leader: Jukka Käyhkö

Project Manager: Pekka Niemelä 2011–14, Hans Våg 2014–16

Project Coordinator: Elina Koivisto 2011–14, Mika Orjala 2014–15

Work Package leaders:

Annamari Markkola, Bernt Johansen, Bruce Forbes, Cecile Menard, Erkki Korpimäki, Jane Jepsen, Johan Olofsson, Jouni Pulliainen, Jukka Käyhkö, Lars Ericson, Lauri Oksanen, Tarja Oksanen, Tove Aagnes Utsi

Senior Researchers:

Annu Ruotsalainen, Jarmo Vehmas, Juha Tuomi, Philip Burgess, Risto Virtanen, Rolf Anker Ims, Sami Aikio, Susanna Pirnes

PostDocs:

Anu Eskelinen, Elina Kaarlejärvi, Elina Koivisto, Judith Sitters, Karita Saravesi, Katrine Hoset, Lise Ruffino, Mariska Te Beest, Martin Biuw, Mysore Tejesvi, Ole Petter L. Vindstad, Patrick Saccone, Piippa Wäli, Sonja Kivinen, Tim Horstkotte

PhD candidates:

Antti Aikio, Dagmar Egelkraut, Hélène Barthelemy, Henni Ylänne, Juval Cohen, Karoliina Huusko, Liisa Huttunen, Maarit Kaukonen, Malin Ek, Maria Tuomi, Miia Kauppinen, Nirmalee Hengodage, Pauliina Wäli, Saija Ahonen, Tuija Pyykkönen, Åsa Larsson Blind

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Background

Northern Fennoscandia evokes a multitude of powerful images: vast landscapes of seemingly pristine character, a biodiversity increasingly threatened by climate change, the homeland of the Sámi and their iconic livelihood revolving around reindeer, or an area of accelerating economic activity and resource extraction. In reality, none of these exist in isolation. Rather, they are firmly interwoven by significant feedbacks between each other. These feedbacks couple the dynamic natural system to the social environment with its diversity of values, priorities and practices. Such a unity of people and their environment is referred to as **social-ecological system** (SES).

Social diversity brings about different perceptions of the environment, and the way for what and how the landscape, its resources and the relationship between different interests and stakeholders should be governed and managed. Nature conservation, resource extraction and the indigenous Sámi livelihood with its particular rights are among the most prominent forms of resource management acting in Northern Fennoscandia. They all have consequences on each other – a challenge for fostering and navigating their co-existence. Further, climate change contributes to a transformation of northern social-ecological systems, and affects different components in a multitude of ways.

The academic community aims to improve our understanding of these environmental and social transformations and their consequences. Furthermore, scientists aim to support the search for optimal solutions for proactively managing these dynamics and thus, to increase the adaptive capacity of northern social-ecological systems.

Reindeer husbandry is a particularly illustrative example of a social-ecological system: in relying on natural grazing conditions, the livelihood needs to respond to weather variations and the pronounced seasonality of the High North, while the consequences of climate change are becoming a local reality. Due to the vast area that reindeer husbandry covers in its practice, it shares the landscape with a multitude of other forms of land use. These overlapping interests call for strategies to enable a shared and sustainable future for the people and the ecosystems in the North.

Structure of the report

Our emphasis lies on the changes that the Fennoscandian tundra ecosystem experiences currently, as well as on reindeer husbandry – one of the dominant, but not the sole land user in the region. The report starts by illustrating reindeer husbandry within a social-ecological framework, SES (Chapter 1). Despite being a simplification of the reality, the SES aims at clarifying the complexity of the livelihood in the context of decision making process, and interaction with other forms of land use, among others. Due to the different seasonal grazing grounds used by reindeer through the year, the framework considers also areas outside the tundra biome.

The report unveils more details of the social-ecological system by outlining the history of reindeer husbandry in northern Fennoscandia, and comparing its current governance in the three countries (Chapter 2). Next, the abiotic and biotic environmental processes are reviewed (Chapters 3 and 4), with an emphasis on the interactions between climate, vegetation and the ecology of keystone herbivories that affect tundra ecosystem functioning.

The human actors in the SES, including reindeer herders and other stakeholders, round off the social-ecological analysis (Chapter 5). We illustrate herders' observations of changes in the tundra biome, as well as attitudes and perceptions of present and future challenges by herders and other stakeholders.

These chapters will merge as a scenario analysis, which illustrates hypothetical futures of reindeer husbandry, depending on policy choices with consequences on the livelihood (Chapter 6). These scenarios are meant as illustrative tools to focus attention on vital processes and decision points that may become decisive for the future of reindeer husbandry.

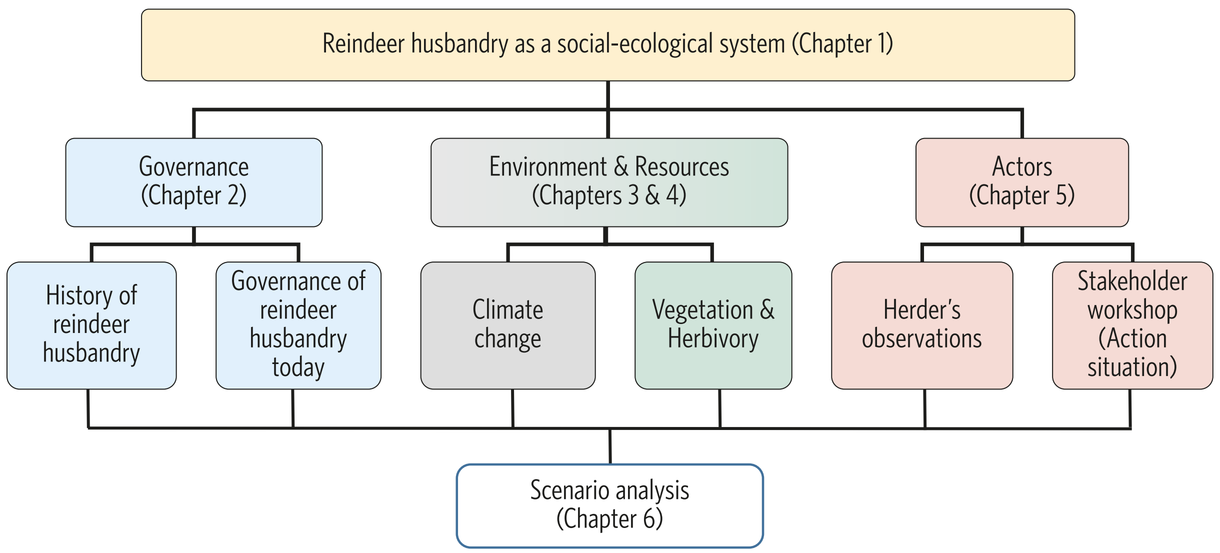

Figure 1. The structure of the report illustrating the concept of social-ecological systems.

1
Reindeer husbandry as a social-ecological system

Political economist and Nobel Memorial Prize winner in Economic Sciences in 2009, Professor Elinor Ostrom, tackled the challenge of how common-pool natural resources, such as forests or fishing waters, should be governed in a sustainable yet profitable way. She designed a framework (Ostrom 2009; McGinnis & Ostrom 2014) for a social-ecological system (SES) that has later been formalised by Hinkel et al. (2014). We utilise the refined Ostrom SES in order to understand reindeer husbandry as a social-ecological system.

The SES has four universal key concepts, namely Environment, Resources, Actors, and Governance (Fig. 2). These concepts have a number of case specific attributed variables that are connected with case-specific attribution relationships.

The exact configuration of a social-ecological system depends on the case at hand, and more specifically, the research question to be tackled. Consequently, there is not just one but numerous potential arrangements for a tundra SES (cf. Forbes 2013). For instance, from the perspective of ecological conservation goals regarding the tundra, the assumption is that a carefully planned and generated seasonal grazing pressure by reindeer may inhibit tree invasion driven by a prolonged growing season (see Chapters 3 & 4). Simultaneously, from a social perspective, careful collaborative planning of grazing management between reindeer herders, management authorities and researchers will support the adaptation capacity of the reindeer herding livelihood in a changing world (Chapter 5). One should also appreciate the fact that the arrangement of reindeer husbandry may not be ideal even today and therefore, re-thinking the livelihood is worthwhile in any case.

By formalisation and understanding of what a social-ecological system consists of and how it operates, one is better qualified to make justifiable management decisions. We have consequently built a SES with the presumption that conscious choices by humans as individuals or as members of collaborative groups can potentially make a significant difference in future outcomes both ecologically and socially. In simple terms, we assume that the outcome (whether or not the tundra will be sustained) will be determined by attributes of both the ecological system (for example climate, vegetation, pasture conditions) and the social system (for example herder's preferences, Sámi culture transformation, regulations related to husbandry). Let us first consider the four key concepts of the system in more detail.

'Environment' refers to factors that are external in the sense that they are not intimately influenced by the variables of the SES, although they form a broader background for the SES in question. In real life, this distinction is a grey area, as eventually everything is inter-connected. But in order to consider what is external and internal, one has to appreciate the

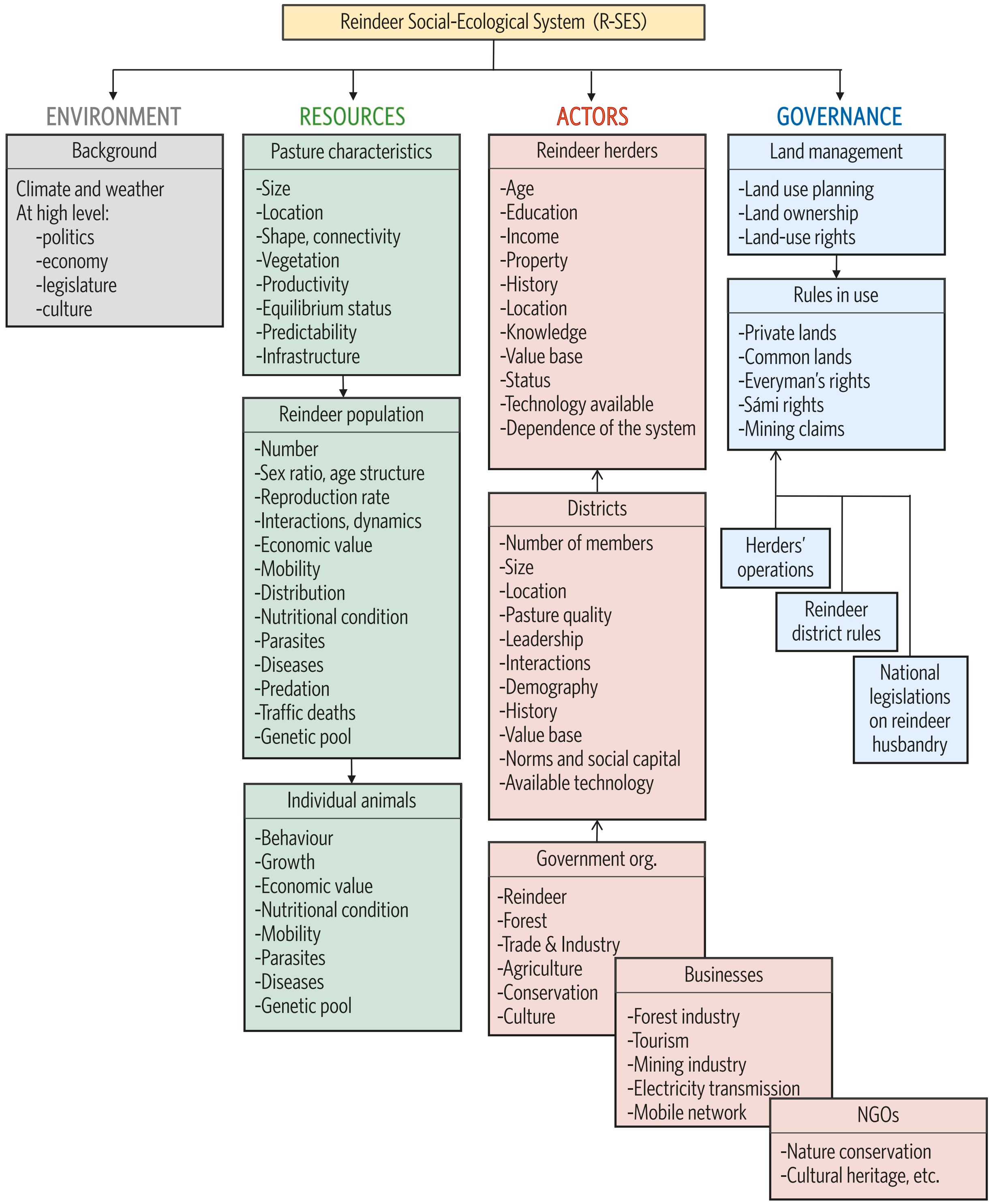

Figure 2. The social-ecological system (SES) framework in the context of tundra ecosystem and reindeer husbandry.

timeframes in question. Often in SES studies, climate is considered as external and affecting the system without much feedback. In our given spatial extent of Northern Fennoscandia and the timespan of decades, climate can be considered external in that it affects the tundra, but is affected through complex global interactions and not directly by the tundra, or reindeer husbandry. However, we assume that the changes that transform the vast circumpolar tundra area will have a long-term impact on the climate at least on hemispheric, if not global scale. Also, broader political, economic and juridical systems are not directly affected by the social-ecological system of reindeer husbandry and are considered external. Typically, changes in nature are gradual while societal changes such as administrative decisions can take place overnight. This discrepancy between the spatiotemporal scales between ecological and socio-administrative influences on a SES (Keskitalo et al. 2016) often complicates the foundation of SES building.

'Resource System' refers to the livelihood's resource base as a whole. It consists of the pasture land and its characteristics such as size, location, boundaries, productivity, predictability and human-constructed facilities. Some of these are rather straightforward properties, such as the physical size of the potential pasture, while some are convoluted and difficult to be solved – for example productivity or quality of the pasture. The reindeer husbandry Resource System can be considered on various hierarchical levels: the whole reindeer herding area of Northern Fennoscandia; the national reindeer herding areas of Finland, Norway and Sweden, respectively; the herding districts and their (potential) sub-units, such as seasonal pastures, and siidas. From a practical management perspective, it is the herding district level which is typically of the highest importance in the system. Individual reindeer owners typically have limited power to act on the resource system level.

The Resource System is constructed of **'Resource Units'**, namely the reindeer. Important attributes of reindeer include their number, reproduction rate, interactions, economic value, mobility and spatio-temporal distribution, plus other distinctive characteristics such as sex ratio, age distribution, nutritional condition, parasites, diseases, predation, traffic deaths and poaching. This is the SES scale where individual reindeer owners' decisions are of importance, although they are also governed from above.

'Actor' forms the third concept of the social-ecological system. Actors are various groups and individuals who are the stakeholders of the SES, such as reindeer herders of a district or land-owners of a municipality, etc. The exact definition of who is or isn't a stakeholder is, again, case-specific. Actors vary in terms of their number, their socioeconomic attributes (age, education, income, properties, etc.), history, location, knowledge, status (leadership, entrepreneurship), technology, and dependence on the system.

The fourth component of the system is **'Governance'**, or the rules of the system. It is quite natural to consider public-sector, i.e. governmental organisations such as ministries or regional authorities, as forming the uppermost level of governance. Non-governmental organisations (for example WWF), private organisations (for example forestry and mining companies) and organisations within the communities (for example herding districts) form other important rule-making organisations. The rules themselves span from constitutional to local norms and strategies.

The variable spatial scale of the rules and policies, such as population, matters, too. Some rules can be European-wide, some national, while some are local. A specific framework of governance is related to the indigenous peoples' rights recognised in international treaties (United Nations ILO-169 agreement) and to national Sámi issues. 'Actors' can also form rule-forming 'units' and thereby these two entities of the SES often overlap.

Given these key concepts as a background, we go into detail of the most important factors that influence reindeer husbandry today, in particular governance structures and interactions with the biophysical environment.

2
Sápmi and reindeer husbandry

Sápmi refers to the area in Sweden, Norway Finland and the Kola Peninsula where the Sámi culture is still alive (Fig. 4). The chapter briefly illustrates the historical development of the livelihood to the present day and highlights major legal and administrative differences in state governance that exist between the three countries.

From hunting to husbandry

In Sápmi, wild reindeer have been a vital resource ever since the Pleistocene period. Starting from the Middle Ages, the nation states of Norway, Sweden (then including Finland) and Russia claimed territory in northern Fennoscandia. The Sámi paid taxes by fishing, hunting fur animals and wild reindeer, as well as by transportation services with reindeer sledges. Taxes were a way for the Sámi to secure their hunting rights against settlers from the South, as well as for the respective state to claim the taxed land as their territory (Cramér & Ryd 2012). Hunting and herding of reindeer existed in parallel, as semi-domesticated reindeer contributed to household needs, for example, as draft animals or decoys for hunting wild reindeer (Björklund 2013).

Today's reindeer husbandry has probably developed through a gradual transition from hunting to herding driven by diverse forces, including economic, social, and ecosystem processes (Bergman et al. 2013). Gradually, herds of semi-domestic reindeer grew in size, and nomadic reindeer husbandry became fully developed in Sápmi by the second half of the 17th century (Lundmark 1982).

In 1751, the borders between the then existing kingdoms Norway-Denmark and Sweden-Finland were settled. The unrestricted crossing of these borders by reindeer herders during their seasonal migrations between summer grazing at the coastal areas and winter grazing in the forest inland was warranted in the Treaty of Strömstad, in an appendix known as the Lapp Codicil (*Lappkodicillen*). Though the crossing of these borders is no longer practiced to the same extent today, this document still has significance in the governance of reindeer husbandry regulations between Sweden and Norway (Regeringen 2009)

Borders and barriers

It was not until the major geo-political conflicts at the end of the 19th century, including the loss of Finland from Sweden to Russia, when borders between the different nation states strongly affected the Sámi in practicing their pastoral livelihood. Eventually, these events created legislative barriers to reindeer husbandry and border crossings became impossible.

The closure of the border between Russia-Finland and Norway in 1852 was disastrous to reindeer herders. They saw themselves confronted with the choice between becoming 'Norwegians' and loosing important winter grazing grounds in the inland of Finland-Russia, while 'Finnish' herders lost vital grazing and fishing grounds in Norway (Cramér & Ryd 2012). Though migration between Norway and Finland via Sweden was still an option for some herders, a second border closure between Russia-Finland and Sweden in 1889 caused the loss of winter grazing areas in Russia-Finland also to 'Swedish' Sámi. The consequence was a shortage of grazing resources in Northern Norway and Sweden. Ultimately, the national borders had dissected the formerly fluid movements caused primarily by ecological factors and split the traditional cultural unity. Eventually, the solution enforced to reduce the overcrowding in the northern parts of Sápmi was the relocation of Northern Sámi to southern parts along the Scandic mountain chain – partly forced, partly voluntarily (Fig. 3).

Industrial development in Sápmi and modernization of reindeer husbandry

The more recent history, especially after World War II, is characterized by an increased sedentarization of reindeer herders and an adaptation to the meat market and its economy (Paine 1994). This rationalization includes the introduction of technical devices for the support of herding practices, such as the "snow mobile revolution" in the 1960's (Helle & Jaakkola 2008), and more recently the use of GPS collars to document the landscape use by reindeer (Löf 2013). Cumulative landscape transformation due to resource extraction by forestry, mining and water power production have increasingly encroached on reindeer grazing grounds (Kivinen at al. 2010, Herrmann et al. 2014). These changes in land use require constant adaption of reindeer husbandry, often requiring high expenses in terms of finances and workload (Löf 2013).

Newly introduced practices include calf slaughter to increase productivity, veterinary treatments and supplementary feeding. The latter practice varies strongly in Sápmi, being more prevalent in Finland compared to Sweden or Norway, where it is mainly used during winters with difficult grazing conditions, for example, due to impenetrable snow cover preventing reindeer from reaching the grazing resources underneath.

Reindeer husbandry at the rift between culture and production

As the history and transformations experienced by reindeer husbandry in Sápmi have demonstrated, the livelihood has so far proven adaptable to political, economic, social and ecological change (Forbes et al. 2006; Tyler et al. 2007, Moen & Keskitalo 2010). Often, herding strategies have been changed and adjusted and have allowed the identity of reindeer husbandry to remain intact as a cultural cornerstone to this day. Thus, reindeer husbandry remains a unifying characteristic in Sámi culture and in the expression of Sámi values and relation to their environment (for example, SSR 2012). In particular, the importance of reindeer husbandry lies in its cultural heritage as a bearer of traditional knowledge and as a connection to the land. For these reasons, it is inappropriate to compare this form of livelihood with agricultural production that is focused on maximized production and profitability (Reinert et al. 2015). Other forms of traditional practices that are combined with reindeer husbandry include hunting, fishing, and traditional handicraft (*duodji*) and, more recently, also tourism.

Reindeer husbandry is today often confronted by a divide of being a traditional livelihood and the need to be economically efficient. Reindeer husbandry thus needs to unify the pillars of ecologic, economic and cultural sustainability. However, differences exist between their definition from a state perspective and a Sámi perspective (Benjaminsen et al. 2016). From a national perspective, the economic income generated by reindeer husbandry in the three countries is low in comparison to other forms of land use, such as salmon farming or forestry.

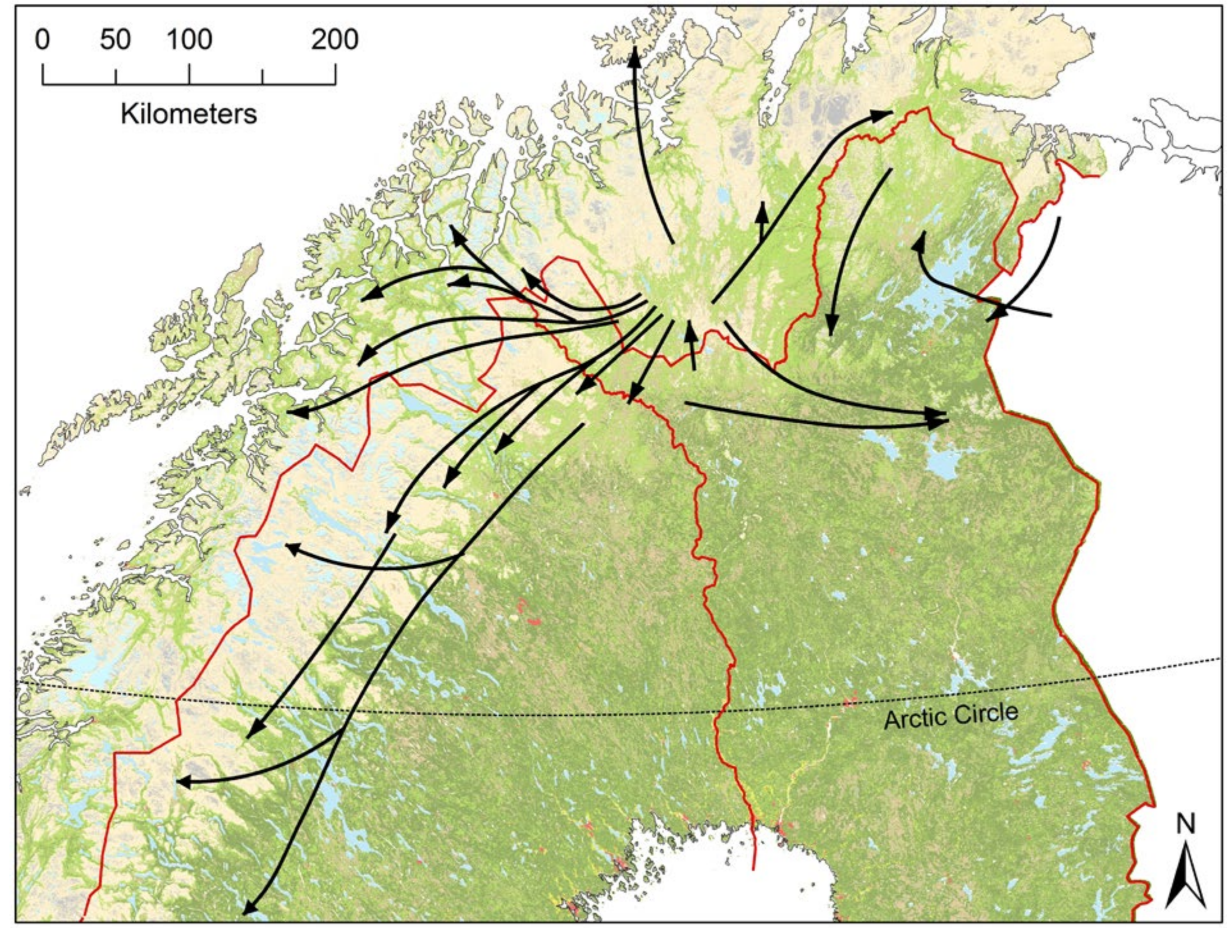

Figure 3. Dislocation of Northern Sámi families after the border closures 1889. Adapted from Aarseth 1989.

Reindeer husbandry in the Nordic countries today

Today, the reindeer husbandry area in Finland, Sweden and Norway covers approximately 40 % of the area in each country (Fig. 4). This area is divided into several **herding districts** or **communities** (Fig 5). The area used for reindeer husbandry is shared with other forms of land use such as forestry, mining, agriculture, hydro power production (reservoirs), wind power, peat extraction, and tourism.

From a legal perspective, the Sámi reindeer husbandry in the three Nordic countries shares a common history. Due to the historical development of the governmental and administrative aspects, the state of reindeer husbandry in the three countries is somewhat different today, with the greatest distinctions to be found between Finland and Norway/Sweden.

Each of the three Nordic countries has enacted a parliamentary law on reindeer husbandry (Reindeer Husbandry Act; RHA):

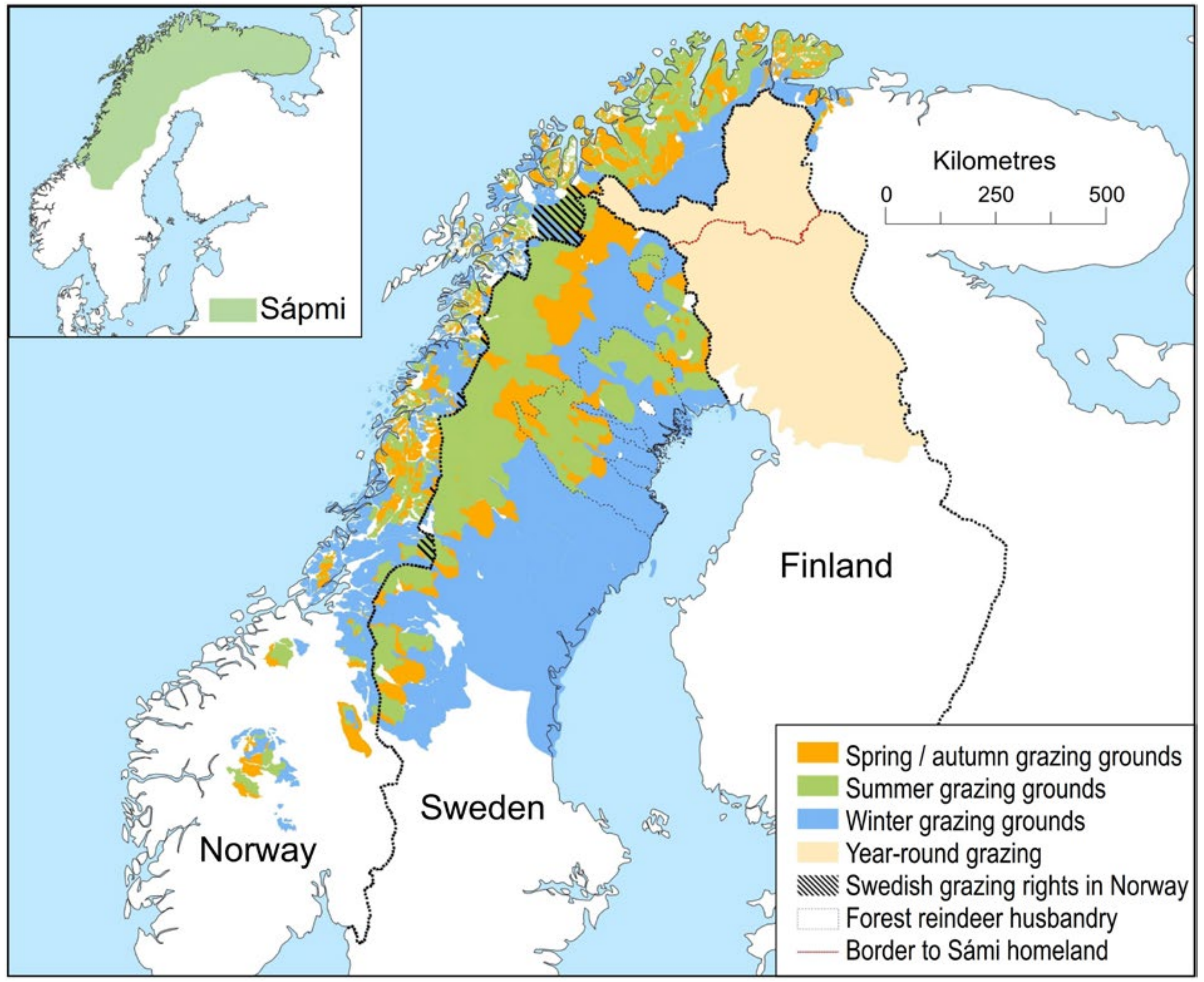

Figure 4. Reindeer grazing grounds and the areal extent of Sápmi.

Poronhoitolaki in Finland, *Lov om reindrift* in Norway and *Rennäringslagen* in Sweden. The most remarkable difference between Finnish and Norwegian/Swedish RHA's is that the Finnish statute omits all references to the Sámi people. The Norwegian and Swedish RHA's start with the protection of the Sámi culture or declaring the rights of the Sámi as legal fundamentals. For instance, the first section of the Swedish RHA declares that the *"right to reindeer husbandry belongs to the Sámi people and is based on the undisturbed possession since time immemorial"*. The first section of the Norwegian RHA states that *"the reindeer husbandry shall be maintained as an important basis for the Sámi culture and society"*.

In Finland, reindeer husbandry is not an exclusive right to the Sámi. The Finnish RHA does not acknowledge the Sámi at all. Instead of protecting the original Sámi privilege, the Finnish legislation grants the reindeer herding right to every citizen of the European Economic Area as long as they reside in the Finnish Reindeer Husbandry Area. Uniquely, in

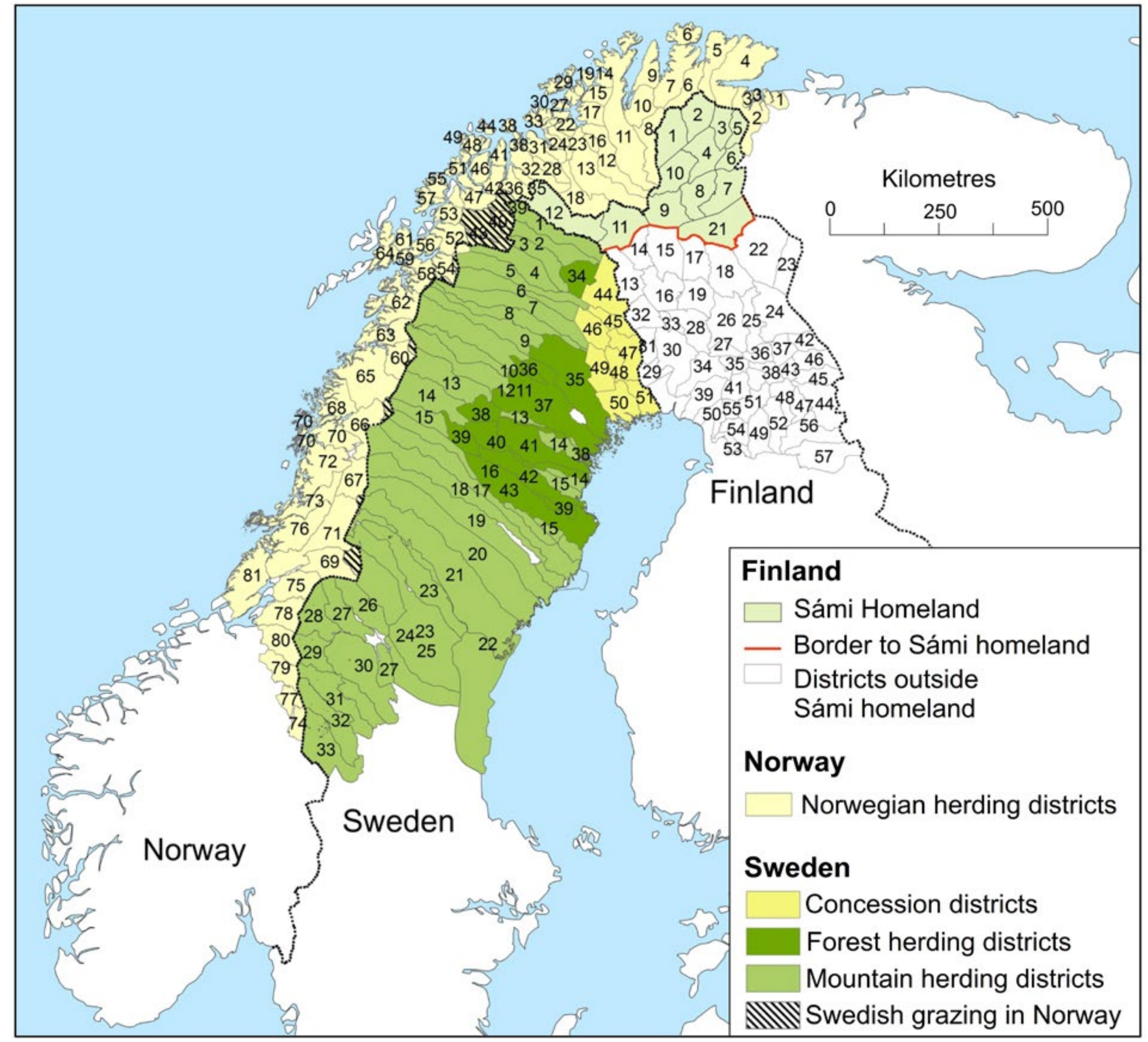

Figure 5. The reindeer herding districts of Northern Fennoscandia. For key to numbers, see Appendix 1.

Finland reindeer husbandry is practiced also by non-Sámi people in addition to Sámi herders. Furthermore, non-Sámi herders form a clear majority of all herders in Finland. The number of people connected with reindeer husbandry (in the form of possessing an own earmark) in the three countries totals at ca. 14000 today, with quite distinctive decrease in Finland (Fig. 6).

Finland

There are 56 herding districts (*paliskunta, pl. paliskunnat*) in Finland (see Fig. 5). All districts are members of the Reindeer Herders' Association (*Paliskuntain yhdistys*), belonging to the Ministry of Agriculture and Forestry. Being responsible for the development of reindeer husbandry and the interests of the districts' members, the

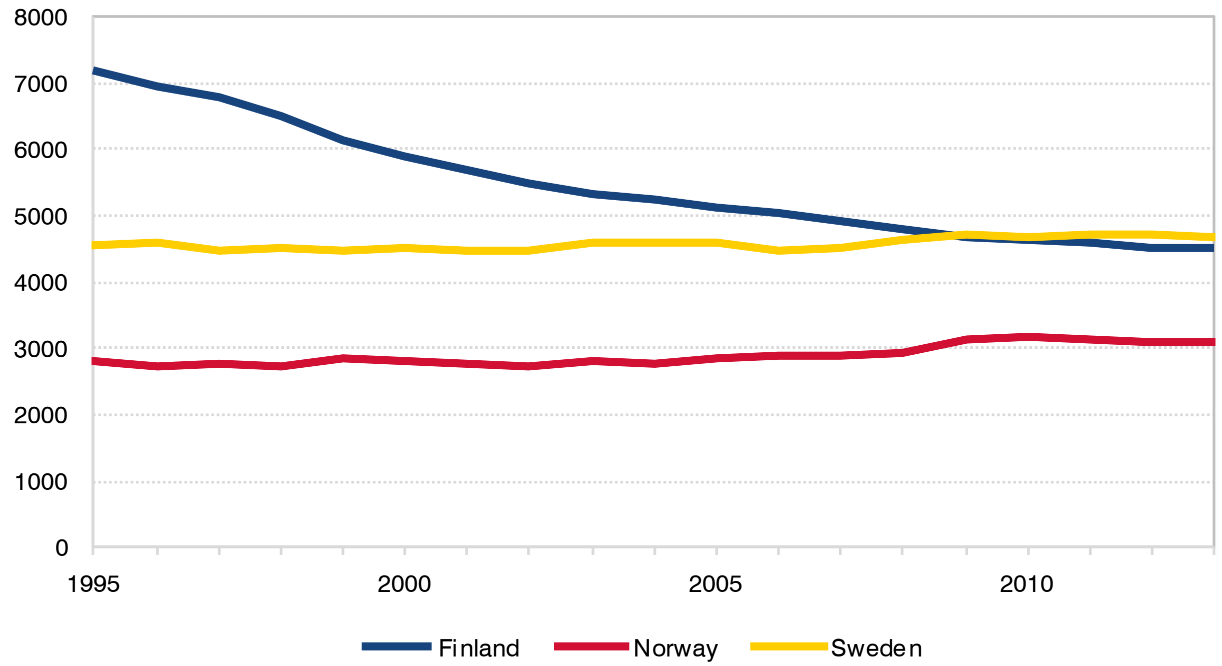

Figure 6. Number of persons connected to reindeer husbandry. In practice this refers to individuals holding an earmark, but does not necessarily indicate practical involvement in everyday herding (cf. Fig. 7). Data from Landbruksdirektoratet (NOR), Paliskuntain yhdistys (FIN) and Sametinget (SWE).

Association has a double role in implementing government decisions and protecting the rights of reindeer owners (Ulvevadet & Klokov 2004). Although there is broad variation in the environmental conditions and cultural practices across the Finnish reindeer husbandry area, governmental decisions apply to all herding districts.

However, the northernmost districts in Finland are considered as "Sámi homeland" (see Figs. 4 & 5) where traditional Sámi reindeer husbandry is a basic right to the Sámi population and is secured against e.g, other forms of land use. Sámi homeland comprises the municipalities of Utsjoki, Inari and Enontekiö, plus the Lappi herding district in Sodankylä community (cf. Fig. 3). Compared to the seasonal migrations between summer and winter grazing grounds in Norway and Sweden, the seasonal rotations in the Finnish herding districts are much less pronounced, as the district borders roughly follow the administrative borders of communities. However, in some of the northernmost districts, fences separate the districts into summer- and winter pastures. In Finland, the number of reindeer owners was approx. 4530 for the year 2013, whereof 1260 (28%) reside in the Sámi homeland, owning 42% of the Finnish semi-domesticated reindeer population (statistics from *Paliskuntain yhdistys)*. However, not all reindeer owners are occupied full-time by the husbandry. The number of both reindeer owners and full-time herders has been declining during the last decades, while the number of reindeer has been close to the maximum allowed limit of 203700 animals (for 2010–2020) (Fig. 7). The Finnish legislation forbids any form of cross-border migration of reindeer between the Nordic countries.

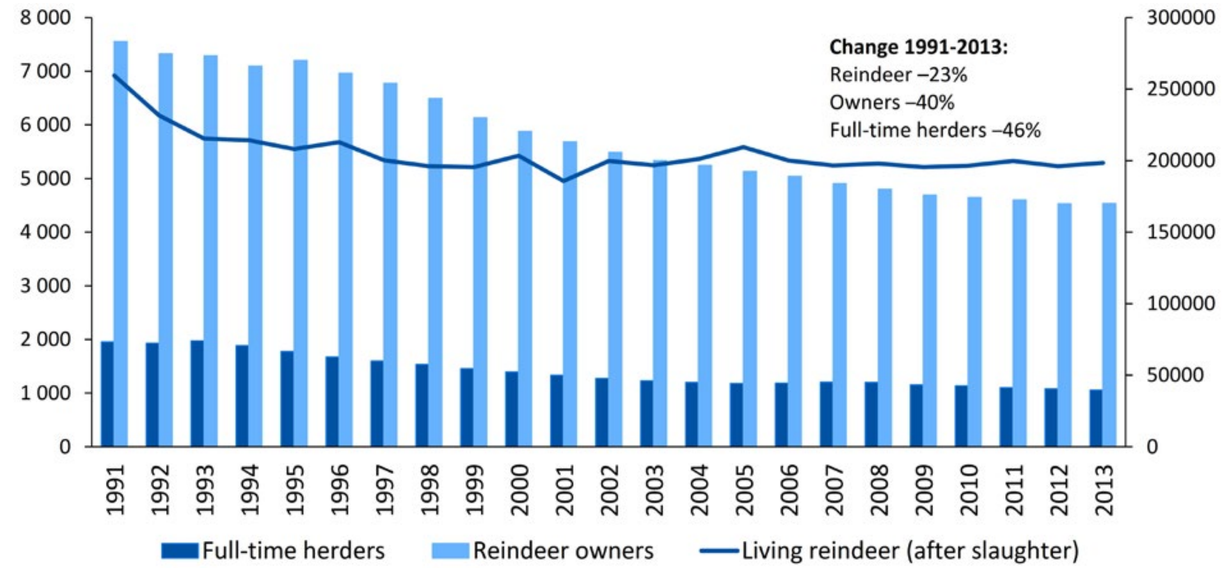

Figure 7. Number of reindeer owners and full-time herders (left axis) and living reindeer (right axis) in Finland 1991–2013. By 2015, the number of full-time herders had fallen to 941. Data from Paliskuntain yhdistys, and MELA 2016.

Norway

The Norwegian Sámi population has the right of immemorial usage ("*alders tids bruk*") to practice reindeer husbandry. The Norwegian Sámi reindeer husbandry area is divided into approximately 71 districts, but their number may vary, as some districts may became merged or divided (Ulvevadet 2008). Most herding districts in Finnmark have their particular summer grazing area close to the Atlantic coast, while their winter pastures are in the inland at the Finnish border. Non-Sámi reindeer husbandry occurs in the southern parts of Norway, in a Concession Area, where reindeer husbandry is practiced with a special permission. By the Norwegian Reindeer Husbandry Act of 2007, reindeer herding districts are divided into operational groups, the *siidas*, composed of one or more reindeer herding families, who herd their reindeer in a common herd. These *siidas* are subdivided into several groups (*siida-andeler*). The organization of these *siidas* may change during years and seasons (Reindriftsforvaltningen, 2013). Today, there are 99 summer *siidas* and 150 winter *siidas*. The number of siida-andeler in 2015 was 534 and the number of people connected to these siida-andeler was 3150. (Landbruksdirektoratet, 2016). Finnmark in northern Norway is home to approximately 75 % of the Norwegian reindeer population.

Sweden

The Reindeer Husbandry Act (1971) gives the Sámi the right to "use the land and water for maintenance for themselves and their reindeer", based on immemorial prescription ("*urminnes hävd*"), i.e. the livelihood has been practiced for such a long time that it became a right (Allard 2011). Two forms of reindeer husbandry exist in Sweden: migratory husbandry between summer grazing grounds in the mountains (Info box 1), and stationary husbandry in the boreal forest. Of the 51 reindeer herding districts (*samebyar*) in Sweden,

Info box 1: Seasonal migrations of reindeer

The low-productive environment and distinct seasonality of Northern Fennoscandia is reflected in the ecological adaptations of reindeer. Accordingly, reindeer prefer different habitats with their specific resources during different seasons to maximize their foraging efficiency in terms of nutrient acquisition in space and time. The Sámi circle of the year is divided into eight discrete seasons, here given their Northern-Sámi terms.

- With the start of **spring** *giđđa* (from late March to early May), migration to calving grounds begins. Reindeer forage predominantly on lichens to sustain themselves during the energy-consuming migration.
- **Spring-summer** *giđđageassi* (from early May to end of June), when calves are born, is an important time for replenishing nutrient deficits from the long winter and, for females, to provide their calves with milk until weaning. Young birch and willow leaves, and freshly emerging vegetation along streams and mires offer now maximally nutritious forage. Reindeer are sensitive to disturbances by predators or people.
- During **summer** *geassi* (from end of June to early August), reindeer graze freely on a high variety of highly palatable herbs, forbs and grasses to maximize their growth and build up reserves for the winter. Snow patches and wind provide relief from insects. Reindeer are temporarily gathered for calf marking during this period.
- In **autumn-summer** *čakčageassi* (from early August to end of September), mushrooms are increasingly included into the diet of reindeer.
- The nutritious quality and availability of green forage declines in **autumn** *čakča* (end of September to early November). This is the time of rut, when bulls spend a large amount of their resources acquired during summer. Migration starts to autumn- and winter grazing grounds.
- Birch forests offer wintergreen grass and heather, and mires also may still carry some green vegetation during early **autumn-winter** *čakčadálvi* (early November to end of December). Gradually, animals have to start digging for food through the accumulating snow.
- During **winter** *dálvi* (end of December to early February), reindeer continue to graze for as long as possible on wintergreen grass and heather in the forest. When snow becomes deep and hard reindeer move to higher ground for thinner snow and to heaths for more abundant lichens. The terrestrial lichens (*Cladonia* spp, *Cetraria* spp.) are rich in carbohydrates and energy, but low in proteins and minerals.
- In **spring-winter** (early February to late March), snow conditions may be so difficult with deep hard snow or ice crusts that reindeer cannot access the food on the ground. Arboreal lichens (*Bryoria fuscescens, Alectoria sarmentosa)* in boreal forests become an important forage resource. The availability of winter and spring-winter grazing resources, constitutes the critical bottleneck in the herding year, because they strongly impact winter survival and calving success of reindeer.

The degree to which reindeer migrate between the seasonal grazing grounds, the distances covered and the means of migration or transportation vary significantly throughout Fennoscandia depending on the husbandry system. In general, pasture rotation in Finland is less pronounced than in Norway and Sweden (cf. Fig. 4).

migratory husbandry is practiced by 33 districts, and stationary husbandry in 10 districts. The remaining 8 districts are concession districts, where reindeer husbandry is practiced with special conditions: reindeer owners may be non-Sámi, but their animals are herded by Sámi. In order for a Sámi to practice reindeer husbandry, it is necessary to be a member in a reindeer herding district (*sameby*). These districts thus act as an economic and administrative unit that regulate reindeer husbandry in a specified area.

The area of reindeer husbandry is divided into all-year grazing grounds, and winter grazing grounds mainly in the boreal forest lowlands. According to the Reindeer Husbandry Act, reindeer herders have the right to graze their animals in the winter grazing area from the 1 October until the 30 April. In 2014, there were 4657 reindeer owners registered in Sweden (statistics from www.sametinget.se).

The dynamics of reindeer populations

Strong fluctuations in reindeer numbers have been recorded in Sápmi since the last century, depending on diverse drivers. Among the most important drivers are large scale climate and short term weather events, particularly during winter (Weladij & Holand 2003, Helle & Kojola 2006). Other environmental factors include diseases before the introduction of parasite treatments, availability of grazing resources and losses to predators, which in some parts of Sápmi can be substantial (Åhman et al. 2014). Management practices, such as slaughtering strategies and state subsidies can strongly affect the number of reindeer (Hausner at al. 2011, Uboni et al. 2016).

Today, upper limits for allowed reindeer numbers are decided for herding districts externally by state authorities based mostly on the carrying capacity of winter grazing grounds. In Finland, the respective authority is the Ministry of Agriculture and Forestry (*Maa- ja metsätalous-ministeriö)*, in Norway, Norwegian Reindeer Husbandry Board" Reindriftsstyre and in Sweden, the county administration board *(Länsstyrelsen)*. In Norway, these relationships are based on animal weights and biomass of lichens on winter pastures (LMD 2008). In Finland, these limits have approximately a 10-year timeframe, while in Sweden the allowed number of reindeer goes back to the year 1946 in Norrbotten and Västerbotten, and to the year 1973 in Jämtland. Today, the number of semi-domesticated reindeer in Finland, Norway and Sweden is fairly similar, ranging between 250,000 in Norway and Sweden, and 200,000 in Finland after the slaughter in autumn (Fig. 8). A historical maximum in all three countries was reached at the beginning of the 1990's.

Reindeer husbandry and other land uses

Extraction of natural resources, such as mining for minerals and hydropower production including dams and artificial lakes can have pronounced impacts on the tundra landscape. Besides their local primary environmental impacts, the infrastructure related to these activities, such as roads, railroads and power lines may affect the tundra system over wider areas.

Forestry is an important land use in the boreal zones of northern Fennoscandia. If climate change increases the productivity of forests on their expansion into hitherto treeless areas in the long term, its impacts are likely to increase in the future in new regions. Furthermore, forestry strongly affects the winter grazing grounds of reindeer in Sweden and Finland. Therefore, changes in land use related to forestry are an important factor when considering the future of reindeer husbandry (Fig. 9).

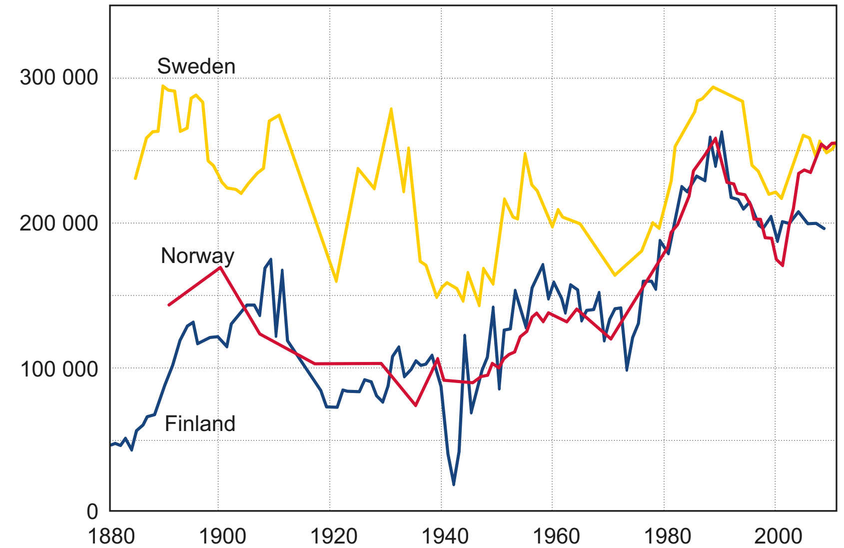

Figure 8. Total populations of semi domesticated reindeer in Sweden, Norway and Finland following the autumn slaughter (1880–2011). After calving in spring, herds are significantly larger. Modified from Bernes et al. 2015.

In addition, diverse tourism activities such as hiking, dog sledging, mountain biking, hunting and snow mobile safaris require specific forms of infrastructure, and can locally have impacts on the land use options for reindeer husbandry (see Chapter 5).

Today, the legal protection of the Sámi culture, including other traditional Sámi livelihoods, is weak, especially in Finland. In regards to land use, there are some signs of improvement. In a landmark case in early 2016, a Sámi collective prevailed against the Swedish state, as their exclusive rights to fishing and hunting inside the area of *Girjas* Sámi village was affirmed. This decision by a Swedish court should logically – due to the common, historical legal basis – have repercussions in Finland and Norway, too.

Figure 9. Forestry is an important form of land use in the Northern Fennoscandian reindeer husbandry area especially in Sweden and Finland. Industrialized forestry has contributed to landscape fragmentation (left) and loss of winter grazing resources, for example by intensive cutting (right). Photos from Sweden.

3
Climate and vegetation in northern Fennoscandia

Current climatic conditions

Climatic conditions vary considerably across Northern Fennoscandia due to the influence of the Atlantic Ocean, the Bothnian Bay, the Scandinavian mountain range and a wide latitudinal gradient. In general, climate is characterized by a long cold season and snow cover that lasts 6–7 months (Tuhkanen 1980; Tveito et al. 2001; Jylhä et al. 2008). The mean annual temperature ranges from less than -3°C in the northernmost part of the region to 3–4°C in the western Norwegian coast characterized by oceanic climate (Fig. 10a). The lowest mean winter temperatures are found in the continental parts of northern Norway in Finnmarksvidda. Growing season is short (Karlsen et al. 2008), and mean summer temperature ranges between 4–14°C in the region. The lowest annual precipitation (less than 450 mm) is received in northern Finland, whereas the highest amounts of precipitation (> 2000 mm) fall on the western side of Scandinavian mountains (Fig. 10b).

Snow usually falls in late October or early November and melts in late April or May (Jylhä et al. 2008). Wind and topography have significant impacts on the local accumulation of snow. For example, mountain ridges and tops can be extremely windblown with a shallow snow cover that melts early in the spring, whereas valleys and depressions accumulate snow that can persist until autumn. Annual snow cover has an important role on ecosystem functions in northern Fennoscandia, as it controls microclimate and plant growing conditions and provides shelter during the cold season (Walker et al 2001).

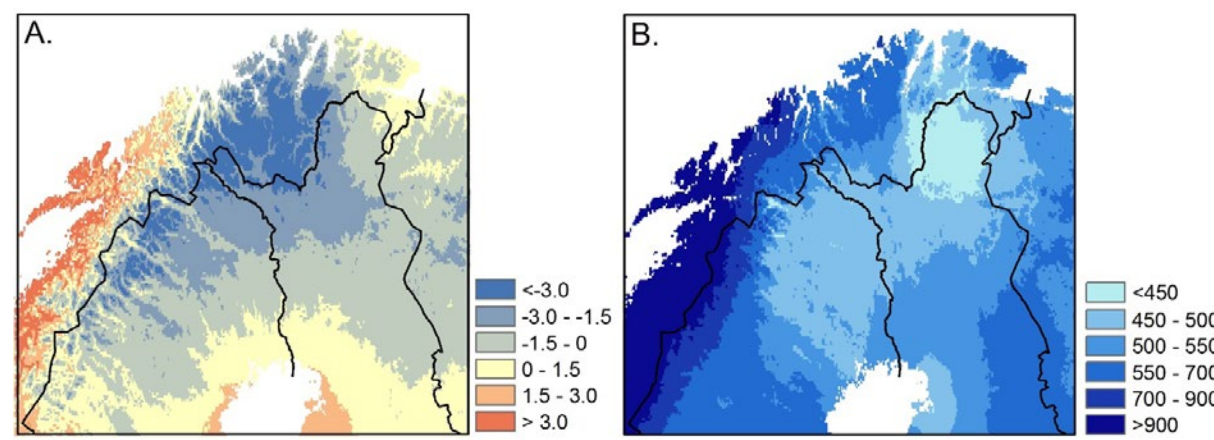

Figure 10 a) Mean annual temperature, and b) precipitation in Northern Fennoscandia. Hijmans et al. 2005, Worldclim 2015.

However, as the Earth's climate is warming, also the northern regions experience changes. While the globally averaged temperature data show a warming of 0.85 °C over the period from 1880 to 2012, the northern circumpolar region has been warming approximately twice as much (Fig. 11). In Finland, for example, the respective warming has been 2.3 °C, and during winter months, almost five degrees (Mikkonen et al. 2015). It is extremely likely that the dominant cause of the observed warming since the mid-20th century has been the human influence.

Vegetation zones

Northern Fennoscandia encompasses several vegetation zones across latitudinal and altitudinal gradients. Vegetation zones are mainly determined by temperature conditions, but further divisions can also be made based on precipitation constituting substantial differences in vegetation formations along the oceanic-continental gradient from west to east based on continental-oceanic variation of climate (Ahti et al. 1968). The northern boreal zone is dominated by birch forests, with forests of Scots pine (*Pinus sylvestris* (L.) in the continental parts of the region. More to the south and east forests of Norway spruce (*Picea abies* (L.) becomes more common combined with large proportions of bogs and mires in the landscape. The tree-line in northern Fennoscandia is typically constituted by mountain birch (*Betula pubescens* ssp. *czerepanovii*). The mountain birch region extends from the southern Scandes through northern Norway and Sweden to the northernmost Finland. Areas above the altitudinal and latitudinal treelines are characterized by arctic and oroarctic tundra including dwarf shrubs, grasses, mosses and lichens (Virtanen et al. 2016). The boundary between mountain birch forests and tundra often constitutes a wide transition zone called forest-tundra ecotone. In addition to temperature, other abiotic factors, such as slope gradient and sediment types, as well as herbivory and human activities affect the position of treeline (Holtmeier & Broll 2005).

Vegetation types of northern Fennoscandia

Spatially and temporally consistent information on vegetation is required in order to understand the factors affecting the current and future distribution of different vegetation communities. Remote sensing data and methods based on repeated measurements of reflected radiation from Earth's surface are highly relevant in mapping vegetation over large areas. Various satellite images have been widely utilized to map vegetation characteristics and changes from local to global scales (Xie et al. 2008).

TUNDRA project produced a vegetation database of Northern Fennoscandia with the aid of selected Landsat TM and ETM+ images from 1994–2003 through six operational stages: (1) spectral classification, (2) spectral similarity analysis, (3) generation of classified image mosaics, (4) ancillary data analysis and integration, (5) contextual correction, and (6) standardization of the final map products. The spatial resolution (the pixel size) of the product is 30 m. The most detailed version of the developed map is differentiated into 21 land cover classes, whereas an aggregated version contains 14 classes (Fig. 12, Appendix 2). This vegetation information has supported several research aspects, such as a revised delineation of tundra areas in Scandinavia (Virtanen et al. 2016), the relationship between snow cover and vegetation distribution (Cohen et al. 2013), plus various reindeer range studies, climate impact studies, and land use aspects for reindeer herders.

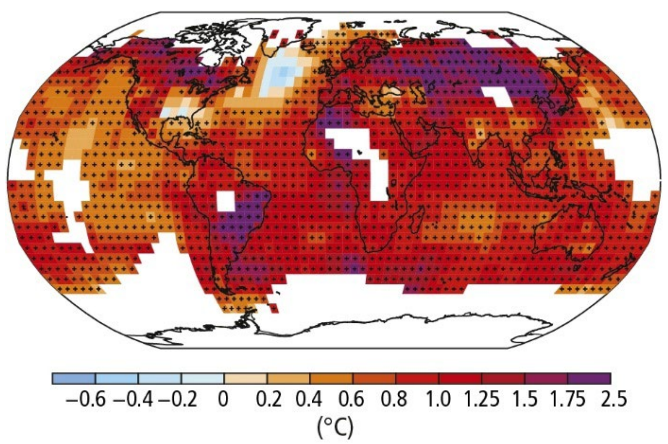

Figure 11. Observed global surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression. IPCC 2013a.

Climate and tundra vegetation in the future

Climate projections

Global climate models are used to examine the current climate and to project future cli-

Info box 2: Climate variability after the last glacial period

Climate and the associated distribution of vegetation zones have varied significantly after the last glacial period. The current post-glacial epoch, the Holocene, began circa 11700 years ago. Around 10000–9000 BP (before present), climate was cooler than today and pioneer plants, such as dwarf shrubs and grasses established themselves after glacial retreat. The relatively warm period at 8 000–5800 BP is called *hypsithermal,* with annual mean temperatures on average two degrees higher than today. Pine forests were found notably further north and at higher altitude than today, and many mountain glaciers retreated or disappeared. At around 5000 BP, climate cooled and became more variable. This caused a gradual retreat of pine, increased development of bogs and mires, and expansion of glaciers. The past 4000 years have been characterized by generally cooler climate with some temperature fluctuations, such as a warmer period called *Medieval Climate Anomaly* at 900–1300 AD and a cooler period called *Little Ice Age* at 1500–1850 AD (Korhola et al. 2002; Lilleøren et al. 2012).

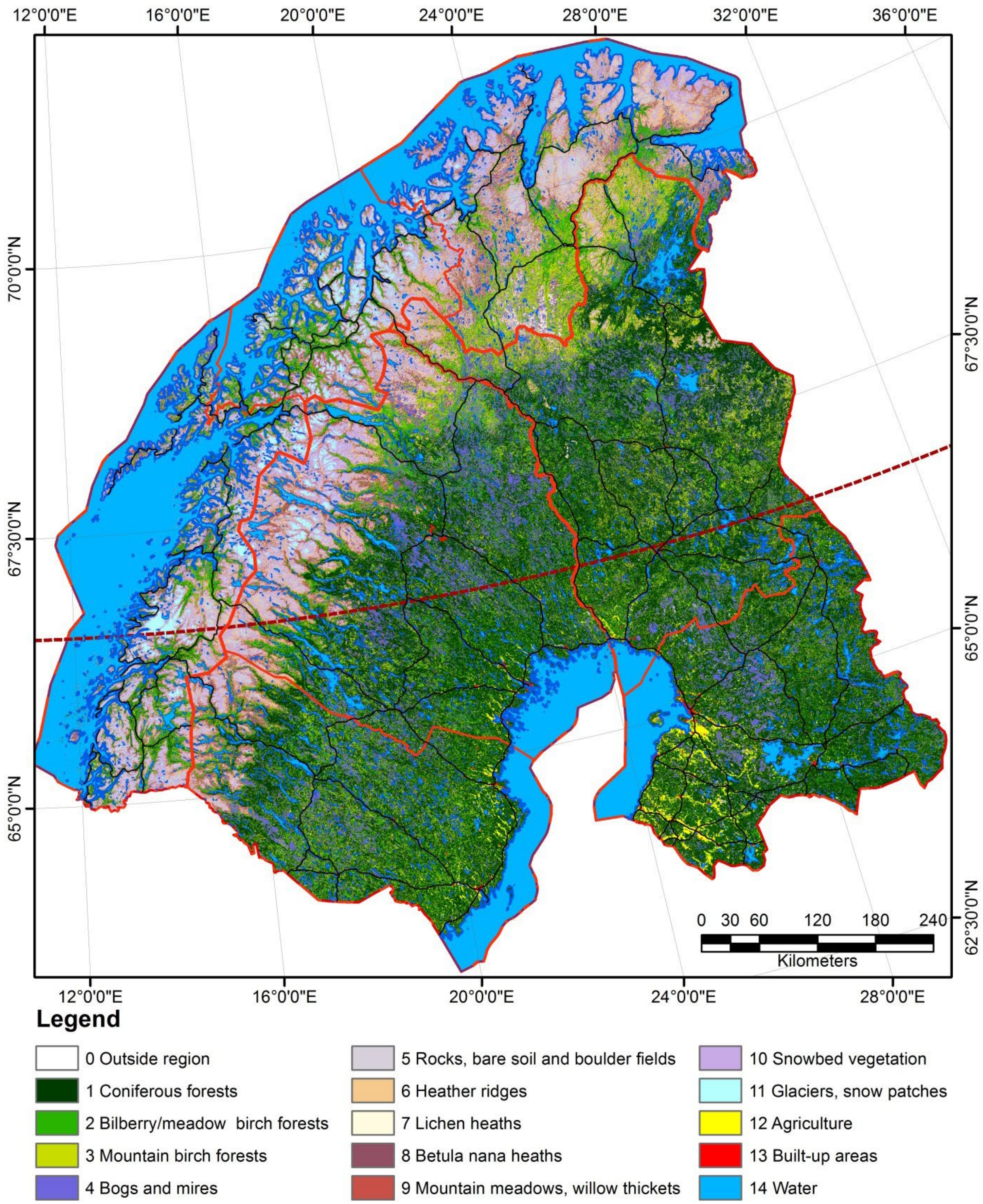

Figure 12. Land cover-land use map of northern Fennoscandia by Bernt Johansen based on Landsat data and ancillary information. This version shows land cover in 14 classes.

matic conditions. Representative concentration pathways (RCP) are the latest scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) and utilized in current climate research. They describe four possible climate futures that depend on how much greenhouse gases are emitted (IPCC 2013). Greenhouse gases contribute to radiative forcing, i.e. the "imbalance" between incoming solar radiation and outgoing infrared radiation, which results in increasing global temperatures. RCPs are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2; van Vuuren et al. 2011), and each pathway gives different warming trends for Northern Europe (Fig. 13).

Even with the lowest radiative forcing values, climate conditions and associated vegetation zones are projected to change considerably in northern Fennoscandia (Figs. 14 and 15). The current treeline coincides relatively well with the 10°C isotherm for the mean summer temperature. Climate projections demonstrate that in 2070, summer temperatures below 10°C may be found only in the high-altitude areas of the Scandinavian mountain range that today mainly consists of glaciers.

Shrub expansion and surface albedo changes

Incident solar radiation reaching Earth's surface is both reflected back to space and absorbed to the surface. The fraction of reflected solar radiation is called albedo. Different surfaces reflect sunlight in different ways. For example, fresh snow reflects a large proportion of incoming sunlight and has high albedo (0.9), whereas oceans and coniferous forests reflect less sunlight and have low albedo (0.06–0.15). The absorbed radiation heats the surface and, among several other factors, affects Earth's energy balance (Dickinson 1983).

Tundra environments in northern Fennoscandia are covered by snow for more than half of the year. In shrub-tundra landscapes,

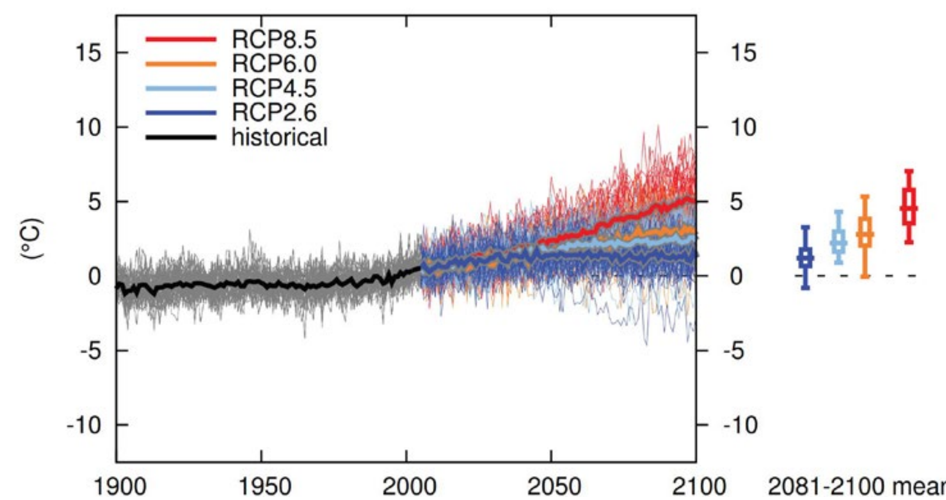

Figure 13. Time series of summer (June-July-August) temperature change in 1900–2100 relative to 1986–2005 in North Europe for four different Representative Concentration Pathways (RCPs; see text for details). IPCC 2013b.

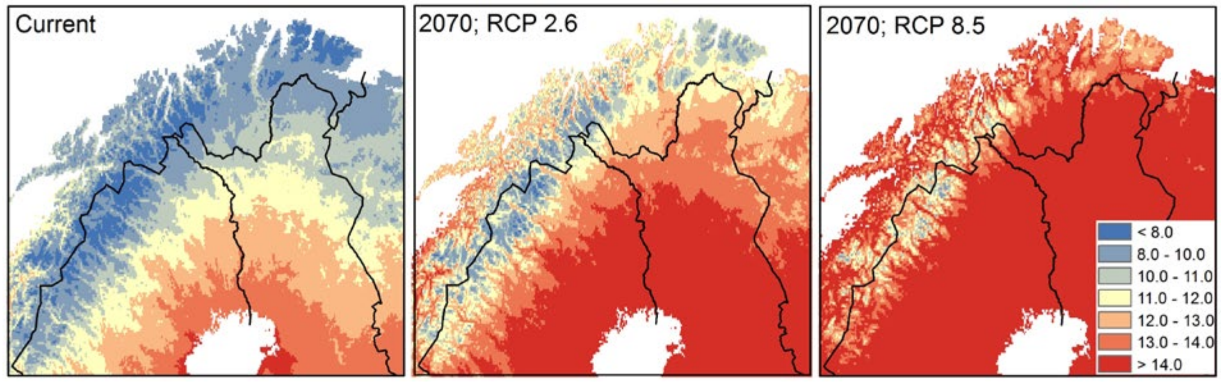

Figure 14. Current mean temperature of the warmest quarter (left) and projected temperatures in 2070 according to RCP 2.6 (middle) and RCP 8.5 (right). Hijmans et al. 2005, Worldclim 2015.

the albedo and energy budget is determined by the relationship between the fractional snow cover and the fraction of vegetation protruding above the snow-pack (Menard et al. 2014b). Shrubs exposed above snow decrease surface albedo and increase the absorption of solar radiation and sensible heat fluxes to the atmosphere. Springtime changes in snow cover extent and duration have the strongest impacts on the amount of reflected radiation at high latitudes, as the long polar night does not contribute much to radiation balances. Projected increases in spring temperatures combined with expansion and densification of shrub vegetation can significantly decrease surface albedo, and amplify global warming (Menard et al. 2014a).

Snowmelt has been found to occur earlier in pastures where reindeer are not present during summer. In these areas, where reindeer do not browse the vegetation during the growing season, more and taller shrubs and trees protrude above the snowpack compared to year-round grazing areas with shorter and sparser vegetation. This results in lower albedo in non-summer pastures

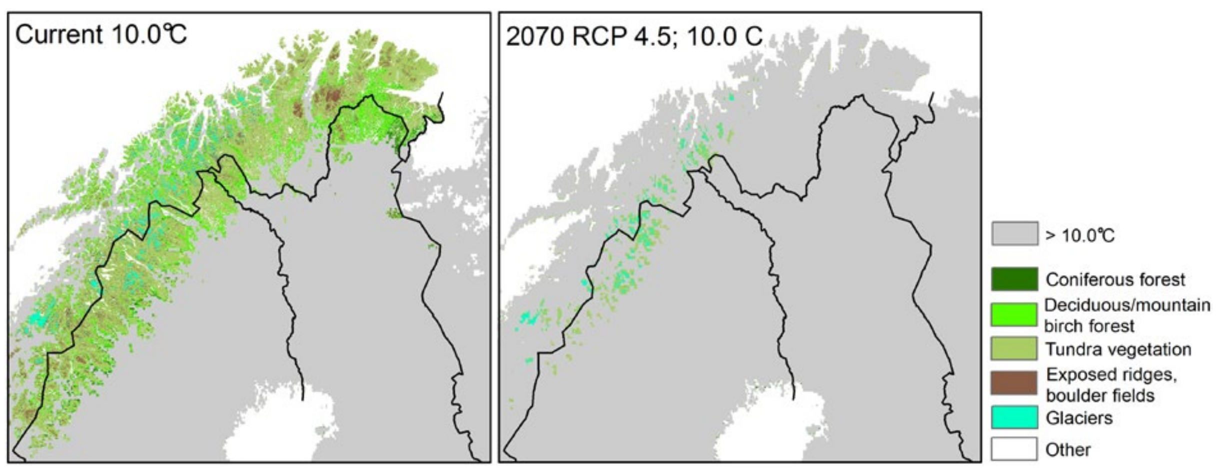

Figure 15. Current and projected mean temperatures (RCP 4.5) of the warmest quarter (Hijmans et al. 2005, Worldclim 2015) and current vegetation types (cf. Fig 10).

during the spring season (Cohen et al. 2013). Reindeer grazing has a clear impact on surface albedo also in moth-damaged mountain birch forests. For example, after moth defoliation, the severely hampered regeneration of mountain birch forest in year-round pastures has been reported to result in a significant 5% increase in spring albedo compared to winter grazed regions (Biuw et al. 2014). It should be noted that variations in snow accumulation and snowmelt are also strongly driven by regional climate and topography in addition to vegetation. The large-scale estimation of the effects of shrub expansion on the energy budget of high-latitude areas should therefore take into consideration, for example, wind redistribution of snow, topography as well as shrub bending and emergence, as they all affect the variability of snow cover (Menard et al. 2014).

4
The impact of herbivory on the tree line and the tundra

Keystone species and their impact on arctic-alpine vegetation dynamics

The most important herbivores that shape the dynamics of vegetation communities at the tree line and above include reindeer (*Rangifer tarandus*), rodents (*Arvicolinae*, voles and lemmings) and geometrid moths (autumnal moth *Epirrita autumnata;* winter moth *Operophtera brumata*) (Fig. 16). The impact of these herbivores differs in its seasonality, frequency, intensity and spatial distribution depending on their respective mobility, and growth forms of preferred vegetation (Table 1).

Figure 16. Herbivores have a strong impact on vegetation communities at the tree line and on the tundra in Northern Fennoscandia; a) reindeer, b) grey red-backed vole, c) lemming, d) autumnal moth caterpillar.

Table 1. Impacts of different herbivores on the vegetation at the tree line and the tundra

	Tundra	Shrubs and dwarf shrubs	Forest (birches)
Reindeer	high impact[1]	affect mainly large shrubs > 30 cm[1]	high impact at forest line, when present in growing season (i.e. year-round grazing)[1]
Rodents	high impact especially in outbreak years, as no control by predators[1]	affect mainly smaller shrubs < 30 cm, irrespective of palatability[1]	controlled by predators, but high impact in outbreak years[2]
Moths	no impact[3]	affect dwarf shrubs in outbreak years in oligotrophic heaths[3]	high defoliation impact in outbreak years[3]

References: 1) Olofsson et al. 2009; 2) Aunapuu et al. 2008; 3) Karlsen et al. 2013

The impact of rodents on the tundra

Rodent populations are characterized by pronounced oscillations with a fairly regular periodicity of five years (Fig. 17). This periodicity is generated by voles, which primarily dwell near the tree line. Lemmings, primarily found at higher altitudes, have less regular outbreaks followed by abrupt crashes. Such outbreaks have occurred in 1978, 1988, 2007 and 2011 (Ekerholm et al. 2001, Olofsson et al. 2014, Ruffino et al. 2016). Between outbreaks, the remain-

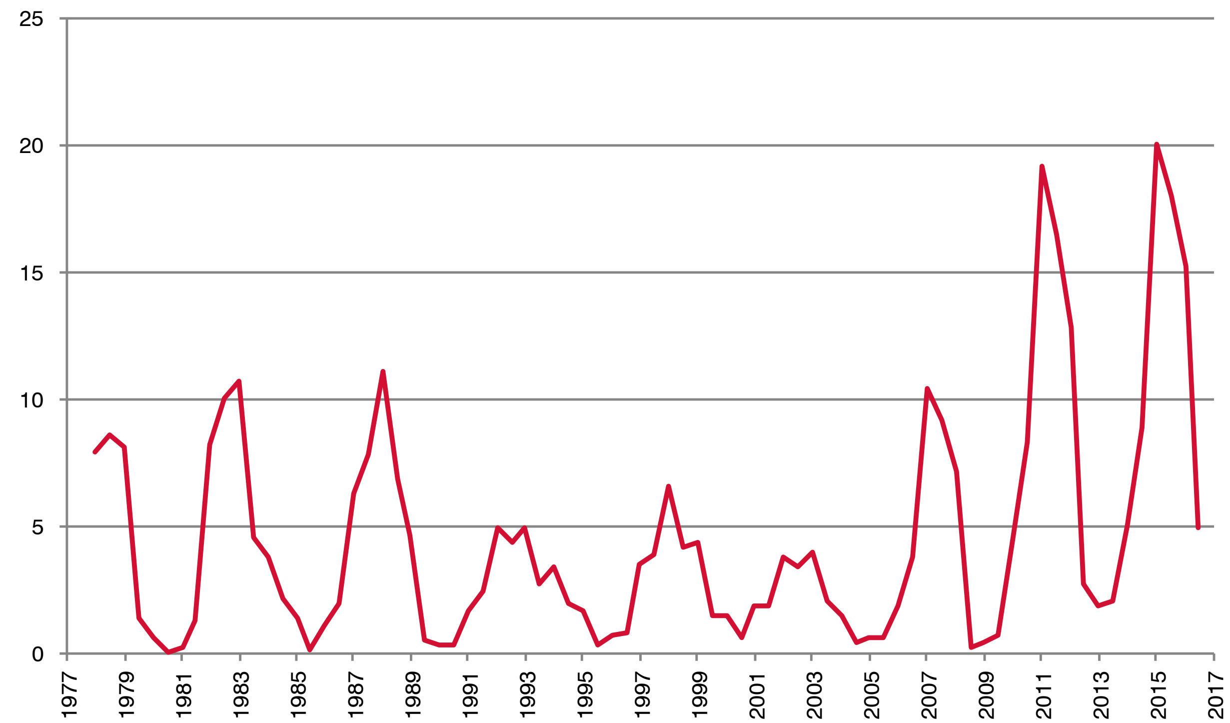

Figure 17. Density oscillations of voles and lemmings on northern Finnmarksvidda, Norway, during 1977–2016. Index values (captures per 100 trap nights) have been smoothed over three successive trapping sessions.

ing lemmings are only found in snowbeds and mires. At the tree line, predation by small mustelids, such as *stoats (Mustela erminea)* and least weasels *(Mustela nivalis)*, is a strong regulator of rodents and keeps their impact low during non-outbreak years (Turchin et al. 2000, Aunapuu et al. 2008) and probably accounts for the periodicity of these oscillations (Turchin et al. 2000, Ekerholm et al. 2001).

Lemmings forage primarily on mosses, grasses and sedges and cannot eat lichens or woody parts of woody plants, though they consume their leaves (Saetnan et al. 2009). However, these plant groups, which lemmings cannot eat, suffer maximally from their effect (Fig. 18). In contrast, their main winter food items, i.e. small mosses, gain from lemming grazing (Olofsson et al. 2014, Virtanen 2000). In winter, lemmings dig their way under the snow to their food items, and whatever is on their way is destroyed. Especially evergreens, which store most of their resources in aboveground organs, suffer heavily. Conversely, small mosses recover from basal cells. In the absence of lemmings, these mosses would become overgrown by stronger competitors, as would also grasses and sedges in the long run (Saccone & Virtanen 2016). In summer, the impact of rodents is rarely detectable due to rapid vegetation growth.

The impact of lemmings is thus important for the maintenance of snow bed vegetation where there is an abundance of forbs, grasses, sedges and palatable deciduous dwarf shrubs.

All in all, rodents have an enormous impact on tundra vegetation, and consequently also on nutrient circulation and carbon balance (Olofsson et al. 2004, Ylänne et al. 2015). These impacts are especially strong in areas above the tree line, where they can be seen even from space (Olofsson et al. 2012).

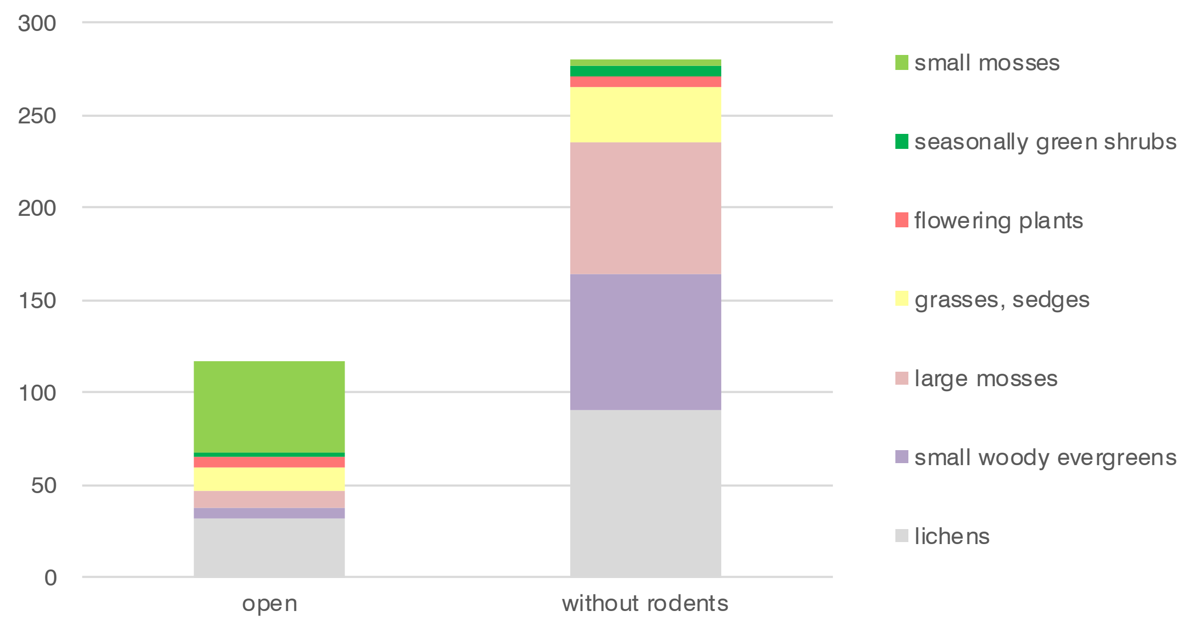

Figure 18. Biomasses (g/m² dry weight) of different plant groups at open plots and in exclosures inaccessible to rodents on heath snowbeds in 2008.

Rodents' impact on woody plants at the tree line

Although voles can cause high damage to deciduous dwarf shrubs, such as bilberry (*Vaccinium myrtillus*), their effect on tree saplings that are growing on the tundra is much less pronounced. Saplings of Eurasian tree line species survived in an experiment regardless of the impact of rodents. The tree species included mountain birch (*Betula pubescens* ssp. *czerepanovii*), larch (*Larix larix*), pine (*Pinus sylvestris*) and spruce (*Picea abies*).

During high vole populations, spruce saplings had the highest survival rate. The rodents' impact on the growth of the surviving saplings was small, though with significant species-specific differences. On average, pines grew best, and mountain birches and larches worst.

In other words, the native mountain birch seems not to be the most successful tree species in the inland climate of northern Fennoscandia, as it is outperformed by the three other species. In particular, spruces have high sapling survival rate, are influenced little by voles and not eaten by reindeer either. Thus, they may become a dominant species at the tree line especially if supported by planting, as has been done in northern Norway. Invasion of evergreen conifers at the tree line would dramatically reduce ground albedo and affect snow conditions (see Chapter 3).

Reindeer and their impact on tundra plant communities

Most of the semi-domesticated reindeer in Sweden and Norway migrate between coastal mountains and inland forests to exploit the seasonally changing vegetation availability (cf. Figs. 4 & 12). Sámi reindeer husbandry has followed this natural pattern, and still does so as much as possible given the constraints imposed by the nation states (see Chapter 2).

In winter, reindeer forage on lichens and vascular plants, including shrubs and grasses (Storeheier et al. 2003). Where reindeer are present above the tree line during winter, their impact is concentrated on wind-swept, snow-free ridges. Nevertheless, the main impact of reindeer on woody and other vascular plants occurs in summer, when reindeer gather in areas with high plant productivity. In early summer, this includes willow and mountain birch scrublands. Willow and birch leaves are primarily consumed during a short period when leaves are young and soft, until other plants, such as herbs, forbs and grasses become maximally nutritious (Fig. 19). Maximum grazing impact on woody plants is thus obtained if reindeer are present in June and early July. Later in the growing season, reindeer prefer moist and nutrient-rich tundra habitats, or vegetation close to snow beds. In these habitats, the grazing pressure, as well as indirect effects such as trampling and nutrient input via urine and faeces, their orders of magnitude can be higher than on average.

Therefore, the impact of summer grazing does not depend on timing only, but also on spatial grazing patterns. Along fences with high densities of reindeer, woody vegetation is often replaced by grassland (Olofsson et al. 2001, Fig. 18). Similar effects can be obtained without fences by keeping the reindeer in compact herds, which was a common practice earlier in Scandinavia (Tømmervik et al. 2010) and is still practiced in some parts of the Arctic (Forbes et al. 2009). Consequently, reindeer have a strong periodic impact on all plants, but not all the time. As grazing reaches destructive intensity, woody plants are replaced by grasses and forbs. If grazing pressure is thereafter

Figure 19. a) Reindeer foraging on fresh birch leaves in late June; b) a reindeer fence separating an intensely used summer range, dominated by grasses, from an autumn range with woody vegetation. Raisduoddar, Norway.

reduced, the grass-forb community is resistant to the invasion of woody plants and may form a good summer pasture, if the emerging plants are preferred forage species. Although the influence is only local, these vegetation shifts can remain visible for centuries, even when active management has ceased (Tømmervik et al. 2010). In contrast, constant nibbling with the same average intensity rather leads to expansion of poorly palatable dwarf shrubs, which indeed is a common situation today (Bråthen et al. 2007). During the mosquito season, reindeer prefer elevated, windy areas. In areas where reindeer have no access to seashore or mountains, this behaviour leads to substantial trampling of lichen rich hills, i.e. important winter habitats of reindeer. During dry weather, lichens will be destroyed by trampling, which reduces the quality of these areas as winter grazing grounds.

Reindeer can also prevent tall herbaceous plants from expanding their range from lower elevations into the tundra as a response to climate change. Reindeer thus have a major role in preventing boreal plants from outcompeting the usually much smaller arctic species (Kaarlejärvi et al. 2013). This suggests that well-planned and targeted reindeer grazing periods could possibly be used as a conservation tool to keep selected tundra habitats open and to maintain tundra plant diversity in future climate conditions (Kaarlejärvi & Olofsson 2014).

Geometrid moths and their impact on the tree line

Folivorous insects rarely cause detectable damage on the tundra. However, the mountain birch forests are periodically defoliated by moth larvae, primarily by autumnal moths (*Epirrita autumnanta*, Fig. 20) in the inland, and by winter moths (*Operophtera brumata)* on the coast (Tenow 1972). Birches respond to defoliation by producing new leaves in late summer, after the caterpillars have pupated. Severe and recurrent defoliation can kill both birches and dwarf shrubs over large areas (Jepsen et al. 2013). Another consequence is a massive nutrient addition to the forest floor in the form of larval faeces and dead larvae, plus an increased penetration of light. Therefore, forest floor can be transformed from a dwarf shrub community to a grass dominated community (Karlsen et al. 2013, Jepsen et al. 2013).

Figure 20. Mountain birch forest in northern Finnish Lapland after a severe defoliation by autumnal moth.

Outbreaks of geometrid moths are a natural component of the mountain birch forests (Tenow 1972). However, in recent decades, warming climate with less extreme winter cold and more benign spring conditions has increased the outbreak ranges of these moths (Jepsen et al. 2008) into more northern and continental areas (Fig. 21). The observed range expansion is probably permitted by both less extreme winter colds (Ammunet et al. 2012) and more benign spring conditions, which affect the phenological match between birch budburst and larval hatching (Jepsen et al. 2011). Midwinter temperatures below -36° C kill the eggs of *E. autumnata*, thus setting a belt of tolerable temperatures for survival between cold air masses accumulating in depressions, such as river valleys and exposed hills at higher elevation (Tenow & Nilssen 1990, Ruohomäki et al. 2000), and exclude moths from the entire Finnmarksvidda (Tenow & Nilssen 1990, Jepsen et al. 2008). In addition, higher spring and summer temperatures increase outbreak severity (Young et al. 2014). An increase in the overlap between outbreak ranges of the different geometrid species leads to longer and more severe outbreaks, as the two species do not always peak at the same time.

On the other hand, warmer and longer summers have made birches more resistant to defoliation, since they have a better chance

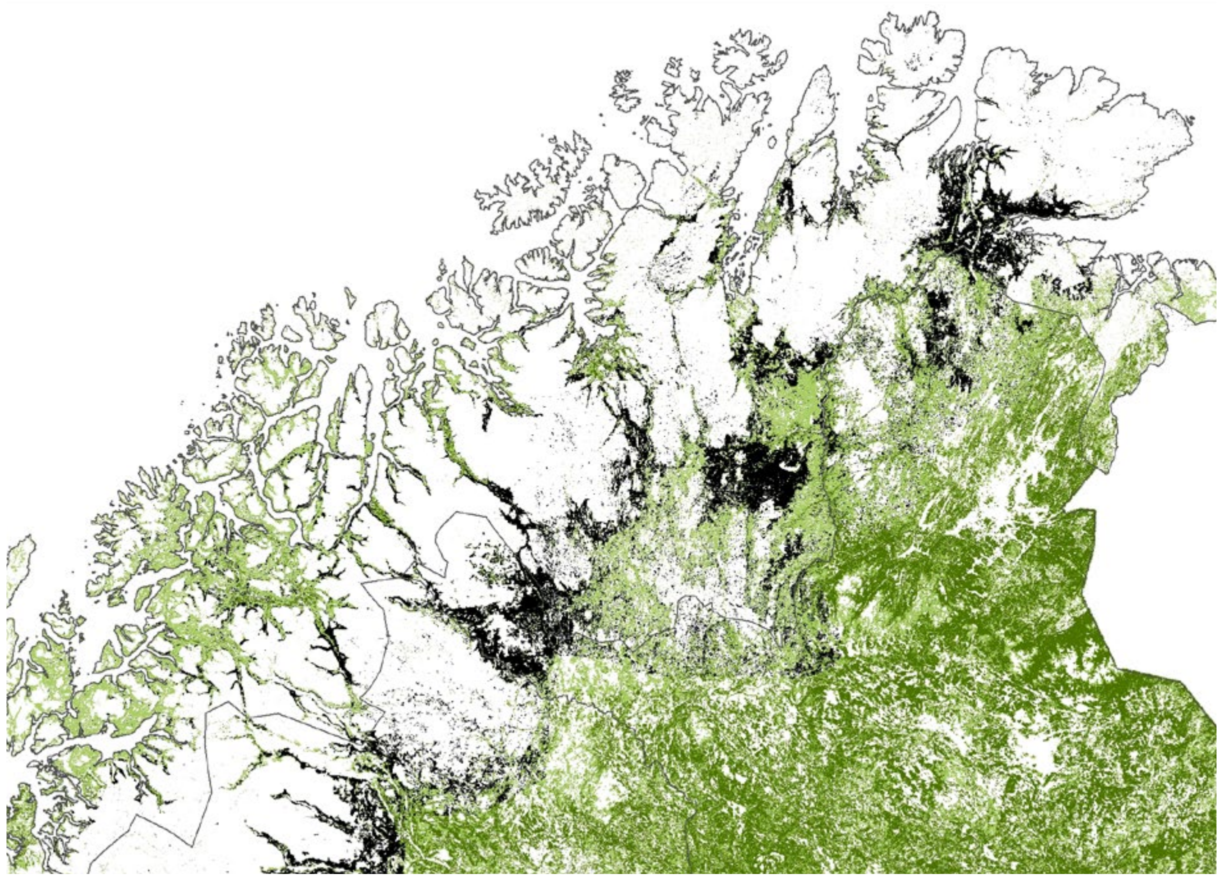

Figure 21. During the previous (2002–2010) moth outbreak cycle in Northern Fennoscandia, 1/3 of the birch forest belt were subject to severe defoliation in one or more years (black shaded area). This is equivalent to 1 million hectares of birch forest. Birch-dominated forest with little or no defoliation is shown in light green, while coniferous dominated forest is shown in dark green. Jepsen et al. 2009.

to compensate their defoliation losses by producing new leaves. Mountain birches can also recover after the death of the main trunk by sprouting from its base. However, it is difficult to estimate the overall impact of rising temperatures on the mountain birches' ability to recover from moth outbreaks. For example, it has been suggested that thermal sum accumulation does not greatly promote the recovery of mountain birches after moth outbreaks (Huttunen et al. 2012, 2013). After a moth outbreak, summer grazing by reindeer leads to increasing birch mortality (Biuw et al. 2014). Moreover, by eating basal recovery sprouts, reindeer can slow down or stop the recovery of birches (Fig. 22).

In summer grazed areas, the interaction of moths and reindeer is therefore changing closed birch forests to tundra or to savannah-like vegetation – an open landscape with scattered birches, having a clear browse line (Biuw et al. 2014). This phenomenon has happened wherever summer grazing has been intense, both along the coast of Norwegian Lapland and in inland areas of Finnish Lapland (Fig. 23).

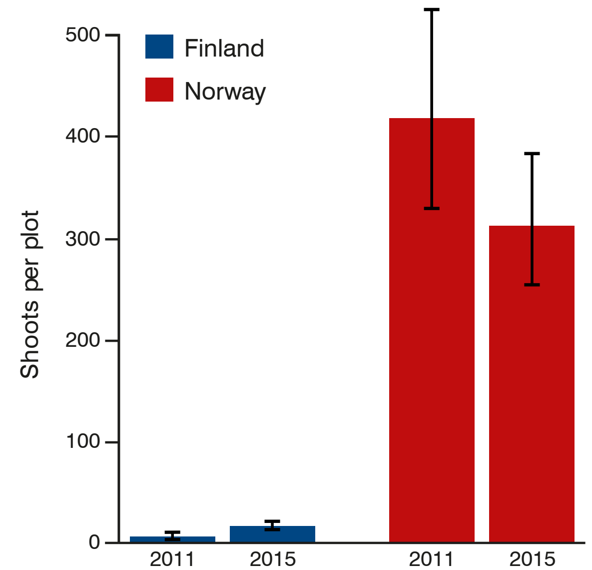

Figure 22. A short-term impact of reindeer grazing regime on birch recovery, after the 2007–08 moth outbreaks that killed the majority of birch stems in the Buolbmat (Polmak, Pulmanki) area at the Finnish-Norwegian border. The Norwegian side is a winter range, while the Finnish side is grazed in all seasons. The condition was analysed in 2011 and again in 2015 (3 and 7 years after the event) and quantified as the number of basal recovery shoots per 30 x 30 m survey plot. Source: unpublished data by Jepsen et al.

Reindeer and their impact on arctic plant biodiversity

By preventing the invasion of trees and tall shrubs and forbs, reindeer can maintain the openness of the tundra, which is a precondition for the survival of many small arctic plants. However, reindeer also have other impacts on plants. Especially the immediate, potentially destructive impacts (trampling and feeding) have obtained much attention in media and have been a serious concern in nature protection, exemplified by the ban of reindeer grazing in the Malla Strict Preserve at Kilpisjärvi, northwest Finnish Lapland, and a similarly motivated attempt to exclude reindeer from the Jávrioaivit Preserve in Nordreisa, Troms, Norway.

In northern Europe, arctic plant biodiversity is strongly dependent on lime-rich areas (Dynesius and Jansson 2000, Pärtel 2002). Such habitats form only a tiny fraction of the Fennoscandian tundra and lie primarily at relatively low altitudes. The threat to arctic biodiversity is thus acute in the entire Fennoscandia.

Figure 23. "Birch savannah" landscapes created by the interaction between moths and reindeer, a) on the island of Sievju / Seiland, Norwegian Lapland, and b) at the rim of Kevo Canyon, Finnish Lapland.

Figure 24. Purple saxifrage (*Saxifraga oppositifolia*). Norrbotten, Sweden.

The open question is whether reindeer grazing can save these plants in a warming climate or whether it aggravates the problem.

A comparison of the overall diversity and occurrence of different plant categories below dolomite rocks showed that the collective abundance of plants red-listed in Finland increases linearly with the intensity of summer grazing by reindeer (Olofsson & Oksanen 2005). The overall diversity was not influenced by reindeer grazing.

Some rare plants may suffer from intense reindeer grazing, while others remain unaffected. However, intense summer grazing is favourable for many arctic alpine rarities, such as the black alpine sedge (*Carex atrata*), the purple saxifrage (*Saxifraga oppositifolia*, Fig. 24), the Siberian thrift (*Armeria maritima* ssp. *sibirica*), and the sulphur buttercup (*Ranunculus sulphurous*). Some of these species tend to be tolerant towards grazing, but are easily outcompeted where no disturbance occurs. Though grazing may damage parts of the rare arctic plants, the net impact of intense summer grazing can be positive on the population level.

5
Human actors in the social-ecological system

Reindeer herders' perceptions of changes in the social-ecological system

TUNDRA research included workshops with reindeer herders in Sápmi, to gather perceptions of the changes that are transforming their pastoral landscape. Items of discussion included vegetation changes, such as increased growth of trees and shrubs, the interaction between reindeer and vegetation, and also non-ecological issues such as land use changes and social aspects of reindeer husbandry. In each country, two districts were chosen (Fig. 25) for the workshops.

The discussions in the workshops produced a wealth of material, naturally with somewhat diverse view angles and opinions. However, it was possible to identify the greatest common concerns that emerged repeatedly in the six districts. These are discussed and analysed further below, but can be summarised under the four SES concepts (see Chapter 1) as follows:

Environment
- Extreme weather conditions (hot summers; freeze-thaw and rain-on-snow during winter)

Resources
- Land use conflicts

Actors
- Lack of self-determination

Governance
- Unclear, diffuse legislation on several levels

Environment and Resources

Regarding changes in the landscape, many similar observations were reported in all of the districts, while some processes were place-specific. In all districts, seasonality is experienced as changing. In particular, winter weather was reported to have become less predictable with large temperature fluctuations over short time spans, frequent freeze-thaw cycles, and rain-on-snow. Hot summers were considered as an example of new extreme events. These effects make it more difficult to plan ahead herding practices.

All districts experienced encroachment of their grazing grounds by other forms of land use, albeit the specific forms of land use differed. However, given the differences in seasonal migration systems between the countries, the seasonal grazing grounds that were considered as most vulnerable differ. For example, in Tuorpon (Sweden), the availability of winter grazing resources in the boreal forest is affected by modern forestry, while Beahcegealli (Norway) faces an incision on their summer grazing areas by the planned Balsfjord Power Line (Statnett 2015). Similarly, participants expressed a common concern that all grazing land was being used, offering few areas as reserve areas.

Workshop participants in all districts observed an increase of trees and shrubs. However, the intensity of this process varied between the districts and countries, due to the large variation in i) grazing systems and ii) the regional differ-

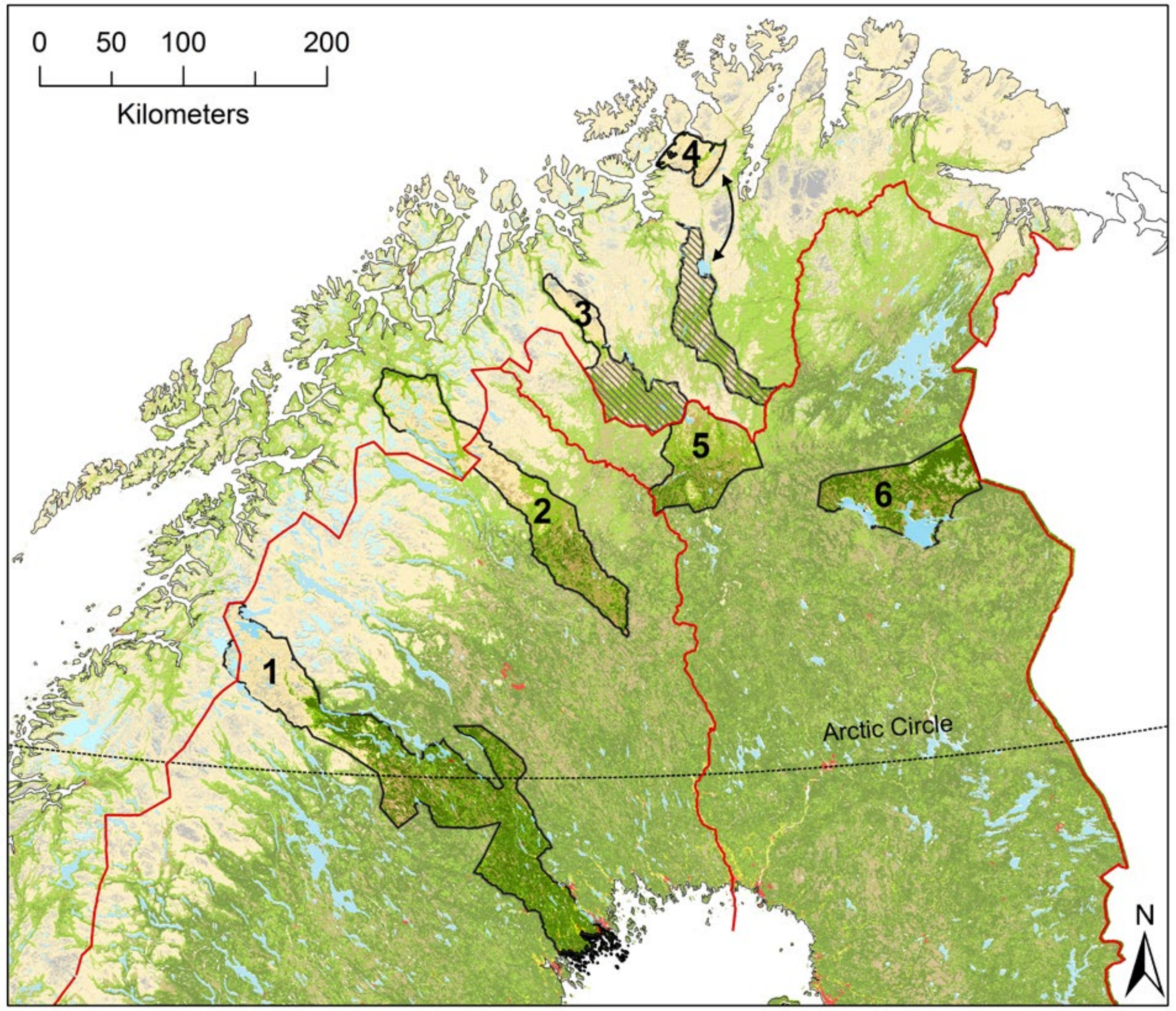

Figure 25. Interactive workshops were conducted in six herding districts, two in each country. Sweden: 1) Tuorpon, and 2) Saarivuoma; Norway: 3) Beahcegealli, and 4) Fiettar (showing separate summer and spring-, autumn-, winter pasture regions); Finland: 5) Näkkälä, and 6) Lappi. The hatched areas in the Norwegian districts denote spring-autumn and winter pastures that are shared with other districts.

ences in biotic and abiotic factors. Consequently, there was no consensus on impacts of reindeer grazing on the growth of shrubs and trees at the Fennoscandian level. However, where increased shrub and tree growth on formerly treeless areas was observed, these processes were considered as primarily unfavourable in all districts. The mechanisms of these adverse effects differ, depending on the specific herding practices and aspects of reindeer ecology that are affected. For example, increased growth of birches affects winter grazing grounds in the herding districts of Fiettar, Beahcegealli (Norway) and Näkkälä (Finland). The increased abundance of trees leads to higher snow accumulation, making it more difficult for reindeer to dig for plants and lichens underneath the snow cover. Workshop participants therefore emphasized the need of a diverse landscape with both open and forested areas, in order to offer accessible grazing resources under different winter weather conditions.

Where grazing grounds during the snow free season are being encroached upon by birches and willows, reindeer leave these areas and select grazing grounds at higher altitudes. Despite these negative consequences of increased growth of trees and shrubs, these transformation were not commonly seen as a major threat to reindeer husbandry in comparison to, for example, negative effects of other forms of land use on the availability of grazing grounds.

Similarly, the significance of drivers contributing to increased growth of trees and shrubs was highly diverse across the districts. However, there was generally a high consensus about the nature of the most important drivers. Besides the grazing impact of reindeer in particular abiotic factors, these include factors such as water availability and thickness of the organic soil layer, both favouring the growth of birch and willow. The abandonment of former land use practices was stressed in contributing to increased abundance of trees and shrubs. For example, cutting trees for firewood has considerably decreased. It is worthwhile emphasising, however, that even though many discussion topics revolved around challenges and difficult situations due to climate change and its impacts on the ecosystem, participants in several districts emphasized the resilience of the livelihood and its ability to adapt to changing conditions.

Actors and Governance

Participants emphasized that the options of conducting reindeer husbandry are strongly influenced by the institutional design in their respective country, in combination with district-specific characteristics. Frictions arise from a diverse set of reasons, such as power relations with other forms of land use, external government decisions that do not allow to set reindeer numbers according to the herders' preference and own perceptions of the carrying capacity of the grazing grounds, or restrictions on herd composition set by market economy. Policies related to the crossing of national borders during migration were also discussed, as well as administrative borders that are in conflict with natural behaviour of reindeer and thus restrict the selection of a preferred habitat.

Consequently, rather than extreme weather conditions or other ecological issues, it is the resources-actors-governance sector that the herders see most problematic. We therefore argue that the greatest challenges in today's reindeer husbandry have to do with imperfect discourse between the stakeholders. This matter can be considered theoretically with the so-called institutional analysis and development (IAD) framework also developed by Ostrom (2011) (Fig. 26). In the IAD framework, the environment, the involved human community and the rules-in-use interact forming the outcome, i.e. the current reality.

Following the IAD framework, our argument of unsatisfactory discourse can be reformulated so that it denotes the imperfect action situations and subsequently, flawed interactions between the stakeholders. There are numerous examples of distrust between the governance and various livelihoods in primary production, including fisheries, agriculture as well as reindeer husbandry. Of these, it is indeed reindeer husbandry that poses the longest list of challenges as it intertwines such a complex

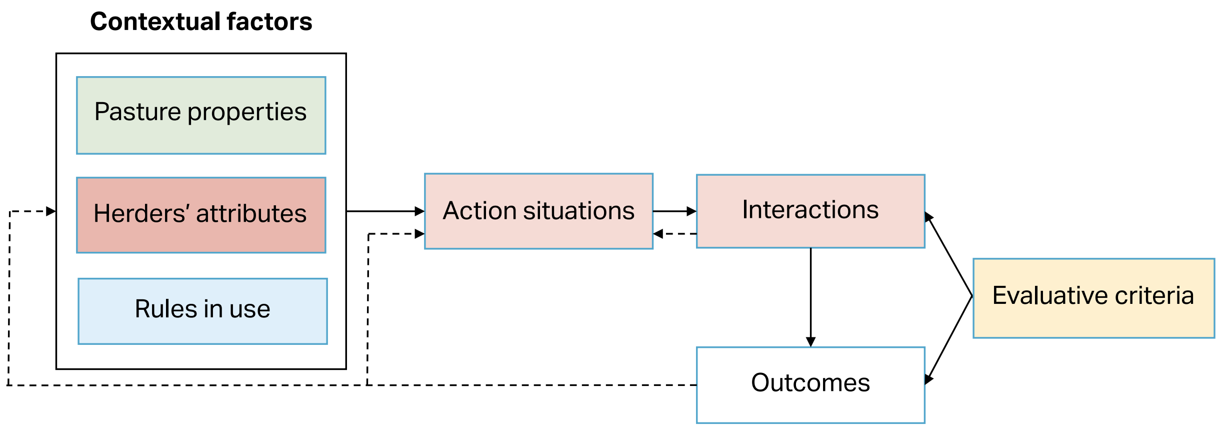

Figure 26. Institutional analysis and development IAD framework (after Ostrom 2011) in reindeer husbandry.

myriad of parameters from ancient cultural heritage to competing land use interest, as has been described also in, for example, Forbes et al. (2006). There is clearly too little interaction and inadequate, unequal discussion between the stakeholders. From the herders' perspective, unclear legislation and lack of self-determination are considered as threats for the livelihood.

To improve the quality of decision making, more and better interaction will be needed between stakeholders. Planning and actions regarding future land use and livelihoods should be co-designed by different stakeholders. To overcome the historical apprehension between the parties, a neutral boundary organisation might serve as an appreciated mediator.

Action situation: the final stakeholder workshop

TUNDRA organized a stakeholder workshop representing an action situation according to the IAD framework (cf. Fig. 26). Reindeer herders, representatives of various ministries and Sámi Parliament as well as regional authorities from all three countries were invited to participate a small-group discussion with TUNDRA researchers regarding the present and future impacts on reindeer husbandry in a Co-Nordic context. The participants were divided into national small-groups to consider the three items of interest listed below. The outcome of the small-group discussions was synthesised into concise narratives.

- What are the most influential factors on reindeer husbandry today?
- What are expected to be the most influential internal and external factors on reindeer husbandry in the future?
- Is it plausible to consider reindeer husbandry as a "conservation tool" to sustain tundra in a warming climate?

Reindeer husbandry today

Participants formulated the most influential factors on reindeer husbandry today as positive, negative or variable in their influence. The origin of these factors was considered either as a long-term (for example several decades) or a recent phenomenon (for example, having occurred within a few years' time). Lastly, the trend of the phenomena was indicated as increasing, stable or decreasing.

Participants discussed factors of both anthropogenic and natural origin. The discussion seemed to focus quite naturally on negative factors, rather large regions, and long timespans. Many of the factors displayed an increasing trend, indicating that the pressure on reindeer husbandry is perceived to increase in the future.

Environmental factors that are challenging to reindeer husbandry mainly relate to weather conditions in every season, but with particular emphasis on winter conditions. These include short-lived events such as snow conditions and freeze-thaw cycles. Predation was another important factor, considered seasonally variable (for example, predation by bear during spring), or increasing in long-term due to growing carnivore populations. Examples of positive factors are related to wind and snow conditions that can reduce work load or assist reindeer herders in their practical work with the animals, for example during seasonal migrations. Stable snow conditions, however, are perceived as becoming infrequent.

Anthropogenic factors are diverse. Negative issues cover topics of direct impact on herding practices, such as off-road traffic and pressure by other forms of land use, as well as borders that hamper traditional herding practices. Indirect effects include ambiguous regulations and decreasing economic support by the state that threaten to weaken the viability of reindeer husbandry. This is a process that has been ongoing over a long period of time.

Positive factors included an increasingly improving attitude towards reindeer husbandry, recognizing its importance in delivering ecosystem services or as a "brand" of high environmental quality. Some regulations that strengthen Sámi rights (for example, *Laponia* in Sweden) support the options to conduct reindeer husbandry regionally. Compared to the negative factors, these positive ones are rather recent events.

Reindeer husbandry in the future

Participants considered the next 20–50 years' development of the livelihood by producing a list of strengths, weaknesses, opportunities and threats – the so-called SWOT analysis. "Strengths" are internal to the livelihood and support its continued existence, while "Weaknesses" may threaten it. External supporting factors are called "Opportunities", while outside pressures are "Threats" (Fig. 27).

Strengths are related to the animals' behaviour and general ecology: their adaptability to various environmental conditions and ability to exploit different kinds of resources. Reindeer herders' cultural background and indigenous knowledge are a source of adaptive capacity in case of disturbances or shocks, while the ability to learn and adjust to new herding practices may help reindeer herders in responding to future pressures. The Sámi culture is regarded as alive and passed down through generations, thus conferring resilience to the livelihood.

Weaknesses include fading traditions, potentially eroding the knowledge base of reindeer herding practices. This was attributed to a lack of self-determination that could curtail reindeer herders' options to practice their livelihood as preferred. Potential negative consequences include dilemmas at the local level, for example in the seasonal rotation of grazing grounds, and in the sharing of the grazing areas between different herding groups.

Increased appreciation by the public was recognized as one of the **opportunities** for a

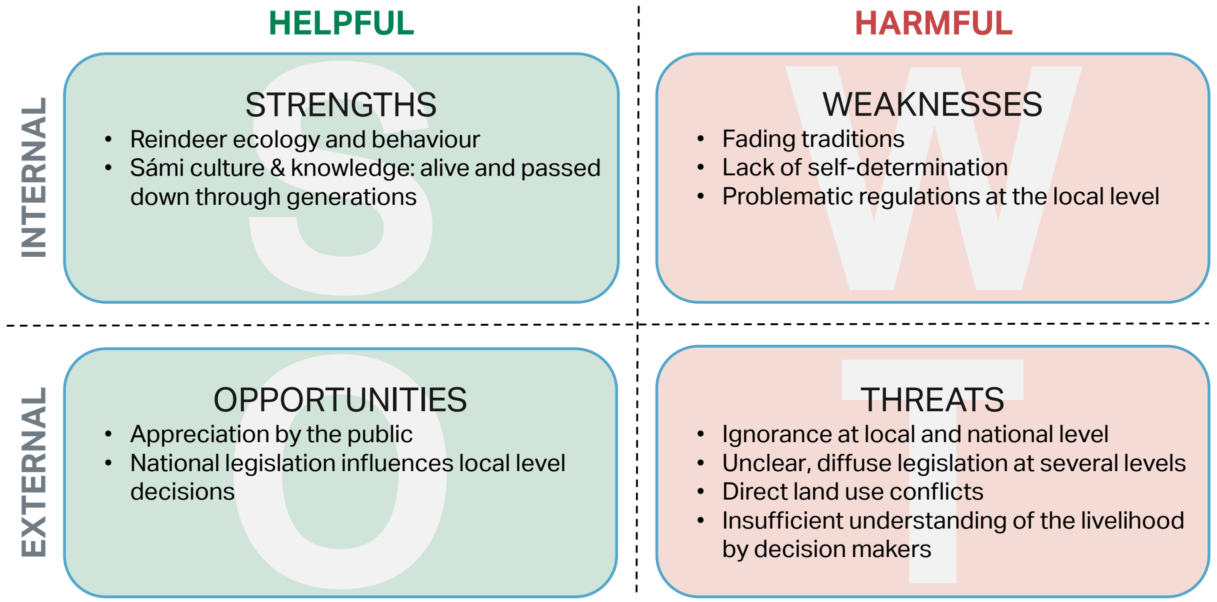

Figure 27. Summary of the key variables considered to be affecting the future of reindeer husbandry, as formulated in the SWOT analyses in small-group discussion of the stakeholder workshop.

viable future of reindeer husbandry. The positive image of the livelihood in producing high quality products with low environmental impact may increase the economic strength, as well as foster the culture. National legislation, which increasingly takes indigenous claims into account, could strengthen the livelihood further. In particular, legislation needs to be responsive to decision-making at the local level, minimising trade-offs with other forms of land use.

Future threats to viable reindeer husbandry include diffuse legislation that exacerbates rather than resolves conflicts. Such development could materialise if decision makers lacked knowledge of reindeer husbandry and its requirements. In such a case the complex feedbacks and consequences resulting from legislation would fail to become realized. This would be detrimental in reducing the adaptive capacity of reindeer husbandry

Reindeer husbandry as a conservation tool

The idea of using reindeer grazing as a conservation tool for preserving the tundra was new to the participants. At first, the participants perceived it difficult to consider implementing reindeer for conservation purposes as it would require substantial changes in grazing practices. Such adjustments would be perceived as emerging from external decisions.

As a second thought, these practices might be able to establish grazing practices in agreement with the self-determination: they could bring about practices that where in place earlier, such as crossing the Swedish-Norwegian border seasonally for suitable pastures. The potential to employ reindeer as a conservation tool would take benefit from the natural behaviour of reindeer to migrate between grazing areas.

The participants disfavoured the idea of conservation tool if it would increase the expenses. Economic provision would be necessary to support the herds' and herders' mobility to fulfil the conservation goals. Targeted grazing would also involve a potential risk of damaging fragile lichens by trampling and thereby affecting negatively the essential winter grazing resources. This is the case for example in inner Finnmark, where the tree line overlaps with lichen-rich winter grazing grounds. This example clearly illustrates the difficult trade-offs involved in ecosystem management and calls for novel solutions in environmental governance for socially desirable and ecologically reasonable management.

6
Exploring potential futures

The stakeholder workshop demonstrated the importance of decision-making and polices in influencing the future of reindeer husbandry. Decision-making is a societal process that often involves difficult choices and trade-offs between different goals and ambitions, depending on the stakeholders involved in the process. To facilitate decision making and arriving at solutions, several essential requirements need to be fulfilled. These include not only the knowledge base on which to build decisions on, but also the understanding of the challenges and need for action, as well as the willingness to act and change.

The scenario approach

Scenario approach has proved to be a useful tool to encourage debate and create fruitful preconditions for decision-making. Scenarios are not projections, predictions, or forecasts – they are rather stories about the future with a logical plot and a narrative governing the manner in which events unfold (Schwartz 1991). A scenario can be described as a description of potentially far-reaching deviations from what we observe today, based on developments and path dependencies that lead to new potential circumstances (Gallopin 2002). It is thus possible to identify branching points, at which different trajectories may result in different futures. Scenarios may help stakeholders – and decision makers in particular – to 'see the forest for the trees', and help in keeping the right track towards the preferred future as a chain of small everyday decisions.

Developing the lessons learned from the stakeholder workshop, we have built qualitative scenario narratives for potential future trajectories of reindeer husbandry related to the tundra regions of Fennoscandia. The scenarios include a component of Sámi traditions and are therefore not directly applicable to southern parts of the Finnish reindeer herding area.

There is a potential to unfold quite different forms of reindeer husbandry in the future depending on the actions and choices taken. We have built four scenarios based on two major parameters related to reindeer husbandry (Fig. 28):

- the degree of land use competition between reindeer husbandry and other activities
- the measure of industrial component in the livelihood

The parameters were selected for their high policy relevance, in other words they represent developments that can be affected by policy decisions in particular during medium and long time perspectives for some decades to come.

In the scenarios, we differentiate reindeer husbandry between two extreme end members along the parameter axes. The livelihood axis stretches between an industrially oriented meat production ('factory herding'), and a diversified livelihood including and appreciating traditional (Sámi) cultural values supported by the ecosystem services offered by the tundra ('natural source of livelihood').

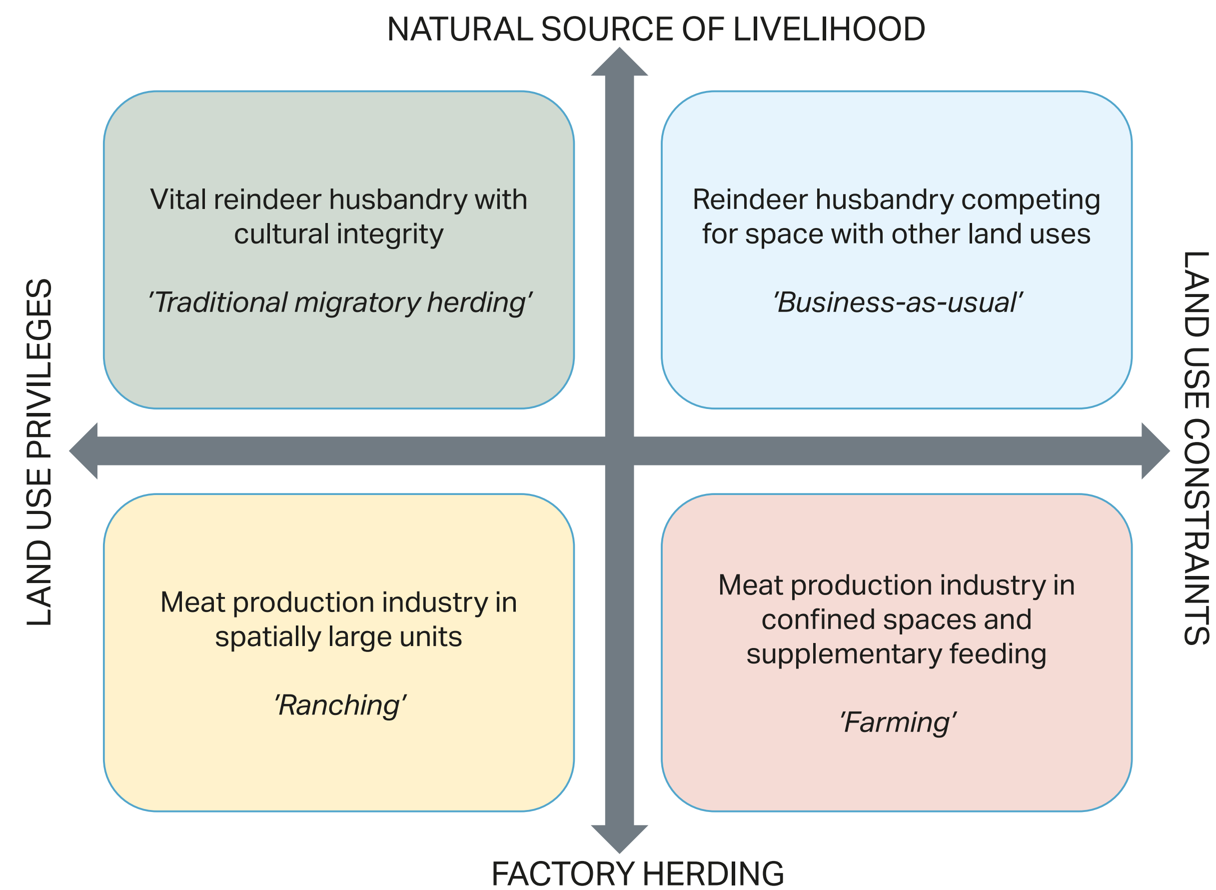

Figure 28. Four scenarios of the potentially unfolding future of reindeer husbandry in Northern Fennoscandia. For further details, see the text and Table 2.

In the industrial form, reindeer husbandry resembles a form of ranching, where people and animals have a more separate existence, and herds are controlled mainly by technological means with decreased seasonal rotation of grazing grounds and stronger reliance on artificial feeding to reduce the dependency on large grazing grounds (Ingold 1980, LaRocque 2014). In comparison, the diversified livelihood involves traditional migratory husbandry and considers animals and people as a more cohesive social unit with grazing control dominated by human presence and labour (Ingold 1980, LaRocque 2014). Mobile reindeer herds would potentially serve as a conservation tool discussed above, supporting climate change mitigation and Fennoscandian biodiversity. Our focus is on those reindeer herding systems that use tundra and near-treeline habitats as summer pastures, as these systems have always been migratory. However, we acknowledge the fact that some Sámi cultures employ stationary herding practices, too. This is especially the case among the Forest Sámi, where summer habitats (open mires) and winter habitats (dry, lichen rich pine forests and spruce forests with arboreal lichens) occur as patches in the same landscape.

The second axis stretches between the end members regarding land use allocation. Pastures and their various attributes (cf. Fig. 2) form the most important resource for reindeer herding. Land allocation is reflected particularly in the size, fragmentation and quality of the grazing grounds, and is often the primary trigger for conflicts between stakeholders. Land allocation results from political decisions and governance actions stemming from the information level and value base of the decision makers. It is, therefore, justifiable to consider land allocation policies between different land uses; to what extent is a landscape reserved for herding practices, as opposed to other activities, such as forestry, mineral extraction, tourism, energy production (reservoirs, wind farms), logistics (power lines, roads, rail roads), settlements, or conservation. The end members of the axis stretch from sustained land use allocation for reindeer livelihood ('land use privileges') to restricted land use allocation for herding ('land use constraints'). Changes in land allocation will often be reflected in herding practices, for example in the degree of seasonal migration and the need for supplementary feeding. In a similar manner, however, also herding practices and their impact on the landscape (for example overgrazing) and other stakeholders (for example crop damages) may generate pressure to alter the land allocation.

Scenario narratives

It is useful to remember that scenarios do not involve any probability component; any of the four scenarios, or their mixture – or something completely different – will gradually unfold, depending on the decisions to be made. Which particular scenario, if any, is preferred by an individual, is a subjective judgement depending on the information and value base of the person. Scenarios themselves do not manifest any value judgments; they are hypothetical, logical examples of a large variety of possible alternatives. However, choices and actions that lead to a future are based on normative values. This discussion is, however, beyond the scope of our scientific analysis.

Traditional migratory herding

Traditional migratory herding scenario involves only little competition by other forms of land use. Low competition in land use implies that no further land fragmentation or other forms of degradation of grazing grounds hampers the migratory movements of animals. Consequently, the circumstances for pasture rotation within and between seasons are maintained, or improved. However, many current challenges faced by reindeer herders – such as the uncertainty of meat price and predation losses/subsidiary system – would remain also in the future (Table 2). There will be no external pressure on significant changes in the number of reindeer and reindeer herders. An important element is the cooperation between reindeer herders and representatives of other forms of land use, such as mining or forestry companies, and administration at regional, national and international levels. Should the societies want to safeguard traditional, migratory Sámi reindeer herding, it would be necessary to consider the North Calotte as a commonly governed pasture area, as different countries have different shortages and surpluses of pastures optimal for different seasons. This would also value the cultural traditions predating the border closures of the mid-1800's (see Chapter 2). This would call for close international collaboration for governing reindeer husbandry in Fennoscandia (Table 2).

Variable herding practices with other land uses (business-as-usual, 'BAU')

The business-as-usual scenario illustrates a future of variable reindeer husbandry – including traditional migratory herding and stationary herding – competing with other forms of land use. This scenario can be considered as a business-as-usual one. High competition in land use may result in shrinking and fragmented pastures. However, other co-existing activities and livelihoods such as tourism may offer opportunities to innovations and cooperation, and may result to luxury meat products and other new reindeer-related products. In this scenario, a smaller proportion of reindeer herders practice the livelihood as a full-time profession and consequently, additional sources of income are needed. As a result, the number of full time herders will decrease somewhat, while the number of part-time herders will increase.

Reindeer ranching

Ranching scenario illustrates a situation where industrial-type reindeer husbandry coincides with low competition in land use. In this scenario, traditional migratory reindeer herding survives alongside intensive ranching, as it may offer luxury 'traditional' meat products as an alternative to the more standard products of the industrial production. Such a situation brings about two "schools of thought", traditional and industrial husbandry, and consequently, problems may emerge regarding for example, policy support.

Due to the different conditions and policies today in different countries and partially in different parts of the reindeer husbandry

area, the developments may vary. In Sweden, for example, most herding units utilizing the tundra in the summer spend the remaining seasons in forested landscapes, influenced by heavy-handed industrial forestry and massive hydroelectric projects. In contrast, in northernmost Norway, winter pastures are not influenced by either large scale forestry or large hydroelectric projects, as mountain birch forests are economically worthless and the central watercourses are legally protected.

Reindeer farming

Farming scenario illustrates a combination of industrial-type reindeer husbandry and high competition in land use. An increase in the demand of reindeer meat, for example, would allow reindeer husbandry to develop towards a meat-producing ranching industry, which would lower reindeer meat price closer to "everyday" meat products. Due to the hard competition in land use and in the market, traditional migratory reindeer herding in its present form will decline or disappear, and be replaced by controlled transport of the animals (for example with trucks) between summer and winter pastures and other technological means to produce reindeer meat, such as an increased practice or artificial feeding, or veterinary treatments. Some reindeer herders grow their business while some others are employed by this newly forming "reindeer industry", or by other livelihoods, perhaps in the south. The number of full-time reindeer herders decreases significantly and, consequently, the average herd size increases remarkably. Also the total number of reindeer may increase.

Table 2. An overview of the variables within the four scenarios of the future of reindeer husbandry in northern Fennoscandia.

VARIABLES	SCENARIOS			
	Traditional ***Vital reindeer husbandry with cultural integrity***	**Business-as-usual** ***Variable reindeer husbandry competing for space with other land uses***	**Ranching** ***Meat production industry in spatially large units***	**Farming** ***Meat production industry with supplementary feeding in confined units***
Economy of reindeer husbandry (income perspective)	Driven by reindeer products. Additional sources of income common.	Economic cooperation with other livelihoods, such as tourism.	Intensive ranching: truck transports and supplemental feeding. Traditional migratory herding a minority.	Industrial reindeer herding dominates. Traditional migratory reindeer herding not competitive.
Policy support to migratory reindeer herders	Policy support depends on the frequency of losses caused by predation, traffic accidents, etc.	Need for policy support increased due to competing land uses.	Dilemma of policy support between migratory and ranching herders.	Traditional migratory herding partially replaced by truck transports between seasonal pastures
Sámi rights and self-determination, survival of the Sámi culture.	Vital Sámi culture, secure rights to land, and influence in resource management decisions.	Traditional migratory herding adapted to land use competition. Traditional Sámi herding culture is at stake.	Traditional Sámi herding culture is struggling due to increasingly industrial practices.	Traditional Sámi herding culture is seriously threatened due to industrialised herding.
Succession planning and continuation of reindeer husbandry	Culture and traditions attract young generation to continue the livelihood.	Young generation often chooses other livelihoods than reindeer herding.	Economic motives dominate over traditions. Traditional migratory reindeer herding vanishes.	Culture and traditions are replaced by economic motives in potential succession.
Number of full-time reindeer herders	No significant change	Slight decrease	Slight decrease	Significant decrease
Reindeer number, herd sizes	No significant change; annual/seasonal variation	Slight decrease	Potential increase; herd sizes vary between migratory and ranch owners.	Potential increase; large herds owned by a few large owners.
Herd composition (age & sex ratio)	Based on Sámi cultural preferences: larger proportion of bulls and castrates than today and in the other scenarios.	Diversity of the herds reflects the diversity in land use competition and situation in the meat market.	Diversity of herds reflects diversity between migratory and ranching preferences.	Aimed at maximized productivity adapted from agricultural practices: large proportion of females and calves.
Stakeholder cooperation	New forms of internal and external cooperation allows flexibility in herd movements.	Cooperation with other stakeholders / land users.	Increasing cooperation between Sámi and other stakeholders.	Cooperation with stakeholders outside traditional Sámi reindeer herding.
Adaptive capacity to ecosystem and land use changes	High. Migratory herding takes advantage of the availability of a large land area.	Low. Migratory herding suffers from fragmented landscape.	Intermediate. Ranching has higher adaptive capacity than migratory herding.	High. Fragmented landscape does not seriously influence farming.
Technology and use of innovative strategies	New technological innovations infiltrate gradually into traditional practices.	New technological innovations are used as available.	New technological innovations are used and developed when possible.	New technological innovations are developed within the industrial reindeer husbandry.
Role of reindeer meat on the market	Luxury product marketed as different animal classes (adults, calves) and diverse animal parts.	Products adjusted to the needs of meat industry.	Diversity of products: diverse animal parts and different qualities are sold at different prices	Standard product sold at prices comparable to other meat. No label of "organic/ environmental production".

Concluding remarks

Our scenarios have illustrated a broad spectrum of potential future developments in the character of reindeer husbandry in the tundra region of Northern Fennoscandia. Power relations in governing the rights and use of the landscape seem to be crucial in determining the future of reindeer husbandry (Chapter 6). This aspect was highlighted by reindeer herders in the workshops, as they emphasized the increasing environmental and anthropogenic challenges that affect the ecological, socio-economic, political and cultural-historic dimension of their livelihood at large spatial and temporal scales (Chapter 5).

Today, reindeer husbandry competes for space with several other forms of land use. Shrinking and fragmenting grazing grounds pushes herders to use all available land for grazing (Chapter 5). Therefore, the future of reindeer husbandry in a changing tundra (Chapters 3 & 4) is affected to a substantial degree by policy decisions that influence what elements in the social-ecological system are either prioritized or weakened, for example reinforcing ecosystem keystones that keep the system resilient.

The potential strategy to employ reindeer grazing as a "conservation tool" is based on reindeer ecology: selective feeding on preferred plant species in different seasons at different habitats, as well as the reaction of these plants to grazing pressure (Chapter 4). However, top-down impacts on plants by herbivores are not the only driver that influences where and when plants can establish in the tundra, because the patterns of various abiotic processes (for example, soil conditions, vegetation period) shape bottom-up constraints and options for seedling establishment (Chapter 5). Consequently, there are strong interaction impacts of grazing and abiotic effects on plant community transition during environmental change. It is this interaction that can potentially be shaped and modulated by reindeer management to fulfil its "conservation potential". Important variables that human decision making can affect include the number and density of reindeer present at specific places in specific times. In reality, these decisions will often involve a trade-off.

To increase the capacity to find satisfying compromises for all involved stakeholders, the integration of different knowledge types to shape collective action seems vital for fostering sustainable governance of reindeer social-ecological systems in Northern Fennoscandia.

These processes may create new stewardship decisions and science-policy interface institutions that are capable of building trust in political decisions and increase mutual understanding between involved parties in a wide social context (Chapter 5).

Summary of the main findings

- Most recent climate projections suggest that by the 2070's, temperature conditions that are warm enough for tree growth (> 10 °C average temperature during summer) will cover almost all of northern Fennoscandia. A warming climate will encourage shrubification and tree growth and therefore decrease the area of tundra biome remarkably.
- The projected increase in spring temperatures will enhance snow melting. Together with the expansion and densification of shrub vegetation, this can significantly decrease surface reflectance (albedo), and have a positive feedback on global climate change. Therefore, preventing shrubification of the tundra and preserving the circumpolar high albedo tundra biome would serve as climate mitigation.
- Herbivores (animals feeding on plants) have a strong impact on both tundra and mountain birch forest vegetation. The most important herbivores include large mammals (reindeer), small mammals (rodents), and insects (geometrid moths). Their exact effect, however, varies between the animal groups and their population dynamics, seasons, weather conditions, and vegetation communities, and is dependent also on the combined impact of different animals.
- Reindeer grazing has the potential to counter-impact the climate-induced shrubification. The maximum grazing impact on woody plants is obtained if reindeer are present in a region in June and early July.
- Grazing has an impact on plant biodiversity. By preventing the invasion of trees, tall shrubs and forbs, reindeer maintain the openness of the tundra, which is a precondition for the survival of many arctic plants. Grazing may also cause damage on these plants, but the net impact of intense summer grazing can be positive at the population level.
- From a transdisciplinary perspective, tundra is not only a biome, but also a social-ecological system (SES) incorporating humans and their activities, including reindeer husbandry.
- Decision making involves various aspects of this complex social-ecological system and is, therefore, always a compromise and a matter of values and opinions.
- Reindeer husbandry exhibits major legal and administrative differences in local, regional, and state governance between Finland, Norway and Sweden. Anticipated changes in climate and within the societies create a demand requiring reindeer husbandry to adapt to the transformations.
- Future is not pre-determined but unveils itself as a chain of decisions and actions. Therefore, various scenarios of the future of the social-ecological system including reindeer husbandry can be foresighted depending on the circumstances, decisions and actions. The scenarios in this work were built around two parameters: land use, and the nature of the livelihood. Four scenarios were formed of future reindeer husbandry: 'traditional', 'business-as-usual', 'ranching' and 'farming'.

- Current tensions between stakeholders – including reindeer herders, other land users, Sámi and non-Sámi persons, and the governance – stem from challenges in valuing simultaneously manifold ecological, cultural, social, and economic matters. The tension may inhibit fruitful discussion and feasible decisions, and may lead to a future that is undesirable for many, if not all parties. There is too little interaction and inadequate, unequal discussion between the stakeholders. From the herders' perspective, unclear legislation and lack of self-determination are considered as threats for the livelihood.
- To improve the quality of decision making, more and better interaction will be needed between stakeholders. Planning and actions regarding future land use and livelihoods should be co-designed by different stakeholders. To overcome the historical apprehension between the parties, a neutral boundary organisation might serve as an appreciated mediator.

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Appendix 1

LIST OF REINDEER DISTRICTS (cf. Fig. 5)

	Norway	Sweden	Finland
1	Østre Sør-Varanger	Könkämä	Kaldoaivi
2	Pasvik	Lainiovuoma	Paistunturi
3	Vestre Sør-Varanger	Saarivuoma	Näätämö
4	Várjjantnjárga	Talma	Vätsäri
5	Rákkonjárga	Gabna	Muddusjärvi
6	Olggut Corga/Oarje-Deatnu	Laevas	Käsivarsi
7	Lágesduottar	Girjas	Muotkatunturi
8	Karasjoka nuartebealli	Baste cearru	Paatsjoki
9	Spierttanjárga	Unna Tjerusj	Hammastunturi
10	Spierttagáisá	Sirges	Ivalo
11	Kárájoga Oarjjabealli	Jåhkågaska tjiellde	Näkkälä
12	Nuorttabealli	Tuorpon	Sallivaara
13	Guovdajohtolat	Luokta-Mávas	Lappi
14	Gearretnjárga	Semisjaur-Njarg	Kuivasalmi
15	Fiettar	Svaipa	Kyrö
16	Beaskádas	Gran	Muonio
17	Seainnus/ Návggastat	Ran	Kemin_Sompio
18	Oarjjabealli	Ubmeje tjeälddie	Sattasniemi
19	Fálá/ Kvaløy	Vapsten	Oraniemi
20	Nuorta-Sievju	Vilhelmina norra	Alakylä
21	Oarjea-Sievju	Vilhelmina södra	Pohjois-Salla
22	Lakkonjárga	Voernese	Syväjärvi
23	Orda	Ohredahke	Kolari
24	Spalca	Raedtievaerie	Salla
25	Stierdná	Jijnjevaerie	Pyhä-Kallio
26	Ábborra	Jovnevaerie	Hirvasniemi
27	Joahkonjárga	Njaarke	Jääskö
28	Beahcegealli	Kall	Poikajärvi
29	Sállan	Handölsdalen	Orajärvi
30	Cuokcavuotna	Tåssåsen	Palojärvi
31	Fávrrosorda	Mittådalen	Vanttaus
32	Cohkolat	Ruvhten sijte	Lohijärvi
33	Silvvetnjárga	Idre	Narkaus
34	Seakkesnjárga ja Silda	Vittangi	Tolva
35	Skárfvággi	Gällivare	Alakitka
36	Bassevuovdi	Serri	Timisjärvi
37	Uløy	Udtja	Niemelä
38	Árdni / Gávvir	Ståkke	Posion_Livo
39	Rosta	Maskaure	Oivanki

	Norway	Sweden	Finland
40	Dividalen	Västra Kikkejaure	Akanlahti
41	Rendalen	Östra Kikkejaure	Isosydänmaa
42	Ivguláhku/Lakselvdalen/Lyngdalen	Mausjaure	Mäntyjärvi
43	Altevatn	Malå	Kuukas
44	Vannøy	Muonio	Kallioluoma
45	Reinøya	Sattajärvi	Pudasjärven_Livo
46	Tromsdalen	Tärendö	Taivalkoski
47	Mauken	Korju	Hossa-Irni
48	Ringvassøy	Pirttijärvi	Oijärvi
49	Rebbenesøy	Ängeså	Ikonen
50	Fagerfjell	Kalix	Jokijärvi
51	Kvaløy	Liehittäjä	Pintamo
52	Gielas		Pudasjärvi
53	Hjerttind		Kollaja
54	Skjomen		Näljänkä
55	Nord-Senja		Kiiminki
56	Grovfjord		Halla
57	Sør-Senja		
58	Frostisen		
59	Tjeldøy		
60	Balvatn		
61	Kongsvikdalen		
62	Stajggo / Hábmer		
63	Duokta		
64	Kanstadfjord / Vester Hinnøy		
65	Saltfjellet		
66	Ildgruben		
67	Byrkie		
68	Hestmannen/Strandtindene		
69	Låarte		
70	Røssåga / Toven		
71	Tjåehkere sijte		
72	Jillen-Njaarke		
73	Voengelh-Njaarke		
74	Svahke		
75	Skæhkere		
76	Åarjel-Njaarke		
77	Femund		
78	Gasken-Laante		
79	Riast / Hylling		
80	Essand		
81	Fovsen-Njaarke		

Appendix 2

VEGETATION CLASS DESCRIPTIONS (cf. Fig. 9)

1. **Coniferous forests.** High productive forest types with a dense canopy layer of Norway spruce and Scots pine. Spruce forests are developed on fresh subsoil, while pine forests are common on dry, moraine subsoil. In Scandinavia coniferous forests are highly affected by forest logging.
2. **Bilberry/meadow birch forests.** Species-rich forests characterized by grasses, herbs and bilberry in the field layer. In northern Scandinavia the tree layer is dominated by birch, often in co-occurrence with grey alder, rowen and tall willows. For meadow forests the ground layer is poorly developed, while mosses are common in bilberry forests.
3. **Mountain birch forests.** Birch forests developed on nutrient-poor subsoil. Two different forest formations constitute the core elements of the unit: one characterized by heather species , dwarf shrubs and mosses, while the second one is often dominated by lichens. The lichen stands are important as reindeer fodder during winter. The main distribution is in continental northern Scandinavia.
4. **Bogs and mires.** Bogs and fens are characterized by a peat layer and by a high level of water table throughout the growing season. Structural differences give rise to a further differentiation into hummock bogs, lawn and carpet fens, and sedge marshes. Mud-bottom fens constitute the wettest parts of mire complexes. Bogs and mires are most common in eastern parts of Northern Fennoscandia.
5. **Rocks, bare soil and boulder fields**. The unit integrates different types of non- to sparsely vegetated areas, mainly located to the high mountain region. The unit further integrate bare rocks and exposed ridges in the the mid- and low-alpine belt. In the lowland the unit comprises slopes of naked rocks along the coast and different types of exploited areas.
6. **Heather ridges.** Ridge vegetation is located to the low- and mid-alpine belt in the mountain region. Different types of *Dryas octopetala* communities are characteristic for the calcareous ridges, while species of ericaceous (Empetrum) plants are characteristic on base-poor subsoil.
7. **Lichen heaths.** Lichen heaths are found in the continental parts of Northern Fennoscandia. Ericaceous species characterize the field layer, while dense carpets of lichens dominate and characterize the ground layer. Over large areas in Northern Fennoscandia severe degradation of the lichen heaths is experienced during the past decades due to high grazing pressure from reindeer.
8. ***Betula nana* heaths.** This map unit is characterized by a bush thicket of Betula nana and gray willows. The ground layer is often characterized by lichens. The main distribution is in continental parts of the Scandinavian mountain range. To some extent the coastal heaths of western Norway are included in the unit.
9. **Mountain meadows.** The unit comprises species rich communities in the mountain region most often located to areas of calcareous subsoil. The snow cover during winter is moderate. The main distinction is between low and tall herb stands and grass-rich communities.
10. **Snowbed vegetation.** These communities are found in depressions with heavy snow during winter. Snow patch plants have to compete an abbreviated growing season and have to pass through growth, flowering and seeding in just few weeks. The main distribution in in western mountains in areas with heavy and long-lasting snow cover. Several community types can be differentiated depending on the duration of snow and nutrient status of the subsoil.
11. **Glaciers, snow patches.** The map unit comprises glaciers and areas with long-lasting snow cover. This map unit is mainly located to the high-mountain region.
12. **Agriculture.** This map unit consists of different types of agricultural areas containing meadows, pastures, annual and permanent crop fields. The spectral content of this map unit is extremely heterogeneous and the separation is made mainly based on ancillary data.
13. **Built-up areas.** The map unit comprises different types of built-up areas.
14. **Water.** The map unit comprises oceans, inland water and broad rivers.

Glossary

Adaptation	Actions and decisions as reaction to change.
Albedo	Fraction of solar radiation reflected by an object. Dark objects have a low albedo and absorb a high level of energy, and increase the energy balance of their surroundings. Light objects have a high albedo and reflect lots of energy.
Arvecolinae	A subfamily of rodents that includes voles, lemmings, and muskrats.
Boreal zone	The vegetation zone between the tundra to the North and the temperate vegetation zone in the South. Mainly dominated by coniferous trees. Also known as taiga.
Dwarf shrub	See shrub
Forb	Flowering plants without woody stems other than grasses
Geometridae	A large family of moths, represented in Fennoscandia by the autumnal moth (*Epirrita autumnata*) and the winter moth (*Operophtera brumata*).
Growing season	The part of the year that allow plants to grow, depending on temperature and precipitation. The growing season shortens with increasing altitude and latitude.
Herding	Herding in our report covers all practical activities and interaction between reindeer and herders, such as calf marking, migration, slaughter or guarding the herd.
Holocene	The geological epoch that began ca. 11,700 years before the year 2000 AD until the present. See also Pleistocene.
Husbandry	Husbandry covers the wider livelihood of reindeer herders, including the cultural dimension attached to it.
Landsat TM / ETM+ images	Landsat images are taken from space by earth-observing satellites. TM (Thematic mapper) sensors record seven bands of image data (three at visible wavelengths, four at infrared) at 30 m resolution. The more recent Enhanced Thematic Mapper Plus (ETM+) has a spatial resolution of 15 m and records 8 wavelengths. Both are used in studies on climate change and albedo.
Lapp Codicil (Lappkodicillen)	An agreement in 1751 between the kingdoms of Denmark-Norway and Sweden that asserted the crossing of the borders by reindeer herders during their seasonal migrations between summer and winter grazing grounds.
Lichens	A symbiotic organism between a fungus and algae, able to grow in nutrient-poor environments. In its growth and reproduction mainly dependent on rainfall. Important winter resources for reindeer.
Lime	Areas rich in lime contain lots of calcium and thus often are associated with a particular plant diversity.
Mustelid	Small predators of the weasel family.
Oro-arctic	Arctic vegetation that is found at high altitudes outside of the actual Arctic.
Pleistocene	The geological epoch that began ca. 2.6 million years ago and lasted until 11,700 years ago. During the Pleistocene, the world experienced several glaciations. The following epoch is the Holocene.
Representative concentration pathways (RCP)	These pathways describe four possible futures for the development of world climate, depending greenhouse gas concentrations. The scenarios describe the "radiative forcing", which is the difference between absorbed solar energy and reflected energy by the Earth. The four values for radiative forcing (in Watts per m^2) until the year 2100 include RCP 2.6, RCP4.5, RCP6, and RCP8.5.
Sápmi	The area in Sweden, Norway Finland and the Kola Peninsula where Sámi culture is still alive.

Scrubland	A vegetation dominated by shrubs, in Fennoscandia including willows and birches.
Sedge	A group of grass-like plants often growing in moist soils or close to water. Valuable reindeer forage from late autumn to early spring, when other plants are not available.
Sensible heat fluxes	Sensible heat fluxes transfer heat energy from the Earth's surface to the atmosphere.
Shrub	Woody plants which normally grow taller than 0.5 m but not over 2 m. Woody plants lower than 0.5 m are dwarf shrubs.
Siida	A small, family or kinship-based unit of traditional organization in reindeer husbandry. The administrative role of *siida* systems varies between the Nordic countries: while *siida* systems are recognized as a legal unit in Norway, they are informal parts of reindeer husbandry in Sweden and Finland.
Snow bed	Plant communities that depend on local topography, such as depressions, favouring a long duration of the snow cover and higher snow cover than in the surroundings.
Social-ecological system	The interconnectedness between people and their environment.
Supplementary feeding	Artificial feeding, such as hay or pellets that is given to reindeer. More commonly applied in Finland than in Sweden and Norway, where it is mainly used during difficult winters.
Tree line	The edge beyond which trees cannot grow for geomorphological, climatic or other environmental reasons. Forests become replaced by low vegetation, often grasses, shrubs and dwarf shrubs (see tundra).
Tundra	Treeless vegetation north to the boreal zone beyond the tree line, often associated with permafrost.
Vascular plants	Plants without a vascular system that transports water, metabolites and nutrients between leaves and the root system.

Turun yliopisto
University of Turku
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DEPARTMENT OF GEOGRAPHY AND GEOLOGY

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